Model Synthesis based on Experience

RAMICS 2023, Augsburg

Yannick Chevalier

(short presentation)

Knowledge and Learning

Epistemic Logics

- Aim at modeling knowledge
- Variety of contexts: multi-agents, with actions, etc.
- But not in relation with learning

Learning

- Oxford dictionary definition:
  knowledge acquired through study, experience, or being taught.
- Goal: propose an epistemic logic based on learning

Application in Computer Science

- We love to analyze specifications
- Complex systems often do not have a specification
  it has to be built from execution traces

Ideal Model for Learning

- Learning increases knowledge, so every learning algorithm has to be a monotonic function f between posets (with $\sqcup$ as the join operation)
- There should be a uniform convergence of learning algorithm. If X is directed then

$$f(\sqcup X) = \sqcup_{x \in X} f(x)$$

- The knowledge acquired in different experiences can be reconciled to get a better knowledge so we always have

$$f(x) \sqcup f(y) = f(x \sqcup y)$$

- f should map finite (compact) elements to compact elements

Setting

- Algebraic morphisms between algebraic lattices
- Prefix-closed sets of traces

Compact elements are finite sets of finite traces

Outline of the construction

Learning goals

- Interpretability:
  - Interaction with a user using FOL formulas
  - Evaluation on a FOL model
- Knowledge
  - Truth in the model is defined by observations
  - Predicates, domain, and interpretation evolve according to cognitions and observations to maintain truth

Epistemic Logic

Origin and Construction of Knowledge

Combines observations and specification

- E.g., specification of a protocol employed on the network
- Truth derived from observations

Neither empiricist (only observations) nor axiomatic (only specification) notion knowledge

Critique of the Pure Reason

- Right combination of transcendental and experimental knowledge explored by Kant
- Traditionally dismissed as an obfuscated subset of FOL
- Resurrected by Longuenesse (1993) and Achourioti and van Lambalgen (2011)
- Slight difficulty in the approach: deductions define the interpretation, which defines the syntax

Construction overview

Ramics example

- Generate all posets of n elements with an internal operation
- Given the specification of quantales, select those posets that are quantales
- Specify interesting characteristics ((in)equations)
- Group quantales according to the characteristics they satisfy
- Look at evolution of these groups when n increases

Construction Overview

General case

- Iterative arbitrary split of data into groups, transformation of data, and evaluation of properties on these groups

  iteration of split, object, and representation functions
- Construct the expected value of these functions on *learning* data
- Use this expected value to decide whether a piece of data conforms to the expectations

  Practical Knowledge
- Construct predicates as set of function composition with maximal expected value
- Domain is the set of equivalence classes of constructions *wrt* to the interpretation of predicates

  This model is the Conceptual Knowledge
- This construction is feasable if there is enough expressions

  Witch's trial (Monty Python), Liar's paradox (Contextuality, Monday's talk)

Data Exchange Systems

Representation and Object terms

- Observations are stored in a source table
- Split and object morphisms create new tables
- Representation morphisms construct constraints on the data in these tables
- FO terms are compositions of morphisms over a single constant X

Interpretation

- X is interpreted as the content of the source table
- Each term is interpreted as the result of the function composition
- These interpretations are algebraic morphisms
- (u, S) denotes observation u and set of terms S

Practical knowledge

Signature Σ, observation u

Judgements

- $t \sqsubseteq d$ with t a representation term
- $1 \sqsubset 0$

Practical knowledge

On learned dataset u:

$$v \mapsto \prod_{t \in \mathrm{Repr}(T(\Sigma))} \mathrm{Val}_v^S(t) \sqsubseteq \mathrm{Val}_u^S(t)$$

with $\mathrm{Val}_{\_}^S(t) = \bot$ if $t \notin S$, and the interpretation of t otherwise

Application: Anomaly detection

- Applied on the CAN Bus (automotive, robotics)
- Very fast learning and monitoring
- Angluin-like: can be improved to remove false results
- "Explainable" results, but difficult to understand

Conceptual knowledge

Motivations

- Human-friendlier: Group objects having the same properties
- Application: Entity resolution

Cognitive state $K = (u, S, O, R)$

- u, S as before
- O sets of ground objects on which we reason
- R set of pure representation terms with shared variables

Form an algebraic lattice

Construction of a Model M_K

Predicates of experience given $O' \times R' \subseteq O \times R$

$$\bigwedge_{r \in R'} r \subseteq \sqcup_\theta r\theta$$

where θ are all substitutions with codomain included in O' and $r\theta \in S$

Stability condition

if $r\theta \in S$ and $o_1, o_2 \in O'$ then $r(\theta[o_1 \leftarrow o_2]_X) \in S$ with X subset of the domain of θ

Motivation for stability

Witches burn, so does wood. Wood floats, so do ducks. Thus if a person weights as much as a duck, she is a witch

Domain

Equivalence classes of O for partial replacement in PoE

Inverse Systems

Goal

- Cognitions: addition of $f \in \Sigma$ or terms in S, O, and R
- Truth maintenance for increasing cognitions
- Model of Kant's framework proposed in A.-v. L. 2011
- Local "Models of experience" indexed by a poset
- Transcendental model: inverse limit of the models of experience with projections to models of experience

Construction

- Inverse system: limit of an expanding diagram in the algebraic lattice category
- Transcendental domain and predicates: Threads in the product of domains and predicates
- Have to check that interpretation is correct

Conceptual Knowledge

Compact cognitive state K

The model M_K constructed over that state

General case

- Continuous lattice: every element is a directed limits of compact cognitive states
- Conceptual knowledge: Inverse limit of the inverse system of models indexed by compact cognitive states below
- Check: same model for compact cognitive states

Conclusion

Future work

- Log analysis
  - Analysis of CAN Bus logs
  - Social network analysis
- Extensions
  - From algebraic to continuous lattices
  - Add names to predicates to enable user interaction
  - Relate with actual ML algorithms to extend applicability

- Technical report: `https://ut3-toulouseinp.hal.science/hal-03829757v2`
- Thanks to reviewers for spotting technical errors

Thanks to Starlight project funded by the EU's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 101021797