Corrected and annotated M2R Exam
Fundamentals of data processing and distributed knowledge
Semantics of Distributed Knowledge part

Duration : 2h15
All documents allowed – *No* communication device allowed

January 2022

Note: Read all the questions carefully before answering. Do not hesitate to justify your answers.
Time and points are indicative.

Course questions [Expectation: 30mn; 5pts]

Here I give only three examples, but it should be around 10 questions, the answers are in the course in general.

Answers to these questions are generally short (if the answer is more than three sentences, it is probably wrong, except for the last one). They are related to the course content.

1. For what is it useful to query different sources?

   For accessing/retrieving more information.

2. What does it means for a structure (formula, theory, network, etc.) to be inconsistent?

   It has no model.

3. In modal logic, is $S \models S'$ defined by $\forall M, M \models S \Rightarrow M \models S'$ or by $\forall M, \forall w \in W_M, M, w \models S \Rightarrow M, w \models S'$? Does one expression implies the other? Why?

   The latter. It entails the former because it will also consider worlds in structures which do not universally satisfy S.

Application [Expectation: 1h45; 15pts]

We will consider three simple sources about sports.

Triple/graphs

Here are three sets of triples:

G_2	G_1	G_3
d:football rdf:type o2:outdry	d:football o1:influences d:handball	d:football rdf:type o3:grdcoll
d:handball rdf:type o2:indry	d:handball o1:influences d:waterpolo	d:natation rdf:type o3:wtrind
d:natation rdf:type o2:inwet	d:natation o1:influences d:waterpolo	d:waterpolo rdf:type o3:wtrcoll

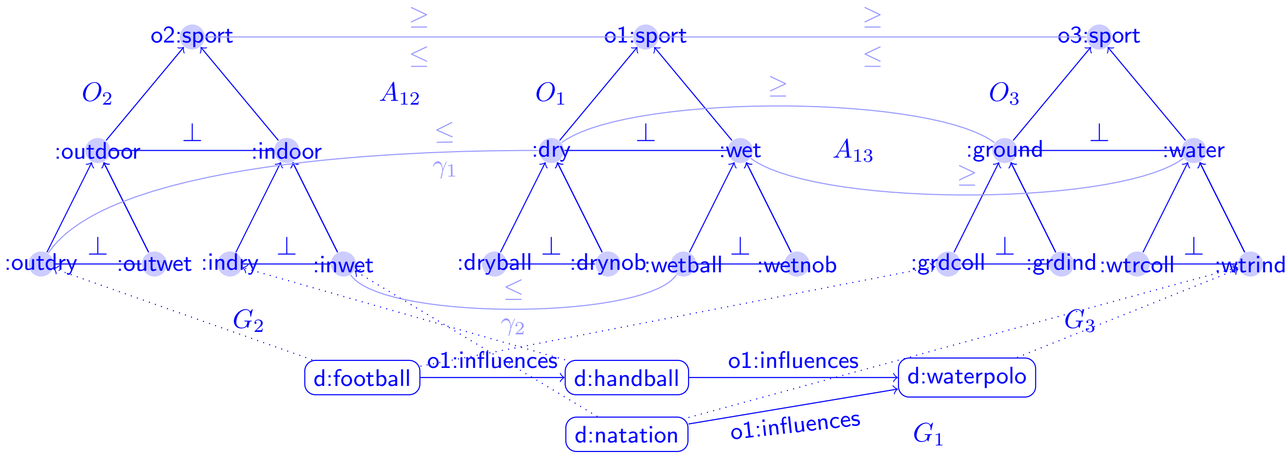

Figure 1: The initial situation.

4. Draw the RDF graphs corresponding to G_1 and G_3.

   See Figure 1 (bottom for the assertions of G_1 and the rdf:type links from resources of the bottom to classes for G_2 and G_3).

5. Does $G_1 \models_{RDF}$ d:waterpolo rdf:type o1:wet?

   No. There is no assertion involving o1:wet in G_1.

6. Does $G_1 \cup G_3 \models_{RDF}$ d:waterpolo rdf:type o3:wtrcoll. d:handball o1:influences d:waterpolo?

   Yes. These are actually triples of these graphs.

Ontologies

Each source has a different ontology based on different criteria. They consider sports as either individual or collective, wet or dry, indoor or outdoor, ball-based or not, etc.

Consider the ontologies O_1, O_2 and O_3 ($\sqsubseteq$=rdfs:subClassOf,$\perp$=owl:disjointWith):

O_2	O_1	O_3
o2:outdoor $\sqsubseteq$ o2:sport	o1:dry $\sqsubseteq$ o1:sport	o3:ground $\sqsubseteq$ o3:sport
o2:indoor $\sqsubseteq$ o2:sport	o1:wet $\sqsubseteq$ o1:sport	o3:water $\sqsubseteq$ o3:sport
o2:outdoor $\perp$ o2:indoor	o1:dry $\perp$ o1:wet	o3:ground $\perp$ o3:water
o2:outdry $\sqsubseteq$ o2:outdoor	o1:dryball $\sqsubseteq$ o1:dry	o3:grdcoll $\sqsubseteq$ o3:ground
o2:outwet $\sqsubseteq$ o2:outdoor	o1:drynob $\sqsubseteq$ o1:dry	o3:grdind $\sqsubseteq$ o3:ground
o2:outdry $\perp$ o2:outwet	o1:dryball $\perp$ o1:drynob	o3:grdcoll $\perp$ o3:grdind
o2:indry $\sqsubseteq$ o2:indoor	o1:wetball $\sqsubseteq$ o1:wet	o3:wtrcoll $\sqsubseteq$ o3:water
o2:inwet $\sqsubseteq$ o2:indoor	o1:wetnob $\sqsubseteq$ o1:wet	o3:wtrind $\sqsubseteq$ o3:water
o2:indry $\perp$ o2:inwet	o1:wetball $\perp$ o1:wetnob	o3:wtrcoll $\perp$ o3:wtrind

7. Draw the ontologies as three RDF graphs representing their hierarchy.

   See Figure 1.

8. Does $O_1 \models_{OWL}$ o1:wetball $\perp$ o1:dry?

   Yes. Because o1:wetball $\sqsubseteq$ o1:wet $\perp$ o1:dry. Or, semantically, because for any model m of O_1, m(o1:wetball) $\subseteq m$(o1:wet) and m(o1:wet) $\cap\, m$(o1:dry) $= \varnothing$, hence m(o1:wetball) $\cap\, m$(o1:dry) $= \varnothing$ and since this holds for every model of O_1, then $O_1 \models_{OWL}$ o1:wetball $\perp$ o1:dry.

9. Does $G_1 \cup O_1 \models_{OWL}$ d:waterpolo rdf:type o1:wet?

   No. Because there is no assertion concerning d:waterpolo, which could entail a type assertion (e.g. ⟨o1:influences, rdfs:range, o1:wet⟩).

10. Does $G_1 \cup G_3 \cup O_1 \cup O_3 \models_{OWL}$ d:waterpolo rdf:type o3:water. d:handball o1:influences d:waterpolo?

    Yes. d:waterpolo rdf:type o3:wtrcol $\sqsubseteq$ o3:water (from $G_3 \cup O_3$) and d:handball o1:influences d:waterpolo (from G_1).

Query

Some agents would like to take advantage of these three sources and answer queries. Consider the three following queries:

q_1

SELECT $?x$, $?y$
WHERE $?x$ o1:influences $?y$

q_2

SELECT $?x$, $?y$
WHERE
$?x$ o1:influences $?y$
$?y$ rdf:type o3:water

q_3

SELECT $?x$, $?y$
WHERE
$?x$ o1:influences $?y$
$?x$ rdf:type o1:dry
$?y$ rdf:type o1:wet

11. What are the results of evaluating q_1, q_2 and q_3 against $O_1 \cup G_1$ ($\mathcal{A}(q[?x, ?y], O_1 \cup G_1)$)?

q_1	q_2	q_3
⟨d:football, d:handball⟩		
⟨d:handball, d:waterpolo⟩		
⟨d:natation, d:waterpolo⟩		

12. What are the results of evaluating q_1, q_2 and q_3 against $O_1 \cup O_2 \cup O_3 \cup G_1 \cup G_2 \cup G_3$ ($\mathcal{A}^{O_1 \cup O_2 \cup O_3}(q[?x, ?y], G_1 \cup G_2 \cup G_3)$)?

q_1	q_2	q_3
⟨d:football, d:handball⟩		
⟨d:handball, d:waterpolo⟩	⟨d:handball, d:waterpolo⟩	
⟨d:natation, d:waterpolo⟩	⟨d:natation, d:waterpolo⟩	

Alignments

Consider the following alignments between O_1 and the two other ontologies:

$A_{12} = \{$o1:sport $\geq$ o2:sport, o1:sport $\leq$ o2:sport, o1:dry $\geq$ o2:outdry, o1:wetball $\geq$ o2:inwet$\}$

$A_{13} = \{$o1:sport $\geq$ o3:sport, o1:sport $\leq$ o3:sport, o1:dry $\geq$ o3:ground, o1:wet $\geq$ o3:water$\}$

13. Does $A_{13} \models_{\Delta}$ ⟨o1:wet, $\geq$, o3:wtrcoll⟩?

    Yes. Because for any pair of models $\langle m_1, m_3\rangle$ of $\langle O_1, O_3\rangle$, A_{13} constrains that m_1(o1:wet) $\supseteq m_3$(o3:water) and for any model m_3 of O_3, m_3(o3:wtrcoll) $\subseteq m_3$(o3:water).

14. Does $\langle\{O_1 \cup G_1, O_3 \cup G_3\}, \{A_{13}\}\rangle \models_{\Delta}$ d:waterpolordf:typeo1:wet (or ⟨d:waterpolo, rdf:type, o1:wet⟩ $\in Cn^{\omega}_{\langle\{O_1 \cup G_1, O_3 \cup G_3\}, \{A_{13}\}\rangle}($

    Yes. Because for any model m_3 of O_3, m_3(d:waterpolo) $\in m_3$(o3:wtrcoll) and the answer above means that m_1(d:waterpolo) $\in m_1$(o1:wet).

Alignment creation game

In the alignment creation game, agents know the leaf class names of other agents' ontologies, but not the definition of these classes, nor subclass (subsumption). The game is played in the following way:

- an agent a asks another agent b to show some object of class c_b;
- agent b answers with an object o;
- agent a identifies in its own ontology the most specific class c'_a to which o belongs;
- if A_{ab} does not entail any correspondence $\langle c_a, \geq, c_b\rangle$, then the outcome of the game is UNKNOWN and agent a adds $\langle c'_a, \geq, c_b\rangle$ to A_{ab};
- if $\langle c_a, \geq, c_b\rangle \in A_{ab}$ then
  - If $c'_a \sqsubseteq c_a$, then the game is a SUCCESS;
  - Otherwise, the game is a FAILURE and agent a replaces $\langle c'_a, \geq c_b\rangle$ in A_{ab} by $\langle c''_a, \geq c_b\rangle$ with c''_a the most specific superclass of c_a and c'_a.

Consider A_{12} between O_1 and O_2 and that agent 1 has received from agent 2 the following set of objects:

c_2	Object	c'_1	status	action
o2:outdry	d:marathon	o1:drynob		
o2:outwet	d:triathlon	o1:drynob		
o2:indry	d:basket	o1:dryball		
o2:inwet	d:diving	o1:drynob		
o2:inwet	d:waterpolo	o1:wetball		
o2:indry	d:judo	o1:drynob		

15. Trace the game by showing how it evolves the alignment A_{12}. I.e. fill the table above (status=SUCCESS, FAILURE, UNKNOWN).

c_2	Object	c'_1	status	action	
o2:outdry	d:marathon	o1:drynob	SUCCESS (γ_1)	none	
o2:outwet	d:triathlon	o1:drynob	UNKNOWN	add	$\gamma_3 = \langle$o1:drynob$, \geq,$ o2:outwet$\rangle$
o2:indry	d:basket	o1:dryball	UNKNOWN	add	$\gamma_4 = \langle$o1:dryball$, \geq,$ o2:indry$\rangle$
o2:inwet	d:diving	o1:drynob	FAILURE (γ_2)	repl γ_2 by	$\gamma_5 = \langle$o1:wet$, \geq,$ o2:inwet$\rangle$
o2:inwet	d:waterpolo	o1:wetball	SUCCESS (γ_5)	none	
o2:indry	d:judo	o1:drynob	FAILURE (γ_4)	repl γ_4 by	$\gamma_6 = \langle$o1:dry$, \geq,$ o2:indry$\rangle$

16. What is the content of A'_{12}, the evolution of A_{12} after these 6 games?

$$A'_{12} = \{\text{o1:sport} \geq \text{o2:sport}, \text{o1:sport} \leq \text{o2:sport}, \text{o1:dry} \geq \text{o2:outdry},$$
$$\text{o1:wet} \geq \text{o2:inwet}, \text{o1:drynob} \geq \text{o2:outwet}, \text{o1:dry} \geq \text{o2:indry}\}$$

This is also displayed in Figure 2.

17. Is the proposed adaptation always correct?

Yes. Because the discarded correspondence is always incorrect. But the added correspondences may be too specific, as shown in the example of γ_4 above. They may be invalidated by a later game.

18. Does it converge to a stable alignment?

Once all possible object types have been played, all remaining correspondences should not create any more failures. However, in this game we have no way to know if they all have been explored (contrary to ARG).

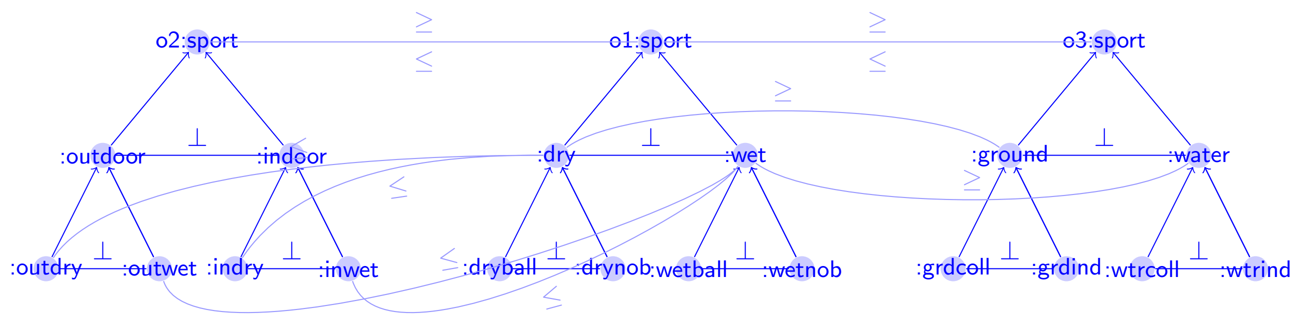

Figure 2: The corrected situation... with A'_{12}.

Query evaluation revisited

19. Provide a decomposition of query q_3 that an agent using ontology O_1 could use in order to evaluate it with respect the alignments A'_{12} and A_{13}?

    q_3, may be partitioned into three queries $q_3^1 = \{\langle ?x, \text{o1:influences}, ?y\rangle\}$, $q_3^2 = \{\langle ?x, \text{rdf:type}, \text{o2:indry}\rangle\}$ and $q_3^3 = \{\langle ?y, \text{rdf:type}, \text{o3:water}\rangle\}$.

20. Provide the answer of each subquery and how it provides an answer to q_3.

    – $\mathcal{A}^{O_1}(q_3^1(\langle ?x, ?y\rangle), G_1) = \mathcal{A}^{O_1}(q_1(\langle ?x, ?y\rangle), G_1)$,
      i.e. $\{\langle \text{d:football}, \text{d:handball}\rangle, \langle \text{d:handball}, \text{d:waterpolo}\rangle, \langle \text{d:natation}, \text{d:waterpolo}\rangle\}$,
    – $\mathcal{A}^{O_2}(q_3^2(\langle ?x\rangle), G_2) = \{\langle \text{d:handball}\rangle\}$
    – $\mathcal{A}^{O_3}(q_3^3(\langle ?y\rangle), G_3) = \{\langle \text{d:waterpolo}\rangle\}$

    Hence, $\mathcal{A}^{O_1}(q_3^1(\langle ?x, ?y\rangle), G_1) \bowtie \mathcal{A}^{O_2}(q_3^2(\langle ?x\rangle), G_2) \bowtie \mathcal{A}^{O_3}(q_3^3(\langle ?y\rangle), G_3) = \{\langle \text{d:handball}, \text{d:waterpolo}\rangle\}$.

Epistemic logic model of agent knowledge

21. Provide a multi-agent epistemic axiomatisation T (translation) of $O_1 \cup G_1$, $O_2 \cup G_2$ and $O_3 \cup G_3$ as knowledge and A'_{12} and A_{13} as beliefs.

$T(G_2 \cup O_2)$	$T(G_1 \cup O_1)$	$T(G_3 \cup O_3)$
K_2o2:outdoor $\sqsubseteq$ o2:sport	K_1o1:dry $\sqsubseteq$ o1:sport	K_3o3:ground $\sqsubseteq$ o3:sport
K_2o2:indoor $\sqsubseteq$ o2:sport	K_1o1:wet $\sqsubseteq$ o1:sport	K_3o3:water $\sqsubseteq$ o3:sport
K_2o2:outdoor $\perp$ o2:indoor	K_1o1:dry $\perp$ o1:wet	K_3o3:ground $\perp$ o3:water
K_2o2:outdry $\sqsubseteq$ o2:outdoor	K_1o1:dryball $\sqsubseteq$ o1:dry	K_3o3:grdcoll $\sqsubseteq$ o3:ground
K_2o2:outwet $\sqsubseteq$ o2:outdoor	K_1o1:drynob $\sqsubseteq$ o1:dry	K_3o3:grdind $\sqsubseteq$ o3:ground
K_2o2:outdry $\perp$ o2:outwet	K_1o1:dryball $\perp$ o1:drynob	K_3o3:grdcoll $\perp$ o3:grdind
K_2o2:indry $\sqsubseteq$ o2:indoor	K_1o1:wetball $\sqsubseteq$ o1:wet	K_3o3:wtrcoll $\sqsubseteq$ o3:water
K_2o2:inwet $\sqsubseteq$ o2:indoor	K_1o1:wetnob $\sqsubseteq$ o1:wet	K_3o3:wtrind $\sqsubseteq$ o3:water
K_2o2:indry $\perp$ o2:inwet	K_1o1:wetball $\perp$ o1:wetnob	K_3o3:wtrcoll $\perp$ o3:wtrind
K_2o2:outdry(d:football)	K_1o1:influences(d:football, d:handball)	K_3o3:grdcoll(d:football)
K_2o2:indry(d:handball)	K_1o1:influences(d:handball, d:waterpolo)	K_3o3:wtrind(d:natation)
K_2o2:inwet(d:natation)	K_1o1:influences(d:natation, d:waterpolo)	K_3o3:wtrcoll(d:waterpolo)

$T(A'_{12})$		$T(A_{13})$	
B_2o1:sport $\sqsupseteq$ o2:sport	B_1o1:sport $\sqsupseteq$ o2:sport		
B_2o1:sport $\sqsubseteq$ o2:sport	B_1o1:sport $\sqsubseteq$ o2:sport	B_1o1:sport $\sqsupseteq$ o3:sport	B_3o1:sport $\sqsupseteq$ o3:sport
B_2o1:dry $\sqsupseteq$ o2:outdry	B_1o1:dry $\sqsupseteq$ o2:outdry	B_1o1:sport $\leq$ o3:sport	B_3o1:sport $\sqsubseteq$ o3:sport
B_2o1:wet $\sqsupseteq$ o2:inwet	B_1o1:wet $\sqsupseteq$ o2:inwet	B_1o1:dry $\sqsupseteq$ o3:ground	B_3o1:dry $\sqsupseteq$ o3:ground
B_2o1:drynob $\sqsupseteq$ o2:outwet	B_1o1:drynob $\sqsupseteq$ o2:outwet	B_1o1:wet $\sqsupseteq$ o3:water	B_3o1:wet $\sqsupseteq$ o3:water
B_2o1:dry $\sqsupseteq$ o2:indry	B_1o1:dry $\sqsupseteq$ o2:indry		

22. Does $T \models_{DEL} B_1$o1:influences(d:handball, d:waterpolo) $\wedge$ B_1o1:dry(d:handball) $\wedge$ B_1o1:wet(d:waterpolo)?

    Yes. Because K_1o1:influences(d:handball, d:waterpolo) entails B_1o1:influences(d:handball, d:waterpolo) and K_2o2:indry(d:handball) and B_1o1:dry $\sqsupseteq$ o2:indry entails B_1o1:dry(d:handball) and finally K_3o3:wtrcoll(d:waterpolo) and K_3o3:wtrcoll $\sqsubseteq$ o3:water entails K_3o3:water(d:waterpolo) which with B_1o1:wet $\sqsupseteq$ o3:water entails B_1o1:wet(d:waterpolo).

    These last inferences are not correct. In fact, it would be necessary that Source 1 endorses G_2 and G_3 for this to hold (e.g. $\forall \phi \in G_i, B_1\phi$).