SILK: Rules, Semantic Web, and Databases
Take a Leap in Scalable Logical Power

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For More Info: http://silk.semwebcentral.org
http://projecthalo.com

** http://www.meetup.com/Semantically-Webbed-Seattle-Meetup-Group

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Outline and Overview

• SILK research program within Vulcan’s Project Halo
  • Language and system for advanced knowledge representation (KR)
  • Digital Aristotle vision: question-answering for science
  • Scalability for social structured knowledge: entry, reuse, querying

• SILK Language, Hyper Logic Programs KR, and RIF-SILK
  • Expressive features: defaults, actions, higher-order, frames, webized, interchange
  • Advanced defaults: prioritized conflict handling, argumentation, omni-directional, tractability

• SILK System
  • Reasoning: layered architecture, transformations, tabling
  • Knowledge Acquisition (KA) and UI: interchange; editing, explanation

• Potential application areas in business and government
  • Horizontal: policies, workflows; ontology mapping, knowledge integration
  • Vertical: e-commerce, defense intelligence, trust, biomed, financial, mobile

• Demo of default rules in SILK GUI: edit, query, explain

• Conclusions
  • Higher-abstraction KR closer to human cognition and social pragmatics
  • Radically extends expressive power of SQL, RDF(S), SPARQL, OWL-RL, RIF-BLD
  • Remedies major limitations of semantic web’s current KR foundation
Vulcan’s Project Halo

• Vision of Digital Aristotle: question-answering for science
  • Put the bulk of the world’s scientific and similar knowledge on-line
  • Answer questions, act as personal tutor, with deep reasoning

• College-level science selected as initial domain focus
  • Good metrics available: textbook-type exam Q’s. Initial domain task focus is:
    • Advanced Placement Exam (AP) in Biology, Physics, and Chemistry
      • Taken by USA high-school students to get credit for 1st-year college courses

• AURA AI expert system developed (2004-)
  • Controlled Natural Language, GUI, Frame-based KR, Problem-Solving
  • Students as users – formulate questions, formulate knowledge

• Semantic MediaWiki+ developed (2007-)

• SILK developed (2008-)
  • Largest* rule research program in USA. Multi-institutional: primarily via contractors.
    • A knowledge representation (KR) language and system (with reasoner, UI, interchange)

* (that we’re aware of)
Aristotle Tutoring Alexander

SILK Contributors current/past (partial list)

- Vulcan (Benjamin Grosof, Mark Greaves, Dave Gunning)
- Stony Brook University (Michael Kifer; students H. Wan, S. Liang, P. Fodor)
- Raytheon BBN Technologies (Mike Dean, Mark Burstein, C. Andersen, B. Ferguson)
- SRI International (Vinay Chaudhri, David Martin, Ken Murray)
- Cycorp (Keith Goolsbey, Doug Lenat, Jon Curtis, Ben Rode)
- Automata (Paul Haley)
- Boeing (Peter Clark)
- Ontoprise GmbH (Daniel Hansch, Jurgen Angele)
- Terrance Swift, consultant
- Richard Fikes, consultant (Stanford University)
- University of Toronto (Sheila McIlraith, S. Sohrabi, H. Ghaderi)
- Texas Tech University (Michael Gelfond, D. Inclezan)
- University of Texas (Bruce Porter, Ken Barker)
- University of Amsterdam (Bert Bredeweg)
- University of Freiburg (Georg Lausen)
- University of Michigan (Michael Wellman)
- Raphael Volz, consultant
SILK’s Goals

• Address fundamental requirements for scaling Semantic Web to widely-authored Very Large KBs in business and science that answer questions, proactively supply info, and reason powerfully

• **Expressiveness + Semantics + Scalability**
  • Push the frontier. Language and system.

• **Better Knowledge Representation (KR)**
  • Expressive power: defeasibility, higher-order. E.g., causal processes in AP Biology.
  • Performance scalability of reasoning, including knowledge updates

• **More effective Knowledge Acquisition (KA)**
  + By Subject Matter Experts (SMEs), not programmers or knowledge engineers
  + Collaboratively – incorporate large #s of SMEs in KB construction & maintenance
    + Leveraging the Web

• **Better KR also for sake of better KA**
  • Web knowledge interchange (with merging) for scalability of collaborative KA
  • The underlying KR is the target for KA: “The KR is the deep UI”
    • Understandability via semantics and expressiveness
    • Raise abstraction level closer to the user’s natural language and cognition
Expressiveness “Brittleness” Areas Targeted

• Defaults/Exceptions/Defeasible *(incl. nonmonotonic reasoning, theory revision, argumentation, truth maintenance)*
  - A kinematics problem situation has standard earth gravity, and no air resistance. [physics AP]
  - A given organism has the anatomybehavior that is typicalnormal for its species, e.g., a bat has 2 wings and flies. [bio AP]
  - Price info for an airplane ticket on Alaska Air’s website is accurate and up to date. [e-shopping]
  - Practical reasoning almost always involves a potential for exceptions

• Hypotheticals
  - If Apollo astronaut Joe golfed a ball on the moon, then standard earth gravity would not apply. [negative hypothetical]
  - If I had swerved my car 5 seconds later than I did, I would have hit the debris in the left lane with my tire. [counterfactual]

• Actions and Causality
  - If a doorkey is incompletely inserted into the keyhole, turning the key will fail. [precondition]
  - During the mitotic stage of prometaphase, a cell’s nuclear envelope fragments [biology AP]
  - After a customer submits an order on the website, Amazon will email a confirmation and ship the item. [Event-Condition-Action (ECA) rule] [policy]

• Processes (i.e., representing and reasoning about processes)
  - Mitosis has five stages; its successful completion results in two cells. [compose] [partial description]
  - If Amazon learns that it will take an unexpectedly long time to stock an ordered item, then it emails the customer and offers to cancel the order without penalty. [exception handling]
  - A Stillco sensor-based negative feedback thermal regulator is adequate to ensure the overnight vat fermentation of the apple mash will proceed within desired bounds of the alcohol concentration parameter. [science-based business process]

Ubiquitous in science, commonsense, business, etc. All are interrelated.
Concept of KR

- A KR $S$ is defined as a triple $(LA, LC, |=)$, where:
  - $LA$ is a formal language of sets of assertions (i.e., premise expressions)
  - $LC$ is a formal language of sets of conclusions (i.e., conclusion expressions)
  - $|=\,$ is the entailment relation.
- $\text{Conc}(A,S)$ stands for the set of conclusions that are entailed in KR $S$ by a set of premises $A$
  - We assume here that Conc is a functional relation.
- Typically, e.g., in FOL and LP, entailment is defined formally in terms of models, i.e., truth assignments that satisfy the premises and meet other criteria.

Remark: In LP KR, $LC$ is not even a subset of $LA$!
Declarative Logic Programs (LP) is the Core KR in today’s world … including the Semantic Web

- 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
  - Semantic Rules
    - Rule Interchange Format (RIF): -BLD, -Core
    - RuleML standards design, including SWRL
  - Semantic Ontologies
    - RDF(S)
    - OWL-RL (= the Rules subset). E.g., Oracle’s implementation of OWL.

- The Semantic Web today is mainly based on LP KR
  - … and thus essentially equivalent to semantic rules
  - You might not have realized that!
SILK’s new KR: **Hyper** Logic Programs

- Extended LP that is the first to **combine** key advanced features
- **Defaults** + **Higher-Order** + **External Actions/Events/Queries**
- + Webized, Frames, (clean) Negation and NAF, Equality, Functions, Skolems, Aggregates, Integrity Constraints, Lloyd-Topor, …
- Tightly interoperates with very broad case of first order logic (FOL), too
  - Any clause, not just Horn. Sound from FOL viewpoint.
- **Transforms knowledge from higher to lower abstraction levels**
  - Higher is good for KA; lower is good for reasoning (code reuse, optimization)
- **Tractable computationally** – complexity is same as Horn LP
  - Polynomial time -- similar to relational DBMS -- if there’s no recursion thru functions
  - Retains pragmatic quality of LP: “intuitionistic” – lack general “reasoning by cases”
- **New approach to defaults**
  - *Argumentation theory*: ~20 “meta-” rules specify debate principles for defeat
  - Much more **expressive**: higher-order, equality, …
  - Much **easier to implement**: ~20 rules instead of 1000’s of lines of code
  - Much more **efficient**: eliminates expensive knowledge recompilation step
  - *Hyper rules*: omni-directional clauses, prioritized handling of multi-way conflicts
SILK’s KR Approach, continued

- **KR Language**
  - Syntax: ASCII presentation syntax, abstract syntax, RIF dialect (RIF-SILK)
  - Semantics: model theory, proof theory. Closely related to the transformations (above).

- **Knowledge Interchange**
  - Via load, or query, or event. E.g., embed a SPARQL query in the body of a rule.
  - KR languages: SPARQL, RDF(S), SQL, ODBC; SILK, RIF, OWL(-RL), Cyc, AURA

- **Reasoning system**
  - Backward inferencing primarily -- i.e., query answering
  - Tabling saves and reuses computation from previous subqueries
    - Supports fast updating and forward inferencing
  - Good efficiency/scalability of performance

- **Synergizes 20 years of LP research progress**
  - Courteous defaults and external actions/queries cf. IBM Common Rules, SweetRules
  - Higher-order cf. HiLog, Common Logic
  - Negation-As-Failure cf. well founded
  - Performance optimizations from DBMS, Prolog, BRMS, AI

- **Extensive requirements analysis, use cases, benchmarking**
Representational Uses for Defaults and Higher-Order

Defaults (cf. Courteous, with Prioritization)
- Negation
- Pragmatic knowledge/reasoning has potential for exceptions and revision
  - Learning and science: may falsify previous hypotheses after observation or communication
- Debate and trust: priorities from authority, reliability, recency
- Updating, merging, change: increase modularity/reuse in KA/KB lifecycle
- Process causality: persistence, indirect ramified effects, interference
- Hypotheticals, e.g., counterfactuals
- Inheritance: more-specific case overrides more-general case
- Policies, regulations, laws – the backbone of society and institutions
- Natural language understanding (NLU) aspects: e.g., co-reference

Higher-Order (cf. Hilog and reification)
- Meta- knowledge and meta- reasoning, generally
- Ontology mapping, KB translation, KR macros, reflection, NLU aspects
- Provenance, multi-agent belief, modals, many aspects of context
RIF-SILK Dialect

• **It’s expressively powerful RIF** (RIF = W3C Rule Interchange Format standard)
  • New dialect defined using RIF’s Framework for Logic Dialects (FLD)
  • Extends (supersumes) RIF-BLD (Basic Logic Dialect) and RIF-Core
    • These are based essentially on Horn LP
  • Notably: adds defaults and external actions (side-effectful)
    • Needed for most of today’s business applications of (non-semantic) rules
    • Retains “Grade AAA” semantics – model-theoretic
    • Retains computational scalability of Horn LP

• **Status**
    • Semantics section is in progress (summarizes previous theory papers)
  • Implemented translator (bidirectional) is in current SILK system
  • Under discussion with W3C: role in next steps of RIF overall
SHOW briefly: RIF-SILK Dialect specification document
Updated: 06-2010  Semantic Web “Stack”

**RIF** = Rule Interchange Format (W3C)
BLD = Basic Logic Dialect
FLD = Framework for Logic Dialects

**RL** = Rule Profile
= Horn FOL expressible
≈ Horn LP expressible
(i.e., DLP++)

Candidate designs for Rule extensions:
SILK, RuleML;
CL (Common Logic)

**SparQL**

**OWL RL**

**RDF Schema**

**RDF Core**

**XML**

**Namespaces**

**URI**

**Unicode**

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Modified from slide by W3C (just added annotation)
SILK Architecture today (V2.2)

- **API Functionality**
  - Higher-order defaults reasoning, combines many other advanced KR features
  - SILK and external KR language support integrated tightly with reasoning engine

- **UI Functionality**
  - Graphical, tabular
  - For Knowledge Engineers

- **Future Items**
  - **UI**: SME-friendlier, English (NL)
  - **KR**: probabilistic, parallelization, more interchange KRs

- **Test Sets Focus**
  - Defaults, Process
  - AP esp. Biology

**External Knowledge & Reasoners**

- KB #1 … KB #n
- Engine #1 Engine #m

**Flora-2 Engine**

- XSB (InterProlog and ODBC interfaces)

**KR Languages**

- SILK, RIF-SILK
- RIF-BLD, OWL-RL
- SPARQL, RDF(S)
- SQL, Cyc, AURA

**API (Java)**

- Language
  - Interoperability
  - Parsing & Serialization
  - Abstract Syntax

- Engine
  - Querying
  - Updating
  - Actions

**UI**

- Advanced
  - Authoring
  - Explanation

- Basic
  - Instant Message
  - Command Line

**Registry of component implementations**
Ecology Ex. of Causal Process Reasoning in SILK

/*   Toxic discharge into a river causes fish die-off.   */
/* Initial facts, and a constraint that fish count is unique */
@[strict] occupies(trout,Squamish);
@[strict] fishCount(0,Squamish,trout,400);   // first argument is an integer time
@[strict] neg (fishCount(?s,?r,?f,?C1) and fishCount(?s,?r,?f,?C2) )  <=  ?C1 != ?C2;
/* Action/event description that specifies causal change, i.e., effect on next state */
@[tag->tdf1] fishCount(?s+1,?r,?f,0)
    <=  occurs(?s,toxicDischarge,?r) and occupies(?f,?r);
/* Persistence (“frame”) axiom */
@[tag->pef1] fishCount(?s+1,?r,?f,?p) <=  fishCount(?s,?r,?f,?p);
/* Action effect axiom has higher priority than persistence axiom */
@[strict] silk:overrides(tdf1,pef1).
/* An action instance occurs */
@[id->UhOh, strict]  occurs(1,toxicDischarge,Squamish).

As desired:  |=  fishCount(1,Squamish,trout,400)
             |=  fishCount(2,Squamish,trout,0)

In Frame syntax:  subject[property -> object]  stands for  property(subject,object).
E-Commerce Ex. of Causal Process Reasoning

/* E-commerce delivery logistics. */
/* Initial fact, and constraint that location is unique */
@[strict] loc(0,PlasmaTV46,WH_LasVegasNV);  // first argument is an integer time
@[strict] neg(loc(?s,?item,?posn1) and loc(?s,?item,?posn2))  <=? posn1 != ?posn2;
/* Action/event description that specifies causal change, i.e., effect on next state */
@tag-mov loc(?s+1,?item,?addr) and neg loc(?s+1,?item,?warehouse)
    <= shipment(?s,?item,?warehouse,?addr) and loc(?s,?item,?warehouse);
/* Persistence ("frame") axioms about location */
@tag-peLoc loc(?s+1,?item,?posn) <= loc(?s,?item,?posn);
@tag-peLoc neg loc(?s+1,?item,?posn) <= neg loc(?s,?item,?posn);
/* Action effect axiom has higher priority than the persistence axioms */
silk:overrides(mov,peLoc)
/* An action instance occurs */
@[id-deliv57, strict] shipment(1, PlasmaTV46, WH_LasVegasNV, Nine_Fog_St_SeattleWA);

As desired:  |= loc(2, PlasmaTV46, Nine_Fog_St_SeattleWA);
    |= neg loc(2, PlasmaTV46, WH_LasVegasNV);

In Frame syntax:  subject[property -> object] stands for property(subject,object).
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.

Several such complex examples drawn from exams or textbooks have been successfully represented in SILK. E.g.:

- "A researcher treats cells with a chemical that prevents DNA synthesis from starting. This treatment traps the cells in which part of the cell cycle?"
The correct answer is: G1 [which is a sub-phase of interphase]

- "In some organisms, mitosis occurs without cytokinesis occurring. This will result in:
  a. cells with more than one nucleus
  b. cells that are unusually small.
  c. cells lacking nuclei.
  d. destruction of chromosomes.
  e. cell cycles lacking an S phase."
The correct answer is: a. [two nuclei form in a cell, but no new cell wall splits the cell]

- “Suppose the typical number of chromosomes in a human liver cell was 12. [Notice this is counterfactual; there are actually 46]. What would the typical number of chromosomes in a human sperm cell be?”
The correct answer is: 6 [half of the number in the liver and most other organs]
Trust Mgmt. Ex. of Higher-Order Defaults in SILK

illustrating also basic Knowledge-level Communication, and Frame syntax

In Frame syntax: subject[property -> object] stands for property(subject,object)

/* Trust policy administration by multiple agents, about user permissions */
/* Admin. Bob controls printing privileges including revocation (neg). */
Bob[controls -> print]. Bob[controls -> neg print]; /* neg print means it’s disallowed.*/
Cara[controls -> ?priv]; /* Cara is the most senior admin., so controls all privileges. */
/* If an administrator controls a privilege and states at a time (t) that a user has a privilege,
then the user is granted that privilege. Observe that ?priv is a higher-order variable. */
@[tag->grant(?t)] ?priv(?user) :- ?admin[states(?t) -> ?priv(?user)] and ?admin[controls(?priv)];
/* More recent statements have higher priority, in case of conflict. */
silk:overrides(grant(?t2), grant(?t1)) <=? t2 > ?t1 ;
/* Admin.’s Bob and Cara make conflicting statements over time about Art’s printing */
  Bob[states(2008) -> neg print(Art)] ;

As desired: |= neg print(Art) and webPage(Art).
  /* Currently, Art is permitted a webpage but not to print. */
Potential Applications in Business and Government

• Horizontal
  • Policies and policy-based workflows
    • Monitor, report, react, handle exceptions, execute, enforce, customize
    • Trust: confidentiality, authorization, compliance, governance
  • Ontology mapping/mediation and knowledge integration
    • Perspective: the mappings themselves constitute ontological knowledge. E.g., a dictionary.

• Vertical
  • E-commerce: shopping & advertising, contracts, customer care, catalogs
  • Defense: intelligence, operations
  • Financial: reporting, regulatory compliance
  • Biomed: pharma, e-science, clinical records and guidance, insurance
  • Mobile: personalize communication

• Many use cases in RIF, RuleML, SWSL documents & prototypes
  • E.g., employ defaults or other features not yet well supported commercially
DEMOS

• SHOW HERE: SemTech-2010 DEMO
  • Default rules in SILK GUI: edit, query, explain; exploiting omni-directionality
    • Business policies about ad placements in news

• Also: Demo’d at ISWC-2009 and RuleML-2009 conferences
  • Scenario of environmental watchdog group’s monitoring workflow
    • Recognize toxic discharge into Ohio River watershed from sharp decline in fish count
    • Alert news media, government agencies, citizens social network
  • Reactive: standing queries trigger external actions upon update events
  • Load imported RDF(S) and RIF-BLD
  • Externally query SPARQL, and Excel via ODBC
  • This demo won an award at RuleML-2009, essentially for best system

• Aim to make videos of demos and post on SILK website.
  • Some already there
Remedying FOL Semantics’ Lack of Scalability

- Hyper LP handles conflict robustly – get consistent conclusions
  - Whereas FOL is a “Bubble” – it’s **perfectly brittle semantically** in face of contradictions from quality problems or merging conflicts.
    - Any contradiction is totally contagious – the conclusions all become garbage

  E.g., OWL beyond the RL subset suffers this problem. So does Common Logic. (Technically, RIF-BLD and RDF(S) are defined via FOL semantics too, although their typical implementations are essentially LP.)

A KB with a million or billion axioms formed by merging from multiple Web sources, is unlikely to have **zero** KB/KA conflicts from:
  - Human knowledge entry/editing
  - Implicit context, cross-source ontology interpretation
  - Updating cross-source
  - Source trustworthiness

- **Hyper LP’s approach provides a critical advantage for KB scalability**
  - **semantically, as well as computationally**
FOL: A Bubble

Extreme sensitivity to conflict limits its scalability in # of axioms and # of merges

Left:
http://www.dailymail.co.uk/sciencetech/article-1199149/Super-slow-motion-pictures-soap-bubble-bursting-stunning-detail.html

Above:
http://img.dailymail.co.uk/i/pix/2007/11_03/BubblePA_468x585.jpg
Conclusions

• Radically extends the KR power of W3C OWL, SPARQL, RIF-BLD – and of SQL
  • Defaults and robust conflict handling – *cope with knowledge quality and context*
  • Higher-order and flexible meta-reasoning – *elevate meta-data to meta-knowledge*
  • Actions and events, cf. production rules and process models – *activate knowledge*

• Raises the KR abstraction level for business users (SMEs) and NL KA/UI

• Use cases in biomed, business policies, ontology mapping, e-commerce, …

• Redefining the KR playing field for Semantic Web, business rules, and rule-based process management
  • Defaults and Higher-Order – yet retain computational web scalability
  • Escape from FOL Bubble– yet retain grade-AAA model-theoretic semantics

• Motto: “Transforming Knowledge”
  • Composes a set of KR transformations for …
    • Expressive extensions – language and semantics
    • Translations between KRs/syntaxes, for interchange
    • Reuse of previous algorithms and implementations

http://silk.semwebcentral.org
Acknowledgements

• **SILK contributors**
  • (previously listed)

• **Other contributors to several key previous KR efforts**
  • RuleML and SWSL (Semantic Web Services Language) standards designs
    • Notably: Harold Boley and Said Tabet
  • SweetRules and Flora-2 systems
    • Notably: Guizhen Yang
SILK –
Transforming Knowledge

Thank You

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OPTIONAL SLIDES FOLLOW
SILK’s ambitious Vision for longer-term Impact

• Key Knowledge Representation (KR) infrastructure sufficient to enable creation of global, widely-authored, very large knowledge bases (VLKBs) about science and business* that answer questions and proactively supply information, using powerful reasoning about rules and processes, that can be customized in their content and actions for individual organizations or people.

• Newest part of Vulcan’s Project Halo which addresses the problems of scale and brittleness in KBs, including the Knowledge Acquisition and UI aspects.

* “Business” here is shorthand for human affairs, incl. government
Sem Tech Industry Requirements targeted by SILK

• Need to raise abstraction level, e.g., for SME and NL KA/UI
  • (SME = Subject Matter Expert, a.k.a. Business User)

• Need robustness & meta-reasoning for web KB integration
  • Cope with conflict, mediation, context, knowledge quality
  • Defaults \implies robustness, modularity \implies scalability
  • Higher-order \implies puts the meta- deeply in knowledge not just data

• Hope: be like advance of the Relational model in DBMS
  • Will Hyper LP be to the 2010s what Relational was to 1970s-80s?
    • (NB: software industry clockspeed was slower back then)
### Semantic Rules KR: Features Comparison

<table>
<thead>
<tr>
<th>Level (“generation”)</th>
<th>Groups of features</th>
<th>SILK V1</th>
<th>Flora</th>
<th>RIF-BLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G. Basic</td>
<td>ie: Horn, chaining, external queries, built-ins (Level Summary)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>2G. Advanced</td>
<td>(Level Summary)</td>
<td>Most!</td>
<td>lots</td>
<td>some</td>
</tr>
<tr>
<td>Equality</td>
<td>(derived via non-fact rules)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Functions</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Convenience Package: Frames, integrity constraints, skolemization</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>R. frames</td>
</tr>
<tr>
<td>Closed-World: unstratified NAF, aggregates, Lloyd-Topor</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Higher-Order</td>
<td>(incl. reification)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Actions (external)</td>
<td>(via procedural attachments)</td>
<td>Developing</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Base Defaults</td>
<td>(prioritized, cf. Courteous)</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Webized syntax</td>
<td>(URI names and XML/RDF KBs)</td>
<td>Developing</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>3G. Hyper</td>
<td>(Level Summary)</td>
<td>Pioneer!</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Higher-Order Defaults</td>
<td></td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Weakened Classical</td>
<td>(sound interchange with default rules)</td>
<td>Developing</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Other Misc.</td>
<td></td>
<td>(NA)</td>
<td>(NA)</td>
<td>(NA)</td>
</tr>
<tr>
<td>Other Expressive</td>
<td></td>
<td>Developing</td>
<td>R. inherit.</td>
<td>-</td>
</tr>
<tr>
<td>Reasoner Efficiency</td>
<td>(upper-tier on OpenRuleBench)</td>
<td>good</td>
<td>good</td>
<td>NA (standard)</td>
</tr>
</tbody>
</table>

- **Summarizes detailed analysis of 40 KR expressive features, 17 systems.**
- **Notes:** R. = Restricted; RIF-BLD = W3C Rule Interchange Format - Basic Logic Dialect.
# Features Comparison – More Systems & Stds

<table>
<thead>
<tr>
<th>Level</th>
<th>Groups of Features</th>
<th>SILK1</th>
<th>Flora</th>
<th>RIF-BLD</th>
<th>Jena</th>
<th>Onto-broker</th>
<th>Jess</th>
<th>IBM C.R.</th>
<th>DLV</th>
<th>SQL</th>
<th>SPA-RQL</th>
<th>Common Logic</th>
<th>OWL2 RL</th>
<th>OWL2 DL</th>
</tr>
</thead>
<tbody>
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| Other Expres.| Dev.                                | inherit.| -    | -       | -    | events      | -    | disju.  | R.  | R.  | classical| -           | -      | classic.
| Efficiency   |                                     | good  | good  | NA      | fair | good        | fair | poor    | good| NA  | NA      | NA          | NA     | NA     |

- Summarizes detailed analysis of 40 KR expressive features, 17 systems.
- Notes: Dev. = Developing, R. = Restricted; C.R.=Common Rules; disju.=disjunctive.
Features Comparison – More Systems & Stds

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<th>Level</th>
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<th>Jena</th>
<th>Ontobroker</th>
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Background on Systems and Standards:

- Jess is a representative commercial production rule (PR) system. PR was shown 5-7 years ago to have a semantic subset (based on the SweetRules translation). The currently most commercially important business rule management systems (BRMS) are based on PR or similar event-condition (ECA) action rules.

- W3C Rule Interchange Format (RIF)’s Basic Logic Dialect (BLD) is its main semantic part. There is also a framework for extensions. RIF is based primarily on RuleML, except for RIF’s Production Rule Dialect (PRD).

- W3C OWL 2 RL is OWL’s Rules subset (based on Description LP).

- Jena is a popular open-source semantic web toolkit, incl. for rules.

- Ontobroker is a commercial forward-chaining LP system.

- IBM Common Rules (C.R.) introduced the base defaults feature.

- Common Logic (CL) is an ISO standard for classical logic, used also by OMG’s Semantic Business Vocabulary and Rules (SBVR) standard.

- DLV is a disjunctive LP system, by Univ. of Calabria (it has OR in rule heads).
SILK – Transforming Knowledge

Thank You

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