Databases – Data Modelling

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Data Modelling :: Phases of Database Design

Database Design

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- **formal model** of the relevant aspects of the real word
- the real world serves as **measure of correctness**

The database states should correspond to the states of the real world.

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Database design is challenging:

- **Expertise**:
  requires expertise in the application domain
- **Flexibility**:
  real world often permits exceptional cases
- **Size**:
  database schema may become huge

Database Design

Due to the complexity, the design is a multi-step process...

Three Phases of Database Design

Conceptual Database Design

- what information do we store
- how are the information elements related to each other
- what are the constraints?
- e.g. ER model or UML model

Logical Database Design

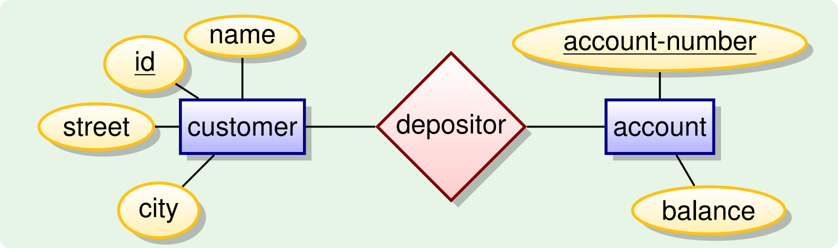
- transformation of the conceptual schema into the schema supported by the database
- e.g. relational model

Physical Database Design

- design indexes, table distribution, buffer sizes,...
- to maximise performance of the final system

Data Modelling :: Entity-Relationship Model

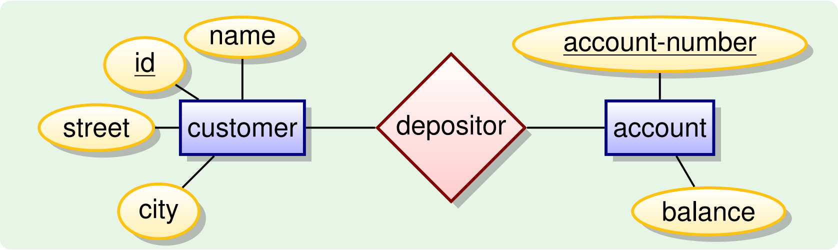
Entity-Relationship Model



The three main ingredients of entity-relationship diagrams are:

- **Entity sets**
- **Attributes**
- **Relationship sets**

Entity-Relationship Model



- **Rectangles** represent entity sets
- **Ellipses** represent attributes
  - **Double ellipses** represent multi-valued attributes
  - **Dashed ellipses** denote derived attributes
- **Diamonds** represent relationship sets
- **Lines** link attributes and relationship sets to entity sets
- **Underline** indicates primary key attributes

Entity Sets

An **entity** is an abstract object

- e.g.: specific person, company, event

Entities have **attributes**

- e.g.: people have names and addresses

An **entity set** is a collection of similar entities

- similar = sharing the same properties (attributes)
- e.g.: set of all persons, companies, trees, holidays

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entity $\approx$ object entity set $\approx$ class

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Comparison with object-oriented programming:

entity $\approx$ object   entity set $\approx$ class

Important difference: the **ER model is static**

- models structure of the data, not the operations
- no methods/functions associated to entity sets

Attributes

An **entity set is represented by a set of attributes**, that is, properties possessed by all entities of the entity set.

```
Customer = (id, name, street, city)
Loan = (loan-number, amount)
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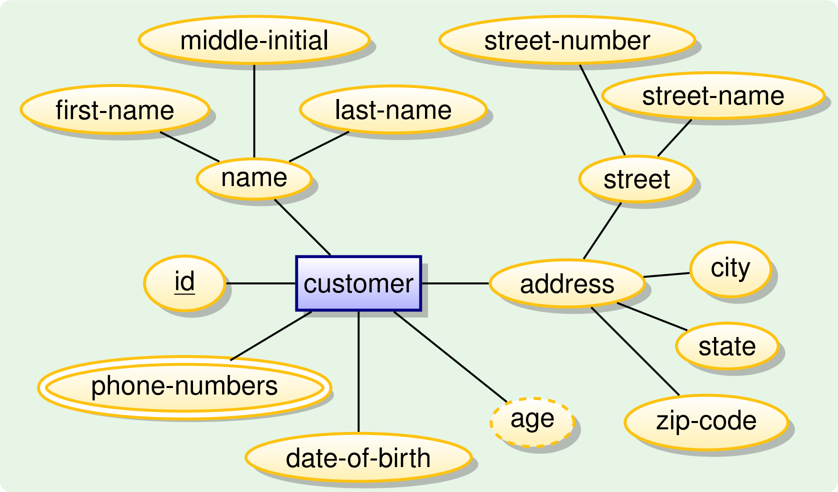
Attribute types

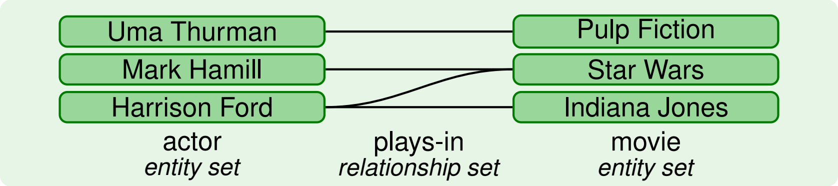
- **simple** and **composite** attributes
  - e.g. street is composed of street name and number
- **single-valued** and **multi-valued** attributes
  - e.g. single-valued: age of a person
  - e.g. multi-valued: person can have multiple phone numbers
- **derived attributes**
  - can be computed from other attributes
  - e.g. age can be computed given the date of birth

Attributes



- *name*, *address* and *street* are composite attributes
- *phone numbers* is a multi-valued attribute
- *age* is a derived attribute (derived from *date-of-birth*)

Relationship Sets



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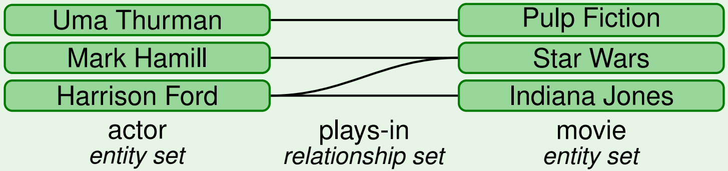
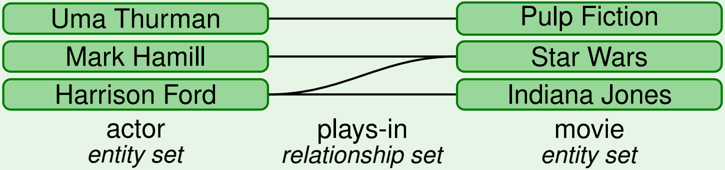


A **relationship** is an association among several entities.

Formally, a relationship is a tuple $(e_1, e_2, \ldots, e_n)$ of entities.

- (Mark Hamill, Star Wars) is a relationship
- (Harrison Ford, Indiana Jones) is a relationship

Relationship Sets



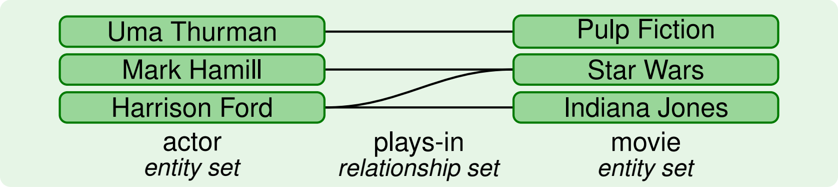
A **relationship set** is a set of relationships of the same kind.

That is, a **relationship set** is a set of tuples $(e_1, e_2, \ldots, e_n)$ where $e_1 \in E_1, \ldots, e_n \in E_n$ are from entity sets $E_1, \ldots, E_n$.

Example of a relationship set

$$\{\ (\text{Uma Thurman, Pulp Fiction}),\\ (\text{Mark Hamill, Star Wars}),\\ (\text{Harrison Ford, Star Wars}),\\ (\text{Harrison Ford, Indiana Jones})\ \}$$

Relationship Sets



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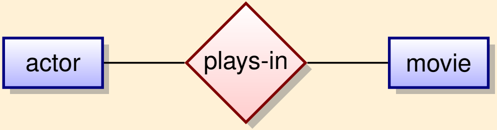
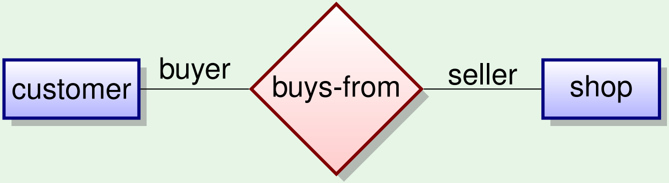
The relationship set *plays-in* between entity sets *actor* and *movie* is indicated as follows in ER models:



Relationship Sets and Role Names

The relationship set connections can be annotated with **role indicators**.



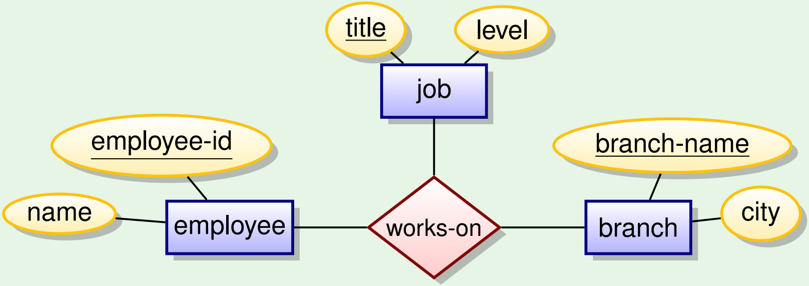
Role indicators improve readability!

Degree of a Relationship Set

The **degree** of a relationship set refers to the number of entity sets participating in the relationship.

- relationship sets of degree 2 are called **binary**
- relationship sets of degree 3 are called **ternary**

Example for a ternary relationship set *works-on*: an *employee* might work on different *jobs* at different *branches* of a company.



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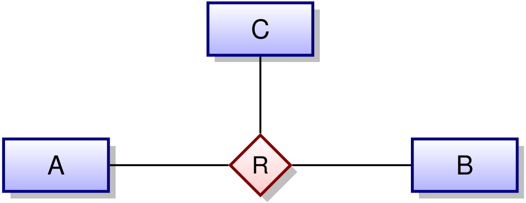
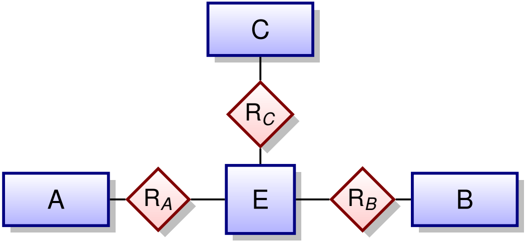


Non-binary relationship sets can be represented using binary ones by creating an artificial entity set.

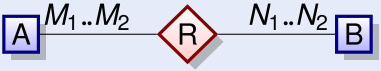


Data Modelling :: Cardinality Limits

Cardinality Limits

Cardinality limits express the number of entities to which another entity can be associated via a relationship set.

There are many different notations. **We use the UML notation!**

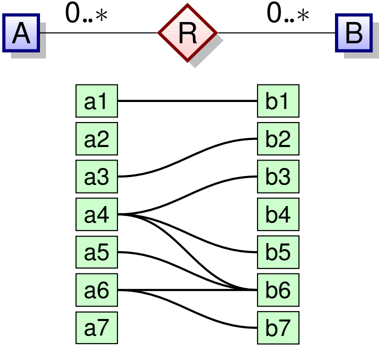


- Every entity *a* from *A* is connected to at least N_1, and at most N_2 entities in *B*.
- Every entity *b* from *B* is connected to at least M_1, and at most M_2 entities in *A*.

Typical cardinality constraints

0..1 = zero or one	0..$*$ = any number
1..1 = precisely one	1..$*$ = at least one

Cardinality Limits: Many-to-Many

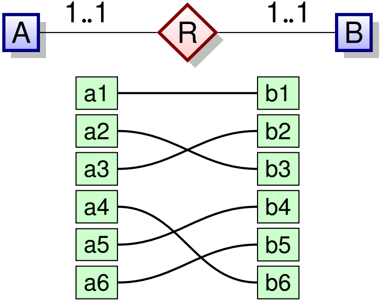


This describes a **many-to-many** relationship set:

- the entities may be connected arbitrarily
- every *a* in *A* can be linked to an arbitrary number of *B*'s
- every *b* in *B* can be linked to an arbitrary number of *A*'s

If the cardinalities are not given, the **default is many-to-many**.

Cardinality Limits: One-to-One

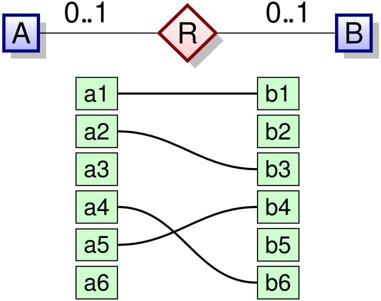


This describes a **one-to-one** relationship set:

- every *a* in *A* is connected to precisely one *b* in *B*
- every *b* in *B* is connected to precisely one *a* in *A*

Note that this corresponds to a bijective function from *A* to *B*.

Cardinality Limits: Zero or One-to-Zero or One

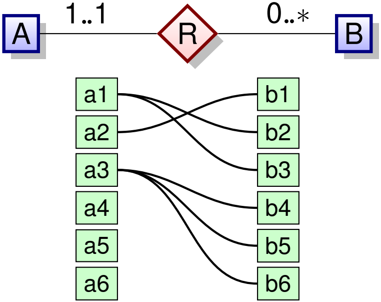


This describes a **zero or one-to-zero or one** relationship set:

- every *a* in *A* is connected to at most one (= 0 or 1) *b* in *B*
- every *b* in *B* is connected to at most one (= 0 or 1) *a* in *A*

Confusingly, this is sometimes also called one-to-one.

Cardinality Limits: One-to-Many



This describes a **one-to-many** relationship set:

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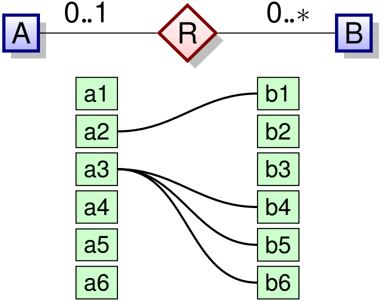
Cardinality Limits: Zero or One-to-Many



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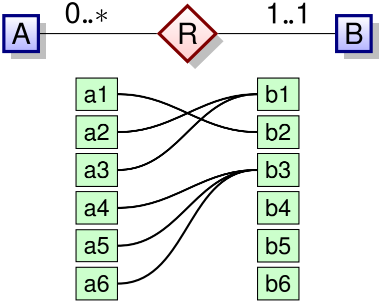
Cardinality Limits: Many-to-One



This describes a **many-to-one** relationship set:

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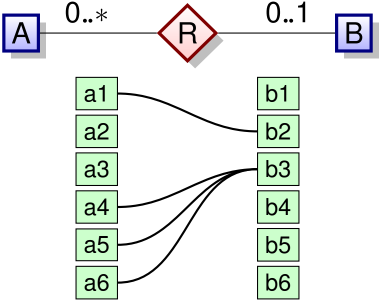
Cardinality Limits: Many-to-Zero or One



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Express the following Cardinality Limits

Every *a* in *A* is connected to precisely one *b* in *B*,
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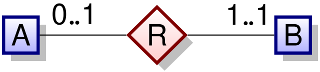

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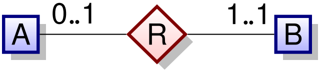

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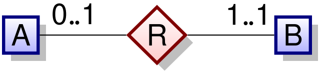

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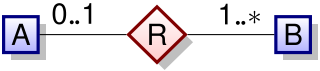

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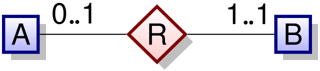

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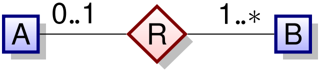

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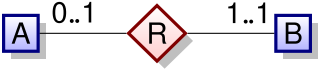

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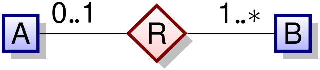

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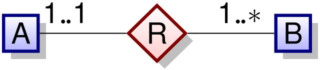

Cardinality Limits: Alternative Notations

There are many different notations for ER models.

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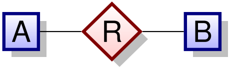
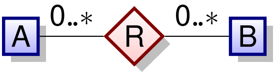
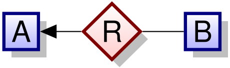
For example:



is alternative for





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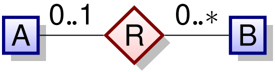

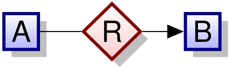

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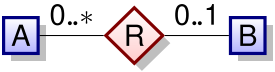

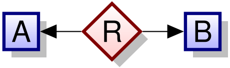

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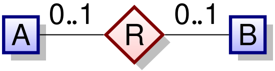
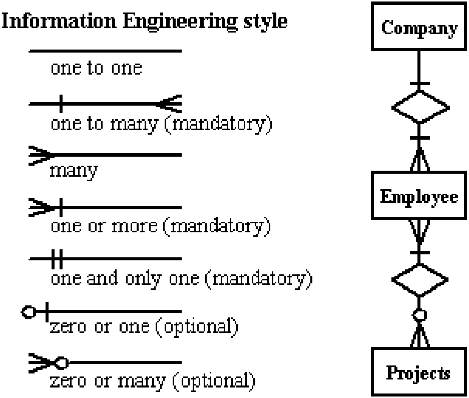


Cardinality Limits: Alternative Notations

There are many different notations for ER models.

For example: Information engineering style



Cardinality Limits: Alternative Notations

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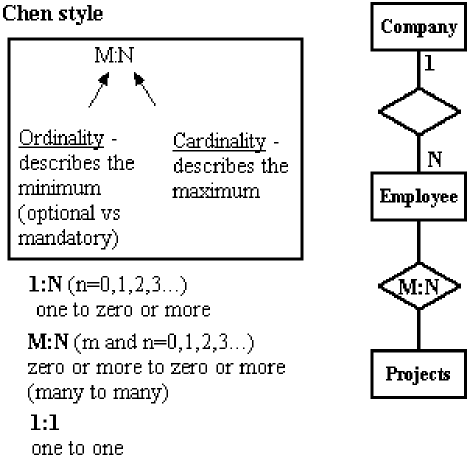
For example: Chen style



Chen style

M:N

Ordinality - describes the minimum (optional vs mandatory)

Cardinality - describes the maximum

1:N (n=0,1,2,3...)
one to zero or more

M:N (m and n=0,1,2,3...)
zero or more to zero or more (many to many)

1:1
one to one

Cardinality Limits: Alternative Notations

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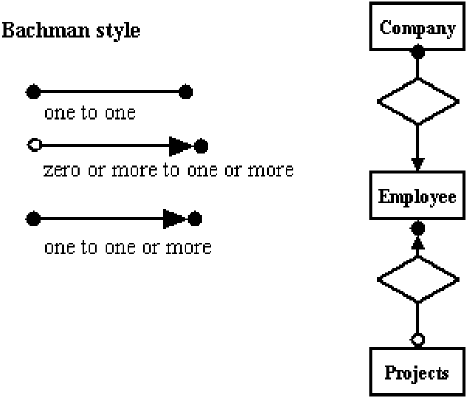
For example: Bachman style



Cardinality Limits: Alternative Notations

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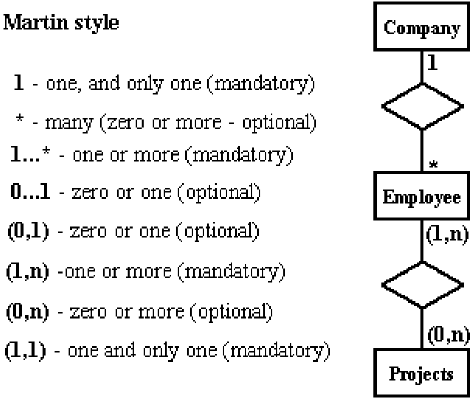
For example: Martin style



Martin style

1 - one, and only one (mandatory)

* - many (zero or more - optional)

1...* - one or more (mandatory)

0...1 - zero or one (optional)

(0,1) - zero or one (optional)

(1,n) -one or more (mandatory)

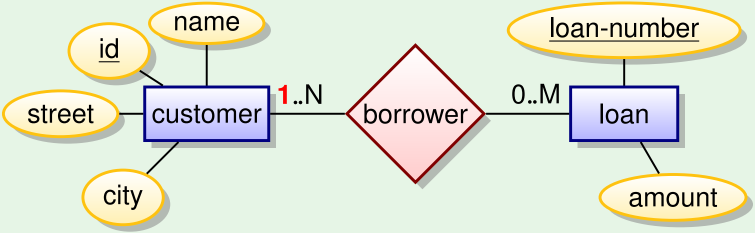
(0,n) - zero or more (optional)

(1,1) - one and only one (mandatory)

Total Participation

Total participation means that every entity in the entity set participates in at least one relationship in the relationship set.

- e.g. every loan must be belong to at least one customer



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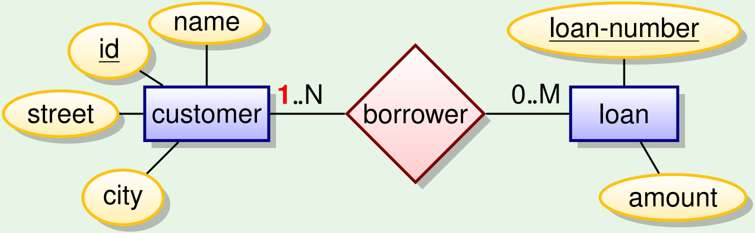
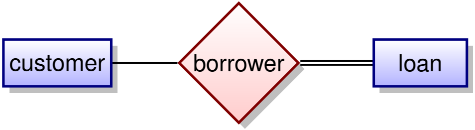


Alternative notation:



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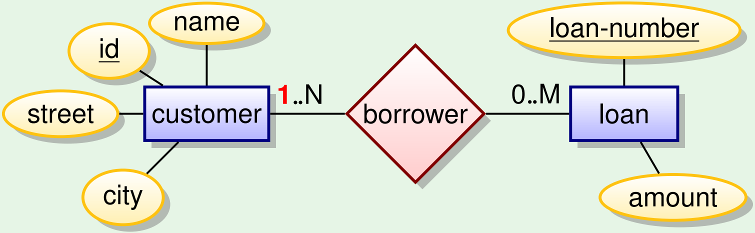
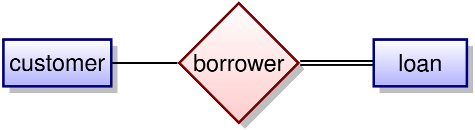


Alternative notation:



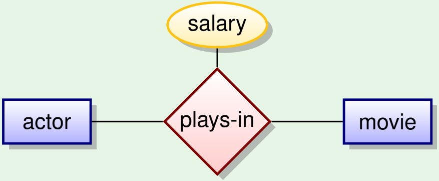
Partial participation means that entities may not participate in any relationship in the set.

Data Modelling :: Relationship Sets with Attributes

Relationship Sets with Attributes

An **attribute** can also be property of a relationship set.

The *plays-in* relationship set between the entity sets *actor* and *movie* may have the attribute *salary*.



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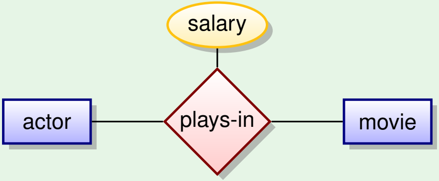
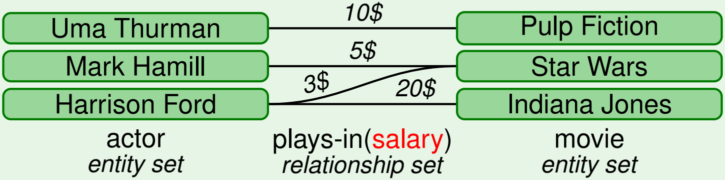


salary

actor

plays-in

movie



Uma Thurman

Mark Hamill

Harrison Ford

10$

5$

3$

20$

Pulp Fiction

Star Wars

Indiana Jones

actor
entity set

plays-in(salary)
relationship set

movie
entity set

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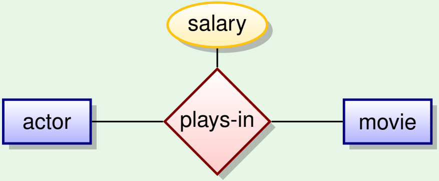
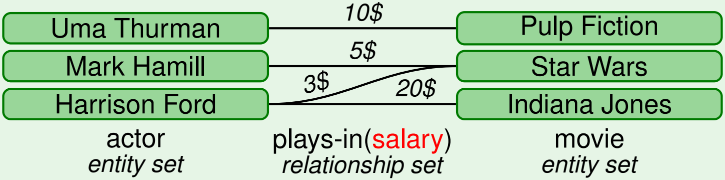




Uma Thurman — *10$* — Pulp Fiction

Mark Hamill — *5$* — Star Wars

Harrison Ford — *3$* — Star Wars

Harrison Ford — *20$* — Indiana Jones

actor
entity set

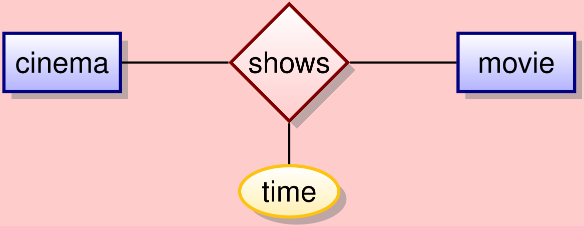
plays-in(salary)
relationship set

movie
entity set

The value of the relationship attributes is **functionally determined** by the relationship $(e_1, \ldots, e_n)$.

Relationship Sets with Attributes

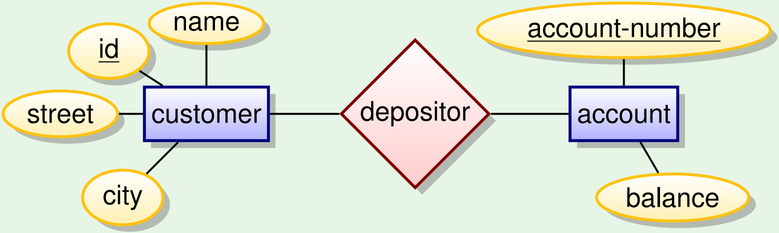
Consequences of the semantics



Suppose a cinema shows a movie twice a day (at 3pm and 6pm).

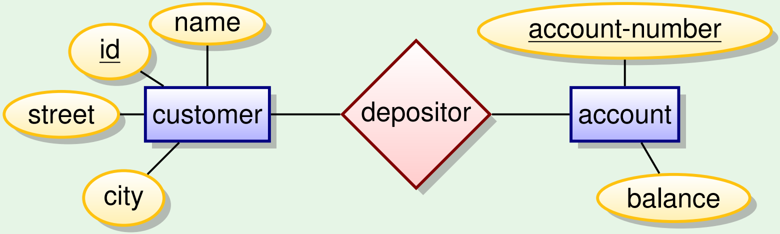
Can this information be stored in the given schema?

Cardinalities affect the ER Design



Assume that we want to record the date of the last access of a customer to an account. We call this attribute *access-date*.

Cardinalities affect the ER Design



Assume that we want to record the date of the last access of a customer to an account. We call this attribute *access-date*.

If the relation from customer to account is **many-to-many**:

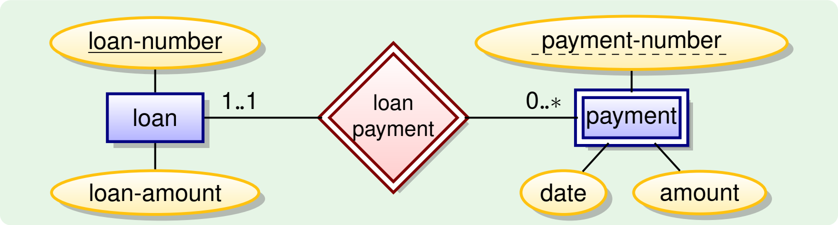
- then *access-date* must be an attribute of *depositor*

If the relation from customer to account is **one-to-many**:

- then *access-date* can be an attribute of *account*

Data Modelling :: Weak Entity Sets

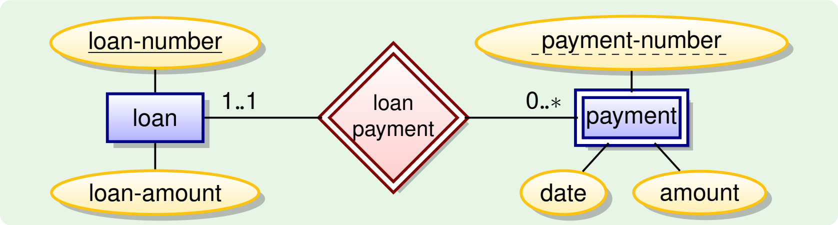
Weak Entity Sets



There can be multiple payments with equal payment-number

- the payment-number is **not a key**

Weak Entity Sets



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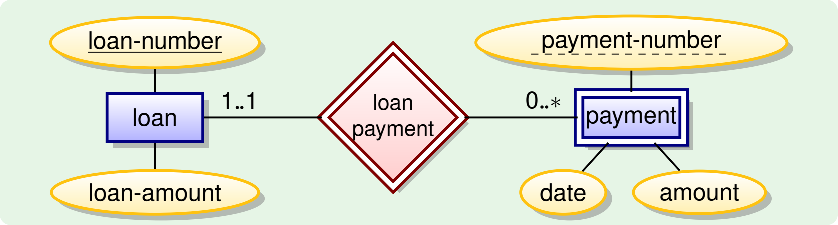

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- the payment-number identifies a payment uniquely only in combination with the loan-number of the associated loan

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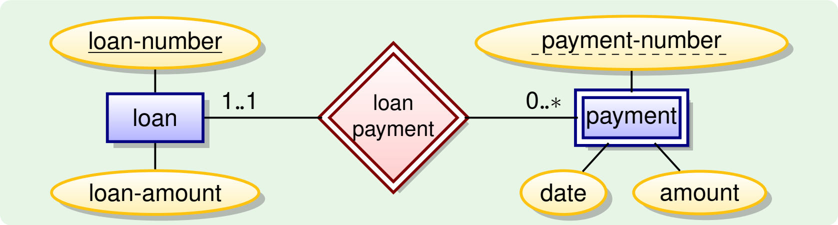

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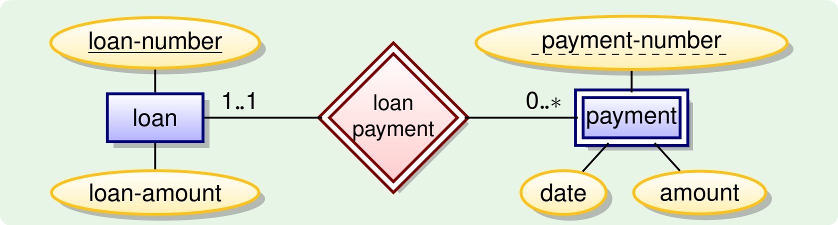
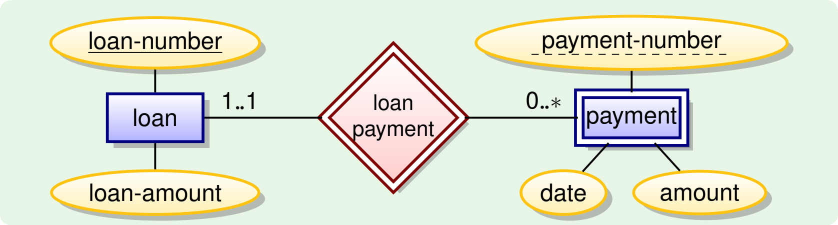
In other words, the **discriminator** payment-number is unique among all payments for a certain loan.

Weak Entity Sets



A **weak entity set** is an entity set without a primary key.

Weak Entity Sets



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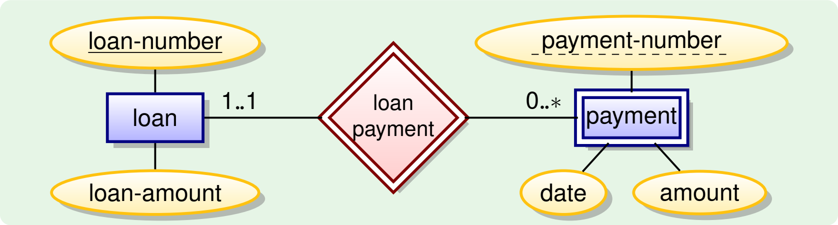
Weak Entity Sets



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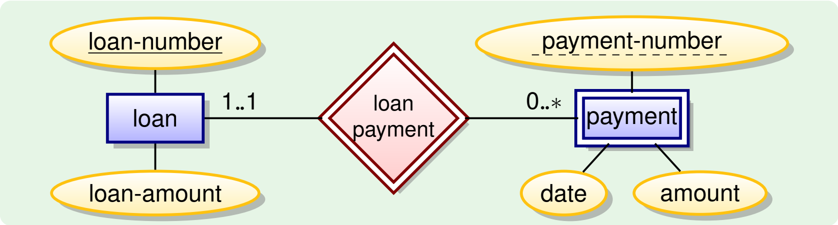
Weak Entity Sets



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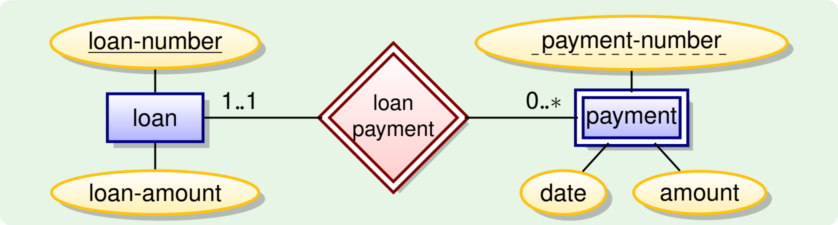
Weak Entity Sets



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- The **discriminator** is a partial key, it distinguishes the weak entity only in combination with the identifying entity.
- Primary key of the weak entity set is a combination of the discriminator and primary key of the identifying entity set.

Weak Entity Sets

Modelling with Weak Entity Sets

Model a set of online quizzes (multiple-choice tests).

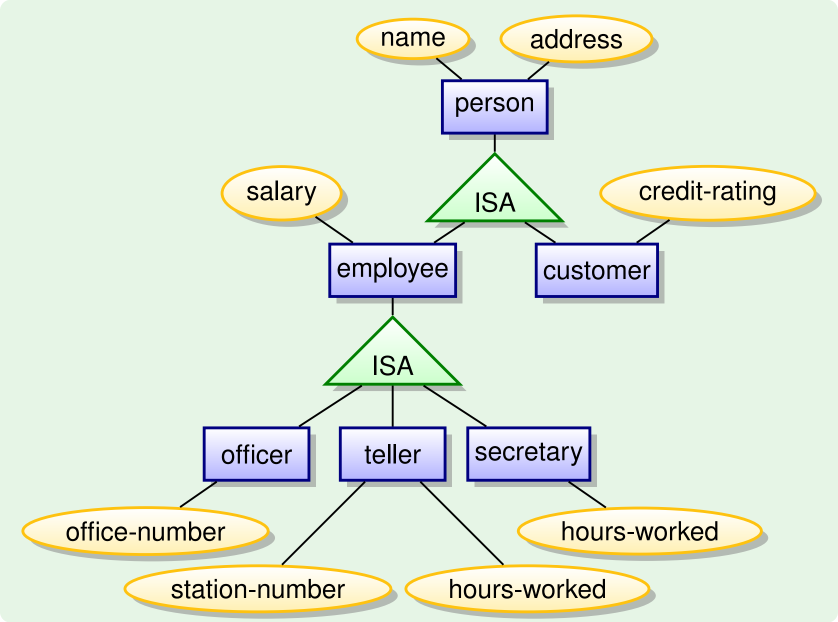
- each quiz is identified by a title
- each question within a quiz is numbered
- each possible answer to a question is referenced by a letter
- for each question and answer the associated text is stored
- answers are classified into correct and incorrect ones

Develop an ER diagram.

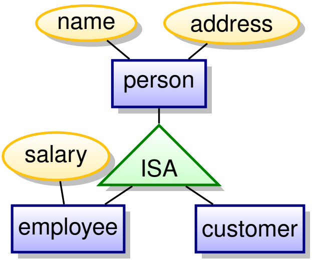
What is the complete key for each of the entity sets?

Data Modelling :: IS-A, ‘Inheritance’

IS-A, 'Inheritance'



IS-A, ‘Inheritance’



Lower-level entity sets are subgroups of the of higher-level entity sets:

- e.g. an employee ‘is a’ person

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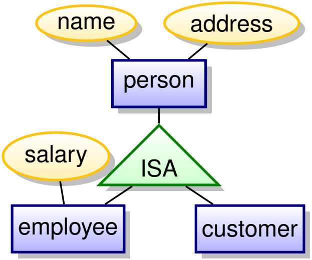

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Lower-level entity sets **inherit all attributes and relationship sets** of the higher-level entity sets.

- e.g. an employee has attributes *name*, *address* and *salary*

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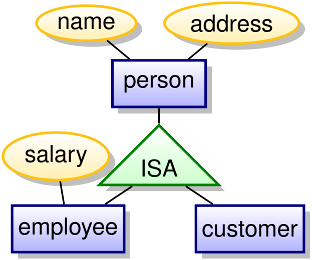

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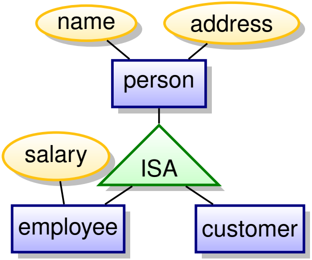
Design Principle: Specialisation

- top-down design process
- identify subgroups within an entity set
- these subgroups become lower-level entity sets which may have attributes or participate in relationship sets that do not apply to the higher-level entity sets

IS-A, ‘Inheritance’



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- e.g. an employee has attributes *name*, *address* and *salary*

Design Principle: Generalisation

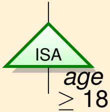
- bottom-up design process
- combine a number of entity sets that share common features into a higher-level entity set

- specialisation and generalisation are both ‘is a’-relations

IS-A, ‘Inheritance’

Membership constraints

- **value-based**: assigns an entity to a specific subclass based on attribute values
  e.g. a *person* of age $\geq$ 18 is an *adult*



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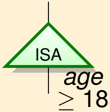

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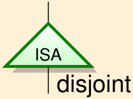

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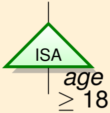

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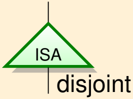
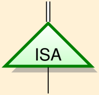


- default is **overlapping**: can belong to multiple subclasses

Completeness constraints

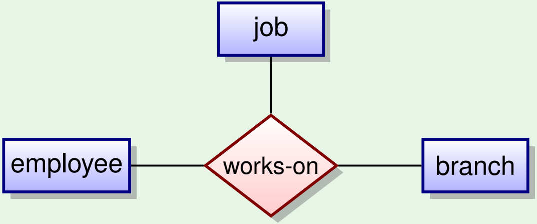
- **total specialisation (generalisation)** constraint: each superclass entity must belong to a subclass; e.g. a *person* is either a *minor* or an *adult*



Data Modelling :: Aggregation

Aggregation

Consider the *works-on* relation we have seen before.



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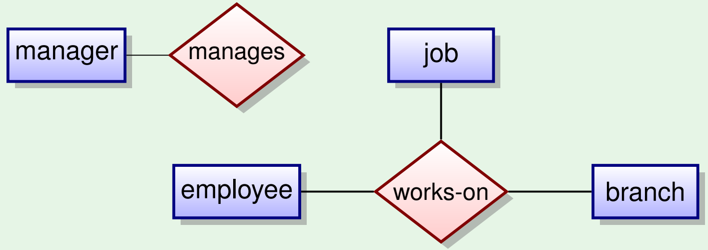
We now want to express that a task performed by an employee might have a manager assigned to it.



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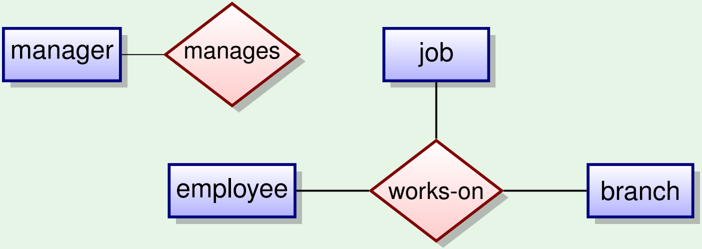

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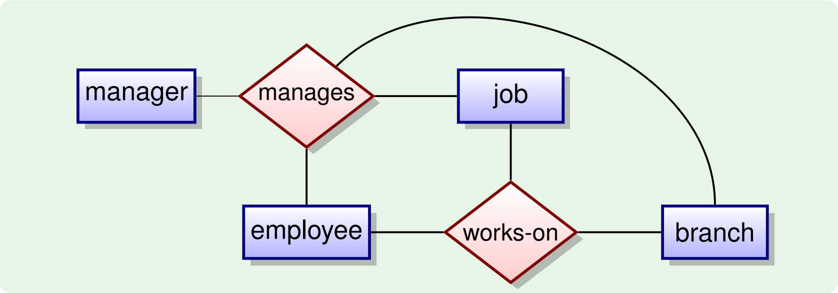

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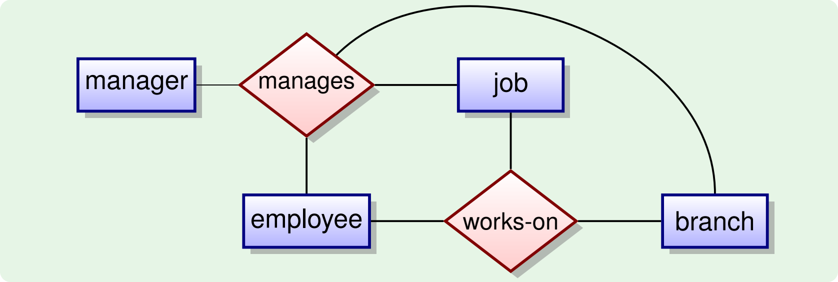

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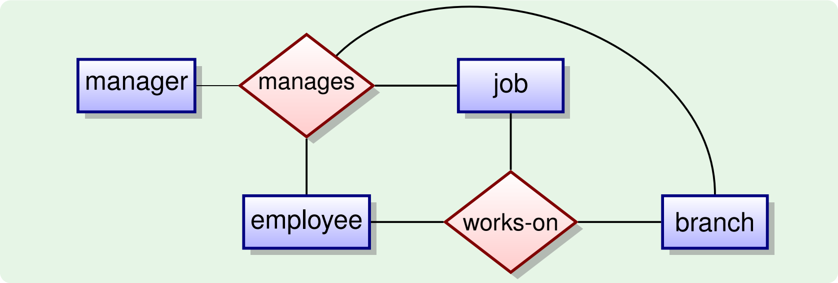
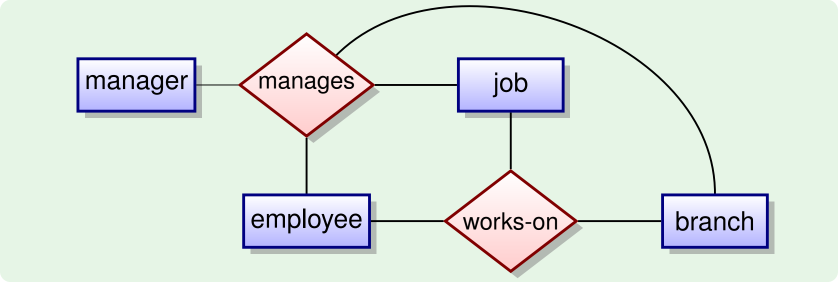


However, this design is not good:

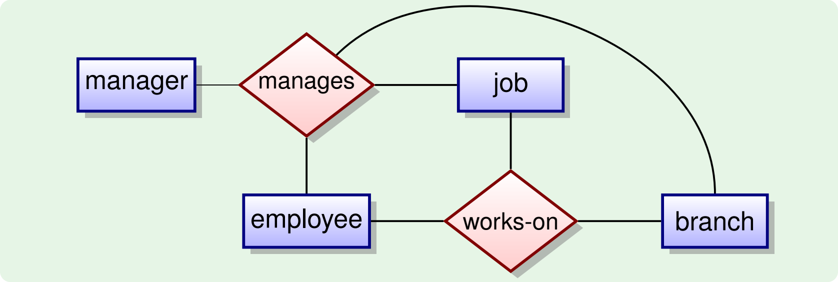
Aggregation



However, this design is not good:

- **does not capture:** every *manages* relationship corresponds to a *works-on* relationship;
- information is represented **redundant/overlapping**;
- **we cannot discard the works-on relationship set:** some *works-on* relationships may not correspond to any *manages* relationship.

Aggregation



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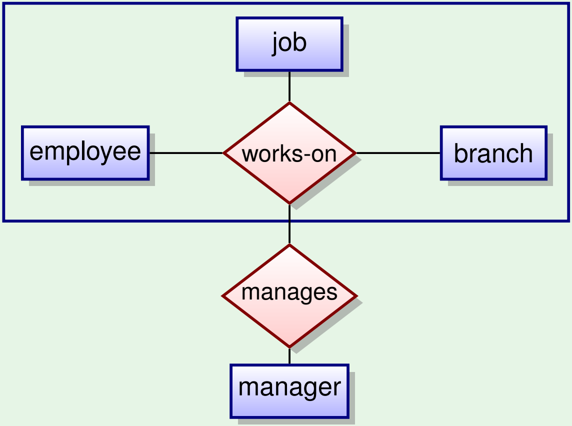
The solution is to eliminate redundancy using **aggregation**!

Aggregation

Aggregation:

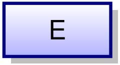
- treat relationship set as an abstract entry

  abstraction of a relationship into a new entry
- allows relations between relations

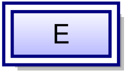


Data Modelling :: Notation Summary

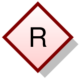
Entity-Relationship Models Summary



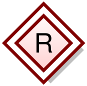
entity set



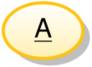
weak entity set



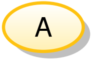
relationship set



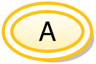
identifying relationship set for weak entity set



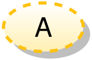
primary key



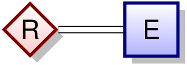
attribute



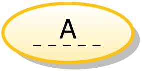
multi-valued attribute



derived attribute

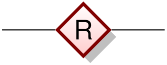


total participation of entity set in relationship

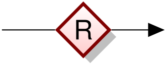


discriminating attribute of weak entity set

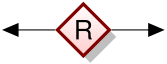
Entity-Relationship Models Summary



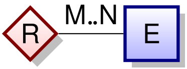
many-to-many relationship



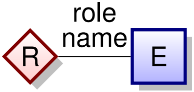
many-to-one relationship



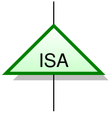
one-to-one relationship



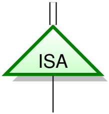
cardinality limits



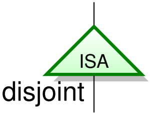
role indicator



ISA (generalisation or specialisation)



total generalisation



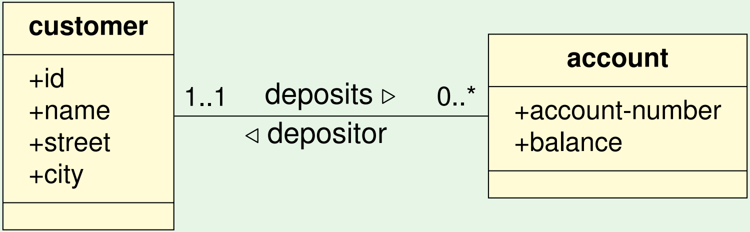
disjoint generalisation

Data Modelling :: Unified Modelling Language

Unified Modelling Language

UML = Unified Modeling Language

Example schema as UML class diagram



customer

+id
+name
+street
+city

1..1 deposits ▷ 0..*

◁ depositor

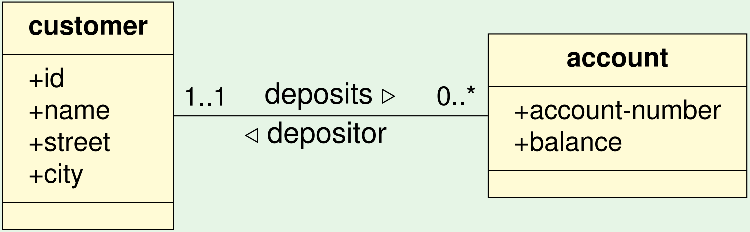
account

+account-number
+balance

Unified Modelling Language

UML = Unified Modeling Language

Example schema as UML class diagram

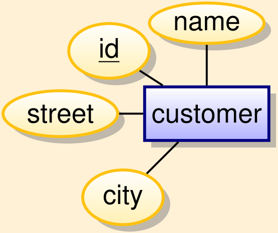


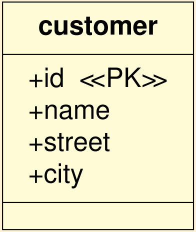
- UML diagrams are similar to ER diagrams

  However, there are important differences!

ER Models vs. UML Class Diagrams

Entity Sets and Attributes



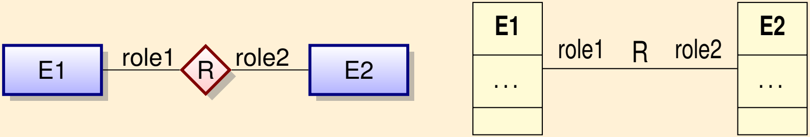

customer

+id ≪PK≫
+name
+street
+city

- In UML attributes are shown within the box of the entity set rather than as separate ellipses in ER models.

ER Models vs. UML Class Diagrams

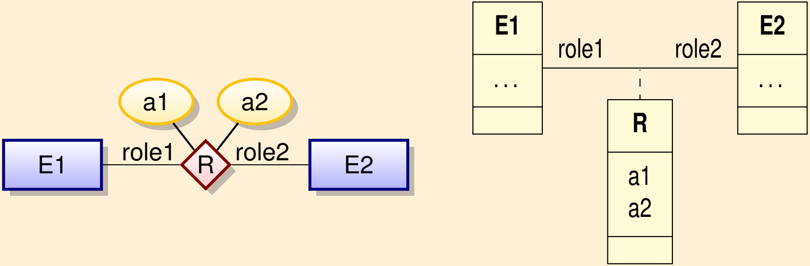
Binary Relationships



- In UML binary relationship sets are represented by a line connecting the entity sets. The name of the relationship set is written adjacent to the line.

ER Models vs. UML Class Diagrams

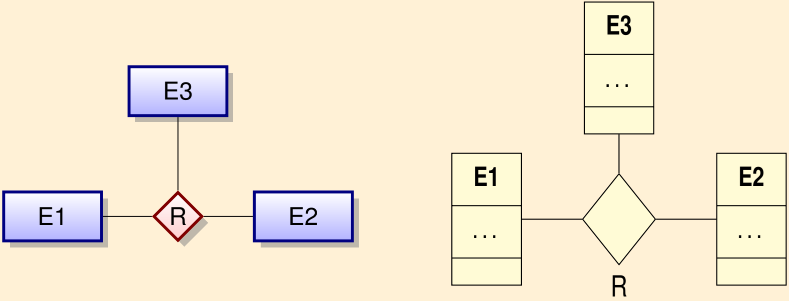
Binary Relationships with Attributes



- If the relationship set has attributes, then the name of the relationship set is written in a box together with the attributes of the relation.
- The box is then connected using a dashed line to the line corresponding to the relationship set.

ER Models vs. UML Class Diagrams

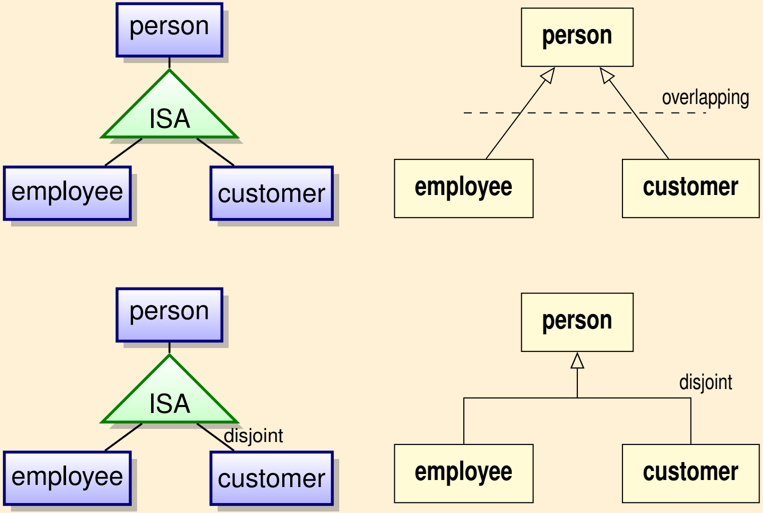
Non-Binary Relationships



- Non-binary relationship sets are drawn using a diamond.

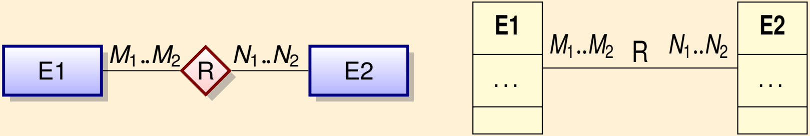
ER Models vs. UML Class Diagrams

Generalisation and Specialisation



ER Models vs. UML Class Diagrams

Cardinality Limits

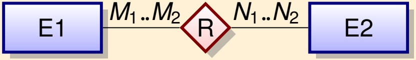


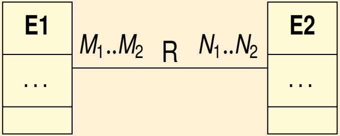
The cardinalities indicate that:

- each E2 entity is related to $\geq M_1$ and $\leq M_2$ entities in E_1
- each E1 entity is related to $\geq N_1$ and $\leq N_2$ entities in E_2

ER Models vs. UML Class Diagrams

Cardinality Limits





The cardinalities indicate that:

- each E2 entity is related to $\geq M_1$ and $\leq M_2$ entities in E_1
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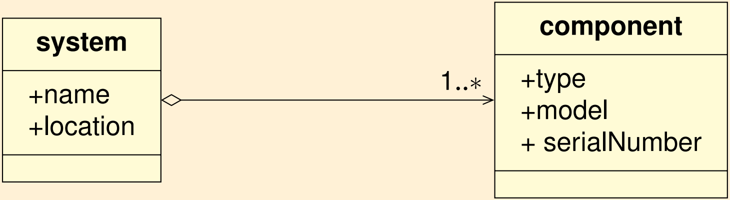
In UML we have the following abbreviations:

- 1 stands for 1..1
- $*$ stands for 0..$*$

Often better to write fully 1..1 and 0..$*$.

UML: Aggregation and Composition

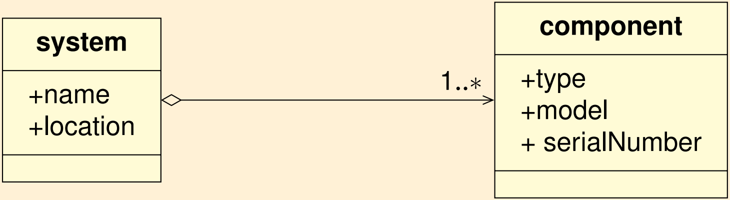
Aggregation in UML



- **Aggregation:** system is a collection of components
- **Composition:** if the diamond would be filled black, it would mean that every component belongs to one system (1..1)

UML: Aggregation and Composition

Aggregation in UML



- **Aggregation:** system is a collection of components
- **Composition:** if the diamond would be filled black, it would mean that every component belongs to one system (1..1)

It is important to note the difference with ER models:

- In ER aggregation allows to treat relations as entities.
- Composition in UML is similar to weak entities in ER.

  However, composition in UML says nothing about keys.

Differences: ER Models vs. UML Class Diagrams

- visual differences — no big deal
- **keys**:
  - ER supports keys (underlining)
  - UML has no standard for indicating keys

    Some people underline, others write PK after the attribute.
- **aggregation**: means something very different
  - in ER: treating a relationship set as an entity
  - in UML: a part-whole relation
    (non-exclusive form of composition)
- **weak entities**:
  - in ER: weak entities are entities without own key
  - in UML: composition is similar, but says nothing about keys