JOHANNES KEPLER UNIVERSITÄT LINZ | JKU

Towards Ontology-based OLAP

Datalog-based Reasoning over Multidimensional Ontologies

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Supported by the Austrian Ministry of Transport, Innovation, and Technology
in program FIT-IT Semantic Systems and Services under grant FFG-829594:
Semantic Cockpit: an ontology-driven, interactive business intelligence tool for comparative data analysis

Agenda

- General Idea
  - Problem/Motivation
  - Multidimensional Ontologies (MDOs)
  - Architecture: Ontology-based OLAP
- Technical Details (very short, see paper)
  - MDO Metamodel
  - Mapping to Datalog
  - Datalog-based Reasoning over MDO Concepts
- Ongoing and Future Work

Problem

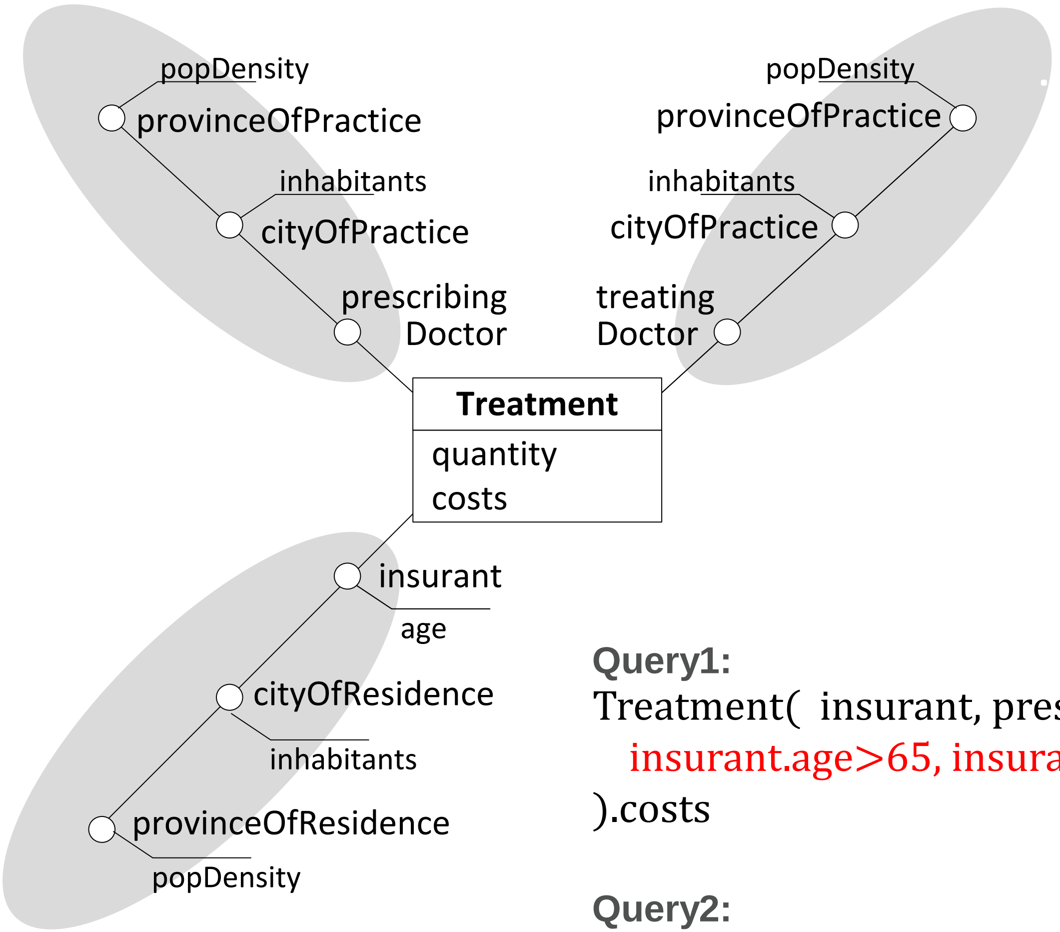
How to

- ***reuse,***
- ***maintain,***
- ***understand,***
- ***share and***
- ***organize***

large sets of multidimensional queries?

(we focus on boolean predicates of selection clauses)

Problem



Query1:

Treatment(insurant, prescribingDoctor, treatingDoctor,;
insurant.age>65, insurant.cityOfResidence.inhabitants>50000
).costs

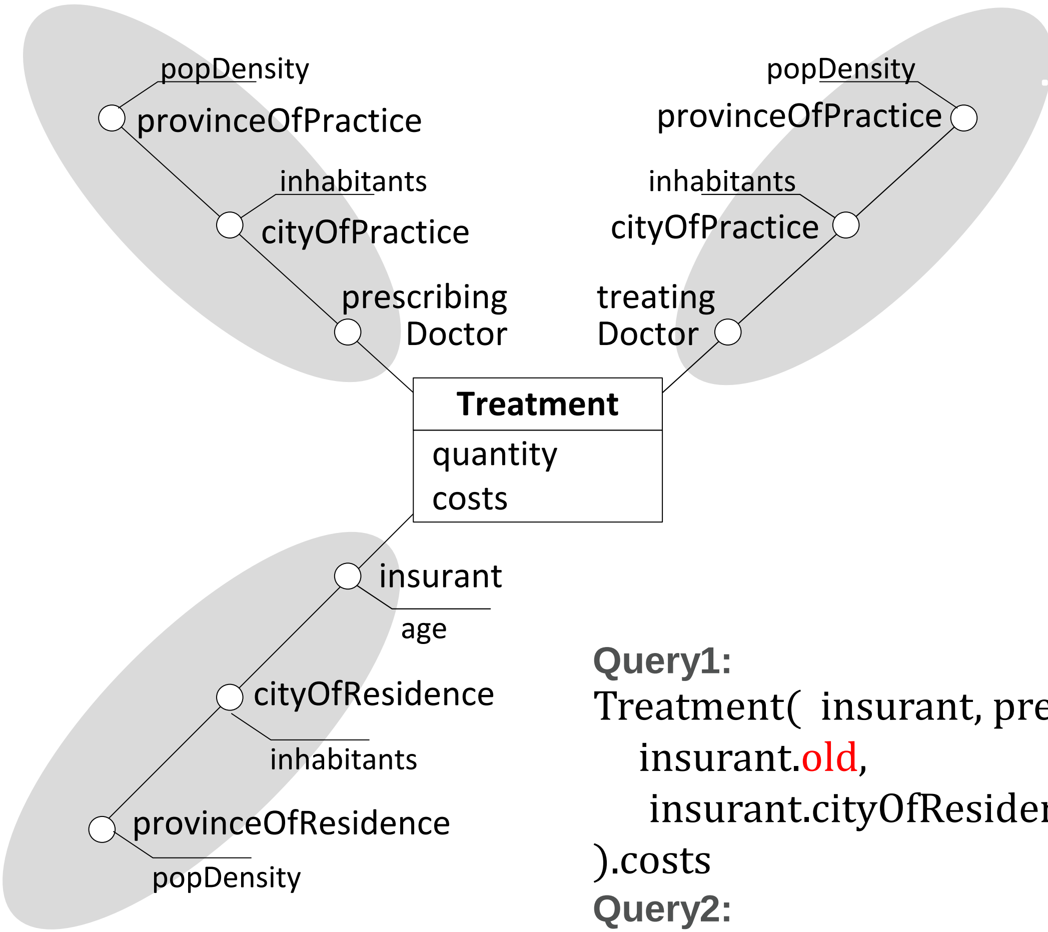
Query2:

Treatment(insurant, prescribingDoctor, treatingDoctor,;
insurant.age>65, insurant.cityOfResidence.inhabitants>100000,
treatingDoctor.cityOfPractice.inhabitants > 50000
).costs

Partial Solution

- Define business terms and use them for querying
- implement business terms as
  - SQL: Views
  - MDX: Named Sets
- Lack of:
  - reasoning support: consistency checking, subsumption checking
  - organization of business terms

Partial Solution



mediumToLargeCity
== inhabitants > 50000

largeCity
== inhabitants > 100000

old
== age > 65

Query1:
Treatment(insurant, prescribingDoctor, treatingDoctor,;
insurant.old,
insurant.cityOfResidence.mediumToLargeCity
).costs

Query2:
Treatment(insurant, prescribingDoctor, treatingDoctor,;
insurant.old, insurant.cityOfResidence.largeCity,
treatingDoctor.cityOfPractice.mediumToLargeCity
).costs

Ontologies to the Rescue

- Ontologies:
  - formal conceptual domain models with
  - richly defined concepts organized in subsumption hierarchies

- use ontologies 'as high-level, conceptual view over data repositories' for querying, as in OBDA:

  Diego Calvanese et al.: *The MASTRO system for ontology-based data access*. Semantic Web (SEMWEB) 2(1):43-53 (2011)

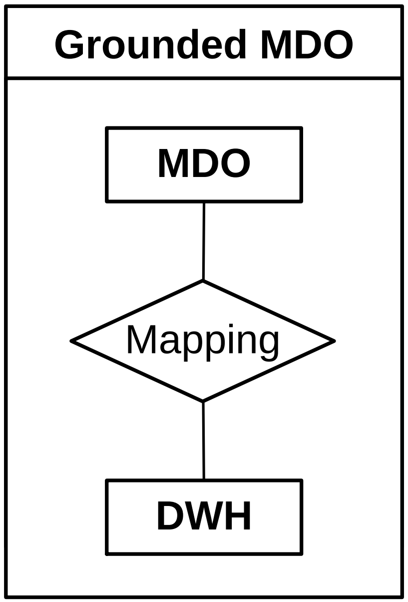
Multidimensional Ontologies (MDOs)

- Conceptual Multidimensional Model (Schema + Individuals)
  + Defined Concepts (Views)
  + Subsumption Reasoning over Defined Concepts

- Separation between Primitive Concepts (Schema) and Defined Concepts (Views) as in:

  Martin Buchheit, Francesco M. Donini, Werner Nutt, Andrea Schaerf: *A Refined Architecture for Terminological Systems: Terminology = Schema + Views*. Artif. Intell. (AI) 99(2):209-260 (1998)

Open-world MDO vs. closed-world DWH



closed world – high level

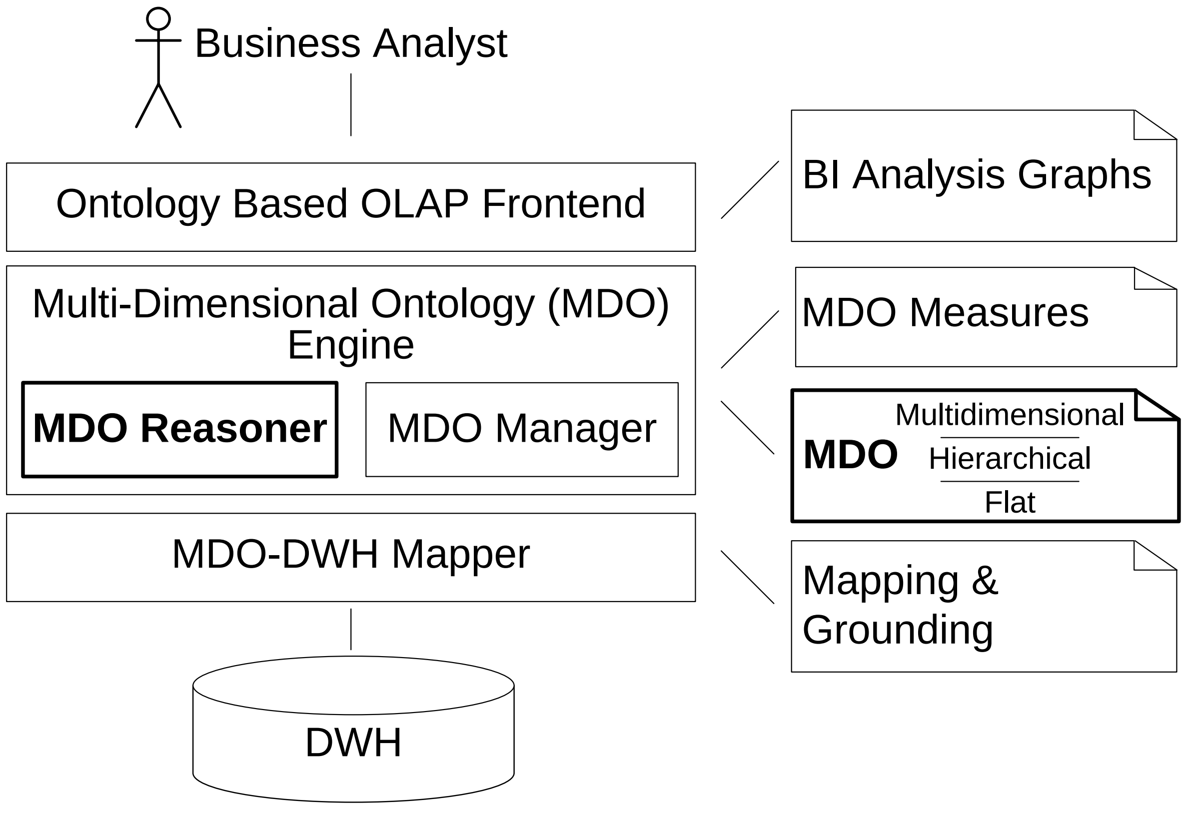
open world – high level

closed world – low level

Other than in OBDA we assume - as a prerequisite for correct aggregation results - that data in a data warehouse is always complete.

A Grounded MDO can be regarded as a model (valid interpretation) of the MDO. Some of the Datalog rules and constraints defining structure and semantics of MDOs only apply to Grounded MDOs.

Architecture: Ontology-based OLAP



Why don’t we use OWL for defining MDOs?

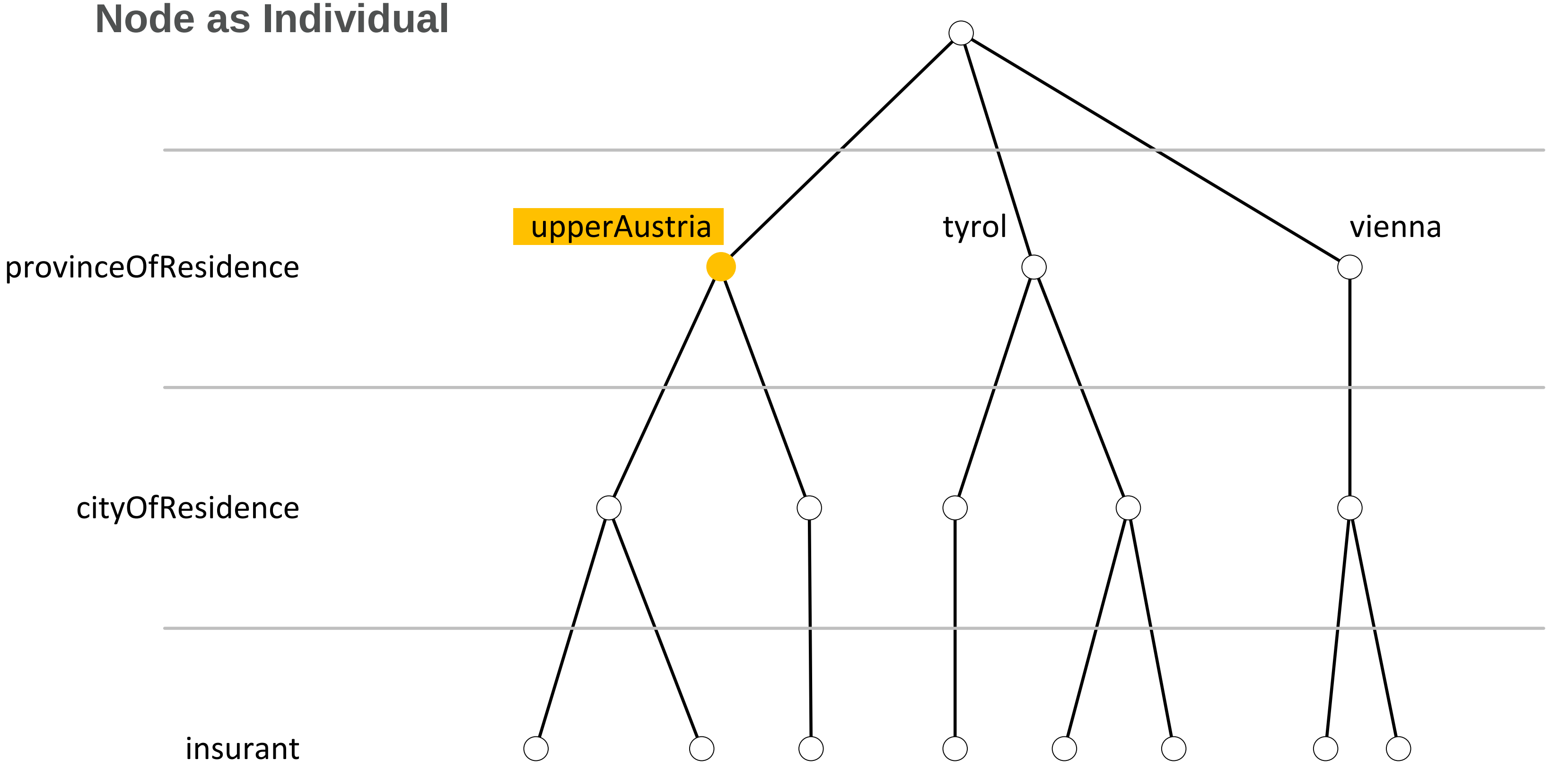
- Worldview of business analysts difficult to represent in OWL:
  - Business analyst: focus on highly-aggregated numbers describing some abstract points in a multidimensional space.
  - Blurring between ABox and TBox: dimension members (nodes) and cells are individuals and classes, thus, classes of dimension members or cells are metaclasses
- OWL does not exploit structural specifities of MDOs
- Future work: MDOs in OWL

  Extend/Restrict OWL for MDOs or build MDOs on top of OWL?
- OWL ontologies in the SemCockpit project:

  Stefan Anderlik, Bernd Neumayr, Michael Schrefl: *Using Domain Ontologies as Semantic Dimensions in Data Warehouses.* ER 2012: 88-101

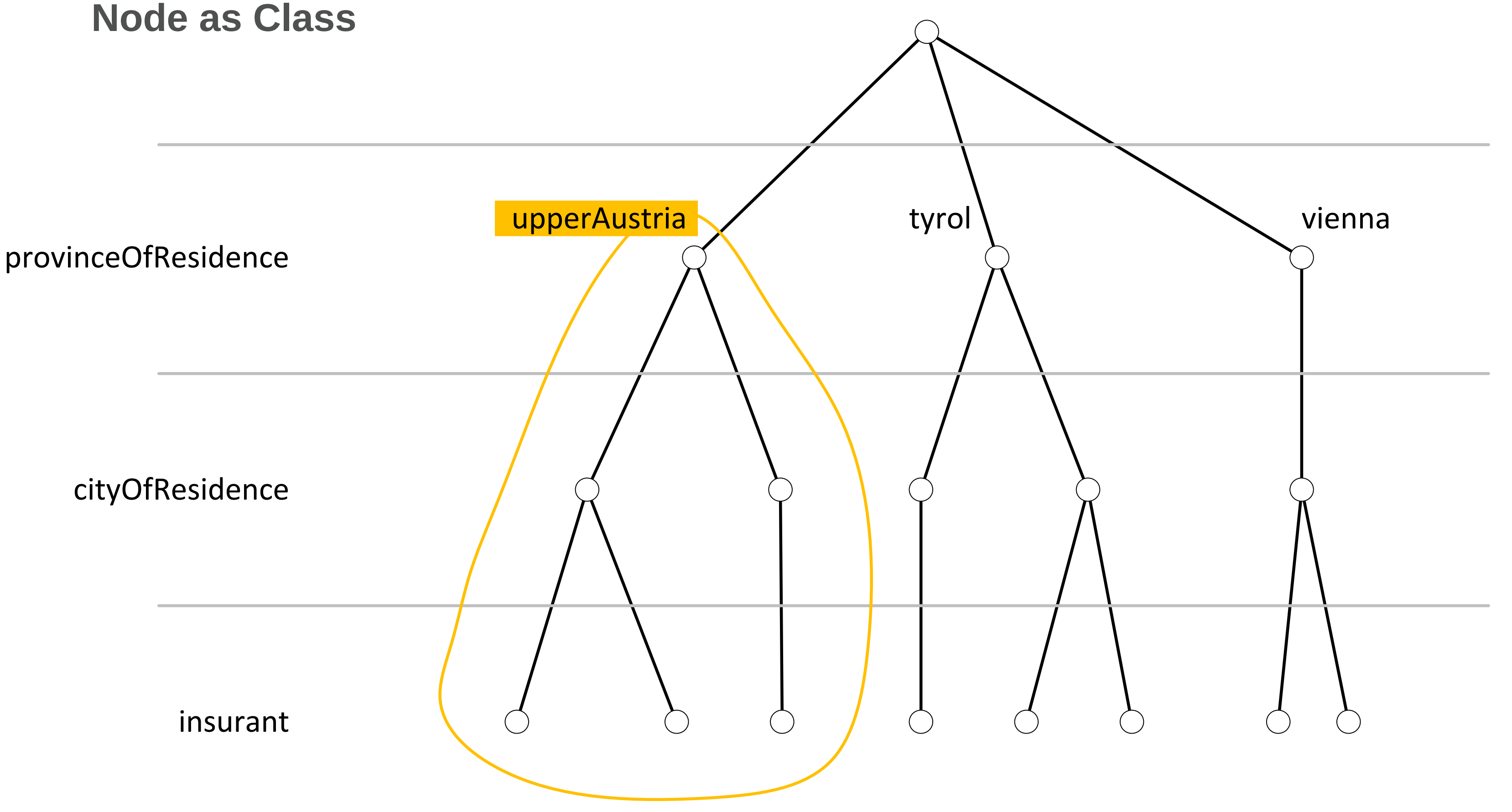
Duality of Nodes

Node as Individual



Duality of Nodes

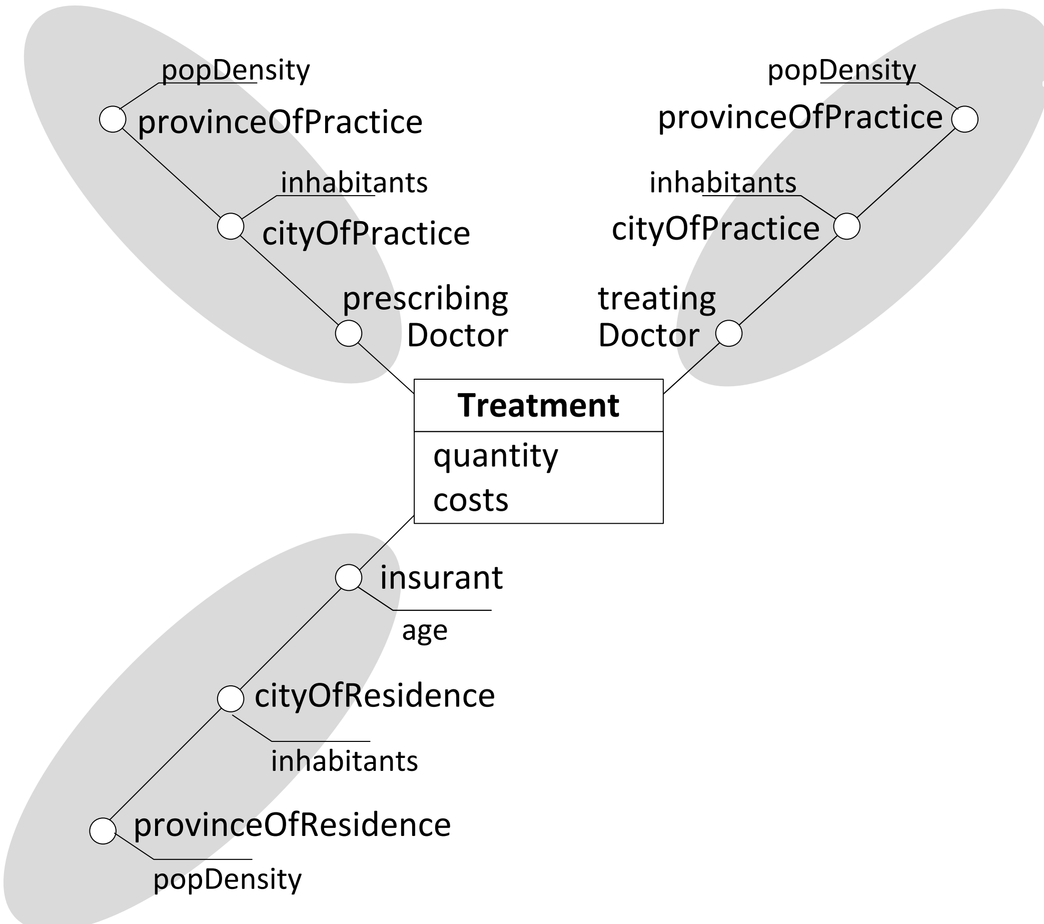
Node as Class



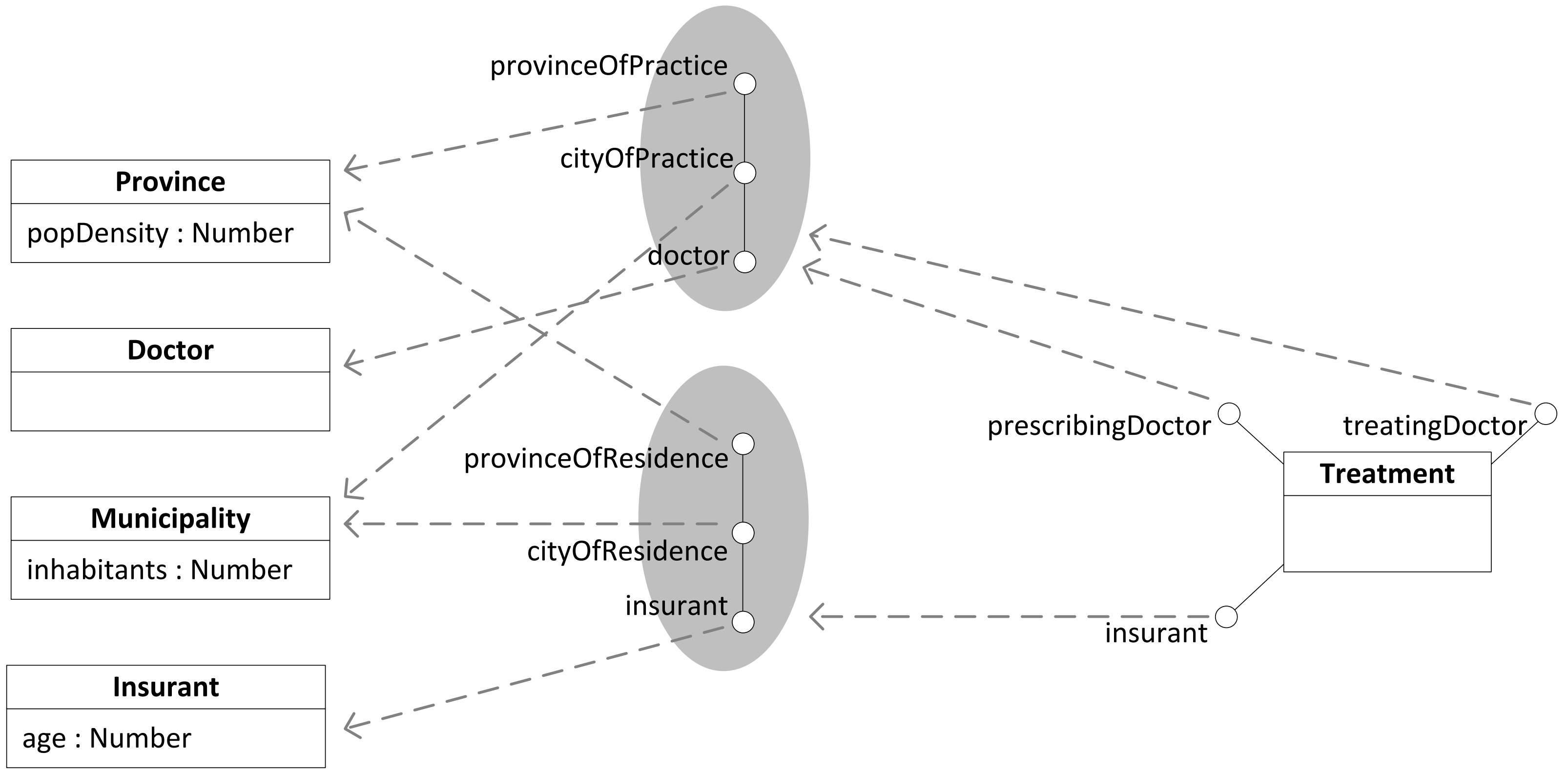
Layered Approach to MDOs

- Decompose multidimensional schema to reusable chunks (primitive concepts) at different layers:
  - Flat: Datatype, Entity types
  - Hierarchical: Hierarchies with Levels
  - Multidimensional: MD-Base, MD-Space
- Different kinds of defined concepts (defined local to primitives)
  - Flat: Datarange, Entity Concept
  - Hierarchical: H-Concept
  - Multidimensional: MD-Concept
- interpreted by different kinds of individuals
  - Flat: Value, Entity
  - Hierarchical: Node
  - Multidimensional: Point

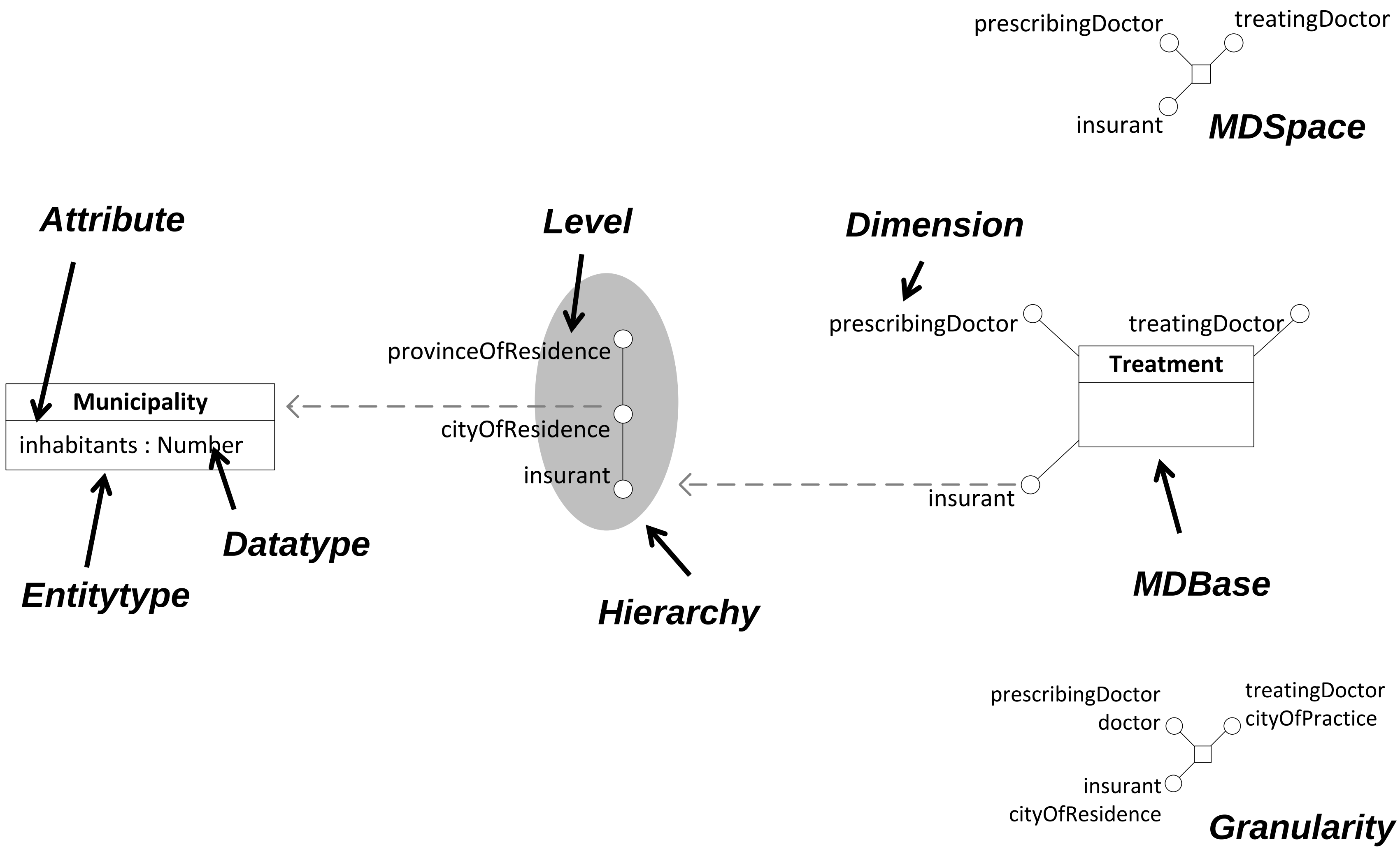
DFM as starting point



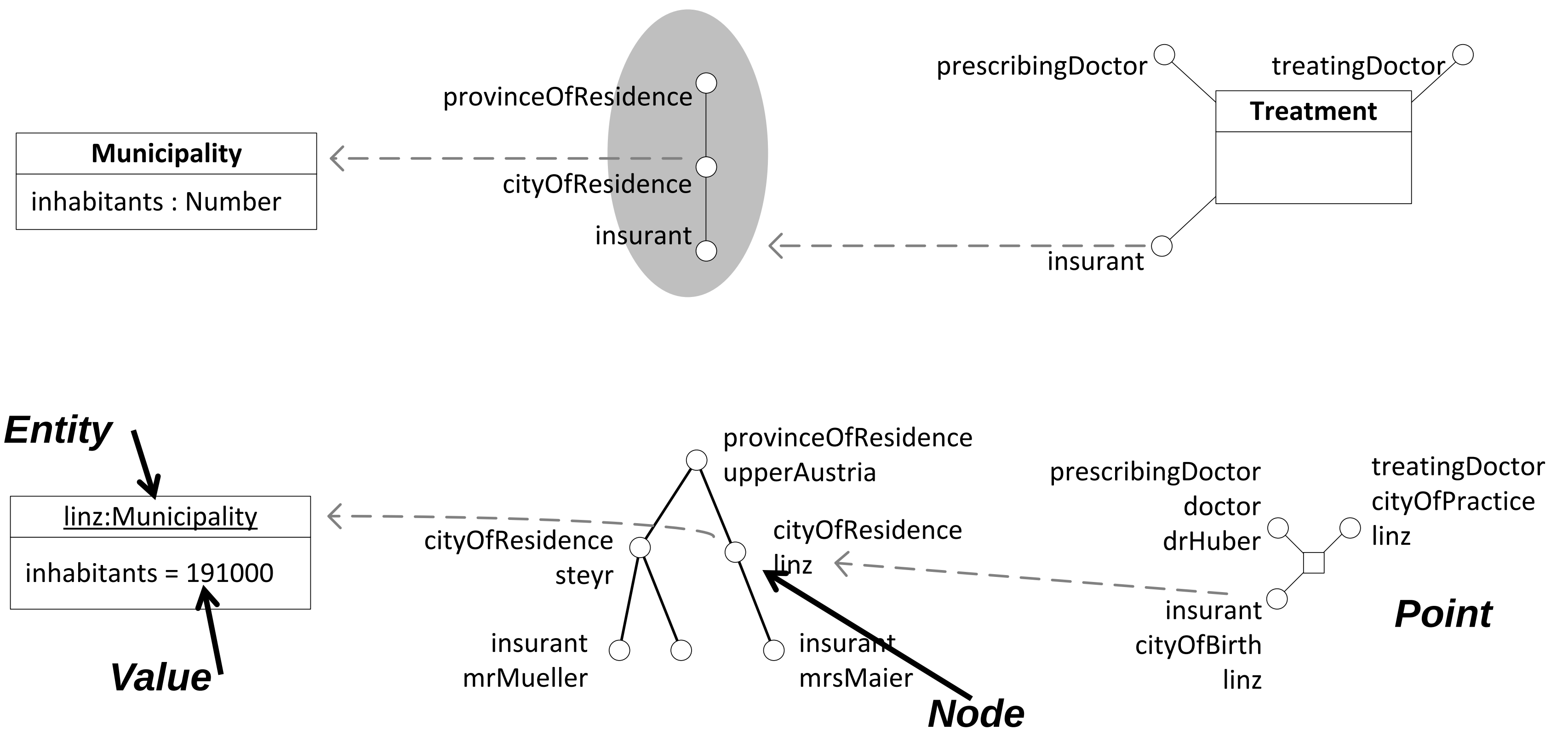
Decompose DFM to reusable chunks: MDO Schema



MDO Schema Language Constructs



MDO Individuals

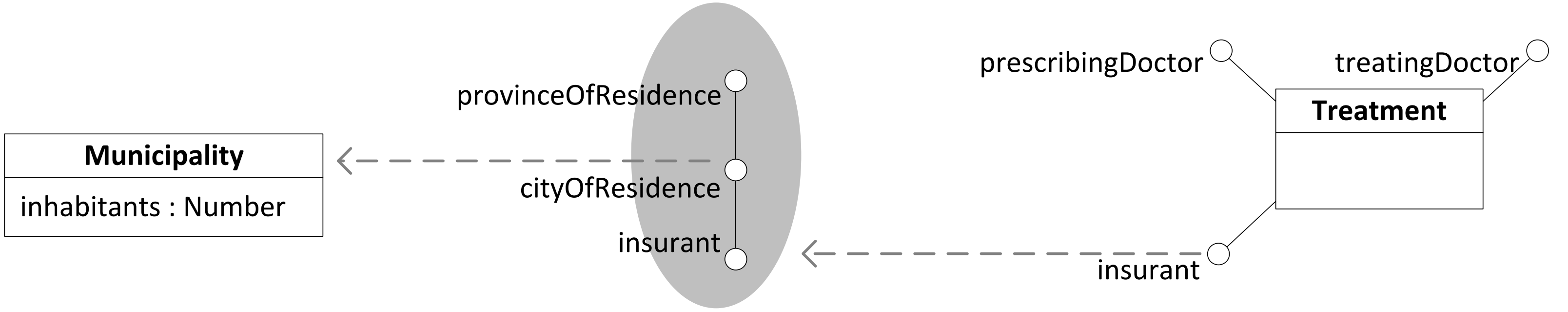


Flat Concepts Definition

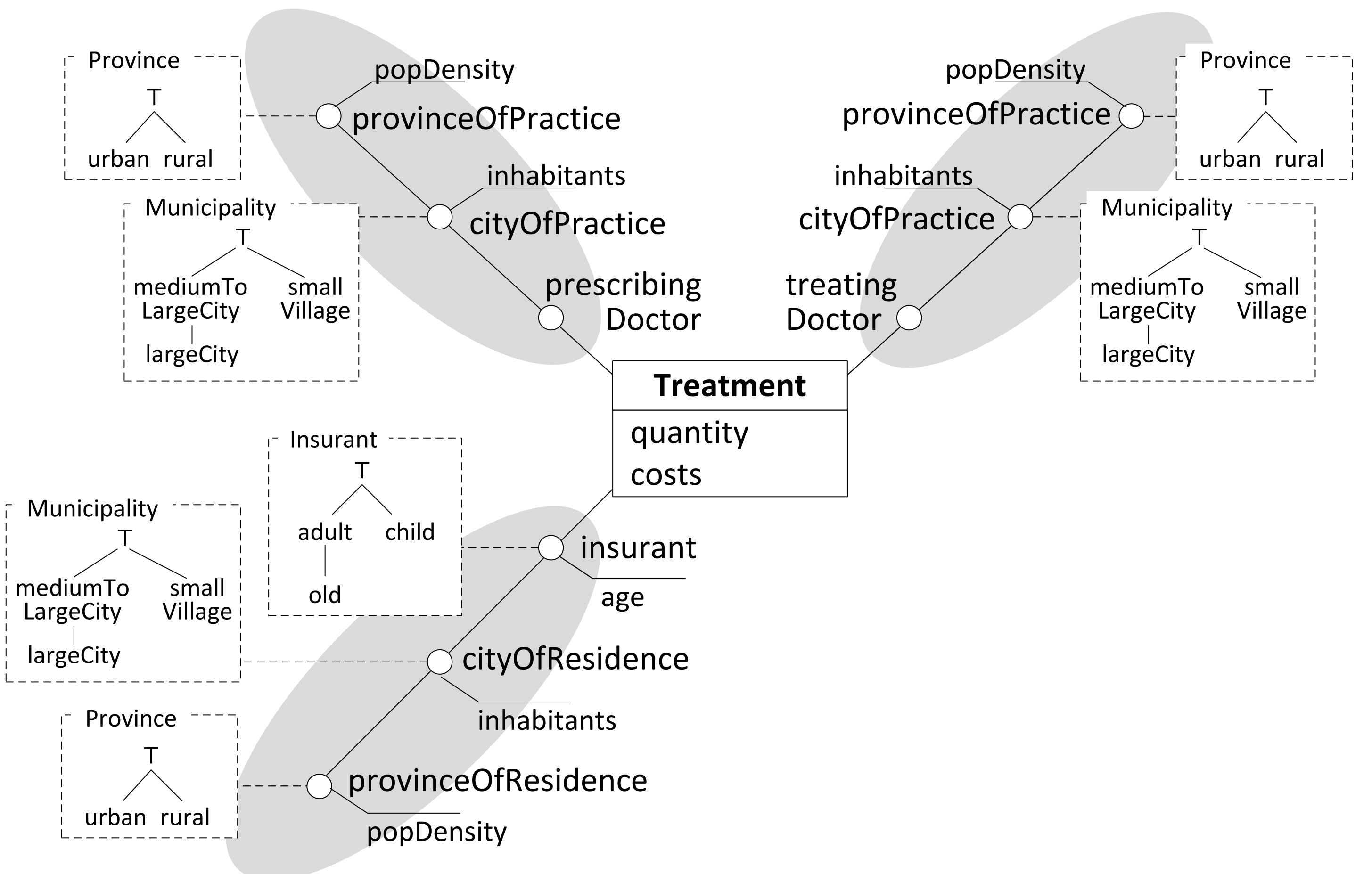
ENTITYTYPE municipality

ENTITYCONCEPT largeCity
== (inhabitants => (from:100000))

ENTITYCONCEPT mediumToLargeCity
== (inhabitants => (from:50000))



Flat Concepts
Subsumption Hierarchies

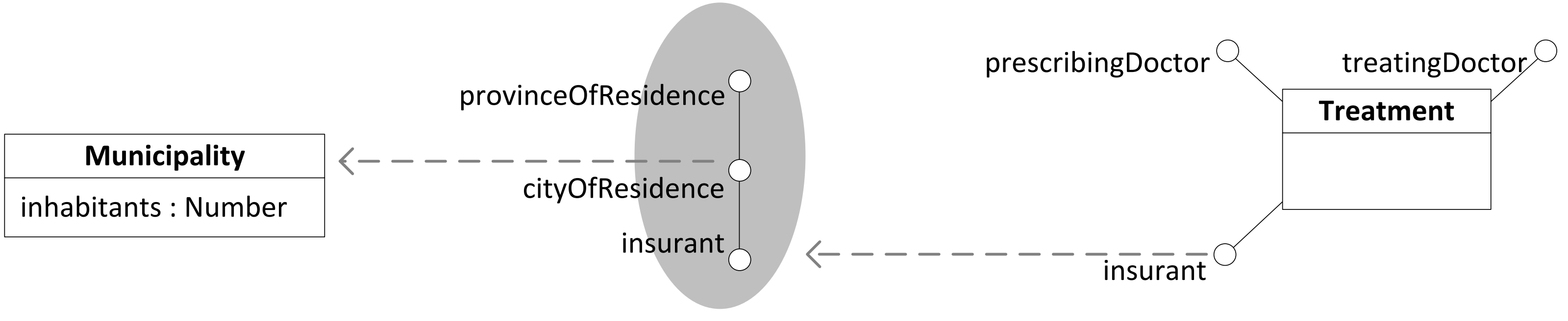


Hierarchical Concepts Definition

HIERARCHY insurant

HCONCEPT livingInRuralArea
== (provinceOfResidence=> rural)

HCONCEPT adultInMediumToLargeCity
== (cityOfResidence => mediumToLargeCity,
insurant => adult)

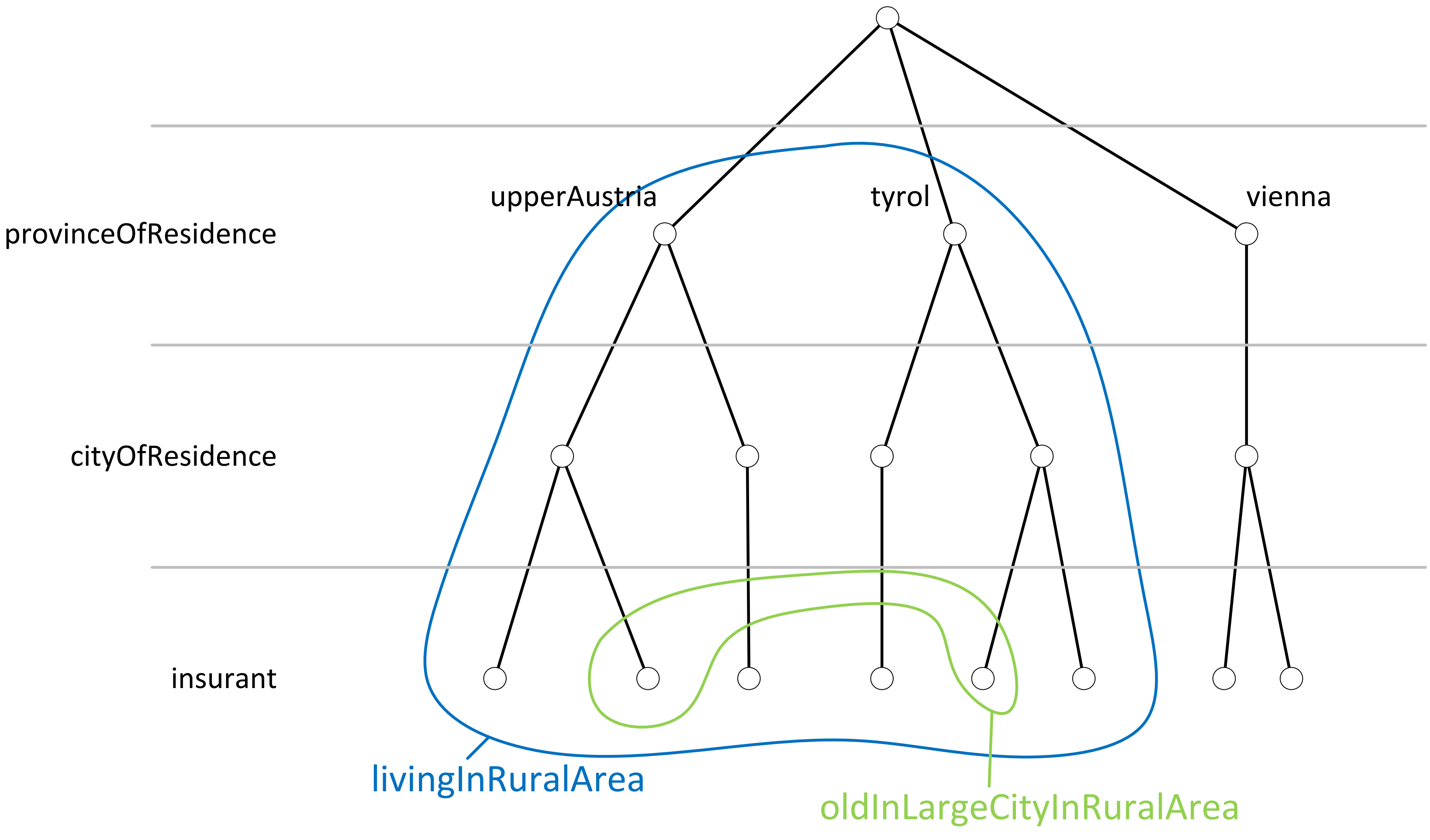


HCONCEPT oldInLargeCity
== (cityOfResidence=> largeCity,
insurant => old)

HCONCEPT oldInLargeCityInRuralArea
== (provinceOfResidence=>rural,
cityOfResidence=> largeCity,
insurant => old)

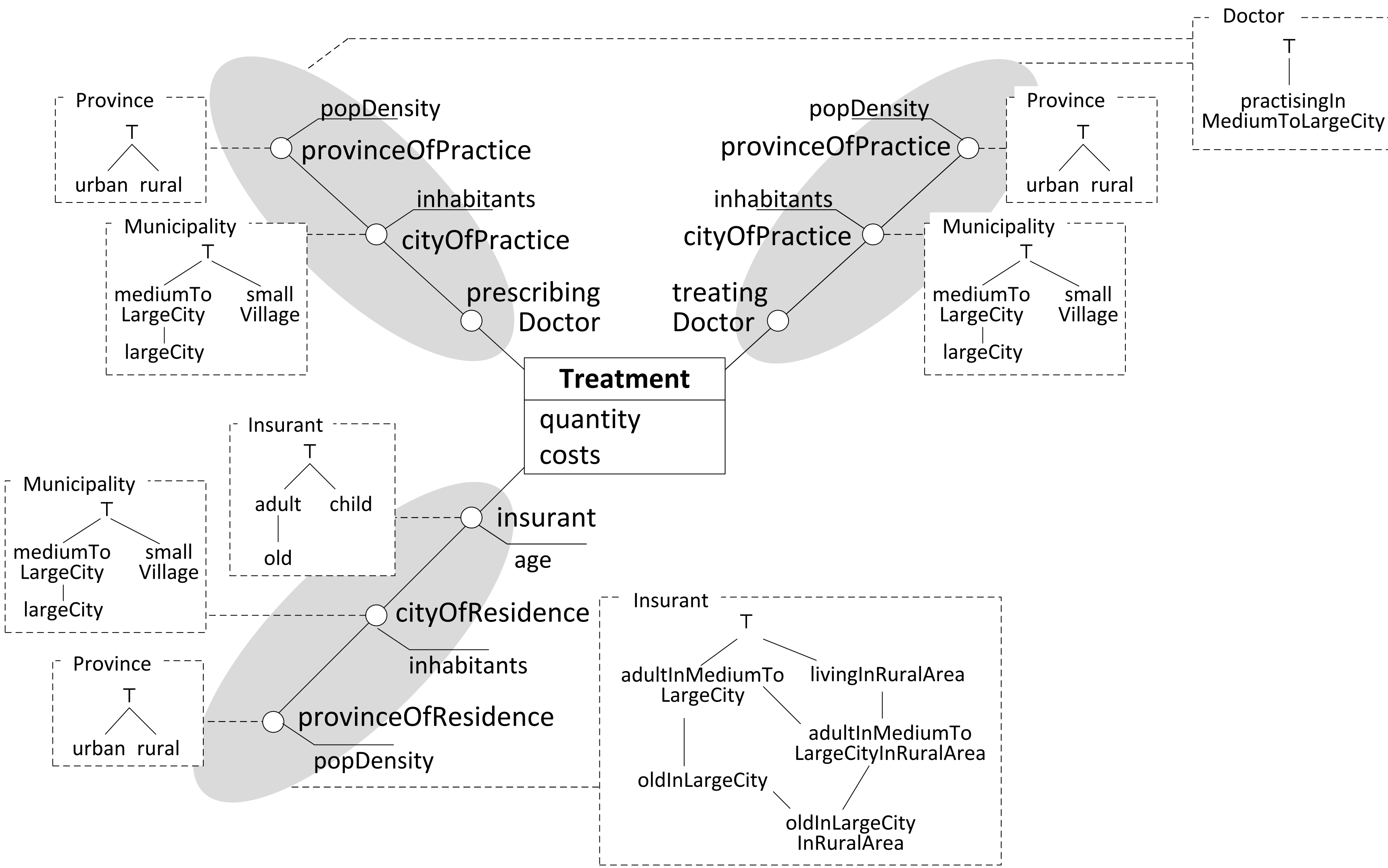
Interpretation of Hierarchical Concepts

Running Example



Hierarchical Concepts
Subsumption Hierarchies

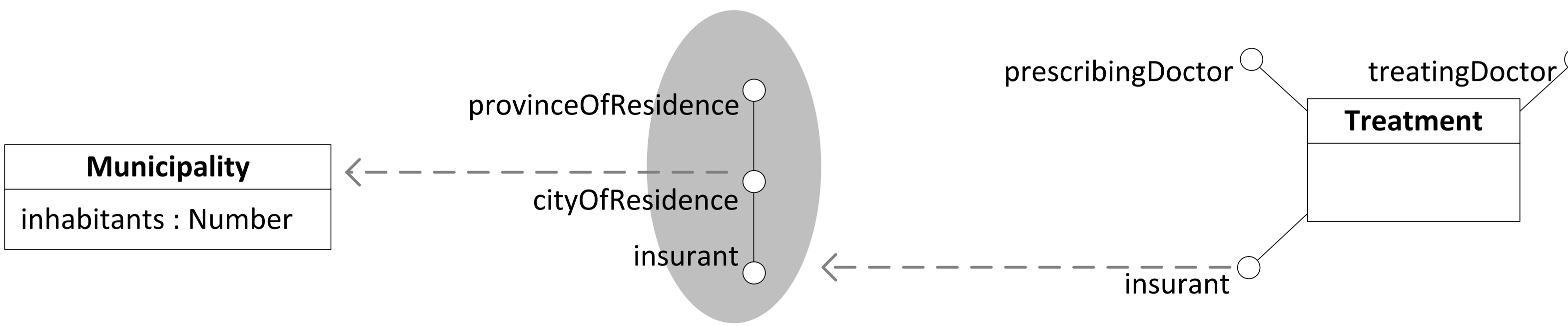
Running Example



Multidimensional Concepts Definition

MDBASE Treatment

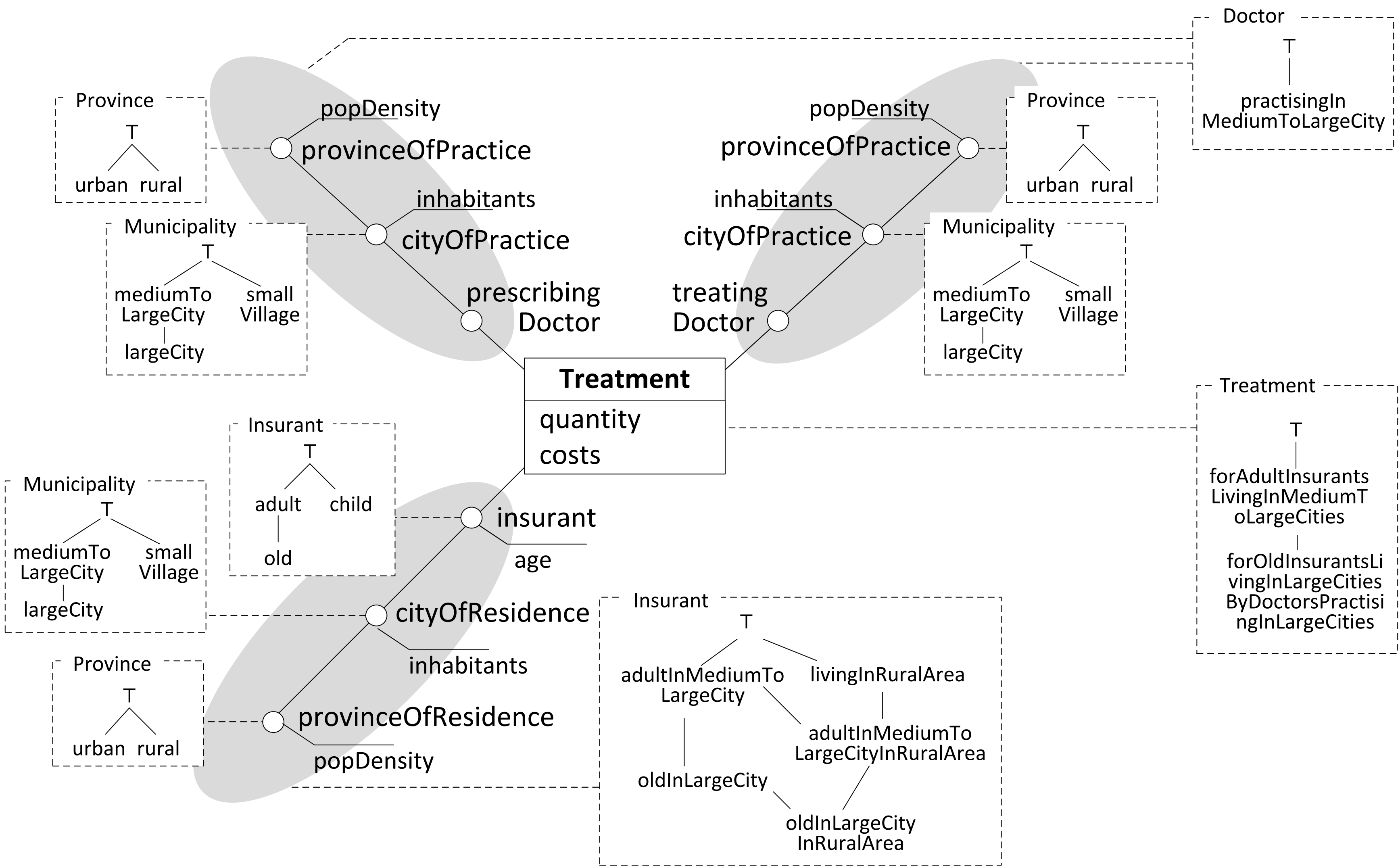
MDCONCEPT forAdultInsurantsLivingInMediumToLargeCities
== (insurant=> adultInMediumToLargeCity)



MDCONCEPT forOldInsurantsLivingInLargeCitiesBy-DoctorsPractisingInMediumToLargeCities
== (insurant=> oldInLargeCity,
treatingDoctor => practisingInMediumToLargeCity)

Multidimensional Concepts Subsumption Hierarchy

Running Example



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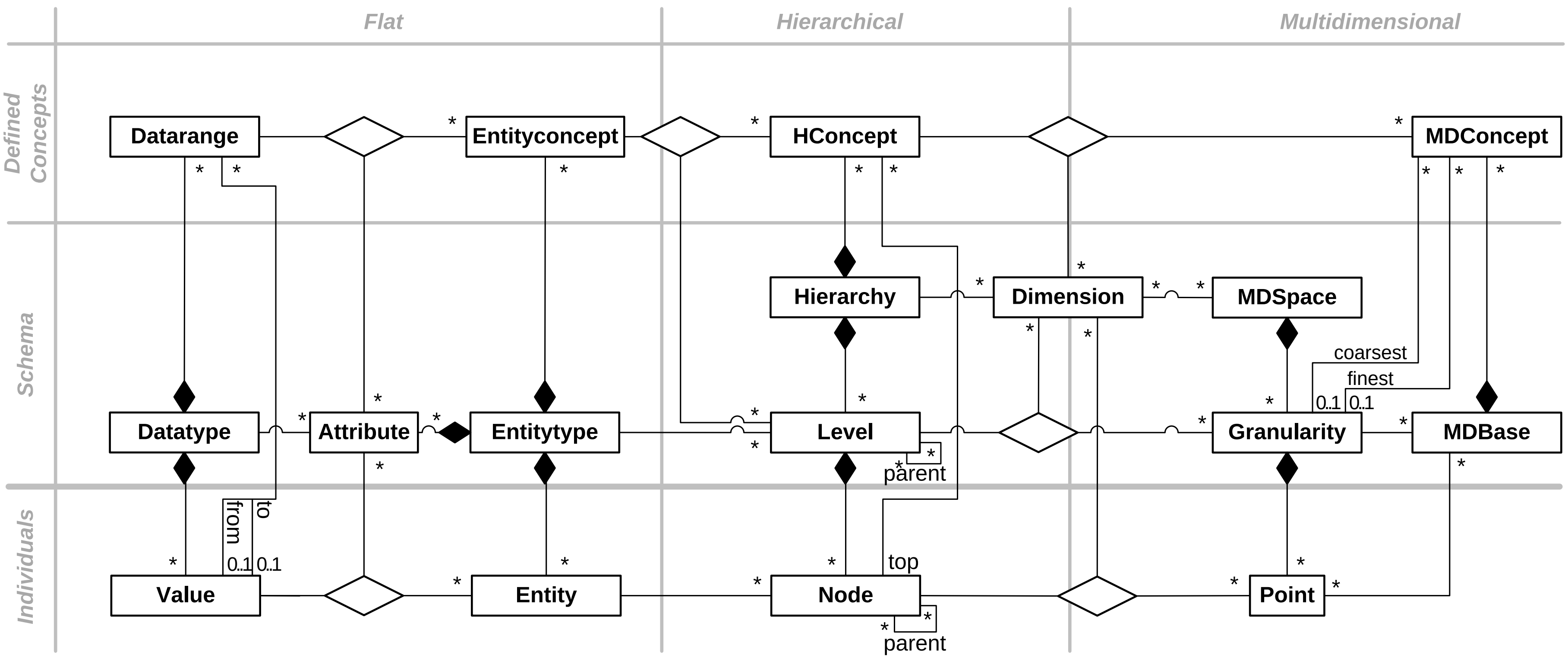
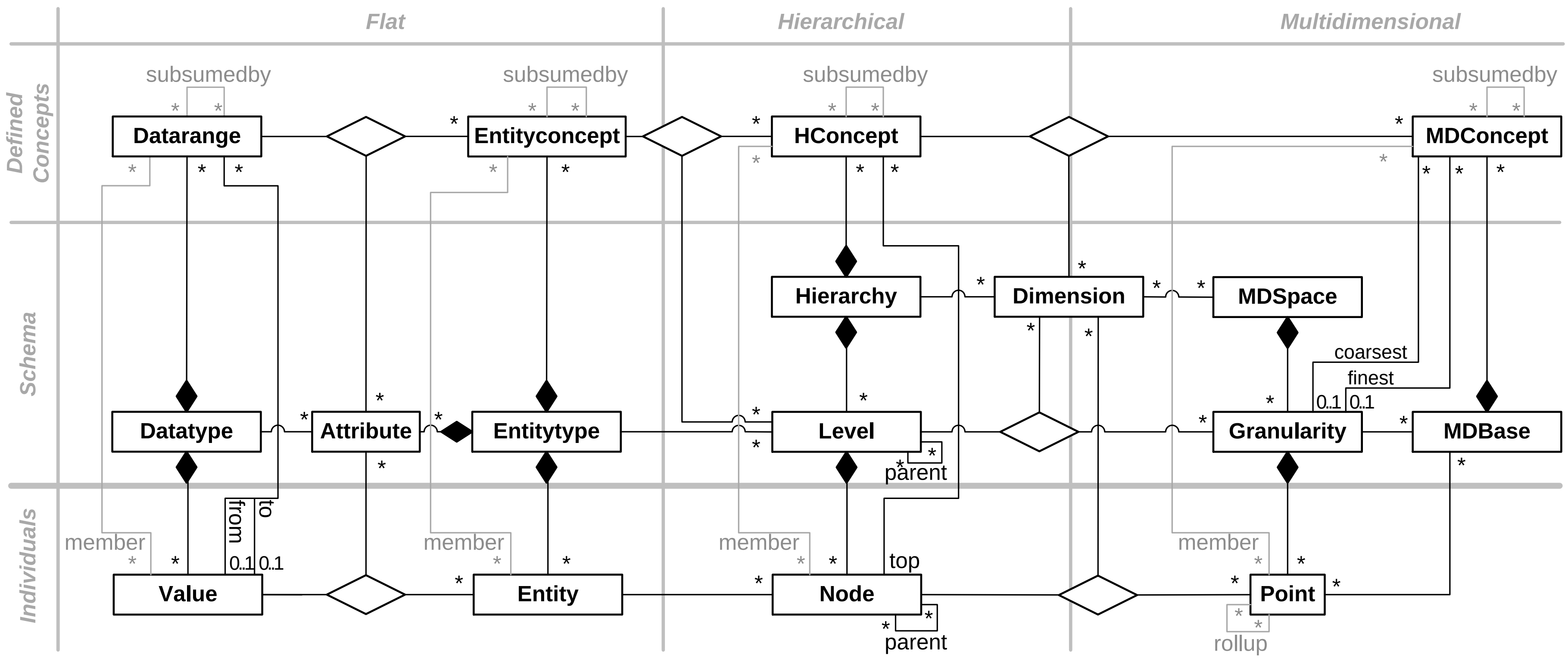
MDO Metamodel

Canonical form of MDOs



MDO Metamodel: Derived Information



MDO in Datalog

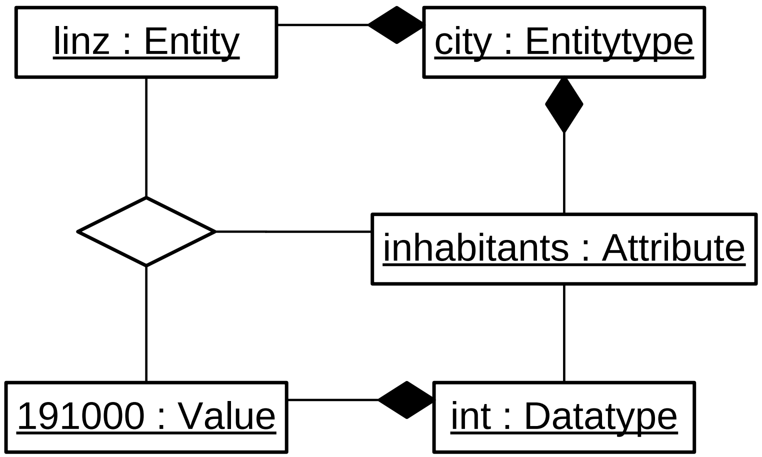
- Why Datalog?
  - concise syntax
  - simple semantics
  - very mature reasoning procedures
- We use standard Datalog with
  - constraints (rules without heads)
  - stratified negation as failure

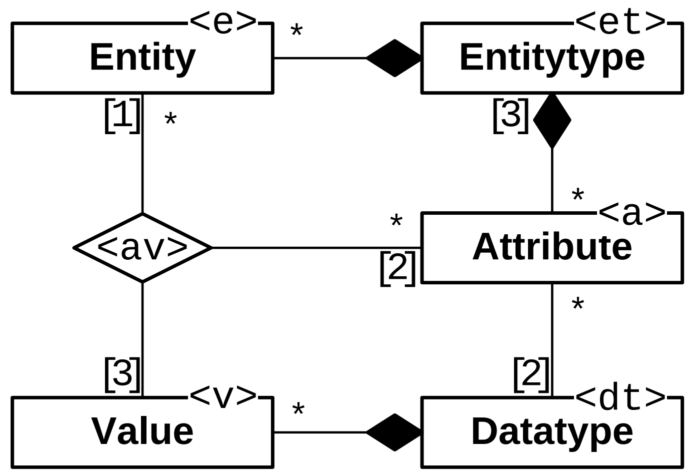
MDO in Datalog

- MDO language construts → Datalog predicates
- Structure and Semantics of MDO → Datalog rules / constraints (some rules only apply to closed-world Grounded MDOs !)
- User-defined MDO → Datalog constants and facts

- Stratification along MDO layers: flat, hierarchical, multidim

MDO in Datalog

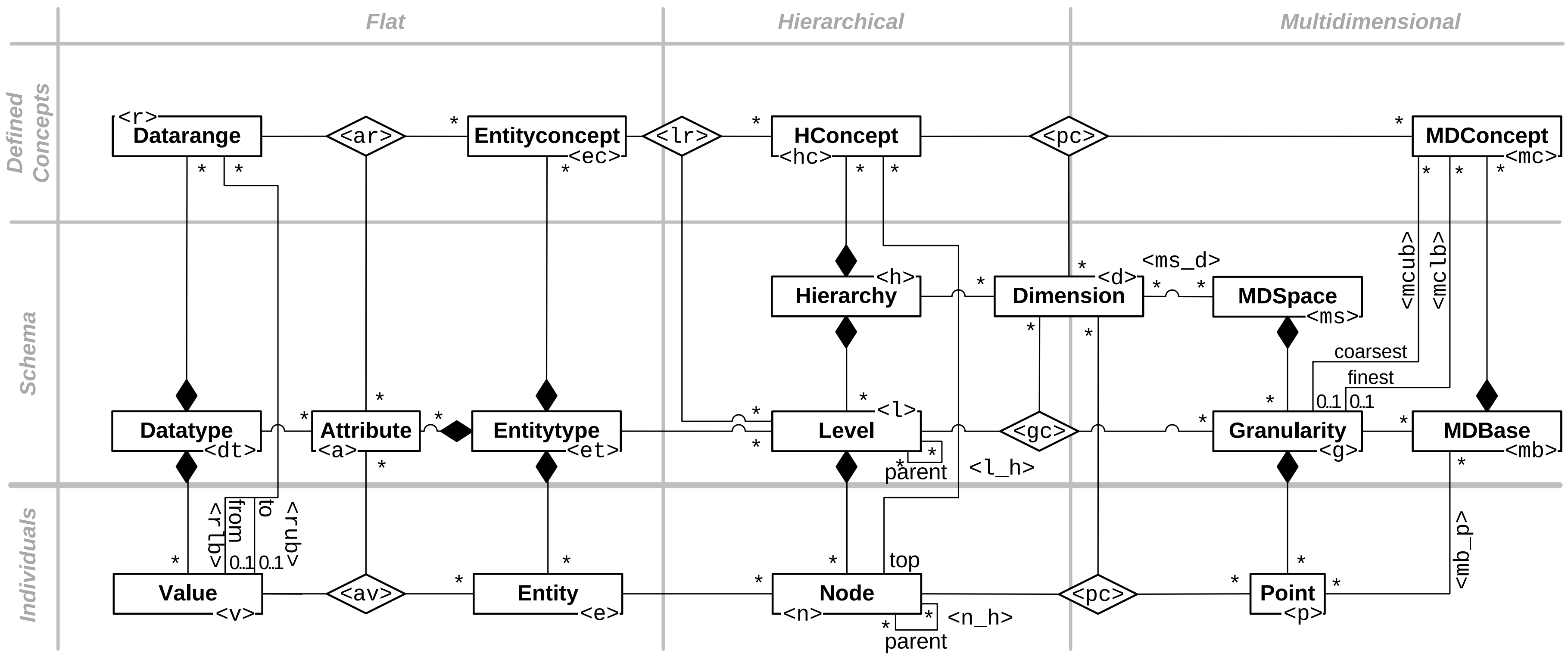




ENTITYTYPE city
  ATTRIBUTE inhabitants -> int
  ENTITY linz
    (inhabitants => 191000)

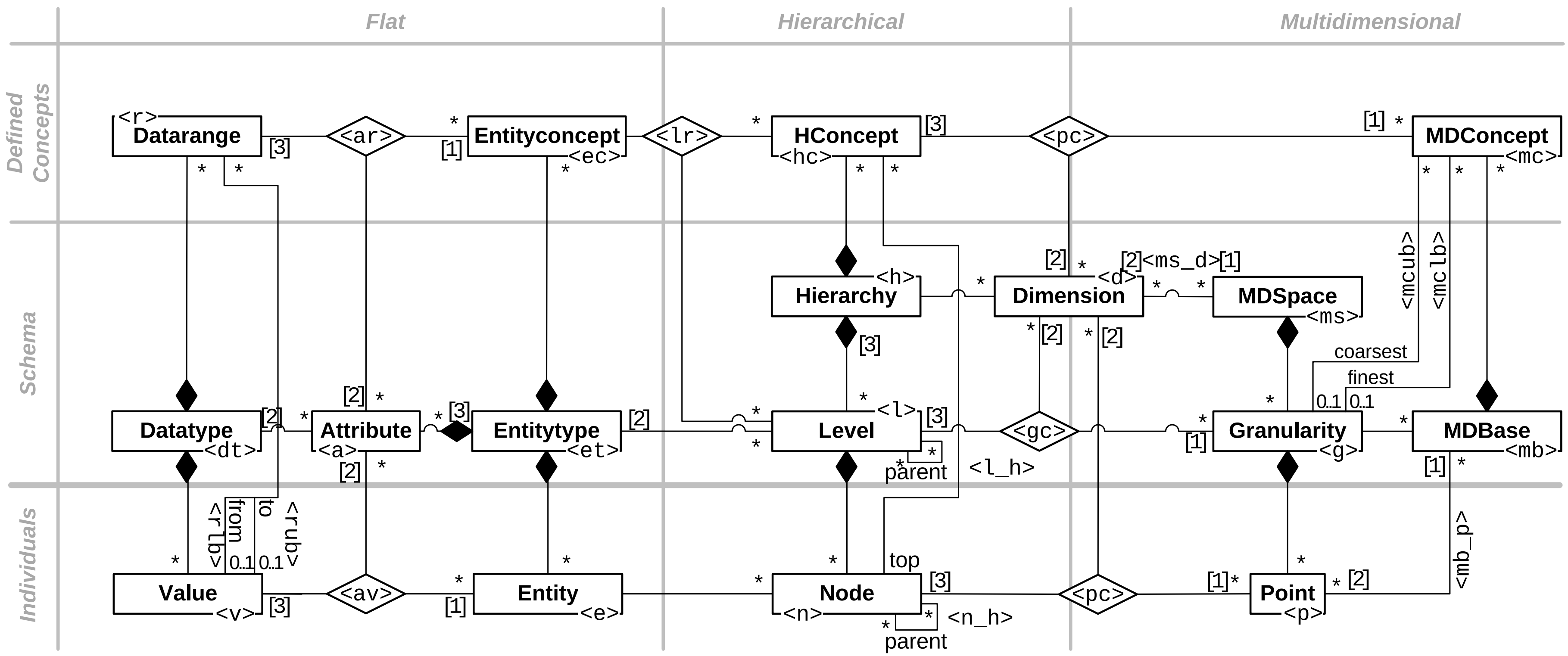
```
et(et_city).
a(a_city_inhabitants,
   dt_int,et_city).
e(et_city_linz,et_city).
av(et_city_linz,
   a_city_inhabitants,191000)
   .
```

MDO Metamodel: Mapping to Datalog (EDB)

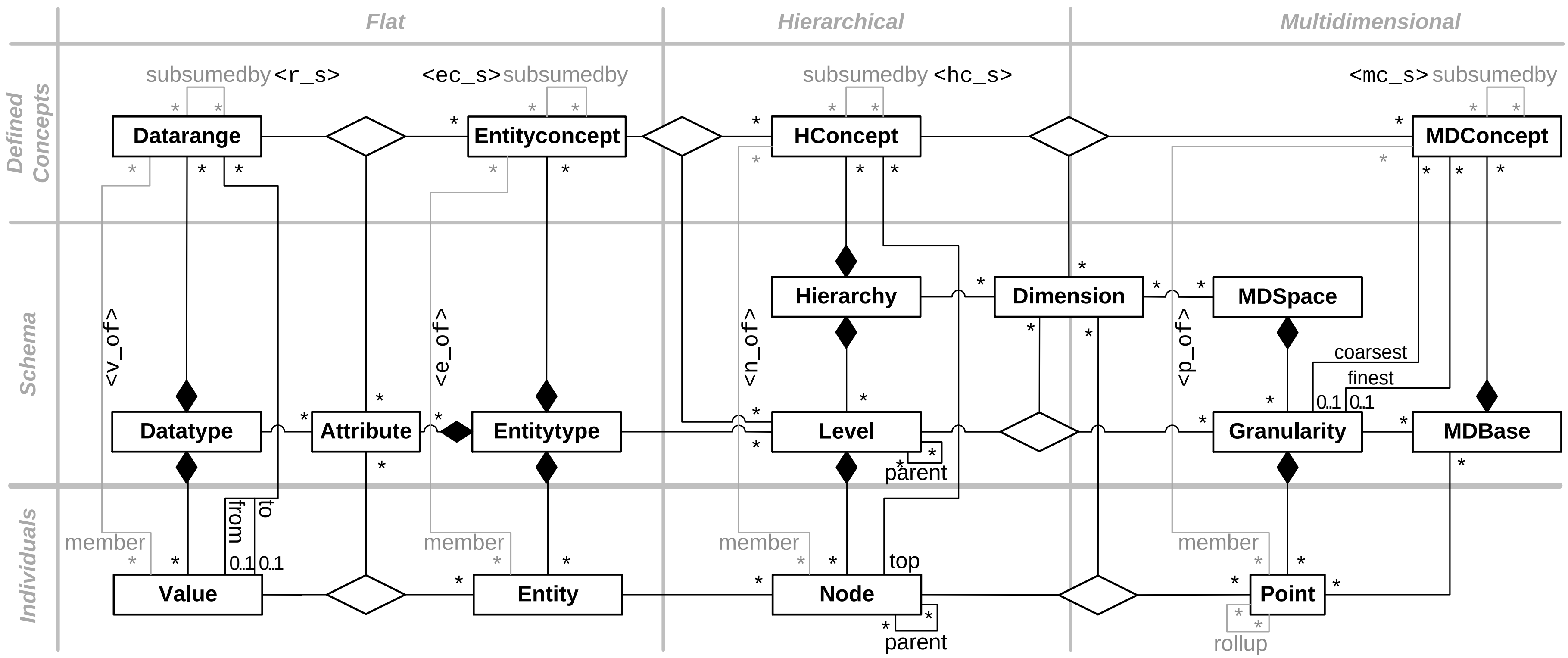


MDO Metamodel: Mapping to Datalog (EDB)

(order of single-valued properties)



MDO Metamodel: Mapping to Datalog (IDB)



Interpretation of Hierarchical Concepts (Concept Membership, Instance Checking)

- A hierarchical concept is interpreted as a subset of the nodes of the hierarchy it belongs to. A node is member of a hierarchical concept if it is a descendant of the root node and for every ancestor level restriction it or one of its ancestors fulfills the restriction. If a node is member of a hierarchical concept, then all its descendant nodes are also members of the hierarchical concept.

```
not_n_of (N,HC) :- n(N,_,_), lr(HC ,Lx ,EC), n(Nx ,Lx ,Ex),
         n_h_tr (N,Nx), not e_of(Ex ,EC).
not_n_of (N,HC) :- n(N,_,_), lr(HC ,Lx ,EC), not n_h_tr_l (N,Lx).
n_h_tr_l (N,L) :- n_h_tr (N,Nx), n(Nx ,L,_).
n_of(N,HC) :- n(N,L,_), l(L,_,H), hc(HC ,H,Nt), n_h_tr (N,Nt),
         not not_n_of (N,HC).
```

Subsumption of Hierarchical Concepts

- A hierarchical concept is subsumed by another hierarchical concept if they belong to the same hierarchy, the root node of the subsumed concept is the same or a descendant of the root node of the subsuming concept, and for every level restriction of the subsuming concept there is the same or a finer restriction in the subsumed concept or the restriction is fulfilled by the root node of the subsumed concept.

```
hc_s(HC,HCx) :- hc(HC,H,N), hc(HCx,H,Nx), n_h_tr(N,Nx),
      not not_hc_s(HC,HCx).
not_hc_s(HC,HCx) :- hc(HC,_,_), lr(HCx,L,ECx),
      not hc_s_lec(HC,L,ECx).
hc_s_lec(HC,L,ECx) :- lr(HC,L,EC), ec_s(EC,ECx).
hc_s_lec(HC,L,ECx) :- hc(HC,_,N), n(Ny,L,Ey), n_h_tr(N,Ny),
      e_of(Ey,ECx).
```

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Ongoing and Future Work

- Extending the MDO formalism
  - Concept definitions over (aggregated) measures
  - Built-in predicates (another kind of primitives)
- MDO in SQL, MDO in OWL
- Mapping between MDO and DWH
- Direct semantics for MDO
  and proof that our Datalog rules are sound & complete
- Apply MDO concepts for definining
  - Complex-derived measures
  - BI Analysis graphs (Neuböck, 2012)
  - Comparative data analysis

Thanks you for your attention!

References

- Stefan Anderlik, Bernd Neumayr, Michael Schrefl: *Using Domain Ontologies as Semantic Dimensions in Data Warehouses*. ER 2012: 88-101
- Thomas Neuböck, Bernd Neumayr, Thomas Rossgatterer, Stefan Anderlik, Michael Schrefl: *Multi-dimensional Navigation Modeling Using BI Analysis Graphs*. ER Workshops 2012: 162-171
- Bernd Neumayr, Michael Schrefl, Konrad Linner: *Semantic Cockpit: An Ontology-Driven, Interactive Business Intelligence Tool for Comparative Data Analysis.* ER Workshops 2011: 55-64
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- Diego Calvanese, Giuseppe De Giacomo, Domenico Lembo, Maurizio Lenzerini, Antonella Poggi, Mariano Rodriguez-Muro, Riccardo Rosati, Marco Ruzzi, Domenico Fabio Savo: *The MASTRO system for ontology-based data access*. Semantic Web (SEMWEB) 2(1):43-53 (2011)