

Semantic Web Services, Rules, and E-Contracting

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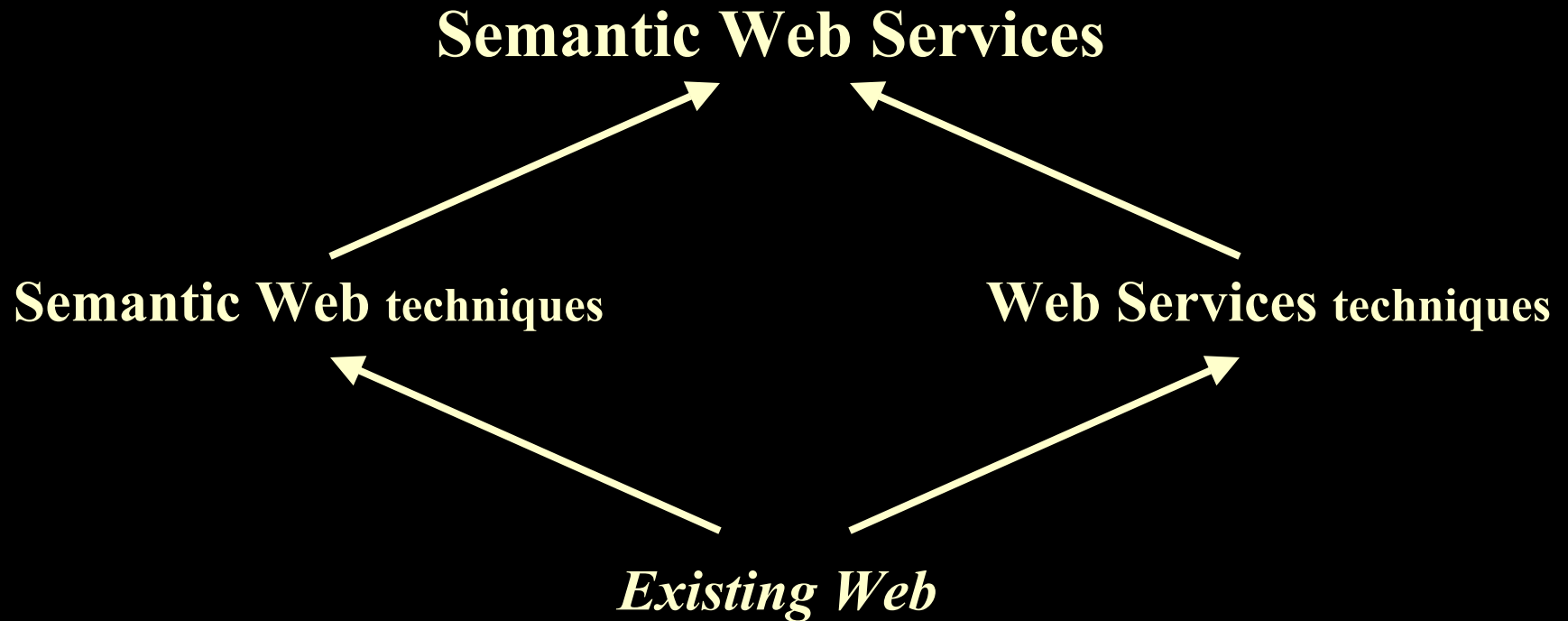
*(ITM = Information Technology & Management, a joint PhD program
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<http://www.hbs.edu/doctoral/programs/itm/index.html>

Outline of Talk

- I. Overview: Semantic Web Services (SWS) and Rules
 - Concepts, Today's Scene, Visions
 - Applications, incl. B2B
- II. E-Contracting via Rule-based SWS
 - SweetDeal Approach, Application Scenario
- III. Overall Requirements and Uses for Rule-based SWS
- IV. Research Directions
 - Theory, Applications, Technologies, Strategy

Next Generation Web



Web Service -- definition

- *(For purposes of this talk:)*
- A procedure/method that is invoked through a Web protocol interface, typically with XML inputs and outputs

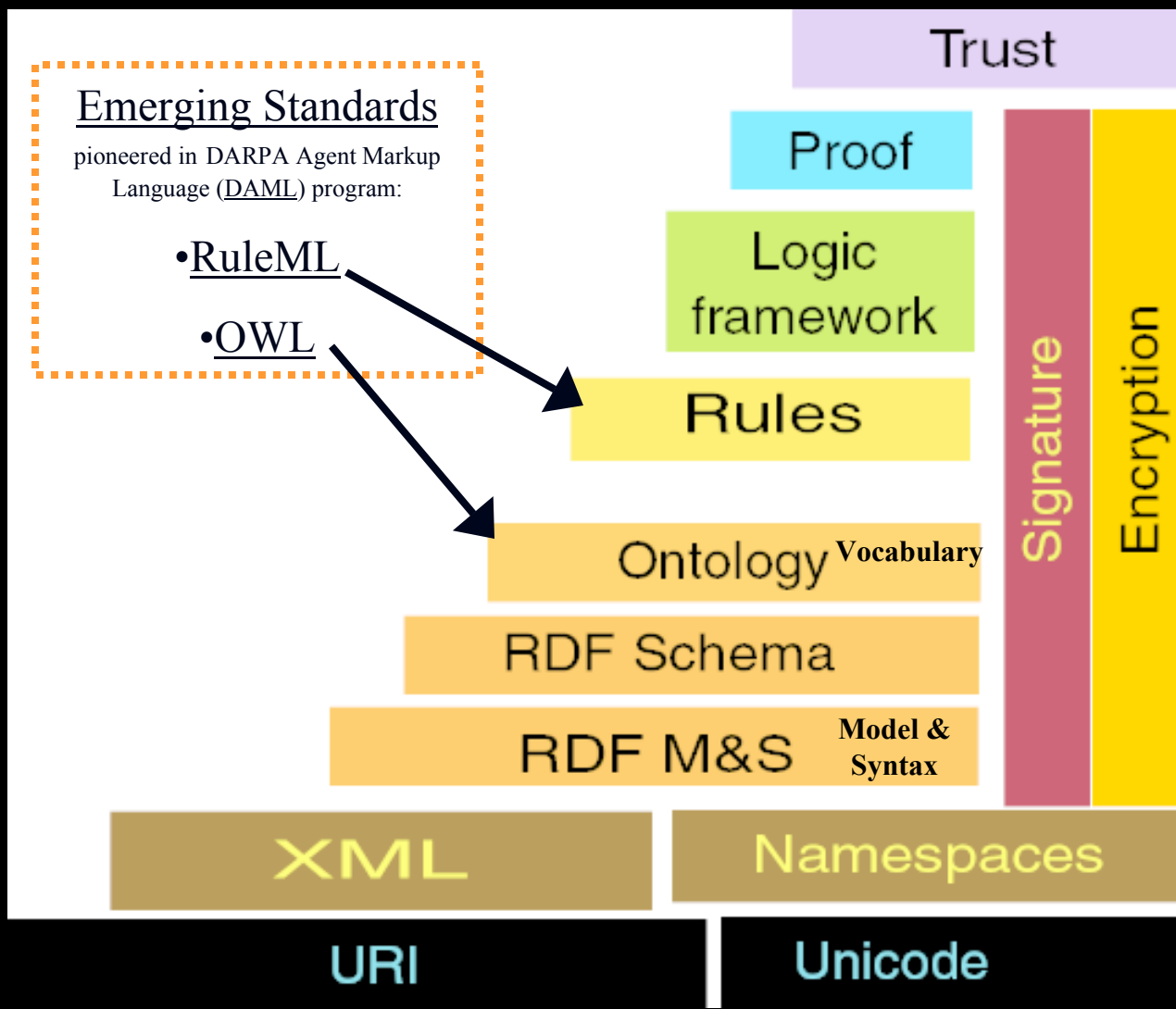
Semantic Web: concept, approach, pieces

- Shared semantics when interchange data \therefore knowledge
- **Knowledge Representation** (cf. AI, DB) as approach to semantics
 - Standardize KR syntax, with KR theory/techniques as backing
- **Web-exposed Databases**: SQL; XQuery (XML-data DB's)
 - Challenge: share DB schemas via meta-data
- **RDF**: “Resource Description Framework” W3C proposed standard
 - Meta-data lower-level mechanics: unordered directed graphs (vs. ordered trees)
 - **RDF-Schema** extension: simple class/property hierarchy, domains/ranges
- **Ontology** = formally defined vocabulary & class hierarchy
 - **OWL**: “Ontologies Working Language” W3C proposed standard
 - Subsumes RDF-Schema and Entity-Relationship models
 - Based on Description Logic (DL) KR \sim subset of First-Order Logic (FOL))
- **Rules** = if-then logical implications, facts \sim subsumes SQL DB's
 - **RuleML**: “Rule Markup Language” emerging standard
 - Based on Logic Programs (LP) KR \sim extension of Horn FOL

Some Semantic Web Advantages for Biz

- Builds upon XML's much greater capabilities (vs. HTML*) for structured detailed descriptions that can be processed automatically.
 - Eases application development effort for **assimilation of data in inter-enterprise interchange**
- **Knowledge-Based E-Markets -- where Agents Communicate**
(Agent = knowledge-based application)
 - ∴ potential to revolutionize interactivity in Web marketplaces: B2B, ...
- Reuse same knowledge for multiple purposes/tasks/app's
 - Exploit declarative KR; Schemas
- * new version of HTML itself is now just a special case of XML

W3C Semantic Web “Stack”: Standardization Steps

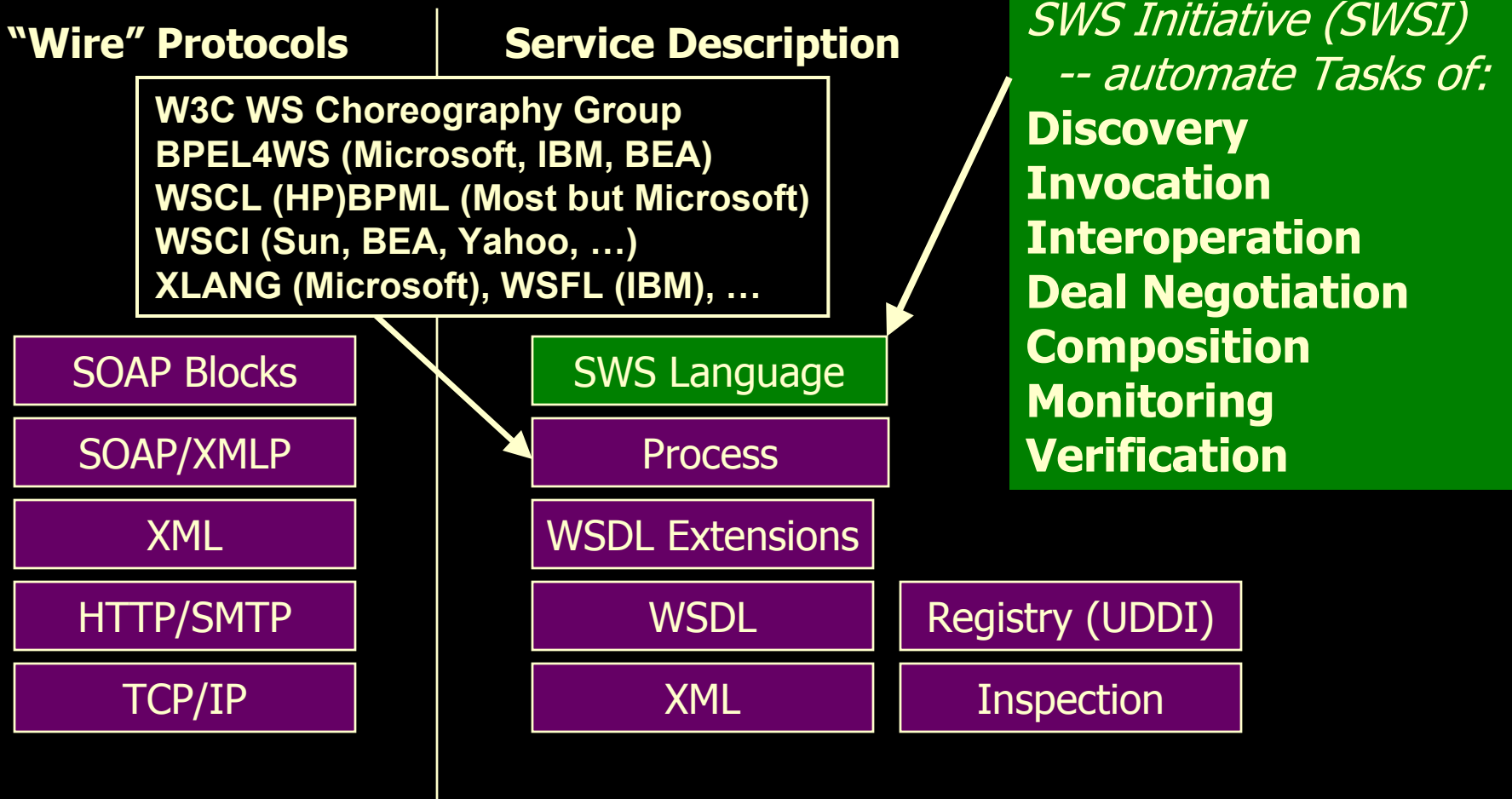


[Diagram <http://www.w3.org/DesignIssues/diagrams/sw-stack-2002.png> is courtesy Tim Berners-Lee]

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
 - Integrated knowledge
- (Semantic Web) Services: e.g., infrastructural
 - Knowledge/info/DB integration
 - Inferencing and translation

SWS Language effort, on top of Current WS Standards Stack



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

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B2B Tasks: Communication for Business Processes with Partners

- B2B business processes involving significant Communication with customers/suppliers/other-partners is overall a natural locus for future first impact of SWS.
- Customer Relationship Management (CRM)
 - sales leads and status
 - customer service info and support
- Supply Chain Management (SCM):
 - source selection
 - inventories and forecasts
 - problem resolution
 - transportation and shipping, distribution and logistics
- orders; payments, bill presentation

Some B2B Tasks (continued)

- bids, quotes, pricing, **CONTRACTING; AUCTIONS**; procurement
- authorization (vs. authentication) for credit or trust
- database-y: e.g.,
 - catalogs & their merging
 - policies
- inquiries and answers; live feedback
- notifications
- trails of biz processes and interactions
- ratings, 3rd party reviews, recommendations
- knowledge management with partners/mkt/society

Vision of Evolution: Agents in Knowledge-Based E-Markets

Coming soon to a world near you:...

- billions/trillions of agents (= k-b applications)
- ...with smarts: knowledge gathering, reasoning, economic optimization
- ...doing our **bidding**
 - but with some autonomy
- *A 1st step: ability to communicate with sufficiently precise shared meaning... via the SEMANTIC WEB*

New Research Application Scenarios for Rule-based Semantic Web Services

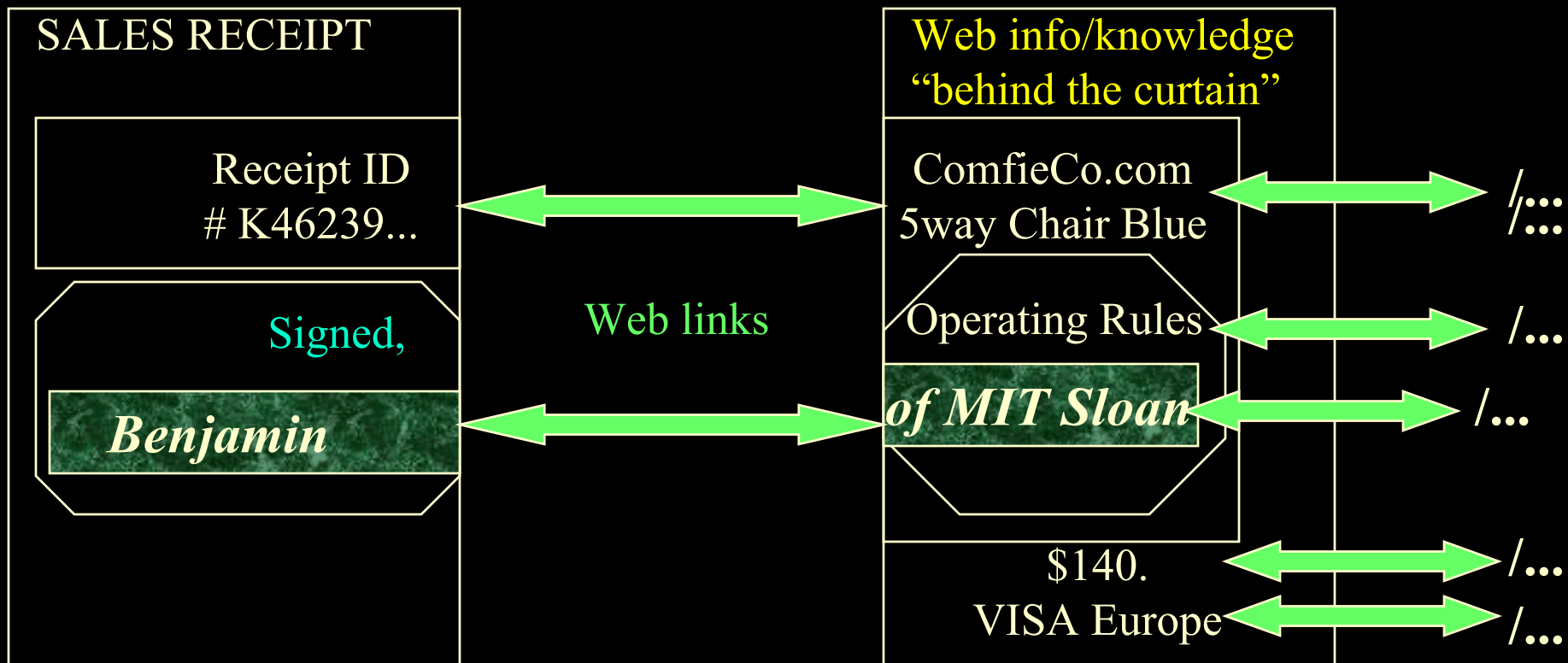
- SweetDeal [Grosf & Poon WWW-2003] configurable reusable e-contracts:
 - Represents modular modification of proposals, service provisions
 - LP rules as KR. E.g., prices, late delivery exception handling.
 - On top of DL ontologies about business processes from MIT Process Handbook
 - Evolved from EECOMS pilot on agent-based manufacturing SCM
(\$51M NIST ATP 1996-2000 IBM, Boeing, TRW, Vitria, others)
- Financial knowledge integration (ECOIN) [Firat, Madnick, & Grosf 2002]
 - Maps between contexts using LP rules, equational ontologies, SQL DB's.
- Business Policies:
 - Trust management (Delegation Logic) [Li, Grosf, & Feigenbaum 2003]:
Extend LP KR to multi-agent delegation. Ex.: security authorization.

Outline of Talk

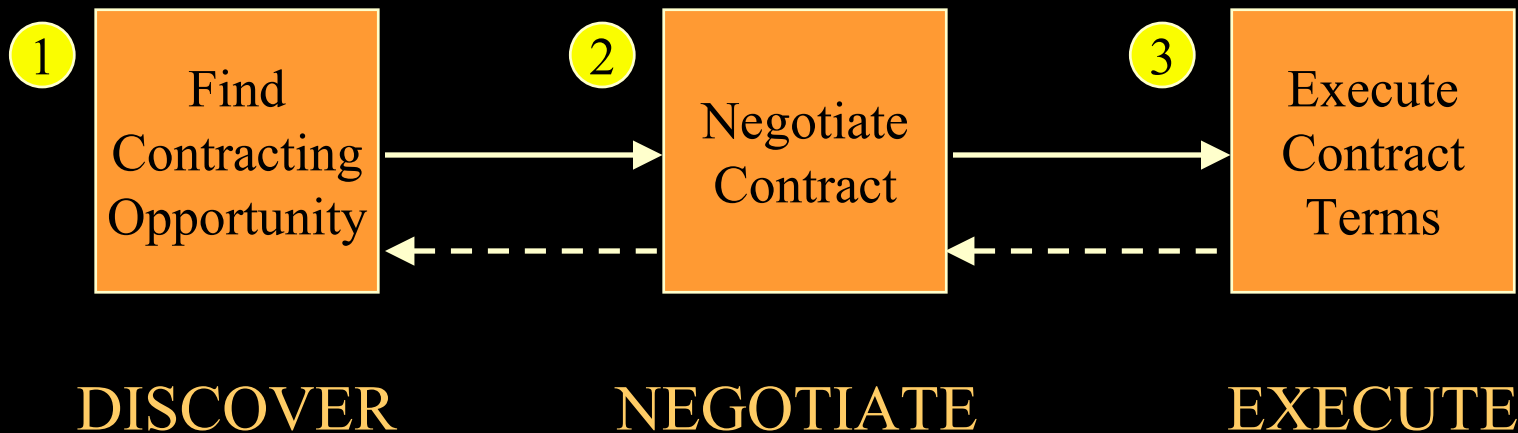
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Looks Simple To Start... then Gets Interestingly Precise

A Vision/Approach of what Web & Agents enable



Contracting 1-2-3



- Applies to any contracting, electronic or not.
- May iterate or interleave these steps.
- Boundaries not necessarily sharp.

What's Doable Today in rule-based agent contracting, based on our approach to rule representation (“SweetDeal”)

- Communicate: with deep shared semantics
 - XML, inter-operable with same sanctioned inferences
 - \Leftrightarrow heterogeneous rule systems / rule-based agents
- Execute contract provisions:
 - infer; ebiz actions; authorize; ...
- Modify easily: contingent provisions
 - default rules; modularity; exceptions, overriding
- Reason about the contract/proposal
 - hypotheticals, test, evaluate; tractably
 - *(also need “solo” decision making/support by each agent)*

Approach:

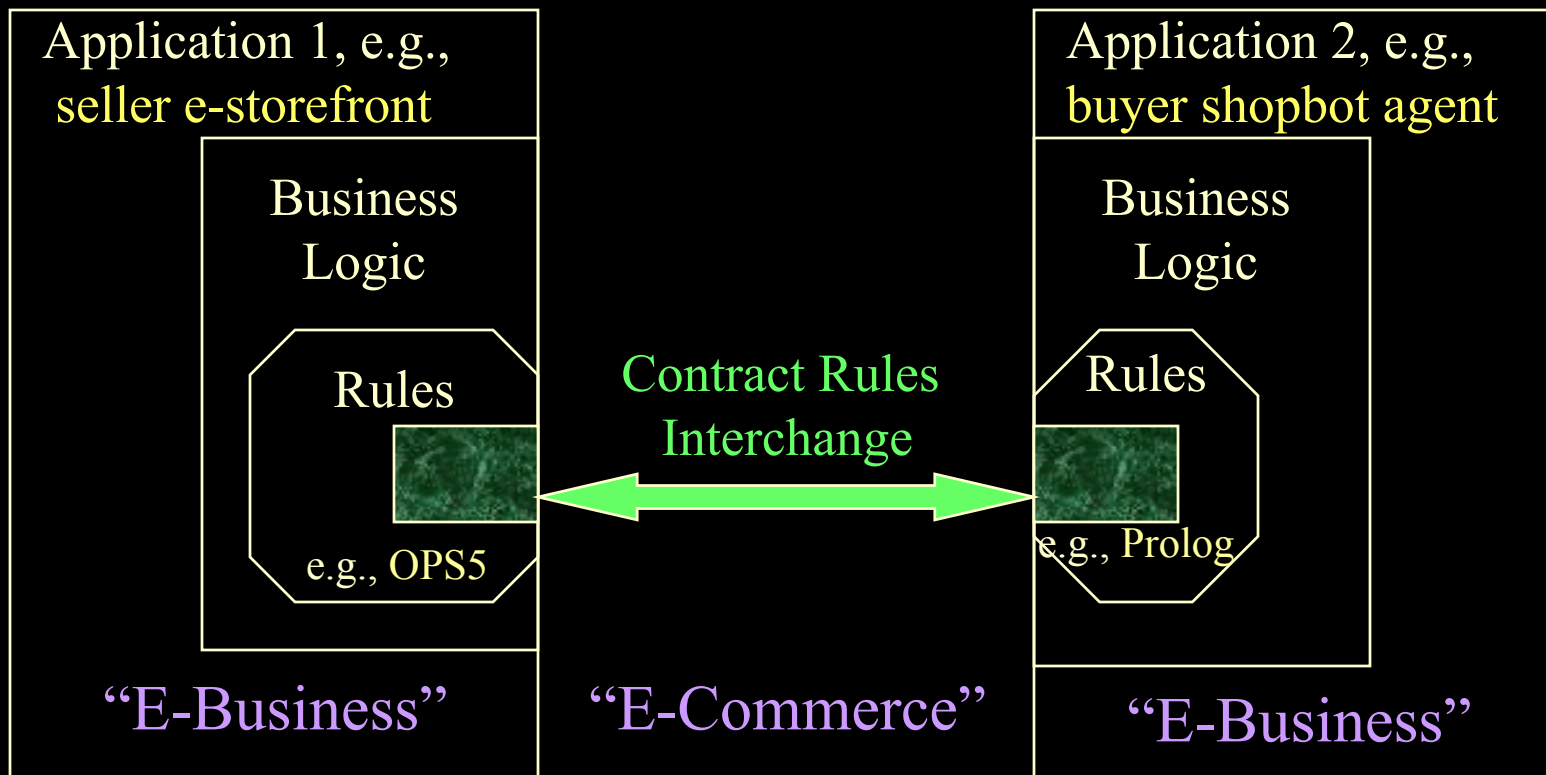
Rule-based Contracts for E-commerce

- 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.

our SweetDeal Approach

- SWEET = Semantic Web Enabling Technology
 - software components, theory, approach
 - pilot application scenarios, incl. **contracting** (SweetDeal)
- Uses/contributes *emerging standards* for XML and knowledge representation:
 - RuleML (co-founder)
 - WebOnt ontologies (W3C)
- Uses *repositories* of business processes and contracts
 - MIT Process Handbook (Sloan IT)
 - legal/regulatory sources: law firms, ABA, CommonAccord, ... *Suggestions welcome!!*

Contract Rules across Applications / Enterprises

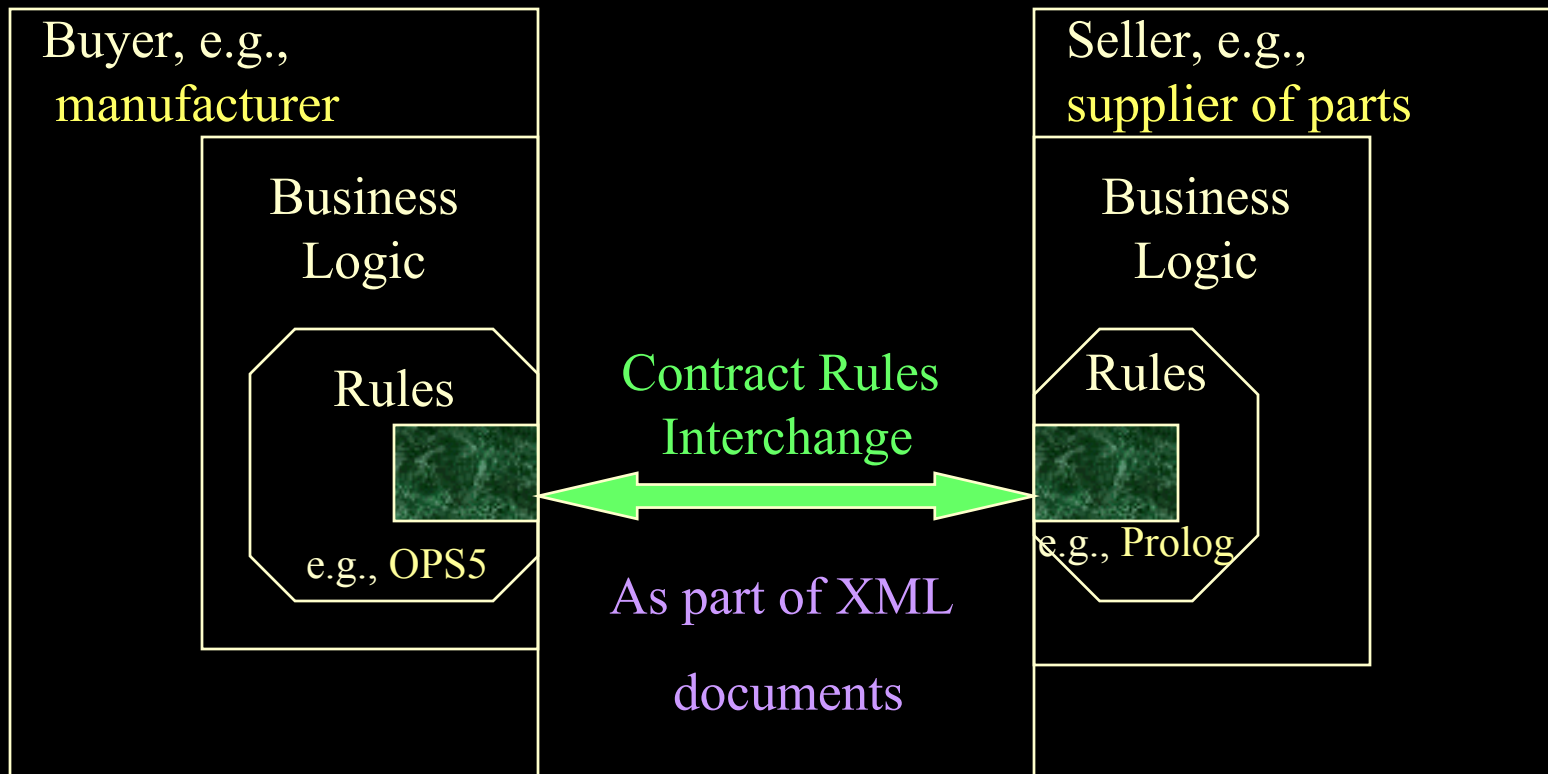


Contracting parties integrate e-businesses via shared rules.

Examples of Contract Provisions Well-Represented by Rules in Automated Deal Making

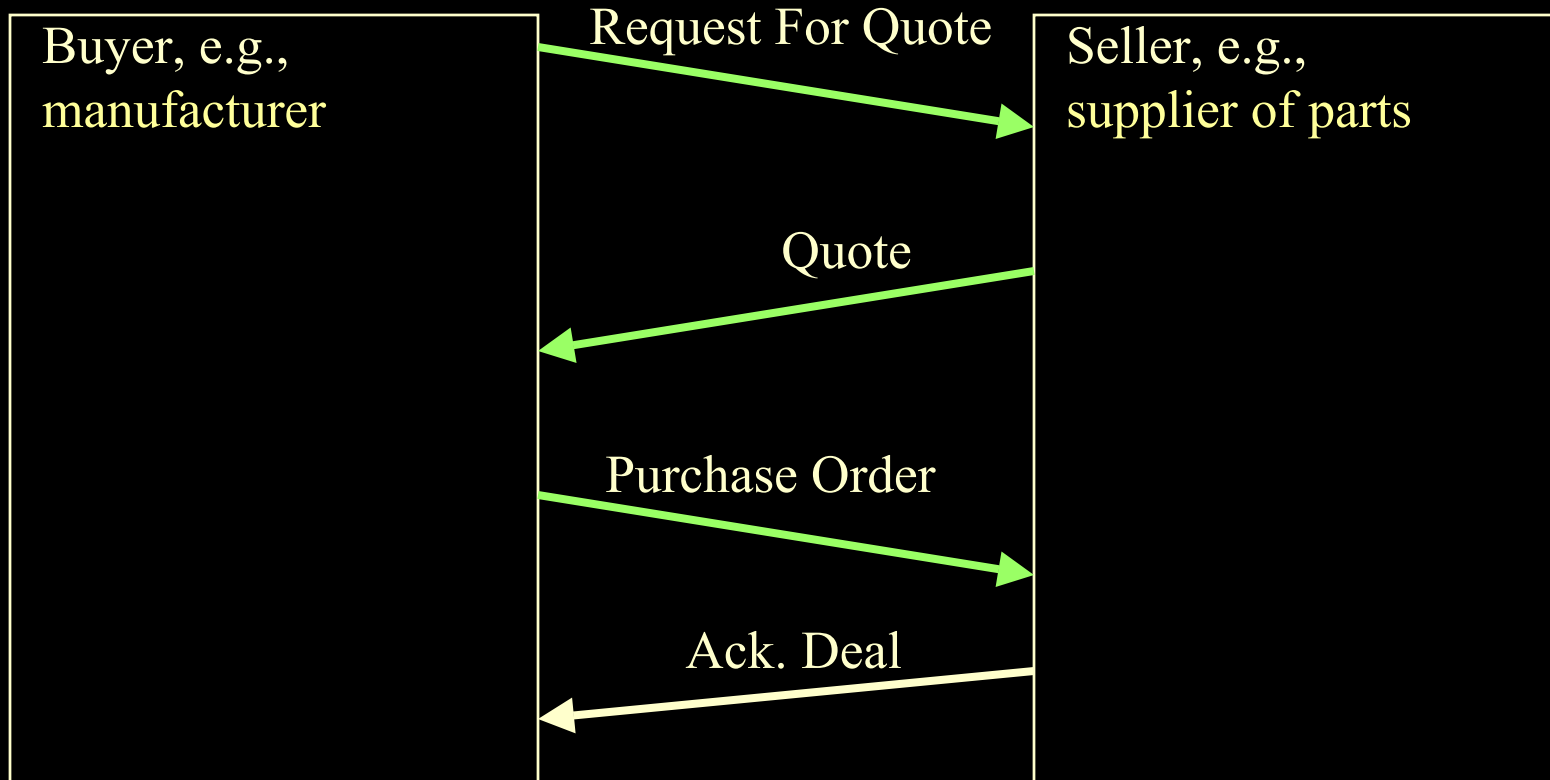
- **Product descriptions**
 - Product catalogs: properties, conditional on other properties.
- **Pricing dependent upon:** delivery-date, quantity, group memberships, umbrella contract provisions
- **Terms & conditions:** refund/cancellation timelines/deposits, lateness/quality penalties, ordering lead time, shipping, creditworthiness, biz-partner qualification, **service** provisions
- **Trust**
 - Creditworthiness, authorization, required signatures
- *Buyer Requirements (RFQ, RFP) wrt the above*
- *Seller Capabilities (Sourcing, Qualification) wrt the above*

Contract Rules during Negotiation

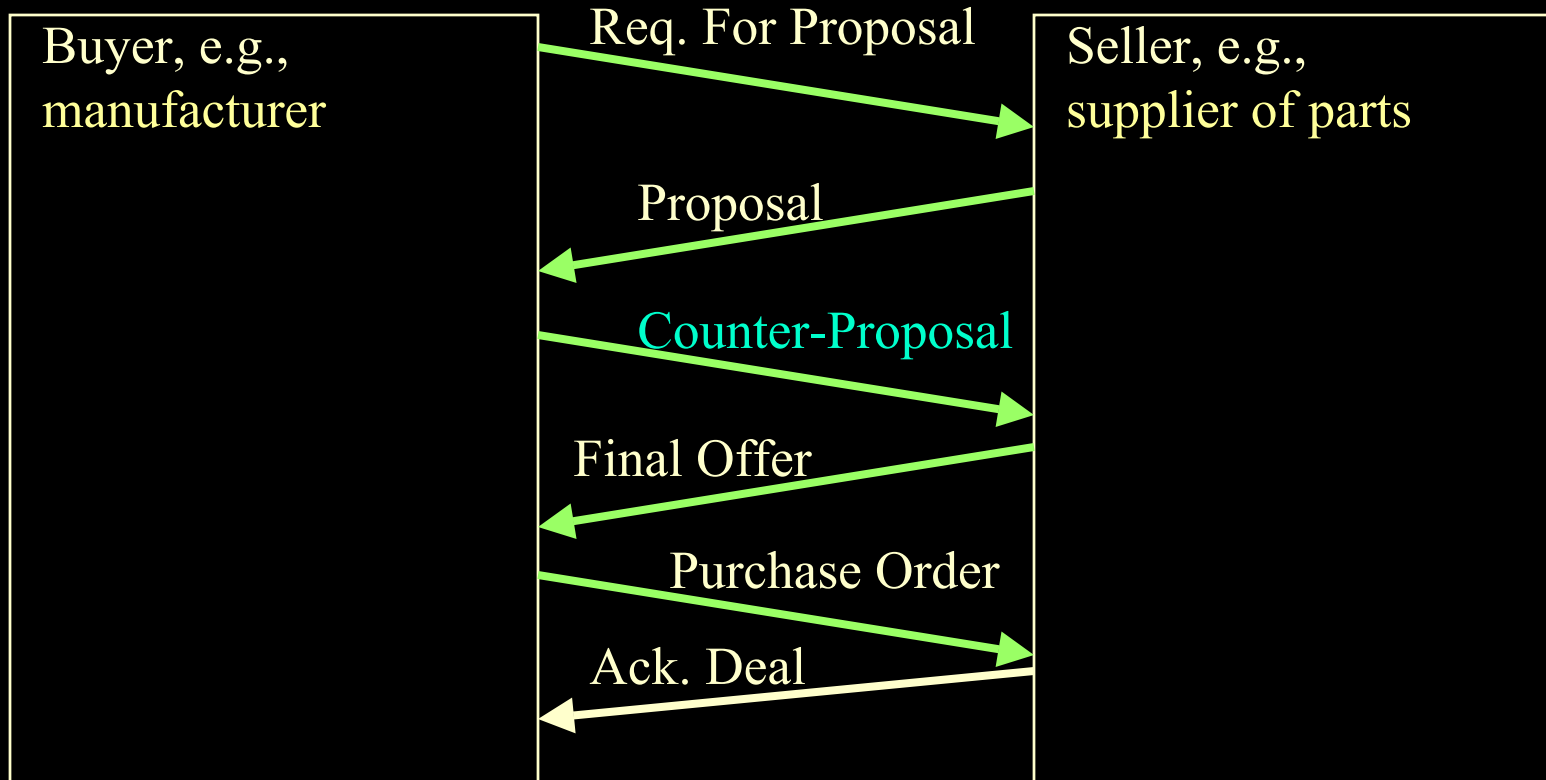


Contracting parties NEGOTIATE via shared rules.

Exchange of Rules Content during Negotiation: example



Exchange of Rules Content during Negotiation: example



Negotiation Example XML Document: Proposal from supplierCo to manufCo

- `<negotiation_message>`
- `<message_header>`
- `<proposal/>`
- `<from> supplierCo </from>`
- `<to> ManufCo </to>`
- `</message_header>`
- `<rules_content>`
- `...[see next slide]`
- `</rules_content>`
- `...`
- `</negotiation_message>`

- Example of similar message document format:

- FIPA Agent Communication Markup Language (draft industry standard).

Courteous LP Example: E-Contract Proposal from supplierCo to manufCo

- ...
- $\langle \text{usualPrice} \rangle \text{ price}(\text{per_unit}, ?\text{PO}, \$60) \leftarrow$
- $\text{purchaseOrder}(?\text{PO}, \text{supplierCo}, ?\text{AnyBuyer}) \wedge$
- $\text{quantity_ordered}(?\text{PO}, ?\text{Q}) \wedge (?Q \geq 5) \wedge (?Q \leq 1000) \wedge$
- $\text{shipping_date}(?\text{PO}, ?\text{D}) \wedge (?D \geq 24\text{Apr}00) \wedge (?D \leq 12\text{May}00).$
- $\langle \text{volumeDiscount} \rangle \text{ price}(\text{per_unit}, ?\text{PO}, \$51) \leftarrow$
- $\text{purchaseOrder}(?\text{PO}, \text{supplierCo}, ?\text{AnyBuyer}) \wedge$
- $\text{quantity_ordered}(?\text{PO}, ?\text{Q}) \wedge (?Q \geq 100) \wedge (?Q \leq 1000) \wedge$
- $\text{shipping_date}(?\text{PO}, ?\text{D}) \wedge (?D \geq 28\text{Apr}00) \wedge (?D \leq 12\text{May}00) .$
- $\text{overrides}(\text{volumeDiscount} , \text{usualPrice}) .$
- $\perp \leftarrow \text{price}(\text{per_unit}, ?\text{PO}, ?\text{X}) \wedge \text{price}(\text{per_unit}, ?\text{PO}, ?\text{Y}) \quad \text{GIVEN } (?X \neq ?\text{Y}).$
- ...

Negotiation Ex. Doc. Rules:

Counter-Proposal from manufCo to supplierCo

- ...
- $\langle \text{usualPrice} \rangle$ price(per_unit, ?PO, \$60) \leftarrow ...
- $\langle \text{volumeDiscount} \rangle$ price(per_unit, ?PO, \$51) \leftarrow
- purchaseOrder(?PO, supplierCo, ?AnyBuyer) \wedge
- quantity_ordered(?PO, ?Q) \wedge (?Q \geq 5) \wedge (?Q \leq 1000) \wedge
- shipping_date(?PO, ?D) \wedge (?D \geq 28Apr00) \wedge (?D \leq 12May00) .
- overrides(volumeDiscount , usualPrice) .
- $\perp \leftarrow$ price(per_unit, ?PO, ?X) \wedge price(per_unit, ?PO, ?Y) GIVEN (?X \neq ?Y).
- $\langle \text{aSpecialDeal} \rangle$ price(per_unit, ?PO, \$48) \leftarrow
- purchaseOrder(?PO, supplierCo, manufCo) \wedge
- quantity_ordered(?PO, ?Q) \wedge (?Q \geq 400) \wedge (?Q \leq 1000) \wedge
- shipping_date(?PO, ?D) \wedge (?D \geq 02May00) \wedge (?D \leq 12May00) .
- overrides(aSpecialDeal, volumeDiscount) .
- overrides(aSpecialDeal , usualPrice) .
- ...

Simply
added
rules!

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) </_body>`
- `</imp>`
- ...
- `</rulebase>`

XML Encoding of Rules in RuleML, Continued

- `<_body>`
- `<andb>`
- `<fclit>`
- `<_opr><rel>purchaseOrder</rel></_opr>`
- `<var>PO</var>`
- `<ind>supplierCo</ind>`
- `<var>AnyBuyer</var>`
- `</fclit>`
- `<fclit>`
- `...`
- `</fclit>`
- `...`
- `</andb>`
- `</_body>`

Commercial Implementation & Piloting

- **IBM CommonRules**: AlphaWorks Java library
 - implements rule-based capabilities:
 - XML inter-operability; prioritized conflict handling
- **Rule Markup Language**: nascent industry standards effort
 - XML Knowledge Representation (KR) → make the Web be “Semantic”
 - KR: **Situated Courteous Logic Programs in XML**
- EECOMS industry consortium including Boeing, Baan, TRW, Vitria, IBM, universities, small companies
 - \$29Million 1998-2000; 50% funded by NIST ATP
 - application piloted
 - contracting & negotiation; authorization & trust

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Flavors of Rules Commercially Most Important today in E-Business

- E.g., in OO app's, DB's, workflows.
- Relational databases, SQL: Views, queries, facts are all rules.
 - SQL99 even has recursive rules.
- Production rules (OPS5 heritage): e.g.,
 - Blaze, ILOG, 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.)*

Vision: Uses of Rules in E-Business

- Rules as 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; → 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 wide: e.g., SQL views, queries.
- Rules in communicating applications, e.g., embedded intelligent agents.

Criteria for Contract Rule Representation

1

- *High-level*: Agents reach **common understanding**; contract is easily **modifiable, communicatable, executable**.

2

- Inter-operate: heterogeneous commercially important rule systems.
- Expressive power, convenience, natural-ness.
- ... but: computational tractability.
- Modularity and locality in revision.
- Declarative semantics.

3

- Logical non-monotonicity: default rules, negation-as-failure.
 - essential feature in commercially important rule systems.
- Prioritized conflict handling.
- Ease of parsing.
- Integration into Web-world software engineering.
- Procedural attachments.

OLP

Courteous

XML

Situated

Also Currently Being Developed in the world today

- Delegations between agents
- XML Ontologies (Vocabularies)
 - knowledge representation: infer with definitional knowledge
 - specific domain/industry vocabularies
- DARPA Agent Markup Language: ontologies, rules
- Industry Standards:
 - Web, incl. Web services
 - Agents, Business Processes, Workflow
 - E-Commerce: ebXML, ...
 - Industry-Specific
 - *Legal XML*
- *Law: Electronic Signatures, ...*
- *Reusable Contract doc's on Web: CommonAccord, our work, ...*

Rule-based Semantic Web Services

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

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

Analysis:

High-Level Requirements for SWS

- Support Biz-Process Communication
 - E.g., B2B SCM, CRM
 - E.g., e-contracts, financial info, trust management.
- Support SWS Tasks above current WS layers:
 - Discovery/search, invocation, deal negotiation, selection, composition, execution, monitoring, verification

New Analysis:

Key Technical Requirements for SWS

- 1. Combine rules with ontologies, from many web sources, with:
 - Rules on top of ontologies
 - Interoperability of heterogeneous rule and ontology systems
 - Power in inferencing
 - Consistency wrt inferencing
 - Scalability of inferencing

- 2. Hook rules (with ontologies) up to web services
 - Ex. web services: enterprise applications, databases
 - Rules use services, e.g., to query, message, act with side-effects
 - Rules constitute services executably, e.g., workflow-y business processes
 - Rules describe services non-executably, e.g., for discovery, deal negotiation
 - On top of web service process models, coherently despite evolving messiness

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3 Areas of New Fundamental KR Theory that enable Key Technical Requirements for SWS

- **1. Description Logic Programs:**
KR to combine LP (RuleML) rules on top of DL (OWL) ontologies, with:
 - Power in inferencing (including for consistency)
 - Scalability of inferencing
- **2. Situated Logic Programs:**
KR to hook rules (with ontologies) up to (web) services
 - Rules use services, e.g., to query, message, act with side-effects
 - Rules constitute services executably, e.g., workflow-y business processes
- **3. Courteous Logic Programs:**
KR to combine rules from many sources, with:
 - Prioritized conflict handling to enable consistency, modularity; scaleably
 - Interoperable syntax and semantics

Research Directions

- Requirements Analysis
- Fundamental KR theory, techniques, tools:
 - Courteous LP, Situated LP, Description LP
 - More: nonmon OO ontologies, multi-agent nonmon, equational ontologies, context mappings, ...
- Web Services / Business Processes Knowledge Bases:
 - MIT Process Handbook – *Open-source version coming*
- Standards: Rules (RuleML/DAML), SWS (SWSI)
- Applications: e-contracting, finance, trust mgm., travel
- Fundamental theory for e-contracting
- Strategy wrt SWS uses, adoption, markets

Contributions to Early Standards Efforts: RuleML, SWSI

- RuleML Initiative
 - Co-Lead, Co-Founder
 - RuleML based largely on IBM CommonRules
 - Designed most key RuleML features
 - RuleML already has basic support for Description LP, Situated LP, Courteous LP
- Active in SWSI, esp. on Rules
 - Member of SWS Language committee
 - Co-chair Industrial Partners forum: several dozen companies
 - Technical challenge: representing service pre- / post-conditions, coherently on top of evolving messiness of WS process models (e.g., BPEL4WS)

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

SWS Adoption Roadmap: Strategy Considerations

- Expect see beginning in a lot of B2B interoperability or heterogeneous-info-integration intensive (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, creates value, increases 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

SW Early Adopters: Areas by Industry or Task

- Early SW techniques already in use:
 - e-contracting, supply chain incl. procurement
 - manufacturing, e.g. computer/electronics (RosettaNet), automotive (Covisint),
 - EECOMS pilot (Boeing, IBM, TRW, Baan)
 - office supplies (OBI)
 - retailing: shopbots and salesbots: comparisons, recommendations
 - extensive standards activity: Oasis ebXML, XML eContracts, UN UBL, EDI

SW Early Adopters: Areas by Industry or Task

- *Continued:* Early SW techniques already in use:
 - cyber goods:
 - financial services (rules; onto translation)
 - travel "agency", i.e.: tickets, packages (AI smarts for scheduling)
 - military intelligence (e.g., funded DAML)

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- SweetDeal e-contracting: student: Terrence Poon
- Situated Courteous Logic Programs: collaborator on implementation: Hoi Chan
- RuleML design: collaborators: Harold Boley, Said Tabet
- Support for the work was provided by DARPA Agent Markup Language program and Center for eBusiness @ MIT Vision Fund

OPTIONAL SLIDES FOLLOW

OWL: SW ontologies KR standard

- Draft Standard of W3C Web Ontologies Working Group (only about a year old), closely based on DAML+OIL precursor from research community. Uses RDF as syntax, extends RDF Schema.
- Based on Description Logic, a logical KR that has subset of expressiveness of first-order classical logic.
- Enables one to represent class hierarchies plus some more expressiveness, e.g., about cardinalities of properties and overlaps of classes.
- Still needs more theoretical and practical work to interoperate and bridge with conventional database schemas (e.g., Entity-Relationship (E-R) models and UML and SQL) and software engineering inheritance (e.g., class hierarchies in object-oriented (OO) languages such as Java and C++).
- Description Logic's commercial adoption, deployment, and application is much much less (yet) than Rules', and hugely less than OO/E-R/UML/SQL.

Prioritized argumentation in an opposition-locale.

Conclusions from opposition-locales previous to this opposition-locale $\{p_1, \dots, p_k\}$

(Each p_i is a ground classical literal. $k \geq 2$.)



Run Rules for p_1, \dots, p_k



Set of Candidates for p_1, \dots, p_k :
Team for p_1 , ..., Team for p_k



Prioritized Refutation



Set of Unrefuted Candidates for p_1, \dots, p_k :
Team for p_1 , ..., Team for p_k



Skepticism



Conclude Winning Side if any: at most one of $\{p_1, \dots, p_k\}$

Courteous LP's: Keys to Tractability

- Overall: mutex's & conflict locales \rightarrow keep tractability.
- LP's: disallow disjunctive conclusions, essentially. **Classical allows \Rightarrow NP-hard.**
- LP's: disallow contraposition ($= \{\neg a \leftarrow ., a \leftarrow b \wedge c.\} \Rightarrow (\neg b \vee \neg c)\}$) which requires disjunctive conclusions. "Directional". **Classical allows \Rightarrow NP-hard.**
- **Highly expressive prioritized rule representations** (e.g., Prioritized Default Logic, Prioritized Circumscription) **allow minimal conflict sets of arbitrary size \Rightarrow NP-hard overhead for conflict handling.**
- Courteous conflict handling involves essentially only pairwise conflicts, i.e., minimal conflict sets of size 2. (Current work: possibly generalize to size k .)
 - Novelty: generalize to **pairwise mutex's beyond $\perp \leftarrow p \wedge \neg p$** , e.g., partial-functional, thus **avoid need for contraposition and larger conflict sets.**
- Courteous conflict handling is local within an opposition locale: a set of rules whose heads oppose each other through mutex's. Refutation and Skepticism are applied within each locale.

WS Stack: some Acronym Expansion

- SOAP = simple protocol for XML messaging
- WSDL = protocol for basic invocation of Web Services, their input and output types in XML
- Choreography = higher-level application interaction protocols in terms of sequences of exchanged message types, contingent branching
 - Currently morphing into a W3C activity
- “Agreement” here = agreement between invoker and provider of the service, described at knowledge level
- *Overall: lots of proprietary jockeying and de-facto mode testing/pressuring of the open-consortial standards bodies (e.g., of W3C) “riding the tiger”*

SWS Tasks at higher layers of WS stack

Automation of:

- Web service discovery

Find me a shipping service that will transport frozen vegetables from San Francisco to Tuktoyuktuk.

- Web service invocation

Buy me “Harry Potter and the Philosopher’s Stone” at www.amazon.com

- Web service deals, i.e., contracts, and their negotiation

Propose a price with shipping details for used Dell laptops to Sue Smith.

- Web service selection, composition and interoperation

Make the travel arrangements for my WWW11 conference.

[Modification of slide also by Sheila McIlraith (Stanford) and David Martin (SRI International)]

SWS Tasks at higher layers of WS stack, continued

- Web service execution monitoring and problem resolution
Has my book been shipped yet? ... [NO!] Obtain recourse.
- Web service simulation and verification
Suppose we had to cancel the order after 2 days?
- Web service executably specified at “knowledge level”
The service is performed by running the contract ruleset through a rule engine.

[Modification of slide also by Sheila McIlraith (Stanford) and David Martin (SRI International)]