# E-R Modeling*

## Part 1: Concepts and Basic Elements

Goals for E-R module:

- Discuss semantic modeling as part of systems analysis and design
- Introduce basic E-R concepts
- Illustrate E-R modeling by discussing a series of examples
- Prepare the student to begin doing E-R modeling

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## Preliminaries: The database design problem

Given the need for a system requiring use of a (relational) database, how should the database be designed? What should the database (logical) *schema* be, i.e., what should the tables (relations) be and what attributes (fields) should they have?

Typical life-cycle for solving this problem:

1. Requirements collection and analysis
2. Conceptual design

   (leading to a conceptual schema via, e.g., an E-R model)
3. Logical design

   (leading to a database (logical) schema)
4. Physical design

Now: conceptual design

## Preliminaries (con't.)

- Requirements typically given in sentences; descriptions of what the system should do or represent. Hence: inherently "semantic."

- Database conceptual modeling attempts to represent requirements in a more rigorous, clear and operationalizable way. "Semantic modeling."

- E-R modeling is a form of semantic modeling. A well-established and accepted form.

  E-R modeling and E-R diagramming is the "industry standard" approach for the initial phases of a database design venture.

# Entity Types

**Entity type:** An entity type represents a concept in the real world. It is given as a pair $(E, \{A_1, \ldots, A_n\})$, where $E$ is the name and $\{A_1, \ldots, A_n\},\ n \geq 0$ are the attributes (value properties) of a type.

**Attribute:** a relevant property of entities of a given type. Each attribute can have *values* from a given *domain*.

**Example 2.1**
*(Continent, {name, area})*
*(City, {name, population, longitude, latitude}),*
*(Province, {name, area, population}),*

□

# Entities

- An **entity set** $e$ of an entity type $E$ is a finite set of entities.
- each **entity** describes a real-world object. Thus, it must be of one of the defined entity types $E$. It assigns a value to each attribute that is declared for the entity type $E$.

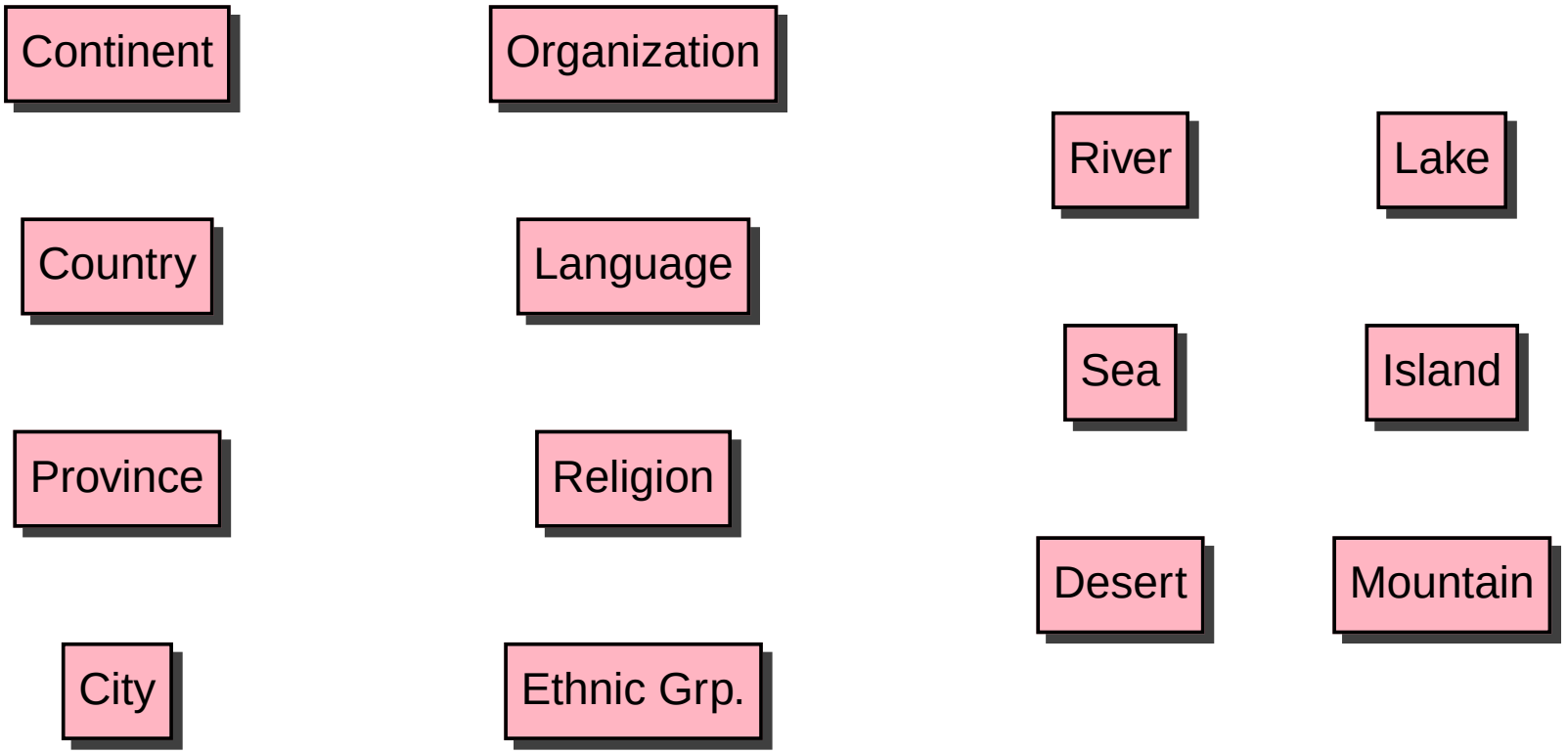
**Example 2.2**

*Entity set of the entity type (City, {name, population, longitude, latitude}):*

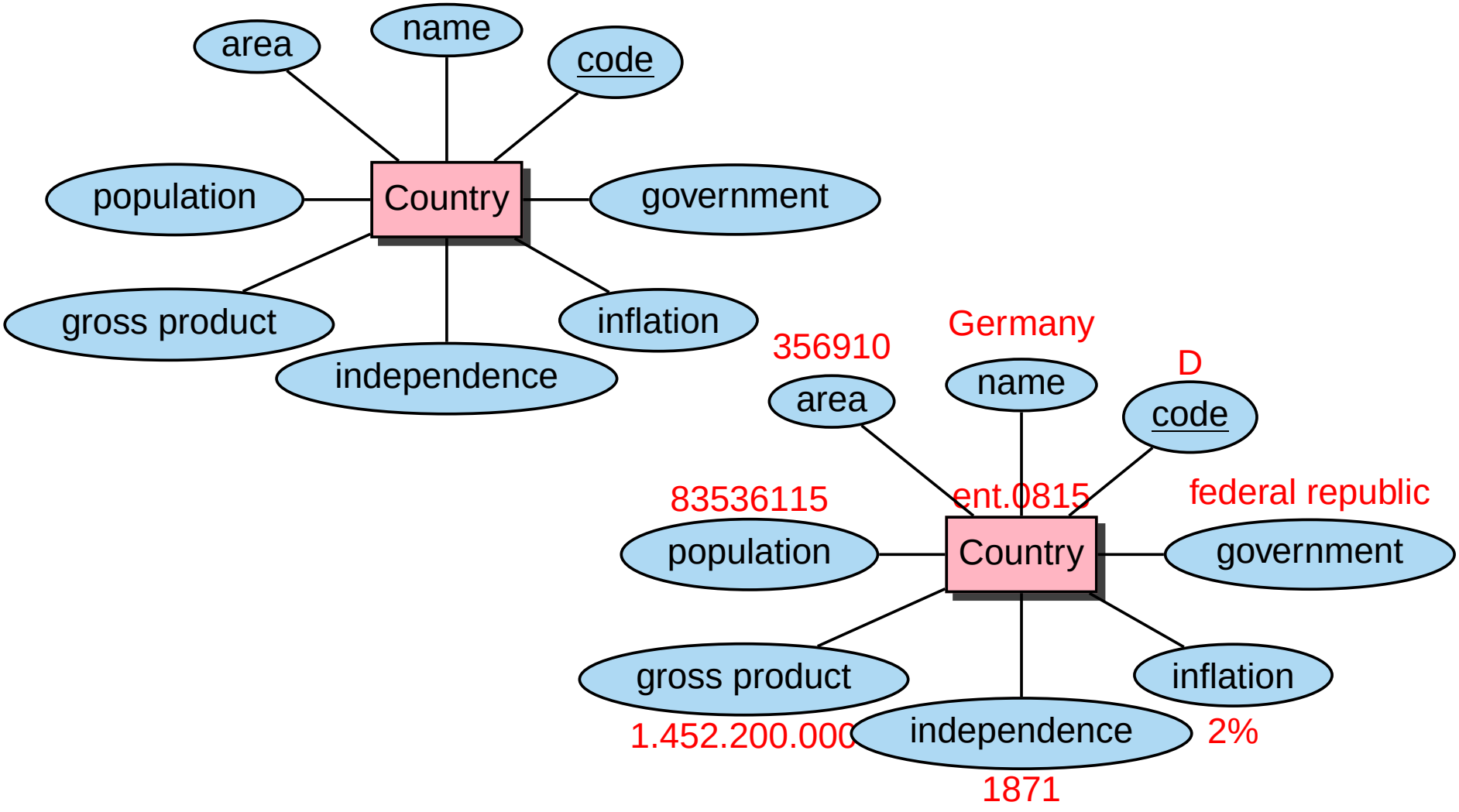
*{(name: Aden, population: 250000, longitude: 50, latitude: 13),*
*(name: Katmandu, population: 393494, longitude: 85,25, latitude: 27,45),*
*(name: Ulan_Bator, population: 479500, longitude: 107, latitude: 48)}* □

# Graphical Representation

- Entity types are represented as rectangles



- Attributes are represented as ovals



# Relationship Types

**Relationship type:** describes a concept of relationships between entities. It is given as a triple $(B, \{RO_1 : E_1, \ldots, RO_k : E_k\}, \{A_1, \ldots, A_n\})$, where $B$ is the name, $\{RO_1, \ldots, RO_k\},\ k \geq 2$, is a list of *roles*, $\{E_1, \ldots, E_k\}$ is a list of entity types associated to the roles, and $\{A_1, \ldots, A_n\}, n \geq 0$ is the set of attributes of the relationship type.

In case that $k = 2$, the relationship type is called **binary**, otherwise $n$**-ary.**

**Roles** are pairwise different – the associated entity types are not necessarily pairwise distinct. In case that $E_i = E_j$ for $i \neq j$, there is a **recursive** relationship.

As long as there are no disambiguities, a role may be identified with the corresponding entity type. Roles are useful e.g. for annotating the semantic aspects of the reality.

**Attributes** describe relevant properties of relationships of a given type.

**Example 2.3**

*(Capital, {City, Country}, ∅),*
*(encompasses, {Continent, Country}, {percent}),*
*(belongsto, {Province, Country}, ∅),*
*(flowsinto, {tributary: River, main: River}, ∅)*

□

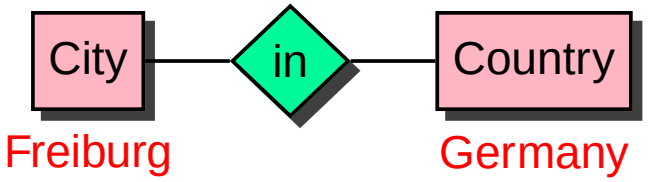
# Relationship Types (Cont'd)

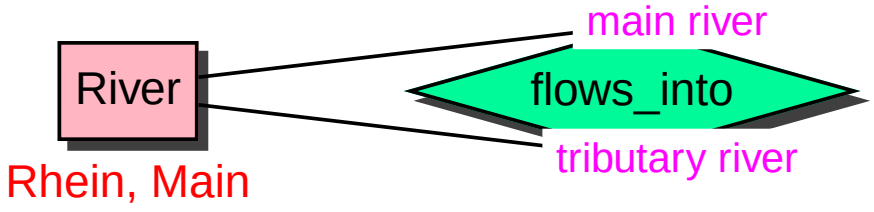
- A **relationship set** $b$ of a relationship type $B$ is a finite set of relationships.
- A **relationship** of a relationship type $B$ is defined by the entities that are involved in the relationship, according to their associated roles. For each role, there is exactly one entity involved in the relationship, and every attribute is assigned a value.

(to be extended with examples)

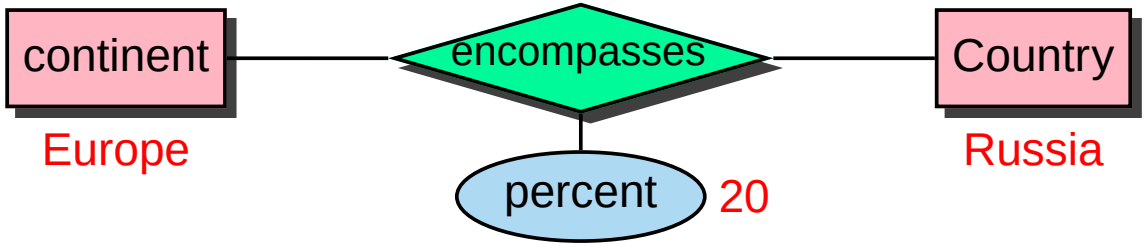
# RELATIONSHIPS

recursive relationship

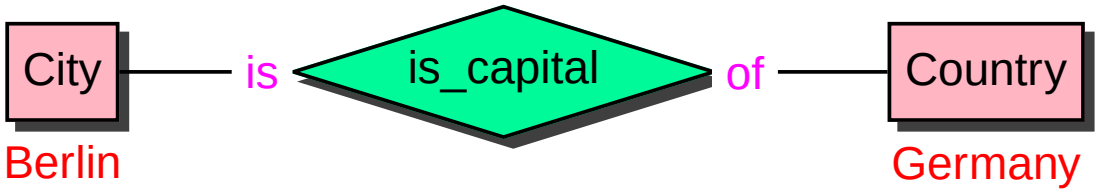


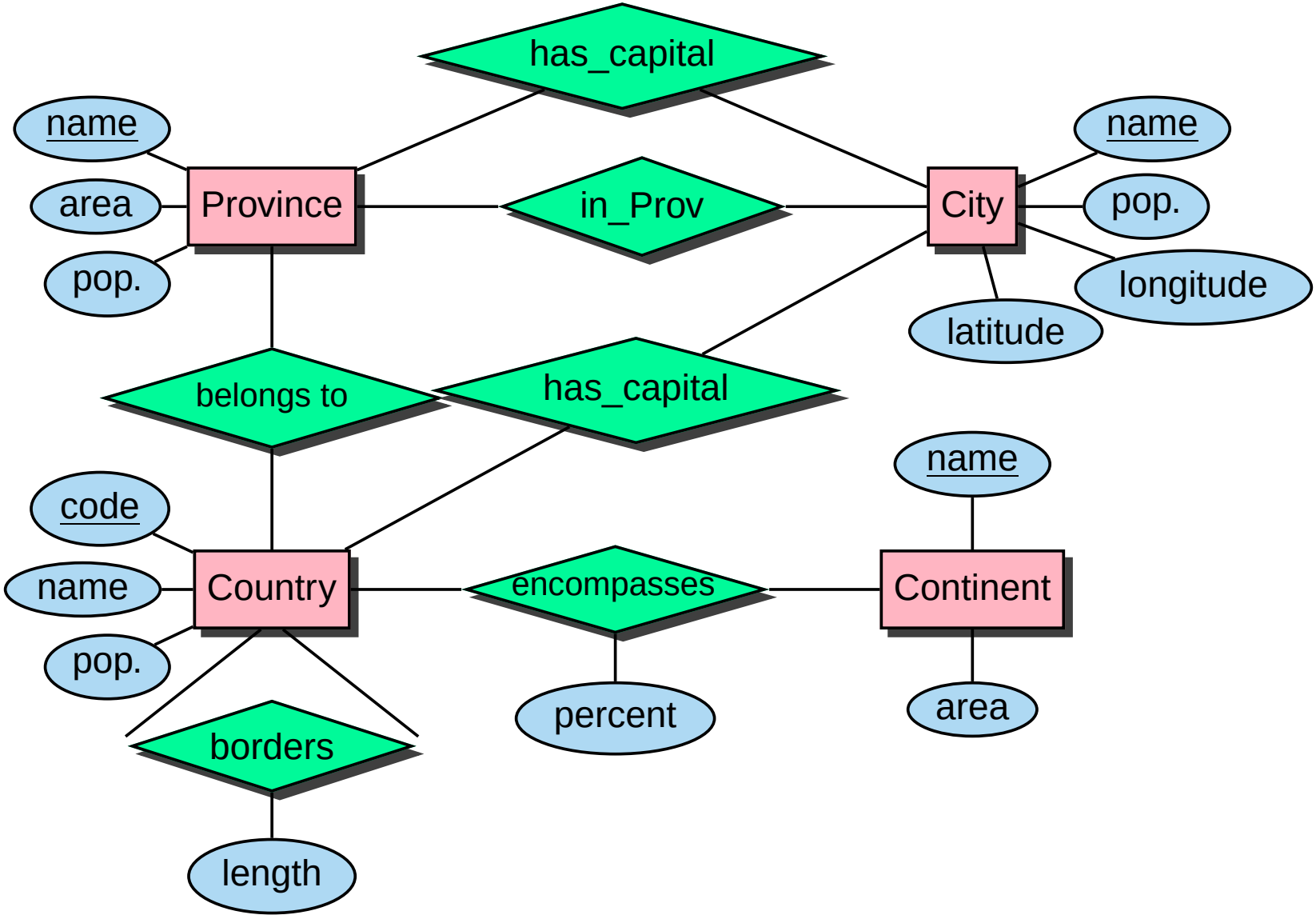

relationship with attributes




relationship with roles



Example: ER Model of a geographical database



# Database States

A **(database) state** associates the entity types and relationship types of a given schema with an **entity set** and a **relationship set**, respectively.

(cf. examples above – can be represented graphical as a graph/network)

## 2.1.2 Integrity Constraints

There are additional constraints on the admissible *database states*.

**Domains:** Every attribute is assigned a domain which specifies the set of admissible values.

**Keys:** a *key* is a set of attributes of an entity type, whose values together allow for a unique identification of all amongst all entities of a given type (cf. *candidate keys, primary keys*).

**Relationship Complexities:** every relationship type is assigned a complexity that specifies the minimal and maximal number of relationships in which an entity of a given type/role may be involved.

**Referential Integrity:** each entity which occurs in a relationship in any database state must also exist in the entity set of this state
(condition is trivial when represented as a graph, but crucial later in the relational model)

... to be described in detail on the following slides

# KEYS

A *key* is a set of attributes of an entity type, whose values together allow for a unique identification of all amongst all entities of a given type (cf. *candidate keys, primary keys*).

For an entity type $(E, \{A_1, \ldots, A_n\})$ and an entity set $e$ of $E$, a set $K \subseteq \{A_1, \ldots, A_n\}$ satisfies the **key constraint** if:

- $K$ uniquely **identifies** any element $\mu \in e$, i.e., for all $\mu_1, \mu_2 \in e$, if $\mu_1$ and $\mu_2$ have the same values for all attributes in $K$, then $\mu_1 = \mu_2$.

Declaring a set of attributes to be a key thus states a condition on all admissible database states.

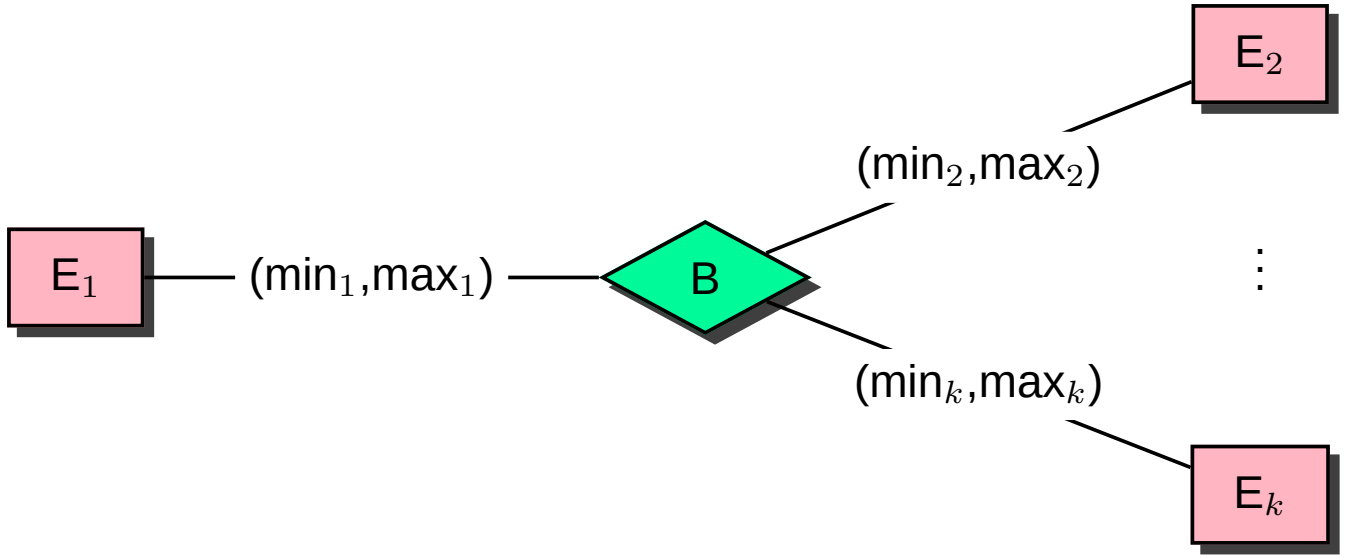
Graphically, key attributes are distinguished by underlining.

# Relationship Complexities

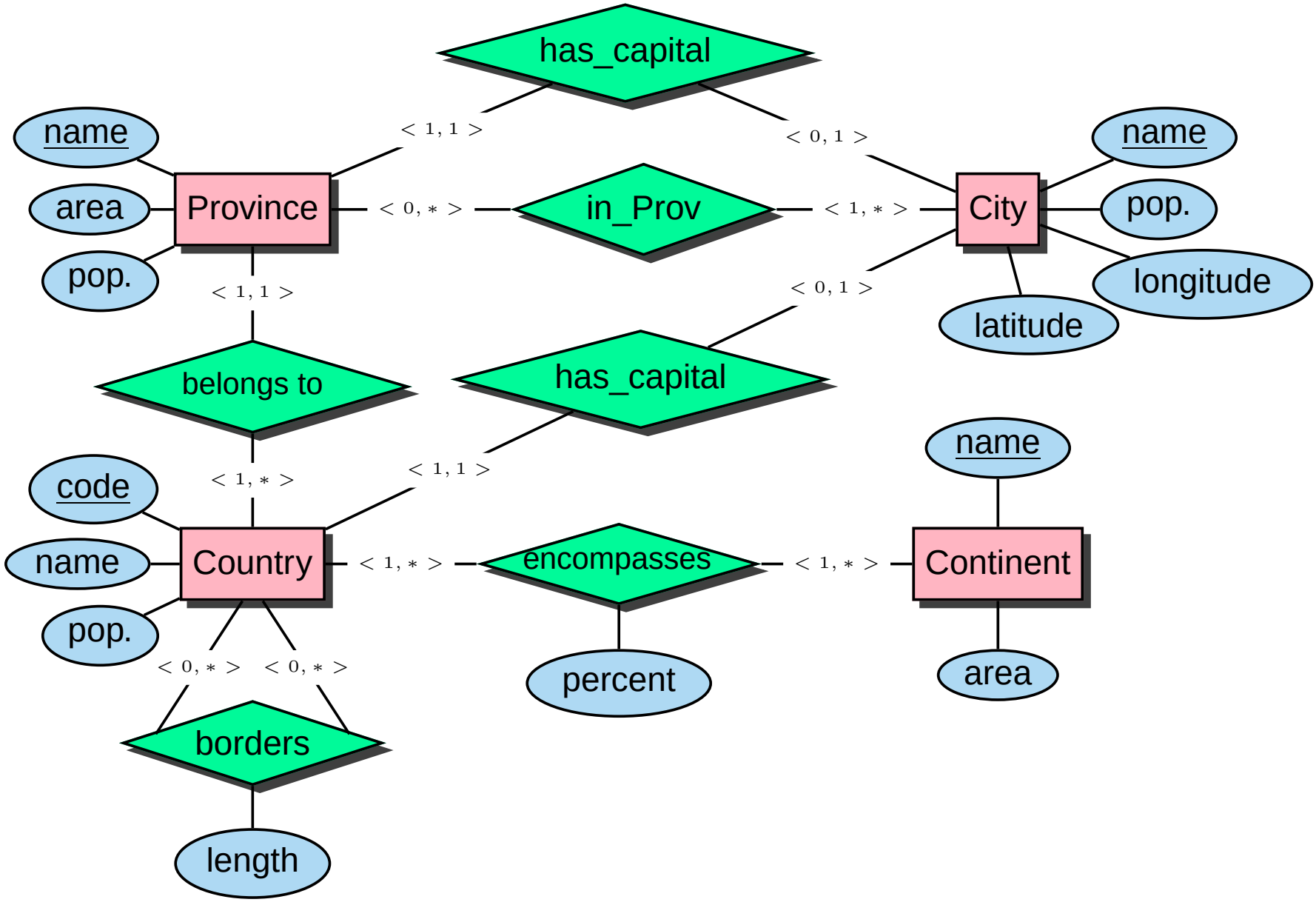
Every relationship type is assigned a complexity that specifies the minimal and maximal number of relationships in which an entity of a given type/role may be involved.

The **complexity degree** of a relationship type $B$ wrt. one of its roles $RO$ is an expression of the form $(min, max)$ where $0 \leq min \leq max$, and $max = *$ means "arbitrary many".

A set $b$ of relationships of relationship type $B$ satisfies the complexity degree $(min, max)$ of a role $RO$ if for all entities $\mu$ of the corresponding entity type $E$, the following holds: there exist at least $min$ and at most $max$ relationships $b$ in which $\mu$ is involved in the role $RO$.



# Example: ER Model of a geographical database



## Additional Notions for Complexity Degrees

For *binary* relationships, the following notions are used:

- if $max_1 = max_2 = 1$, it is called a $1:1$-relationship.
  is_capital(country:city) is a 1:1-relationship
- if $max_1 > 1, max_2 = 1$, it is called a $n:1$-relationship (functional relationship) from $E_2$ to $E_1$, and a $1:n$-relationship from $E_1$ to $E_2$.
  has_city(country:city) is a 1:n-relationship
- Otherwise, it is called an $n:m$-relationship.
  borders(country:country) is an n:m-relationship

# Referential Integrity

Each entity which occurs in a relationship in any database state must also exist in the entity set of this state.

For a relationship type $B$ with relationship set $b$, a role $RO$ of $B$ that is connected to an entity type $E$ with entity set $e$, $b$ and $e$ **satisfy the referential integrity** wrt. $RO$, if for every entity $\mu$ that is associated with some $\nu \in b$ under the role $RO$, $\mu \in e$ holds.

**Note:**

- referential Integrity is inherent to the ER Model, thus, it is not necessary to care for it.
- there are data models (e.g., the *relational model* (which is described later) where referential integrity must be enforced explicitly).
  (postpone the discussion to the relational model)

## 2.1.3 Further Concepts

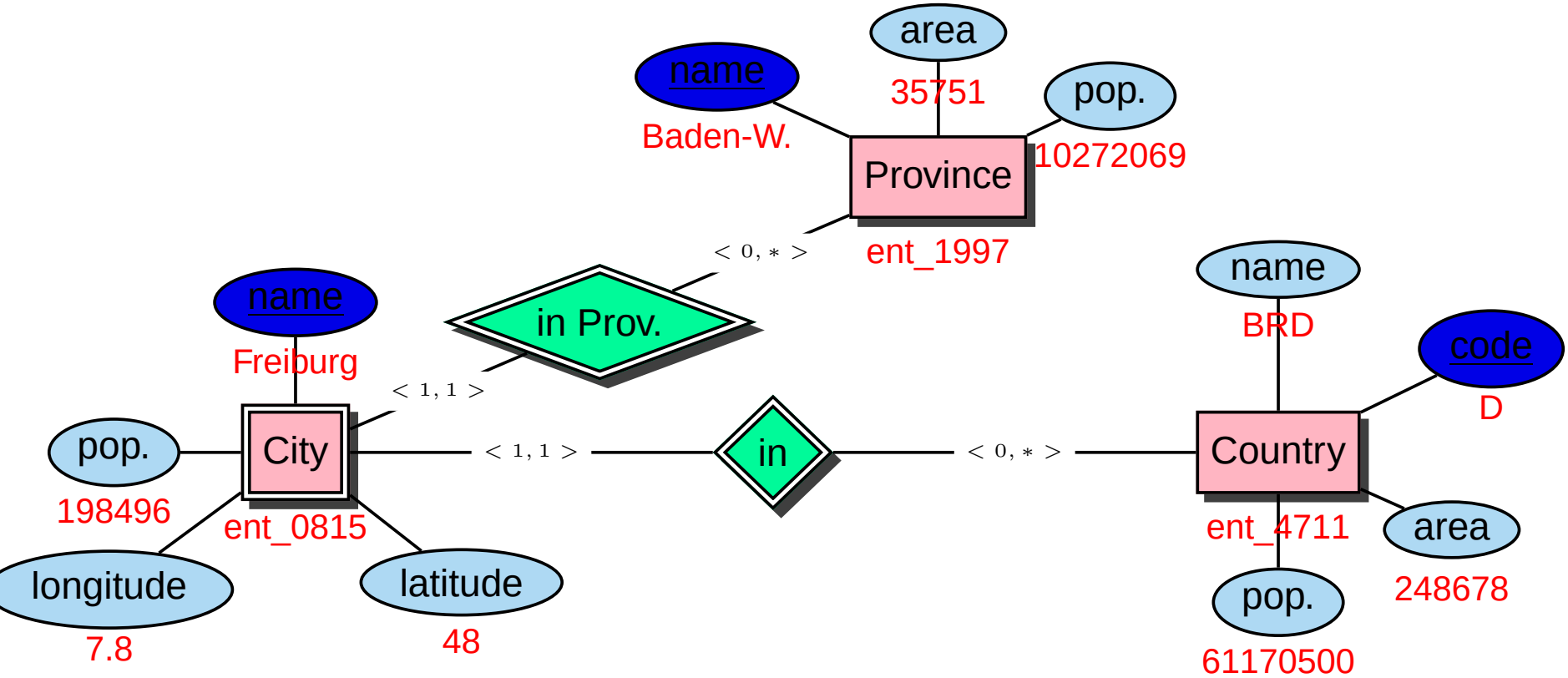
### Weak Entity Types

A weak entity type is an entity type without a key.

Thus entities of such types must be identified by the help of another entity (see the following figure).

- Weak entity types must be involved in at least one $n:1$-relationship with a strong entity type (where the strong entity type stands on the 1-side).
  - this relationship is called an *identifying relationship*,
  - the corresponding entity type is called an *identifying entity type*.
- They must have a **local** key, i.e., a set of attributes that can be extended by the primary keys of the corresponding strong entity type to provide a key for the weak entity type (*key inheritance*).
- Note that weak entity types and their identifying relationship types have a special notation.

# Weak Entity Types



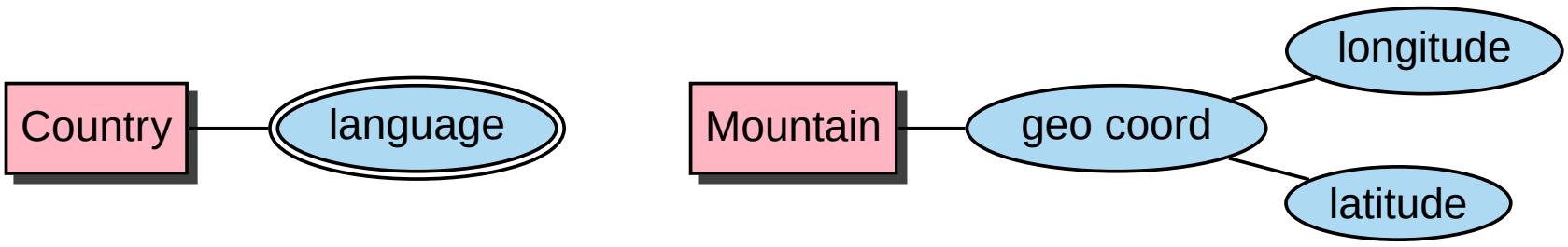

There is also a Freiburg/CH

and Freiburg/Elbe, LowerSaxonia (Niedersachsen)

# Extensions of the ERM: Attributes

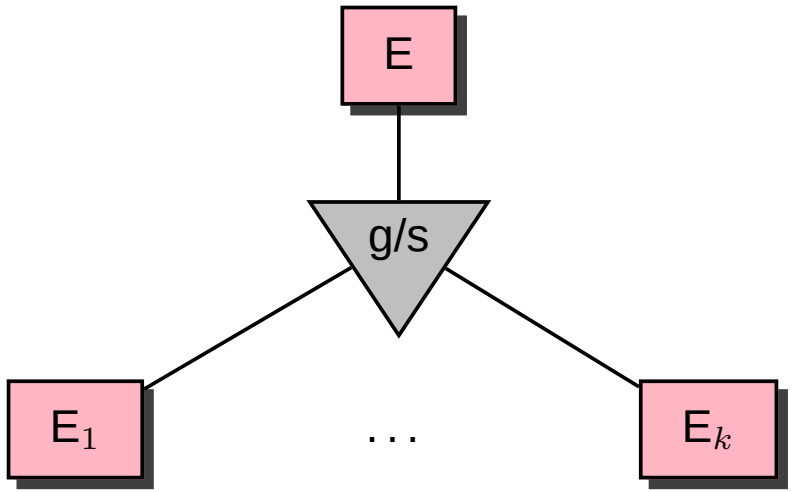
Attributes can be

- set-valued or multi-valued,
- structured



# Extensions of the ERM: Generalization/Specialization

Abstractions that allow for grouping entities of different, but related types to a more general type.

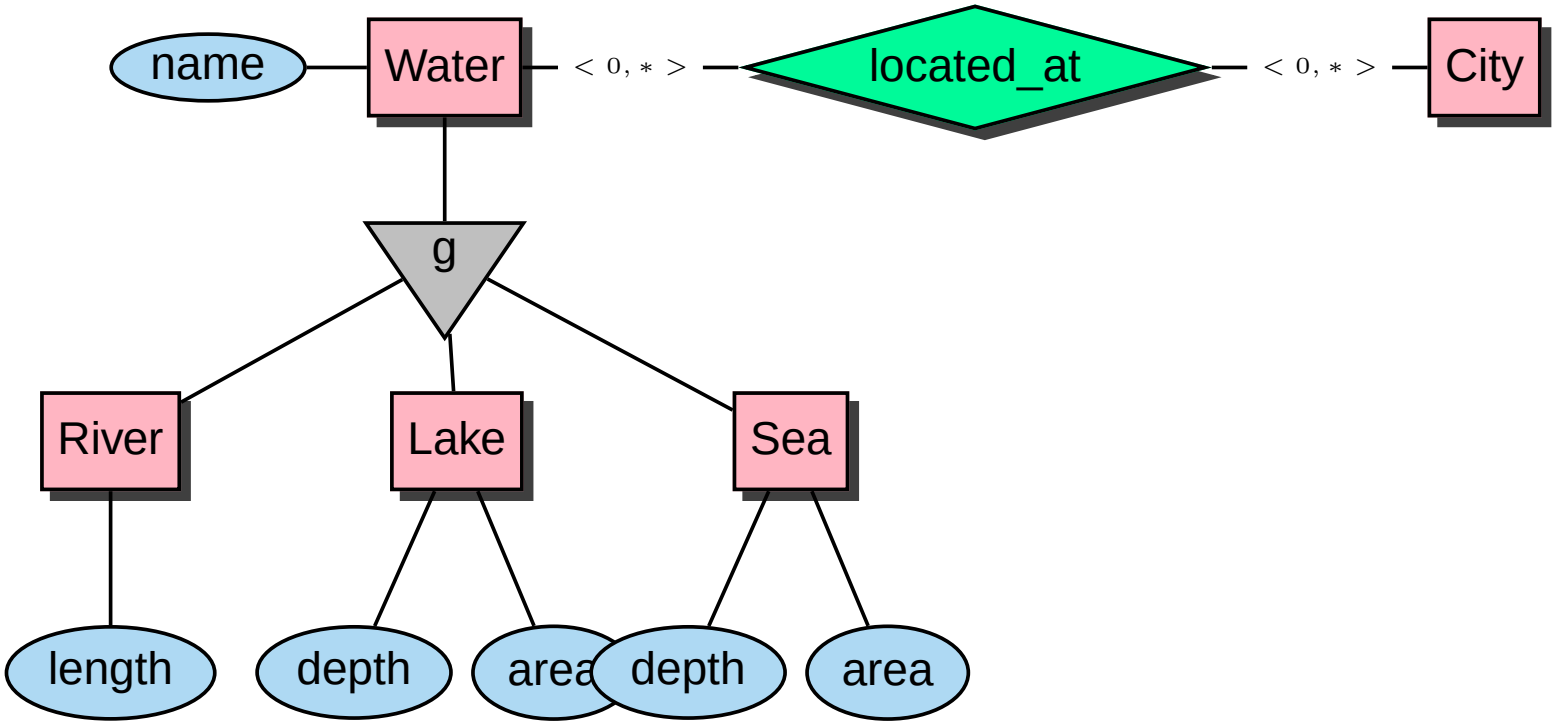



$E$ is called **supertype**, $E_i$ are **subtypes** for $1 \leq i \leq k$. Each entity of a subtype s also an entity of the supertype.

- The common attributes and relationships are assigned to the more general type.
- The attributes and relationships of the supertype are also applicable to the subtypes (which may define further attributes and relationships).

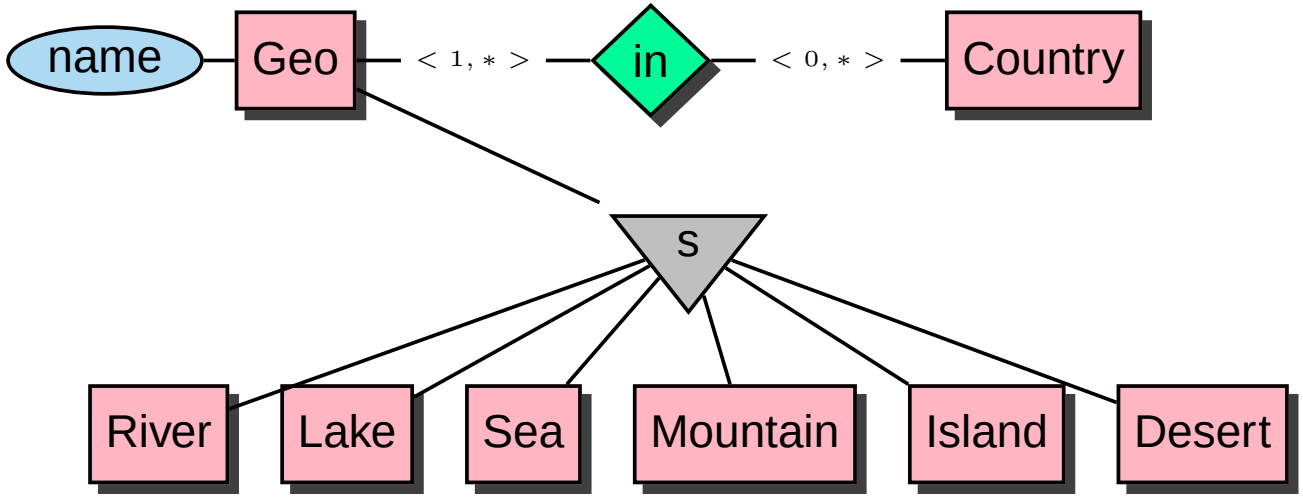
# GENERALIZATION/SPECIALIZATION

- Generalization: rivers, lakes, and seas are *waters*. These can e.g. be involved in *located-at* relationships with cities:



# GENERALIZATION/SPECIALIZATION

- Specialization: MONDIAL does not describe all geographical things, but only rivers, lakes, seas, mountains, deserts, and islands (no lowlands, highlands, savannas, fens, etc). All such geographical things have in common that they are involved in *in*-relationships with countries:



# GENERALIZATION/SPECIALIZATION

## Integrity Constraints

- Common integrity constraints **ISA:** ISA is satisfied in a database state if the entity sets of the subtypes are subsets of the entity sets of the supertype,
- optional integrity constraint **Disjointness:** if the entity sets of the subtypes are disjoint,
- optional integrity constraint **Covering:** if the union of the entity sets of the subtypes cover the entity set of the supertype.

# Fan traps

A fan trap occurs when a model represents a relationship between entity types, but the pathway between certain entity occurrences is ambiguous. It occurs when 1:m relationships fan out from a single entity.


A single site contains many departments and employs many staff. However, which staff work in a particular department?
The fan trap is resolved by restructuring the original ER model to represent the correct association.

# Chasm traps

A chasm trap occurs when a model suggests the existence of a relationship between entity types, but the pathway does not exist between certain entity occurrences.It occurs where there is a relationship with partial participation, which forms part of the pathway between entities that are related.

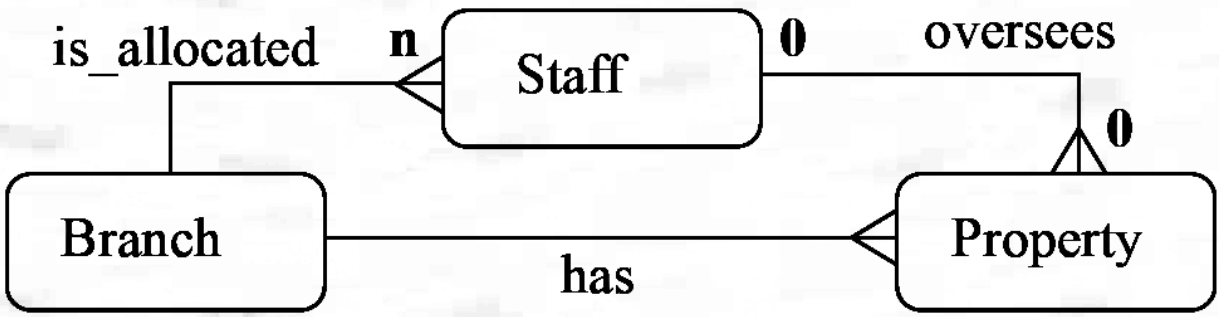

•A single branch is allocated many staff who oversee the management of properties for rent. Not all staff oversee property and not all property is managed by a member of staff.

•What properties are available at a branch?

•The partial participation of Staff and Property in the oversees relation means that some properties cannot be associated with a branch office through a member of staff.

•We need to add the missing relationship which is called ‘has’between the Branch and the Property entities.

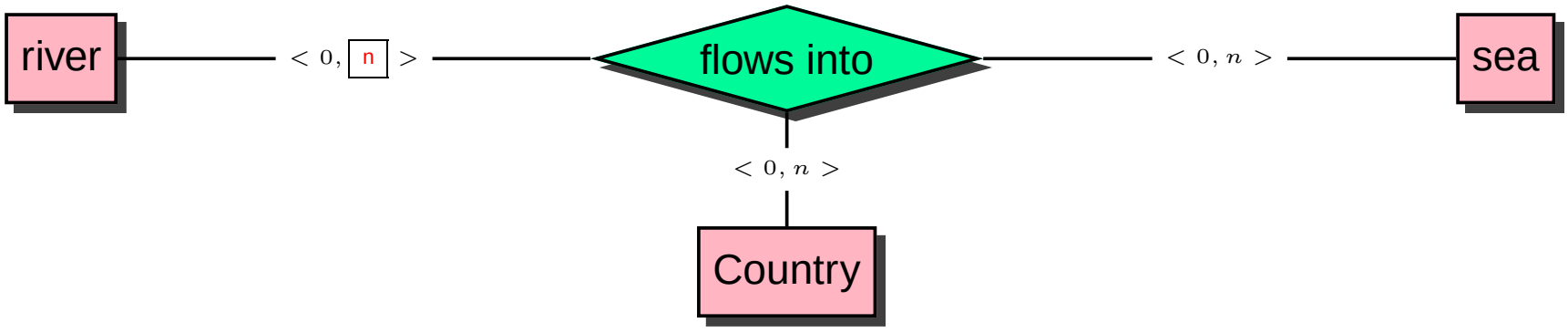
•You need to therefore be careful when you remove relationships which you consider to be redundant.



# EXTENSIONS OF THE ERM: AGGREGATION

The ERM does not allow to define relationship types that involve relationship types (note that attributes of relationship types are allowed). This restriction is overcome by defining artificial entity types.

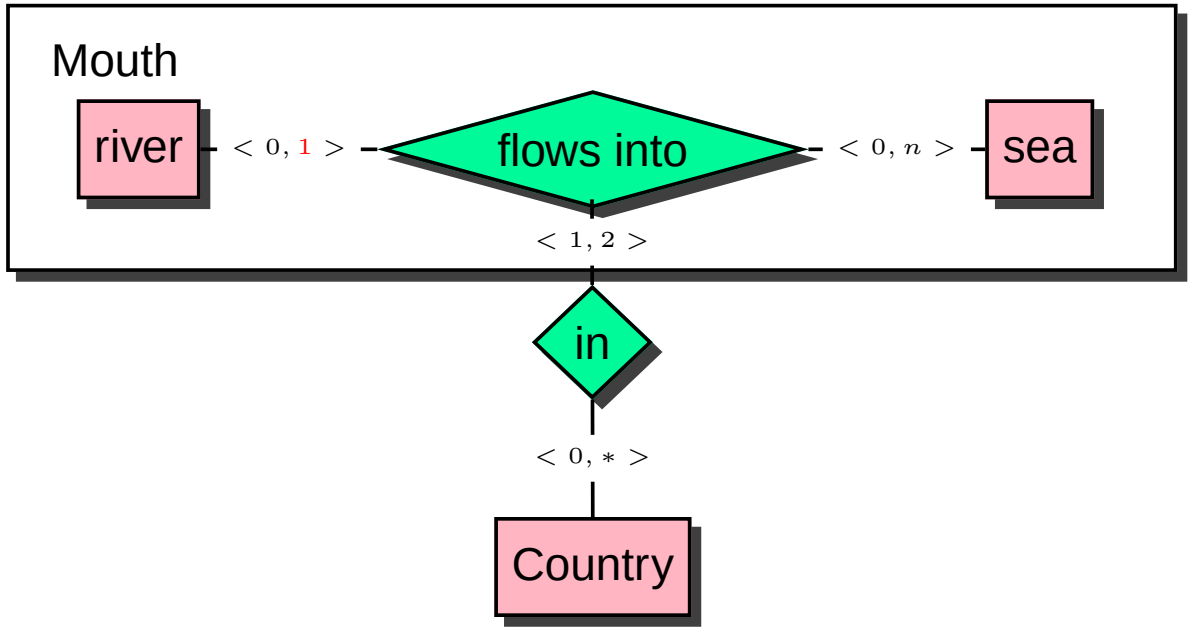
A river flows into a sea/lake/river; more detailed, this point can be described by giving one or two countries.




This representation is ambiguous: A river could flow in two seas!?

# AGGREGATION

Using aggregation, this information can be specified much clearer by introducing an *aggregate type mouth*:




The complexity degrees allow for expressing a more detailed semantics than with the plain ternary relationship type.

## 2.1.4 Discussion ERM

- With the structuring concepts of the ERM and its extensions, the *static* aspects of a relevant excerpt of the real world can be modeled semantically adequate in a natural way.
- The graphical representation is also understandable for non-computer-scientists.
- The ERM is useful
  - in the early stages of the design of the database (i.e., when designing the conceptual schema) when discussions with the potential users take place.
  - for documentation (!)
- The ERM can easily be transformed into the data models of existing, real-world database systems (especially, into the relational model – as will be shown in the sequel).
- There are no relevant DBMS that use the ERM directly. They are subsumed by **object-relational** and **object-oriented** DBMS [cf. Lecture on *Information Systems*] (and recently also by XML-based DBMS [cf. Lectures *Databases in the Internet* and *Semistructured Data and XML*]).