Semantic Web Technologies II

SS 2009

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OWL – Open-World Semantik und Semantische Erweiterungen

Dr. Sudhir Agarwal
Dr. Stephan Grimm
Dr. Peter Haase
PD Dr. Pascal Hitzler
Denny Vrandecic

Übersicht

- Ontology Modelling under OWA
  - Open vs. Closed World Assumption
  - Application of OWL: Matchmaking
  - Patterns / best practises in OWA Modelling

- Semantic Extensions to OWL
  - Nonmonotonic Extensions - Overview
  - Autoepistemic DL
  - Circumscriptive DL

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Open-World Assumption

- Characteristics
  - No assumptions about incomplete knowledge
  - Feauture of logics with classical model-theoretic semantics (e.g. DLs)
- Example

$$KB = \{ Professor(John), teaches(John,Ben), Undergraduate(Ben) \}$$

$$KB \not\models \forall teaches.Undergraduate(John)$$

$$KB \cup \{ \leq 1\ teaches\ (John) \} \models \forall teaches.Undergraduate(John)$$

Closed-World Assumption

- Characteristics
  - What cannot be proven is assumed to be wrong
  - Assumption to have full knowledge about instances

- Example

$$KB = \{\ Professor(John),\ teaches(John, Ben),\ Undergraduate(Ben)\ \}$$

$$KB \models_{\text{CWA}} \forall teaches.Undergraduate(John)$$

Open world semantics and Queries

- Example DL knowledge base

$$KB = \{ Graduate \sqsubseteq Student, \\ Undergraduate \sqsubseteq Student, \\ Graduate(mary) \}$$

- Intuitive answers to some queries

„Is Mary a graduate student?“ → **yes**

„Is Mary an undergraduate student?“ → **don‘t know**

„Is Mary not a graduate student?“ → **no**

Open World Semantics and Queries

- Answering queries by checking for entailment

  $KB \models \alpha$ → ***yes***

  $KB \models \neg\alpha$ → ***no***

  otherwise → ***don't know***

- Former example

  $KB \models Graduate(mary)$ ***yes***

  $KB \not\models Undergrad(mary) \wedge KB \not\models \neg Undergrad(mary)$ ***don't know***

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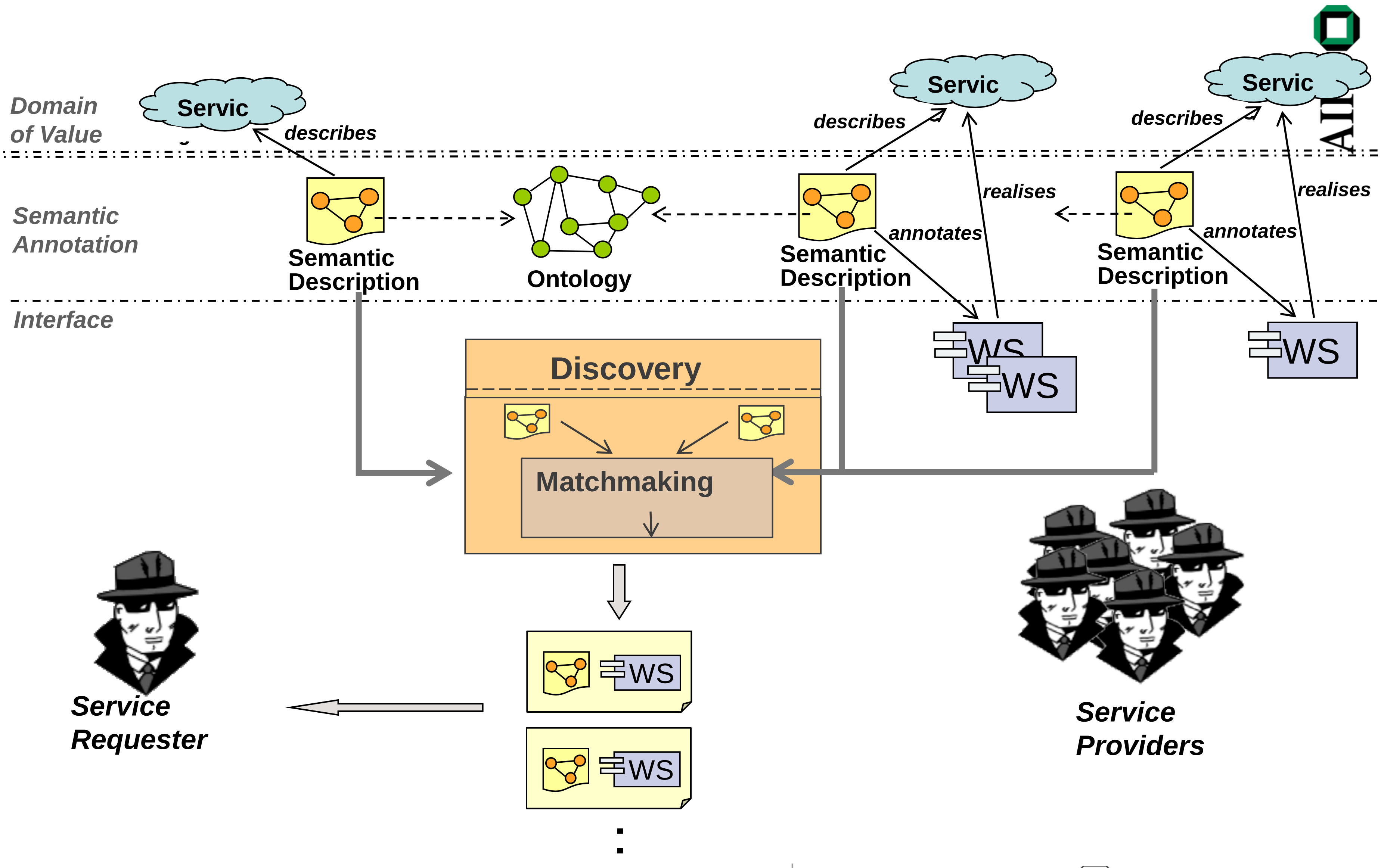
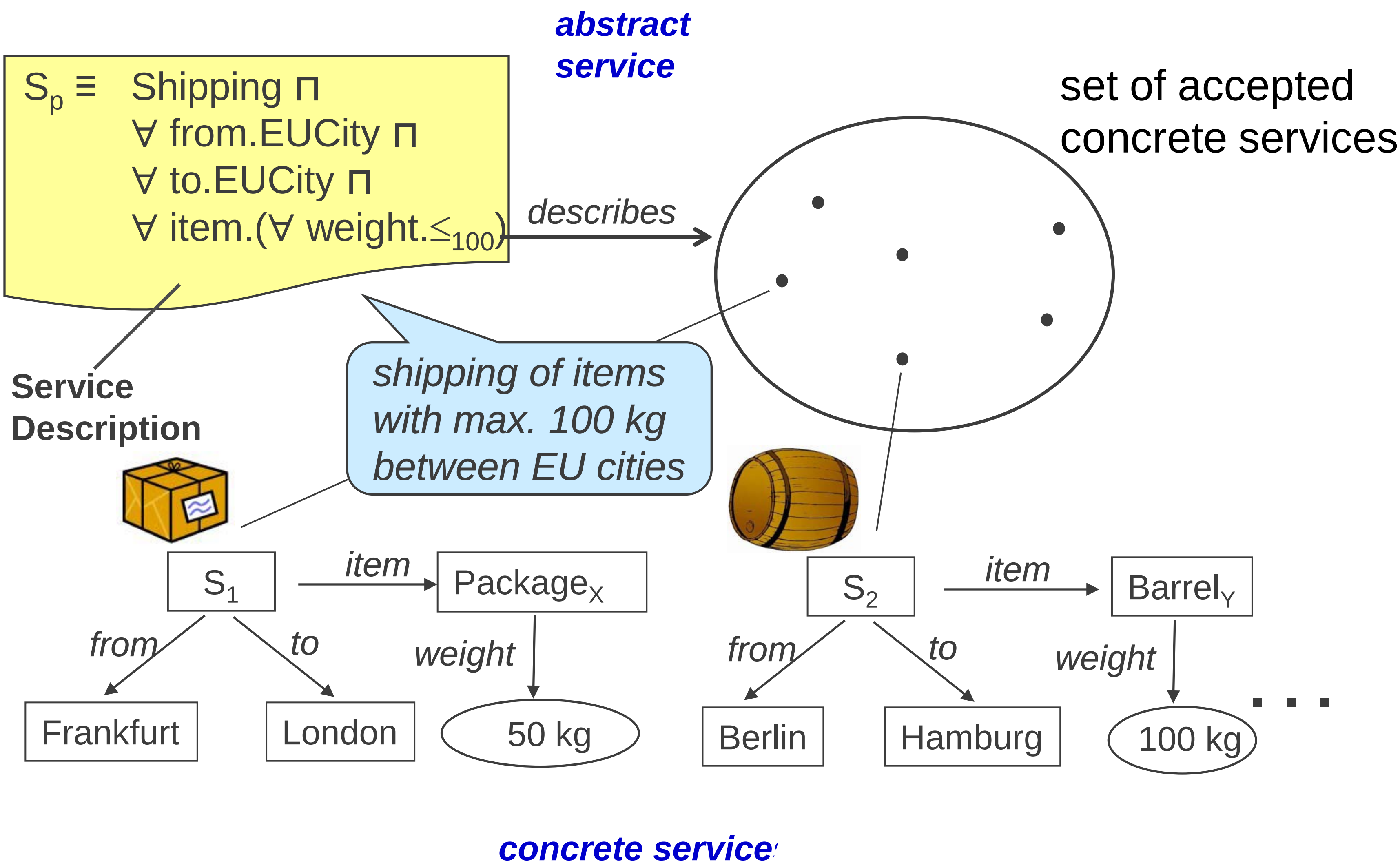
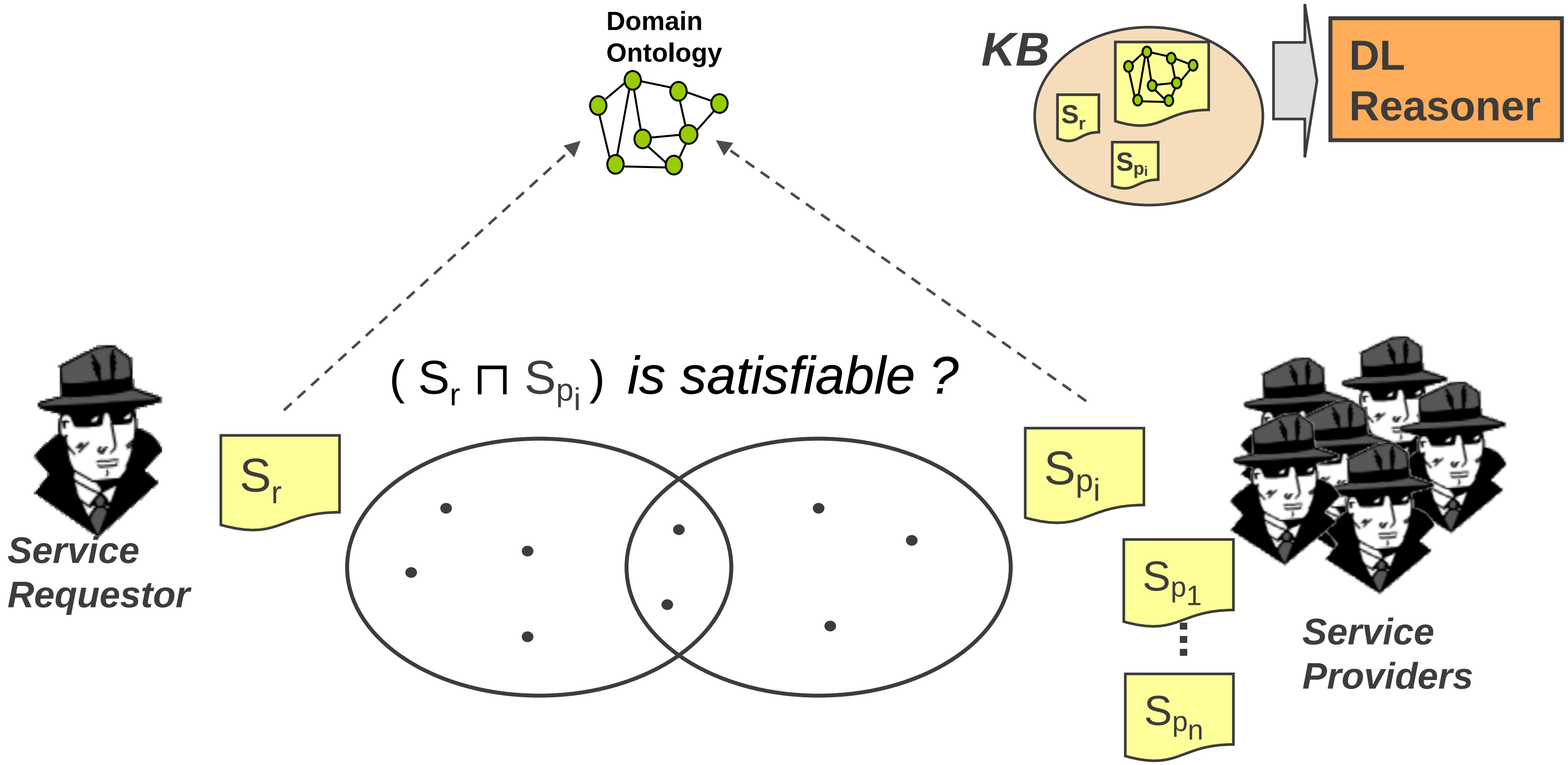
OWL Matchmaking for Service Discovery



Service Descriptions in OWL



Matching OWL Service Descriptions

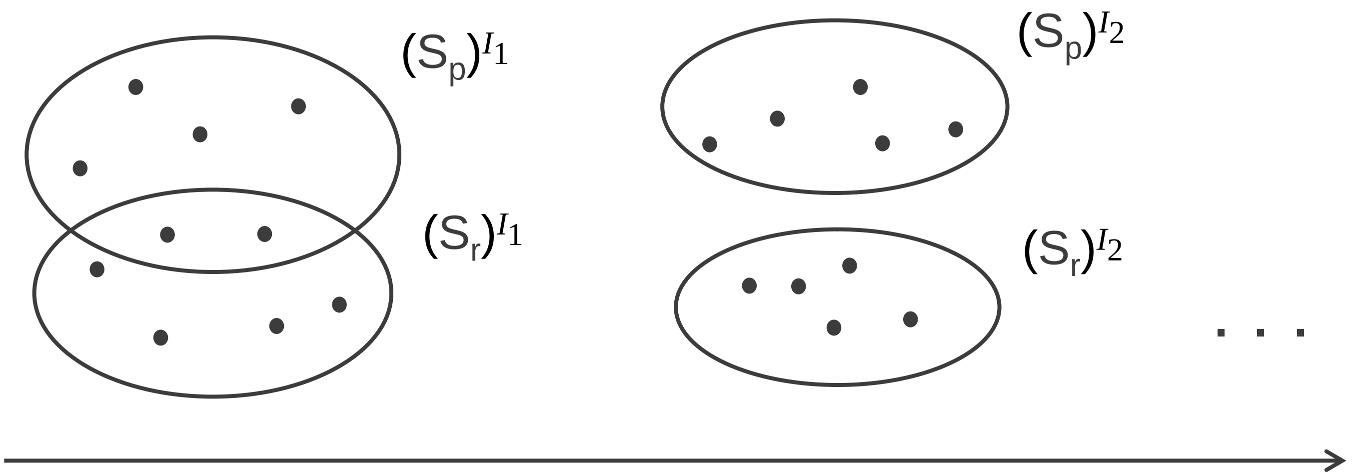


- Matching Service Descriptions of Requesters and Providers by intersection
  - do they specify common concrete services?

DL Inference for Matching

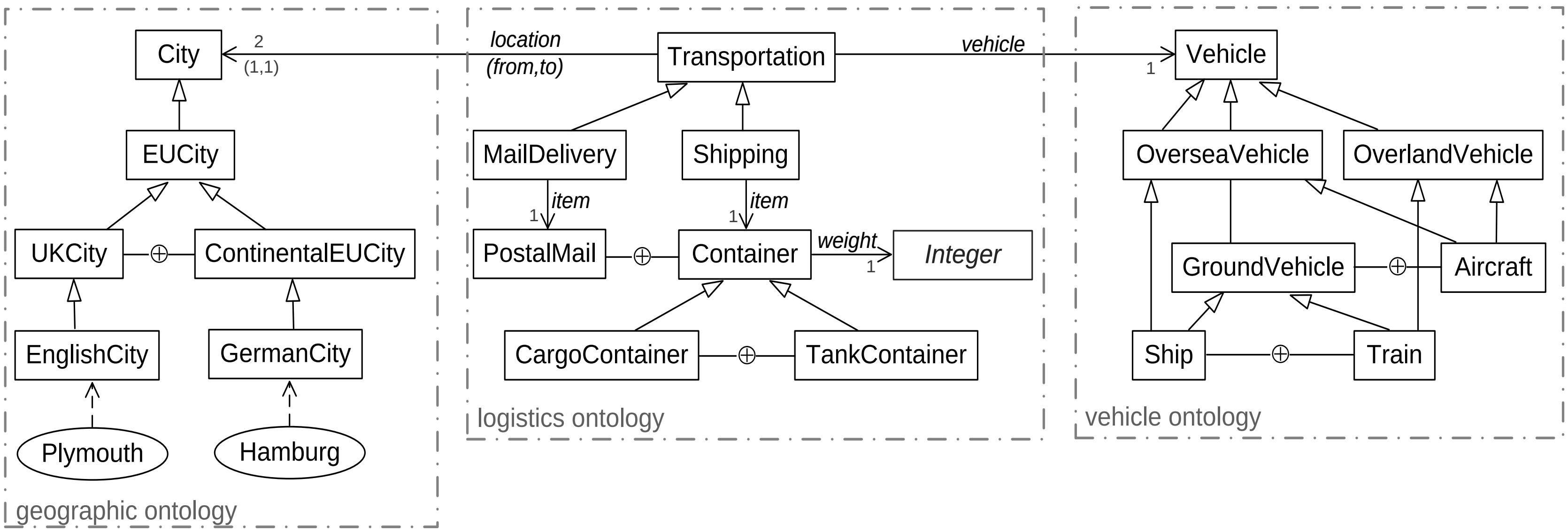
- **Satisfiability of Concept Conjunction**

$(S_r \sqcap S_p)$ is satisfiable w.r.t. *KB*



- $(S_r)^I \cap (S_p)^I \neq \emptyset$ in **some** model of *KB*
- Intuitiuon:
  - incomplete knowledge issues can be resolved such that request and offer overlap

Matching in Logistics Scenario



Transportation ⊑ (∃**location.UKCity** ⊓ ∃**location.ContEUCity** ⊓ ∀**vehicle.OverseaVehicle**)

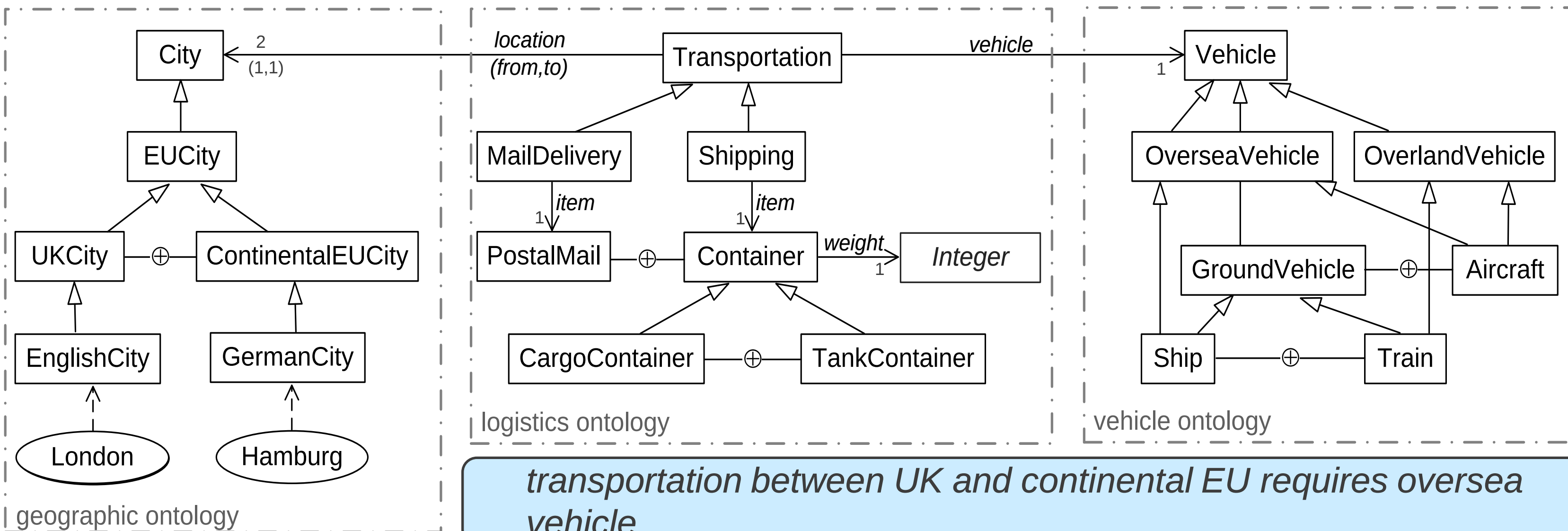
⊔ ∀**location.UKCity**

⊔ ∀**location.ContEUCity**

Axiom

transportation between UK and continental EU requires oversea vehicle

Matching in Logistics Scenario



transportation between UK and continental EU requires oversea vehicle

request transportation of a cargo container from London to Hamburg by any vehicle but aircrafts

OWL **R**

$S_r \equiv \text{Shipping} \sqcap$
$\exists\ \text{from} . \{\text{London}\} \sqcap$
$\exists\ \text{to} . \{\text{Hamburg}\} \sqcap$
$\exists\ \text{item} . \text{CargoContainer} \sqcap$
$\exists\ \text{vehicle} . \neg\text{Aircraft}$

provide shipping of containers between EU cities by Ship

✓ P_A OWL

$S_{pA} \equiv \text{Shipping} \sqcap$
$\forall\ \text{location} . \text{EUCity} \sqcap$
$\exists\ \text{item} . \text{Container} \sqcap$
$\exists\ \text{vehicle} . \text{Ship}$

provide shipping of containers between EU cities by any vehicle but ships

✗ P_B OWL

$S_{pB} \equiv \text{Shipping} \sqcap$
$\forall\ \text{location} . \text{EUCity} \sqcap$
$\exists\ \text{item} . \text{Container} \sqcap$
$\forall\ \text{vehicle} . \neg\text{Ship}$

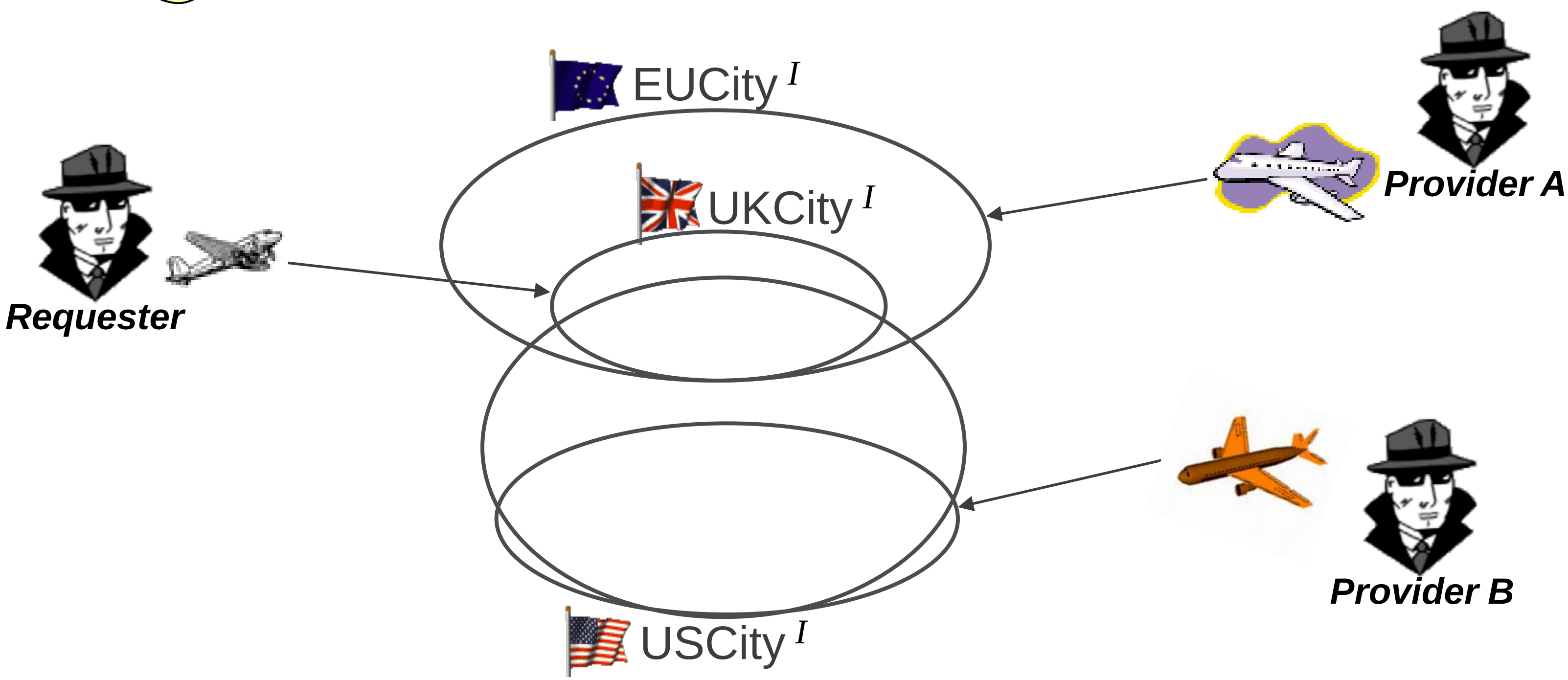
Problematic Matching under OWA

Domain Ontology $KB = \{ UKCity \sqsubseteq EUCity, Shipping \sqsubseteq \exists from.\top$

request $S_r \equiv Shipping \sqcap \forall from.UKCity$

offer A $S_{pA} \equiv Shipping \sqcap \forall from.EUCity$

offer B $S_{pB} \equiv Shipping \sqcap \forall from.USCity$



Problematic Matching under OWA

Domain Ontology $KB = \{ UKCity \sqsubseteq EUCity , UKCity \sqsubseteq \exists from.\top$

request $S_r \equiv Shipping \sqcap \forall from.UKCity$

offer A $S_{pA} \equiv Shipping \sqcap \forall from.EUCity$

offer B $S_{pB} \equiv Shipping \sqcap \forall from.UKCity$

$R_r \sqcap R_{p_A}$ is satisfiable w.r.t. KB ✓

$R_r \sqcap R_{p_B}$ is satisfiable w.r.t. KB

Domain Ontology $KB' = KB \cup \{ EUCity \sqsubseteq \neg USCity \}$

$R_r \sqcap R_{p_B}$ is unsatisfiable w.r.t. KB ✓

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  - Some patterns / best practises in OWA Modelling

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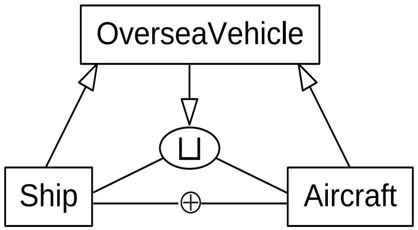
Modelling Patterns for Proper Matching

- **Disjoint Partitioning**
  - subsumption + disjointness + coverage
  - default for taxonomies



$\text{Ship} \sqcap \text{Aircraft} \sqsubseteq \bot$

$\text{OverseaVehicle} \sqsubseteq \text{Ship} \sqcup \text{Aircraft}$

OWL R

$S_r \sqsubseteq \exists \text{ vehicle . Ship}$

require ship as vehicle

P OWL

$S_p \sqsubseteq \forall \text{ vehicle . Aircraft}$

allow only aircraft as vehicle

negative match requires disjointness

OWL R

$S_r \sqsubseteq \exists \text{ vehicle . OverseaVehicle}$

use oversea vehicle

P OWL

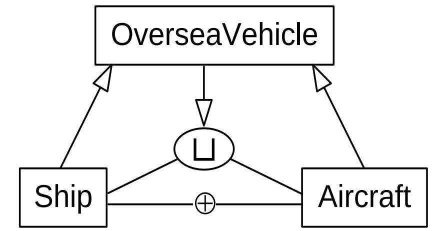
$S_p \sqsubseteq \forall \text{ vehicle . } \neg\text{Ship} \sqcap \neg\text{Aircraft}$

prohibit aircraft and ship as vehicle

negative match requires coverage

Modelling Patterns for Proper Matching

- **Disjoint Partitioning**
  - subsumption + disjointness + coverage
  - default for taxonomies



- **Mandatory Properties**
  - existential restriction or minimum cardinality
  - explicit restriction of properties by default, if not explicitly optional

$\text{Shipping} \sqsubseteq \exists\, \text{vehicle} . \top$

OWL R

$S_r \sqsubseteq \forall\, \text{vehicle} . \text{Ship}$

allow only ship as vehicle

P OWL

$S_p \sqsubseteq \forall\, \text{vehicle} . \text{Aircraft}$

allow only aircraft as vehicle

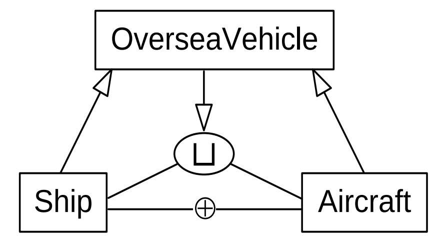
enforce use of some vehicle

Modelling Patterns for Proper Matching

Karlsruhe Institute of Technology

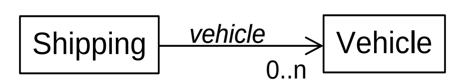
AIFB

- **Disjoint Partitioning**
  - subsumption + disjointness + coverage
  - default for taxonomies



- **Mandatory Properties**
  - existential restriction or minimum cardinality
  - explicit restriction of properties by default, if not explicitly otional

- **Quantitative Property Closure**
  - maximum cardinality restrictions
  - explicit restriction of properties with natural bound



$\text{Shipping} \sqsubseteq \; \leq 1 \text{ vehicle}$

prevent use of two vehicles

OWL R

$S_r \sqsubseteq \forall \text{ vehicle . Ship}$

P OWL

$S_p \sqsubseteq \forall \text{ vehicle . Aircraft}$

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Nonstandard Semantics

- Uncertainty and Vagueness
  - Probabilistic DL (uncertainty)
    - „Any Professor lectures some course with a probability of at least 0.9“

      $\mathit{Professor} \sqsubseteq \exists \mathit{lectures.Course}\ [0.9;1]$
  - Fuzzy DL (vagueness)
    - „Logics is a difficult course to degree 0.8“

      $\langle \mathit{DifficultCourse}(\mathit{Logics})\ ,\ 0.8 \rangle$
- Paraconsistent Reasoning
  - Reasoning despite inconsistencies in the knowledge base
  - One Approach: four-valued logics (e.g. *ALC*4)
- Nonmonotonic Reasoning

(Non-)Monotonicity of Reasoning

- Agent collects knowledge in the web

Agent

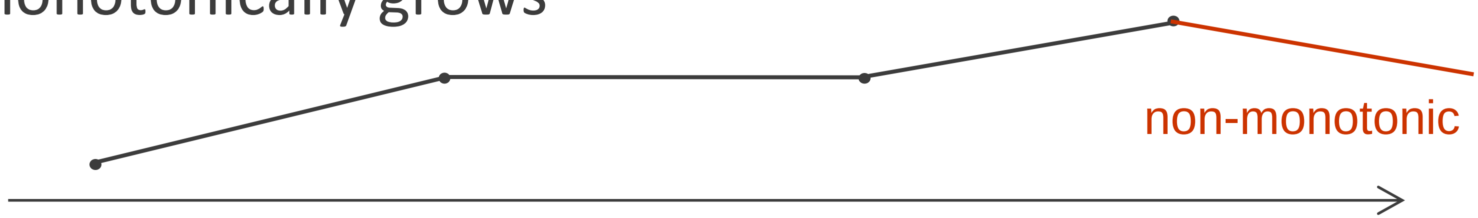
$KB \cup \{f_a,f_b\} \cup \{f_c\} \cup \ldots$

- Reasoning allows to derive implicit knowledge

Agent

$KB \vDash \{f_a, f_b, f_c, f_x, f_y, \ldots\}$

- Reasoning is monotonic if the derived knowledge monotonically grows



$KB \vDash \{f_a,f_b\}$

$KB \cup \{f_c\} \vDash \{f_a,f_b,f_c,f_d\}$

$KB \cup \{f_c,f_d\} \vDash \{f_a,f_b,f_c,f_d\}$

$KB \cup \{f_c,f_d,f_e\} \vDash \{f_c,f_d\}$

. . .

Defeasible Inference

- Inferences in OWL are universally true
  - based on description logics (monotonic)
  - conclusions only drawn from ensured evidence (OWA)
- Defeasible Inferences are based on common-sense conjectures
  - conclusions drawn based on assumptions about what typically holds
  - retracted in the presence of counter-evidence
- Example

$$KB = \{Pizza \sqcap \forall topping.\neg Chili(margarita)\}$$

$$KB \not\models \neg SpicyDish(margarita)$$

***Assumption*: Pizzas with non-chili toppings only are typically non-spicy**

$$KB \mid\approx \neg SpicyDish(margarita)$$

$$KB \cup \{SpicyDish(margarita)\} \mid\not\approx \neg SpicyDish(margarita)$$

NMR in the Semantic Web

- Information in the web is inherently incomplete
  - NMR provides means to handle situations of incomplete knowledge
- Equip SW agents with common-sense
  - NMR accounts for default assumptions and conjectures

Nonmonotonic Formalisms

- Autoepistemic Logic
  - belief operator

    $\forall x : \neg \mathit{hasTopping}(x,chili) \wedge \neg \mathbf{B}\ \mathit{SpicyDish}(x) \rightarrow \neg \mathit{SpicyDish}(x)$
- Default Logic
  - rules with exceptions

    $$\frac{\neg \mathit{hasTopping}(x,chili)\ \mathbf{:}\ \neg \mathit{SpicyDish}(x)}{\neg \mathit{SpicyDish}(x)}$$
- Circumscription
  - minimization of abnormality predicates

    $\forall x : \neg \mathit{hasTopping}(x,chili) \wedge \neg \mathrm{min}(\mathit{AbnormalPizza})(x) \rightarrow \neg \mathit{SpicyDish}(x)$
- LP formalisms
  - minimal models and negation-as-failure

    $\mathit{NonSpicyDish}(x)\ \ \mathbf{:}\!-\ \ \sim \mathit{SpicyDish}(x) \wedge \sim \mathit{hasTopping}(x,chili)$

Local Closed-World Reasoning

- OWA
  - distinction between negative knowledge and lack of knowledge
    - draw conclusions only if there is enough evidence
- CWA
  - negative knowledge coincides with lack of knowledge
    - draw some (negative) conclusions if there is no counter-evidence
- LCWA
  - start from OWA and treat dedicated parts of the domain model under CWA

- Realisation of LCW Reasoning through non-monotinic extensions of DL
  - Autoepistemic DL
  - Circumscriptive DL

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The Autoepistemic Operator **K**

- **K** *C* = *„known to belong to C"*
  - concept closure by LCW assumption
    – assuming full knowledge about instances of *C*
- **K** *City* = *„known cities"*
  - { x : $KB \models$ *City*(x) }
- Syntax of *ALC**K***

$$\begin{array}{rcl} C, D & \longrightarrow & A \mid \top \mid \bot \mid C \sqcap D \mid C \sqcup D \mid \neg C \mid \forall r.C \mid \exists r.C \mid \mathbf{K}C \\ r & \longrightarrow & p \mid \mathbf{K}p \end{array}$$

K-Operator - Example

- Querying for Cities
  - Knowledge base

$$KB = \{ \quad UKCity(London), City(Tokio), City \sqsubseteq EUCity \sqcup USCity, \\ UKCity \sqsubseteq EUCity, EUCity \sqsubseteq City, USCity \sqsubseteq City \quad \}$$

  - Asking for cities in EU or US classically

$$\{?x : KB \models EUCity \sqcup USCity(?x)\} = \{London, Tokio\}$$

  - Asking for cities known to be in EU resp. US

$$\{?x : KB \models \mathbf{K}EUCity \sqcup \mathbf{K}USCity(?x)\} = \{London\}$$

  - Asking for cities not known to be in EU resp. US

$$\{?x : KB \models \neg\mathbf{K}EUCity \sqcap \neg\mathbf{K}USCity(?x)\} = \{Tokio\}$$

    - No classical way of retrieving *Tokio*

Model-Theoretic Semantics for K-Operator

epistemic interpretation

$(\mathcal{I}, \mathcal{W})$

DL interpretation

Models of KB

$\mathcal{M}(KB)$

$$\top^{\mathcal{I},\mathcal{W}} = \Delta^{\mathcal{I}} \quad , \quad \bot^{\mathcal{I},\mathcal{W}} = \emptyset$$

$$A^{\mathcal{I},\mathcal{W}} = A^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \quad , \quad p^{\mathcal{I},\mathcal{W}} = p^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$$

$$\begin{aligned}
(C \sqcap D)^{\mathcal{I},\mathcal{W}} &= C^{\mathcal{I},\mathcal{W}} \cap D^{\mathcal{I},\mathcal{W}} \\
(C \sqcup D)^{\mathcal{I},\mathcal{W}} &= C^{\mathcal{I},\mathcal{W}} \cup D^{\mathcal{I},\mathcal{W}} \\
(\neg C)^{\mathcal{I},\mathcal{W}} &= \Delta^{\mathcal{I}} \setminus C^{\mathcal{I},\mathcal{W}} \\
(\forall r.C)^{\mathcal{I},\mathcal{W}} &= \{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in r^{\mathcal{I},\mathcal{W}} \rightarrow b \in C^{\mathcal{I},\mathcal{W}}\} \\
(\exists r.C)^{\mathcal{I},\mathcal{W}} &= \{a \in \Delta^{\mathcal{I}} \mid \exists b.(a,b) \in r^{\mathcal{I},\mathcal{W}} \wedge b \in C^{\mathcal{I},\mathcal{W}}\} \\
(\mathbf{K}C)^{\mathcal{I},\mathcal{W}} &= \bigcap_{\mathcal{J} \in \mathcal{W}} C^{\mathcal{J},\mathcal{W}} \\
(\mathbf{K}r)^{\mathcal{I},\mathcal{W}} &= \bigcap_{\mathcal{J} \in \mathcal{W}} p^{\mathcal{J},\mathcal{W}}
\end{aligned}$$

- interpretation of closed concepts **K***C*
  - as the intersection of extensions over all models

Concept Satisfiability with **K**

$$KB = \{\, EUCity(London)\ , EUCity(Paris)\ , USCity(New\ York)\ \}$$

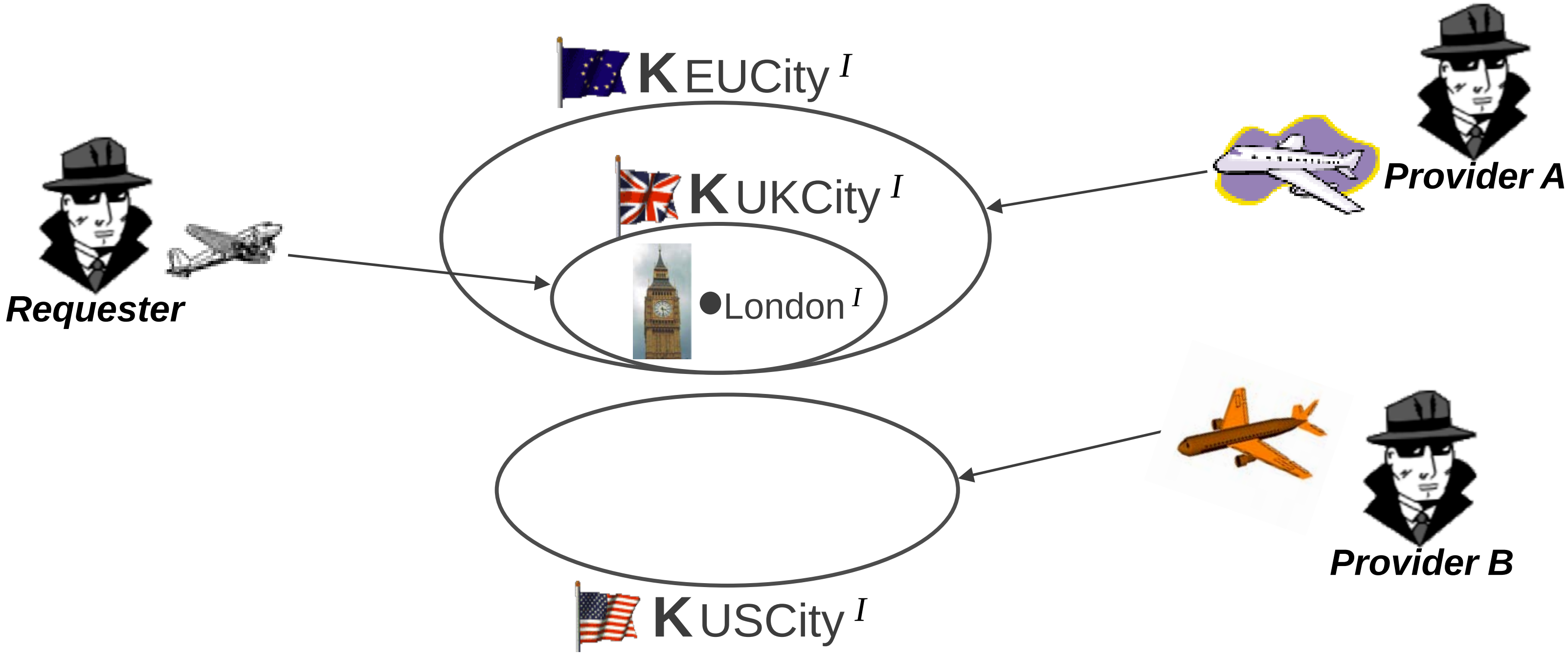
Matching with **K**-Operator

Domain Ontology $KB = \{\, UKCity \sqsubseteq EUCity \,,\, UKCity \sqsubseteq \exists from.\top \,,\, UKCity(London) \,\}$

request $S_r \equiv Shipping \sqcap \forall from.\mathbf{K}UKCity$

offer A $S_{pA} \equiv Shipping \sqcap \forall from.\mathbf{K}EUCity$

offer B $S_{pB} \equiv Shipping \sqcap \forall from.\mathbf{K}UKCity$



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Circumscription Patterns for DL

- DL with circumscription
  - minimising extensions of DL-predicates explicitly
- circumscription pattern CP for knowledge base *KB*

$$\mathsf{CP} = (M, V, F) \qquad\qquad \mathrm{circ}_{\mathsf{CP}}(KB)$$

- Example:

$$\begin{aligned} KB \quad = \quad \{ & \, EUCity \sqsubseteq \exists\, currency.\{Euro\} \sqcup AbnormalEUCity, \\ & UKCity \sqsubseteq EUCity \sqcap \neg\exists\, currency.\{Euro\}, \\ & EUCity(Berlin), \; UKCity(London) \quad \} \end{aligned}$$

$$\mathsf{CP} = (M = \{AbnormalEUCity\}, V = \{EUCity, UKCity, currency\}, F = \emptyset)$$

$$\mathrm{circ}_{\mathsf{CP}}(KB) \models \exists\, currency.\{Euro\}(Berlin)$$

$$\mathrm{circ}_{\mathsf{CP}}(KB) \not\models \exists\, currency.\{Euro\}(London)$$

Model-Theoretic Semantics for Circumscription

- Preference relation $<_{CP}$ on Interpretations

$\mathcal{I} <_{CP} \mathcal{J}$ if for two interpretations $\mathcal{I}$ and $\mathcal{J}$:

$$
\begin{array}{ll}
(i) & \Delta^{\mathcal{I}} = \Delta^{\mathcal{J}} \\
(ii) & a^{\mathcal{I}} = a^{\mathcal{J}} \text{ for all individuals } a \\
(iii) & p^{\mathcal{I}} = p^{\mathcal{J}} \text{ for all } p \in F \\
(iv) & p^{\mathcal{I}} \subseteq p^{\mathcal{J}} \text{ for all } p \in M \\
(v) & \text{there is } p \in M \text{ such that } p^{\mathcal{I}} \subset p^{\mathcal{J}}
\end{array}
$$

comparing interpretations by their extensions for minimized predicates

- models of a circumscribed KB are minimal w.r.t. $<_{CP}$

$$\mathcal{M}(\mathrm{circ}_{CP}(KB)) := \{\mathcal{I} \in \mathcal{M}(KB) \mid \neg\exists \mathcal{J} \in \mathcal{M}(KB) : \mathcal{J} <_{CP} \mathcal{I}\}$$

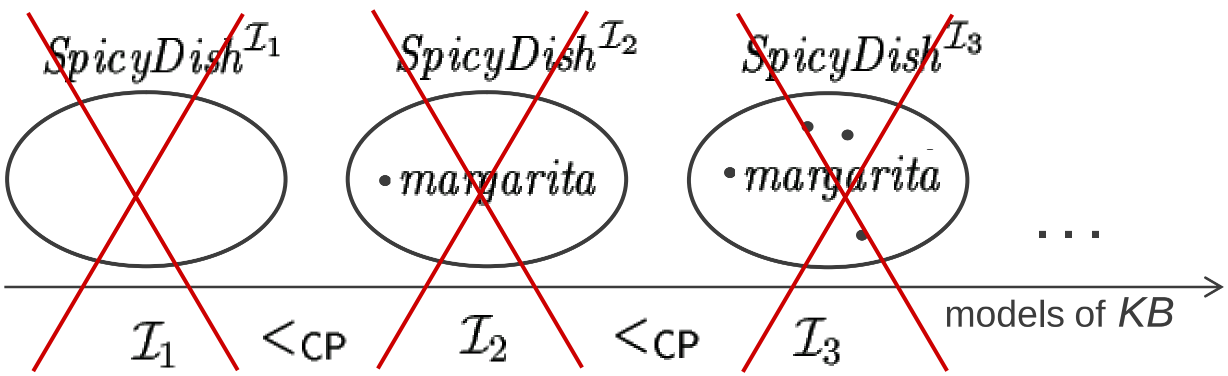
Concept Minimisation

- Trade models for conclusions
  - the less models the more conclusion
  - nonmonotonicity: regain models by learning new knowledge

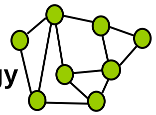
- Example

$$KB = \{Pizza \sqcap \forall topping.\neg Chili(margarita)\} \cup \{SpicyDish(margarita)\}$$

$$\text{CP} = (\{SpicyDish\}^M, \{Pizza, Chili\}^V)$$



Matching with Circumscription

Domain Ontology  $KB = \{ UKCity \sqsubseteq EUCity , UKCity \sqsubseteq \exists from.\top , UKCity(London) \}$

request $S_r \equiv Shipping \sqcap \forall from.UKCity$

offer A $S_{pA} \equiv Shipping \sqcap \forall from.EUCity$

offer B $S_{pB} \equiv Shipping \sqcap \forall from.UKCity$

$$\mathsf{CP} = (M = \{UKCity, EUCity, USCity\}, V = \{< \mathsf{Rest} >\}, F = \emptyset)$$

$R_r \sqcap R_{p_A}$ is satisfiable w.r.t. $\mathrm{circ}_{\mathsf{CP}}(KB)$ ✓

$R_r \sqcap R_{p_B}$ is unsatisfiable w.r.t. $\mathrm{circ}_{\mathsf{CP}}(KB)$ ✓

$\min(UKCity) \sqcap \min(EUCity)$ is satisfiable w.r.t. $\mathrm{circ}_{\mathsf{CP}}(KB)$

$\min(UKCity) \sqcap \min(USCity)$ is unsatisfiable w.r.t. $\mathrm{circ}_{\mathsf{CP}}(KB)$

$$\mathcal{I}_0 = (UKCity^{\mathcal{I}_0} = \{x^{\mathcal{I}_0}\}, EUCity = \{x^{\mathcal{I}_0}\}, USCity = \emptyset)$$

Zusammenfassung (Semantik-Block)

- OWL – Semantik
  - Interpretationen und Modelle
  - Logische Konsequenz
- Ontologiemodellierung mit OWL
  - Intuition für OWL Modellierungskonstrukte
  - Modellierung und Inferenz mit Protégé
  - Typische Patterns / Fallen
- Nichtmonotone Erweiterungen
  - Autoepistemischer Operator K
  - Circumscriptive DL