SILK's Expressive Semantic Web Rules and Challenges in Natural Language Processing

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

PROJECT HALO

VULCAN

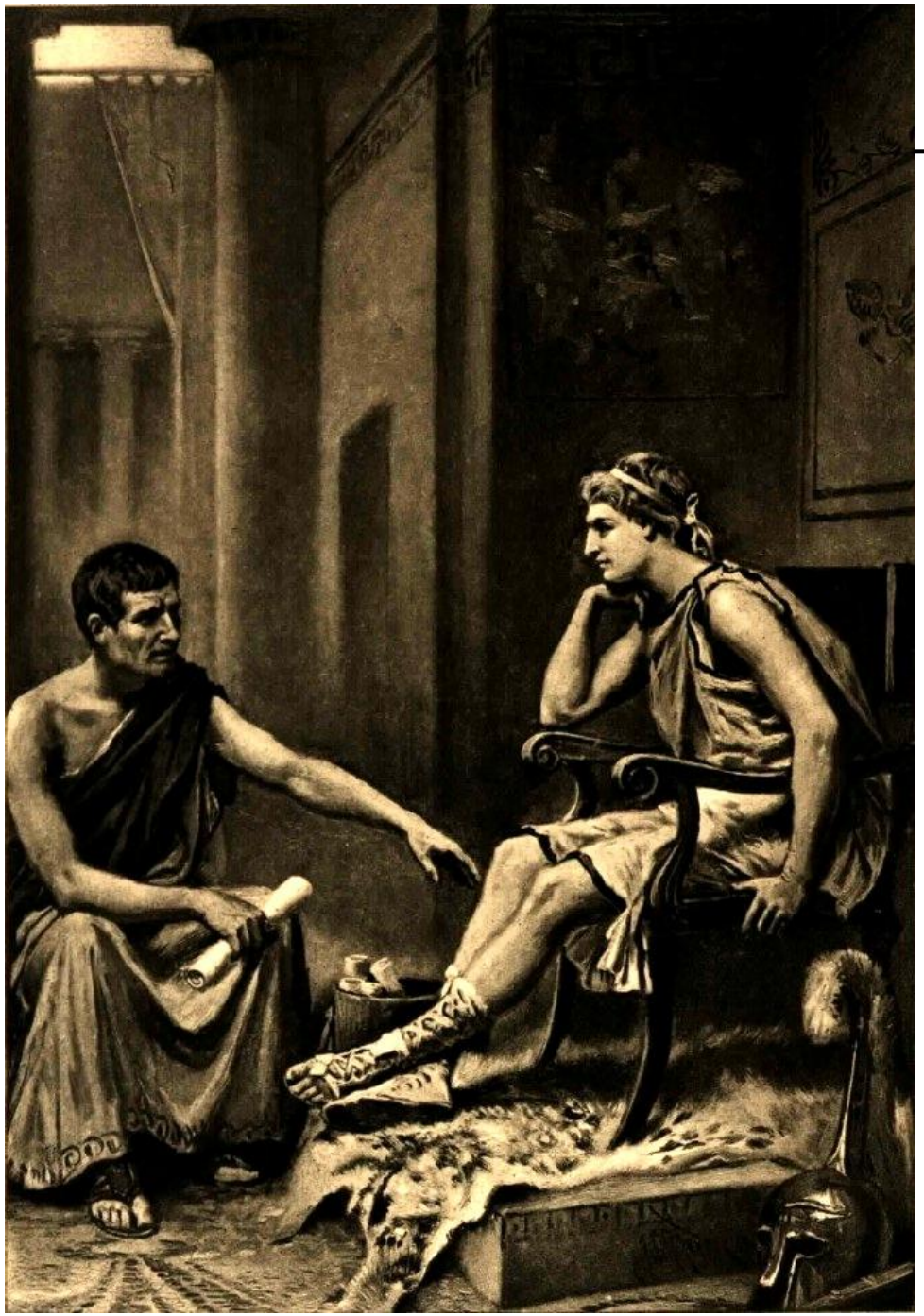
Outline and Overview

- **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-)**
  - Leading semantic wiki. Open-source. Simple rules, light ontologies.
- **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

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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 anatomy/behavior that is typical/normal 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] [*conflict* between defaults, resolved by *priority* among them]
  - 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)
    - *Remark: In LP KR, LC is not even a subset of LA!*
  - |= is the entailment relation.
    - 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.

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

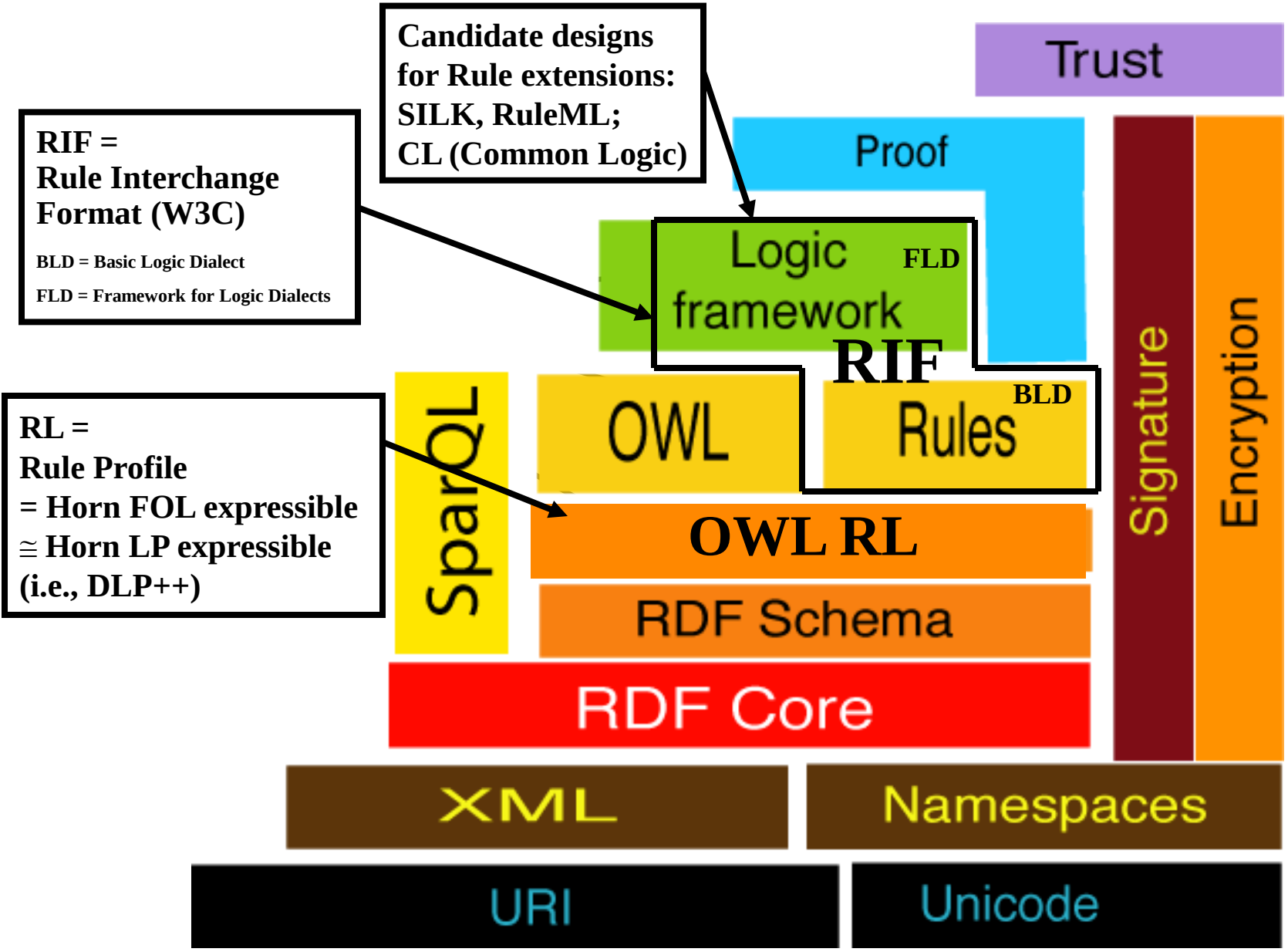
Higher-Order (cf. Hilog and reification)

- 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

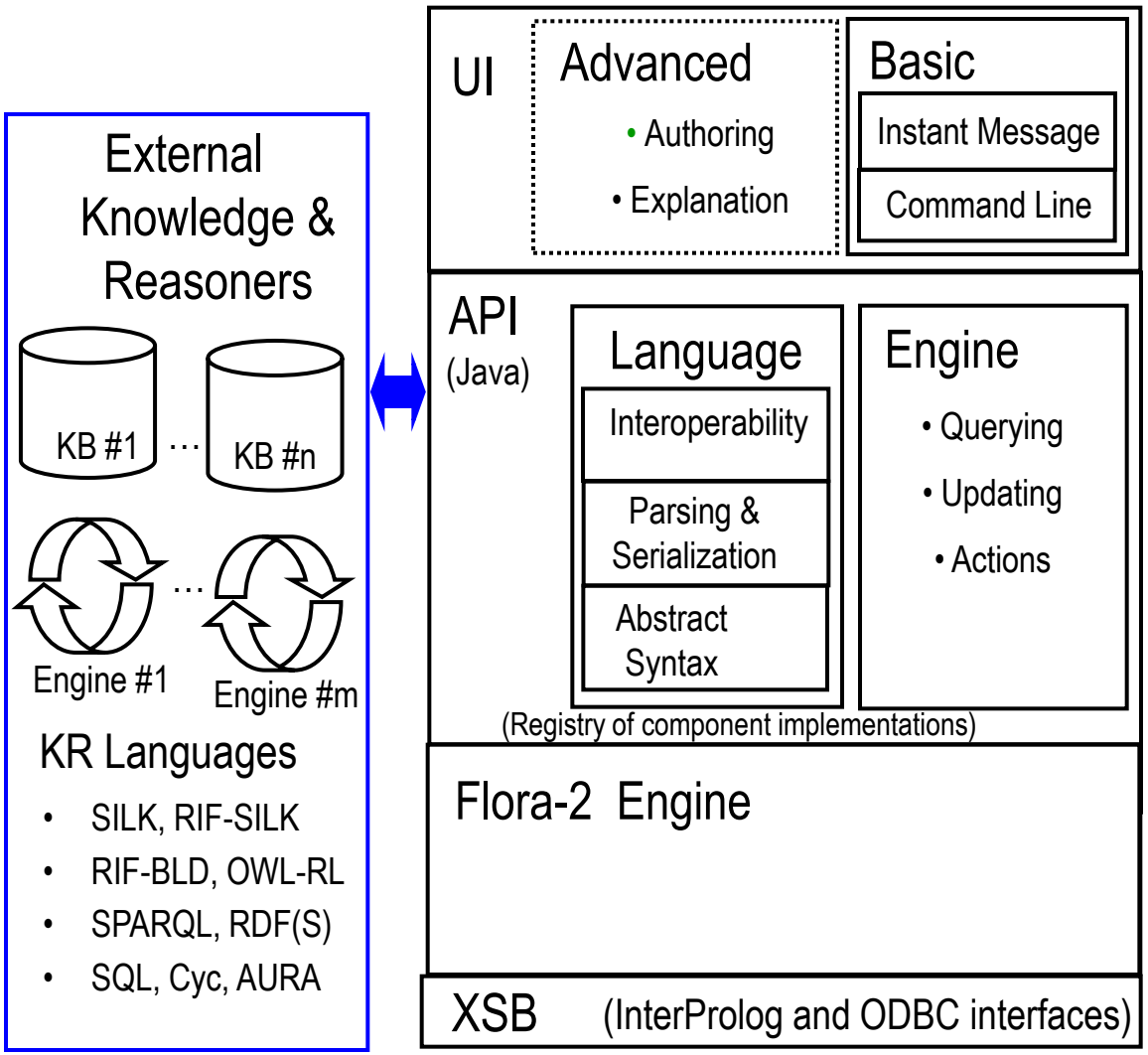
- **It's expressively powerful RIF** (RIF = W3C Rule Interchange Format standard)
  - New dialect defined using RIF's Framework for Logic Dialects (FLD)
  - Extends (supersumes) RIF-BLD (Basic Logic Dialect) and RIF-Core
    - These are based essentially on Horn LP
  - Notably: adds defaults and external 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**
  - Draft specification – public (initial version 12/2009, current 2/2010)
    - 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

Updated: 06-2010 Semantic Web "Stack"



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

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

Overall quite similar to ecology ex.

```
/*    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).

Complex AP Biology Examples

- **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 */
  @[strict] Cara[states(2007) -> print(Art)] and  Cara[states(2007) -> webPage(Art)] ;
   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

- **Demo'd at SemTech-2010 conference**
  - **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***

- **Videos of demos on SILK website**
  - ***Some already there; more to come***

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

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SILK TRANSFORMING KNOWLEDGE

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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

SILK
TRANSFORMING KNOWLEDGE

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http://silk.semwebcentral.org

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Current & Near-Term Directions of Work

- **System: performance optimizations; testing & debugging**
- **Logical KR Language: polishing; standardization**
- **Add uncertainty reasoning: probabilistic, inductive. Initially "shallow".**
- **Applications to education: prototyping an e-textbook ("HaloBook")**
  - Biology at 1st-year college level. Use AURA as well as SILK.
- **Leveraging Cyc KB (3+ Million axioms) via translation ←→ SILK**
  - General: processes, time, space. Domain-specific: Biology, related chemistry etc.
  - NL interpretation and generation (~1+ Million axioms)
- **NLP interpretation and generation, including semantic aspect**
  - In user interaction
  - For Subject Matter Experts (SMEs), rather than only Knowledge Engineers skilled in KR
  - To support users formulating questions and entering knowledge
  - To support system formulating answers and explanations
- **SILK an interesting target and method for (restricted) NLP**
  - Mapping between NL ←→ SILK. SILK expressive advantages of higher-order, defeasible.
  - Using SILK to assist semantic NLP. Can do the syntactic too in SILK (e.g. LP parsing).

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

SILK – Transforming Knowledge

Thank You

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OPTIONAL SLIDES FOLLOW

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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

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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 $\Rightarrow$ robustness, modularity $\Rightarrow$ scalability
  - Higher-order $\Rightarrow$ 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)

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Semantic Rules KR: Features Comparison

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

- **Summarizes detailed analysis of 40 KR expressive features, 17 systems.**
- Notes: R. = Restricted; RIF-BLD = W3C Rule Interchange Format - Basic Logic Dialect.

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Features Comparison – More Systems & Stds

Level	Groups of Features	SILK1	Flora	RIF-BLD	Jena	Onto-broker	Jess	IBM C.R.	DLV	SQL	SPA-RQL	Common Logic	OWL2 RL	OWL2 DL
Basic	Horn chain. etc.	Y	Y	Y	Y	Y	Y	Y	Y	R.	R.	Y	R.	R.
Advan ced	*(Level summary)*	**Most!**	lots	some	some	some	some	some	some	some	some	some	some	some
	Equality	Y	Y	Y	R.	R.	R.	N	Y	R.	R.	Y	R.	Y
	Functions	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	N
	Frames etc.	Y	Y	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.
	Closed-World	Y	Y	N	N	Y	R.	R.	most	R.	R.	N	N	N
	Higher-Order	Y	Y	N	N	N	R.	N	N	R.	R.	Y	R. bit	R. bit
	Actions	Dev.	N	N	N	N	Y	Y	N	N	N	N	N	N
	Base Defaults	Y	N	N	N	N	N	Y	N	N	N	N	N	N
	Webized	Dev.	R.	Y	Y	R.	R.	R.	R.	N	Y	Y	Y	Y
Hyper	*(Level summary)*	**1st!**	N	N	N	N	N	N	N	N	N	N	N	N
	H-O. Defaults	Y	N	N	N	N	N	N	N	N	N	N	N	N
	Weak. Classi.	Dev.	N	N	N	N	N	N	N	N	N	N	N	N
Misc.		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	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

Level	Groups of Features	SILK1	Flora	RIF-BLD	Jena	Onto-broker	Jess	IBM C.R.	DLV	SQL	SPA-RQL	Common Logic	OWL2 RL	OWL2 DL
Basic	Horn chain. etc.													
Advanced	*(Level summary)*													
	Equality													
	Functions													
	Frames etc.													
	Closed-World													
	Higher-Order													
	Actions													
	Base Defaults													
	Webized													
Hyper	*(Level summary)*													
	H-O. Defaults													
	Weak. Classi.													
Misc.														
	Other Expres.													
	Efficiency													

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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