WELCOME! to the ISWC-2010 Tutorial

Web Rules:
Fundamentals, Applications, and Standards

***presented by* Benjamin Grosof* and Mike Dean** ;**

also authored by Michael Kifer**

**** Vulcan Inc.   ** Raytheon BBN Technologies   *** Stony Brook University***

INSTRUCTIONS! All participants, please:

- Download the tutorial slideset
  at http://www.mit.edu/~bgrosof/#ISWC2010RulesTutorial
  Also at: http://silk.semwebcentral.org
- Sign in on the participants list (hard copy sheet) with your name, organization, email;
  optionally also add your interests, homepage URL

Top-Level Outline of Tutorial

A. Introduction, Overview, and Uses

B. Concepts and Foundations

C. Conclusions and Directions

+ Appendix: References and Resources

Background Assumed:

- basic knowledge of first-order logic, relational databases, XML, RDF

Outline of Part A. Intro & Uses

1. Overview of tutorial, and get acquainted
2. What are: Rules on the Web, Semantic Rules/Web/Tech
3. Uses and Kinds of rules
   - Commercial, web. Current, envisioned.
   - Requirements. Business value, IT lifecycle.
   - Strategic roadmapping of future adoption
4. Example Use Cases
   - E-commerce: pricing, ordering policies, contracts
   - E-science: ecological process, mechanics context
   - Trust: compliance, policies, e.g. financial services
   - Info integration, ontology mapping, business reporting
   - Processes: policy-based workflow, causal action effects, Semantic Web Services

NB: (2.)-(4.) are interleaved.

Outline of Part B. Concepts & Foundations

1. Overview of Logical Knowledge Representations
   - Logic Programs (LP) and its relationship to First Order Logic (FOL)
   - Rule-based Ontologies: Description Logic, Description LP
2. SILK's Hyper LP: Putting it all together
3. Basics: Horn Case; Functions
4. F-Logic, Frame Syntax, Object Oriented Style
5. HiLog, Higher-Order Syntax, Reification, Meta-Reasoning
6. W3C Rule Interchange Format (RIF): Dialects, Framework
   - Rules in W3C Web Ontology Language (OWL-RL); via RIF
7. Nonmonotonic LP: Defaults, Negation, Priorities, FOL Interchange
   - Semantics for Default Negation
   - Courteous LP, Argumentation Theories
   - Omni-directional Rules, FOL-Soundness, Remedying FOL's Fragility
8. Procedural Attachments to Actions, Queries, Built-ins, and Events
   - Production/Situated LP, Production Rules
9. Additional Features: Integrity Constraints, Inheritance, Lloyd-Topor, Equality, Skolemization, Aggregation, Datatypes, "Constraints"

Outline of Part C. Conclusions & Directions

1. More about Tools
2. … incl. SILK
3. Conclusions
4. Directions for Future research

Appendix: References and Resources

(General Discussion)

Rough Schedule, Overall

~14:00-14:30   Part A: Intro & Uses

~14:30-15:45   Part B: Concepts & Foundations

~15:45-16:15   Coffee Break

~16:15-17:40   Part B, continued: Concepts & Foundations

~17:40-18:00   Part C: Conclusions & Directions

PART A. SLIDES FOLLOW

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Learning Goals for Tutorial

1. Overview of current state of logical KR theory, applications, languages, standards, tools/systems, market

2. Relationship to Web and Semantic Tech, overall

3. Introduction to the research issues

"Semantic" Technology

- "Semantic" in "semantic web" and "semantic rules" means:
  - 1. Knowledge-based

    … and …
  - 2. Having meaning independent of algorithm and implementation
  - Equipped with an interoperable conceptual abstraction

    … based on <u>declarative</u> <u>knowledge representation</u> (<u>KR</u>)

    = Shared principles of what inferences are sanctioned from a given set of premises

What are Rules on the Web

- <u>Convergence</u> of three streams is well along the way
  1. Using Web for <u>interchange</u> of rules, even pre-Web legacy kinds
     - XML syntax for rules. Transcend organizational silos.
  2. Rules working in <u>Web context</u>, using:
     - Web data, schemas, ontologies; Web services, queries, databases
  3. Rules using <u>semantic</u> knowledge representation (KR)
     - Semantics are required for effective sharing of knowledge and tools
- Web as <u>scope</u> for rule-based <u>structured knowledge</u>
  - Enrich the Web as a knowledge platform – public and intranets
  - <u>Collaborative</u> knowledge acquisition (KA), e.g., Wiki's
  - Web-located knowledge bases (KBs) and KR services
- $\Rightarrow$ Semantic rules on the Web
  - Standardization is a key activity currently. 1st wave just completed.

Semantic Web in context of Web

hazy still: ***Semantic Web Services***

Semantic Web techniques

Automated Knowledge Bases

Rules (RuleML, RIF)

Ontologies (OWL, RDFS)

Databases (SQL, SPARQL)

Web Services techniques

APIs on Web

(WSDL/SOAP, REST)

Two interwoven aspects:

- Program: Web Services
- Data: Semantic Web

XML

First Generation Web

Semantic Web: concept, approach, pieces

- Shared semantics when interchanging data ∴ knowledge
- Knowledge Representation (cf. AI, DB) as approach to semantics
  - Standardize KR syntax, with KR theory/techniques as backing
- Web-exposed Databases: relational and XML/RDF data/queries
  - Challenge: share database schemas via meta-data
  - RDF = "Resource Description Framework" W3C standard
- Ontology = formally defined vocabulary
  - OWL: "Web Ontology Language" W3C standard
    - Taxonomic class/property hierarchy, property-value restrictions, decidable subset of FOL
  - Ex.: Lions are a subcategory within felines
  - Ex.: Every health care visit has a required copayment amount
- Rules = if-then logical implications, facts ~subsumes relational DBs
  - RIF: "Rule Interchange Format" W3C standard
    - Based on Logic Programs (LP) Knowledge Representation
    - Based on RuleML (Rule Markup & Modeling Language) standards design
    - Production rule languages
  - Ex.: Any student who has abused printing privileges is prohibited from using color printers
  - Ex.: AAA members get a weekend discount of 20% on suites, at hotel chain X
  - Ex.: During the mitosis phase of an animal cell's lifecycle, all DNA is replicated

Flavors of Rules Commercially Most Important today in E-Business

- E.g., in OO applications, DBs, workflows.

- Relational databases, SQL: Views, queries, facts are all rules.
  - SQL99 even has recursive rules.
- Production rules (OPS5 heritage): e.g.,
  - Jess, ILOG, Blaze, Haley: rule-based Java/C++ objects.
- Event-Condition-Action rules (loose family), cf.:
  - business process automation / workflow tools.
  - active databases; publish-subscribe.
- Prolog. *"logic programs" as a full programming language.*
- *Lesser: other knowledge-based systems.*
- *Emerging: Semantic-based technology*

Above are "Currently Commercially Important (CCI)"

Commercial Applications of Rules today in E-Business

- There are many. An established area since the 1980's.
  - Expert systems, policy management, workflow, systems management, financial & insurance, e-commerce, trust, personal messaging, defense intelligence, ….
  - Far more applications to date than of Description Logic.

- Advantages in systems specification, maintenance, integration.

- Market momentum: moderately fast growing
  - Fast in early-mid 1980's.
  - Slow late 1980's-mid-1990's.
  - Picked up again in late 1990's. (Embeddable methodologies.)
  - Accelerating in 2000's.

Vision: *Uses of Rules in E-Business*

- Rules are an important aspect of coming world of Internet e-business: rule-based business policies & business processes, for B2B & B2C.
  - represent seller's offerings of products & services, capabilities, bids; map offerings from multiple suppliers to common catalog.
  - represent buyer's requests, interests, bids; $\rightarrow$ matchmaking.
  - represent sales help, customer help, procurement, authorization/trust, brokering, workflow.
  - high level of conceptual abstraction; easier for non-programmers to understand, specify, dynamically modify & merge.
  - executable but can treat as data, separate from code
    - potentially ubiquitous; already widely used: e.g., SQL views, queries.
- Rules in communicating applications, e.g., embedded intelligent agents.

Semantic Rules: Differences from Rules in the 1980's / Expert Systems Era

- Get the <u>KR</u> right (knowledge representation)
  - More <u>mature</u> research understanding
  - <u>Semantics</u> independent of algorithm/implementation
  - <u>Cleaner</u>; avoid general programming/scripting language capabilities
  - Highly <u>scaleable</u> <u>performance</u>; better algorithms; choice for interoperability
  - Highly <u>modular</u> wrt updating; use prioritization
  - → Highly <u>dynamic</u>, <u>scaleable</u> <u>rulebase authoring</u>: distributed, integration, partnering
- Leverage <u>Web</u>, esp. XML
  - Interoperable syntax
  - Merge knowledge bases
- Embeddable
  - Into <u>mainstream</u> software development environments (Java, C++, C#); not its own programming language/system (cf. Prolog)
- Knowledge <u>Sharing</u>: intra- or inter- enterprise
- <u>Broader</u> set of Applications

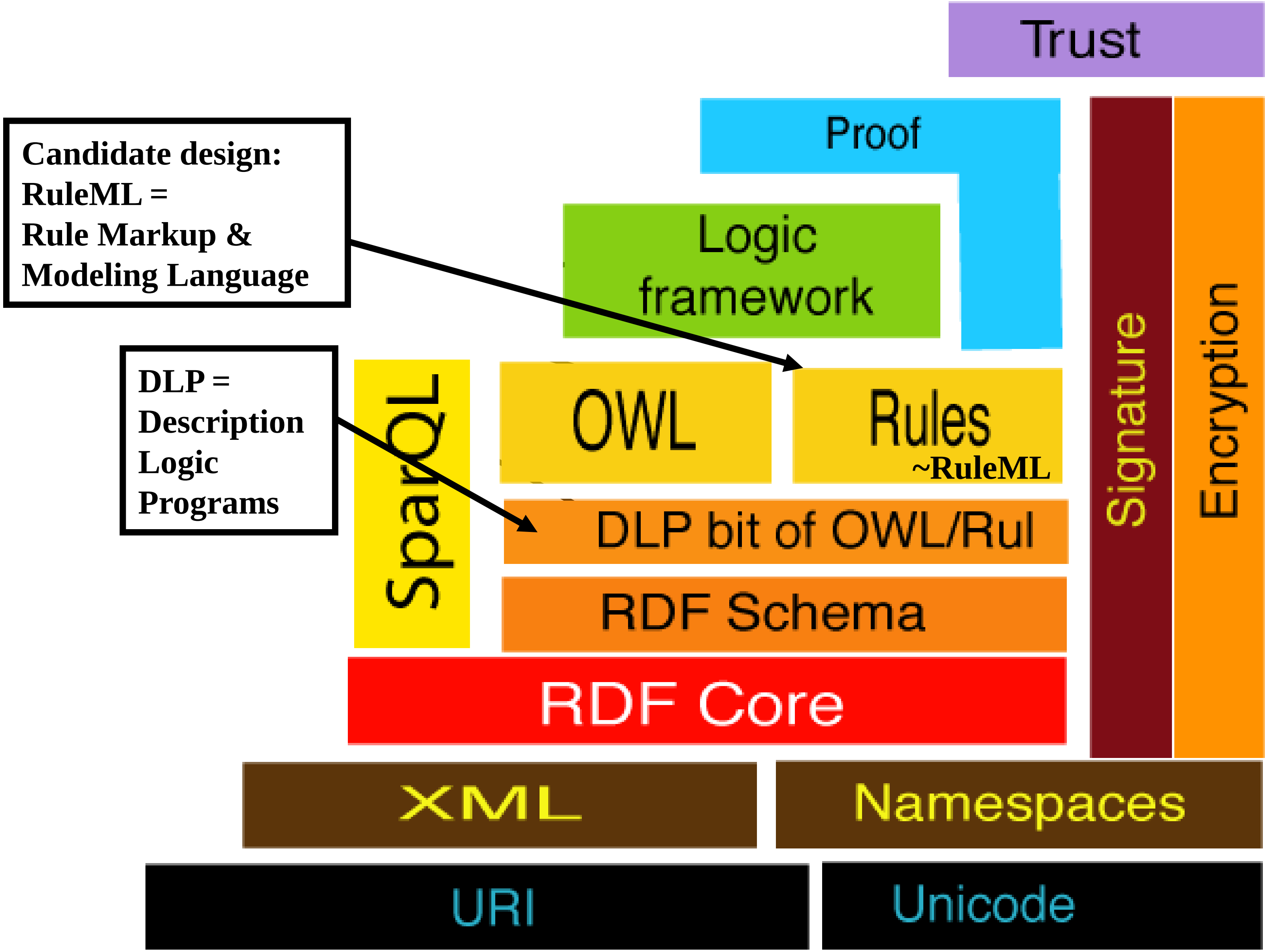
Value of Rules as form of KR

- Rules as a form of KR (*knowledge representation*) are especially useful
  - relatively mature from basic research viewpoint
  - good for prescriptive specifications (vs. descriptive)
    - a restricted programming mechanism
  - integrate well into commercially mainstream software engineering, e.g., OO and DB
    - easily embeddable; familiar
    - vendors interested already: Webizing, application development tools
- ⇒ Identified as part of mission of the W3C Semantic Web Activity, in about 2001

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!**

08-2005 W3C Semantic Web "Stack": Standardization Steps



Modification of slide by W3C (just added annotation)

Updated: 10-2010 Semantic Web "Stack"

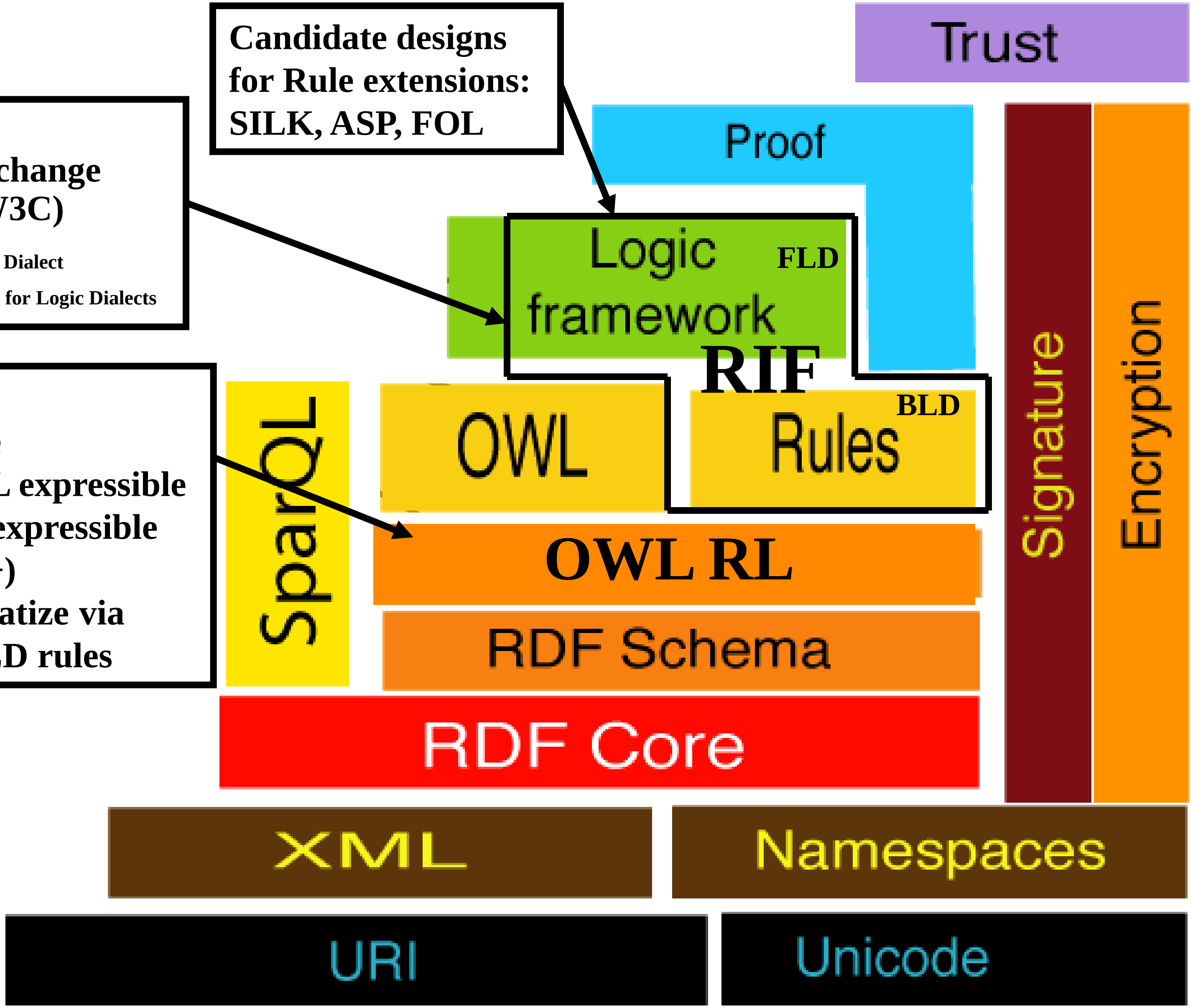
Candidate designs
for Rule extensions:
SILK, ASP, FOL

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++)
E.g., axiomatize via
~70 RIF-BLD rules



Modified from slide by W3C (just added annotation)

Overview of Key Languages & Standards

1. Database Queries & Facts are Rules
   - SQL; W3C SPARQL & RDF, also XQuery & XML-Schema
2. W3C Rule Interchange Format (RIF)
   - -BLD, -Core: Basic LP (no defaults or actions)
   - -FLD: Framework for extensions (defaults & much more)
   - -PRD: Production rules (*lacks model-theoretic semantics*)
3. RIF Precursor: Rule Markup/Modeling Language (RuleML)
   - Main focus is LP, with extensions; FOL too
   - SWRL function-free Horn; predecessor to RIF-BLD
   - SWSL for Web Services modeling; related: WSML
4. Rules in and for ontologies and ontology languages
   - W3C OWL-RL, RDF Schema
5. SILK: Hyper Logic Programs – advanced expressiveness
6. ISO Common Logic (successor to KIF): FOL (with HiLog)
7. OMG Sem. of Business Vocabulary & Business Rules (SBVR)

Overview of Key Tools

1. Rule systems designed to work with RDF/OWL/RIF
   - Commercial-world: Jena; Oracle; IBM; others
   - Research-world: SILK; SweetRules; cwm; others
2. Prolog and Production Rule systems
   - XSB; Jess; others
3. Advanced Expressiveness
   - FLORA-2 and SILK; IBM CommonRules
4. Rules in Semantic Wikis
   - Semantic MediaWiki+
5. Some Available Large Rule Bases
   - OpenCyc, Process Handbook, OpenMind

Need for Other Kinds of Ontologies besides OWL

- Forms of ontologies practically/commercially important in the world today*:
  - SQL DB schemas
  - “Conceptual models” in UML and E-R (Entity-Relationship)
  - OO inheritance hierarchies, procedural interfaces, datatype declarations
  - XML Schema
  - OWL is still emerging, wrt deployed usage – dwarfed by all the above
  - RIF – early emerging
  - LP/FOL/BRMS predicate/function signatures
  - Builtins (e.g., SWRL/RuleML)
  - Equations and conversion-mapping functions
- Overall relationship of OWL to the others is as yet largely unclear
  - There are efforts on some aspects, incl. UML.
  - Bright spot is OWL-RL relationship to RIF: formulated as a set of RIF-BLD axioms.
- OWL cannot represent the nonmon aspects of OO inheritance
- OWL does not yet represent, except quite awkwardly:
  - n-ary relations
  - ordering (sequencing) aspects of XML Schema

- (*NB: Omitted here are statistically flavored ontologies that result from inductive learning and/or natural language analysis.)

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EEСOMS 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: **precedence** 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) ;
silk:overrides(reduceTight, prefCust) ; // *reduceTight has higher priority than prefCust*
// *The below exclusion constraint specifies that orderModifNotice is unique, for a given order.*
silk: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 ≠ . "silk:" is a namespace prefix.

EECOMS Supply Chain: Early Commercial Implementation & Piloting

- EECOMS agile supply chain collaboration industry consortium including Boeing, Baan, TRW, Vitria, IBM, universities, small companies
  - $29Million 1998-2000; 50% funded by NIST ATP
  - application piloted IBM CommonRules and early approaches which led to SweetDeal, RuleML, SweetRules, RIF, and SILK
    - contracting & negotiation; authorization & trust

Example: E-Commerce Pricing *Offer from SupplierCo to Buyer*

```
@usualPrice   price(per_unit, ?PO, $60)   :-
        purchaseOrder(?PO, supplierCo, ?AnyBuyer) and
        quantity_ordered( ?PO, ?Q) and (?Q ≥ 5) and (?Q ≤ 1000) and
        shipping_date(?PO, ?D) and (?D ≥ "2000-04-24") and (?D ≤ "2000-05-12") ;
@volumeDiscount   price(per_unit, ?PO, $51)   :-
        purchaseOrder(?PO, supplierCo, ?AnyBuyer) and
        quantity_ordered( ?PO, ?Q) and (?Q ≥ 100) and (?Q ≤ 1000) and
        shipping_date(?PO, ?D) and (?D ≥ "2000-04-28") and (?D ≤ "2000-05-12") ;
silk:overrides(volumeDiscount , usualPrice) ;   // volumeDiscount rule has higher priority
 //  The below exclusion constraint says the value of price is unique for a given PO
silk:opposes(price(per_unit, ?PO, ?X), price(per_unit, ?PO, ?Y))   :-   ?X  != ?Y ;
...
```

- Notation:
  "*@foo*" is an annotation preamble to a rule that specifies the rule's tag. "?" prefixes a logical variable.
  The "overrides" predicate specifies prioritization ordering.
  An exclusion constraint specifies what constitutes a conflict.
  "!="means ≠ . "silk:" is a namespace prefix.

Pricing Example --
XML Encoding of Rules in RuleML

```
<rulebase>
  <imp>
    <rlab>usualPrice</rlab>
    <head>
      <cslit>
        <opr><rel>price</rel></opr>
         <ind>per_unit</ind>
         <var>PO</var>
         <ind>$60</ind>
     </cslit>
   </head>
   <body>    …  (see next page, if included)    </_body>
  </imp>
…
</rulebase>
```

- *NB: This uses an older version of RuleML markup syntax. RIF syntax is similar, but RIF* ***Basic*** *Logic Dialect cannot express defaults.*

Ecology Ex. of Causal Process Reasoning (in SILK)

```
/*   Toxic discharge into a river causes fish die-off.   */
/* Init. facts, and an "exclusion" constraint that fish count has a unique value */
  occupies(trout,Squamish);
  fishCount(0,Squamish,trout,400);  / * 1st argument of fishCount is an integer time */
  silk:opposes(fishCount(?s,?r,?f,?C1), fishCount(?s,?r,?f,?C2)) :- ?C1 != ?C2;
/* Action/event description that specifies causal change, i.e., effect on next state */
@tdf1 fishCount(?s+1,?r,?f,0) :- occurs(?s,discharge,?r) and occupies(?f,?r);
/* Persistence ("frame") axiom */
  @pefc1  fishCount(?s+1,?r,?f,?p) :- fishCount(?s,?r,?f,?p);
/* Action effect axiom has higher priority than persistence axiom */
 silk:overrides(tdf1,pefc1);
/* An action instance occurs */
  @UhOh  occurs(1,toxicDischarge,Squamish);
```

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

Notes: @… declares a rule tag. ? prefixes a variable. :- means if. != means ≠. opposes indicates an exclusion constraint between two literals, which means "it's a conflict if".

E-Commerce Ex. of Causal Process Reasoning (in SILK)

/* E-commerce delivery logistics. */

/* Initial fact, and prevention constraint that location is unique */

loc(0,PlasmaTV46,WH_LasVegasNV);

silk:opposes(loc(?s,?item,?posn1), loc(?s,?item,?posn2)) :- ?posn1 != ?posn2;

/* Action/event description that specifies causal change, i.e., effect on next state */

@mov1 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 */

@peloc1 loc(?s+1,?item,?posn) :- loc(?s,?item,?posn);

/* Action effect axiom has higher priority than the persistence axioms */

silk:overrides(mov1,peloc1);

silk:overrides(mov1,peloc2);

/* An action instance occurs */

@de7 shipment(1, PlasmaTV46, WH_LasVegasNV, 9_Fog_St_SeattleWA);

As desired: **$\models$ loc(2, PlasmaTV46, 9_Fog_St_SeattleWA);**

$\not\models$ loc(2, PlasmaTV46, WH_LasVegasNV);

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 is 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. */

@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;

/* Admins Bob and Cara make conflicting statements over time about Ann's printing */

Cara[states(2007) -> print(Ann)]; Cara[states(2007) -> webPage(Ann)];

Bob[states(2008) -> neg print(Ann)];

As desired: **|= neg print(Ann); webPage(Ann);**

/* Currently, Ann is permitted a webpage but not to print. */

Notes: @[…] declares a rule tag. ? prefixes a variable. :- means if. != means ≠. neg is strong negation. There is an implicit exclusion (silk:opposes) between P and neg P, for every literal P.

Physics Ex. of Contextual Assumptions (in SILK)

```
/* "P8: Joe drops a glove from the top of a 100m cliff.
         How long does the fall take in seconds?" */
// Initial problem-specific facts
AP_problem(P8);  fall_event(P8);  P8[height->100];
// Action description that specifies causal implications on the continuous process
?e[time->((2 * ?h / ?n)^0.5)] :- fall_event(?e) and ?e[height->?h,  net_accel->?n];
?e[net_accel->(?g - ?a)] :- fall_event(?e) and
                                  ?e[gravity_accel->?g,  air_resistance_accel->?a];
 // Other facts
?e[gravity_accel->9.8] :- loc(?e, Earth);
?e[gravity_accel->3.7] :- loc(?e, Mars);
// Contextual assumptions for answering Advanced Placement exam (AP) problems
@implicit_assumption loc(?e, Earth) :- AP_problem(?e);
silk:opposes(loc(?e, Earth), loc(?e, Mars));
@implicit_assumption ?e[air_resistance_accel->0] :- AP_problem(?e);
silk:overrides(explicitly_stated, implicit_assumption);
```

As desired: |= P8[net_accel->9.8, time->4.52];   // 4.52 = (2*100/9.8)^0.5

Physics Ex. of Contextual Assumptions (in SILK)

```
/*  "P8: Joe drops a glove from the top of a 100m cliff on Mars.
          How long does the fall take in seconds?" */
/* Initial problem-specific facts*/
  AP_problem(P8);  fall_event(P8);  P8[height->100];
  @explicitly_stated   loc(P8,Mars);

...

As desired:    |=   P8[net_accel->3.7,  time->7.35];   //  7.35  =  (2*100/3.7)^0.5];
```

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Challenge: Capturing Semantics around Policies

- Deep challenge is to capture the semantics of data and processes:
  - To represent, monitor, and enforce policies – e.g., trust and contracts
  - To map between definitions of policy entities, e.g., in financial reporting
  - To integrate policy-relevant information powerfully

Policies for Compliance and Trust Mgmt.: Role for Semantic Web Rules

- Trust Policies usually well represented as rules
  - Enforcement of policies via rule inferencing engine
  - E.g., Role-based Access Control
    - This is the most frequent kind of trust policy in practical deployment today.
  - W3C P3P privacy standard, OASIS XACML, XML access control emerging standard, …

- Ditto for Many Business Policies beyond trust arena, too
  - "Gray" areas about whether a policy is about trust vs. not: compliance, regulation, risk management, contracts, governance, pricing, CRM, SCM, etc.
  - Often, authorization/trust policy is really a part of overall contract or business policy, at application-level. Unlike authentication.
  - Valuable to reuse policy infrastructure

Trust Policies and Compliance in US Financial Industry Today

- Ubiquitous high-stakes Regulatory Compliance requirements
  - Sarbanes Oxley, SEC (also in medical domain: HIPAA), etc.
- Internal company policies about access, confidentiality, transactions
  - For security, risk management, business processes, governance
- Complexities guiding who can do what on certain business data
- Often implemented using rule techniques

- Often misunderstood or poorly implemented leading to vulnerabilities
- Typically embedded redundantly in legacy silo applications, requiring high maintenance
- Policy/Rule engines lack interoperability

Example Financial Authorization Rules

Classification	Application	Rule
Merchant	**Purchase Approval**	If credit card has fraud reported on it, or is over limit, do not approve.
Mutual Funds	**Rep trading**	“*Blue Sky*:” State restrictions for rep’s customers.
Mortgage Company	**Credit Application**	TRW upon receiving credit application must have a way of securely identifying the request.
Brokerage	**Margin trading**	Must compute current balances and margin rules before allowing trade.
Insurance	**File Claims**	Policy States and Policy type must match for claims to be processed.
Bank	**Online Banking**	User can look at own account.
All	**Householding**	For purposes of silo (e.g., statements or discounts), aggregate accounts of all family members.

Slide also by Chitravanu Neogy

Verticals that appear good candidates for Early Adoption of SW Rules for Privacy

- Financial
  - Cf. discussion earlier in this talk
  - Historically, an early adopter of information technology overall esp. for integration
  - Large sector of global economy
  - Privacy/trust policies very important, distributed & heterogeneous
- Medical
  - Privacy/trust policies very important, distributed & heterogeneous
  - Expecting help on privacy from information technology
  - Large sector of global economy
- Police/Military
  - Privacy/trust policies very important, distributed & heterogeneous
  - Looking for help on privacy from information technology
  - Major funder of SW basic research to date, e.g., DARPA Agent Markup Language program 2000-2005
- In many other realms, there is a large gap between <u>revealed</u> vs. avowed preferences for value of privacy/confidentiality.

Advantages of Standardized SW Rules

- Easier Integration: with rest of business policies and applications, business partners, mergers & acquisitions
- Familiarity, training
- Easier to understand and modify by humans
- Quality and Transparency of implementation and enforcement
  - Provable guarantees of implementation behavior
- Reduced Vendor Lock-in
- Expressive power
  - Principled handling of conflict, negation, priorities

Advantages of SW Rules, cont'd:
Loci of Business Value

- Reduced system dev./maint./training costs
- Better/faster/cheaper policy admin.
- Interoperability, flexibility and re-use benefits
- Greater visibility into enterprise policy implementation => better compliance
- Centralized ownership and improved governance by Senior Management
- Rich, expressive trust management language allows better conflict handling in policy-driven decisions

Some Answers to:
"Why does SW/SWS Matter to Business?"

- 1. "Death. Taxes. Integration." - They are always with us.
- 2. "Business processes require communication between organizations / applications." - Data and programs cross org./app. boundaries, both intra- and inter- enterprise.
- 3. "It is the *automated knowledge* economy, stupid!" - The world is moving towards a knowledge economy. And it is moving towards deeper and broader automation of business processes. The first step is automating the use of <u>structured</u> knowledge.
  - Theme: *reuse* of knowledge across multiple tasks/apps/orgs

SW Early Adoption Candidates: High-Level View

- "Death. Taxes. Integration."
- Application/Info Integration:
  - Intra-enterprise
    - EAI, M&A; XML infrastructure trend
  - Inter-enterprise
    - E-Commerce: procurement, SCM
  - Combo
    - Business partners, extranet trend

SW Adoption Roadmap: Strategy Considerations

- Likely first uses in a lot of B2B interoperability or heterogeneous-info-integration intensive applications (e.g., finance, travel)
  - Actually, probably 1st intra-enterprise, e.g., EAI
- Reduce costs of communication in procurement, operations, customer service, supply chain ordering and logistics
  - increase speed, create value, increase dynamism
  - macro effects create
    - stability sometimes (e.g., supply chain reactions due to lag; other negative feedbacks)
    - volatility sometimes (e.g., perhaps financial market swings)
  - increase flexibility, decrease lock-in
- Agility in business processes, supply chains

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   - E-commerce: pricing/ordering policies, contracts
   - E-science: ecological process
   - Trust: compliance, policies, e.g. financial services
   - Info integration, ontology mapping, business reporting
   - Processes: policy-based workflow, causal action effects, Semantic Web Services

NB: (2.)-(4.) are interleaved.

Ontology Translation Via Rules

- Use rules to represent mappings from data source to domain ontologies
  - Rules can be automatically or manually generated
  - Can support unit of measure conversion and structural transformation
- Example using SWRL
  - http://www.daml.org/2004/05/swrl-translation/Overview.html
- http://snoggle.semwebcentral.org

Uses of Semantic Rules for XBRL

- Ontology mappings: contextual, reformulation
  - *Examples*:
    - Price with vs. without shipping, tax
    - Earnings last 4 qtrs vs.{last 3 qtrs + forecast next qtr}
    - Profit with vs. without depreciation
    - Historical info when statutory treatment changes
    - Implicit context: use a typical definition of revenue
  - Your vs. my pro-forma or analytic view
    - Between companies, governmental jurisdictions
  - Exception handling, special cases, one-time events
    - Footnotes – "where the real action is"
    - *Example:* Revenue includes sale of midtown NYC headquarters bldg

Example: Exception in Ontology Translation (in SILK)

/* 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));
silk: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. silk:overrides(X,Y) means X is higher priority than Y.

Equational Ontological Conflicts in Financial Reporting

\# of customers = # of end_customers + # of distributors

Gross Profit = Net Sales – Cost of Goods

P/E Ratio = Price / Earnings(last 4 Qtr)

Price = Nominal Price + Shipping

\# of customers = # of end_customers + # of prospective customers

Gross Profit = Net Sales – Cost of Goods – Depreciation

P/E Ratio = Price/ [Earnings(last 3 Qtr) + Earnings(next quarter)]

Price = Nominal Price + Shipping + Tax

" heterogeneity in the way data items are *calculated* from other data items *in terms of definitional equations*"

Slide also by Aykut Firat and Stuart Madnick

EOC in Primark Databases

Top 25 US Co. by Net Sales (Disclosure DB)

Rank	Company	Net Sales (000's)		Date
1	General Motors Corp	168,828,600	?	12/31/95
2	Ford Motor Co	137,137,000		12/31/95
3	Exxon Corp	121,804,000	?	12/31/95
4	Wal Mart Stores Inc	93,627,000		01/31/96
5	AT&T	79,609,000		12/31/95
6	Mobil Corp	73,413,000	?	12/31/95
7	International Business M	71,904,000		12/31/95
8	General Electric Co	70,028		
…	…	…		

Top 25 International Co. by Net Sales (Worldscope DB)

Rank	Company	Net Sales (000's)	Date
1	Mitsubishi Corporation	165,848,468	03/31/96
2	General Motors Corp	163,861,100	12/31/95
…	…	…	…
8	Exxon Corp	107,893,000	12/31/95
…	…	…	…
16	International Business M	71,940,000	12/31/95
17	General Electric Co	69,948,000	12/31/95
20	Mobil Corp	64,767,000	12/31/95
…	…	…	…

Primark was a company that owned:

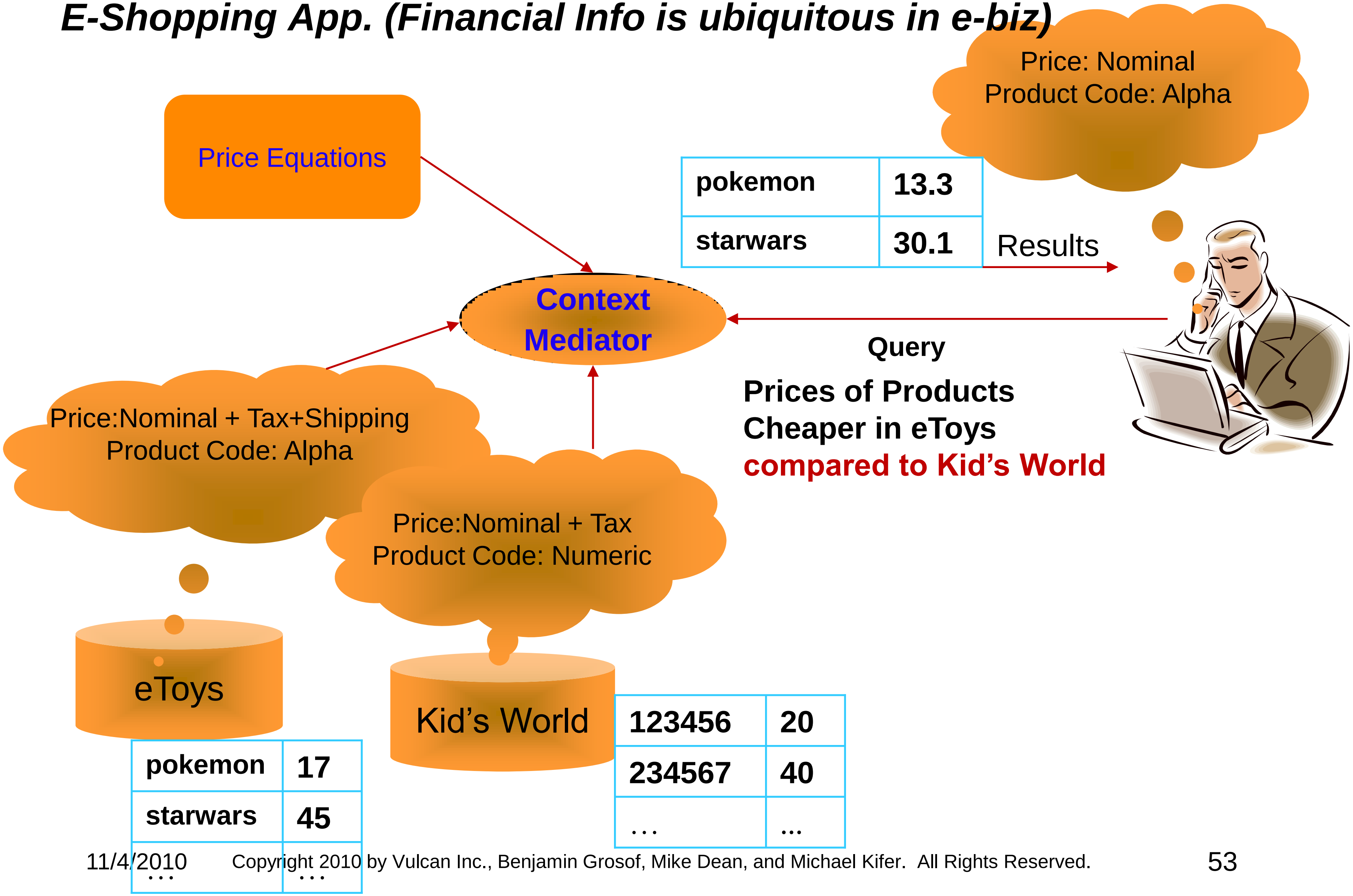
- Disclosure
- Worldscope
- DataStream

Information services

Solution Approach: ECOIN

Extended COntext INterchange MIT Sloan prototype

E-Shopping App. (Financial Info is ubiquitous in e-biz)



pokemon	13.3
starwars	30.1

pokemon	17
starwars	45
…	…

123456	20
234567	40
…	…

ECOIN Approach, continued

- Context-based loosely-coupled integration
- Symbolic Equation Solving combined with LP

XBRL INTERNATIONAL

MEMBERS LOG-IN | SEARCH THE S

XBRL® eXtensible Business Reporting Language

Home SITE GUIDE EVENTS CONTACT US XBRL AROUN WORLD

- **WHAT IS XBRL**
- Benefits and Uses
- How XBRL Works
- FAQ
- LATEST NEWS
- XBRL IN ACTION
- XBRL AND BUSINESS
- TECHNICAL INDEX
- TAXONOMIES
- SPECIFICATIONS
- BEST PRACTICES
- TECHNICAL SUPPORT
- EDUCATION AND TRAINING
- ABOUT THE ORGANISATION
- HOW TO JOIN
- **MEMBERS' AREA**
- INFORMATION FOR MEMBERS
- e-GROUPS
- SUPPLY CHAINS

An Introduction to XBRL

XBRL is a language for the electronic communication of business and financial data whicl revolutionising business reporting around the world. It provides major benefits in the preparation, analysis and communication of business information. It offers cost savings, greater efficiency and improved accuracy and reliability to all those involved in supplying using financial data.

XBRL stands for eXtensible Business Reporting Language. It is one of a family of "XML" languages which is becoming a standard means of communicating information between businesses and on the internet.

XBRL is being developed by an international non-profit consortium of approximately 450 r companies, organisations and government agencies. **It is an open standard, free of lice fees.** It is already being put to practical use in a number of countries and implementatio XBRL are growing rapidly around the world.

This site provides information about the nature, uses and benefits of XBRL. It explains h individuals and companies can join the effort to move forward and make use of the langu

A Simple Explanation

The idea behind XBRL, eXtensible Business Reporting Language, is simple. Instead of treating financial information as a block of text - as in a standard internet page or a print document - it provides an identifying tag for each individual item of data. This is comput readable. For example, company net profit has its own unique tag.

The introduction of XBRL tags enables automated processing of business information by computer software, cutting out laborious and costly processes of manual re-entry and comparison. Computers can treat XBRL data "intelligently": they can recognise the information in a XBRL document, select it, analyse it, store it, exchange it with other computers and present it automatically in a variety of ways for users. XBRL greatly incre the speed of handling of financial data, reduces the chance of error and permits automati checking of information.

Companies can use XBRL to save costs and streamline their processes for collecting and reporting financial information. Consumers of financial data, including investors, analysts financial institutions and regulators, can receive, find, compare and analyse data much m rapidly and efficiently if it is in XBRL format.

XBRL can handle data in different languages and accounting standards. It can flexibly be adapted to meet different requirements and uses. Data can be transformed into XBRL by suitable mapping tools or it can be generated in XBRL by appropriate software.

The How XBRL Works page gives further explanation of XBRL, while Benefits and Uses se out how different types of organisation can gain from the standard.

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NB: (2.)-(4.) are interleaved.

Contracts in E-Commerce Lifecycle

- Discovery, advertising, matchmaking
  - Search, sourcing, qualification/credit checking
- Negotiation, bargaining, auctions, selection, forming agreements, committing
  - Hypothetical reasoning, what-if'ing, valuation
- Performance/execution of agreement
  - Delivery, payment, shipping, receiving, notification
- Problem Resolution, Monitoring
  - Exception handling

Approach: *Rule-based Contracts for E-commerce*

- Rules as way to specify (part of) business processes, policies, products: as (part of) contract terms.
- Complete or partial contract.
  – As default rules. Update, e.g., in negotiation.
- Rules provide high level of conceptual abstraction.
  – easier for non-programmers to understand, specify, dynamically modify & merge. E.g.,
  – by multiple authors, cross-enterprise, cross-application.
- Executable. Integrate with other rule-based business processes.

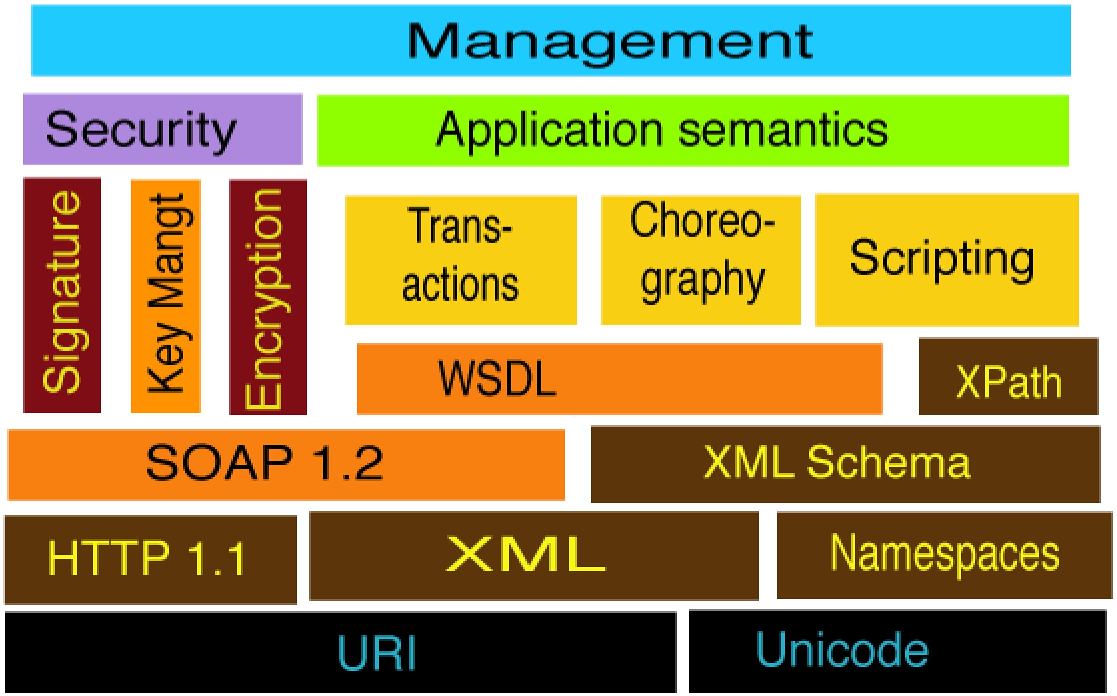
Semantic Web Services

- Convergence of Semantic Web and Web Services
- Consensus definition and conceptualization still forming
- Semantic (Web Services):
  - Knowledge-based service descriptions, deals
    - Discovery/search, invocation, negotiation, selection, composition, execution, monitoring, verification
    - Advantage: **reuse** of knowledge across apps, these tasks
  - Integrated knowledge
- (Semantic Web) Services: e.g., infrastructural
  - Knowledge/info/DB integration
  - Inferencing and translation

Rule-based Semantic Web Services

- Rules often good to executably specify service process models
  - e.g., business process automation using procedural attachments to perform side-effectful/state-changing actions ("effectors" triggered by drawing of conclusions)
  - e.g., rules obtain info via procedural attachments ("sensors" test rule conditions)
  - e.g., rules for knowledge translation or inferencing
  - e.g., info services exposing relational DBs
- Infrastructural: rule system functionality as services:
  - e.g., inferencing, translation

W3C Web Services Stack (2004)



NOTES:

WSDL is a Modular Interface spec
SOAP is Messaging and Runtime
Also:
- UDDI is for Discovery
- BPEL4WS, WSCI, …
  are for transactions
- Routing, concurrency, …

Diagram courtesy Tim Berners-Lee: http://www.w3.org/2004/Talks/0309-ws-sw-tbl/slide6-0.html

SWS Language effort (2005), on top of Web Services Standards Stack

"Wire" Protocols | **Service Description**

W3C WS Choreography Group
BPEL4WS (Microsoft, IBM, BEA)
WSCL (HP)BPML (Most but Microsoft)
WSCI (Sun, BEA, Yahoo, …)
XLANG (Microsoft), WSFL (IBM), …

"Wire" Protocols:
- SOAP Blocks
- SOAP/XMLP
- XML
- HTTP/SMTP
- TCP/IP

Service Description:
- SWS Language
- Process
- WSDL Extensions
- WSDL
- XML

- Registry (UDDI)
- Inspection

SWS Initiative (SWSI)
-- automate Tasks of:
Discovery
Invocation
Interoperation
Deal Negotiation
Composition
Monitoring
Verification

[Slide authors: Benjamin Grosof (MIT Sloan), Sheila McIlraith (Stanford) , David Martin (SRI International), James Snell (IBM)]

Semantic Web Services Framework (SWSF)

- By Semantic Web Services Initiative (SWSI) http://www.swsi.org
  - Coordinated global research and standards design in SWS during 2002-2005
  - Researchers from universities, companies, government
  - Industrial partners; DAML and WSMO backing
  - Collaborators: OWL-S, WSMO, RuleML, DAML
- Designed SWSF in 2005: http://www.daml.org/services/swsf/1.0/
  - Rules & FOL language (SWSL/RuleML)
  - Ontology for SWS (SWSO)
    - Drawn largely from OWL-S and PSL
  - Application Scenarios
  - *Also: requirements analysis*
- Influential, explored the issues
  - ⇒W3C SAWSDL – Semantic Annotations for WSDL and XML Schema
    - Extension mechanism – a hook – with shallow semantics in itself

SWS(F) Tasks Form 2 Distinct Clusters, each with associated Central Kind of Service-description Knowledge and Main KR

1. Security/Trust, Monitoring, Contracts, Advertising/Discovery, Ontology-mapping Mediation
   - Central Kind of Knowledge: Policies
   - Main KR: Nonmonotonic LP (rules + ontologies)

2. Composition, Verification, Enactment
   - Central Kind of Knowledge: Process Models
   - Main KRs: FOL + Nonmonotonic LP

Rule-based Semantic Web Services

- Rules/LP in appropriate combination with DL as KR, for RSWS
  - DL good for <u>categorizing</u>: a service overall, its inputs, its outputs
- Rules to describe <u>service process models</u>
  - rules good for representing:
    - <u>preconditions</u> and <u>postconditions</u>, their contingent relationships
    - <u>contingent</u> behavior/features of the service more generally,
      - e.g., exceptions/problems
  - familiarity and naturalness of rules to software/knowledge engineers
- Rules to specify <u>deals about services</u>: cf. e-contracting.

Services Engineering Lifecycle

1. Expressive standardized semantic rules can help with several long-standing challenges in services engineering, across the whole lifecycle:
   - Reuse, interoperability, integration, context, transparency, governance
   - Cost reduction, agility
   - Etc.

2. Frequent tasks:
   - Monitoring: events / exceptions → react, policy-based agile workflows
   - Confidentiality: authorizations for access, transactions
   - Contractual: ads, trades / e-commerce, SLAs

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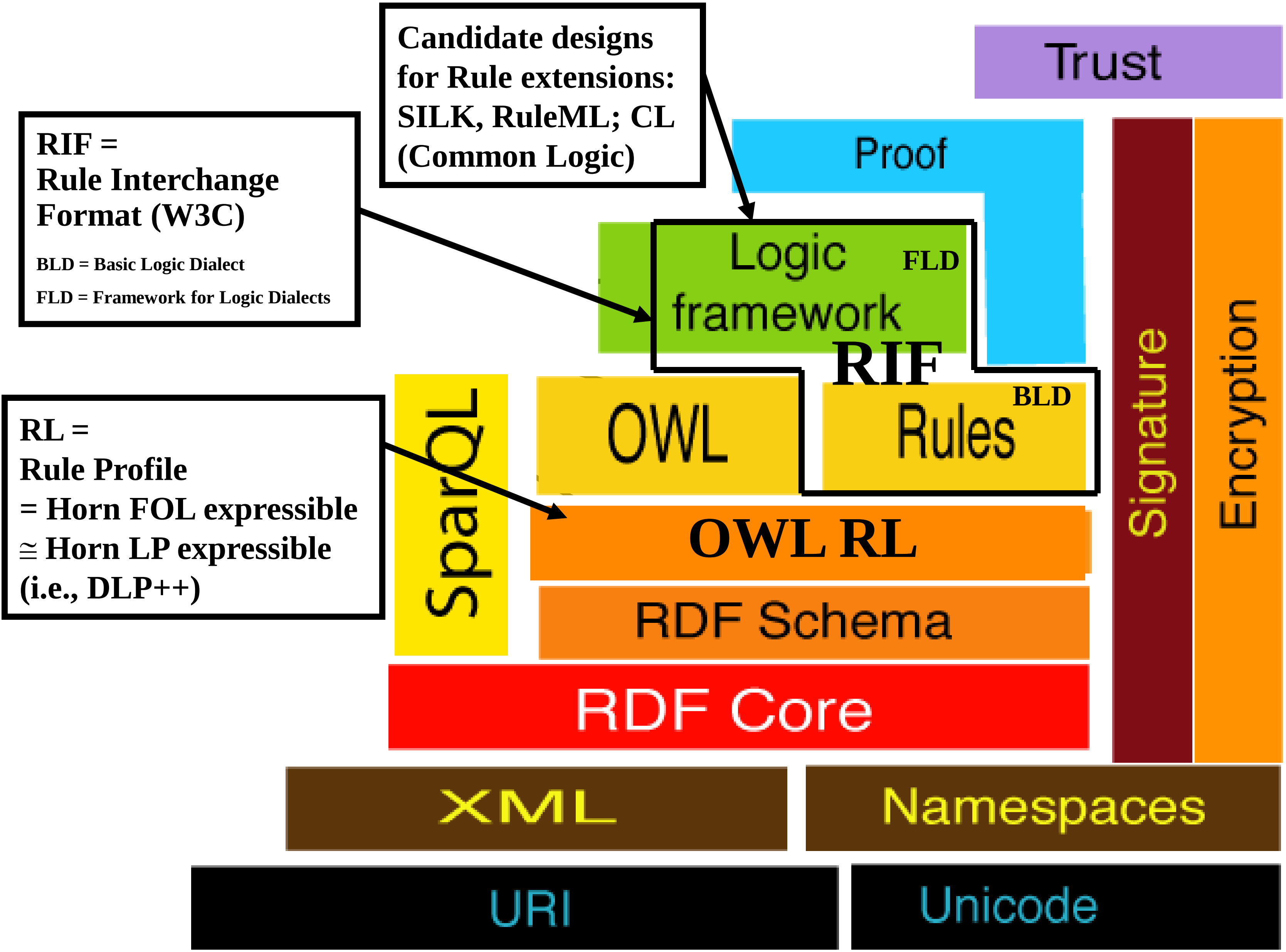
PART B. SLIDES FOLLOW

Outline of Part B. Concepts & Foundations

1. Overview of Logical Knowledge Representations
   - Logic Programs (LP) and its relationship to First Order Logic (FOL)
   - Rule-based Ontologies: Description Logic, Description LP
2. SILK's Hyper LP: Putting it all together
3. Basics: Horn Case; Functions
4. F-Logic, Frame Syntax, Object Oriented Style
5. HiLog, Higher-Order Syntax, Reification, Meta-Reasoning
6. W3C Rule Interchange Format (RIF): Dialects, Framework
   - Rules in W3C Web Ontology Language (OWL-RL); via RIF
7. Nonmonotonic LP: Defaults, Negation, Priorities, FOL Interchange
   - Semantics for Default Negation
   - Courteous LP, Argumentation Theories
   - Omni-directional Rules, FOL-Soundness, Remedying FOL's Fragility
8. Procedural Attachments to Actions, Queries, Built-ins, and Events
   - Production/Situated LP, Production Rules
9. Additional Features: Integrity Constraints, Inheritance, Lloyd-Topor, Equality, Skolemization, Aggregation, Datatypes, "Constraints"

Updated: 06-2010 Semantic Web "Stack"



Modified from slide by W3C (just added annotation)

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 <u>entailment</u> 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 <u>models</u>, i.e., truth assignments that satisfy the premises and meet other criteria.

Background: Example KR's

1. Relational <u>databases</u>: relational algebra.
   - This is a restricted form of declarative Logic Programs ("Datalog Horn").
2. Mathematical <u>classical logic</u>: first-order logic (FOL), higher-order logic.
   - Used in verification of programs, for example.
3. <u>Rules</u> in various flavors.
   - Central abstraction: declarative Logic Programs, which extend Horn FOL.
     - (Core) SQL database is an LP rulebase.
4. Many others: Bayesian probabilistic networks, inductive learning, Description Logic, fuzzy logic, temporal modal logic, etc.

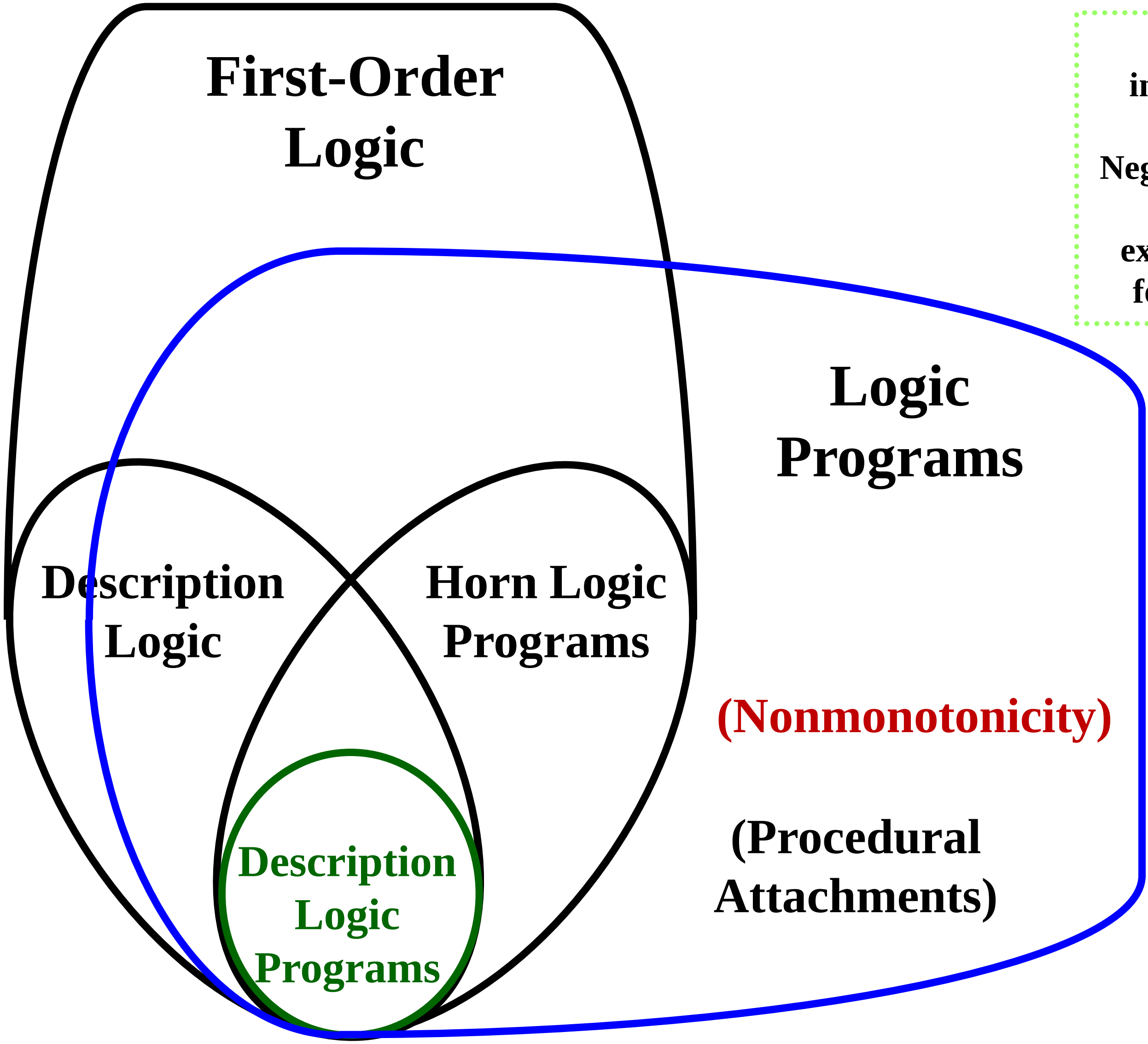
Knowledge Representation: What's the Game?

- Expressiveness: useful, natural, complex enough
- Reasoning algorithms
- Syntax: encoding data format   -- here, in XML
- Semantics: principles of sanctioned inference, independent of reasoning algorithms
- Computational Tractability (esp. worst-case): scale up in a manner qualitatively similar to relational databases: computation cycles go up as a polynomial function of input size

Overview of Logic Knowledge Representation (KR) and Markup Standards

- First Order Logic (FOL). Also called "classical logic", as is HOL (below).
  - Standards efforts:
    - ISO Common Logic (CL); FOL RuleML
  - Restriction: Horn FOL
  - Restriction: Description Logic (DL) – overlaps with Horn
    - Standard: W3C OWL-DL (Web Ontology Logic)
  - Extension: Higher Order Logic (HOL)
    - HiLog = higher order syntactically, but reducible to first order
- Logic Programs (LP)
  - (Here: in the *declarative* sense.)
  - Standard: W3C RIF (Rule Interchange Format)
  - Standard designs for additional expressiveness: RuleML / SWSL / SILK
  - Extension features: HiLog; also:
    - Nonmonotonicity: Negation, Defaults (cf. Courteous)
    - Procedural attachments for external queries, events, actions
  - Restriction: Horn LP
  - Restriction: Description Logic Programs (DLP) – overlaps with DL

Venn Diagram: Expressive Overlaps among KRs



NB: Nonmon LP, including Courteous, relies on Default Negation as fundamental underlying KR expressive mechanism for nonmonotonicity

Description Logic cf. OWL 2: *KR Expressiveness*

- Restriction of First Order Logic (FOL)
  - Strongest restriction is on the patterns of variable appearances
    - Cannot represent many kinds of chaining (joins) among predicates
  - No logical functions
- Allows:
  - Class predicates of arity 1
  - Property predicates of arity 2 (Indirectly can represent n-ary predicates)
  - Membership axioms: foo instanceOf BarClass
  - Inclusion axioms between classes (possibly complex)
    - C1 subclassOf C2
    - I.e., x instanceOf C1 $\Rightarrow$ x instanceOf C2
  - Complex class expressions, e.g.
    - Electrical device that has two speakers and a 120V or 220V power supply
  - Property chaining, with some restrictions *(feature added to OWL 2)*
- Good for representing:
  - Many kinds of ontological schemas, including taxonomies
  - Taxonomic/category subsumptions (with strict inheritance)
  - Some kinds of categorization/classification and configuration tasks

Summary of Computational Complexity of KRs

- *For task of inferencing, i.e., answering a given query.*
  - *Tractable = time is polynomial in n, worst-case; n = |premises|*

- First Order Logic (FOL)
  - Intractable for Propositional (co-NP-complete)
  - Undecidable in general case
  - Decidable but intractable for Description Logic

- Logic Programs (LP) with extensions for negation, defaults, HiLog, frames, attached procedures, …
  - Tractable for broad cases; same as Horn
    - $O(n^2)$ for Propositional with negation and defaults
    - Complexity qualitatively similar to Relational DBs
    - Truly Web-scaleable, therefore
  - Undecidable in general (cause: infinite recursion through functions)

More on Computational Complexity of LP

- O(n) for propositional Horn. (Ditto in FOL.)
- O(n·m) for propositional with negation (well-founded), where m = # atoms ($m \leq n$)
  - Defaults add no increase in the complexity bound (reducible linearly to NAF)
- Typically-met restrictions:
  - Constant-bounded number of distinct variables per rule (VB restriction)
    - In DL form of DLP, VB ≡ constant-bounded number of distinct DL quantifiers (incl. min/max cardinality) in class descriptions per inclusion axiom
  - Time per attached procedure call is tractable (AT restriction)
- Most feature extensions can be added to LP without affecting tractability
- Key restriction to ensure tractability (or decidability) is to:
  - Avoid blow-up from <u>recursion through logical functions</u> (of arity > 0)
    - ⇒ Keep the relevant set of ground atoms tractable (or finite)
    - Here, recursion means dependency cycles among rules
  - E.g., function-free is a simple sufficient condition
    - Then # of ground atoms = $O(n^{v+1})$, where v is the bound in VB
  - *More research on detailed theory and algorithms is needed, however*

Updated: 10-2010 Semantic Web “Stack”

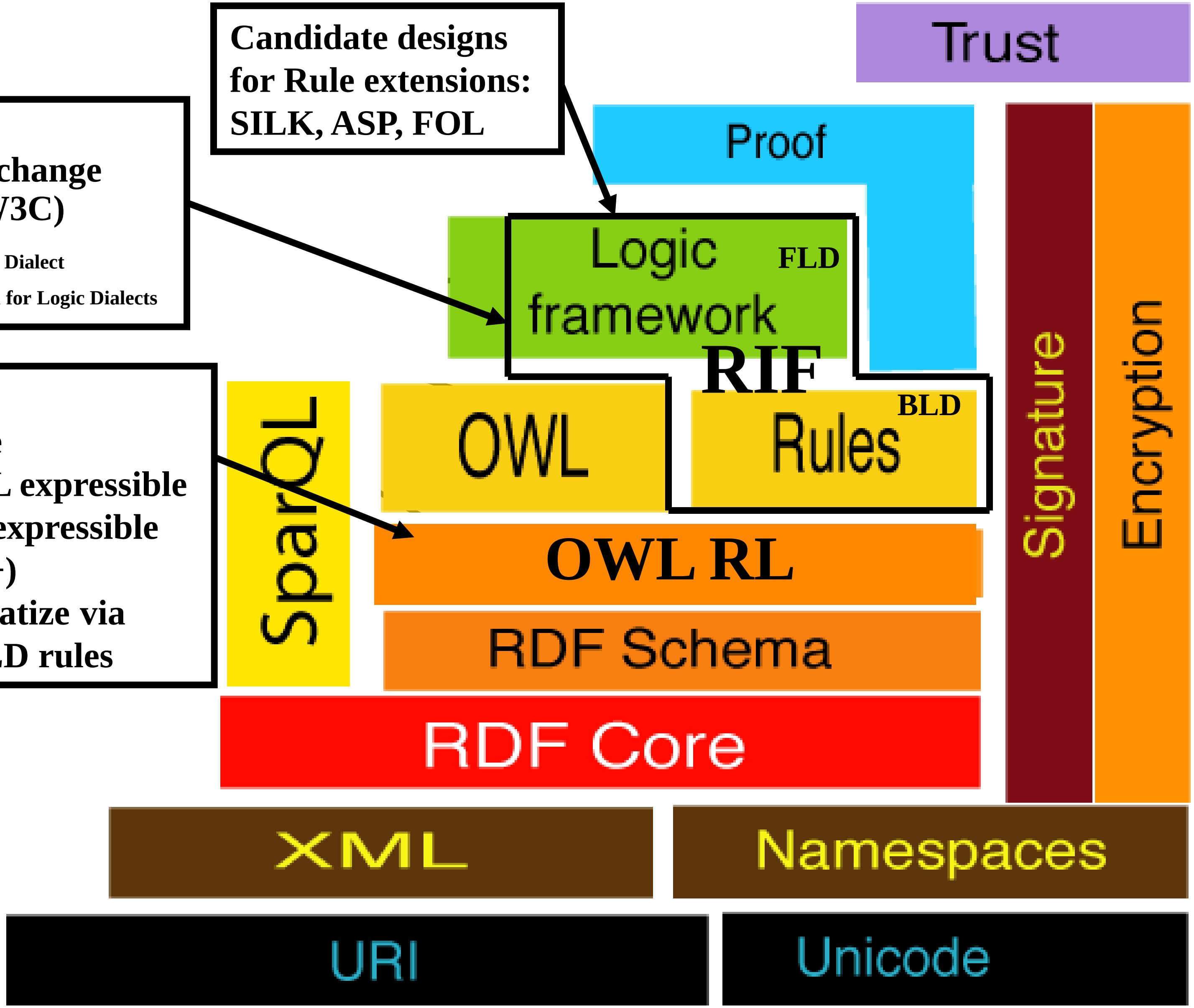
Candidate designs for Rule extensions: SILK, ASP, FOL

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++)
E.g., axiomatize via
~70 RIF-BLD rules



Modified from slide by W3C (just added annotation)

KR View of Semantic Web related standards

Hazy wrt Standardization: more Framework

– Uncertainty (probabilistic, fuzzy); Provenance (proof, trust)

Logical Framework standards/designs: RIF-FLD, RuleML, SILK

LP (Logic Programs)

- **Umbrella standards/designs**
  - SILK
  - RuleML-LP
- **Database Query Standards***
  - SQL
  - SPARQL
  - XQuery
- **Business Rules Families***
  - Production
    - RIF-PRD
  - ECA (Event-Condition-Action)
  - Prolog

FOL (First Order Logic)

- **Umbrella standards/designs:**
  - CL (ISO Common Logic)
  - RuleML-FOL
- **Semantic/Web Standards (other)**
  - RDF
  - RDFS (Schema)
  - OWL RL (Rule Profile)
  - RIF-BLD (Basic Logic Dialect)
    - (and SWRL)
  - OWL DL (Description Logic)
  - OWL Full
  - SBVR (OMG Semantic Business Vocabulary and Rules)

*Via KR mapping to LP, maybe with restrictions

KR View of Semantic Web related standards

Hazy wrt Standardization: more Framework

– Uncertainty (probabilistic, fuzzy); Provenance (proof, trust)

Logical Framework standards/designs: RIF-FLD, RuleML, SILK

LP

- **Horn**
- **Rest**

FOL

- **Umbrella standards/designs:**
  - CL (ISO Common Logic)
  - RuleML-FOL
- **Semantic/Web Standards (other)**
  - RDF
  - RDFS (Schema)
  - OWL RL (Rule Profile)
  - RIF-BLD (Basic Logic Dialect)
    - (and SWRL)
  - OWL DL (Description Logic)
  - OWL Full
  - SBVR (OMG Semantic Business Vocabulary and Rules)

*

*Via KR mapping to LP (sound, nearly complete)

KR View of Semantic Web related standards

Hazy wrt Standardization: more Framework

– Uncertainty (probabilistic, fuzzy); Provenance (proof, trust)

Logical Framework standards/designs: RIF-FLD, RuleML, SILK

LP

- **Umbrella standards/designs**
  - SILK

*

Sound, but incomplete

➢ lack disjunctiveness

(no reasoning-by-cases)

FOL

*Via KR mapping to LP (hypermonotonic)

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SILK research program (2008-) in Vulcan's Project Halo

- **For 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. E.g., textbooks/exams.
  - 1st yr college-level Biology is current domain focus: complex causal processes
- **Advanced KR language and system, for esp. defaults & processes**
  - Largest* rule research program in USA. Multi-institutional: primarily via contractors.
  - 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
- **Potential application areas in business and government**
  - Horizontal: policies, workflows; ontology mapping, knowledge integration
  - Vertical: e-commerce, defense intelligence, trust, biomed, financial, mobile
- **http://silk.semwebcentral.org**

* (that we're aware of)

SILK Contributors current/past (partial list)

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

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.

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]

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

SILK's KR: Hyper Logic Programs

- **New Extension of LP that is the first to combine key advanced features**
- **Defaults + Higher-Order + External Actions/Events/Queries**
  - + Webized, Frames, Negation (neg and naf), Equality, Functions, Skolems, Aggregates, Integrity Constraints, Lloyd-Topor, …
- **Omni-directionality: new feature**
  - Permit head disjunction, treat via directionalization. Handle multi-way conflicts.
  - Much broader FOL-sound interchange: any clause or universal formula, not just Horn
- **Transforms knowledge from higher to lower abstraction levels**
  - Raises expressive abstraction level. Higher is good for **knowledge acquisition (KA)**
  - Lower is good for reasoning (code reuse, optimization) and knowledge interchange
- **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"
- **Uses new *argumentation theory* approach to defaults**
  - ~20 "meta-" rules specify debate principles for defeat. Much easier to implement than code.
  - Enables much more expressiveness (e.g., HiLog). Much more efficient when updating.
- **RIF-SILK dialect extends RIF-BLD (Basic Logic Dialect)**

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

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

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Horn FOL

- The Horn subset of FOL is defined relative to clausal form of FOL
- A Horn clause is one in which there is at most one positive literal.

  It takes one of the two forms:

  1. $H \lor \neg B1 \lor \ldots \lor \neg Bm$. A.k.a. a definite clause / rule
     - Fact H . is special case of rule (H ground, m=0)
  2. $\neg B1 \lor \ldots \lor \neg Bm$. A.k.a. an integrity constraint

  where $m \geq 0$, H and Bi's are atoms. (An atom = pred(term_1,…,term_k) where pred has arity k, and functions may appear in the terms.)

- A definite clause (1.) can be written equivalently as an implication:
  - Rule := $H \Leftarrow B1 \land \ldots \land Bm$. where $m \geq 0$, H and Bi's are atoms

    head if body ;

- An integrity constraint (2.) can likewise be written as:
  - $\perp \Leftarrow B1 \land \ldots \land Bm$. A.k.a. empty-head rule ($\perp$ is often omitted).

  For refutation theorem-proving, represent a negated goal as (2.).

Horn LP Syntax and Semantics

- Horn LP syntax is similar to implication form of Horn FOL
  - The implication connective's semantics are a bit weaker however. We will write it as $\leftarrow$ (or as :-) instead of $\Leftarrow$.
  - Declarative LP with model-theoretic semantics
  - Same for forward-direction ("derivation" / "bottom-up") and backward-direction ("query" / "top-down") inferencing
  - Model M(P) = a set of (concluded) ground atoms
    - Where P = the set of premise rules
- Semantics is defined via the least fixed point of an operator T_P. T_P outputs conclusions that are immediately derivable (through some rule in P) from an input set of intermediate conclusions I_j.
  - $I_{j+1} = T_P(I_j)$; $I_0 = \varnothing$ (empty set)
    - I_{j+1} = {all head atoms of rules whose bodies are satisfied by I_j}
  - M(P) = LeastFixedPoint(T_P) ; where LFP = the I_m such that $I_{m+1} = I_m$
  - Simple algorithm: `DO` {run each rule once} `UNTIL` {quiescence}

Example of Horn LP vs. Horn FOL

- Let P be:
  - DangerousTo(?x,?y) ← PredatorAnimal(?x) ∧ Human(?y);
  - PredatorAnimal(?x) ← Lion(?x);
  - Lion(Simba);
  - Human(Joey);
- I1 = {Lion(Simba), Human(Joey)}
- I2 = {PredatorAnimal(Simba),Lion(Simba), Human(Joey)}
- I3 = {DangerousTo(Simba,Joey), PredatorAnimal(Simba),Lion(Simba), Human(Joey)}
- I4 = I3. Thus M(P) = I3.

- Let P' be the Horn <u>FOL</u> rulebase version of P above, where ⇐ replaces ←.
- Then the ground atomic conclusions of P' are exactly those in M(P) above.
- P' also entails various non-ground-atom conclusions, including:

1. Non-unit derived clauses, e.g., DangerousTo(Simba,?y) ⇐ Human(?y).
2. All tautologies of FOL, e.g., Human(?z) ∨ ¬Human(?z).
3. Combinations of (1.) and (2.), e.g., ¬Human(?y) ⇐ ¬DangerousTo(Simba,?y).

Horn LP Compared to Horn FOL

- <u>Fundamental Theorem connects Horn LP to Horn FOL</u>:
  - M(P) = {all ground atoms entailed by P in Horn <u>FOL</u>}

- Horn FOL has additional non-ground-atom conclusions, notably:
  - non-unit derived clauses; tautologies
- Can thus view Horn LP as the <u>f-weakening</u> of Horn FOL.
  - "f-" here stands for "<u>f</u>act-form conclusions only"
  - A restriction on form of <u>conclusions</u> (not of premises).
- Horn <u>LP</u> – differences from Horn <u>FOL</u>:
  - Conclusions Conc(P) = essentially a set of ground atoms.
    - Can extend to permit more complex-form queries/conclusions.
  - Consider Herbrand models only, *in typical formulation and usage*.
    - P can then be replaced equivalently by {all ground instantiations of each rule in P}
    - But can extend to permit: extra unnamed individuals, beyond Herbrand universe
  - Rule has non-empty head, *in typical formulation and usage*.
    - Can extend to detect violation of integrity constraints

The "Spirit" of LP

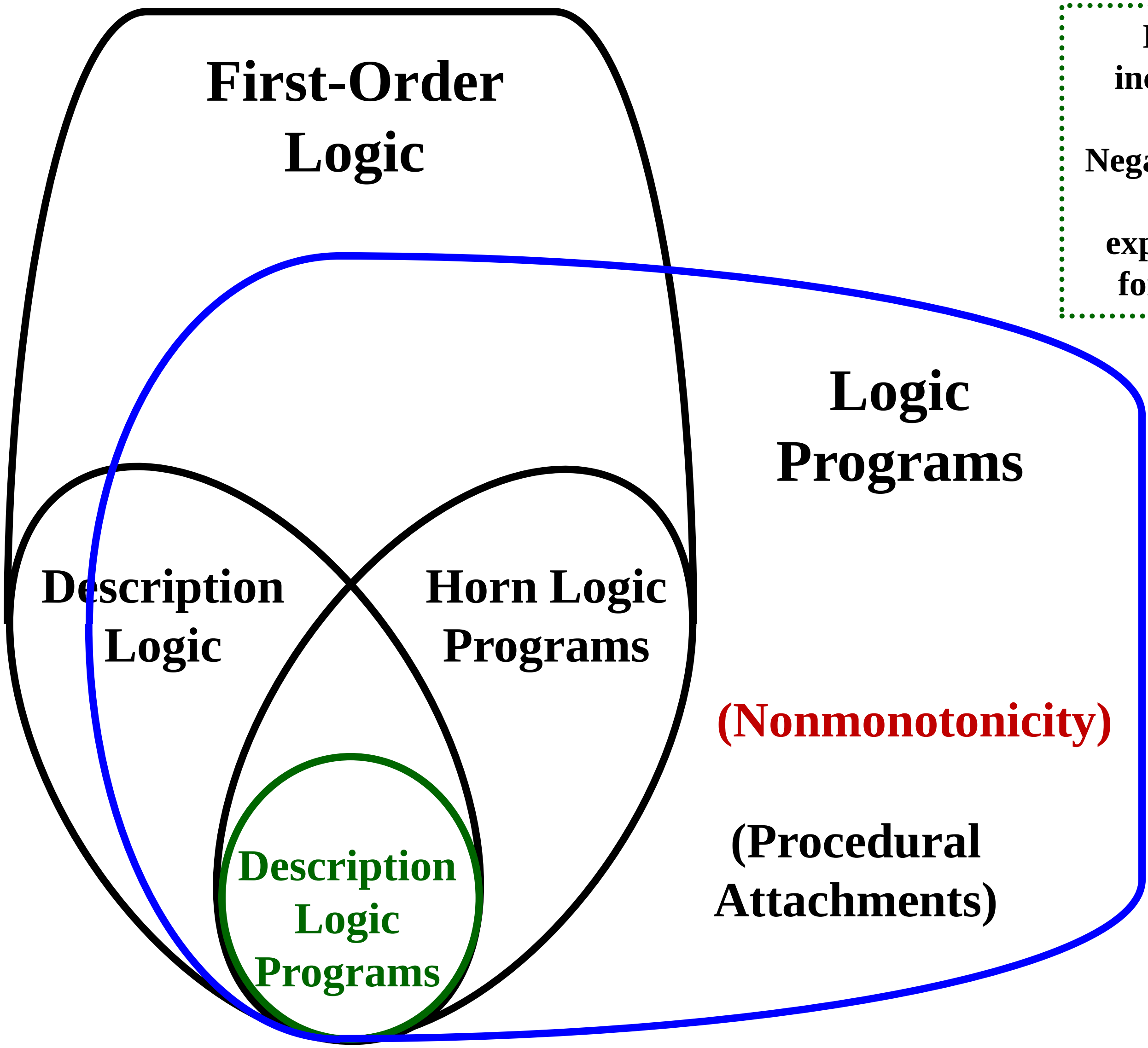
The following summarizes the "spirit" of how LP differs from FOL:

- "Avoid Disjunction"
  - Avoid disjunctions of positive literals as expressions
    - In premises, intermediate conclusions, final conclusions
    - (conclude (A or B)) only if ((conclude A) or (conclude B))
  - Permitting such disjunctions creates exponential blowup
    - In propositional FOL: 3-SAT is NP-hard
    - In the leading proposed approaches that expressively add disjunction to LP with negation, e.g., propositional Answer Set Programs
  - No "reasoning by cases", therefore
- "Stay Grounded"
  - Avoid (irreducibly) non-ground conclusions

LP, unlike FOL, is straightforwardly extensible, therefore, to:

- Nonmonotonicity – defaults, incl. NAF
- Procedural attachments, esp. external actions

Venn Diagram: Expressive Overlaps among KRs



NB: Nonmon LP, including Courteous, relies on Default Negation as fundamental underlying KR expressive mechanism for nonmonotonicity

Requirements Analysis for Logical Functions

- Function-free is a commonly adopted restriction in practical LP/Web rules today
  - DB query languages: SQL, SPARQL, XQuery
  - RDFS
  - Production rules, and similar Event-Condition-Action rules
  - OWL

- BUT functions are often needed for Web (and other) applications. Uses include:
  - HiLog and reification – higher-order syntax
    - For <u>meta-</u> reasoning, e.g., in knowledge exchange or introspection
      - Ontology mappings, provenance, KB translation/import, multi-agent belief, context
      - KR macros, modals, reasoning control, KB modularization, navigation in KA
      - Meta-data is important on the Web
  - Skolemization – to represent existential quantifiers
    - E.g., RDF blank nodes
  - Convenient naming abstraction, generally
    - steering_wheel(my_car)

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Frame Syntax and F(rame)-Logic

- An object-oriented first-order logic
- Extends predicate logic with
  - Objects with complex internal structure
  - Class hierarchies and inheritance
  - Typing
  - Encapsulation
- A basis for object-oriented logic programming and knowledge representation

$$\frac{\text{O-O programming}}{\text{F-logic}} = \frac{\text{Relational programming}}{\text{Predicate calculus}}$$

- Background:
  - Basic theory: [Kifer & Lausen SIGMOD-89], [Kifer, Lausen, Wu JACM-95]
  - Path expression syntax: [Frohn, Lausen, Uphoff VLDB-84]
  - Semantics for non-monotonic inheritance: [Yang & Kifer, ODBASE 2002]
  - Meta-programming + other extensions: [Yang & Kifer, Journal on Data Semantics 2003]

Major F-logic Based Languages

- *FLORA-2* - an open source system developed at Stony Brook U.
- *OntoBroker* – commercial system from Ontoprise.de
- *WSMO* (Web Service Modeling Ontology) – a large EU project that developed an F-logic based language for Semantic Web Services, *WSML-Rule*
- *SWSI* (Semantic Web Services Initiative) – an international group that proposed an F-logic based language *SWSL-Rules* (also for Semantic Web Services)
- RuleML supports it as an included extension, developed in collaboration with SWSI
- *TRIPLE* – an open source system for querying RDF
- *SILK*

F-logic Examples

Object Id

attributes

Object description:

John[*name* –> ‘John Doe’ and *phones* –> {6313214567, 6313214566},
children –> {Bob, Mary}]

Mary[*name* –>’Mary Doe’, *phones* –> {2121234567, 5129297945},
children –> {Anne, Alice}]

Structure can be nested:

Sally[*spouse* –> John[*address* –> ‘123 Main St.’]]

F-Logic Examples (cont.'d)

ISA hierarchy:

John # Person // *class membership*
Mary # Person
Alice # Student

Student ## Person // *subclass relationship*

Class & instance in different contexts

Student # EntityType
Person # EntityType

F-Logic Examples (cont.'d)

"Methods": like attributes, but can take arguments

?S[*professor*(?Course) –> ?Prof] **: -**

?S:student[*took*(?Semester) –>?Course[*taught*(?Semester)–> ?Prof]];

- *professor*, *took*, *taught* – 1-argument methods
- object attributes can be viewed as 0-ary methods

Queries:

?− Alice[*professor*(?Course) –> ?P], ?Course # ComputerScienceCourse;

Alice's CS professors.

F-Logic Examples (cont.'d)

Browsing the IsA hierarchy:

?– John # ?X ; *// all classes of which John is a member*

?– Student ## ?Y; *// all superclasses of class* student

*Rule defining a **virtual** class of red cars*

Defining a virtual class:

?X # RedCar **:–** ?X # Car and ?X[*color* –> red];

Rule defining a method that returns attributes whose range is class ?Class

Complex meta-query about schema:

?O[*attributesOf*(?Class) –> ?*Attr*] **:–**
?O[?*Attr* –>?Value] and ?Value # ?Class;

Remark: Semantics for HiLog & F-Logic

- The F-logic and HiLog semantics & proof theory
  - Generalize terms and literals
  - Not limited to rules/LP
  - Apply also to classical logic (FOL) – and other logics
  - Sound & complete

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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
- Appears promising for OWL Full and its use of RDF [Kifer; Hayes]

- Implemented in FLORA-2 and SILK
  - Also partially exists in XSB, Common Logic, others
- [Chen, Kifer, Warren, "HiLog: A Foundation for Higher-Order Logic Programming", J. of Logic Programming, 1993]

Examples of HiLog

Variables over predicates and function symbols:

p(?X,?Y) **:-** ?X(a,?Z) and ?Y(?Z(b));

Variables over atomic formulas (*reification***):**

p(q(a));

r(?X) **:-** p(?X) and ?X;

A use of HiLog in FLORA-2 and SILK **(**e.g., even more complex schema query**):**

?Obj[*unaryMethods*(?Class) –> ?*Method*] **:-**
?Obj[?*Method*(?Arg) –> ?Val] and ?Val # ?Class;

Meta-variable*: ranges over unary method names*

Reification

- Blending HiLog with F-logic also allows **reification** – making objects out of formulas:

    john[believes -> **${**mary[likes -> bob]**}**]

- Introduced in [Yang & Kifer, ODBASE 2002]

- Rules can also be reified

Object made out of the formula mary[likes -> bob]

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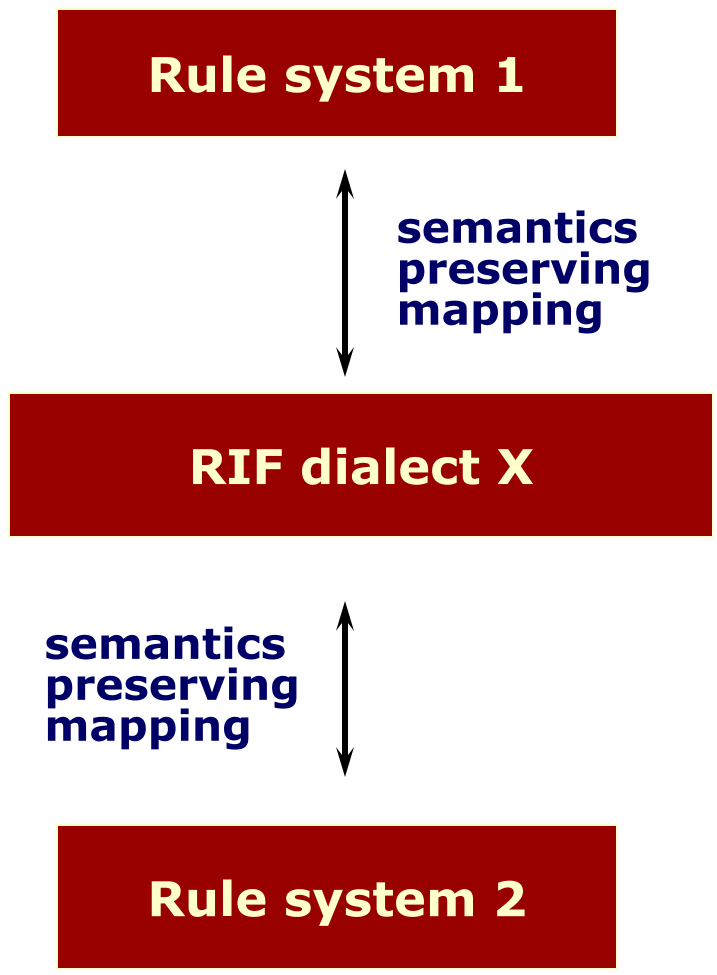
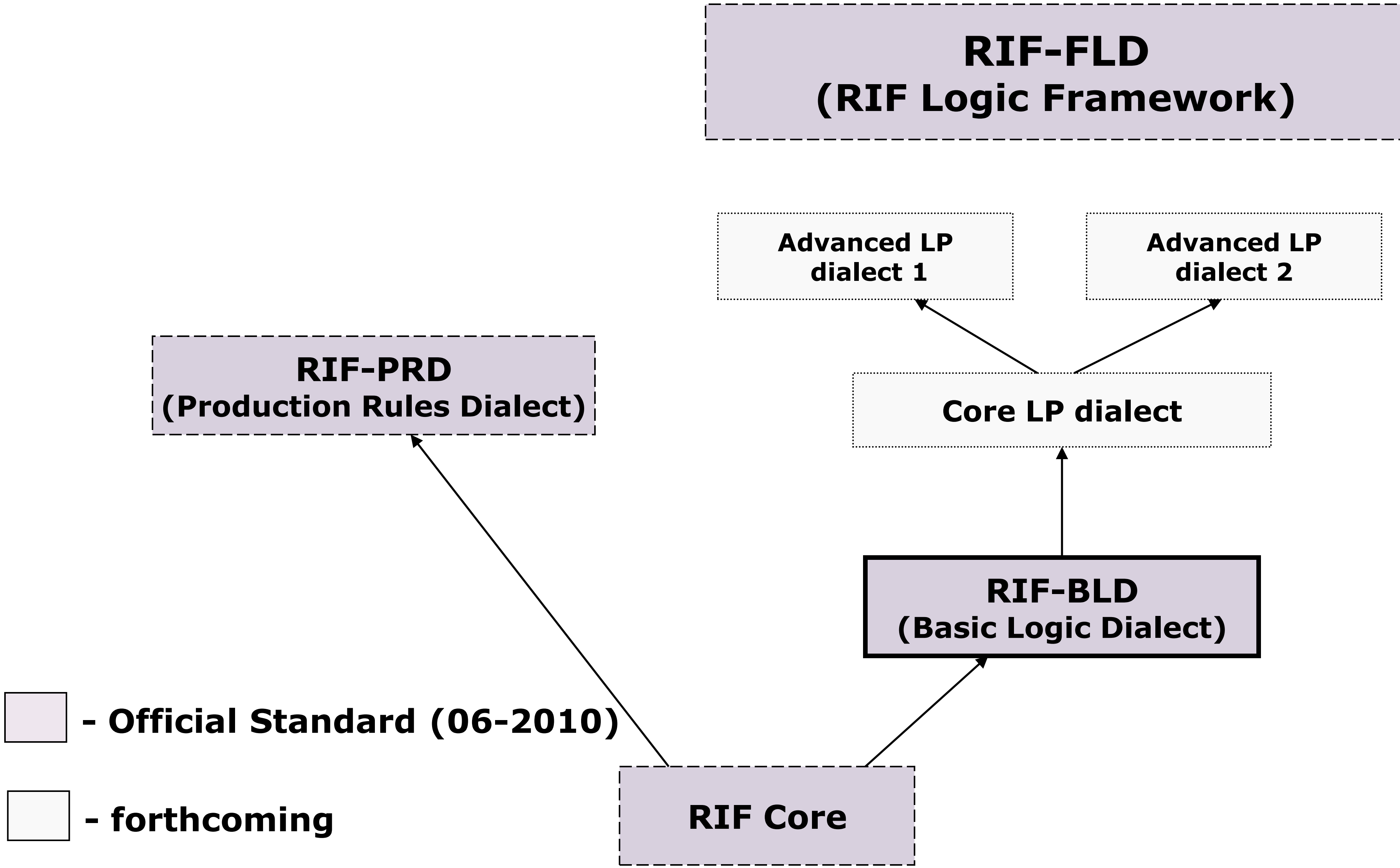
What is RIF?

- A collection of *dialects* (rigorously defined rule languages)
- Intended to facilitate rule sharing and exchange
- XML is medium of exchange
- Dialect consistency

  Sharing of RIF machinery:
  - XML
  - syntactic elements
  - elements of semantics



Current State of RIF



The Basic Logic Dialect (BLD)

- Basically Horn rules (no negation) plus
  - Frames
  - Predicates/functions with named arguments
  - Equality both in rule premises and conclusions
- Web-ized
  - XML data types
  - IRIs throughout
- Semantic Web integration
  - Can import RDF and OWL
  - BLD + OWL $\supset$ SWRL

RIF-CORE and RIF-PRD

- RIF-Core is defined by restricting BLD
  - No function symbols
  - Equality only in rule body
  - Decidable (module the built-ins)
- RIF-PRD – a separate branch of dialects
  - Contains RIF-Core
  - Procedural, not logic-based
  - Shares much of the notational machinery with BLD

Why RIF Framework (RIF-FLD)?

- Too hard to define dialects from scratch
  - RIF-BLD is just a tad more complex than Horn rules, but requires more than 30 pages of dense text
- Instead: define dialects by *specializing* from another dialect
  - RIF-BLD can be specified in < 3pp in this way
- A "*super-dialect*" is needed to ensure that all dialects use the same set of concepts and constructs
- RIF Framework is intended to be just such a super-dialect
- Several LP dialects are defined by specializing RIF-FLD
  - -SILK http://silk.semwebcentral.org/RIF-SILK.html
  - -CLPWD (core well-founded) http://ruleml.org/rif/RIF-CLPWD.html
  - -CASPD (core ASP) http://ruleml.org/rif/RIF-CLPWD.html
- Even RIF-BLD was initially defined by specialization from RIF-FLD

RIF-FLD Features

- Not a completely specified logic by itself: dialects are required to specify a number of parameters (to specialize)
- Highly extensible syntax and semantics
- Supports most forms of non-monotonic reasoning (e.g., various forms of negation, defaults)
- … And classical logic

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OWL-RL

- RL is a standard OWL 2 “Profile” (= subset) designed for implementations based on rules (LP)
- Syntactic restriction of OWL 2
  - Omits DisjointUnion, ReflexiveObjectProperty, cardinalities > 1, owl:real, and owl:rational
  - I.e., Horn + a little
- Inspired by Description Logic Programs (DLP) and pD*.
- PTIME-complete complexity.
- Includes a partial axiomatization as 70+ rules
- http://www.w3.org/TR/2009/REC-owl2-profiles-20091027/#OWL_2_RL

OWL-RL in RIF

- Representation of OWL 2 RL axiomatization rules in RIF-Core
- Can be implemented via either
  - Static rules
  - Translation algorithm
- E.g., approach is used in Oracle, SILK
- http://www.w3.org/TR/rif-owl-rl/
  - Currently a W3C Working Group Note

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)
    - http://silk.semwebcentral.org/RIF-SILK.html
    - 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

RIF and OWL-RL in SILK V2.2

- RIF support
  - Import RIF-BLD
  - Export RIF-BLD (lossy)
  - Import RIF-SILK
  - Export RIF-SILK
- OWL-RL support
  - Import RDF/XML
  - Import Turtle
  - OWL-RL in RIF static rules

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Concept of Logical Monotonicity

- A KR S is said to be <u>logically monotonic</u> when in it:

$$P1 \subseteq P2 \quad \Rightarrow \quad Conc(P1,S) \subseteq Conc(P2,S)$$

- Where P1, P2 are each a set of premises in S
- I.e., whenever one adds to the set of premises, the set of conclusions non-strictly grows (one does not retract conclusions).

- *Monotonicity is good for pure mathematics.*
  - *"Proving a theorem means never having to say you are sorry."*

Nonmonotonicity – its Pragmatic Motivations

- Pragmatic reasoning is, in general, nonmonotonic
  - E.g., policies for taking actions, exception handling, legal argumentation, Bayesian/statistical/inductive, etc.
  - Monotonic is a special case – simpler in <u>some</u> regards
- Most commercially important rule systems/applications use nonmon
  - A basic expressive construct is ubiquitous there:
    - <u>Default Negation</u> a.k.a. Negation-As-Failure (NAF)
      - BUT with varying semantics – <u>often not fully declarative</u> cf. LP
        - Primarily due to historical hangovers and lack of familiarity with modern algorithms
  - Another expressive construct, almost as ubiquitous there, is:
    - <u>Priorities</u> between rules
- Such nonmonotonicity enables:
  - Modularity and locality in revision/updating/merging

Default Negation: Intro

- Default negation is the most common form of negation in commercially important rule and knowledge-based systems.
- Concept/Intuition for **~**q ; ~ stands for default negation
  - q is not derivable from the available premise info
  - fail to believe q
  - … but might also not believe q to be false
  - A.k.a. "*weak*" negation, or NAF. In ASCII: "naf"
- Contrast with: **¬**q ; ¬ stands for strong negation
  - q is believed to be false
  - A.k.a. *"classical"* negation. In ASCII: "neg"

LP with Negation As Failure

- Normal LP (NLP), a.k.a. *Ordinary* LP (OLP)
  - Adds NAF to Horn LP
- Syntax: Rule generalized to permit NAF'd body literals:
  - $H \leftarrow B_1 \wedge \ \ldots \wedge B_k \wedge \sim B_{k+1} \wedge \ldots \wedge \sim B_m$;

  where m ≥ 0, H and Bi's are atoms

- Semantics has subtleties for the fully general case.
  - Difficulty is interaction of NAF with "recursion", i.e., cyclic dependencies (thru the rules) of predicates/atoms.
  - Lots of theory developed during 1984-1994
  - Well-understood theoretically since mid-1990's

Semantics for LP with Default Negation

- For fully general case, there are two major alternative semantics
- Both agree for a broad restricted case: *stratified* ordinary LP
- *Well Founded* Semantics (WFS): popular, widely used
  - Tractable for the propositional case. Often linear, worst-case quadratic.
  - Major commercial focus. E.g., XSB, OntoBroker.
  - Employs a 3rd truth value u ("undefined"), when non-stratified ("unstratified")
  - Definition uses iterated minimality: Horn-case then close-off; repeat til done.
  - Major limitation: cannot reason by cases
- *Answer Set Programs (ASP)*: popular as research topic
  - Enables a limited kind of disjunction in heads, conclusions
  - Good for combinatorial KR problems requiring nonmonotonicity
  - Only 2 truth values $\Rightarrow$ sometimes ill-defined: no set of conclusions
    - Generalizes earlier "*stable model semantics*"
  - Can reason by cases! $\Rightarrow$ Intractable for propositional case

Basic Example of LP with NAF

- RB1: (NB: this example is purely fictional.)
  - price(Amazon, Sony5401, ?day, ?cust, 49.99)
    ← inUSA(?cust) ∧ inMonth(?day, 2004_10) ∧ ~onSale(?day);
  - price(Amazon, Sony5401, ?day, ?cust, 39.99)
    ← inUSA(?cust) ∧ inMonth(?day, 2004_10) ∧ onSale(?day);
  - inMonth(2004_10_12, 2004_10);
  - inMonth(2004_10_30, 2004_10);
  - inUSA(BarbaraJones);
  - inUSA(SalimBirza);
  - onSale(2004_10_30);
- RB1 entails: (among other conclusions)
  1. Price(Amazon, Sony5401, 2004_10_12, BarbaraJones, 49.99)
  2. Price(Amazon, Sony5401, 2004_10_30, SalimBirza, 39.99)
- RB2 = RB1 updated to add: onSale(2004_10_12);
- RB2 does NOT entail (1.). Instead (nonmonotonically) it entails:
  3. Price(Amazon, Sony5401, 2004_10_12, BarbaraJones, 39.99)

Brief Examples of Non-Stratified Normal LP

- RB3:
  - a;
  - c $\leftarrow$ a $\wedge$ ~b;
  - p $\leftarrow$ ~p;
- Well Founded Semantics (WFS) for RB3 entails conclusions {a,c}. p is not entailed. p has "*undefined*" (u) truth value (in 3-valued logic).
- ASP Semantics for RB3: ill defined; there *is no* set of conclusions.
  - *(NOT there is a set of conclusions that is empty.)*

- RB4:
  - a;
  - c $\leftarrow$ a $\wedge$ ~b;
  - p $\leftarrow$ ~q;
  - q $\leftarrow$ ~p;
- WFS for RB4 entails conclusions {a,c}. p,q have truth value u.
- ASP Semantics for RB4 results in two alternative conclusion sets: {a,c,p} and {a,c,q}. Note their intersection {a,c} is the same as the WFS conclusions.

(Review:) Semantics of Horn LP

- Declarative LP with model-theoretic semantics
  - Same for forward-direction ("derivation" / "bottom-up") and backward-direction ("query" / "top-down") inferencing
- Model M(P) = a set of concluded ground atoms
  - Where P = the set of premise rules

Semantics is defined via the least fixed point of an operator T_P. T_P outputs conclusions that are immediately derivable (through some rule in P) from an input set of intermediate conclusions I_j.

- $I_{j+1} = T_P(I_j)$; $I_0 = \varnothing$ (empty set)
  - I_{j+1} = {all head atoms of rules whose bodies are satisfied by I_j}
- M(P) = LeastFixedPoint(T_P) ; where LFP = the I_m such that $I_{m+1} = I_m$
- Simple algorithm: DO {run each rule once} UNTIL {quiescence}

Well Founded Semantics: Least Model

P : an rulebase over language L

M : a <u>partial</u> Herbrand interpretation

– a set of literals (atoms and *naf* atoms) in the Herbrand Base

– all other atoms/literals have truth value *u* which means "undefined"

Consider ground cases.

- M is a model of P when it satisfies every rule in P
- A model M is a <u>least</u> model of P if it is minimal with respect to ≤
  - $M1 \leq M2$ iff $M1^+ \subseteq M2^+$ and $M1^- \supseteq M2^-$
    - M^+ = the set of *naf*-free literals in M; M^- = the set of *naf* literals in M
    - I.e., the usual notion of "minimal" for LP models
  - If P is Horn, i.e., *naf*-free, then M is said to be the <u>minimal</u> model.
    - In this case, M is simply the least fixed point of T_P (last slide)
      - … and is straightforwardly computed via an iteration

Well-Founded Model: Quotient

- The well-founded semantics for LP, i.e., for NAF, is defined as a least model obtained by an iterative process (follows general outline of [*Przymusinski 94]'s WFS definition).
- Quotient of a rulebase w.r.t. an interpretation:
  - Let Q be a set of rules, and J a partial Herbrand interpretation for Q
  - The quotient $\frac{Q}{J}$ is obtained by:
    - In the body of each rule in Q, replace $\sim L$ by $J(\sim L)$

The resulting quotient LP is *almost* a set of plain Horn rules.

Because J is a partial, not total, interpretation, it's a bit more complicated.

The quotient includes appearances of *u*. It is said to be *semi-positive*.

A semi-positive LP can be viewed as a *pair* of Horn LPs:

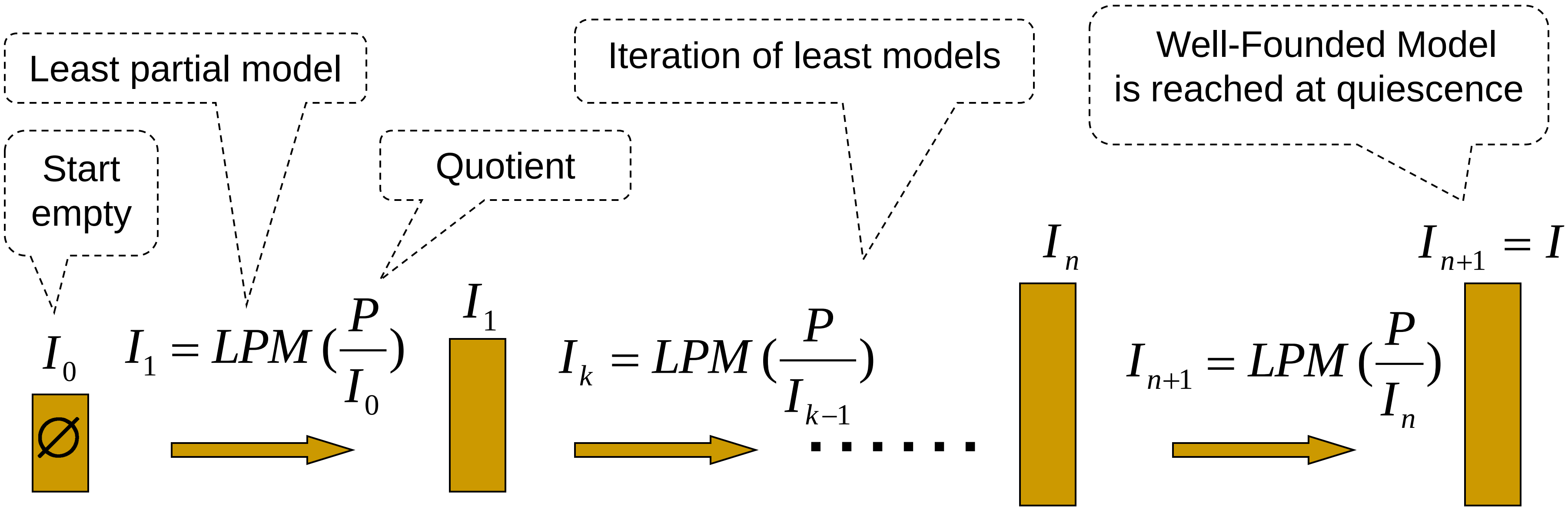
– a *lower-bound* LP (in which *u* is replaced by *f*)

– an *upper-bound* LP (in which *u* is replaced by *t*)

A semi-positive LP's least partial model (LPM) is simple to compute, by taking the least fixed points of the lower-bound and upper-bound.

* Przmusinski, Teodor. "Well Founded and Stationary Models of Logic Programs". *Annals of AI and Mathematics*, 1994.

Well-Founded Model of LP



- The WFM of *P* = the iteration until quiescence of:
  a) Take the quotient of P w.r.t. the previous iteration's interp
  b) Find the least partial model (LPM) of that quotient rulebase.

- Observation: The above is an "outer loop" iteration
  that contains an "inner loop" iteration
  of least fixed point (LFP), within LPM in b)

Computing *Well Founded Semantics for LP*

- Always exactly one set of conclusions (entailed ground atoms)
- Tractable to compute all conclusions, for broad cases:
  - $O(n^2)$ for Propositional case of Normal LP
  - $O(n^{2v+2})$ for VB Datalog case (v = max # vars per rule)
  - NAF only moderately increases computational complexity compared to Horn (frequently linear, at worst quadratic)
- *By contrast, for Stable Semantics:*
  - *There may be zero, or one, or a few, or very many alternative conclusion sets*
  - *Intractable even for Propositional case*
- Proof procedures are known that handle the non-stratified general case
  - backward-direction: notably, SLS-resolution
    - Fairly mature wrt performance, e.g., tabling refinements
  - forward-direction
    - Reuse insights from backward-direction. Restrict to function-free.
    - Fairly mature wrt performance. Room to improve: esp. for updating.

Some Implementations of Unstratified LP

- Well Founded:
  - XSB (research / commercial; open source)
  - Ontoprise (commercial)
  - Intellidimension (commercial)
  - SweetRules (research; open source)
  - SILK (research / commercial)

- Answer Set Programs:
  - Smodels (research)
  - DLV (research / commercial)
  - Clasp (research)

- *There are a number of others, esp. research*

Negation-As-Failure Implementations: Current Limitations in Many Systems

- Practice in Prolog and other currently commercially important (CCI) rule systems is often "sloppy" (incomplete / cut-corners) relative to canonical semantics for NAF
  - in cases of recursive rules, WFS algorithms required are more complex
  - ongoing diffusion of WFS theory & algorithms, beginning in Prologs

- Current implemented OLP inferencing systems often do not handle the fully general case in a semantically clean and complete fashion.
  - Many are still based on older algorithms that preceded WFS theory/algorithms

- Other CCI rule systems' implementations of NAF are often "ad hoc"
  - Lacked understanding/attention to semantics, when developed

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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

Defeasible Reasoning

- **Rules can be true by default but may be defeated**
  - A form of commonsense reasoning
- **Application domains:**
  - policies, regulations, and law
  - actions, change, and process causality
  - Web services
  - inductive/scientific learning
  - natural language understanding
  - …
- **Existing approaches:**
  - Courteous Logic Programs (Grosof , 1997)
    - The main approach used commercially (IBM Common Rules, 1999)
  - Defeasible logic (Nute, 1994) *[similar to Courteous LP]*
  - "Prioritized defaults" (Gelfond & Son, 1997)
  - Preferred answer sets (Brewka & Eiter, 2000)
  - Compiling preferences (Delgrande et al., 2003)
  - …

Semantical ***KR Approaches to Prioritized LP***

The currently most important for Semantic Web are:

1. Courteous LP
   - KR extension to Ordinary LP
   - In RuleML, since 2001
   - 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

Courteous LP: the What

- **Updating/merging of rule sets: is crucial, often generates conflict.**
- **Courteous LP's feature prioritized handling of conflicts.**
- **Specify scope of conflict via a set of exclusion constraints**
  - Each is a preventive spirit integrity constraint on a set of competing literals
    - It says that not all of the competing literals can be entailed as true.
    - opposes(p, q) ≈ (⊥ :- p and q) // Case of 2 competing literals
  - opposes(discount(?product,"5%"), discount(?product,"10%"));
  - opposes(loyalCustomer(?cust,?store), premiereCustomer(?cust,?store));
- **Permit strong negation of atoms: (NB: a.k.a. (quasi-) "classical" negation.)**
    - ¬p means p has truth value *false* . ¬p is also written as: neg p in ASCII.
    - implicitly, for every atom p: opposes(p, ¬p);
- Priorities between rules: partially-ordered.
  - Represent priorities via reserved predicate that compares rule tags:
    - overrides(rule1, rule2) means rule1 is higher-priority than rule2.
    - Each rule optionally has a rule tag whose form is a functional term.
    - overrides can be reasoned about, just like any other predicate.

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

Courteous LP: Advantages

- Facilitate updating and merging, modularity and locality in specification.
- Expressive: strong negation, exclusions, partially-ordered prioritization, reasoning to infer prioritization.
- Guarantee consistent, unique set of conclusions.
  - **Exclusion is enforced**. E.g., never conclude discount is both 5% and that it is 10%, nor conclude both p and ¬p.
- Scalable & Efficient: low computational overhead beyond ordinary LPs.
  - Tractable given reasonable restrictions (VB Datalog):
    - extra cost is equivalent to increasing v to (v+2) in Ordinary LP, worst-case.
  - By contrast, more expressive prioritized rule representations (e.g., Prioritized Default Logic) add NP-hard overhead.
- Modular software engineering:
  - Transform: CLP → → OLP. Via simple "argumentation theory" approach.
    - Add-on to variety of OLP rule systems, with modest effort.

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: **precedence** 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) ;
silk:overrides(reduceTight,  prefCust) ;    // reduceTight has higher priority than prefCust
// The below  exclusion constraint specifies that orderModifNotice is unique, for a given order.
silk: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 ≠ . "silk:" is a namespace prefix.

Courteous LP Semantics: *Prioritized argumentation in an exclusion locale.*

Conclusions from exclusion-locales previous to this exclusion-locale {p1, p2}

(p1 and p2 are each a ground classically-signed literal.)

Run Rules for p1, p2

Set of Candidates for p1, p2:
Team for p1, ..., Team for pk

Prioritized Refutation

Set of Unrefuted Candidates for p1, p2:
Team for p1, Team for p2

Skepticism

Conclude Winning Side if any: at most one of {p1, p2}

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
- **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

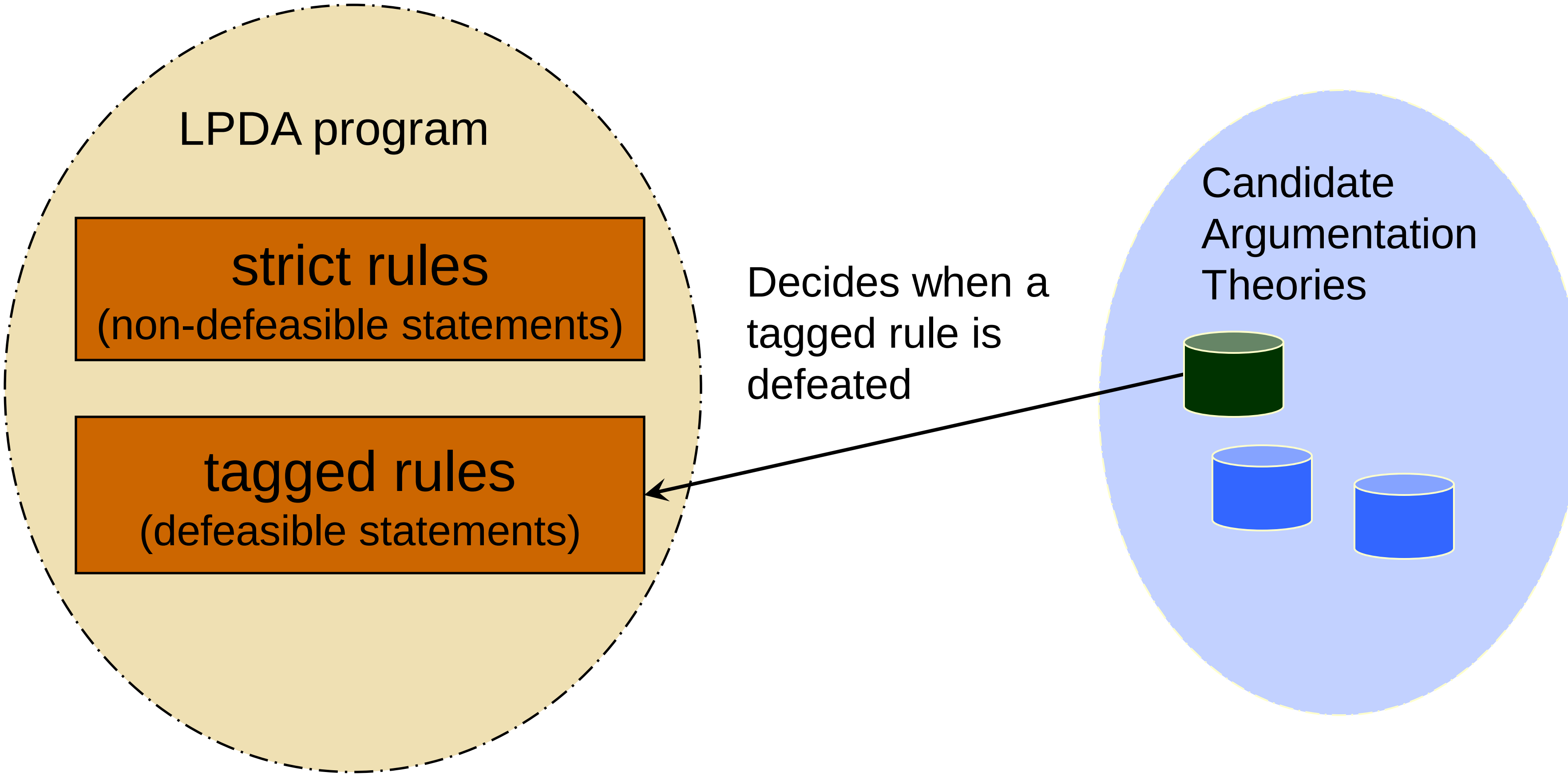
LPDA Approach, Continued

- **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 SILK via an extension of FLORA-2

LPDA Framework

- **L**ogic **P**rograms with **D**efaults and **A**rgumentation theories



Slide courtesy Hui Wan

Example – AT for Courteous ($\mathcal{AT}^{\mathcal{GCLP}}$)

```
$defeated(?R)     :-  $defeats(?S, ?R);
$defeats(?R, ?S) :-  $refutes(?R, ?S) or $rebuts(?R, ?S);
```

Prioritization (user specified)

```
$refutes(?R, ?S) :-  $conflict(?R, ?S), overrides(?R, ?S);
$refuted(?R)       :-  $refutes(?R2, ?R);
$rebuts(?R, ?S)  :-  $conflict(?R, ?S),
                          naf $refuted(?R), naf $refuted(?S);
```

Default negation (NAF)

Meta predicates ("Reflection")

```
$candidate(?R)    :-  body(?R, ?B), call(?B);
$conflict(?R, ?S)  :-  $candidate(?R), $candidate(?S),
                          opposes(?R, ?S);
opposes(?R, ?S)    :-  opposes(?S, ?R).
opposes(?L1,?L2) :-  head(?L1, ?H), head(?L2, neg ?H);
```

Exclusion (user specified)

Explicit negation

Modified from slide courtesy also of Hui Wan

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Omni-directional Rules: Clausal case

- **Hyper LP introduces the concept of an *omni-directional ("omni")* rule. Basic case is clausal:**
  - *@G F* ; where *F* has the syntactic form of a FOL clause
    - The prioritization tag (@G) is optional. Outer universal quantification is implicit.
  - E.g., @hi wet(lawn, nextMorning(?night)) or neg occur(rain, ?night) ;

- **A clausal hyper rule is transformed, i.e., *directionalized*, from**

  @G L1 or L2 or … or Lk; where each Li is an atom or the neg of an atom

  into a set of k directed rules, one for each choice of head literal:

  @G L1 :- neg L2 and neg L3 and … and neg Lk;

  @G L2 :- neg L1 and neg L3 and … and neg Lk;

  …

  @G Lk :- neg L1 and neg L2 and … and neg Lk-1;

  naf-free !

- **This is called the set of *directional variant* rules.**

- (NB: In a sophisticated Courteous variant, the directionalization transformation also outputs an *exclusion* statement that better handles multi-way conflicts.)

- **Still no reasoning by cases!!! Cf. unit/linear resolution strategy in FOL.**

Examples of Directionalization

- **@hi wet(lawn, nextMorning(?night)) <== Occur(rain, ?night) ; /* Causal */**

  is transformed into:
  - **@hi Wet(lawn, nextMorning(?night) :- Occur(rain, ?night) ;**
  - **@hi neg Occur(rain, ?night) :- neg Wet(lawn, nextMorning(?night) ;**

- **neg (Cat(?x) and Bird(?x)) ; /* OWL-DL disjoint classes */**

  is transformed into:
  - **neg Cat(?x) :- Bird(?x) ;**
  - **neg Bird(?x) :- Cat(?x) ;**
- **neg Approved(?p) <== neg Validated(?p) ; /* SBVR: Car Rental Constraint */**

  is transformed into:
  - **neg Approved(?p) :- neg Validated(?p) ;**
  - **Validated(?p) :- Approved(?p) ;**
- **mtg(3p) or mtg(4p) or mtg(5p) ; /* Scheduling: Joe's meeting time */**

  is transformed into:
  - **mtg(5p) :- neg mtg(3p) and neg mtg(4p) ;**
  - **mtg(4p) :- neg mtg(3p) and neg mtg(5p) ;**
  - **mtg(3p) :- neg mtg(4p) and neg mtg(5p) ;**

Omni-directional Rules: General case

- **Permit the formula *F* to:**
  - Be a universal formula (reduces to clauses)
  - Use Skolemization … Thus be "nearly full" FOL form
  - Use HiLog and Frame features
- **Permit a rule body too**
  - *@G F* :- *B* ;
  - Adds *B* to the body of each directional variant rule
  - Special case: *F* is a literal
- **Omni-directionality raises the KR abstraction level**
  - Hide directionality (:-) as well as NAF (naf)
  - Use instead: neg (strong negation), <== (strong/material implication), and defeasibility (Courteous)
- **Implemented in SILK** [V2.2 first demo'd at SemTech-2010]

Current and Future Directions for Omnis

- **Special treatment for certain expressive constructs**
  - External actions are head-only. External queries and aggregates are body-only.
- **Value in KA tasks and domains**
- **Optimize**
- **Multi-way conflicts: nuances of edge-case behavior**
- **Existentials**
- **Extensibility towards “reasoning by cases” in FOL and ASP**
- **Other study & theory**
  - Closed-world

Hypermon Mapping between Hyper LP and FOL

- **Hyper LP has a tight relationship to FOL, akin to that for Horn LP**
- **We can define this relationship via a *hypermonotonic* mapping *T***
  - Consists of a pair of mappings (*T1*, *T2*), one for each interchange direction
- ***T1* maps a hyper rule into a universal FOL axiom:**
  - Replace :- by <== , and ignore the tag
  - E.g., @G F :- B ; →→→→ F <== B ;
  - NB: Some non-onerous expressive restrictions apply *(current work)*
- ***T1* maps a (true) Hyper LP conclusion into a FOL axiom with same formula**
- ***T2* maps a universal FOL axiom into an omni rule with same formula**
- **Then from FOL viewpoint, entailment in Hyper LP is <u>sound and incomplete</u>**
- **... Even though Hyper LP is nonmonotonic!!!**
- **Thus (restricted) Hyper LP is <u>*FOL-Sound*</u> w.r.t. the interchange mapping *T***
- **The incompleteness is desirable when there is conflict**
  - Conflict-free case: Sound Hyper LP reasoning is sound w.r.t. FOL
    - But incomplete – lacks reasoning by cases
  - Conflict-ful case: Hyper LP reasoning is usefully selective unlike FOL

Interchange of Hyper LP ← → FOL

- **Omnis are a natural source/target for interchange with FOL**
- There is a (bi-)mapping ***T*** that's useful for such interchange. Its essence is:

Hyper LP		FOL
@G E ;	←	E ;
@G F :- B ;	→	F <== B ;

(E, F, and B are formulas. Certain restrictions apply: the formulas must be universal. The prioritization tag G is a term.)

- **W.r.t. *T*: Hyper LP is sound and incomplete from FOL viewpoint**
- When there is conflict, Hyper LP reasoning is usefully selective unlike FOL
- **Usage 1: Import clausal/universal FOL into Hyper LP**
  - Can give prioritization to the imported rules
    - E.g., based on source authority, recency, reliability
- **Usage 2: Import Hyper LP conclusions into FOL**
  - E.g., in conflict-free case. Hyper LP there lacks "reasoning by cases"
- **Greatly generalizes well-known special case for definite Horn LP**
  - Handles negation (neg) and attendant conflicts
  - Can cover "nearly full"* FOL, OWL, Common Logic, SBVR

* via skolemization

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*

PROJECT HALO

VULCAN

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

KR Conflict Handling – A Key to Scalability

BEFORE		**AFTER**
KR: Classical Logic (FOL, OWL)	⇒	**KR: LP with Defaults (Courteous-style)**

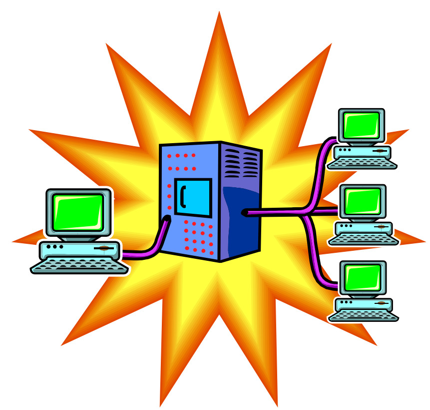
Contradictory conflict is globally contagious, invalidates all results.

⇒

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

Knowledge integration involving conflict is labor-intensive, slow, costly.

⇒



Knowledge integration involving conflict is highly automated, faster, cheaper.

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Heavy Reliance on Procedural Attachments in Currently Commercially Important Rule Families

- E.g., in OO applications, DBs, workflows.

- Relational databases, SQL: Built-in sensors, e.g., for arithmetic, comparisons, aggregations. Sometimes effectors: active rules / triggers.

- Production rules (OPS5 heritage): e.g., Jess
  - Pluggable (and built-in) sensors and effectors
- Event-Condition-Action rules:
  - Pluggable (and built-in) sensors and effectors

- Prolog: e.g., XSB.
  - Built-in sensors and effectors. More recent systems: more pluggability of the built-in attached procedures.

Additional Motivations in Semantic Web for Procedural Attachments

- Query over the web
- Represent services
- Shared ontology of basic built-in purely-informational operations on XML Schema datatypes
  - E.g., addition, concatenation
  - E.g., in RuleML & SWRL, N3.
- Hook rules to web services, generally

Providing Declarative Semantics for Procedural Attachments

- **Procedural attachments historically viewed in KR theory as … well … *procedural* ;-) … rather than declarative.**
  - Not much theoretical attention
- Needed for Semantic Web: a *declarative* KR approach to them

- **<u>Production</u> LP is probably the most important approach today**
  - E.g., SILK, RuleML, SweetRules, IBM Common Rules, predecessors
    - Formerly called ***<u>Situated</u>*** LP
  - Provides <u>disciplined expressive abstraction</u> for two broad, often-used categories of procedural attachments:
    - External Queries: Purely-informational Tests – permitted in rule bodies
    - Side-effectful External Actions – permitted in rule heads
  - Makes <u>restrictions</u>: assumptions become explicit
  - Declarative semantic guarantees, interoperability
  - Embodies primarily <u>analytical insight</u>, initially
  - Provides also: <u>expressive generalizations</u>, <u>algorithms/techniques</u>

Ex. Action Rule for Toxic Discharge

```
silk:action(sendEmail(?ContactEmail, ?Message, ?Time))
    :-
    occurs(polluted(?River),?Time) and
    emergencyContact(?River,?ContactEmail,?Message) ;
```

// NB: draft syntax modified from version at RuleML-2009 demo

Production LP: Overview II

- Point of departure: LPs are pure-belief representations, but most practical rule systems want to invoke external procedures.
- Production/Situated LP's feature a semantically-**clean** kind of **procedural attachments**. I.e., they hook beliefs to drive procedural APIs outside (a.k.a. "external" to) the rule engine.
- Procedural attachments perform
  - **external queries** ("sensing") when testing a body atom
  - **external actions** ("effecting") upon concluding a head atom

  The attached procedure is invoked during inferencing.
- A procedural attachment associates an "internal" predicate/atom with an "external" procedural call pattern, e.g., a Java method. Such associations are specified as part of the extended KR.

Production LP: Overview III

- phoneNumberOf(?person,?num) :- BoeingBluePages.getPhoneMethod(?person,?num);
  // internal predicate/fact inferred based on external query that invokes attached procedure
- ATTMobile.sendTextMethod(?num,?string) :- shouldSendTextMsg(?num,?string);
  // external action that invokes attached procedure is inferred based on internal conclusion fact

- Specify binding-signature for each sensing attached procedure
  - For each argument ?xi: whether ?xi is an input (“bound”) vs. an output arg.
    - Simplest signature is that all args are input args
  - OK to declare multiple binding signatures per sensoring attached procedure.
- Also specify datatypes of arguments in attached procedures signatures

- Attached procedures can be invoked/loaded remotely (e.g., Java, web services)

- Overall: cleanly separate out the procedural semantics as a declarative extension of the pure-belief declarative semantics. Easily separate chaining from action. (Declarative = Independent of inferencing control.)

Production LP: Overview IV

- PLP is KR for Hooking Rules to Services
  - With ontologies
  - Esp. Web services
  - Declaratively
- Rules use services
  - E.g., to query, message, act with side-effects
- Rules constitute services executably
  - E.g., workflow-y business processes

Semantics of Production LP I

- Definitional: complete inferencing+action occurs during an "episode" – intuitively, run all the rules (including invoking effectors and sensors as we go), then done
- Effectors can be viewed as all operating/invoked after complete inferencing has been performed
  - Independent of inferencing control
  - Separates pure-belief conclusion from action

Semantics of Production LP II

- Sensors can be viewed as accessing a virtual knowledge base (of facts). Their results simply augment the local set of facts. These can be saved (i.e., cached) during the episode.
  - Independent of inferencing control
- The sensor attached procedure could be a remote powerful DB or KB system, a web service, or simply some humble procedure.
- Likewise, an effector attached procedure could be a remote web service, or some humble procedure. An interesting case for SW is when it performs updating of a DB or KB, e.g., "delivers an event".
- Terminology:
  - *Situated Inferencing* = inferencing with sensing and effecting, i.e., inferencing+action

Semantics of Production LP III

- Conditions (can view as restrictions or assumptions):
  - Effectors have only *side* effects: they do not affect operation of the (episode's) inferencing+action engine itself, nor change the (episode's) knowledge base.
  - Sensors are purely informational: they do not have side effects (i.e., any such can be ignored).
  - Timelessness of sensor and effector calls: their results are not dependent on when they are invoked, during a given inferencing episode.
  - "Sensor-safeness": Each rule ensures sufficient (variable) bindings are available to satisfy the binding signature of each sensor associated with any of its body literals – such bindings come from the other, non-sensor literals in the rule body. During overall "testing" of a rule body, sensors needing such bindings can be viewed as being invoked after the other literals have been "tested."

Updating & Events ***in Production LP***

- "Event" is a set of facts/rules, constituting an update to KB
- An interesting kind of thing to do with a Production LP is to update its premises, and perform incremental inferencing+action.
  - new PLP $P2$ = (update $U2$) $\cup$ (previous $P1$)
  - Incremental inferencing+action is defined as:
    - Generate the inferences that are novel

      NovelConclusions = Conclusions($P2$) – Conclusions($P1$)

    - Perform the external actions (effecting) associated with NovelConclusions
- Extension to PLP:
  - An event delivery channel is an attached procedure that delivers events as updates
    - Listening to such a channel can be viewed as a persistent external query

Algorithms for PLP Implementation

- The most complicated aspect of implementing the Production feature of LP is to ensure sensor-safeness, i.e., that sensing is attempted only after sufficient bindings are available (for a given atom being tested/queried, in a given rule).
- This is roughly similar to implementing safe negation (NAF) in Normal LP, but somewhat more complicated conceptually and algorithmically.
- It is more similar to some of the techniques developed in bottom-up evaluation, magic sets, relational database tabling, etc., of OLP's where binding signatures (a.k.a. "modes") are considered.

Production Rules (PR)

- Big sector commercially
  - Jess semi-open Java tool, popular among researchers
  - Drools open source Java tool, got popular in last 3 yrs
- PR2LP, LP2PR: via SweetRules approach (2002, 2005)
  - Horn: fairly simple; several systems implement it now
  - External actions and queries: use PLP restrictions
  - NAF: use insights of stratification and well-founded semantics & proof theory, PR salience and modules
- ECA (Event-Condition Action rules) are similar to PR
- RIF-PRD (Production Rules Dialect)
  - procedural operational semantics, leverages RIF-Core (subset of RIF-BLD)
- OMG Production Rules Representation: meta-model

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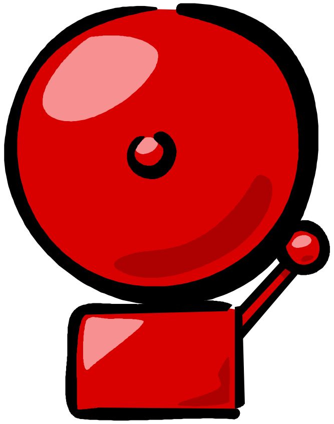
Integrity Constraints

Two styles with quite different semantics:

1. Alarm: Rule that detects a violation
   – Typical: the rule reports/notifies that constraint is violated
     – Other rules infer resulting actions to take
   – E.g., many BRMS, SILK



…VERSUS…

2. Model-cutting: Rule that forces global contradiction when axiom is violated
   – Typical: no model, lose all useful entailments!!
   – E.g., FOL

Lloyd-Topor Expressive Features

- Via the Lloyd-Topor transformation, it is straightforward to extend the expressiveness of LP with additional FOL-type connectives and quantifiers, as syntactic sugar: [Lloyd 1987]
  - $\vee, \exists, \forall, \leftarrow$ in body; $\wedge, \forall, \leftarrow$ in head
    - Freely nested within body or within head
    - Negation is freely nested in body, too
  - *Stays tractable!*
- <u>Disallowed</u>: $\vee, \exists$ in head (these are disjunctive)
- Some features are monotonic (do not rely on NAF):
  - $\vee, \exists$ in body; $\wedge, \forall, \leftarrow$ in head
  - These can be applied as syntactic sugar to Horn LP
- Other features are nonmonotonic (do rely on NAF):
  - $\forall, \leftarrow$ in body
- Many rule systems and languages support a subset of Lloyd-Topor features
  - E.g., RIF, RuleML, SILK, Prolog, Jess, CommonRules

Default Inheritance cf. OO

- Ubiquitous in object-oriented languages & applications
- Defaults naturally increase reuse, modularity
- OWL and FOL cannot represent defaults (they are monotonic)
- Requirement for semantic web service process ontologies
  - Need to jibe with mainstream web service development methodologies, based on Java/C#/C++ etc.

- Approach: Represent OO default-inheritance ontologies using nonmon LP rules
  1. [Grosof & Bernstein 2003] Courteous Inheritance approach
     - Transforms inheritance into Courteous LP (in RuleML, using SweetRules)
     - Represents MIT Process Handbook (ancestor of PSL)
       - 5,000 business process activities; 38,000 properties/values
       - Linear-size transform (n + constant).
  2. [Yang & Kifer, 2006] approach
     - Transform inheritance into essentially Normal LP (using FLORA-2)

Additional Expressive Features in Rules & LP, e.g., SILK

- Explicit equality (and equivalence) reasoning
  - In head of non-fact rules, therefore derived
  - Interaction with nonmonotonicity
  - Key characteristic: substitutivity of equals for equals
  - Related to Herbrand aspect of LP semantics
- Existentials, skolemization
  - RDF blank-nodes, anonymous individuals [Yang & Kifer]
  - Related to Herbrand aspect of LP semantics
- Aggregation (operate on entailed lists): count, total, min, max, etc.
  - Depends on nonmonotonicity, stratification
- Datatypes – they are basic but fairly straightforward
- "Constraints" (e.g., equation/inequality systems)
  - Commonly: via external query/assert to specialized solver
- *Also:* Reasoning within the KR about the results of side-effectful actions
  - E.g., Transaction Logic [Kifer *et al*], Golog [Reiter, Lin, *et* al]
    - These are research-world, not commercial, today

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PART C. SLIDES FOLLOW

Outline of Part C. Conclusions & Directions

1. More about Tools
2. … incl. SILK
3. Conclusions
4. Directions for Future research

Appendix: References and Resources

(General Discussion)

More about Tools

1. *Rule systems designed to work with RDF/OWL:*
   Commercial-world: Jena

- Jena SW suite has rule (and RDF/OWL) capabilities
  - Open source, popular, Java
  - Basic Horn-ish
  - Supports forward, backward, and mixed direction inferencing
  - Operates directly on RDF/OWL statements, without copying in/out
  - Works well with RDF(S). Suite includes OWL capabilities
  - Rules are used to implement RDFS and OWL reasoners

More about Tools

1. *Rule systems designed to work with RDF/OWL/RIF, continued:*

    Commercial-world: Oracle; IBM; other

- Oracle has rule capabilities in semantic tech suite, as part of its flagship database platform
  - Oracle Spatial RDF, now in its 3rd production release, motivated and implements OWL-RL. It also supports user-defined rules using its own rule syntax.
  - Also has production-rule type products, including recently acquired Haley Ltd. – a leader in NL KA – and Ruleburst
  - In development: support for W3C RIF-BLD (Basic Logic Dialect)
- Various others do too, e.g., Ontotext, Ontoprise, VIStology
- IBM (e.g., Ilog unit)
  - In development: support for W3C RIF-BLD

More about Tools

1. *Rule systems designed to work with RDF/OWL, continued:*
   Research-world: SweetRules; cwm; others

- SweetRules has semantic translator from DLP subset of OWL to LP Rules in RuleML and SWRL. Open source, Java. Not maintained.
- Cwm implements N3: RDF + rules. N3 is a popular syntax for RDF. Semantically hazy in some regards, but overlaps a lot with LP. Open source, Python.
- SweetRules pioneered design and implementation of fully semantic interoperability of nonmon LP with Jess production rules, and generally supports Courteous Production LP
- KAON2 implements primarily monotonic rules in FOL & LP
- Numerous others
  - Protege 3 and 4, Pellet, KAON2, and others support SWRL
  - OWLJessKB was an early tool employing Jess to support a subset of OWL DL
  - Several systems combine SWRL with Jess, cf. SweetRules approach

More about Tools

2. *Prolog and Production Rule systems*
   - XSB: semantic, Prolog, full WFS negation, fast, C with available Java front end (Interprolog)
   - Jess: production rules, popular, Java, free for non-commercial use but not open source
   - YAP and SWI open source Prologs are on a development trajectory towards WFS and SW

   - Benchmarking: OpenRuleBench
     - Open source tools for benchmarking rule systems
     - Benchmarking study: [S. Liang, M. Kifer, *et al.* WWW-2009]; extended report on website.
     - XSB, OntoBroker, YAP Prolog, DLV all did well
     - http://openrulebench.semwebcentral.org

More about Tools

3. *Advanced Expressiveness*
   - FLORA-2: open source, built in/on XSB Prolog, has HiLog, Frame, reification, skolemization features
   - SILK: extends FLORA-2 with Courteous defaults, attached procedures, hypermonotonic translation, APIs. Partly in Java. Planned release to be free for non-commercial use.
   - IBM CommonRules (1999) supports Courteous Defaults and Production-LP style external actions. Cheap or free, Java.

4. *Basic Rules in Semantic Wikis*
   - Semantic MediaWiki+ (SMW+) is a leading Semantic Wiki. It extends the software Wikipedia runs. Open source, PHP. Developed mainly by Vulcan/Ontoprise. Adds RDF and lightweight RDFS/OWL ontologies.
   - Has “Simple Rules” and querying features: basic Horn LP.

More about Tools

5. *Some Available Large Rule Bases*

- OpenCyc / ResearchCyc
  - Open source / free for non-commercial use
  - ~ 1 Million / 3 Million axioms. Large 25 year effort.
  - Idiosyncratic semantically, but overlaps with LP
  - ReCyc: translation to SILK is in development (by Vulcan with Cycorp/SRI)
- Open Process Handbook
  - Open source. Semantic Wiki–ish. http://ccs.mit.edu/ph
  - 5,000 business processes, each with ~10 axioms
  - Lots of text and links too. 15 year effort.
  - Translatable to Courteous LP, via approach along lines of SweetPH approach [A. Bernstein, B. Grosof 2003-2005 reports] http://www.mit.edu/~bgrosof/#SweetPH
- OpenMind – collaborative commonsense KB
  - Open source. ~1 Million axioms. Built by Web users.
  - Lacks declarative semantics
  - http://openmind.media.mit.edu

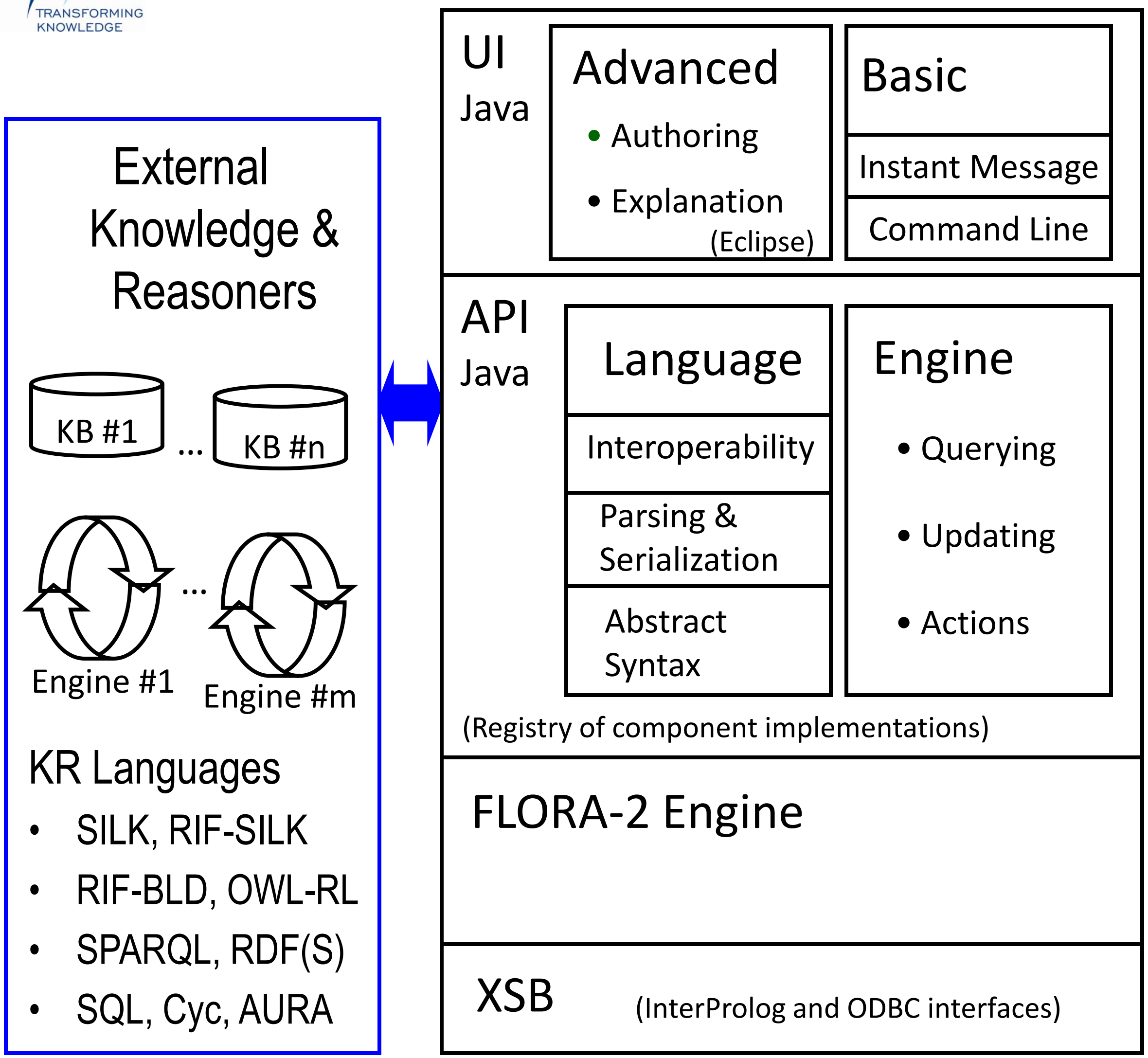
Outline of Part C. Conclusions & Directions

1. More about Tools
2. … incl. SILK
3. Conclusions
4. Directions for Future research

Appendix: References and Resources

(General Discussion)

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
  - Biology (1^{st} yr college)

Semantic Rules KR: Features Comparison

Level ("generation")	Groups of features	*SILK 2.2*	*FLORA-2*	*RIF-BLD*
1G. Basic	ie: Horn, chaining, external queries, built-ins *(Level Summary)*	Y	Y	Y
2G. Advanced	*(Level Summary)*	**The 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)	Y	N	N
	Base Defaults (prioritized, cf. Courteous)	Y	N	N
	Webized syntax (URI names and XML/RDF KBs)	Y	N	Y
3G. Hyper	*(Level Summary)*	**Pioneer**	**N**	**N**
	Higher-Order Defaults (incl. handle **multi-way** conflict)	Y	N	N
	FOL-Sound (when interchange non-Horn **clauses** ↔ FOL)	Y	N	N
Other Misc.		(NA)	(NA)	(NA)
	Other Expressive	Developing	Inheritance	-
	Reasoner Efficiency (upper-tier on OpenRuleBench)	good	good	NA (standard)

- **Summarizes detailed analysis of 40 KR expressive features, 17 systems.**
- Notes: R. = Restricted

Features Comparison – More Systems & Stds

Level	Groups of Features	*SILK 2.2*	*FLORA -2*	*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.
Advanced	*(Level summary)*	**Most**	lots	some	some	some	some	some	some	some	some	some	some	some
	Equality	Y	Y	Y	R.	R.	R.	N	Y	N	R.	Y	R.	Y
	Functions	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	N
	Frames etc.	Y	Y	R.	R.	Y	R.	R.	R.	R.	R.	R.	R.	R.
	Closed-World	Y	Y	N	N	Y	R.	R.	Y	R.	R.	N	N	N
	Higher-Order	Y	Y	N	N	N	R.	N	N	N	R.	Y	R. bit	R. bit
	Actions	Y	Y	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	Y	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
	FOL-Sound	Y	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-ance	-	-	-	events	-	disju.	R.	R.	classical	-	classic-al
	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.= CommonRules; disju.=disjunctive.

Features Comparison – More Systems & Stds

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 largely 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 FOL (classical logic), used also by OMG's Semantics of Business Vocabulary and Rules (SBVR) standard.

- DLV is a disjunctive LP system, by U. Calabria (it supports disjunction in rule heads)

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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

SILK DEMOS

- **If time allows, SHOW HERE: RuleML-2010/SemTech-2010 DEMO**
  - **Default rules in SILK GUI: edit, query, explain; exploiting omni-directionality**
    - Business policies about ad placements in news
- **ISWC-2010 official demo + poster (in demo+poster session)**
  - “A SILK Graphical UI for Defeasible Reasoning, with a Biology Causal Process Example”
- **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***

Outline of Part C. Conclusions & Directions

1. More about Tools

2. … incl. SILK

3. Conclusions

4. Directions for Future research

Appendix: References and Resources

(General Discussion)

Overall Conclusions

1. Theme: Centrality to Web
   - More than most people realize, LP Rules are central to the Web, both current and future
   - Relational, XML, and RDF databases/querying is LP
   - Thriving commercial business rules market sector, based on production rules / event-condition-action rules, is moving to the Web, and translates largely to LP
   - Often used for ontologies: represent, implement, map
   - Semantic tech and semantic web is largely already LP-based

Overall Conclusions, continued

2. Theme: Incremental Evolution
   - LP Rules, and Semantic Web overall, is incremental technologically wrt relational and Web DBMS

3. Theme on KR expressiveness: Reducibility
   - LP feature extensions built up in layers
   - E.g., Lloyd-Topor, HiLog, Frame syntax, Courteous Defaults, and Hyper Rules each reduce tractably to Normal LP

Overall Conclusions, cont.'d more

- W3C rules standards already: RIF, OWL-RL
- Expressive rules coming soon: RIF-SILK
- Defeasibility, higher-order – without sacrificing tractability
- Reactiveness – without sacrificing semantics
- Hyper LP more suitable than FOL as foundation in many aspects
- Many many applications in services engineering

SILK's Hyper LP – Conclusions

- **Radically extends the KR power of W3C OWL, SPARQL, and RIF – 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*

- **Redefines 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
  - Hope: be like advance of the Relational model in DBMS

- **Implementation Theme: "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

BRMS Industry Roadmap: facing disruption

- **Semantic rules is a prospectively truly disruptive innovation for the existing business rules management systems (BRMS) industry sector**

- **See "The New Rules of Business" [Grosof EBRC-2007 keynote]**
  - Strategic analysis of evolving market dynamics and what players should do about it
    - Done with a Management professor hat on
  - http://www.mit.edu/~bgrosof/#EBRC2007Talk

Key Directions for Future Research

1. Expressiveness
   - Relationship between FOL and Default LP
   - Distributed, Disjunction, Probabilistic, Abduction, Fuzzy
   - Induction
   - Misc. smaller issues: equality, aggregation, "constraints", …
2. Reasoning performance
   - Forward-direction, truth maintenance, termination
   - Parallelization (tremendous opportunities)
3. Knowledge acquisition and UI
   - Explanation
   - Limited natural language
   - Business users / Subject Matter Experts (SMEs)
   - Collaboration
4. Applications and Tools
   - *Build. Experiment.*

Key Directions for Future Research, cont'd

5. XBRL – Align & Integrate with Semantic Web, LP
6. Bridge to legacy forms of structured knowledge
   - Production and ECA rules (extend known techniques)
   - Ontologies, e.g., E-R, UML, mappings
   - Tool Integration, incl. KA UI

- (1.) More Details:

i. Induction
   - Progress is largely gated by: Reasoning performance, Probabilistic

ii. Equality and "Constraints"
   - Use of specialized solvers, e.g., equations, inequalities
   - Procedural attachments for functions.
   - Efficiency in substitutivity for inequality
   - Non-Herbrand

iii. Aggregation:
   - Unstratified

ADDITIONAL REFERENCES & RESOURCES FOLLOW

References & Resources I: Standards on Rules and Ontologies

- http://www.ruleml.org RuleML *Includes links to some tools and examples.*
- http://www.w3.org/Submission/2004/SUBM-SWRL-20010521 SWRL
  - http://www.daml.org/committee Joint Committee. Besides SWRL this includes:
    - http://www.w3.org/Submission/2005/SUBM-SWRL-FOL-20050411/ SWRL-FOL
    - http://www.ruleml.org/fol FOL RuleML (also see RuleML above)
  - http://www.daml.org/rules DAML Rules
- http://www.swsi.org Semantic Web Services Initiative. Especially:
  - Semantic Web Services Language (SWSL), incl. SWSL-Rules and SWSL-FOL and overall requirements/tasks addressed
- http://cl.tamu.edu Common Logic (successor to Knowledge Interchange Format)

- Also: Object Management Group (OMG) has efforts on rules and ontologies (cooperating with RuleML and W3C)
- Also: JSR94 Java API effort on Rules (cooperating with RuleML)

References & Resources II: Standards on Rules and Ontologies

- http://www.w3.org World Wide Web Consortium, esp.:
  - …/2005/rules/ Rule Interchange Format
  - …/2007/owl/ OWL 2 – see esp. OWL RL Profile
  - …/2001/sw/ Semantic Web Activity, incl RDF, OWL, SPARQL, and RIF
  - …/2002/ws/ Web Services Activity, incl. SOAP and WSDL
  - www-rdf-rules@w3.org Rules discussion mailing list
  - www-sws-ig@w3.org Semantic Web Services discussion mailing list
  - P3P privacy policies
  - XQuery XML database query

- http://www.oasis-open.org Oasis, esp. on web policy & web services:
  - XACML XML access control policies
  - ebXML e-business communication in XML
  - Legal XML
  - BPEL4WS Business Processes as Web Services
  - Web Services Security

Refs & Resources III: LP with Negation

- Przymusinski, T., “Well Founded and Stationary Models of Logic Programs”, Annals of Artificial Intelligence and Mathematics (journal), 1994. *Constructive model theory, and proof theory, of well founded semantics for LP.*
- Van Gelder, A., Schlipf, J.S., and Ross, K.A., “The Well-Founded Semantics for General Logic Programs”, Journal of the ACM 38(3):620-650, 1991. *Original theory of well founded semantics for LP.*
- Gelfond, M. and Lifschitz, V., The Stable Model Semantics for Logic Programming, Proc. 5th Intl. Conf. on Logic Programming, pp. 1070-1080, 1988, MIT Press. *Original theory of stable semantics for LP. Answer set programs extend this.*
- Lloyd, J.W., “Foundations of Logic Programming” (book), 2nd ed., Springer-Verlag, 1987. *Includes Lloyd-Topor transformation, and correspondence of semantics to FOL in definite Horn case. Reviews theory of declarative LP. Somewhat dated in its treatment of theory of NAF since it preceded well founded and stable semantics.*
- Baral, C., and Gelfond, M., “Logic Programming and Knowledge Representation”, J. Logic Programming, 1994. *First and last parts review theory of declarative LP. Stronger on stable semantics than on well founded semantics.*
- Gelfond, M., “Answer Sets” (book chapter 7). In: Handbook of Knowledge Representation. Elsevier, 2007. *Up-to-date exposition of answer set programs.*

Resources IV: More Key LP Theory

- "Description Logic Programs: Combining Logic Programs with Description Logic", by B. Grosof, I. Horrocks, R. Volz, and S. Decker, Proc. 12th Intl. Conf. on the World Wide Web (WWW 2003), 2003. *On DLP KR and how to use it.*
- "Logical Foundations of Object-Oriented and Frame-Based Languages", by M. Kifer, G. Lausen, and J. Wu, *J. ACM* 42:741-843, 1995.
- "HiLog: A Foundation for Higher-Order Logic Programming", by W. Chen, M. Kifer, and D.S. Warren, *J. Logic Programming* 15(3):187-230, Feb. 1993.
  - H. Wan, B. Grosof, M. Kifer, P. Fodor, S. Liang, Logic Programming with Defaults and Argumentation Theories, 25th International Conference on Logic Programming (ICLP 2009), Pasadena, California, July 2009. *On LP defaults approach.*

References & Resources V: Misc. on Rules and Ontologies

- http://ccs.mit.edu/ph MIT Process Handbook, incl. Open Process Handbook Initiative
- Bernstein, A. and Grosof, B. "Beyond Monotonic Inheritance: Towards Semantic Web Process Ontologies". Working reports, 2003-2005. http://www.mit.edu/~bgrosof/#SweetPH
- "Semantic Web Services Framework" (SWSF), V1.0+, by Battle, S., Bernstein, A., Boley, H., Grosof, B., Gruninger, M., Hull, R., Kifer, M., Martin, D., McIlraith, S., McGuinness, D., Su, J., and Tabet, S. (alphabetic), May 2005. Technical Report (~200 pages).
- Grosof, B., "Representing E-Commerce Rules Via Situated Courteous Logic Programs in RuleML", Electronic Commerce Research and Applications (journal) 3(1):2-20, 2004. *On situated courteous LP KR, RuleML overview, and e-commerce applications of them.*
- Grosof, B. and Poon, T., "SweetDeal: Representing Agent Contracts with Exceptions using Semantic Web Rules, Ontologies, and Process Descriptions", Intl. Journal of Electronic Commerce 8(4):61-98, Summer 2004. *On SweetDeal e-contracting app.*
- Firat, A., Madnick, S., and Grosof, B., "Financial Information Integration in the Presence of Equational Ontological Conflicts", Proc. Workshop on Information Technologies and Systems, 2002. *On ECOIN. Also see A. Firat's PhD thesis, 2003.*

- Hebeler, J., Fisher, M., Blace, R., Perez-Lopez, A., and Dean, M., *Semantic Web Programming*, Wiley, 2009. *A whole book.*

Resources VI: DL Safe SWRL rules

- OWLED's DL Safe SWRL Rules Task Force [1] [2], whose proposals have already been implemented in Pellet and KAON2.
  - [1] http://wiki.webont.org/page/DL_Safe_SWRL_Rules
  - [2] http://code.google.com/p/owl1-1/wiki/SafeRules

References & Resources VII: Misc. on Rules and Ontologies

- Grosof, B., Gandhe, M., and Finin, T., "SweetJess: Translating DamlRuleML To Jess". Proc. Intl. Wksh. On Rule Markup Languages for Business Rules on the Semantic Web, 2002 (the 1st RuleML Workshop, held at ISWC-2002). See extended and revised working paper version, 2003. *On SweetJess translation/interoperability between RuleML and production rules.*
- Forgy, C.L., "Rete: A Fast Algorithm for the Many Pattern / Many Object Pattern Match Problem". Artificial Intelligence 19(1):17-27, 1982. *On the key Rete algorithm for production rules inferencing.*
- Friedman-Hill, E., "Jess in Action" (book), 2003. *On Jess and production rules.*
- Ullman, J., "Principles of Knowledge Base and Database Systems Vol. I" (book), 1988. *See esp. the chapter on Logic Programs, incl. algorithm for stratification.*
- http://xsb.sourceforge.net XSB Prolog. See papers by D. Warren *et al.* for theory, algorithms, citations to standard Prolog literature (also via http://www.sunysb.edu/~sbprolog)
- Horrocks, I. and Patel-Schneider, P., paper on OWL Rules and SWRL, Proc. WWW-2004 Conf. *On SWRL theory incl. undecidability.*
- Horrocks, I. and Bechhofer, S., paper on Hoolet approach to SWRL inferencing via FOL theorem-prover, Proc. WWW-2004 Conf. *On SWRL inferencing.*

References & Resources VIII: More Courteous and Situated

- Grosof, B., Labrou, Y., and Chan, H., "A Declarative Approach to Business Rules in Contracts", Proc. 1st ACM Conf. on Electronic Commerce, 1999, ACM Press. *On courteous LP KR with mutexes and its e-contracts applications.*
- Grosof, B., "Courteous Logic Programs: Prioritized Conflict Handling for Rules", Proc. Intl. Logic Programming Symposium., 1997. See extended version: IBM Research Report RC 20836, 1997. *Basic version courteous LP (since generalized).*
- Grosof, B., "A Courteous Compiler from Generalized Courteous Logic Programs To Ordinary Logic Programs", (IBM) research report extension to "Compiling Courteous Logic Programs Into Ordinary Logic Programs", 1999. Available via http://ebusiness.mit.edu/bgrosof or IBM incl. in CommonRules documentation. *Details on courteous compiler/transform.*
- Grosof, B., Levine, D.W., Chan, H.Y., Parris, C.J., and Auerbach, J.S., "Reusable Architecture for Embedding Rule-based Intelligence in Information Agents", Proc. Wksh. on Intelligent Information Agents, at ACM Conf. on Information and Knowledgte Management, ed. T. Finin and J. Mayfield, 1995. Available also as IBM Research Report RC 20305. *Basic situated LP paper. Also see 1998 patent.*
- Grosof, B., "Building Commercial Agents: An IBM Research Perspective (Invited Talk). Proc. 2nd Intl. Conf. on the Practical Applications of Intelligent Agents and Multi-Agent Technology (PAAM97), pub. The Practical Applications Company, 1997. Also available as IBM Research Report RC 20835. *Overview of situated LP.*

Resources IX: Misc. Papers

- "SWRL: A Semantic Web Rules Language Combining OWL and RuleML", V0.7+, by I. Horrocks, P. Patel-Schneider, H. Boley, S. Tabet, B. Grosof, and M. Dean, Nov. 2004. Technical Report.

- RuleML website, especially design documents and list of tools. Ed. by H. Boley, B. Grosof, and S. Tabet, 2001-present. http://www.ruleml.org

- "Web Service Modeling Ontology (WSMO)" by J. de Bruijn et al., 2005. Technical Report.

- "A Declarative Approach to Business Rules in Contracts: Courteous Logic Programs in XML", by B. Grosof et al., Proc. EC-99.

- "A Policy Based Approach to Security for the Semantic Web", by L. Kagal et al., Proc. ISWC-2003.

- "Financial Information Integration in the Presence of Equational Ontological Conflicts", by A. Firat et al., WITS 2002 conf.

- "Delegation Logic: A Logic-based Approach to Distributed Authorization", *ACM Trans. on Info. Systems Security (TISSEC)*, by N. Li et al., 2003

Resources X: SILK

- SILK project page: http://silk.semwebcentral.org/
  - RR-2009 keynote slideset, by B. Grosof
  - H. Wan, B. Grosof, M. Kifer, P. Fodor, S. Liang, Logic Programming with Defaults and Argumentation Theories, 25th International Conference on Logic Programming (ICLP 2009), Pasadena, California, July 2009. *On LP defaults approach.*
  - Also:
    - SemTech-2010 invited talk slideset, by B. Grosof
    - S. Liang, P. Fodor, H. Wan, M. Kifer, OpenRuleBench: An Analysis of the Performance of Rule Engines, 18th International World Wide Web Conference (WWW 2009), Madrid, Spain, April 2009.
    - B.Grosof, Opportunities for Semantic Web knowledge representation to help XBRL, Position Paper, Workshop on Improving Access to Financial Data on the Web, Arlington, Virginia, October 2009.

Resources XI: Misc. Presentations

- SemTech-2010 Rules Track, coorganized by RuleML: http://semtech2010.semanticuniverse.com/rules
  – Presentations about RIF, SILK, Oracle, IBM, others
  – Abstracts available on webpage above
  – For slides, see SemTech-2010 conference materials, or contact authors

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