An ontology-driven unifying metamodel for UML Class Diagrams, EER, and ORM2

C. Maria Keet

School of Mathematics, Statistics, and Computer Science,
University of KwaZulu-Natal, South Africa,
keet@ukzn.ac.za

joint work with Pablo Rúben Fillottrani
Universidad Nacional del Sur, Argentina

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Setting

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  - one formalization including *all* (structural, static) language features, where each of the languages is a fragment;
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⇒ First step: identify commonalities and differences in terminology, syntax, semantics, and ontological commitments of the structural components of the three main languages (EER, UML Class Diagrams v2.4.1, ORM2)

⇒ Metamodel

A motivation why first metamodelling

$\mathcal{DLR}_{ifd}$	**OWL 2 DL**	**FOL**
– no implementation	+ several automated reasoners, relatively scalable	– few reasoners, not really scalable
– no interoperability	+ linking with ontologies doable	– no interoperability with existing infrastructures
– no integration	+ 'integration' with OntoIOP	+ 'integration' with OntoIOP
+ formalisation exist	– formalisation to do	± formalisation exist
+ little feature mismatch	– what to do with OWL 2 DL features not in the CM languages and vv.	+ little feature mismatch
– modularity infrastructure	+ modularity infrastructure	– modularity infrastructure

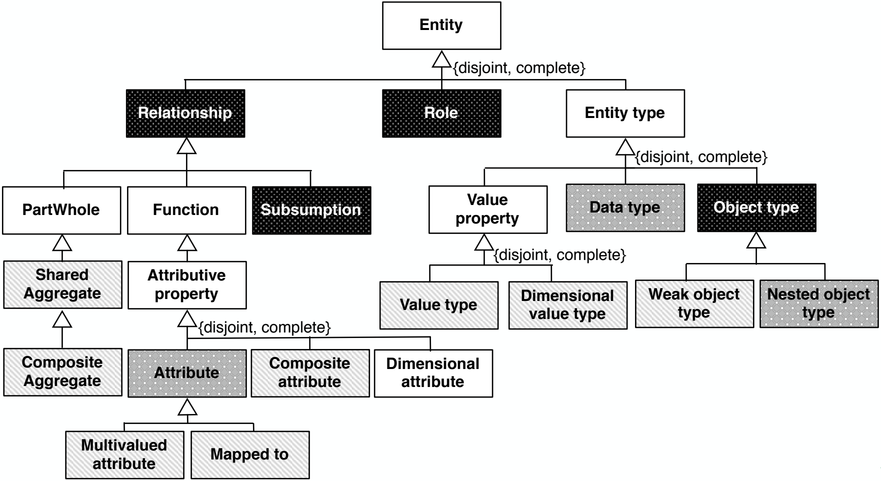
Ontology-driven

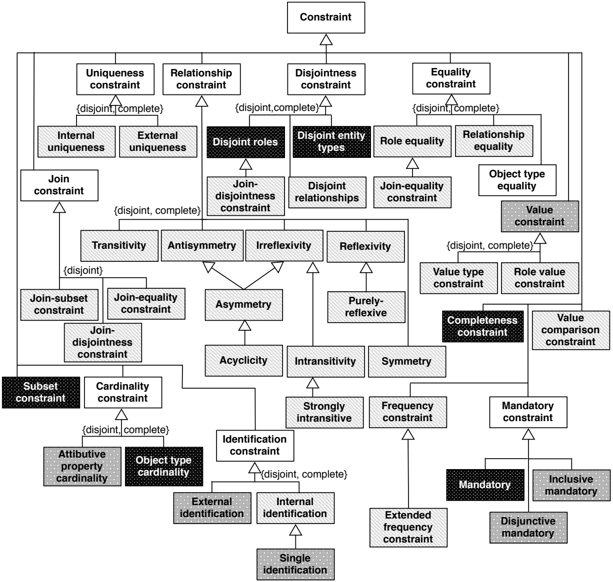
- Uncover ontological decisions embedded in the modelling language, among others:
  - Positionalism of relations (nature of relations)
  - Identification mechanisms (identity)
  - Attributes, ‘attribute-free’ or ‘attribute-hidden’ (attributions, quality properties)
  - Subrelations (meaning of a sub-relation)
  - Any differences/similarities for constraints (e.g., on when a relationship may be objectified)

Notes for the metamodel

- We use UML Class Diagram notation for the metamodel
- Not all constraints can be represented in that diagram, but added as textual constraint
- It has some redundancies (from a logic-based perspective), e.g., multivalued attributes
- Not all features may be 'good' features, but we do not judge about elegance (can be addressed in a formalization)
- Table with naming conventions for UML, EER, ORM2, and the metamodel terms

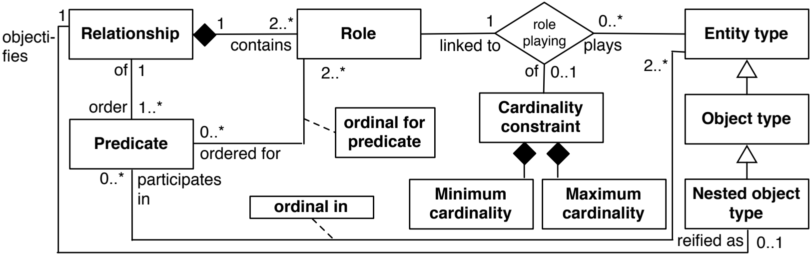
Principal static entities of the metamodel




Constraint
Uniqueness constraint
Relationship constraint
Disjointness constraint
Equality constraint
{disjoint, complete}
Internal uniqueness
External uniqueness
{disjoint,complete}
Disjoint roles
Disjoint entity types
{disjoint, complete}
Role equality
Relationship equality
Join constraint
Join-disjointness constraint
Disjoint relationships
Join-equality constraint
Object type equality
Value constraint
{disjoint, complete}
Transitivity
Antisymmetry
Irreflexivity
Reflexivity
{disjoint, complete}
Value type constraint
Role value constraint
{disjoint}
Join-subset constraint
Join-equality constraint
Asymmetry
Purely-reflexive
Completeness constraint
Value comparison constraint
Join-disjointness constraint
Acyclicity
Intransitivity
Symmetry
Subset constraint
Cardinality constraint
Strongly intransitive
Frequency constraint
Mandatory constraint
{disjoint, complete}
Identification constraint
Attibutive property cardinality
Object type cardinality
{disjoint, complete}
Mandatory
Inclusive mandatory
External identification
Internal identification
Extended frequency constraint
Disjunctive mandatory
Single identification

- UML, EER, and ORM are all **positionalist** [Keet(2009)]
  - *n*-ary relationship
  - Role that an entity plays in a relationship
  - No order on the roles (or: 'relationship' as a set of roles), but one can add an order
  - Relationship composed of roles
- Optional predicate, with order and no roles
- Cardinality
- Nested object type

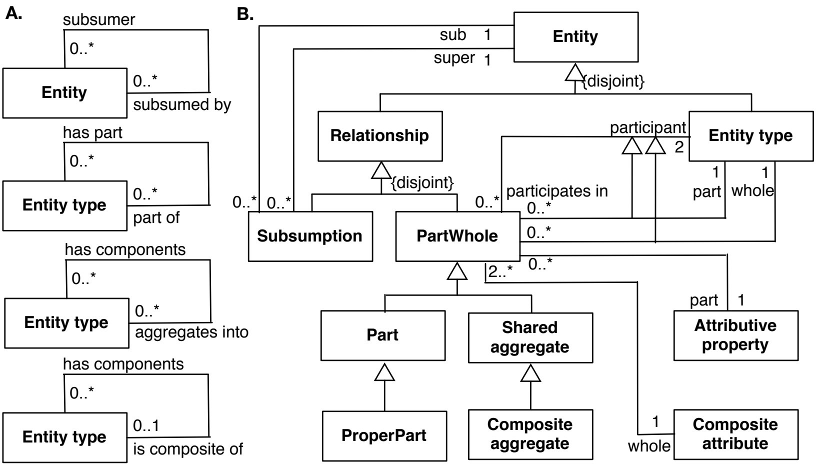
Principal relationships between Relationship, Role, and Entity type



Notes

- Relations between roles and a predicate can only exist if there is a relation between those roles and the relationship that that predicate is an ordering of (i.e., it is a join-subset)
- Entities that participate in the predicate must play those roles that compose the relationship of which that predicate is an ordered version of it

Subsumption and aggregation



What are attributes?

- An *attribute* (A) is a binary relationship between a relationship or entity type ($R \cup E$) and a data type (D), i.e., $A \mapsto R \cup E \times D$
- An attribute is no more, and no less
- For instance, one can have an attribute hasColour, that relates an object type to a string; e.g, hasColour $\mapsto$ Flower $\times$ `String`

Attribution in Ontology and ontologies

- Principally as *quality property*, formalised as unary predicate
- Separate relation to endurants or perdurants
- Separate relation to 'values' (qualia) of an attribution

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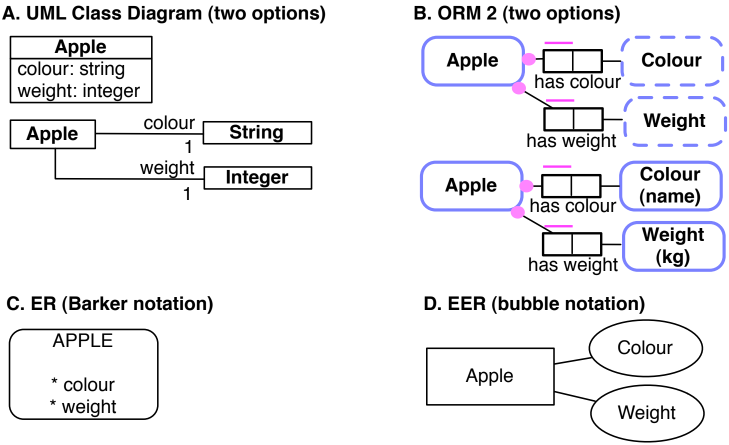
- Separate relation to 'values' (qualia) of an attribution
- Implemented as such in foundational ontologies, such as DOLCE and GFO
- Practically, the same quality property can be related to more than one entity

Examples of ‘attributes’ in UML, EER, ORM



Dimensional attributes and value types

- *dimension* for the value: implicit meaning in the values for some data types, which has to do with measurements
- e.g., hasHeight $\mapsto$ Flower $\times$ $\texttt{Integer}$ does not contain any of that information, but somehow has to be included

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- How? e.g.:
  - hasHeight $\mapsto$ Flower $\times$ `Integer` $\times$ cm
    or perhaps with an approach along the line of:
  - hasHeight $\mapsto$ Flower $\times$ Height
  - mapped_to $\mapsto$ Height $\times$ `Integer`
  - hasDimension $\mapsto$ Integer $\times$ cm

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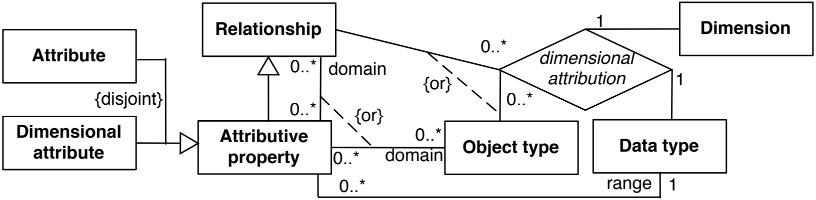
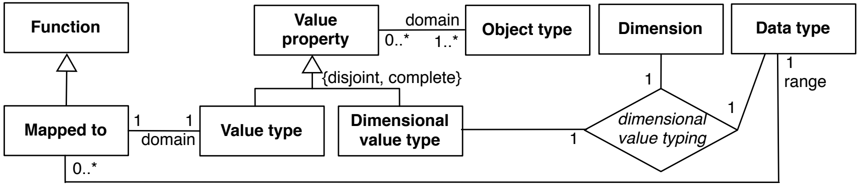
  - mapped_to $\mapsto$ Height $\times$ `Integer`
  - hasDimension $\mapsto$ Integer $\times$ cm
- Within the scope of unification, add the notion of dimension (not a whole system of recording measurement data for a specific scenario)

Attributes in the metamodel



Value types in the metamodel



Related work: data and schema level

- Mapping and transformation algorithms using a common hypergraph, for small subsets of ER, UML, and ORM; set-based semantics vs. a model-theoretic semantics [Boyd and McBrien(2005)]
- Physical schema layer [Bowers and Delcambre(2006)]

Related work: conceptual data modelling and software engineering

- Compare the languages through their metamodels in ORM, highlight differences [Halpin(2004)]
- Metamodel for a part of ER and a part of NIAM in CoCoA and implemented in MViews, Pounamu [Venable and Grundy(1995), Grundy and Venable(1996), Zhu et al.(2004)]; omits, a.o., value types, composite attributes, and e.g., NIAM is forced to have the attributes as in ER
- (linking/integrating conceptual models represented in the same conceptual data modelling language [Atzeni et al.(2008), Fillottrani et al.(2012)])

Related work: Knowledge representation and reasoning

- Approach: mainly, choose a logic and show it fits neatly/sufficiently with one or more conceptual data modelling languages
- Separate partial formalisations various logics; a.o., [Berardi et al.(2005), Calvanese et al.(1998), Halpin(1989), Hofstede and Proper(1998), Queralt and Teniente(2008)]
- Partial unifications, using e.g., $\mathcal{ALUNI}$ [Calvanese et al.(1999)], several *DL-Lite* fragments [Artale et al.(2007)], $\mathcal{DLR}_{\text{ifd}}$ [Keet(2008)]
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- They cannot simply be linked up and implemented
- Distributed Ontology Language [Mossakowski et al.(2012)] and system that is currently being standardised by ISO (`http://ontoiop.org`).

Conclusions

- Unifying, ontology-driven metamodel capturing most of ORM/FBM, EER, and static UML v2.4.1 w.r.t their static, structural, entities, their relationships, and constraints
- The only intersection among all these conceptual data modelling languages are role, relationship, and object type
- Adhere to the positionalist commitment of the meaning of relationship
- Attributions are represented differently in each language, but, ontologically, they denote the same notions
- Several implicit aspects, such as dimensional attribute and its reusability and relationship versus predicate, have been made explicit
- Common constraints: disjointness, completeness, simple mandatory, object type cardinality

Current work

- Two papers submitted
- Near future: formalisation in FOL, then OWL 2 DL subset
- Extension of tool that will aid the process of complex systems design and information integration

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