Hypermonotonic Reasoning: Unifying Nonmonotonic Logic Programs with First Order Logic

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Outline

A New Fundamental Approach to Unifying

- 1. Nonmonotonic Logic Programs (LP)

…with…

- 2. First Order Logic (FOL)

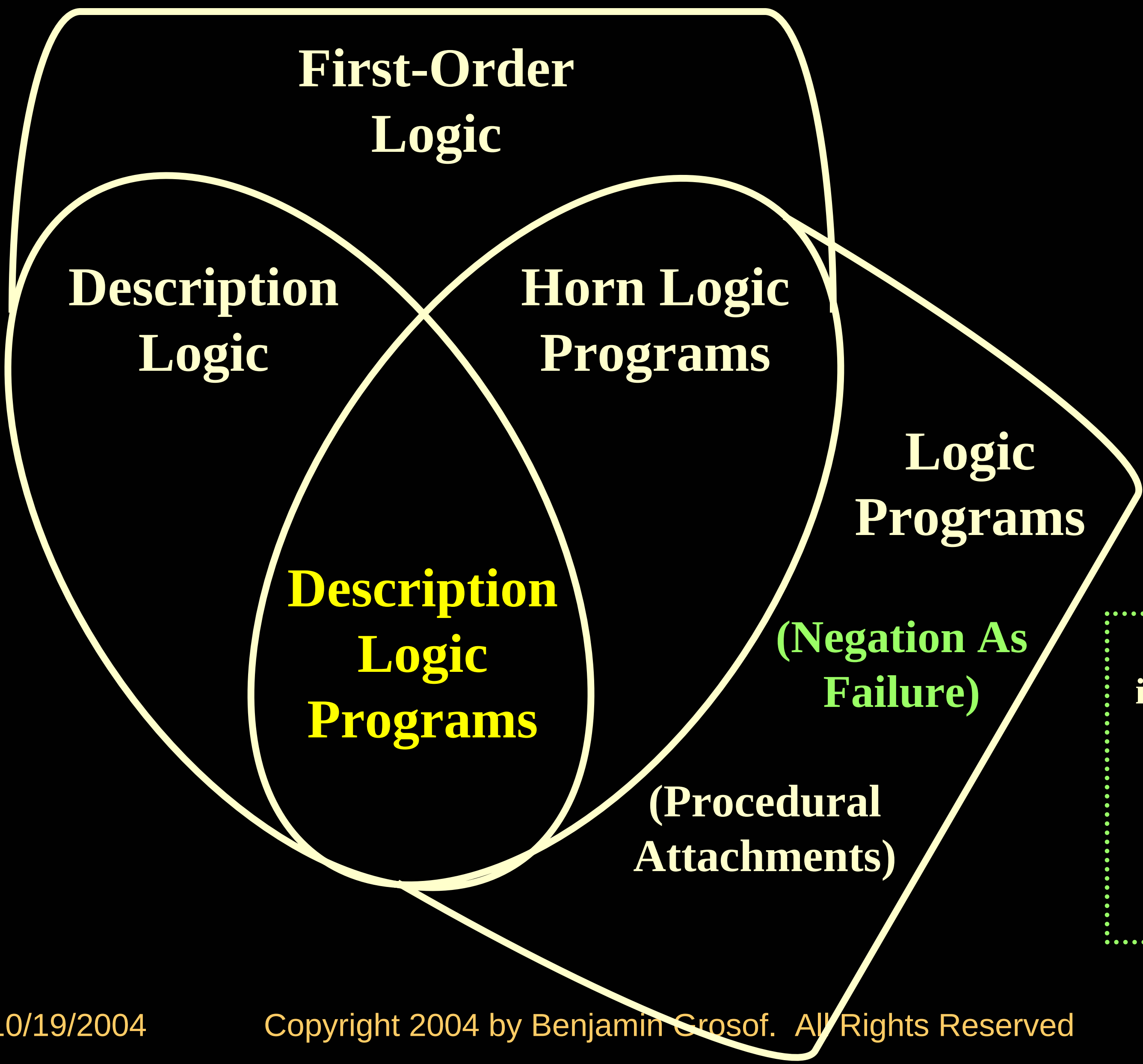
- Motivations
- Concept of Hypermonotonicity
- Results on: Nonmon LP as Incomplete FOL
  - Approach: Reformulate Nonmon LP as Hypermonotonic
- Discussion and Research Directions

Aspiration: Unifying FOL and Nonmon LP

- A challenge, a holy grail:
  - Wouldn't it be nice to have a single Knowledge Representation (KR) that unifies all of FOL and nonmon LP?
  - … or at least more of FOL and nonmon LP?

- Physics analogy: "A unified field theory for Semantic Web KR"

Venn Diagram: Expressive Overlaps among KR's



NB: Nonmon LP, including Courteous, relies on NAF as fundamental underlying KR expressive mechanism

Motivations I: Some Potential Uses for
Unifying FOL and Nonmon LP KR's for Rules+Ontologies

- Tightly integrate full OWL ontologies (OWL-DL and OWL-Full) with nonmon LP rules. Increase expressiveness of DLP to all of OWL.
  - Semantics; algorithms; ensure consistency
- Cope robustly with conflict between ontologies, e.g., merging OWL ontologies from many sources
- Permit FOL for ontologies beyond DL/OWL
  - E.g., process models cf. NIST's PSL standard and Semantic Web Services Initiative's SWSL emerging standards proposal (http://www.swsi.org)
  - E.g., ECOIN work on equational ontologies and context integration (http://context2.mit.edu/coin)
- Integrate nonmon frame/OO ontologies with mon DL/FOL ontologies

Motivations II: Some Potential Uses for

Unifying FOL and Nonmon LP KR's for Rules+Ontologies

- Integrate SWSL's 2 "wings":
  - LP rules language & service-concept ontologies for contracts, policies, ads, mappings, etc. (SCAMP tasks)
  - FOL language & service-concept ontologies for process model, synthesizing composition, verification, etc. (e.g., cf. PSL)
    - Actually also desire default reasoning to minimize ramifications in reasoning about actions (e.g., cf. Golog)

- Unify the KR foundation of the Semantic Web
  - Represent all the current* major pieces:
    - Rules, ontologies, databases, RDF, queries
    - Semantic Web Services   service descriptions
  - Overcome what has been a major hang-up for Joint Committee and Semantic Web Services Initiative efforts on SW standards design.

(*NB: SW in future should also include probabilistic/statistical KR.)

Logical Hypermonotonicity

The following is current work (paper is in progress).

- New Definition: logical hypermonotonicity:
- A KR S is "hypermonotonic", wrt monotonic KR B, when:
  1. S is nonmonotonic
  2. Each premise (respectively, conclusion) expression in S can also be viewed* as a premise (respectively, conclusion) expression in B.
  3. S is sound wrt B, but (in general) incomplete wrt B
     - I.e., Let X stand for a set of premises, Conc(X,Y) stand for the set of conclusions that are entailed in KR Y by the set of premises X. Then:
       - Forall P. Conc(P,S) $\subseteq$ Conc(P,B) but not vice versa

- More Details:
  - A KR Y is defined as a triple (LP, LC, $\Rightarrow$), where LP is a formal language of sets of premises (i.e., premise expressions), LC is a formal language of sets of conclusions (i.e., conclusion expressions), and $\Rightarrow$ is the entailment relation. We assume here that $\Rightarrow$ is a functional relation.
  - *More generally, one can generalize to have a mapping T from the premises/conclusions of S to the premises/conclusions of B.

Hypermon: Discussion of Definition

- Hypermon is a restricted case of nonmon, in which the nonmon KR's entailed conclusions can be viewed as always unobjectionable, i.e., sanctioned, by an associated mon KR that provides a background "reference" semantics for the premises in the nonmon KR.

- *By contrast, in the previously typical perspective on nonmon, the nonmon reasoning is viewed as unsound, i.e., it goes beyond what the mon semantics sanctions, e.g., as a way to handle "incompleteness" of the (mon semantics of the) available premise info.*

Hypermon: Discussion of Definition, cont.'d

- The spirit of conflict handling is a good match to the hypermon concept. E.g., suppose B is FOL.
  - When P is inconsistent according to FOL, then it's arguably often quite desirable that S is incomplete wrt FOL, since FOL produces a global meltdown in which all sentences are entailed.
  - Even if P is consistent according to FOL, then it's "not so bad" that S is incomplete. In practical inferencing over FOL, since that is computationally and/or algorithmically complex, incompleteness is often acceptable. I.e., many practical FOL tools are (in general) incomplete.
    - The hypermon KR can be viewed as a semantically characterized class of incomplete FOL reasoning tools.

Nonmon LP as Hypermon wrt FOL

Caveat: The following results are in preliminary and summary form.

- Let OLP stand for Ordinary LP (a.k.a. Normal LP, a.k.a. "General" LP), and CLP stand for Courteous LP.
- We assume here the semantics of OLP and CLP is based on the Well Founded Semantics. (NB: this assumption can be generalized.) A conclusion is entailed iff it has truth value *t* in the WFS.
- Obs.: OLP is unsound wrt FOL, if NAF is mapped to classical negation. I.e., Closed World is required as an extra assumption, essentially. Thus OLP is not (directly) hypermon wrt FOL. (NB: If instead NAF is not viewed as a classically interpretable expressive construct, then also OLP is not hypermon wrt FOL.)

Nonmon LP as Hypermon wrt FOL, cont.'d

- However, with some cleverness and the use of Courteous LP, we can establish a hypermon relationship of nonmon LP to FOL. This relationship will actually encompass both OLP and CLP.
- Let CLP2 stand for NAF-free Courteous LP, i.e., CLP restricted to prohibit (explicit) NAF. (NB: CLP2 does include the classical negation operator $\neg$, however.)
- CLP2 has a straightforward very simple mapping (T) to FOL: each rule is viewed as a clause in FOL; likewise, each mutex (mutual exclusion integrity constraint).
- Theorem: CLP2 is hypermon wrt FOL.

Nonmon LP as Hypermon wrt FOL, cont.'d more

- Theorem: OLP is expressively reducible to CLP2 via a relatively simple transformation TM on the premises.

  The transformation TM is local and linear-time. E.g.*, let TM be defined as:

  1. Replace every NAF'd atom ~p(t) by fp(t). Here, p is a predicate, t is a tuple of terms of appropriate arity for p, ~ is the NAF operator, and fp is a newly introduced predicate.
  2. Add the two rules:
     a. fp(t) $\leftarrow$.
     b. $\neg$fp(t) $\leftarrow$ p(t). Here $\neg$ is the classical negation operator.

  *There are multiple similar alternative such transformations.
- Theorem: CLP is expressively reducible to CLP2, in like fashion.
- Theorem: OLP and CLP are thus hypermon wrt FOL, under mapping TM (i.e., "indirectly") .

Nonmon LP as Hypermon wrt FOL, *cont.'d more*

- Theorem: CLP is always consistent from the viewpoint of FOL. (I.e., it has a consistent set of conclusions.)
- Can thus view conflictful merging/updating in CLP2 as sound, consistent, and incomplete from FOL viewpoint.
- The fundamental KR relationships can be used in more ways too:
  - Import FOL axioms (e.g., ontologies) to become (nonmon) LP rules, mutex's
    - As LP premises
      - E.g., as initial rules or as dynamically sensed facts
  - Export (nonmon) LP conclusions as facts to become FOL axioms

Nonmon LP as Hypermon wrt FOL, *cont.'d yet more*

- Provides path to formally define and investigate:
  - Merging of LP KB's with FOL KB's, in terms of conclusions or premises, when conflict is absent or present.

- *Further Results in Development, e.g.:*
  - Special cases when (nonmon) LP is consistent, or its updates are monotonic, wrt a given FOL or LP sub-theory/background-theory.
    - E.g., $\exists x.q(x)$ in FOL is consistent with CLP in which all rules with q in head mention q positively.
  - Other interesting hypermonotonic KR's:
    - Identify previous ones; tweak or design new ones
  - Extend fundamental CLP expressiveness.

Meaning of the Name: Inspiration behind "Hyper"

Naming inspirations for why call CLP2 "hyper"monotonic:

1. Fun … and hopefully catchy too ☺
2. Available: hardly appears in previous literature.
3. Analogy: jumping through hyperspace
   a. Similar to "hyper"link or "hyper"text
   b. Overcomes the apparent barrier/limitation of how inconsistency behaves (global fragilility/propagation) in classical logic. "Tunnels through a wormhole" to a consistent, typically contentful, set of conclusions (with localized propagation scope for unresolved conflicts). Enters a regime with different characteristics – monotonic relative to the FOL semantics, but nonmonotonic wrt updates within the LP semantics. Transcends the previous category boundary of monotonicity vs. nonmonotonicity.
      – In science-fiction (and in tachyon physics), traveling through hyperspace overcomes the apparent barrier/limitation of how speed behaves (bounded by speed of light) in normal space-time. Enters a regime with different characteristics – respects the behavior of normal space-time but moves information/matter/energy faster in its own regime. Transcends the previous category boundary framed by relativity theory.

Broader High-Level Research Objectives

-- forms a Discussion Agenda

Core SW/KR Research Challenges on Combining Rules with Ontologies

- Integrating rules with ontologies
  - Rules refer to ontologies (e.g., in RuleML)
  - Rules to specify ontologies (e.g., Description Logic Programs)
  - Rules to map between ontologies (e.g., ECOIN)
  - Combined rules + ontologies knowledge bases (e.g., RuleML + OWL)

- Describing business processes & web services via rules + ontologies
  - Capture object-oriented process ontologies
    - Default inheritance via rules (e.g., Courteous Inheritance)
    - Develop open source knowledge bases (e.g., MIT Open Process Handbook Initiative)
    - Rules in process models, e.g., cf. OWL-S, PSL

Summary of Objectives Motivating SweetRules and Hypermon: Integrating Distributed Rules and Ontologies

Address "the 5 D's" of real-world reasoning ⇒ *desired improvements*:

1. **D**iversity – Existing/emerging kinds of ontologies and rules have heterogeneous KR's. *Handle more heterogeneous systems.*
2. **D**istributedness - of ownership/control of ontology/rule active KB's. *Handle more source active KB's.*
3. **D**isagreement - Conflict (contradiction) will arise when merging knowledge. *Handle more conflicts.*
4. **D**ynamism - Updates to knowledge occur frequently, overturning previous beliefs. *Handle higher rate of revisions.*
5. **D**elay - Computational scaleability is vital to achieve the promise of knowledge integration. *Achieve Polynomial-time (~ databases).*

Summary of Objectives Motivating SweetRules and Hypermon:

Integrating Distributed Rules and Ontologies, cont.'d

BEFORE

AFTER

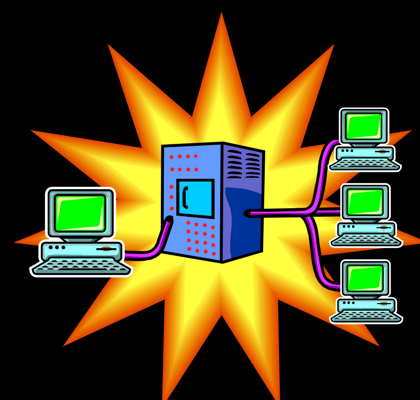
Contradictory conflict is globally contagious, invalidates all results.

⇒

Contradictory conflict is contained locally, indeed tamed to aid modularity.

Knowledge integration tackling the 5 D's (esp. diversity and distributedness) is labor-intensive, slow, costly.

⇒



Knowledge integration is highly automated, faster, cheaper.