Tools, methods, and purposes for teaching logic

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Plan

1. Current situation in logic
2. Renewing logic teaching
3. Which applications?
4. Course content
5. Assessment and Conclusion

Plan

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Logic-based applications

- Logic-based applications are ubiquitous, for instance logic stands at the center of computing:
  - theoretically: Turing machines, computing models [12]
  - digitally: von Neumann architecture, digital circuits [10]
  - algorithmically:
    - propositional logic SAT solving [3],
    - temporal logic-based model-checking [4],
  - ...
- Logic is impactful, but it struggles to get the attention it deserves!

Logic is at a crossroads

- There have never been so many applications of logic in our lives,
- but the teaching of logic is pretty much falling into oblivion
  - logic courses are struggling to attract students' interest and be offered regularly,
  - and are considered abstract, difficult, and unrelated to modern concerns ...

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What is logic?

- Reasoning is a fundamental cognitive ability that
  - leverages knowledge to make sense of the world and inform our decisions.
- Logic has devised
  - formal languages with unambiguous semantics and reasoning methods,
  - in fact, an effective “calculus of thoughts”.

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Tools for Teaching Logic!

- Tools and innovative approaches for teaching logic are of paramount importance,
- but this is not enough!
- Logic education cannot be renewed without embracing applications head on:
  - logic teaching must distance itself from tradition and
  - put applications in the foreground.
- Applications now, theory later!

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Tradition

- Logic is naturally taught by
  - precisely developing and justifying the theoretical foundations
  - before turning to applications.
- Obvious drawback: one may never get to meaningful applications!
- Full-fledged applications in further advanced courses only yields more logic classes to maintain and justify.
- Outcome: Students may hence never see logic in action, jeopardizing the next generation's training!

Current context

- This teaching tradition is at odds with our current task-oriented society, where
  - outcomes,
  - skillsets,
  - and the ability to achieve objectives is everything.
- Universities are utterly anxious to avoid the trap of knowledge without skillsets and are blurring the distinction between fundamental and professional degrees.
- Logic teaching simply cannot ignore this current context.

Applications

- This teaching tradition also grossly downplays the fundamental challenges of applications, where modeling and effectively inferring meaningful information is of utmost importance.
- Tailoring theoretical results to a significant application is a contribution of immense value.
- Applications are also a central driving force for notable theoretical developments.

Plan

Knowledge processing

- Making the most of digital data is central to our information society.
- Machine Learning is currently the central data processing method, taking high volumes of data to accurately predict correct outcomes.
- Cognition cannot be reduced to function prediction [5] and
- a further type of Data Science, emphasizing structure and relationships, is emerging.
- As the study of correct reasoning, logic naturally plays a vital role in this approach.

Data science

- This data science is devised around ontologies as understood in computer science,
  - i.e., structured terminologies,
  - as considered by the Semantic Web initiative [8].
- These ontologies are formal representations of knowledge, and Description Logic [2] provides the theoretical setting.
- This approach is particularly suited for structured domains such as,
  - the materials, geospatial, and biomedical fields [1].
- Ontologies are also known as Knowledge Graphs [6].

Description Logic

- fragment(s) of first-order logic restricted to
  - unary and binary relations
  - and guarded quantification as in the standard translation for modal logic
    - $\forall y.(r(x,y) \rightarrow C(y))$,
    - $\exists y.r(x,y) \wedge C(y)$,
  - and counting guarded quantifiers ("this many")
- alternatively, multi-modal logic with counting guarded quantifiers.
- The predominant inference method used for Description Logic is the tableau method, extending that for first-order logic [11].

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DIC9305

- *DIC9305 Logique, informatique et sciences cognitives*[1]
- Given every other year to students of the
  - *Doctorate in Cognitive Informatics*
- a multi-disciplinary program with students from the humanities, computer science, ...
- in fact, half a course (8 weeks, 3 hours a week).

[1] www.labunix.uqam.ca/∼villemaire_r/9305.html (French)

Week 1: Applications First

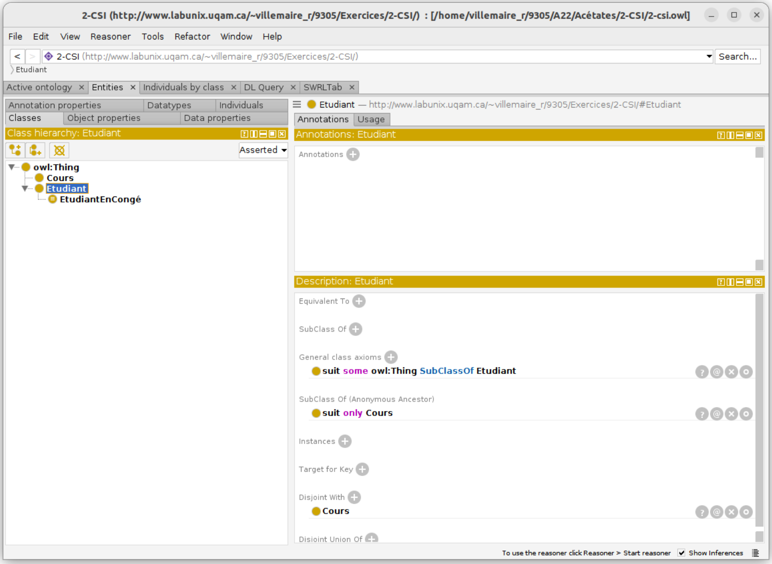
- At the very first class, after a general introduction/overview of the course, students are invited to install (on their laptop or lab. workstation):
  - Protégé[2] [9], an ontology development tool,
  - with Hermit[3] [7] a tableau-based reasoner.

[2] protege.stanford.edu
[3] www.hermit-reasoner.com

Week 2: Knowledge, Inference

- Massive Data in digital form is available in many fields.
- Ontologies are formal representation of knowledge.
- As a logic-based technologies, ontologies allow to develop precise modelizations and infer implicit knowledge.
- W3C (World Wide Web Consortium) standards:
  - Resource Description Framework (RDF) triple: $roger - follows - DIC9305$,
  - Web Ontology Language (OWL): a representation for Description Logic.
- Description Logic:
  - Concept: unary relation, e.g., *Course*
  - role: binary relation, e.g., *follows*
  - individual: constant, e.g., *roger*, $DIC9305$
- A simple example with Protégé and reasoner inference.

Protégé


2-CSI (http://www.labunix.uqam.ca/~villemaire_r/9305/Exercices/2-CSI/) : [/home/villemaire_r/9305/A22/Acétates/2-CSI/2-csi.owl]
File Edit View Reasoner Tools Refactor Window Help
2-CSI (http://www.labunix.uqam.ca/~villemaire_r/9305/Exercices/2-CSI/)
Search...
Etudiant
Active ontology
Entities
Individuals by class
DL Query
SWRLTab
Annotation properties
Datatypes
Individuals
Classes
Object properties
Data properties
Class hierarchy: Etudiant
Asserted
owl:Thing
Cours
Etudiant
EtudiantEnCongé
Etudiant — http://www.labunix.uqam.ca/~villemaire_r/9305/Exercices/2-CSI/#Etudiant
Annotations
Usage
Annotations: Etudiant
Annotations
Description: Etudiant
Equivalent To
SubClass Of
General class axioms
suit some owl:Thing SubClassOf Etudiant
SubClass Of (Anonymous Ancestor)
suit only Cours
Instances
Target for Key
Disjoint With
Cours
Disjoint Union Of
To use the reasoner click Reasoner > Start reasoner
Show Inferences

Week 3-4: Description Logic

- $\forall follows.Course$
- $\exists follows.Comp\_Course$
- $\leq 3 follows.Course$
- Statements: Subsumption $\exists follows.Course \sqsubseteq Student$
  - axioms are of this form,
  - the reasoner will also infer statements of that form.
- Modeling: develop, infer, analyze, correct, ...
- Semantics.

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Week 5-6: Modelization

- Mostly hands-on work:
  - you need enough information (axioms) for the reasoner to conclude,
  - modeling is about eliciting the crucial facts and
  - can be done in different, possibly non-equivalent ways,
  - don't overload a model with irrelevant details,
  - the reasoner is also a tool to experiment with your model.
- Mention various Description Logics, complexity, OWL fragments.

Week 7-8: Theory

- Propositional Calculus: semantics, tableau proof system, completeness.
- First-order logic: semantics, tableau proof system, completeness,
  - semi-decision procedure as the tableau could be infinite.
- Description Logic as a first-order logic fragment,
  - DL semantics agrees with first-order,
  - mention that the tableau method can be made to yield a finite structure, hence a decision procedure.
- Exercises building tableaux: “structure directed case analysis” with the *Tree Proof Generator*[4].

[4] www.umsu.de/trees

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Reflection: Foundations

- Description Logic is an adequate introduction to first-order logic since it allows to present:
  - its syntax,
  - the usual first-order semantics,
  - and completeness through the tableau method.
- Description logic is also a good starting point for studying (multi-)modal logic(s) since its roles (binary relations) are indeed modalities in the Kripke sense.
- Such a course is therefore an adequate introduction to logic that should allow further study of the domain.

Reflection: Lessons learned

- Students are surprised by completeness, deduction, mechanical reasoning.
- Modeling flexibility, missing crucial aspects will strike through rapid prototyping.
- Students develop neat modeling skills, identifying tradeoffs.

Reflection: Data Science

- Data Science through Ontologies has technological potential.
- Targeted areas must however already offer some nomenclature, classification, taxonomy, conceptualization, ...
- Existing formal conceptualization can be quite brittle (WikiData), jeopardizing further reasoning.
- Much research going on, with some nice applications, still more to be done.

Conclusion

- Logic is an active field of research with striking impactful applications.
- But there is too little logic teaching in universities currently.
- There is meaning in life, Machine Learning cannot be the full story, logic is vital!
- Our community should embrace applications head-on and reach out to this outcome-oriented society.
- Logic can be taught through knowledge modelization.
- I had the privilege to teach a course among these lines, hopefully, I will be able to renew, if not expand, this experience!

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