# Database Security

## Security Tasks

- Authentification: verifying the id of a user
- Authorization: checking the access privileges
- Auditing: looking for violations (in the past)

# Data Security

Dorothy Denning, 1982:

- "Data Security is the science and study of methods of protecting data (...) from unauthorized disclosure and modification"

- Data Security = <u>Confidentiality</u> + <u>Integrity</u>

# How to attack an IT System?

- Misuse of Authority
- Inference and Aggregation
- Masking
- Bypass Access Control
- Browsing
- Trojans
- Hidden Channels

# Security in Databases

- Privacy (Confidentiality)
  - Do not allow access to private information
  - But support statistic analyses over private information
  - Avoid inference attacks (e.g., there is only one 42y man)
  - Q does not leak info for secret S if: **$P(S \mid Q) = P(S)$**

```
SELECT count(*)
FROM    Patient
WHERE age=42
      and sex=‘M’
      and diagnostic=‘schizophrenia’
```

OK?

```
SELECT name
FROM    Patient
WHERE age=42
      and sex=‘M’
      and diagnostic=‘schizophrenia’
```

Not OK

# SQL Injection

Problem: Naïve implementation of GUIs:

Login:

User: fred

Password: *********

Search Box in Application (SQL Interface in Anwendung):

Search: Dr. Lee

SELECT…FROM…WHERE doctor=‘Dr. Lee’ and patientID=‘fred’

# SQL Injection

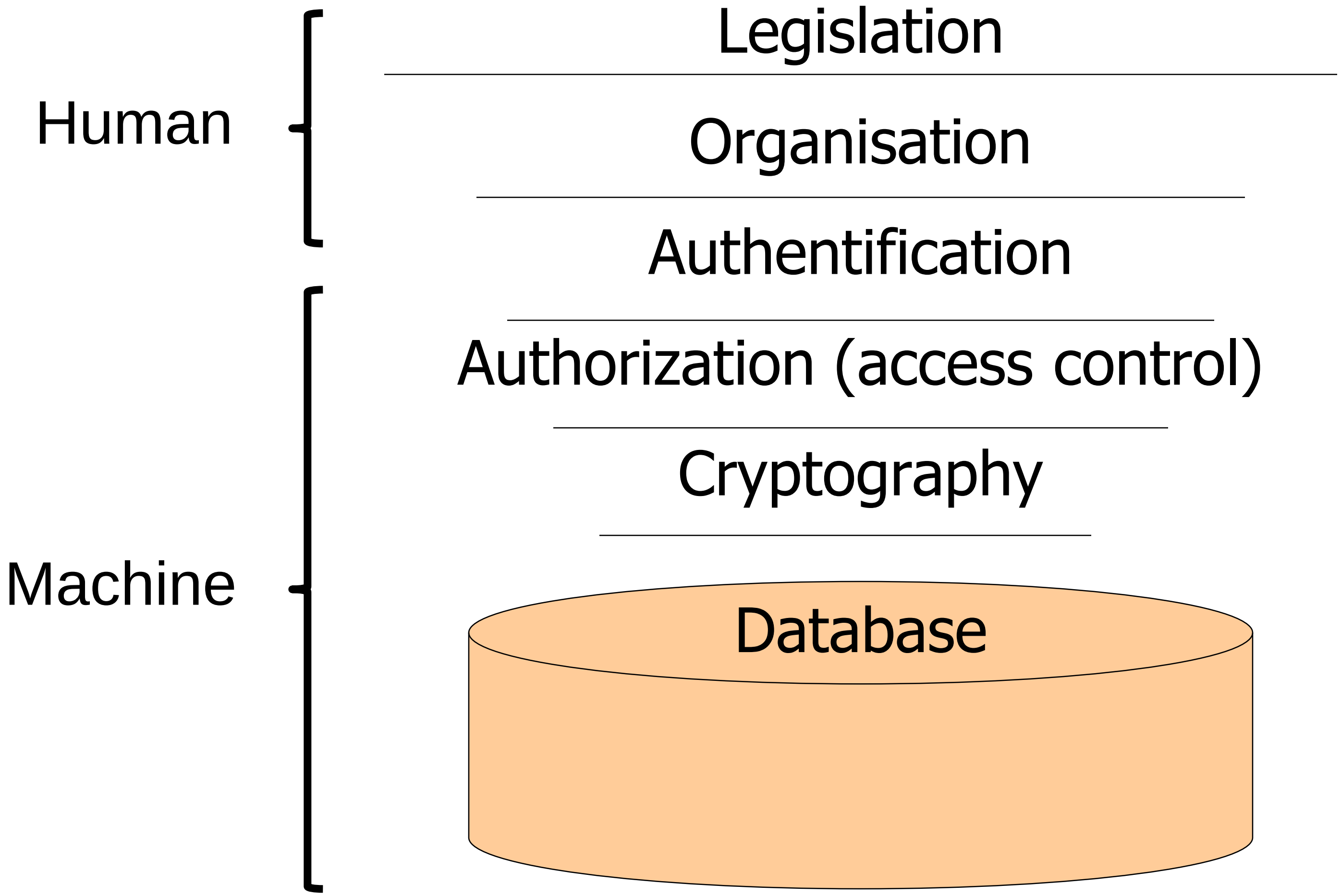
Another example of poor application implementation:

Search: Dr. Lee'; DROP TABLE Patients; --

# SQL Injection: Summary

- The DBMS does the right thing.
  - Why does SQL injection work so often?
- Quick & Dirty Reply:
  - Bad Programmers
  - (easy fix if you are careful in your Java code)
- Sad Truth:
  - Security is implemented in the app and not in the DBMS.
  - (similar discussion as for integrity constraints)
  - Question: How many users does your project DB manage?
    - (Probably, no project has more than one user!)

# Layers of Security




Problem: When human meets machine.

- Authentification and sometimes authorization

# Discretionary Access Control

Access rules (*o, s, t, p, f*):

- o ∈ O, set of *objects* (e.g., table, tuple, attribute)
- *s* ∈ *S*, set of *subjects* (e.g., user, processes, apps)
- *t* ∈ *T*, set of *access rights* (e.g., read, write, delete)
- *p* a predicate (e.g., *Level* = „FP")
- *f* a Boolean value specifying whether *s* may *grant* the privilege (*o, t, p*) to another subject *s*'.

# Discretionary Access Control

| | Unix | SQL |
|---|---|---|
| S | User, groups | User |
| O | Files, directories | DB, tables, tuples, attributes, views |
| T | Read, write, execute | CRUD |
| P | Not supported | Supported via views |
| F | Fixed (owner, root) | Grant option |

# Discretionary Access Control

## Implementation:

- Access matrix
- Views
- „Query Modification“

## Disadvantages:

- Creator of data needs to manage authorizations
- Managing authorizations is cumbersome and error-prone

- Exercise: Find all functional dependencies in the access matrix of Unix! Normalize the access matrix of unix!

# Access Control in SQL

Example:

**grant select**

**on** Professor

**to** eickler;

o=Professor, s=eickler, t=SELECT
implicit: p=true, f=false

**grant update** (Legi, Lecture, PersNr)

**on** tests

**to** eickler;

o=$\Pi$(tests), s=eickler, t=UPDATE
implicit: p=true, f=false

# Access Control in SQL

## Other privileges:

- Delete
- insert
- create references (inference attack)
- grant option (f = true)

## Revoke privileges

```
revoke update (Legi, Lecture, PersNr)
    on tests
    from eickler cascade;
```

# Views

## Implementation of predicates (p in the (o,s,t,p,f) model)

```
create view FirstSemesterStudents as
    select *
    from Student
    where Semester = 1;
grant select
    on FirstSemesterStudents
    to tutor;
```

## Protecting personal records by aggregation

```
create view StrictProf (Nr, AvgGrade) as
    select Nr, avg(Grade)
    from tests
    group by Nr;
```

# Group Access Rights

```
CREATE VIEW StudentGrades AS
 SELECT * FROM tests t
 WHERE EXISTS (SELECT * FROM Student
   WHERE  Legi = t.Legi AND Name = USER)

GRANT SELECT ON StudentGrades
      TO <StudentGroup>
```

- Give students right to access their own test results.
  - specific to Oracle
  - magic „Name = USER" predicate not standardized

# Auditing

- Components of Audits
  - Logging: keep a record of all (interesting) activities
  - Analyze the logs
  - (Ideally query logs with DBMS – in practice not poss.)

```
audit session by system
    whenever not successful;

audit insert, delete, update on Professor;
```

# Summary: Security in SQL

## Cons:

- coarse granularity: objects are tables or views – not tuples
  - Example: auction system; read your own bids, but not bids of others
- responsibility to manage privileges with creator of table
  - Not necessarily the creator of the data
- difficult to deal with DBMS access violations in app layer
  - (Analogous to "Integrity Constraints")

## Implications

- Access control is implemented at the app tier
- App access DB as "super-user"
- **Security features of DB are not used**

## Goal: Increase managability of privileges.

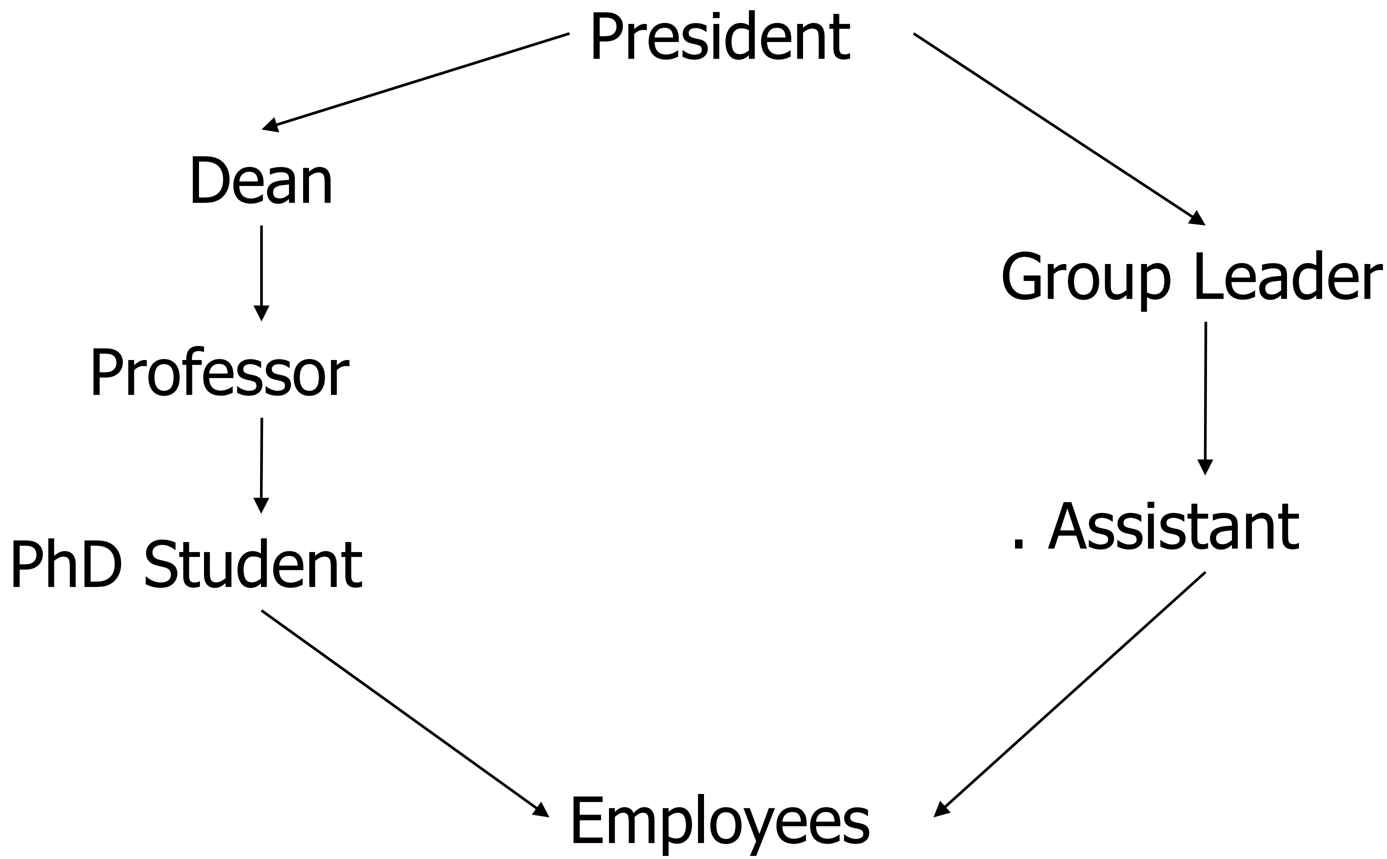
# Kinds of Privileges

- explicit / implicit privileges
- positive / negative privileges
- strong / weak privileges

## Authorization Algo:

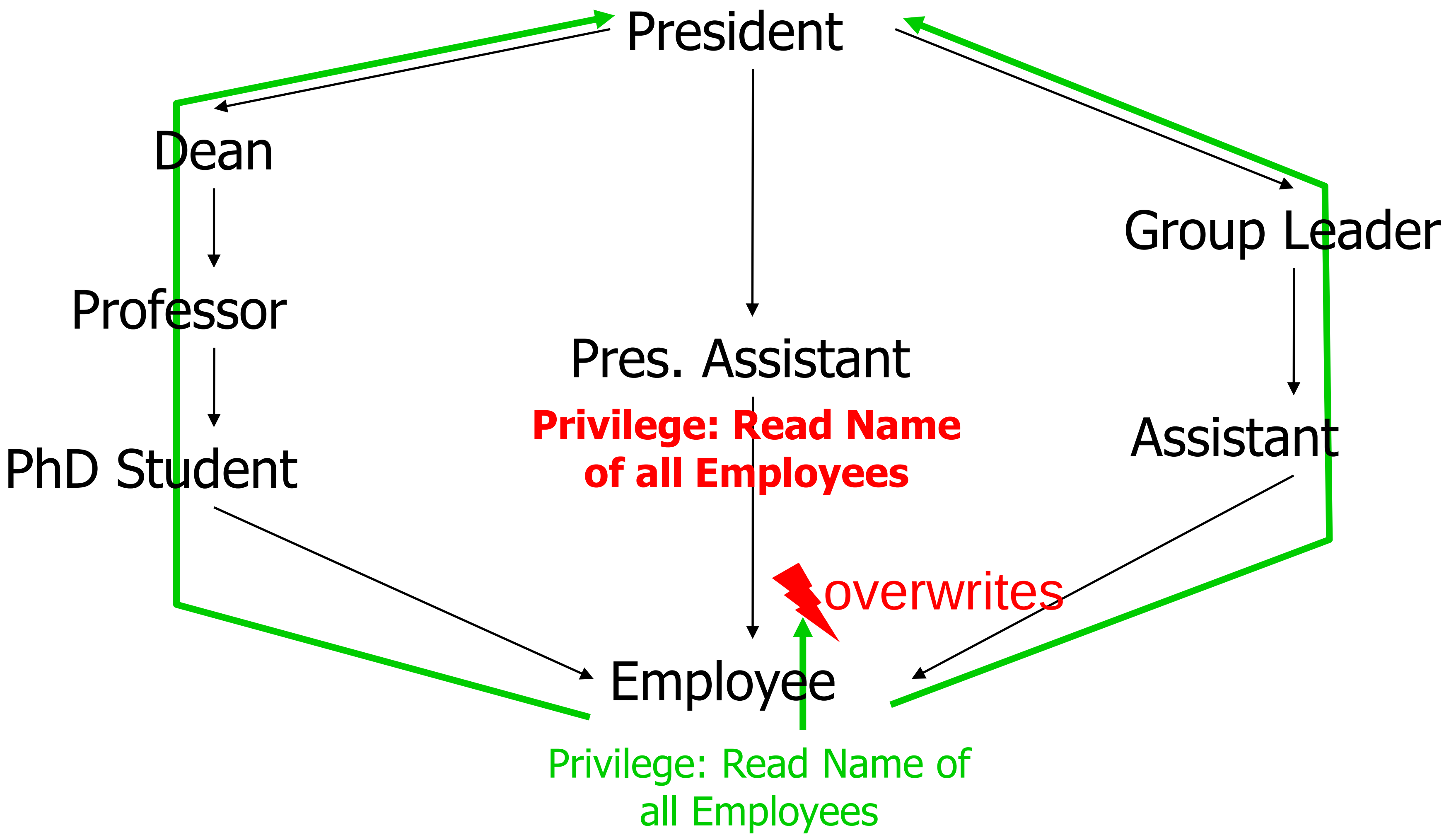
**Input: (o, s, t)** (May Subject *s* access Object *o* using Operation *t* ?)
**Output: Boolean** (grant access / refuse access)
**if** (exists explicit or implicit strong privilege *(o, s, t)* )
    **then** return true
**else if** (exists explicit or implicit strong negative privilege *(o, s, ¬t)* )
    **then** return false
**else if** (exists explicit or implicit weak privilege *(o, s, t)* )
    **then** return true
**else if** (exists explicit or implicit weak negative privilege *(o, s, ¬t)* )
    **then** return false
return false // default: reject

# Implicit Authorization: Subject Hierarchy




- explicit positive privilege at one level
  ⇒implicit positive privileges on all higher levels
- explicit negative privilege at one level
  ⇒implicit negative privilege on all lower levels

# Strong and Weak Privileges



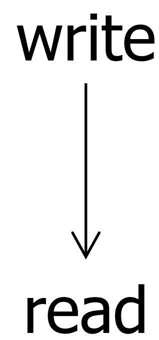

**strong pos. privilege**

weak pos. Privilege

**strong neg. privilege**

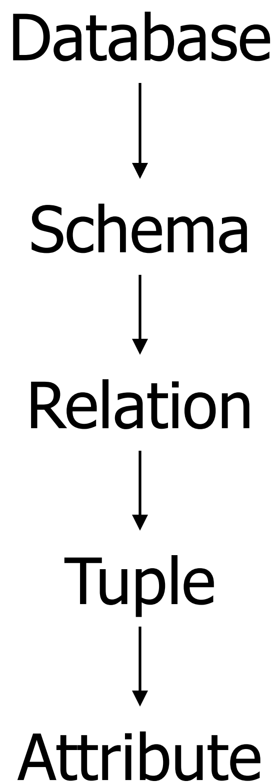
weak neg. privilege

# Implicit Privileges: Operation Hierarchy



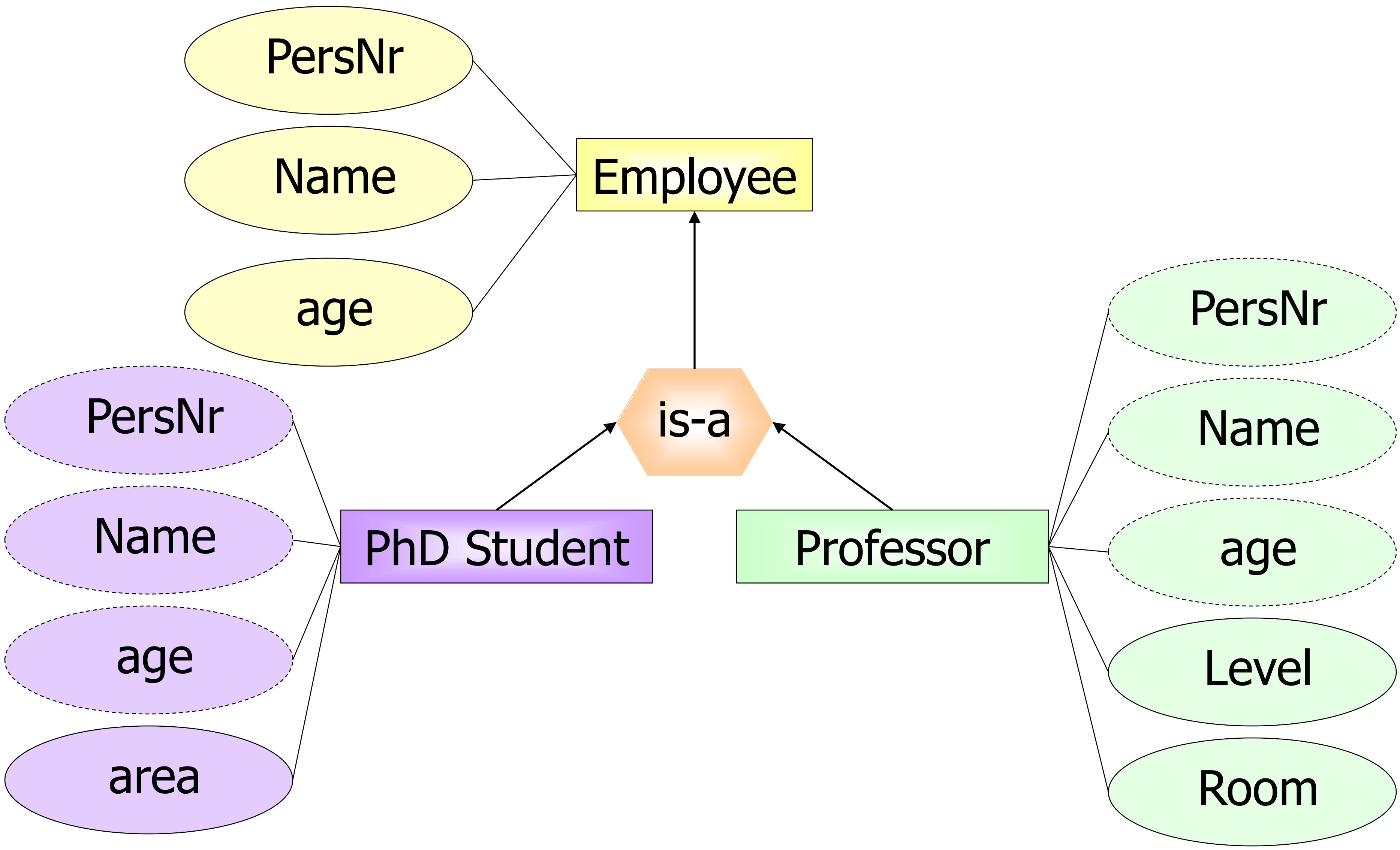

- explicit positive privilege at one level
  - ⇒implicit positive privileges on all lower levels
- explicit negative privilege at one level
  - ⇒implicit negative privilege on all higher levels

# Implicit Privileges: Object Hierarchy




- Implications depend on operations!

# Implicit Privileges: Type Hierarchy



# Implicit Privileges: Type Hierarchy

User Groups:

- Group leaders may read the name of all employees
- PhD students may read the name of all professors

Queries:

- Read the name of all PhD students
- Read the name of all professors

# Implicit Privileges: Type Hierarchy

Rules:

- Privilege on A.x implies Privilege on B.x if B is subtype of A
- Privilege on Class A implies Privilege on A.x if x is inherited from supertype
- Privilege on Class A does NOT imply Right on B.x if B is subtype of A and x is defined in B.

# Mandatory Access Control

- Classification of „importance" of subjects and objects
- *clear(s)*, for Subject *s*
- *class(o)*, for Object *o*
- Main idea: control *data flow* from low to high levels
  - *s* may read *o* iff $class(o) \leq clear(s)$
  - Class of *o* depends on importance of creator *s*
    $clear(s) \leq class(o)$
- Used in military: data flows bottom-up
  - (control flows from top-down)

# Multi-level Databases

Goal: User should not know what he/she cannot see!

„s“ < „ts“; Id is key of the SecretAgent relation

| SecretAgent | | | | | | |
|---|---|---|---|---|---|---|
| TC | Id | IC | Name | NC | Skills | SC |
| ts | 007 | s | Bond, James | s | meucheln | ts |
| ts | 008 | ts | Clouseau | ts | spitzeln | ts |

View of a user who is classified as „s“

| SecretAgent | | | | | | |
|---|---|---|---|---|---|---|
| TC | Id | IC | Name | NC | Skills | SC |
| s | 007 | s | Bond, James | s | - | s |

Problems:

- „s“ user inserts tuple with Id „008“
- „s“ user modifies the Skills of „007“

# Multi-level Relations

Multilevel-Relation $\mathcal{R}$ with schema

$$\mathcal{R} = \{A_1, C_1, A_2, C_2, \ldots, A_n, C_n, TC\}$$

Instances $\mathcal{R}_C$ with tuples of the form

$$[a_1, c_1, a_2, c_2, \ldots, a_n, c_n, tc]$$

- Visibility of tuples in $\mathcal{R}_C$ : $c_i \geq c_\kappa$ for all attr. i; key $\kappa$
- Visibility of attributes in $\mathcal{R}_C$ : $a_i$ is visible if $clear(s) \geq c_i$
- $tc \geq c_\iota$ (classification of tuple; not used here)

# Integrity Constraints

$\kappa$ is the (logical) key of Multi-level Relation $\mathcal{R}$

**Entity-Integrity.** $\mathcal{R}$ is entity consistent iff, for all instances $\mathcal{R}_c$ of $\mathcal{R}$ and all $r \in \mathcal{R}_c$:

1. $A_i \in \kappa \Rightarrow r.a_i \neq \text{Null}$
2. $A_i, A_j \in \kappa \Rightarrow r.c_i = r.c_j$
3. $A_i \notin \kappa \Rightarrow r.c_i \geq r.c_\kappa$ ($c_\kappa$ is class of the key)

- All visible tuples of R can be identified by their key at all levels.
  - It is possible to hide some (non-key) attributes of a tuple.

# Integrity Constraints

$\kappa$ is the (logical) key of Multi-level Relation $\mathcal{R}$

**Null-Integrity.** $\mathcal{R}$ is Null consistent iff, for all instances $\mathcal{R}_c$ of $\mathcal{R}$:

1. $\forall r \in \mathcal{R}_c$ : $r.a_i$ = Null $\Rightarrow r.c_i = r.c_\kappa$
2. $\mathcal{R}_c$ has no subsumptions. That is, there are no two tuples r, s so that for all attributes $A_i$:
   - $r.a_i = s.a_i$ and $r.c_i = s.c_i$ OR
   - $r.a_i \neq$ Null and $s.a_i$ = Null

- (See next slides for subsumption violations.)

# Subsumption-free Relations

a) $R_{ts}$

| SecretAgent | | | | | | |
|---|---|---|---|---|---|---|
| TC | Id | IC | Name | NC | Skill | SC |
| s | 007 | s | Bond, James | s | - | s |

b) Correct update of $R_{ts}$ by user classified as „ts“

| SecretAgent | | | | | | |
|---|---|---|---|---|---|---|
| TC | Id | IC | Name | NC | Skill | SC |
| ts | 007 | s | Bond, James | s | meucheln | ts |

c) Incorrect update of $R_{ts}$ by user classified as „ts“

| SecretAgent | | | | | | |
|---|---|---|---|---|---|---|
| TC | Id | IC | Name | NC | Skill | SC |
| s | 007 | s | Bond, James | s | - | s |
| ts | 007 | s | Bond, James | s | meucheln | ts |

# Integrity Constraints

**Inter-instance Integrity:**

for $c' < c$, $R_{c'}$ can be computed from $R_c$

$$R_{c'} = f(R_c, c')$$

Filter function $f$ can be defined as follows:

1. foreach $r \in R_c$, $r.C_K \leq c'$ create $s \in R_{c'}$ such that

$$s.a_i = \begin{cases} r.a_i & \text{if } r.c_i \leq c' \\ \text{Null} & \text{otherwise} \end{cases}$$

$$s.c_i = \begin{cases} r.c_i & \text{if } r.c_i \leq c' \\ r.c_k & \text{otherwise} \end{cases}$$

2. $R_{c'}$ does not contain any other tuples.
3. Eliminate subsumed tuples.

# Integrity Constraints

**Poly-instantiation Integrity.** For all instances $R_c$ and all attributes $A_i$ the following functional dependency holds:

$$\{\kappa, C_\kappa, C_i\} \rightarrow A_i$$

- $\kappa$ is the visible key of each instance

- If all integrity constraints are met, then a multi-value relation can be implemented as a set of (regular) relations on top of a (regular) relational database system.