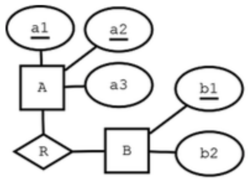
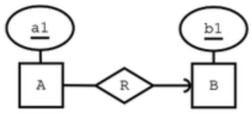
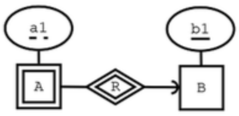
E-R diagrams and database schemas



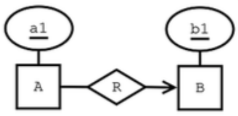

```
A(a1,a2,a3)
B(b1,b2)
R(a1,a2,b)
    (a1,a2) -> A.(a1,a2)
    b       -> B.b1
```




```
A(a1,b)
    b -> B.b1
B(b1)
```

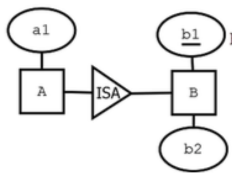



```
A(a1,b)
    b -> B.b1
B(b1)
```




```
ER-Approach:
 A(a1)
 B(b1)
 R(a,b)
   a -> A.a1
   b -> B.b1

Null Approach:
 A(a1,b (or Null))
   b -> B.b1
 B(b1)
```




```
ER-Approach:
 B(b1,b2)
 A(b1,a1)
   b1 -> B.b1

Null-Approach:
 B(b1,b2,a1(or Null))

OO-Approach:
 A(b1,b2,a1)
 B(b1,b2)
```

Functional dependencies

Definition (tuple, attribute, value). A **tuple** has the form

$$\{A_1 = v_1, \ldots, A_n = v_n\}$$

where $A_1, \ldots, A_n$ are **attributes** and $v_1, \ldots, v_n$ are their **values**.
Definition (signature, relation). The **signature** of a tuple, S, is the set of all its attributes, $\{A_1, \ldots, A_n\}$. A **relation** R of signature S is a set of tuples with signature S. But we will sometimes also say "relation" when we mean the signature itself.
Definition (projection). If t is a tuple of a relation with signature S, the **projection** $t.A_i$ computes to the value v_i.
Definition (simultaneous projection). If X is a set of attributes $\{B_1, \ldots, B_m\} \subseteq S$ and t is a tuple of a relation with signature S, we can form a simultaneous projection,

$$t.X = \{B_1 = t.B_1, \ldots, B_m = t.B_m\}$$

Definition (functional dependency, FD). Assume X is a set of attributes and A an attribute, all belonging to a signature S. Then A is **functionally dependent** on X in the relation R, written $X \to A$, if

- for all tuples t,u in R, if $t.X = u.X$ then $t.A = u.A$.

If Y is a set of attributes, we write $X \to Y$ to mean that $X \to A$ for every A in Y.
Definition (multivalued dependency, MVD). Let X,Y,Z be disjoint subsets of a signature S such that $S = X \cup Y \cup Z$. Then Y has a **multivalued dependency** on X in R, written $X \twoheadrightarrow Y$, if

- for all tuples t,u in R, if $t.X = u.X$ then there is a tuple v in R such that
  - $v.X = t.X$
  - $v.Y = t.Y$
  - $v.Z = u.Z$

Definition. An attribute A **follows** from a set of attributes Y, if there is an FD $X \to A$ such that $X \subseteq Y$.
Definition (closure of a set of attributes under FDs). The **closure** of a set of attributes $X \subseteq S$ under a set FD of functional dependencies, denoted $X+$, is the set of those attributes that follow from X.
Definition (trivial functional dependencies). An FD $X \to A$ is **trivial**, if $A \in X$.
Definition (superkey, key). A set of attributes $X \subseteq S$ is a **superkey** of S, if $S \subseteq X+$.
A set of attributes $X \subseteq S$ is a **key** of S if

- X is a superkey of S
- no proper subset of X is a superkey of S

Definition (Boyce-Codd Normal Form, BCNF violation). A functional dependency $X \to A$ **violates BCNF** if

- X is not a superkey
- the dependency is not trivial

A relation **is in Boyce-Codd Normal Form** (BCNF) if it has no BCNF violations.
Definition (prime). An attribute A is prime if it belongs to some key.
Definition (Third Normal Form, 3NF violation). A functional dependency $X \to A$ **violates 3NF** if

- X is not a superkey
- the dependency is not trivial
- A is not prime

Definition (trivial multivalued dependency). A multivalued dependency $X \twoheadrightarrow A$ is trivial if $Y \subseteq X$ or $X \cup Y = S$.
Definition (Fourth Normal Form, 4NF violation). A multivalued dependency $X \twoheadrightarrow A$ **violates 4NF** if

- X is not a superkey
- the MVD is not trivial.

Algorithm (BCNF decomposition). Consider a relation R with signature S and a set F of functional dependencies. R can be brought to BCNF by the following steps:

1. If R has no BCNF violations, return R
2. If R has a violating functional dependency $X \to A$, decompose R to two relations
   - R_1 with signature X^+
   - R_2 with signature $X \cup (S - X^+)$
3. Apply the above steps to R_1 and R_2 with functional dependencies projected to the attributes contained in each of them.

Algorithm (4NF decomposition). Consider a relation R with signature S and a set M of multivalued dependencies. R can be brought to 4NF by the following steps:

1. If R has no 4NF violations, return R
2. If R has a violating multivalued dependency $X \twoheadrightarrow Y$, decompose R to two relations
   - R_1 with signature $X \cup Y$
   - R_2 with signature $S - Y$
3. Apply the above steps to *R1* and *R2*

Concept (minimal basis of a set of functional dependencies; not a rigorous definition). A **minimal basis** of a set F of functional dependencies is a set F- that implies all dependencies in F. It is obtained by first weakening the left hand sides and then dropping out dependencies that follow by transitivity. Weakening an LHS in $X \to A$ means finding a minimal subset of X such that A can still be derived from F-.
Algorithm (3NF decomposition). Consider a relation R with a set F of functional dependencies.

1. If R has no 3NF violations, return R.
2. If R has 3NF violations,
   - compute a minimal basis of F- of F
   - group F- by the left hand side, i.e. so that all depenencies $X \to A$ are grouped together
   - for each of the groups, return the schema $XA_1 \ldots A_n$ with the common LHS and all the RHSs
   - if one of the schemas contains a key of R, these groups are enough; otherwise, add a schema containing just some key

Relational algebra

relation ::=

relname	**name of relation (can be used alone)**
$\mid$ $\sigma_{\text{condition}}$ relation	**selection (sigma)** `WHERE`
$\mid$ $\pi_{\text{projection+}}$ relation	**projection (pi)** `SELECT`
$\mid$ $\rho_{\text{relname (attribute+)?}}$ relation	**renaming (rho)** `AS`
$\mid$ $\gamma_{\text{attribute*,aggregationexp+}}$ relation	**grouping (gamma)** `GROUP BY, HAVING`
$\mid$ $\tau_{\text{expression+}}$ relation	**sorting (tau)** `ORDER BY`
$\mid$ δ relation	**removing duplicates (delta)** `DISTINCT`
$\mid$ relation $\times$ relation	**cartesian product** `FROM, CROSS JOIN`
$\mid$ relation $\cup$ relation	**union** `UNION`
$\mid$ relation $\cap$ relation	**intersection** `INTERSECT`
$\mid$ relation $-$ relation	**difference** `EXCEPT`
$\mid$ relation $\bowtie$ relation	`NATURAL JOIN`
$\mid$ relation $\bowtie_{\text{condition}}$ relation	**theta join** `JOIN ON`
$\mid$ relation $\bowtie_{\text{attribute+}}$ relation	`INNER JOIN`
$\mid$ relation $\bowtie^{o}_{\text{attribute+}}$ relation	`FULL OUTER JOIN`
$\mid$ relation $\bowtie^{oL}_{\text{attribute+}}$ relation	`LEFT OUTER JOIN`
$\mid$ relation $\bowtie^{oR}_{\text{attribute+}}$ relation	`RIGHT OUTER JOIN`

projection ::=

expression	**expression, can be just an attribute**
$\mid$ expression $\rightarrow$ attribute	**rename projected expression** `AS`

aggregationexp ::=

aggregation($*\mid$attribute)	**without renaming**
$\mid$ aggregation($*\mid$attribute) $\rightarrow$ attribute	**with renaming** `AS`

expression, condition, aggregation, attribute ::=

as in SQL, but excluding subqueries

SQL

```
statement ::=
      CREATE TABLE tablename (
    * attribute type inlineconstraint*
    * [CONSTRAINT name]? constraint deferrable?
    ) ;
  |
      DROP TABLE tablename ;
  |
      INSERT INTO tablename tableplaces? values ;
  |
      DELETE FROM tablename
    ? WHERE condition  ;
  |
      UPDATE tablename
      SET setting+
    ? WHERE condition ;
  |
      query ;
  |
      CREATE VIEW viewname
      AS ( query ) ;
  |
      ALTER TABLE tablename
   +  alteration ;
  |
      COPY tablename FROM filepath ;
        ## postgresql-specific, tab-separated

query ::=
      SELECT DISTINCT? columns
    ? FROM table+
    ? WHERE condition
    ? GROUP BY attribute+
    ? HAVING condition
    ? ORDER BY attributeorder+
  |
      query setoperation query
  |
      query ORDER BY attributeorder+
        ## no previous ORDER in query
  |
      WITH localdef+ query

table ::=
      tablename
  |   table AS? tablename  ## only one iteration allowed
  |   ( query ) AS? tablename
  |   table jointype JOIN table ON condition
  |   table jointype JOIN table USING (attribute+)
  |   table NATURAL jointype JOIN table

condition ::=
      expression comparison compared
  |   expression NOT? BETWEEN expression AND expression
  |   condition boolean condition
  |   expression NOT? LIKE 'pattern*'
  |   expression NOT? IN values
  |   NOT? EXISTS ( query )
  |   expression IS NOT? NULL
  |   NOT ( condition )
```

```
type ::=
     CHAR ( integer ) | VARCHAR ( integer ) | TEXT
   | INT | FLOAT

inlineconstraint ::=     ## not separated by commas!
     PRIMARY KEY
   | REFERENCES tablename ( attribute ) policy*
   | UNIQUE | NOT NULL
   | CHECK ( condition )
   | DEFAULT value

constraint ::=
     PRIMARY KEY ( attribute+ )
   | FOREIGN KEY ( attribute+ )
       REFERENCES tablename ( attribute+ ) policy*
   | UNIQUE ( attribute+ ) | NOT NULL ( attribute )
   | CHECK ( condition )

policy ::=
     ON DELETE|UPDATE CASCADE|SET NULL
deferrable ::=
     NOT? DEFERRABLE (INITIALLY DEFERRED|IMMEDIATE)?
tableplaces ::=
     ( attribute+ )

values ::=
     VALUES ( value+ )  ## VALUES only in INSERT
   | ( query )

setting ::=
     attribute = value

alteration ::=
     ADD COLUMN attribute type inlineconstraint*
   | DROP COLUMN attribute

localdef ::=
     WITH tablename AS ( query )

columns ::=
     *         ## literal asterisk
   | column+

column ::=
     expression
   | expression AS name

attributeorder ::=
     attribute (DESC|ASC)?

setoperation ::=
     UNION | INTERSECT | EXCEPT

jointype ::=
     LEFT|RIGHT|FULL OUTER?
   | INNER?

comparison ::=
     = | < | > | <> | <= | >=
```

```
expression ::=
      attribute
  |   tablename.attribute
  |   value
  |   expression operation expression
  |   aggregation ( DISTINCT? *|attribute)
  |   ( query )

value ::=
      integer | float | string ## string in single quotes
  |   value operation value
  |   NULL

boolean ::=
      AND | OR

## triggers

functiondefinition ::=
  CREATE FUNCTION functionname() RETURNS TRIGGER AS $$
  BEGIN
*   triggerstatement
  END
  $$ LANGUAGE 'plpgsql'
  ;

triggerdefinition ::=
  CREATE TRIGGER triggernane
    whentriggered
    FOR EACH ROW|STATEMENT
  ? WHEN ( condition )
    EXECUTE PROCEDURE functionname
    ;

whentriggered ::=
    BEFORE|AFTER events ON tablename
  | INSTEAD OF   events ON viewname

events ::= event | event OR events
event  ::= INSERT | UPDATE | DELETE

triggerstatement ::=
    IF ( condition ) THEN statement+ elsif* END IF ;
  | RAISE EXCEPTION 'message' ;
  | statement ;  ## INSERT, UPDATE or DELETE
  | RETURN NEW|OLD|NULL ;

elsif ::= ELSIF ( condition ) THEN statement+
```

```
compared ::=
     expression
   | ALL|ANY values

operation ::=
     "+" | "-" | "*" | "/" | "%"
   | "||"

pattern ::=
    % | _ | character  ## match any string/char
  | [ character* ]
  | [^ character* ]

aggregation ::=
    MAX | MIN | AVG | COUNT | SUM


## privileges

statement ::=
   GRANT  privilege+ ON object TO user+ grantoption?
 | REVOKE privilege+ ON object FROM user+ CASCADE?
 | REVOKE GRANT OPTION FOR privilege
     ON object FROM user+ CASCADE?
 | GRANT rolename TO username adminoption?

privilege ::=
   SELECT | INSERT | DELETE | UPDATE | REFERENCES
 | ALL PRIVILEGES ## | ...

object ::=
   tablename (attribute+)+ | viewname (attribute+)+
 | trigger ## | ...

user ::= username | rolename | PUBLIC

grantoption ::= WITH GRANT OPTION

adminoption ::= WITH ADMIN OPTION

## transactions

statement ::=
  START TRANSACTION mode* | BEGIN | COMMIT | ROLLBACK

mode ::=
   ISOLATION LEVEL level
 | READ WRITE | READ ONLY

level ::=
   SERIALIZABLE | REPEATABLE READ | READ COMMITTED
 | READ UNCOMMITTED

## indexes

statement ::=
   CREATE INDEX indexname ON tablename (attribute+)?
```

JSON

Both json* and member* indicate comma-separated lists. Strings are in double-quotes, numbers use decimal dot.

```
json ::= object | array | string | number | boolean
object ::= "{" member* "}"
member ::= string ":" json
array ::= "[" json* "]"
```

JSON Path: Expressions are built from operators, the result is an array with all matching json elements. The syntax below is from Postgres JSON Paths, using `..` instead of `.**` and `?[(condition)]` instead of `?(condition)` is also allowed.
`$` is the path for the root of the document
`.` is the child access operator (e.g. `$.name` gives the value of the name attribute of the root node)
`.*` is the wild-card access operator, it selects all attribute values of an object, or all items in an array
`.**` is the recursive descent operator (e.g. `$.**.name` gives the value of the name attribute of all objects in the document)
`[n]` is array indexing (n is an integer)
`[*]` is the wild-card indexing operator, it selects all items in arrays
`[a,b,c]` selects multiple attributes (in double quotes) or array indexes
`?(condition)` is used to filter values
`@` is the current object in conditions (`$.*?(@.x>1)` gets attributes of the root node whose x attribute exceeds 1)

JSON Schema: Each schema is a JSON document.
false matches nothing
true matches everything (same as {})
Objects contain any number of keywords (as keys), that limit what is accepted. Keywords and types of values:

- `"enum"` (array) accepts only the listed values.
- `"type"` (string) accepts only the given type, one of object/array/string/number/integer/boolean.
- `"minimum","maximum","minLength","maxLength","minProperties","maxProperties","minItems","maxItems"` (integer) specifies bounds for numbers, string lengths, array lengths and number of attributes respectively.
- `"properties"` (object with name:schema pairs) specifies schemas for attributes of objects.
  E.g. `{"properties":{"x":{"type":"string"}, "y":false}}` accepts only objects where the type of attribute "x" is a string (or "x" does not exist) and attribute "y" does not exist.
- `"additionalProperties"` (schema) specifies the schema for all attributes not mentioned in "properties".
- `"required"` (array of strings) accepts only objects that have all the listed attributes
- `"items"` (schema) accepts only arrays where all items are accepted by the given schema
- `"contains"` (schema) accepts only arrays that where at least one item is accepted by the given schema
- `"uniqueItems"` (boolean) if boolean is true, accepts only arrays where items are unique
- `"allOf", "anyOf", "oneOf"` (array of schemas) accepts only what is accepted by all of, at least one of, or exactly one of the given schemas.
- `"not"` (schema) accepts only what is not accepted by the given schema.
- `"definitions"` (object with name:schema pairs) specifies named schemas, that can be used with `"$ref"`. Only used in the root object of a schema.
- `"$ref"` (string) accepts values that are accepted by the referenced schema. Use `"#"` to refer back to the root of the schema. Use `"#\definitions\x"` to refer to definition "x".