Ontology-driven Integration and Analysis for Semantic Applications in Business Intelligence and National Security

Ontology and Semantic Web Technical Exchange Meeting
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Talk Abstract
Paradigm shift over time: Syntax -> Semantics

Increasing sophistication in applying semantics
- Relevant Information (Semantic Search & Browsing)
- Semantic Information Interoperability and Integration
- Semantic Correlation, Mining, Analysis, Early Warning
Ontology at the heart of the Semantic Web; Relationships at the heart of Semantics

Ontology provides underpinning for semantic techniques in information systems.

- A model/representation of the real world (relevant concepts, entities, attributes, relationships, domain vocabulary and factual knowledge, all connected via a semantic network). Basic of agreement, applying knowledge

- Enabler for improved information systems functionalities and the Semantic Web:
  - Relevant information by (semantic) Search, Browsing
  - Interoperability and Integration
  - Actionable information by (semantic) information correlation and analysis

- Relationships – what makes ontologies richer (more semantic) than taxonomies
  ... see “Relationships at the Heart of Semantic Web: Modeling, Discovering, Validating and Exploiting Complex Semantic Relationship
Broad Scope of Semantic (Web) Technology

- **Current Semantic Web Focus**
  - Lots of Useful Semantic Technology (interoperability, Integration)
  - Agreement About
    - Function
    - Execution
    - Qos
  - Other dimensions: how agreements are reached, ...
Move from Syntax to Semantics in Information System (*a personal perspective*)

**Semantics** (Ontology, Context, Relationships, KB)
- VideoAnywhere
- InfoQuilt
- OBSERVER
- Semantic Web, some DL-II projects, Semagix SCORE, Applied Semantics

**Metadata** (Domain model)
- VisualHarness
- InfoHarness
- InfoSleuth, KMed, DL-I projects, Infoscopes, HERMES, SIMS, Garlic, TSIMMIS, Harvest, RUFUS, ...

**Data** (Schema, “semantic data modeling”)
- Mermaid
- DDTS
- Multibase, MRDSM, ADDS, IISS, Omnibase, ...

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**Generation III**
- (information brokering)
- 1997...

**Generation II**
- (mediators)
- 1990s

**Generation I**
- (federated DB/multidatabases)
- 1980s
Ontology-driven Information Systems are becoming reality

Software and practical tools to support key capabilities and requirements for such a system are now available:

- Ontology creation and maintenance
- Knowledge-based (and other techniques) supporting Automatic Classification
- Ontology-driven Semantic Metadata Extraction/Annotation
- Utilizing semantic metadata and ontology
  - Semantic querying/browsing
  - Information and application integration - normalization
  - Analysis/Mining/Discovery - relationships

Achieved in the context of successful technology transfer from academic research (LSDIS lab, UGA’s SCORE technology) into commercial product (Semagix’s Freedom)
Practical Experiences on Ontology Management today

- What types of ontologies are needed and developed for semantic applications today?
  - Is there a typical ontology?
- How are such ontologies built?
- Who builds them? How long it takes? How are ontologies maintained?
  - People (expertise), time, money
- How large ontologies become (scalability)?
- How are ontologies used and what are computational issues?
Types of Ontologies (or things close to ontology)

- Upper ontologies: modeling of time, space, process, etc
- Broad-based or general purpose ontology/nomenclatures: Cyc, CIRCA ontology (Applied Semantics), WordNet
- Domain-specific or Industry specific ontologies
  - News: politics, sports, business, entertainment
  - Financial Market
  - Terrorism
  - (GO (a nomenclature), UMLS inspired ontology, …)
- Application Specific and Task specific ontologies
  - Anti-money laundering
  - Equity Research
Building ontology

Three broad approaches:

- social process/manual: many years, committees
  - Based on metadata standard
- automatic taxonomy generation (statistical clustering/NLP): limitation/problems on quality, dependence on corpus, naming
- Descriptive component (schema) designed by domain experts; Description base (assertional component, extension) by automated processes

Option 2 is being investigated in OntoMiner project (an ontology learning system at UGA);
Option 3 is currently supported by Semangix Freedom
Metadata and Ontology: Primary Semantic Web enablers

Types of Metadata and Annotations

- **Ontology**
  (Example: Anatomy, Diagnostics, ...)

- **Semantic Metadata**
  (Example ontology-driven metadata:
  Region: Upper Abdomen
  Organ: Liver
  Pathological Structure: Abscess, Abscess located in Liver)

- **Structural Metadata**
  (document structure: DTDs, XSL,
  clustering and similarity processing: concept extraction)

- **Syntactic Metadata**
  (language, format, document length, creation date, source,
  audio bit rate, encryption, affiliation, date last reviewed, authorization, ...)

- **Data**
  (Structured, semi-structured and unstructured)
Semagix Freedom Architecture
(a platform for building ontology-driven information system)
Ontologies Semagix has designed:

- Few classes to many tens of classes and relationships (types); very small number of designers/knowledge experts; desciptional component (schema) designed with GUI
- Hundreds of thousands to several million entities and relationships (instances/assertions)
- Few to tens of knowledge sources; populated by knowledge extractors
- Primary scientific challenges faced: entity ambiguity resolution and data cleanup
- Total effort: few person weeks
Ontology Example (Financial Equity domain)

Equity Metabase Model

Equity Ontology Descriptional Component

Equity Ontology

Equity Metabase Model

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Ontology Creation and Maintenance Steps

1. Ontology Model Creation (Description)
2. Knowledge Agent Creation
3. Automatic aggregation of Knowledge
4. Querying the Ontology

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Step 1: Ontology Model Creation

Create an Ontology Model using Semagix Freedom Toolkit GUIs

- This corresponds to the schema of the description part of the Ontology
- Manually define Ontology structure for knowledge (in terms of entities, entity attributes and relationships)
- Create entity class, organize them (e.g., in taxonomy)
  - e.g. Person
    - BusinessPerson
    - Analyst
    - StockAnalyst . . .
- Establish any number of meaningful (named) relationships between entity classes
  - e.g. Analyst works for Company
  - StockAnalyst tracks Sector
  - BusinessPerson own shares in Company . . .
- Set any number of attributes for entity classes
  - e.g. Person
    - Address <text>
    - Birthdate <date>
  - StockAnalyst
    - StockAnalystID <integer>

<table>
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<th>Entity Class</th>
<th>Relationship</th>
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<tr>
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</tr>
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<td></td>
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</tr>
</tbody>
</table>
Step 1: Ontology Model Creation

Create an Ontology Model using Semagix Freedom Toolkit GUIs (Cont.)

- Configure parameters for attributes pertaining to indexing, lexical analysis, interface, etc.

- Existing industry-specific taxonomies like MESH (Medical), etc. can be reused or imported into the Ontology
Step 2: Knowledge Agent Creation (Automation Component)

Create and configure Knowledge Agents to populate the Ontology

- Identify any number of trusted knowledge sources relevant to customer’s domain from which to extract knowledge
  - Sources can be internal, external, secure/proprietary, public source, etc.

- Manually configure (one-time) the Knowledge Agent for a source by configuring
  - which relevant sections to crawl to
  - what knowledge to extract
  - what pre-defined intervals to extract knowledge at

- Knowledge Agent automatically runs at the configured time-intervals and extracts entities and relationships from the source, to keep the Ontology up-to-date
Step 3: Automatic aggregation of knowledge

Automatic aggregation of knowledge from knowledge sources

- Automatic aggregation of knowledge at pre-defined intervals of time
- Supplemented by easy-to-use monitoring tools
- Knowledge Agents extract and organize relevant knowledge into the Ontology, based on the Ontology Model
  - Tools for disambiguation and cleaning
- The Ontology is constantly growing and kept up-to-date
Step 4: Querying the Ontology

Semantic Query Server can now query the Ontology

- Incremental indexing
- Distributed indexing
- Knowledge APIs provide a Java, JSP or an HTTP-based interface for querying the Ontology and Metadata
Ontology with simple schema

- **Ontology for a customer in Entertainment Industry primarily for repertoire management**
- **Ontology Schema (Descriptional Component)**
  - Only few high-level entity classes, primarily *Product* and *Track*
  - A few attributes for each entity class
  - Only a few relationship types, e.g.: “has track”
  - Many-to-many relationship between the two entity classes
    - A product can have multiple tracks
    - A track can belong to multiple products
Entertainment Ontology (Assertional Component)

- Description base of 10 to 20 million objects (entity, relationship, attribute instances in ontology)
- Extracted by Knowledge Agents from 6 disparate databases

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Technical Challenges Faced

◆ ‘Dirty’ data
  ❖ Inconsistent field values
  ❖ Unfilled field values
  ❖ Field values appearing to mean the same, but are different

◆ Non-normalized Data
  ❖ Different names to mean the same object (schematic heterogeneity)

◆ Upper case vs. Lower case text analysis

◆ Modelling the ontology so that appropriate level (not too much, not too less) of information is modelled

◆ Optimizing the storage of the huge data
  ❖ How to load it into Freedom’s main memory system

◆ Scoring (for identity resolution) and pre-processing (for normalization) parameters changed frequently by customer, necessitating constant update of algorithms

Not all problems solved, many are identified and reported
Effort Involved

- **Ontology Schema Build-Out** (descriptive component)
  
  Essentially an iterative approach to refining the ontology schema based on periodic customer feedback
  
  - Due to iterative decision making process with the multi-national customer, overall finalization of ontology took 3-4 weeks to complete; not complex otherwise

- **Ontology Population** (assertional component/description base)
  
  - 6 Knowledge Agents, one for each database; writing agents took about a day
  
  - Automated extraction using Knowledge Agents took a few days for all the Agents, with a few days of validation
Example of Ontology with complex schema

- Ontology for Anti-money Laundering (AML) application in Financial Industry
- Ontology Schema (Descriptional Component)
  - About 50 entity classes
  - About 100 attribute types
  - About 60 relationship types between entity classes
AML Ontology Schema (Assertional Component)

Subset of the entire ontology
Ontology Schema (Assertional Component)

- About 1.5M entities, attributes and relationships
- 4 different (licensed or public) sources for knowledge extraction
  - Dun and Bradstreet
  - Corporate 192
  - Companies House
  - Hoovers

**Effort Involved**

- Ontology schema design: less than a week
- Automated Ontology population using Knowledge Agents: a few days
Technical Challenges Faced

- Complex ambiguity resolution at entity extraction time
- Modelling the ontology to capture adequate details of the domain for intended application
  - Ensuring that the risk algorithm (link score analysis) can be implemented with the needed parameters
- Knowledge extraction from sources that needed extended cookie/HTTPS handling
- Programming ontology modelling through API
  - Adding entities on the fly (dynamic ontology)
Overcoming the key issue of resolving ambiguities in facts & evidence

- Aggregation and normalization of any type of fact and evidence into the domain ontology
  - Resolution of issues over terminology
    - i.e. “Benefit number” is an alias of “SSN”
  - Resolution of issues over identity
    - i.e. is executive “Larry Levy” an existing entity or a new entity?
  - Enabling decisions to be made on the trustworthiness of existing facts
    - Which source did the data originate from?
    - How much supporting evidence was there?
    - How much of the supporting evidence can be substantiated?
  - Validating and enforcing constraints, e.g. cardinality
    - President of the United States (has cardinality) = Single
    - Terrorist (has cardinality) = Multiple
Overcoming the key issue of resolving ambiguities in facts & evidence (Contd…)

- Managing temporal aspects of the domain
  - Expiration of entity instances
  - E.g., “Hillary Clinton” is no longer the First Lady of the United States but was until “May 3rd 2001”
- Providing auditing capabilities
  - Stamping evidence with date, time and source
  - E.g., Terrorist: “Seamus Monaghan”; date extracted: “2003-01-30; time extracted: 16:45:27; source; FBI Watch list
- Ontological relationships makes for more expressive model and provide better semantic description (compared to taxonomies)
  - Information can be presented in natural language format
  - E.g., “Bob Scott” is a founder member of business entity “AIX LLP” that has traded in “Iran” that is on “FATF watch-list”
Disambiguating important reference data e.g. Social Security Number

- beneficiary number
- claim number
- folder number
- payee number
- customer number

- date of birth
- height
- sex
- religion

Terminology is normalized through entity aliases

Relationship and attribute matching provide powerful means of disambiguating and normalizing data from multiple systems
Ontology Storage and Access

- Ontology typically stores millions of entities, attributes and relationships for any given application
- Natural implication → how to store it efficiently and most optimally so that accessing ontology does not degrade performance?
- What are the storage scheme possibilities?
  - Database storage (RDBMS)
  - can logic-based /prolog systems handle this size and computation?
  - . . .
- Any of the above typical storage schemes poses performance challenges for mass applications
Application Scenario

Ontology-driven semantic integration all types of structured and unstructured content

Freedom domain model

Freedom Metabase

High performance Query Engine

Content Agents
Agent Monitor
Agent Scheduler
Agent Builder

XML/Feeds
Websites
Chat rooms
Email
Reports
Documents

Unstructured Content Sources

Knowledge Agents
Agent Monitor
Agent Scheduler
Agent Builder

Evidence Sources

Law Enforcement
Airline Reservations
INS
Watch lists
Credit / Finance / Electoral Registers

Dynamic Domain Specific Data

Evidence Sources

Evidence
Commentary
Observations

Semantic Metadata enhancement

FBI
FAA
CIA
LEA
INS

Federal Bureau of Investigation
Federal Aviation Administration
Central Intelligence Agency
Local Emergency Apparatus
Immigration and Naturalization Service

Power • Through • Relevance
Overcoming the challenges of integrating legacy and open source systems

- Extraction Agents utilize any existing data and content interfaces – no need to change legacy systems
- Processing several hundred content formats – no need to repurpose content
- The National Security or BI domains can be extended by incrementally adding structured and unstructured content sources
- Domain Ontology can be modified easily to reflect changes to:
  - structured and unstructured content sources
  - the intelligence domain
Information Extraction and Metadata Creation

Key challenge:
Create/extract as much (semantics) metadata automatically as possible
Braves refuse to offer Galarraga arbitration

Posted: Thursday December 07, 2000 8:15 PM

ATLANTA (AP) -- The Braves refused to offer salary arbitration to Andres Galarraga on Thursday, apparently ending the first baseman's career in Atlanta.

Atlanta did offer arbitration to six of its former players who became free agents: pitchers Andy Ashby, Terry Mulholland, John Burkett and Scott Kamieniecki, first baseman Wally Joyner and outfielder Bobby Bell.

Ashby and Joyner, who were eligible for a one-year contract, turned down the offers.

Galarraga, who was eligible for a two-year contract, had the 1999 season of one year of arbitration.

After missing the 1999 season because of cancer, Galarraga returned to the field but missed most of the season with an inflamed elbow.

Free agents not offered arbitration by their former teams can negotiate with them until May 1.

The Braves made an offer Wednesday morning, but Galarraga reportedly said it was too low. Galarraga is seeking a two-year contract.

Players offered arbitration have until Dec. 19 to accept or reject the offers and can negotiate with their former teams through Jan. 8.
Ontology-directed Metadata Extraction
(Semi-structured data)

Web Page

Enhanced Metadata Asset

Extraction Agent

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Semantic Enhancement Server: Semantic Enhancement Server classifies content into the appropriate topic/category (if not already pre-classified), and subsequently performs entity extraction and content enhancement with semantic metadata from the Semagix Freedom Ontology.

How does it work?
- Uses a hybrid of statistical, machine learning and knowledge-base techniques for classification
- Not only classifies, but also enhances semantic metadata with associated domain knowledge

Enabling powerful linking of actionable information and facilitating important semantic applications such as knowledge discovery and link analysis

(user's task of manually retrieving all the information he needs to know is greatly minimized; he can spend more time making effective decisions)

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Blue-chip bonanza continues

Dow above 9,000 as HP, Home Depot lead advance; Microsoft upgrade helps techs.

August 22, 2002: 11:44 AM EDT

By Alexandra Twin, CNN/Money Staff Writer

New York (CNN/Money) - An upgrade of software leader Microsoft and strength in blue chips including Hewlett-Packard and Home Depot were among the factors pushing stocks higher at midday Thursday.

With the Dow Jones Industrial Average spending time above the 9,000 level.

Around 11:40 a.m. ET, the Dow Jones Industrial Average gained 95.06 to 9,022.09, continuing a more than 1,300-point resurgence since July 23. The Nasdaq composite gained 9.12 to 1,418.37.

The Standard & Poor's 500 index rose 9.61 to 958.97.

Hewlett-Packard ( HPQ: up $0.33 to $15.03, Research, Estimates) said a report shows its share of the printer market grew in the second quarter, although another report showed that its share of the computer server market declined in Europe, the Middle East and Africa.

Home Depot ( HD: up $1.07 to $33.75, Research, Estimates) was up for the third straight day after topping fiscal second-quarter earnings estimates on Tuesday.

Tech stocks managed a turnaround. Software continued to rise after Salomon Smith Barney upgraded No. 1 software maker Microsoft ( MSFT: up $0.55 to $52.83, Research, Estimates) to "outperform" from "neutral" and raised its price target to $59 from $56. Business software makers Oracle ( ORCL: up $0.18 to $10.94, Research, Estimates), PeopleSoft ( PSFT: up $1.17 to $20.67, Research, Estimates) and BEA Systems ( BEAS: up $0.28 to $7.12, Research, Estimates) all rose in tandem.
Automatic Semantic Annotation

Enhancement

Rich Semantic Metatagging

Value-added Voquette Semantic Tagging

Value-added relevant metatags added by Semagix to existing COMTEX tags:
- Private companies
- Type of company
- Industry affiliation
- Sector
- Exchange
- Company Execs
- Competitors
Semantic Query Processing and Analytics

- Semagix Solution: In-memory semantic querying (semantic querying in RAM)
  - Complex queries involving Ontology and Metadata
  - Incremental indexing
  - Distributed indexing
  - High performance: 10M queries/hr; less than 10ms for typical search queries
  - 2 orders of magnitude faster than RDBMS for complex analytical queries

- Knowledge APIs provide a Java, JSP or an HTTP-based interface for querying the Ontology and Metadata
Cocaine scandal sets society hearts fluttering

Investigators are attempting to establish whether the suspect, Palermo businessman Alessandro Martello, was bluffing when he claimed to work as Mr Micciche’s assistant and to have the use of an office in the ministry’s Rome headquarters.

Mr Martello’s arrest warrant, signed last week along with 10 others, alleged that he had not hesitated to deliver a consignment of cocaine inside the ministry itself, confident in the knowledge that his influential connections would protect him from suspicion.

The cocaine scandal has been a gift for the opposition, which promptly tabled a parliamentary question for the economics minister Giulio Tremonti, asking how many times the alleged pusher had visited his ministry and whether it was true that he had the use of an office there.

The minister has yet to reply, but it has emerged that Mr Martello’s frequent visits were the result of his work as a consultant for a company promoting investment in southern Italy. "What he does in his private life has nothing to do with us," his now ex-employer said.

The businessman, who is now in prison, asked the junior minister to intercede on his behalf with a bank where he was having trouble opening an account. Mr Micciche, addressed familiarly as "Gianfrancuccio", said he would see what he could do.

Prime minister Silvio Berlusconi is already engaged in an extenuating personal battle with Milan’s anti-corruption magistrates, so the alleged drug entanglements of a junior Sicilian minister are the last thing he needs.

Italian government
Italian parliament
Italian president
Italian government

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Application to semantic analysis/intelligence (Contd…)

- “Terrorist Meeting” inferred by classification of the email
- Is corroborated by ontological analysis of key terms i.e. “meeting”, and
- Is proven by automatic extraction and semantic enhancement of Terrorists leading to inference that two terrorist organizations are involved in non-terrorism event
- Important metadata - Afghanistan (country) is automatically extracted and enhanced with semantic metadata relating to the entity i.e. Afghanistan is the home of Al Qaeda, Mohammed Atta is a senior member of Al Qaeda

Classification Metadata: Terrorist Meeting

Semantic Metadata extracted from the e-mail:
- “Mohamed Atta” is Terrorist – direct inference
- “Abdulaziz Alomari” is Terrorist – direct inference
- “Mohammed Atta” is a senior member of “Al Qaeda” – direct inference
- “Abdulaziz Alomari” is a senior member of Saudi Misaal – direct inference
- “Al Qaeda” is based in “Afghanistan” – direct and indirect inference
- “Saudi Misaal” is based in “Saudi Arabia” – indirect inference
Semantic Associations Discovery on the Semantic Web

- Discovering complex relationships from very large metabase
- Semantic Association Identification and Knowledge Discovery for National Security Applications, NSF-funded project at LSDIS Lab, UGA (Grant No. 0219649)

Research in progress

RDF Description Base wrt to this schema is populated from 30+ sources
\( \rho \text{-PathAssociated}(\text{Transfer1, Iraq}) \)

- \( \text{Transfer1} \rightarrow \text{Account2} \rightarrow \text{IraqInternationalBank} \rightarrow \text{Iraq} \)
- \( \text{Transfer1} \rightarrow \text{Account2} \rightarrow \text{SaddamHussein} \rightarrow \text{Iraq} \)
- \( \text{Transfer1} \rightarrow \text{Account2} \rightarrow \text{SaddamHussein} \rightarrow \text{IraqGovernment} \rightarrow \text{Iraq} \)
\texttt{\(\rho\text{-}join\text{\textunderscore}Associated}(\text{Account2, Email1})\)

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<tr>
<td>Account2 (\rightarrow) SaddamHussein</td>
</tr>
<tr>
<td>Email1 (\rightarrow) SaddamHussein</td>
</tr>
</tbody>
</table>
p-IsoAssociated(Account2, Account1)

Account2 → at → IraqInternationalBank → locatedIn → Iraq
Account1 → at → PakistanInternationalBank → locatedIn → Pakistan

Account2 → p_holder → SaddamHussein → fromLocation → Iraq
Account1 → p_holder → OsamaBinLaden → fromLocation → SaudiArabia

Account2 → p_holder → SaddamHussein → leaderOf → IraqGovernment → locatedIn → Iraq
Account1 → p_holder → OsamaBinLaden → leaderOf → AlQaeda → locatedIn → Afghanistan
Conclusion

◆ Great progress from work in semantic information interoperability/integration of early 90s until now, re-energized by the vision of Semantic Web, related standards and technological advances

◆ Technology beyond proof of concept

◆ But lots of difficult research and engineering challenges ahead

◆ More:
  (Research) [http://lsdis.cs.uga.edu/proj/SAl/](http://lsdis.cs.uga.edu/proj/SAl/)

◆ Demos available