Hilog, Defeasibility, and the Foundations of Practical Meta-Knowledge: A Brief Introduction

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Meta in Rulelog – *Extension of LP*

Rulelog has several expressive features for **meta** knowledge

- Overall: mix meta knowledge with "base" knowledge, in fine grain
  - Just as the web/markup mixes meta in *data* with "base" data, in fine grain
- **Hilog**: any atom can be treated as a term. Used also in Common Logic.
  - Provides higher-order syntax (bit restricted)
  - Semantics reduces (transforms) to first-order, and uses logical functions.
- Reification: any formula can be treated as a term. A.k.a. *quoting*.
  - Provides modal syntax
- Rule id's: enables meta-statements about assertions (i.e., about rules)
  - Every assertion has a rule id, that is a constant in the logical language
  - Useful for provenance, defeasibility, restraint, and other purposes
- **Defeasibility**: any rule can have exceptions (non-monotonically)
  - Strong negation (neg). Prioritized conflict handling. Cancellation of rules.
  - Argumentation-theory approach: specify via rules the principles of defeat
- Restraint: bounded rationality, using the "undefined" (u) truth value
  - u represents "not bothering"
  - Specify via rules the principles of such "not bothering"
  - Radial restraint: treat as u every atom/literal whose size exceeds a fixed radius

Examples of Reification

- Reification (a.k.a. quoting) makes a term out of a formula:

  believes(john, **${** likes(mary,bob) **}**)

  Term made out of the formula likes(mary,bob)

- Variables can be back-quoted:

  jealousOf(john,?X) :- believes(john, ${likes(mary, `?X)}.

  Back-quoting of ?X makes its scope be outside the quoted formula that ?X appears within

- See, e.g., [Yang & Kifer, ODBASE 2002]

- Rules, not just formulas, can be reified as well

Examples of Hilog

Hilog permits predicates and functions to be any term: a variable or a complex term, not just a constant

p(?X,?Y) :– ?X(a,?Z) and ?Y(f(?Z)(b)).

***Variable as predicate**: ranges over predicate names of arity 2*

***Variable as function:** ranges over function names of arity 1*

***Complex-term as function:** ranges over function names of arity 1*

Hilog also permits variables over atomic formulas. This is a kind of reification:

p(q(a)).
r(?X) :– p(?X) and ?X.

***Meta-variable**: ranges over unary method names*

Introduced in [Chen, Kifer, Warren, "HiLog: A Foundation for Higher-Order Logic Programming", J. of Logic Programming, 1993]

Rule ID's

- Simple, but important, feature
- Each (assertion) statement gets a unique rule id
- The id can be explicitly specified
  - @!{myRule17} H :- B.
- Or if implicit, is a skolem essentially
  - H :- B. → gets treated as: @!{gensym0897} H :- B.

- Enables various useful kinds of meta-knowledge, by asserting properties of the rule id
  - Provenance, e.g., createdBy(myRule17, Benjamin)
  - Defeasibility
  - Rule-based transformations, e.g., for language extensibility, UI, NLP

Uses of Hilog and Reification and Rule ID's

Overall: for knowledge exchange and introspection

- Ontology mappings
- KB translation/import
- KR macros
- Modals (incl. deontic, alethic)
- Multi-agent belief
- Provenance and other aspects of context
- Reasoning control, incl. restraint bounded rationality
- KB modularization
- Navigation in KA (knowledge acquisition)
- …

- Argumentation-theory approach to defeasibility
  - Principles of defeat (i.e., of debate) are meta rules that use Hilog and rule id's

HiLog Transformation

- HiLog semantics is defined via a transformation
- A simplified version of that, which gives intuition:
  - Rewrite each atom p(a,b) → holds_2(p,a,b)
    - Generic predicate constants holds_1, holds_2, …
  - Treat each term in similar manner
    - f(a,b) → apply_2(f,a,b)
    - Generic function constants apply_1, apply_2, …
- General case of transformation heavily uses logical functions
  - ⇒⇒ creates a challenge in implementation

Knowledge often has Exceptions

- **A.k.a. knowledge is *defeasible* (i.e., can be "defeated")**
- **"A (eukaryotic) cell has a nucleus." … Except when it doesn't ☺**
  - A cell has no nucleus during anaphase. Red blood cells have no nuclei.
  - A cell has two nuclei between mitosis and cytokinesis. Some fungi are multinucleate.
- **Exceptions / special cases are inevitably realized over time**
  - E.g., knowledge is incomplete, multiple authors contribute, …
- **Requiring entered knowledge to be strictly / universally true (exception-free) is impractical**
  - Precludes stating generalities (the typical) and thus the population of authors
  - "The perfect is the enemy of the good"
- **Exceptions manifest as contradictions, i.e., conflict**
- **Leveraging multiple sources of knowledge (e.g., KB merging) requires conflict resolution**
  - Errors. Confusions. Omitted context.

Defeasibility is Indicated When…

- **Useful generalities – <u>and</u> potential exceptions – coexist**
  - Specify knowledge in detail/precision <u>appropriate</u> for various circumstances
- **Governing doctrine, definitions, or other knowledge, cannot be assured to be conflict-free, e.g.:**
  - Multiple sources of governing doctrine exist
    - Typically, no central authority resolves all conflict promptly
  - Truth depends on context
    - Yet context is rarely made fully explicit
- **Many broad realms are full of exceptions**
  - Policies, regulations, laws — and the workflows they drive
    - Multiple jurisdictions, organizations, contracts, origins
  - Learning and science. Updating. Debate.
    - May falsify previous hypotheses after observation or communication
  - Causal processes: changes to state, from interacting/multiple causes
  - Natural language (text interpretation): “there’s a gazillion special cases”

EECOMS Example of Conflicting Rules: Ordering Lead Time

- Vendor's rules that prescribe how buyer must place or modify an order:
- A) 14 days ahead if the buyer is a qualified customer.
- B) 30 days ahead if the ordered item is a minor part.
- C) 2 days ahead if the ordered item's item-type is backlogged at the vendor, the order is a modification to reduce the quantity of the item, and the buyer is a qualified customer.
- D) 45 days ahead if the buyer is a walk-in customer.

- Suppose more than one of the above applies to the current order? **Conflict!**
- Helpful Approach: **<u>precedence</u>** between the rules.
  - E.g., D is a catch-case: A > D , B > D , C > D
- Often only *partial* order of precedence is justified.
  - E.g., C > A , but no precedence wrt B vs. A, nor wrt C vs. B.

Ordering Lead Time Example in LP with Courteous Defaults

```
@prefCust   orderModifNotice(?Order,14days)   :-
        preferredCustomerOf(?Buyer,SupplierCo),   purchaseOrder(?Order,?Buyer,SellerCo) .
@smallStuff   orderModifNotice(?Order,30days)  :-
        minorPart(?Buyer,?Seller,?Order),   purchaseOrder(?Order,?Buyer,SupplierCo) .
@reduceTight   orderModifNotice(?Order,2days)   :-
        preferredCustomerOf(?Buyer,SupplierCo) and
        orderModifType(?Order,reduce) and
        orderItemIsInBacklog(?Order) and
        purchaseOrder(?Order,?Buyer,SupplierCo) .
\overrides(reduceTight,  prefCust) .    // reduceTight has higher priority than prefCust
// The below  exclusion constraint specifies that orderModifNotice is unique, for a given order.
\opposes(orderModifNotice(?Order,?X), orderModifNotice(?Order,?Y))   :-   ?X != ?Y .
```

- Rule D, and prioritization about it, were omitted above for sake of brevity.
- Above rules are represented in Logic Programs KR, using the Courteous defaults feature
- Notation:
  - ":-" means "if". "@…" declares a rule tag. "?" prefixes a logical variable.
    "\overrides" predicate specifies prioritization ordering.
    An exclusion constraint specifies what constitutes a conflict.
    "!=" means ≠ .

Example: Ontology Translation, leveraging hilog and exceptions

/* Company BB reports operating earnings using R&D operating cost which includes price of a small company acquired for its intellectual property. Organization GG wants to view operating cost more conventionally which excludes that acquisition amount. We use rules to specify the contextual ontological mapping. */

```
@{normallyBringOver}  ?categ(GG)(?item)  :- ?categ(BB)(?item).
@{acquisitionsAreNotOperating}   neg ?categ(GG)(?item) :-
     acquisition(GG)(?item) and (?categ(GG) :: operating(GG)).
\overrides(acquisitionsAreNotOperating, normallyBringOver).  /* exceptional */
acquisition(GG)(?item) :- price_of_acquired_R_and_D_companies(BB)(?item).
R_and_D_salaries(BB)(p1001).   p1001[amount -> $25,000,000].
R_and_D_overhead(BB)(p1002).   p1002[amount -> $15,000,000].
price_of_acquired_R_and_D_companies(BB)(p1003).   p1003[amount -> $30,000,000].
R_and_D_operating_cost(BB)(p1003).  /* BB counts the acquisition price item in this category */
R_and_D_operating_cost(GG) :: operating(GG).
Total(R_and_D_operating_cost)(BB)[amount -> $70,000,000].  /* rolled up by BB cf. BB's definitions */
Total(R_and_D_operating_cost)(GG)[amount -> ?x] :- … .  /* roll up the items for GG cf. GG's definitions */
```

As desired: |= R_and_D_salaries(GG)(p1001)

|= neg R_and_D_operating_cost(GG)(p1003) /* GG doesn't count it */

|= Total(R_and_D_operating_cost)(GG)[amount -> $40,000,000]

Notation: @{…} declares a rule tag. ? prefixes a variable. :- means if. X :: Y means X is a subclass of Y. \overrides(X,Y) means X is higher priority than Y.

Ex.'s: Causal Chains & Change in Biology

- **The change of state effected by process causality requires defeasibility in KR**
  - A cause's effect is an exception to the persistence of previous state
  - When two causes interfere, one's effect is an exception to the other's effect
- **Causal process reasoning is a large portion of AP Biology, often requiring multi-step causal chains and/or multiple grain sizes of description to answer a question**
- **E.g., Rulelog was piloted on such causal process reasoning in biology using SILK**
- **Hypothetical question about causal interference in an experiment:**
  1. "A researcher treats cells with a chemical that prevents DNA synthesis from starting.
  2. This treatment traps the cells in which part of the cell cycle?"

  Answer: G1 [which is a sub-phase of interphase]
- **Counterfactual hypothetical question:**
  1. " Suppose the typical number of chromosomes in a human liver cell was 12. [It's actually 46.]
  2. How many chromosomes would there be in a human sperm cell?"

  Answer: 6. [I.e., half the number in the liver and most organs.]

Priorities are available and useful

- Priority information is naturally available and useful. E.g.,
  - recency: higher priority for more recent updates
  - specificity: higher priority for more specific cases (e.g., exceptional cases, sub-cases, inheritance)
  - causality: higher priority for causal effects (direct or indirect) of actions than for inertial persistence of state ("frame problem")
  - authority: higher priority for more authoritative sources (e.g., legal regulations, organizational imperatives)
  - reliability: higher priority for more reliable sources (e.g., security certificates, via-delegation, assumptions, observational data).
  - closed world: lowest priority for catch-cases
- Many practical rule systems employ priorities of some kind, often implicit. E.g.,
  - rule sequencing in Prolog and production rules
    - Courteous LP subsumes this as a special case (totally-ordered priorities)
    - Also Courteous LP enables: merging, more flexible & principled treatment

Semantic KR Approaches to Prioritized LP

The currently most important for Semantic Web are:

1. [Courteous LP]
    - KR extension to normal LP
    - In RuleML, since 2001; in LegalRuleML, since 2012
    - Commercially implemented and applied
        - IBM CommonRules, since 1999
2. Defeasible Logic
    - Closely related to Courteous LP
        - Less general wrt typical patterns of prioritized conflict handling needed in e-business applications
        - In progress: theoretical unification with Courteous LP [Wan, Kifer, Grosof RR-2010]

Argumentation Theories approach to Defaults in LP

- **Combines Courteous + Hilog, and generalizes**
- **New approach to defaults: "argumentation theories"**
  - Meta-rules, in the LP itself, that specify when rules ought to be defeated
  - [Wan, Grosof, Kifer, *et al*. ICLP-2009; RR-2010]
- **Extends straightforwardly to combine with other key features**
  - E.g., Frame syntax, external Actions, Omniformity, …
- **Significant other improvements on previous Courteous**
  - Eliminates a complex transformation
  - Much simpler to implement
    - 20-30 background rules instead of 1000's of lines of code
  - Much faster when updating the premises
  - More flexible control of edge-case behaviors
  - Much simpler to analyze theoretically

Argumentation Theories approach, Continued*

- **More Advantages**
  - 1st way to generalize defeasible LP, notably Courteous, to HiLog higher-order and F-Logic frames
  - Well-developed model theory, reducible to normal LP
  - Reducibility results
  - Well-behavior results, e.g., guarantees of consistency
  - Unifies almost all previous defeasible LP approaches
    - Each reformulated as an argumentation theory
    - E.g., Defeasible Logic (see Wan, Kifer, and Grosof RR-2010 paper)
  - Cleaner, more flexible and extensible semantics
    - Enables smooth and powerful integration of features
    - Applies both to well founded LP (WFS) and to Answer Set Programs (ASP)
  - Leverages most previous LP algorithms & optimizations

- **Implemented** in Flora-2; used in SILK and Coherent Knowledge Systems

* Original name: LPDA = LP with Defaults and Argumentation Theories

For More Info

- See the ff. longer AAAI-13 Rules tutorial, available at http://coherentknowledge.com/publications :
  - Benjamin Grosof, Michael Kifer, and Mike Dean. Semantic Web Rules: Fundamentals, Applications, and Standards (abstract). Conference Tutorial (Slides for 4-hour tutorial), 27th AAAI Conference on Artificial Intelligence (AAAI-13), Bellevue, Washington, July 15, 2013.
  - This is the latest iteration of a tutorial that since 2004 has been presented at numerous scientific conferences on web, semantic web, and AI.
  - A book is in early stages of preparation based on this tutorial.

- For Survey of KR's: also see 10/24/2013 session of Ontolog Forum
- For Rulelog overview: also see 6/20/2013 session of Ontolog Forum
- For Restraint: see [Grosof & Swift, AAAI-13] and [Andersen et al, RuleML-2013 and similar WLPE-2013] (all available at http://coherentknowledge.com/publications)

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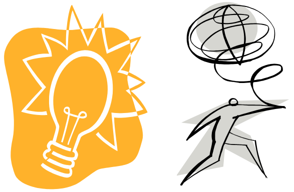

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OPTIONAL SLIDES FOLLOW

Declarative Logic Programs (LP) is the Core KR today

- **LP is the core KR of structured knowledge management today**
  - **Databases**
    - Relational, semi-structured, RDF, XML, object-oriented
    - SQL, SPARQL, XQuery
    - Each fact, query, and view is essentially a rule
  - **Business Rules – the commercially dominant kinds** (production/ECA rules, Prolog)
  - **Semantic Rules**
    - RuleML standards design, incl. SWRL. The main basis for RIF.
    - W3C Rule Interchange Format (RIF): -BLD, -Core. E.g., Jena tool.
  - **Extension: Rulelog.** E.g., Coherent's tool.
  - **Semantic Ontologies**
    - W3C RDF(S)
    - W3C OWL-RL (= the Rules subset). E.g., Oracle's tool for OWL.
  - **Overall: LP is "the 99%", classical logic is "the 1%"**

- **Relational DB's were the first successful semantic technology**
  - LP is the KR/logic that was invented to formalize them
- **The Semantic Web today is mainly based on LP KR** … and thus essentially equivalent to semantic rules
  - **You might not have realized that!**

Declarative *Logic Programs (LP) – Family of KR's*

- Normal LP
  - Rule syntax: $H \leftarrow B_1 \wedge \ldots \wedge B_k \wedge$ naf $B_{k+1} \wedge \ldots \wedge$ naf B_m . $(m \geq 0)$
    - H and Bi's are atoms.
    - $\leftarrow$ is a kind of implication that lacks contraposition.
      Its lhs and rhs are called the rule's "head" and "body", respectively.
    - naf ("negation-as-failure") is a kind of negation that is logically non-monotonic. Intuitively, naf Bi means "not believe Bi".
  - Semantics (well-founded) is defined constructively via an iterated fixed point.
    - It has 3 truth values: *true*; *false* in the naf sense; and an intermediate "*undefined*", which can represent paradoxicality.

HiLog

- A higher-order extension of predicate logic, which has a tractable first-order syntax
  - Allows certain forms of logically clean, yet tractable, meta-programming
  - Syntactically appears to be higher-order, but semantically is first-order and tractable
- Used in ISO Common Logic to syntactically extend FOL
  - Also appears promising for OWL Full and its use of RDF [Kifer; Hayes]
- Implemented in Flora-2 and SILK
  - Also partially exists in XSB, others
- [Chen, Kifer, Warren, "HiLog: A Foundation for Higher-Order Logic Programming", J. of Logic Programming, 1993]

Courteous LP: Advantages

- Facilitate updating and merging, modularity and locality in specification.
- Expressive: strong negation, partially-ordered prioritization, reasoning to infer prioritization.
- Guarantee consistent, unique set of conclusions.
  - E.g., never conclude both p and ¬p, nor that discount is both 5% and that it is 10%.
- Scalable & Efficient: low computational overhead beyond ordinary LPs.
  - Tractable given reasonable restrictions (VB + function-free):
    - extra cost is equivalent to increasing v to (v+2) in normal LP, worst-case.
  - By contrast, more expressive prioritized rule representations (e.g., Prioritized Default Logic) add NP-hard overhead.
- Modular software engineering:
  - Transform into normal LP, via argumentation theory approach

Ubiquity of Priorities
in Commercially Important Rules -- and Ontologies

- Updating in relational databases
  - more recent fact *overrides* less recent fact
- Static rule ordering in Prolog
  - rule earlier in file *overrides* rule later in file
- Dynamic rule ordering in production rule systems (OPS5)
  - "meta-"rules can specify agenda of rule-firing sequence
- Event-Condition-Action rule systems rule ordering
  - often static or dynamic, in manner above
- Exceptions in default inheritance in object-oriented/frame systems
  - subclass's property value *overrides* superclass's property value, e.g., method redefinitions
- All lack Declarative KR Semantics

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