3. Data Models for Engineering Data

Conventional and Specific Ways to Describe Engineering Data

Overview

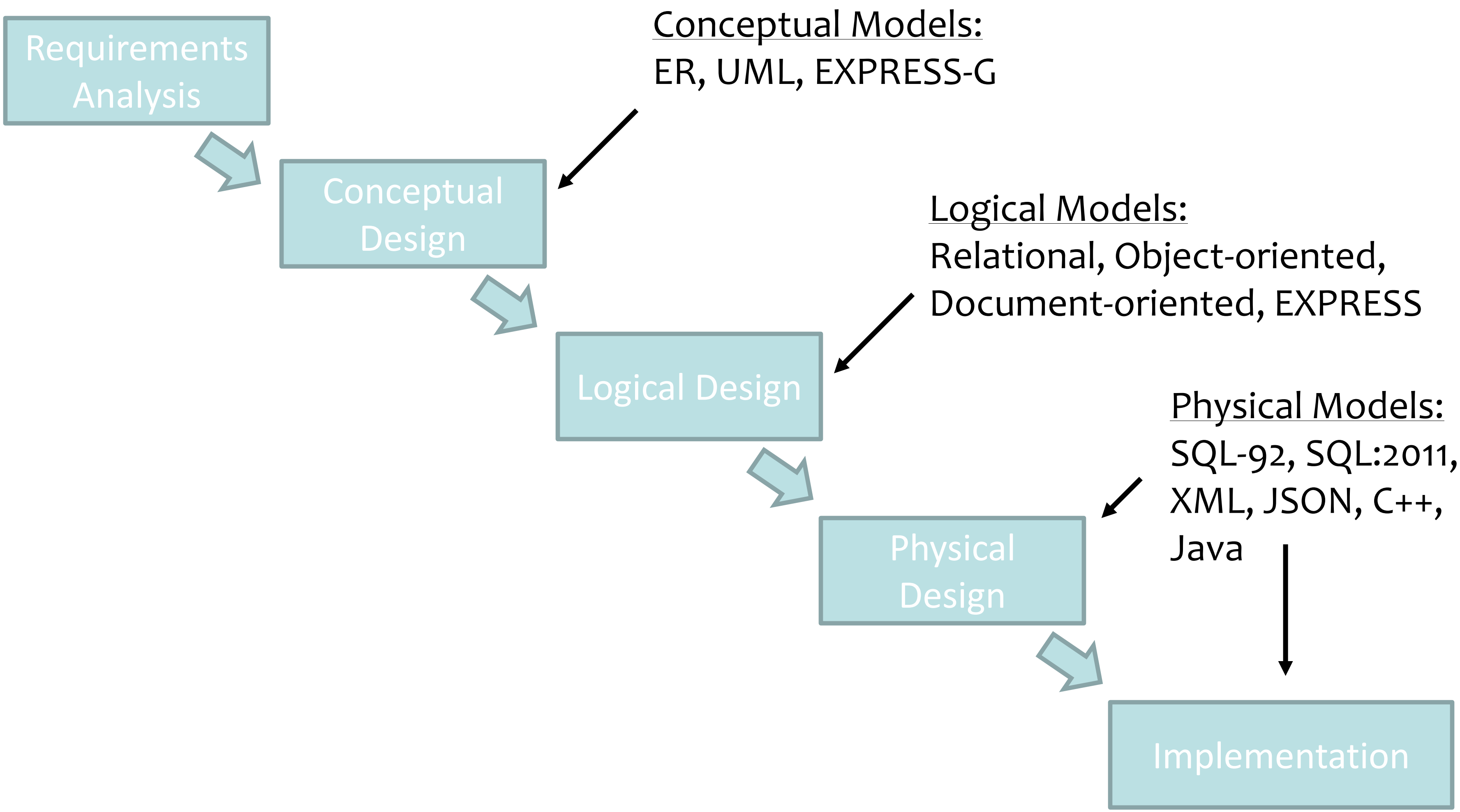
- Conventional Models
  - Overview of Data Models
  - Logical Models
    - Databases and the Relational Data Model
    - Object-oriented Data Models
    - Semi-structured Data Models
  - Conceptual Models
    - The Entity Relationship Model (ER)
    - The Unified Modeling Language (UML)
- Engineering Data Models
  - The Standard for the Exchange of Product Model Data (STEP)
    - STEP EXPRESS as a modeling language
    - EXPRESS-G as a graphical/conceptual model
  - STEP files

Reminder: Data Model

A **data model** is a model that describes in an abstract way how data is represented in an information system or a database management system.

- A data model defines syntax and semantics, i.e.
  - How can data be structured (syntax)
  - What does this structure mean (semantics)
- Very generic term for many applications
  - Programming languages have their data models (e.g. C++ and Java have object-oriented data models)
  - Conceptual design methods (e.g. ER, UML) represent a data model
  - File formats either apply a data model (e.g. XML) or implement their own
  - Database management systems implement data(base) models

Information System Design Phases



Types of Data Models

- **Conceptual Models**
  - Describing the concepts of the given Universe of Discourse and their relationships
  - Information requirements of system/users
  - Independent of final structure implementation
  - Often using graphical notation
- **Logical Models**
  - Describes the logical structure of information (data) in the system to be developed
  - Independent of specific (database) systems or (programming) languages
- **Physical/Implementation Models**
  - Describes all details of how information is represented

The Relational Model (RM)

- Developed since early 1970s based on mathematical theory of relations and operations performed on them (relational algebra)
- **SQL** (Structured Query Language) as a strong standard to access relational databases
- Relational Database Management Systems (RDBMS) implement RM, most often based on SQL
- RDBMS are state of the art for database storage

SQL/RM: Basic Concepts

- Data is stored as **rows**/records (tuples*) **in tables** (relations) **with** values for each **column** (attribute)
- Rows can be identified by special columns called **primary keys**, for which a unique value must exist
- **Foreign keys** can be used to establish connections across data in different tables
- Constraints can be specified to grant consistency

* Terms in brackets relate to relational theory/mathematics

SQL/RM: Simple Example

PartID	Name	Weight	SupplierID
GT-876-140425	Plunger	143.5	1
FT-852-130707	Shaft	77.0	3
FT-855-140809	Bolt	15.7	1
TT-707-778	Case	22.8	2

SupplierID	Name	Location
1	Reed & Sons	New York
2	CaseStudio	Boston
3	ToolTime	Austin

SQL/RM: Tables

Column

Table

PartID	**Name**	**Weight**	**SupplierID**
GT-876-140425	Plunger	143.5	1
FT-852-130707	Shaft	77.0	3
FT-855-140809	Bolt	15.7	1
TT-707-778	Case	22.8	2

Row

SQL/RM: Primary Keys

Primary Key

PartID	**Name**	**Weight**	**SupplierID**
GT-876-140425	Plunger	143.5	1
FT-852-130707	Shaft	77.0	3
FT-855-140809	Bolt	15.7	1
TT-707-778	Case	22.8	2

Primary Key Value

SQL/RM: Foreign Keys

Foreign Key

PartID	**Name**	**Weight**	**SupplierID**
GT-876-140425	Plunger	143.5	1
FT-852-130707	Shaft	77.0	3
FT-855-140809	Bolt	15.7	1
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SupplierID	**Name**	**Location**
1	Reed & Sons	New York
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3	ToolTime	Austin

The Structured Query Language (SQL)

- Language to access databases structured according to Relational Model
  - Developed based on RM
  - Introduces some minor differences to RM
  - Not a programming language
- Consists of several parts, most importantly:
  - Actual query language to read data
  - Data Definition Language (DDL) to create (empty) databases, tables, etc.
  - Data Manipulation Language (DML) to insert, modify and delete data

SQL: Query Language

```
SELECT <columns>
FROM   <tables>
WHERE  <condition>;
```

- Declarative language:
  - Result is described, not how it is computed
  - Actual execution can be optimized by DBMS
- Typical structure: SFW-block (SELECT-FROM-WHERE)
- Input as well as result are always tables
- Used from programming languages via standardized or proprietary application programming interfaces (ODBC, JDBC, etc.)

SQL: Query Language Example 1

```
SELECT name, weight
FROM   part
WHERE  weight > 50;
```

Name	Weight
Plunger	143.5
Shaft	77.0

SQL: Query Language Example 2

```
SELECT p.name, s.name
FROM   part p, supplier s
WHERE  p.supplierid = s.supplierid
  AND  s.name LIKE 'Reed%';
```

Part.Name	Supplier.Name
Plunger	Reed & Sons
Bolt	Reed & Sons

SQL: Data Definition Language

```
CREATE TABLE part (
        partid          INTEGER PRIMARY KEY,
        name            VARCHAR(50) NOT NULL,
        weight          DECIMAL(10,2),
        supplierid      INTEGER REFERENCES supplier(supplierid)
);
```

- DDL= Part of SQL language used to define schema elements (tables, constraints, views, etc.)

SQL: Data Manipulation Language (DDL)

```
INSERT INTO supplier VALUES (4,'Rex & Smith', 'Baltimore');
```

```
UPDATE supplier
SET location='Woburn'
WHERE supplierid=2;
```

```
DELETE FROM part
WHERE supplierid=1;
```

- DML = Part of SQL language to insert, modify and delete data

Engineering and RDBMS

- RDBMS often used for
  - Product Lifecycle Management (Product Data Management, Engineering Data Management)
  - Applications for generic tasks, e.g. Enterprise Resource Planning, Workflow Management Systems, Supply Chain Management, etc.
- RDBMS less often or not used for
  - Direct structured storage of product definition data
- Details in Section 4

Object-oriented Data Models

- Enhanced semantic modeling
  - Allows more flexible and re-usable definitions
  - More semantic concepts add complexity to data model/languages
- Developed gradually until major breakthrough in 1980s
- Similar concepts of data modeling applied for numerous application fields in computer science, e.g.
  - Object-oriented Analysis and Design (e.g. UML)
  - Object-oriented Programming (e.g. C++, Java)
  - Object-oriented Databases (e.g. db4o, Versant)
  - Object-relational Databases (SQL since SQL:1999)
  - Object-oriented User Interfaces

OO: Enhanced Semantic Modeling

- **Objects** as instances (data) of classes
- User-defined **Classes** as definitions (schema) of
  - The structure of objects with **Attributes** and **Relationships**
  - The behavior of objects by **Methods** (class functions)
- **Encapsulation** to differentiate between appearance to use user of objects of classes (interface) and their internal structure and behavior (implementation)
- Re-usability of definitions by **Specialization** among classes
  - **Inheritance:** specialized classes (subclasses) also posses the attributes, relationships and methods of the classes they were derived from (superclasses)
  - **Polymorphism:** objects of a subclass are also objects of the superclass and can be used accordingly

OO: Attributes

- Attributes represent properties of objects of a class, for which an object carries concrete values
- Defined based on data types
  - Basic data types defined of implementation model (e.g. `int, float, char` in C++)
  - Pre-defined complex types (e.g. `string` in C++)
  - User-defined complex types (e.g. classes for `Address`, `Date`, `Coordinates`, etc.)

```
class Part
{
        ...
        string name;
        int    version_id;
        Date   lastModified;
        ...
};
```

This and all following examples on OO are in C++

OO: Methods

- Specification of behavior of objects in terms of functions on that object
- **Interface (Signature, declaration):**
  - Specifies how the method can be used
  - External view of the method
  - Name, parameters and return value
- **Implementation (definition):**
  - Provides executable source code for method
  - Internal view of the methode
- Interface and implementation may be separated (e.g. in C++)
- Constructors as special methods to create objects of that class

```
class Part
{
	...
	Part(string n);
	void createNewVersion();
	...
};

...

Part::Part(string n)
{
		name = n;
		version_id = 1;
}

void Part::createNewVersion()
{
		version_id++;
}
```

OO: Relationships

- 1:1 and N:1 Relationships between different objects most often represented by pointers (physical address, e.g. C++) or references (logical, e.g. Java)
- Bidirectional, 1:N and N:M relationships require additional type construction

```
class Part
{
   ...
   Engineer* responsibleEngineer;
   ...
};


class Engineer
{
   ...
   string name;
   string department;
   set<Part*> designedParts;
   ...
};
```

OO: Encapsulation

- External (interface) and internal (implementation) structure of class maybe specified
- Typically access modifiers such as
  - Public: attribute or method accessible from everywhere
  - Private: only accessible within methods of this class
  - Protected: accessible within this class and in subclasses
  - Package (Java only): within this library

```
class Part
{
   public:
      Part(string n);
      void createNewVersion();
   private:
      string name;
      int version_id;
      Date lastModified;
      Engineer*
              responsibleEngineer;

};
```

OO: Objects and Classes

- Objects of classes
  - Defined within source code, i.e. function and method implementation
  - Notion class implies set of objects conforming to the defined structure
  - Carry values for attributes
  - Methods are called on objects, e.g. using notations like `obj.method()` or `obj->method()`

```
class Part
{
   public:
      Part(string n);
      void createNewVersion();
   private:
      string name;
      int version_id;
      ...
};

// Main program

int main()
{
   Part* obj1 = new Part("Wheel");
   Part* obj2 = new Part("Hub");
   ...
   obj1->createNewVersion();
   ...
   return 0;
}
```

OO: Specilization

- Relationship between classes to model more specific subsets of objects with additional properties and methods
- **Inheritance:** attributes and methods defined in superclass are also defined in subclass (also referred to as subtyping)
- **Polymorphism:** wherever objects of a superclass can be used, object of any subclass of it can be used, too

```
class Part
{
   public:
      Part(string n);
      void createNewVersion();
   private:
      string name;
      int version_id;
      Date lastModified;
      Engineer* responsibleEngineer;
};


class ManufacturedPart : public Part
{
   private:
      string manufacturingDepartment;
};


class PurchasedPart : public Part
{
   private:
      string vendor;
};
```

OO and Engineering Data

- Rich semantic modeling suitable to support complex data structures
- Typical implementation model of engineering applications
  - Conceptual Modeling
  - Programming and Development
  - File Storage
- Some concepts integrated with STEP data models EXPRESS and EXPRESS-G
  - Specialization
  - Relationships
- Object-oriented and Object-Relational Databases suitable but not commonly used for Engineering Data

XML

- **eXtensible Markup Language**
  - Hierarchical structure of nested elements (tags)
  - Elements may have attributes
  - Actual data on the leave level
  - Mix of content (data) and description (schema, metadata)
- Developed based on SGML (document processing) to exchange any kind of data on the Web
- Inspired by HTML (also based on SGML), which is only useful to exchange documents
- Can be considered a neutral text format for files
- Application-specific schemas of valid documents can be defined by Document Type Definitions (DTD) or XML Shema (XSD)
- Standard software/libraries for XML processing publically available

XML Example: EAGLE .sch File

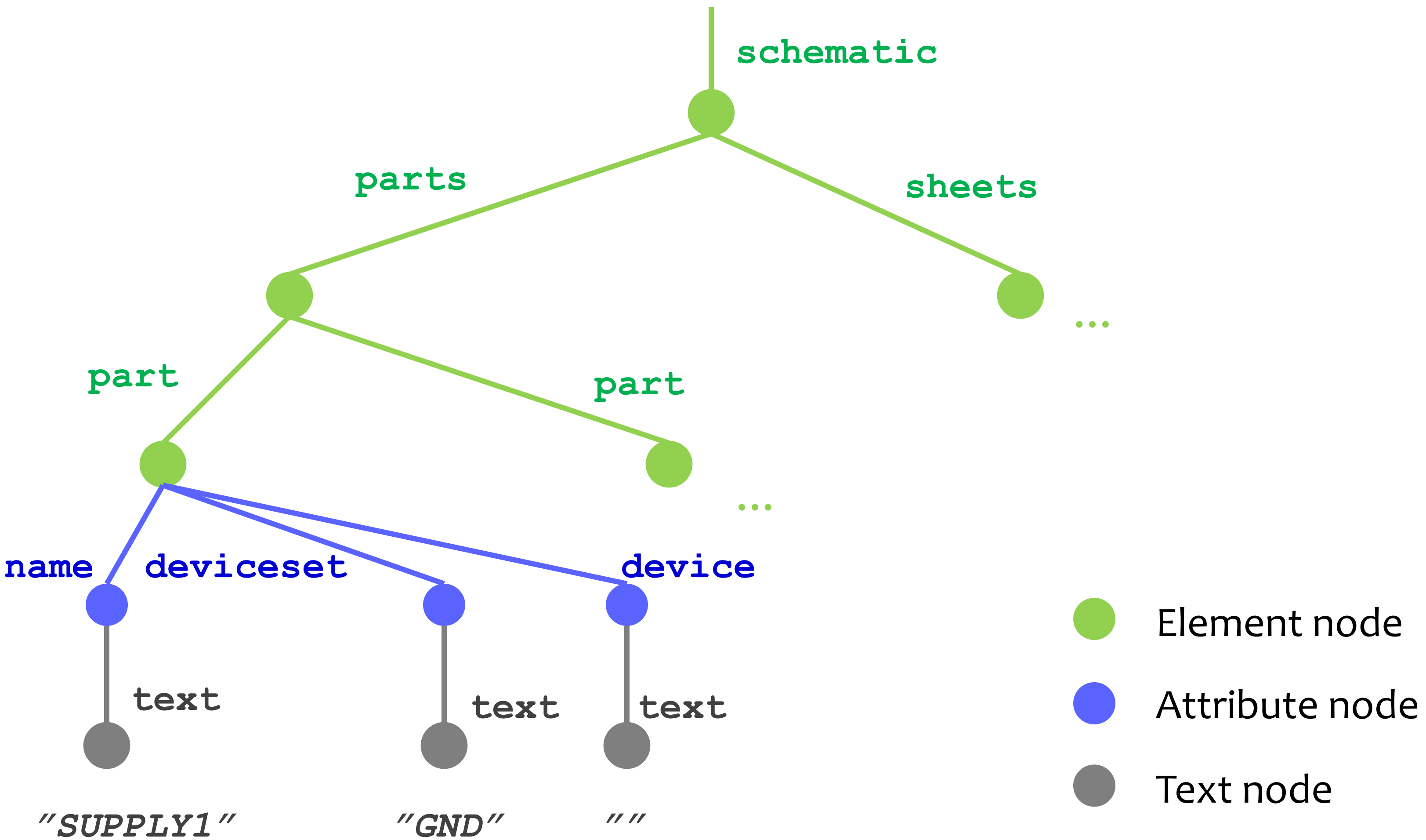
```
<schematic>
  <parts>
    <part name="SUPPLY1" deviceset="GND" device=""/>
    <part name="C1" deviceset="C-EU" device="050-024X044" value="22pF"/>
  </parts>
  <sheets>
    <sheet>
      <instances> <!-- Positions the parts on the board. E. g.: -->
        <instance part="SUPPLY1" gate="GND" x="132.08" y="187.96"/>
        <instance part="C1" x="-50.8" y="200.66" rot="R270"/>
      </instances>
      <nets>
        <net name="N$1" class="0">
          &lt;segment&gt;
            <wire x1="9.44" y1="19.04" x2="8.9" y2="19.04" width="0.15"/>
            <wire x1="8.9" y1="19.04" x2="8.9" y2="20.66" width="0.15"/>
            <wire x1="8.9" y1="20.66" x2="2.4" y2="20.66" width="0.15"/>
            <pinref part="C1" pin="5"/>
            <pinref part="SUPPLY1" pin="1"/>
        &lt;/segment&gt;
      </net>
    </nets>
   </sheet>
  </sheets>
</schematic>
```

[Source: Philipp Ludwig]

XML Structure and Data Model

- Markup language intended to describe structure within documents and document collections in files or databases
- Data logically represented according to **Document Object Model (DOM)** as hierarchy/tree of
  - Element nodes (labeled internal nodes)
  - One labeled root node (represents document content)
  - Text nodes as leaf nodes represent actual data
  - Attribute nodes as special sub-nodes with a child text node
- Structure is
  - **Well-formed:** conforms to general XML rules
  - **Valid:** possible nesting of elements, attributes, etc. conform to a schema defined as Document Type Definition (DTD) or XML Schema (XS)

XML DOM Example



XML Example: eagle.dtd

- DTD used for schema definition, i.e. valid .sch files
- Small excerpt of eagle.dtd (publically available):

```
<!ELEMENT schematic (description?, libraries?, attributes?,
                 variantdefs?, classes?, parts?, sheets?, errors?)>
<!ATTLIST schematic
         xreflabel %String; #IMPLIED
         xrefpart %String; #IMPLIED
         >
…

<!ELEMENT part (attribute*, variant*)>
<!ATTLIST part
         name %String; #REQUIRED
         library %String; #REQUIRED
         deviceset %String; #REQUIRED
         device %String; #REQUIRED
         technology %String; ""
         value %String; #IMPLIED
         >
```

XML in Engineering

- Many formats based on XML
- Especially intended for data exchange
- Some examples:
  - **Collada** for interactive 3D applications
  - **3DXML** for the exchange of geometrical data
  - **EAGLE** board (BRD) and schema (SCH) files for electronic circuits (see above)
  - **CAEX** general purpose language for the exchange of engineering data by European consortium
  - **AutomationML** for plant engineering
  - ...

JSON

- JavaScript Object Notation
- More recent, “lightweight” alternative to XML
- Also provides Schema definition language
- Developed for Web and Cloud applications
- In Engineering:
  - No major usage
  - Current development of CAD JSON export to support web-based interoperability

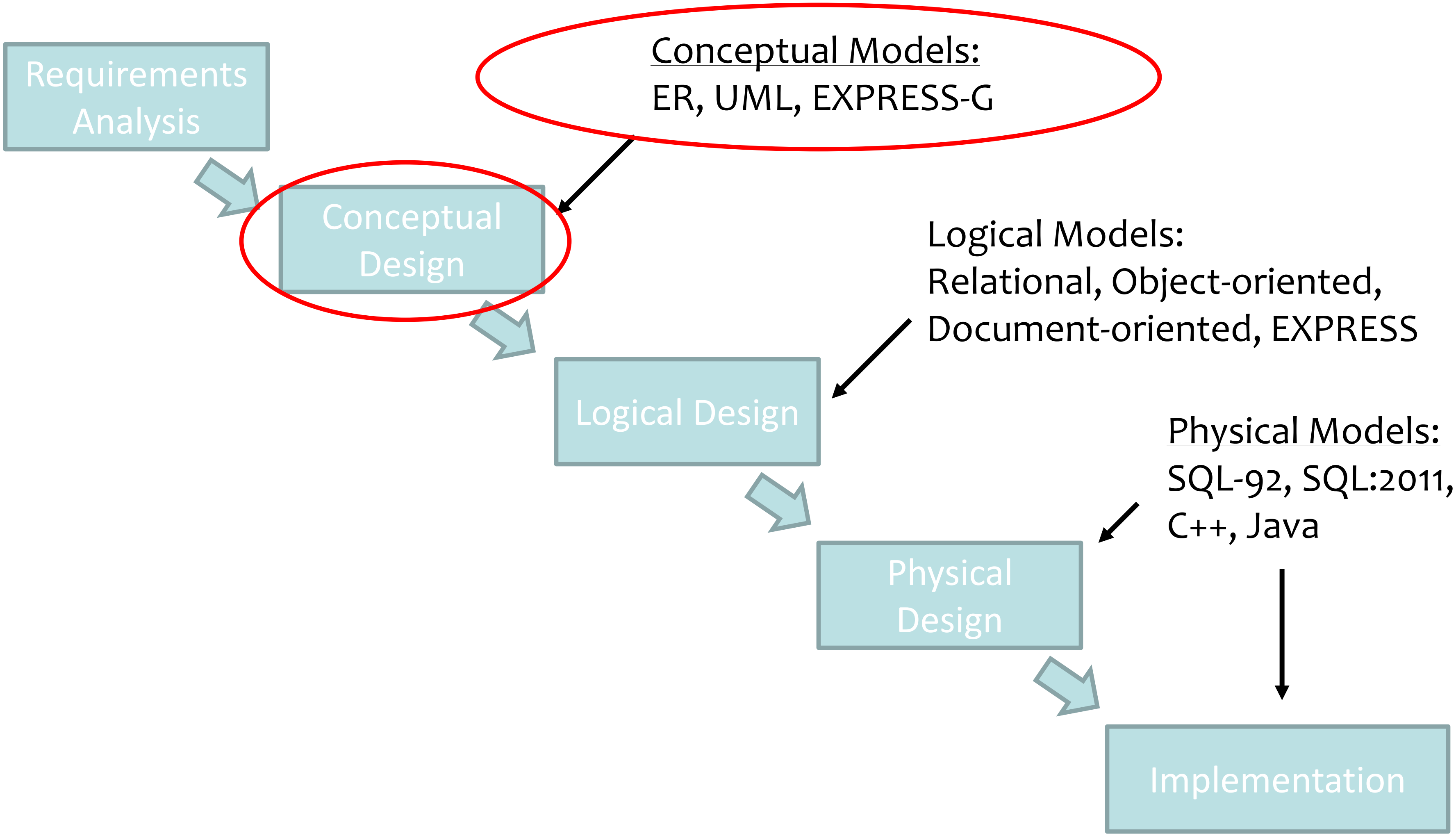
```
{
   "firstName": "John",
   "lastName": "Smith",
   "age": 25,
   "phoneNumber":
   [
      {
         "number": "212 555-1234"
      },
      {
         "type": "fax",
         "number": "646 555-4567"
      }
   ]
}
```

Based on [http://en.wikipedia.org/wiki/JSON]

Conceptual Models

- Used during Conceptual Design
  - Early development phase
  - Independent of implementation
  - Focus on completeness and soundness description of universe of discourse
- Typically using graphical notation
- Covered here:
  - General purpose models:
    - Entity Relations Model (ERM or ER Model)
    - Unified Modeling Language (UML)
  - Specialized model for application areas
    - EXPRESS-G for engineering data

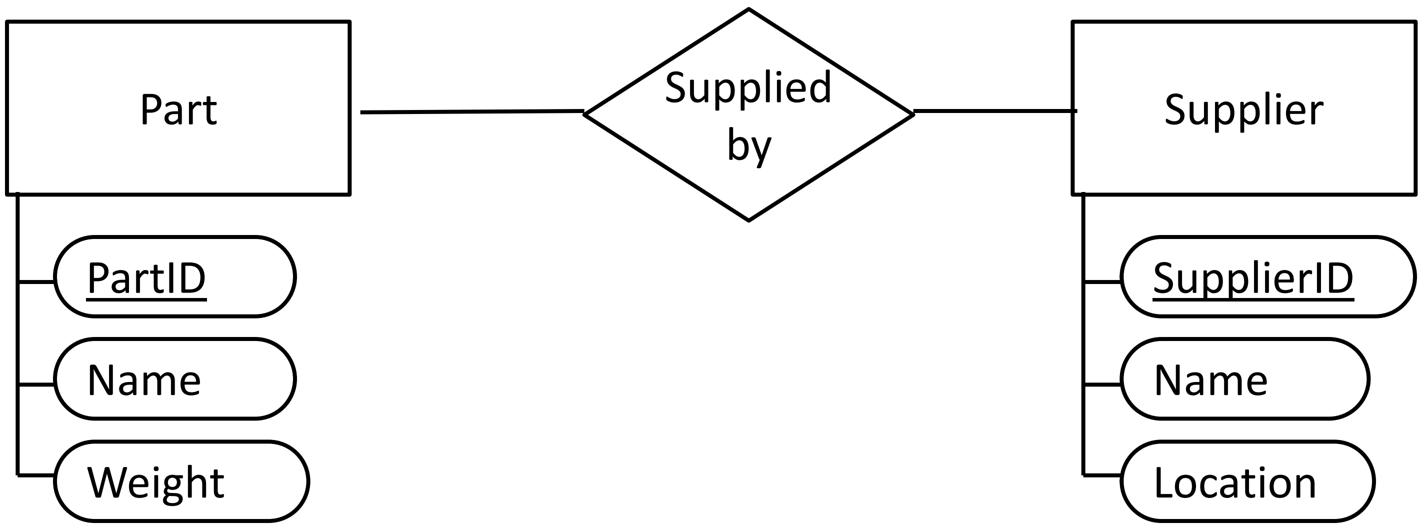
Focus of Conceptual Models



The Entity Relationship (ER) Model

- Developed by Peter Chen in 1976
- Commonly used for design of relational databases
- Set of rules for mapping ER concepts to tables
- Several derivatives with more efficient notation, e.g.
  - Idef1x
  - Crows foot/Barker’s notation
- Several extension, to introduce more powerful (e.g. object-oriented) concepts

ER Model: Basic Concepts



- **Entity types (rectangles):** represent sets of real-world entities with common attributes
- **Attributes (ovals or rounded boxes):** hold property values of entities, keys (underlined) as identifying attributes
- **Relationship types (diamond shaped boxes):** possible relationship between instances of entity types

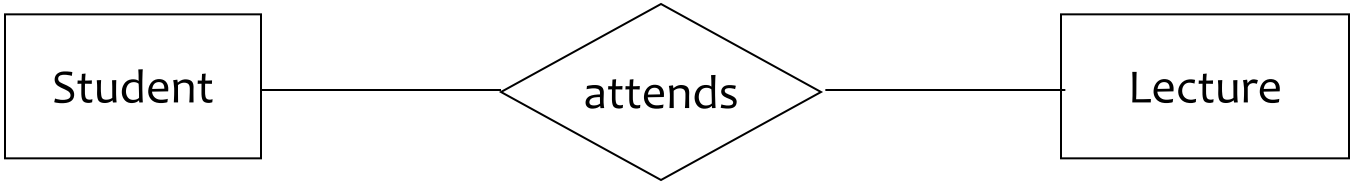
Schallehn: Data Management for Engineering Applications

ER Concepts: Cardinalities /1

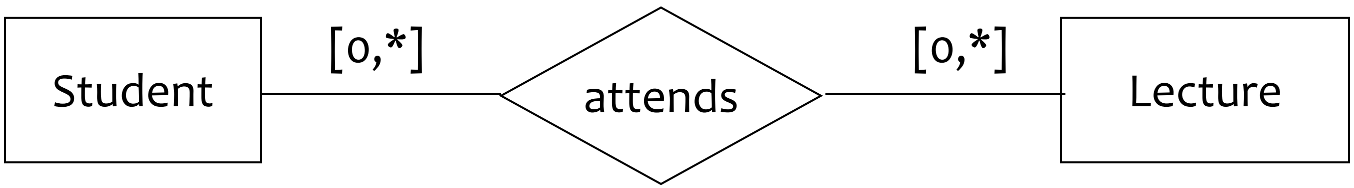
Equivalent to:

- **Cardinalities:** indicate how often instances of entity types might participate in a certain relations
- Min/max cardinalities or, alternatively but less precise, only maximum value
- Optional relationships: minimum cardinality is zero
- 1:1, 1:N or N:M relationships (example above: 1:N relationship) as typical classes of relationships based on cardinalities

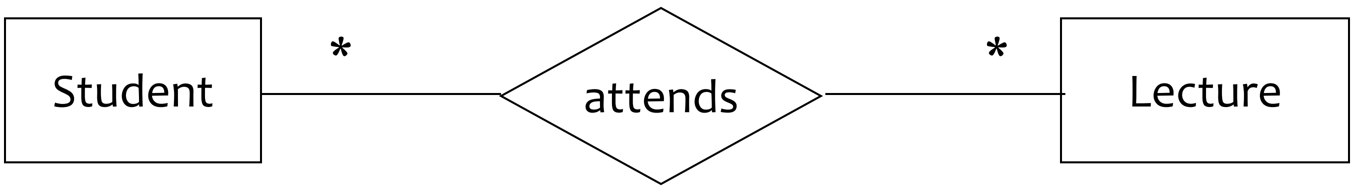
ER Concepts: Cardinalities /2



Equivalent to:

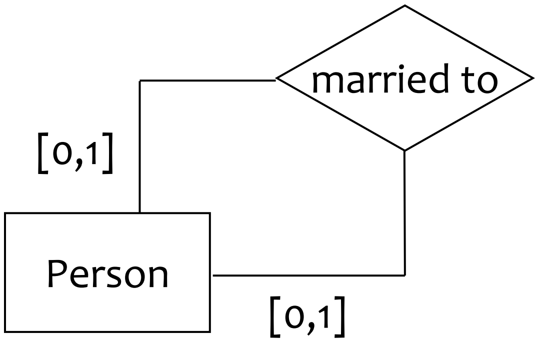


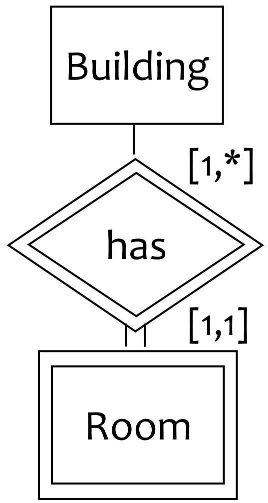
or

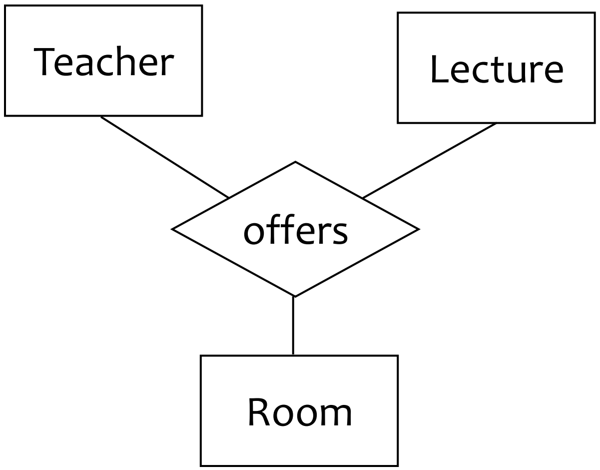


- Example above: N:M relationship
- Unspecified cardinalities indicate default case of optional N:M relationship

ER Concepts: Further Relationships







Self-referential relationships on the type-level

Relationships expressing existential dependencies (weak entity types)

Relationships between more than two entity types (n-ary relationships)

Mapping ER Schema to Relational

- Simple rules
  - Entity types map to tables
  - Attributes map to columns
  - Key attributes map to primary key columns
  - N:M relationships map to tables with keys of participating entity types as columns
  - 1:1 relationships
    - Non-optional: entity types and relationship can be merged into one table
    - Optional: map to table with keys of participating entity types as columns
  - 1:N relationships
    - Non-optional: entity types and relationship can be merged into one table
    - Optional: map to table with keys of participating entity types as columns
- Some variance allowed to improve performance, simplicity, etc.

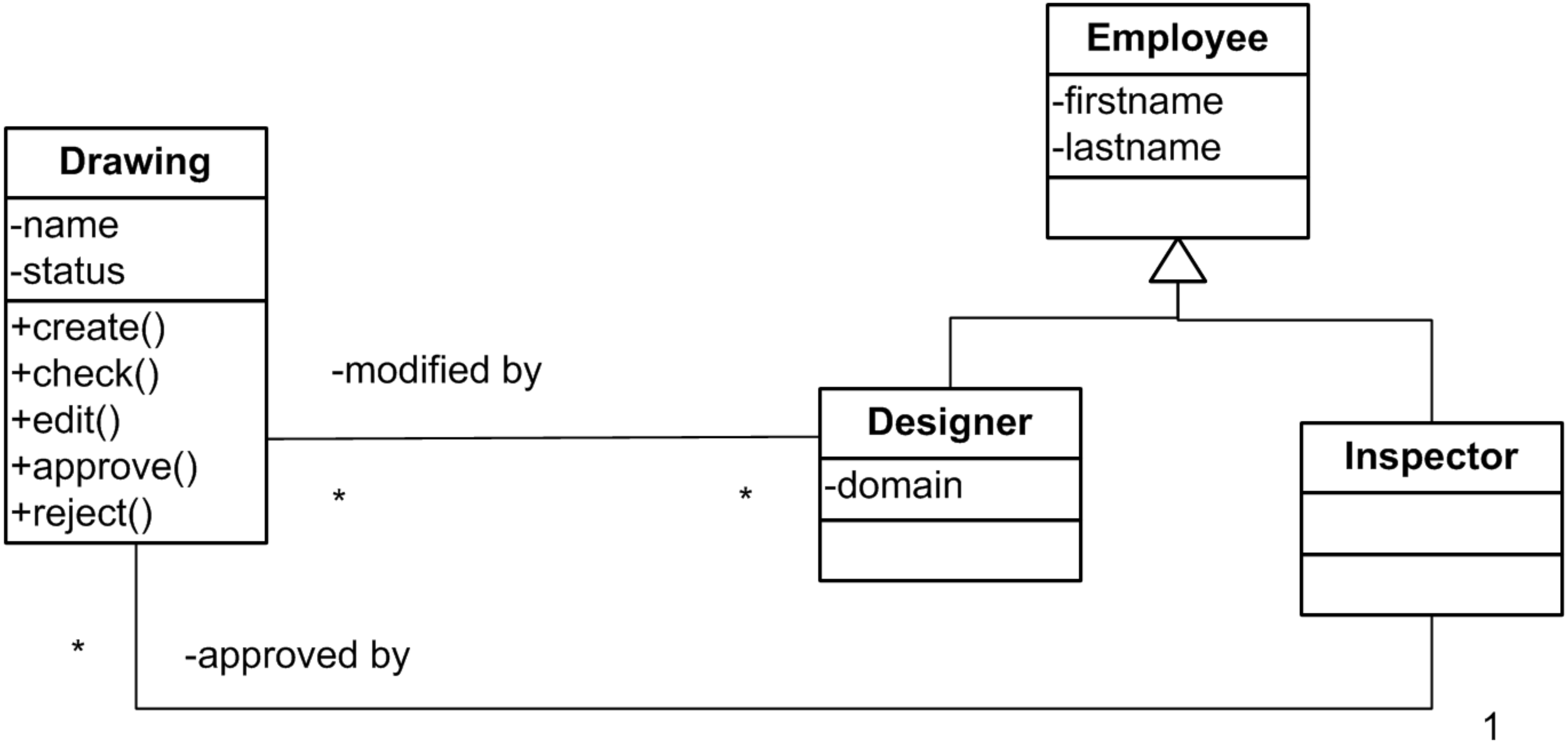
The Unified Modeling Language (UML)

- Object-oriented modeling language/model for general software engineering
- Developed in mid 1990s as a combination of several languages/conceptual models
- Contains several diagram types for describing different aspects of structure and behavior
  - Class diagrams
  - Object diagrams
  - State diagrams
  - Sequence diagrams
  - Etc.
- Class diagrams useful to describe database or file schemas

UML Class Diagrams

- Cover basic data model aspects such as ER Model
  - Classes entity types
  - Attributes and key attributes for classes
  - Relationships with cardinalities
- In addition, object-oriented concepts:
  - Specialization and inheritance
  - Encapsulation
  - Methods

UML Class Diagram Example



STEP

- **STandard for the Exchange of Product model data**
- Developed since 1984 by international consortium
- Standardized since 1990s as **ISO 10303**
- Contains
  - General methods for describing data and schemas
  - Definitions of generic file formats
  - Application-specific methods for engineering domains

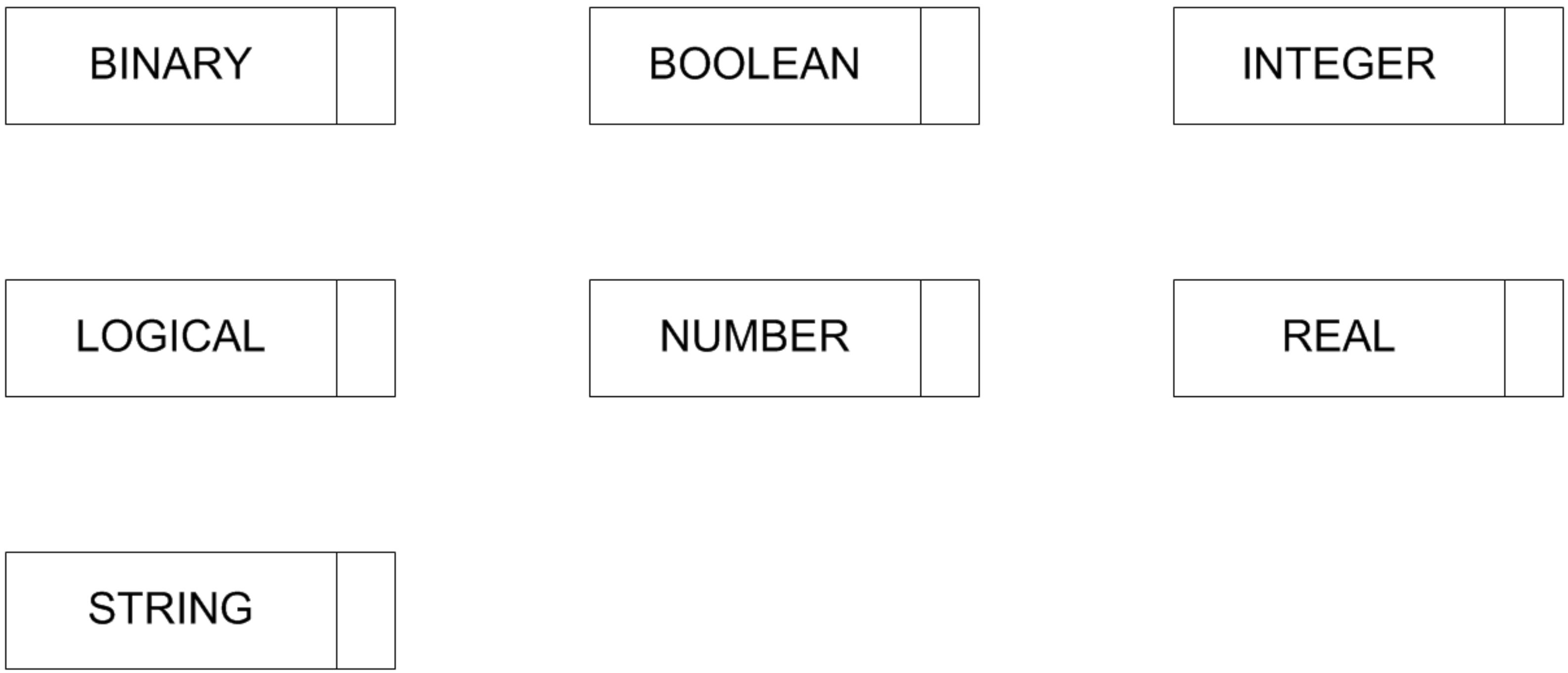
STEP Parts relevant for Data Modeling

- Parts most relevant for data modeling
  - 10303-1x — Description Methods, e.g.
    - **10303-11** — **EXPRESS and EXPRESS-G**
  - 10303-2x — Implementation Methods, e.g.
    - **10303-21** — **STEP files**
    - **10303-22** — **Standard Data Access Interface SDAI**
    - **10303-23, 24 …** — **SDAI C++, C etc. Language Bindings**
    - **10303-28** — **STEP XML**
  - Further 10303-XX — Integrated generic resources
    - 10303-42 — Geometric and topological representation
    - 10303-52 — Mesh-based topology
  - 10303-2XX — Application Protocols
    - …
    - …

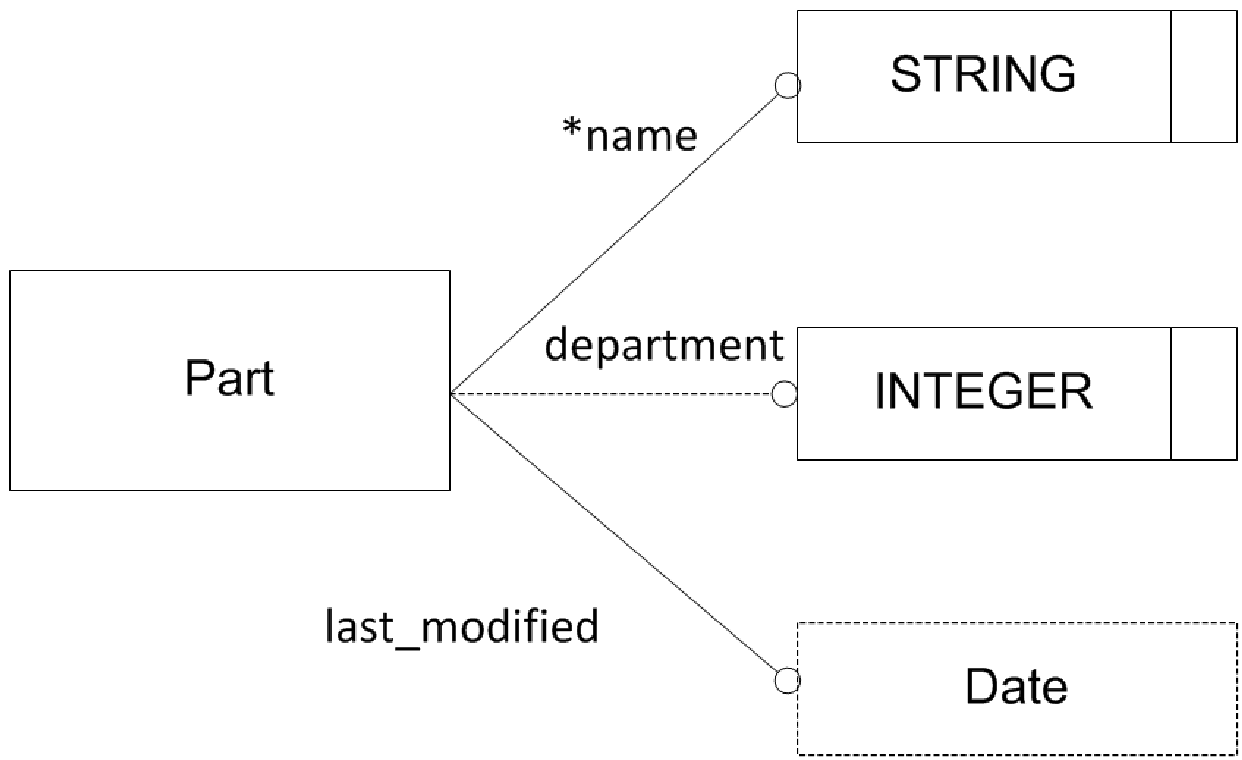
EXPRESS and EXPRESS-G

- Represent Data Model of STEP Standard
- EXPRESS: textual notation
  - Formal notation to describe data structures
- EXPRESS-G: graphical notation
  - Easy to understand
  - Most concepts of EXPRESSED can be described 1:1, except for complex constraints
- For storage/implementation mapped to file format (10303-21) or concrete language (10303-22 ff.)

EXPRESS-G: Basic Data Types



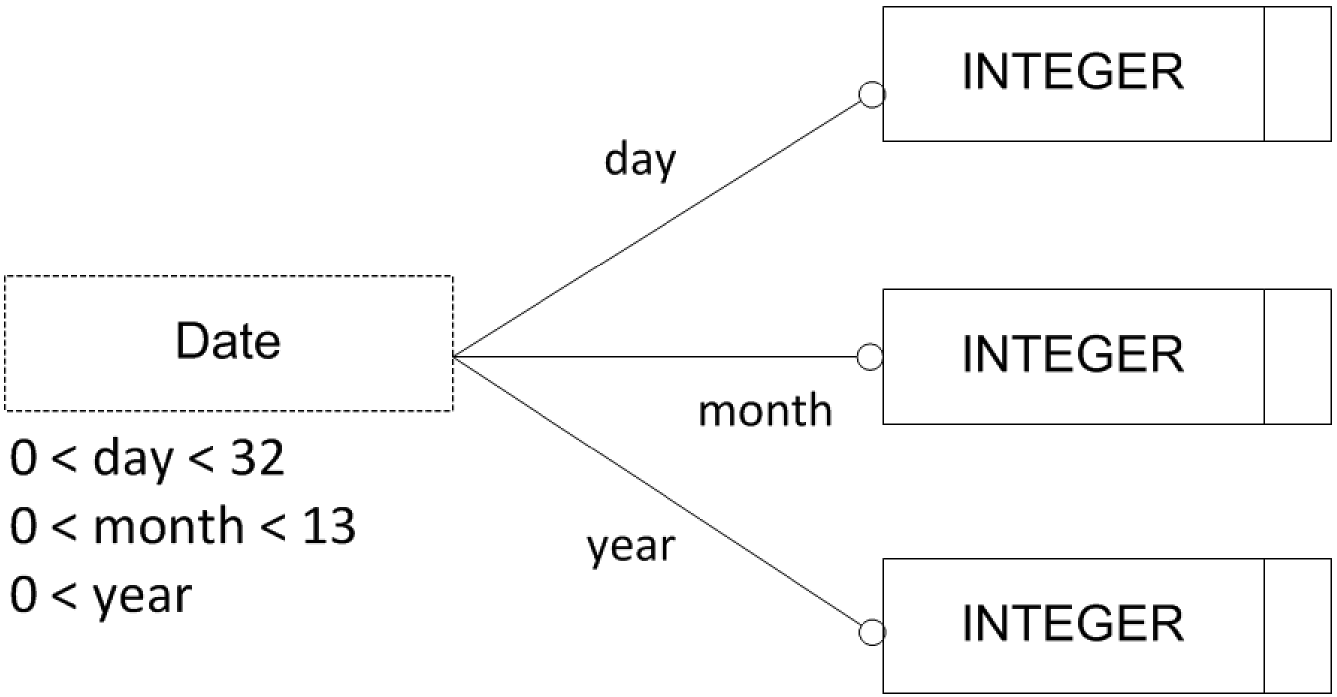
EXPRESS-G: Entity Types and Attributes /1



Entities and Attributes (Remarks)

- Entity types as plain rectangles
- Attributes as relationships to basic types or defined types

EXPRESS-G: Defined Types



0 < day < 32

0 < month < 13

0 < year

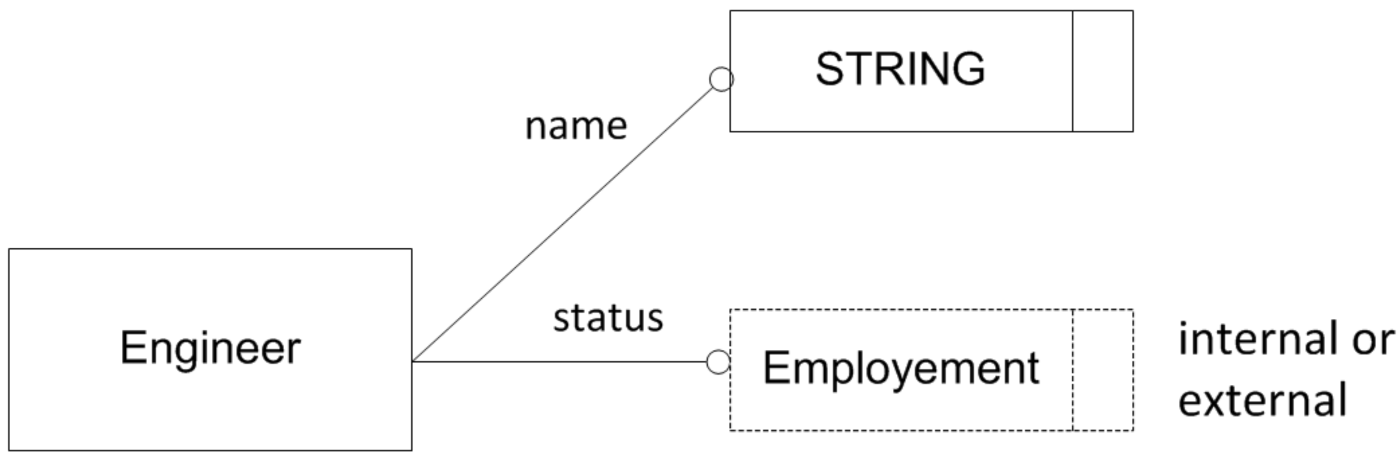
EXPRESS: Entity Types and Attributes /1

```
SCHEMA Parts;

TYPE Date
        day                 : INTEGER;
        month               : INTEGER;
        year                : INTEGER;
WHERE
  WR1: (SELF\day > 0) AND (SELF\day < 32);
  WR1: (SELF\month > 0) AND (SELF\month < 13);
  WR1: (SELF\year > 0);
END TYPE;

ENTITY Part
        name                : UNIQUE STRING;
        department          : OPTIONAL INTEGER;
        last_modified       : Date;
END ENTITY;

…

END SCHEMA;
```

Defined Types (Remarks)

- Can be used just like basic types
- Defined as
  - based on one basic or
  - composed of several basic or defined types
- Constraints maybe used to
  - Limit domain of values
  - Specify any consistency requirement

EXPRESS-G: Enumeration Data Type



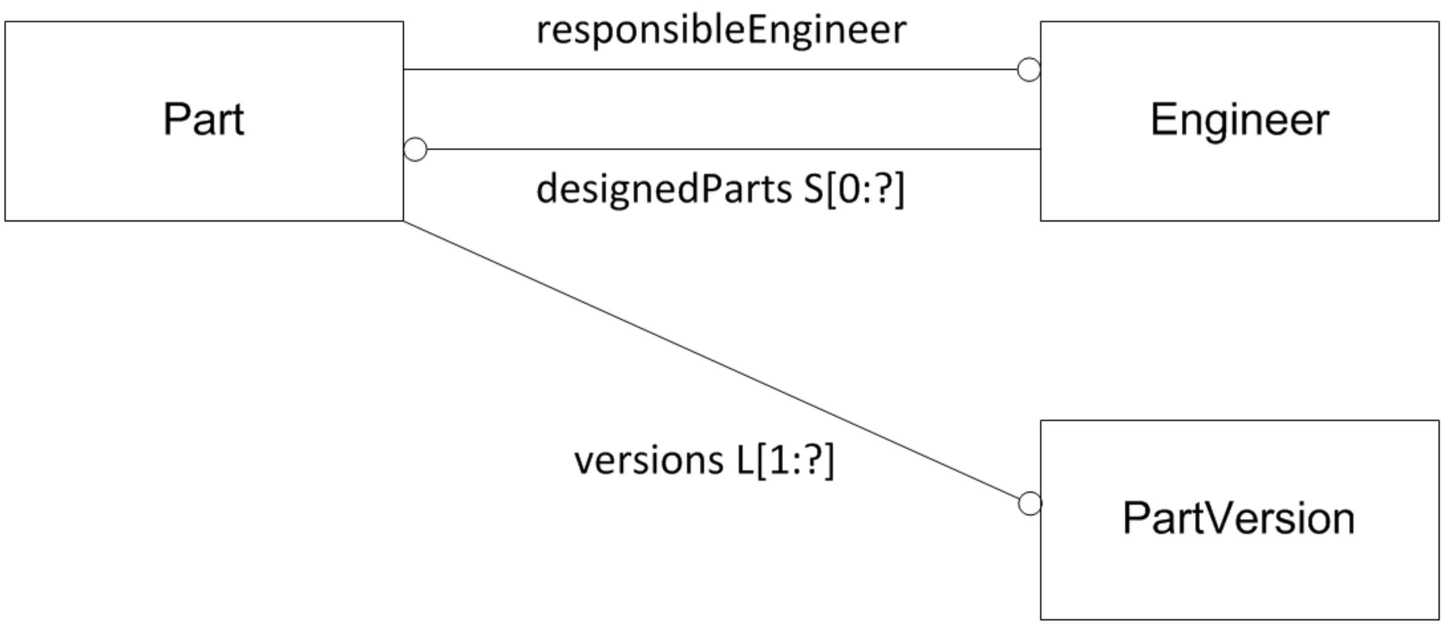
EXPRESS: Enumeration Data Type

```
SCHEMA Parts;

…

ENTITY Engineer
         name                  : STRING;
         status                : ENUMERATION OF (internal,external);
END ENTITY;

…

END SCHEMA;
```

Enumeration Data Type (Remarks)

- Enumeration is special type for categorical attribute
- Consists of definition of small set of possible values

EXPRESS-G: Relationships



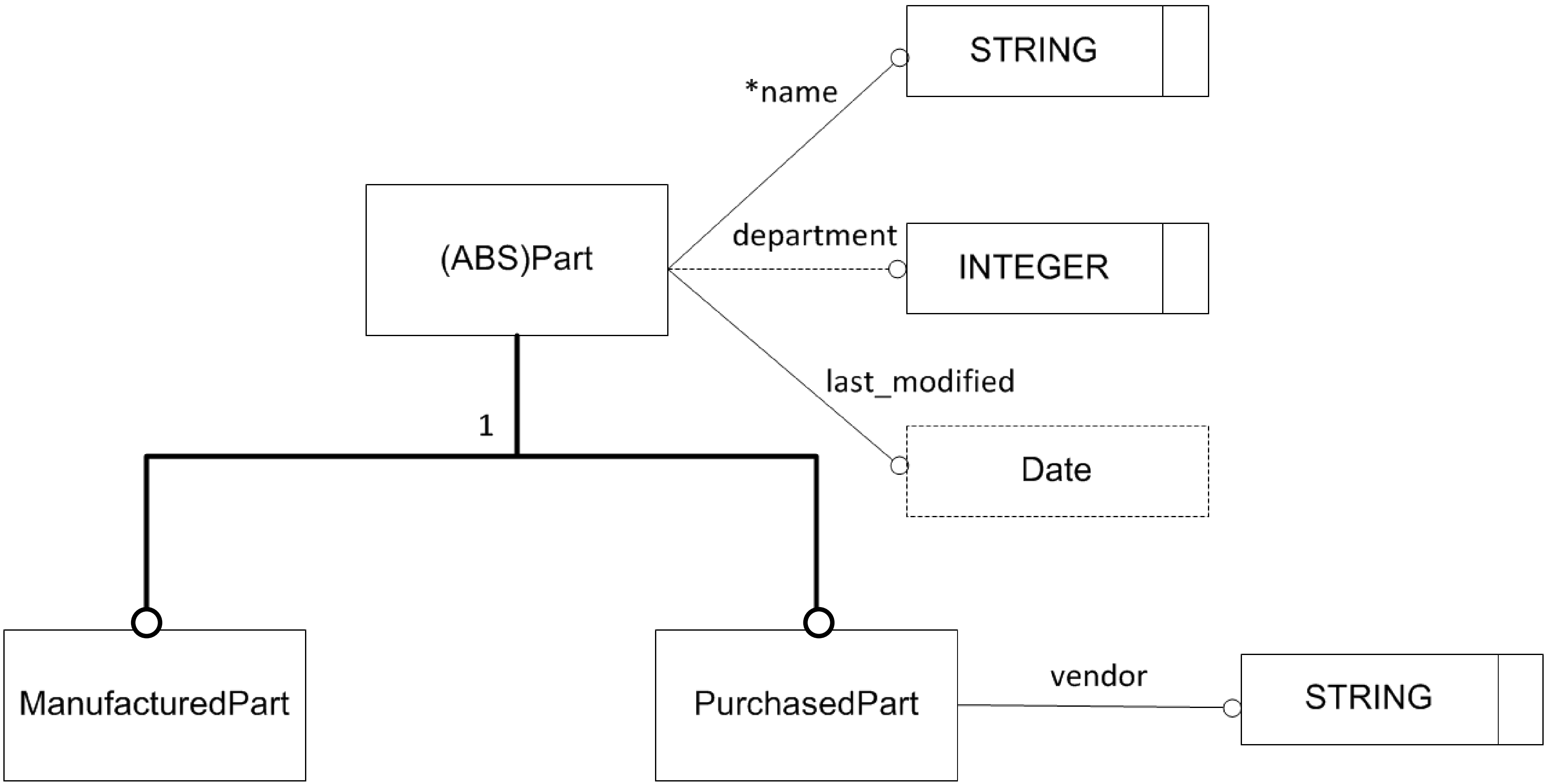
EXPRESS Relationships

```
SCHEMA Parts;

…

ENTITY Part
        …
        responsibleEngineer       : Engineer;
        versions                  : LIST[1:?] OF PartVersion;
END ENTITY;

ENTITY Engineer
        designedParts             : SET[0:?] OF Part;
END ENTITY;



…

END SCHEMA;
```

Relationships (Remarks)

- Relationships between entity types are directional
- Bidirectional relationships represented as two relationships
- Multiple participation can be represented by Aggregation types
  - List (L): ordered collection
  - Set (S): unordered collection without duplicates
  - Bag (B) : unordered collection with duplicates
  - Array (A): collection of fixed size (ordered, with duplicates)
- Cardinalities with [min:max] notation where ? indicates an arbitrary cardinality

EXPRESS-G: Subtyping



EXPRESS: Subtyping

```
SCHEMA Parts;

…

ENTITY Part
        ABSTRACT SUPERTYPE OF
                (ONEOF (ManufacturedPart, PurchasedPart));
        …
END ENTITY;

ENTITY MaufacturedPart
        SUBTYPE OF (Part);
END ENTITY;

ENTITY PurchasedPart
        SUBTYPE OF (Part);
        vendor           : STRING;
END ENTITY;


…

END SCHEMA;
```

Subtyping (Remarks)

- Inheritance (supertype attributes are also defined for subtype) and polymorphism (substitutability) are supported
- Multiple inheritance (more than one supertype) is possible
- Instances may be of several subtypes at the same time
  - Can be constrained by cardinalities, e.g. ONEOF = instance only of either one of the specified subtypes

Further EXPRESS-G Constructs

- **Schemas** as blocks consisting of entities and relations
- **Select types** to represent alternatives of various (entity or defined) types to use for relationship
- **Methods** according to object-oriented concepts
- Derived attributes as calculated properties
- **Communication relationships** to indicate interactions
- Entity and page **references** for complex or
- …

ISO 10303-21: STEP Files

- ASCII-based textual file format for step data
- File extensions `.stp` or `.step` for files according to application protocols
- Commonly used for data exchange in engineering
- Typically structured according to an EXPRESS schema
- Files typically consists of
  - ISO-10303-21-declaration in first line
  - Short HEADER section containing metadata, including a reference to the schema (typically STEP Application Protocol)
  - DATA section with lines each representing a numbered entity instance according to schema

AP 214 EXPRESS Schema (Excerpt)

```
(* SCHEMA geometry_schema; *)

 ENTITY cartesian_point
   SUPERTYPE OF (ONEOF(cylindrical_point, polar_point, spherical_point))
   SUBTYPE OF (point);
    coordinates  : LIST [1:3] OF length_measure;
 END_ENTITY;
```

[Source: steptools.com]

Example AP214 .STEP File

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION( ( '' ), ' ' );
FILE_NAME( 'pumpHousing.stp', '2004-04-13T21:07:11', ( 'Tim Olson' ), ( 'CADSoft Solutions
                                        Inc' ), ' ', 'ACIS 12.0', ' ' );
FILE_SCHEMA (('AUTOMOTIVE_DESIGN { 1 0 10303 214 2 1 1}'));
ENDSEC;
DATA;
. . .
#3716 = POINT_STYLE( ' ', #6060, POSITIVE_LENGTH_MEASURE( 1.00000000000000E-06 ), #6061 );
#3717 = CARTESIAN_POINT( '', ( -1.10591425372267, 3.05319777988191, 0.541338582677165 ) );
#3718 = CURVE_STYLE( '', #6062, POSITIVE_LENGTH_MEASURE( 1.00000000000000E-06 ), #6063 );
#3719 = LINE( '', #6064, #6065 );
#3720 = CURVE_STYLE( '', #6066, POSITIVE_LENGTH_MEASURE( 1.00000000000000E-06 ), #6067 );
#3721 = CIRCLE( '', #6068, 1.75849340964528 );
#3722 = CURVE_STYLE( '', #6069, POSITIVE_LENGTH_MEASURE( 1.00000000000000E-06 ), #6070 );
#3723 = CIRCLE( '', #6071, 0.540114611464642 );
#3724 = SURFACE_STYLE_USAGE( .BOTH., #6072 );
#3725 = FACE_OUTER_BOUND( '', #6073, .T. );
. . .
ENDSEC;
END-ISO-10303-21;
```


[Source: Paul Bourke
http://paulbourke.net/dataformats/]

STEP SDAI

- **Standard Data Access Interface ISO 10303-22** defines standard bindings to languages (C, C++, Java) for STEP data access
- Similar to an API for an RDBMS (ODBC, JDBC) or ODBMS defines basic functionality such as
  - Sessions
  - Database connectivity
  - Data dictionary
- Defines mappings of EXPRESS types to language constructs, e.
- Not specific to geometrical data → used more often for other applications

Further Readings

[1] Ramez Elmasri, Shamkant B. Navathe: Fundamentals of Database Systems. Addison-Wesley

[2] Owen Jon: STEP – An Introduction. Information Geometers, 1997

[3] Douglas A. Schenck, Peter R. Wilson: Information Modeling the EXPRESS Way. Oxford Press, 1993.