Radial Restraint: A Semantically Clean Approach to Bounded Rationality for Logic Programs†

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Paper presentation (15-min.) and also poster presentation
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‡ http://www.aaai.org/Conferences/AAAI/aaai13.php

Overview

- Motivation: extend databases to richer/meta* knowledge
  - →→ Need logical functions in LP
  - LP = declarative logic programs: the logic of SQL and pure Prolog
- Problem: functions create potential for runaway computation
  - Fundamental in semantics: potentially infinite set of answers to a query
  - Example: num(0). num(succ(?x)) :- num(?x). Query ?- num(?y).
    Answers for ?y: 0, succ(0), succ(succ(0)), succ(succ(succ(0))), …
- New Approach: radial restraint – a form of bounded rationality
  - Specify a bound on normed depth of terms that are reasoned about
  - Extend reasoning procedure (SLG) with term abstraction. Incurs low overhead.
- Leverages "*undefined*" truth value to represent "not bothering"
  - The other 2 truth values are *true* and *false* (cf. negation-as-failure)
  - Extends LP's well-founded semantics where *undefined* is used for paradoxicality
  - Sound, even when reasoning is non-monotonic
- Provides "valves" to ensure computational scalability
- Fully semantic, enabling social scalability

* For more info, see [Grosof et al, AAAI-13 Semantic Web Rules Tutorial] – largely about Rulelog

Paper Abstract (same as in Proceedings)

- Declarative logic programs (LP) based on the well-founded semantics (WFS) are widely used for knowledge representation (KR).
- Logical functions are desirable expressively in KR,
  but when present make LP inferencing become undecidable.
- In this paper, we present radial restraint: a novel approach to bounded rationality in LP.
- Radial restraint is parameterized by a norm that measures the syntactic complexity of a term, along with an abstraction function based on that norm.
- When a term exceeds a bound for the norm, the term is assigned the WFS's third truth-value of undefined.
- If the norm is finitary, radial restraint guarantees finiteness of models and decidability of inferencing, even when logical functions are present.
- It further guarantees soundness, even when non-monotonicity is present.
- We give a fixed-point semantics for radially restrained well-founded models which soundly approximate well-founded models.
- We also show how to perform correct inferencing relative to such models, via
  SLGABS, an extension of tabled SLG resolution that uses norm-based abstraction functions.
- Finally we discuss how SLGABS is implemented in the engine of XSB Prolog, and scales to knowledge bases with more than 10^8 rules and facts.

Motivations I

- LP is the logic of databases (SQL, SPARQL, XQuery) and pure Prolog
  - Also it's the logic of:
    - Production/event-condition-action business rules (the declarative fragment)
      - $ multi-billion industry
    - Rule-based basic semantic web ontologies: RDF-Schema, OWL-RL
  - LP – not FOL – is "the 99%" of practical structured info management today
  - (LP = declarative logic programs)

- The practically-used fragment of LP is primarily function-free
  - All the above except pure Prolog are essentially limited to function-free
  - (Function here means function symbol of arity > 0)

Motivations II

- Want richer expressively, yet also scalable
  - Richness to represent natural language, science, policy (incl. contracts, regulation, law), info integration mappings, meta-knowledge, etc.
    - E.g., cf. Rulelog*, which extends LP
  - Scalability includes:
    - Computational, e.g., tractability (worst-case polynomial time)
    - Social, for authoring/consumption by wide set of organizations/people

- Functions are needed for such higher-abstraction KR/KA
  - Skolemization for existential knowledge
  - Hilog for meta knowledge, e.g., defeasibility and textual logic*
  - (Higher-abstraction means higher level of conceptual abstraction)
  - (KR = Knowledge Representation & reasoning)
  - (KA = Knowledge Acquisition)

* For more info, see [Grosof et al, AAAI-13 Semantic Web Rules Tutorial]

Problem of Runaway

- Problem: functions create potential for runaway computation
  - Due to recursion through functions
  - Fundamental in semantics: potentially infinite set of answers to a query
  - Leads to undecidability of inferencing

- Example: numberline
  - Assert
    - number(0).
    - number((s(?x)) :- number(?x). // s is a function, mnemonic for “successor”
      // “?” prefixes a variable. “:-” can be read as “if”.
  - Query ?- num(?y).
  - Set of answers is infinite: 0, s(0), s(s(0)), s(s(s(0))), …

- FOL (first order logic) suffers from this potential for runaway, too

Past Workaround

- Technique often used in practice to stop runaway, e.g., in Prolog:
  - Cut off inferencing when bound on term nestedness depth is exceeded
  - Assign *false* (naf) truth value beyond that

- Drawbacks
  - Not semantic: One configuration of one instance of one implementation
  - Not sound, when knowledge/reasoning is non-monotonic (e.g., defeasible)

New Approach: Radial Restraint

- A form of bounded rationality
  - Specify a bound on normed depth of terms that are reasoned about
  - Intuition: Provides “valves” to ensure computational scalability
- Leverages “*undefined*” truth value to represent “not bothering”
  - The other 2 truth values are *true* and *false* (cf. negation-as-failure)
  - Extends LP’s well-founded semantics (WFS) which has *undefined*
- Stops runaway
- Ensures soundness, even when reasoning is non-monotonic
- Fully semantic, enabling social scalability

- Approach includes semantics, extending the WFS
- Previous usage for *undefined* in WFS is to represent paradoxicality
  - Such paradoxicality can arise from cyclic dependency through naf (a.k.a. “unstratified” naf)
  - Intuition: oscillatory instability is treated as meta-stable
  - Example 1: p :- naf p.
  - Example 2: p :- naf q. q :- naf p.

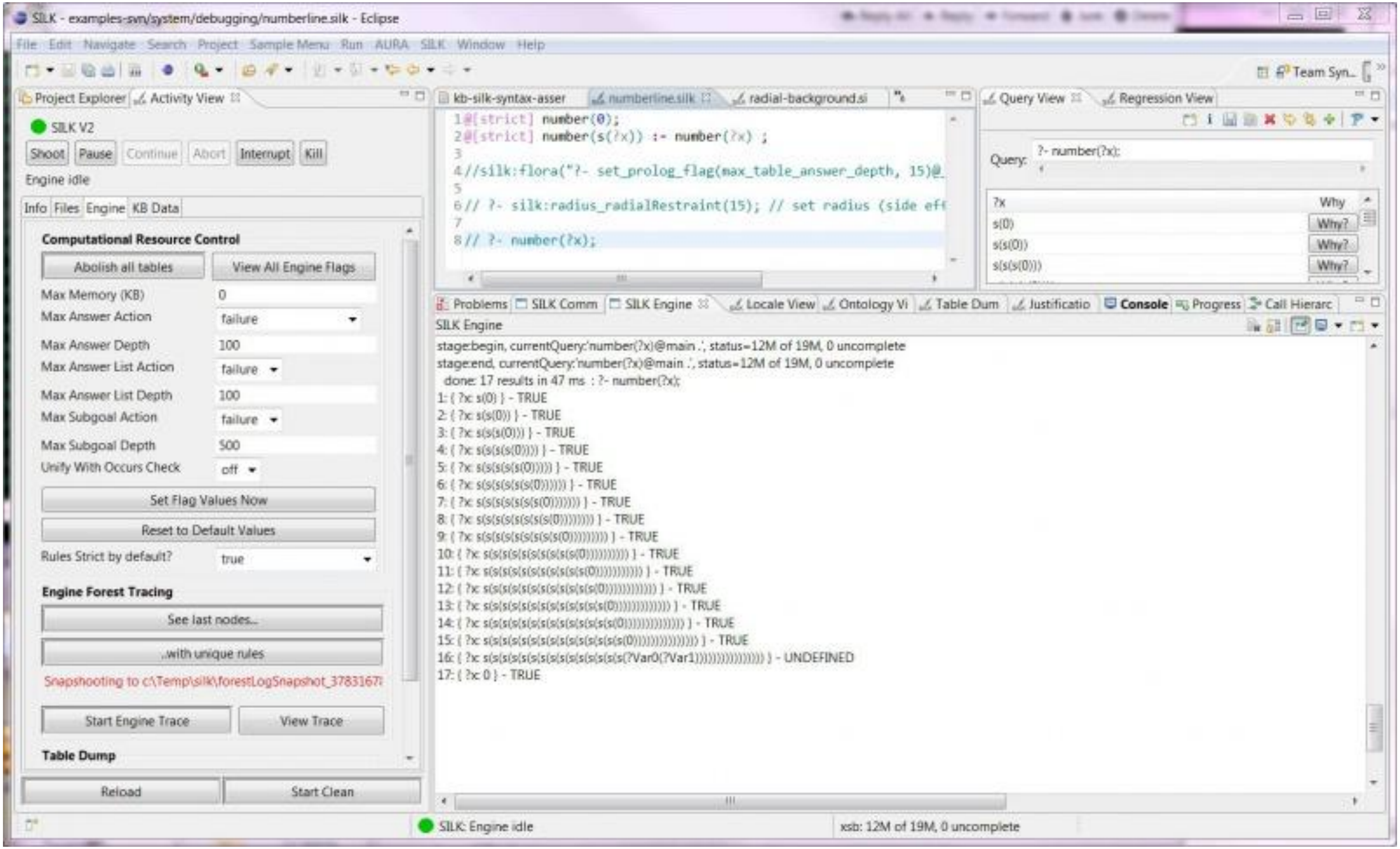
Details of Technical Approach

- Develop a technical approach based on term abstraction
- In term abstraction: replace a subterm by a (fresh) variable
- View Herbrand universe/base as a tree of (ground) terms
- Beyond the radial frontier in that tree, everything goes misty, i.e., *undefined*
- Radius bounds a norm on terms
- The norm can be size, nestedness, or more complex

- I.e., one sacrifices (normed) term depth of reasoning beyond what's anticipated as relevant

- Ensures finiteness, decidability

Example: Numberline, revisited



- Here, radius is 15.

Screenshot is from UI in Vulcan Inc.'s SILK system.

Proof theory and Implementation

- Approach includes full proof theory
  - Extends SLG resolution → SLGABS
  - SLG is state-of-art LP inferencing procedure which uses "tabling"
  - Tabling = query-driven but saves/reuses work on subgoals
    - Mixes backward and forward inferencing

- Implemented in XSB: LP system that supports logical functions and well founded semantics, with excellent completeness
  - Open source

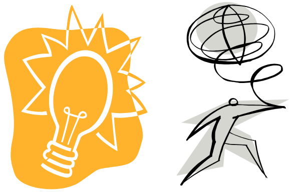
- Scales to knowledge bases with over 100 Million rules and facts

- Incurs low overhead (computationally)
  - Compared to SLG without radial restraint

Follow-on, Ongoing, and Future Work

- Analyze how ensures tractability not just decidability
  - "Dial-your-own" polynomial degree (radius choice is the dial)
- More kinds of restraint: "skipping", unsafety, unreturn, anytime
  - See [Anderson et al: RuleML-2013 (best demo award); WLPE-2013]
    - About advanced knowledge base debugging in Rulelog
  - Meta power (expressively) of Rulelog enables the bounded rationality to be specified declaratively within the logic/KR (language) itself
- Extend to other logics, incl. classical
- Opens a field – theoretical and empirical – of finding conditions for restraint that are useful
- Perspective: meta power in reasoning → transcend the XOR trade-off between expressiveness versus decidability/tractability in KR

KR = Knowledge Representation



Thank You

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