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Design and Implementation of a Semantic Web Solution for Real-time Reservoir Management

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About CiSoft

CiSoft: Center for Interactive Smart Oilfield Technologies
http://cisoft.usc.edu

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- USC-Chevron Center of Excellence for Research and Academic Training on Interactive Smart Oilfield Technologies
- **Established**: December 2003
- **Disciplines**: Petroleum Engineering, Chemical Engineering, Material Science, Physics, Computer Science, Electrical Engineering, Industrial Engineering
- **MS Degree** in Petroleum Engineering with emphasis on Smart Oilfield Technologies (SOFT)

RESEARCH AREAS	
• Integrated Asset Management	• Reservoir Management
• Well Productivity Improvement	• Data Management Tools
• Robotics and Artificial Intelligence	• Immersive Visualization
• Embedded and Networked Systems	

Outline

- Integrated Asset Management
  - Objectives
  - Role of semantic web
  - Software development methodology
- IAM Ontology
  - Ontology design
  - Change management and dirty queries
- Remarks
  - Lessons learnt
  - Areas of interest

CiSoft Integrated Asset Management (IAM)

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- What is IAM?
  - A **comprehensive transformation** approach to **integrated** oilfield operations
  - A software application that can help asset team members simulate decisions before making them
- Objectives
  - Increase integration between different functions
  - Enable asset level "what if" scenarios
  - Create a knowledge base of activities and decisions
  - Reduce risk and uncertainty in decision making
- Challenges
  - Data silos are not interoperable
  - Data is semi-structured
  - Multiple organizations and classes of users

CiSoft What IAM provides to users

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- Efficient access to data and information
  - Reduces time spent looking for data
  - Answers complex queries across semi-structured data sets
- Consistent view of information
  - Reconciles different views of the same information
  - Creates shared "situational awareness" of the asset
- Context of information creation and usage
  - Leads to more meaningful interpretation of data
  - Acts as organizational memory for the workflow
- Non-functional: Non-disruptive, extensible, scalable, usable, etc.

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The IAM “Metacatalog”

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- Problem
  - Simulation models embody different realizations of uncertainty and development strategies for an asset
  - Models are created by different user groups at different times; it is difficult to maintain consistency of assumptions
  - No intuitive search functionality available to domain experts (“Show me most recently history matched model”)
- Solution: The IAM Metacatalog
  - Metadata repository at the core of the IAM application
  - Focus on answering “What does the data mean”? (vs. “How do I access the data”)
  - Key parameters and assumptions from various models are extracted and stored in the metacatalog
  - Also stores relationships between data objects and their provenance

Why Semantic Web Technologies

- Expressivity and richness of data model
- Organic growth capability for domain models/knowledge
- Inferencing and Rule Based Reasoning
- Flexibility of querying
- Ease of domain expert to understand and contribute to domain models
- Standards based (No vendor lock-in)
- Promoted by W3C

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IAM R&D Timeline

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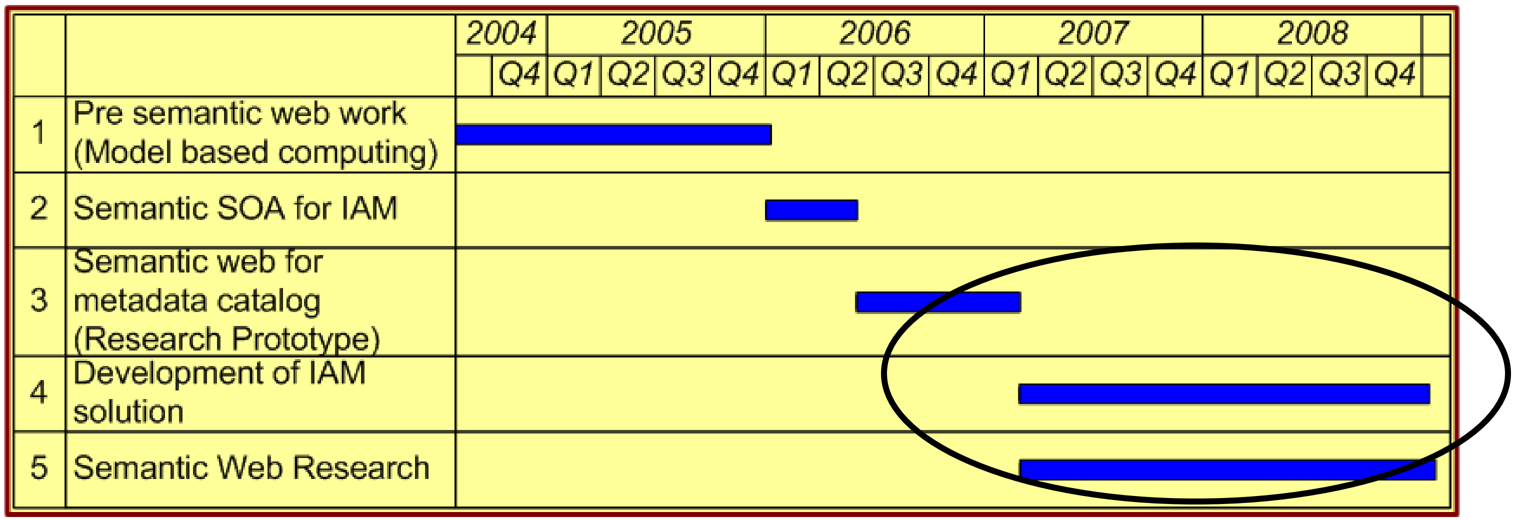

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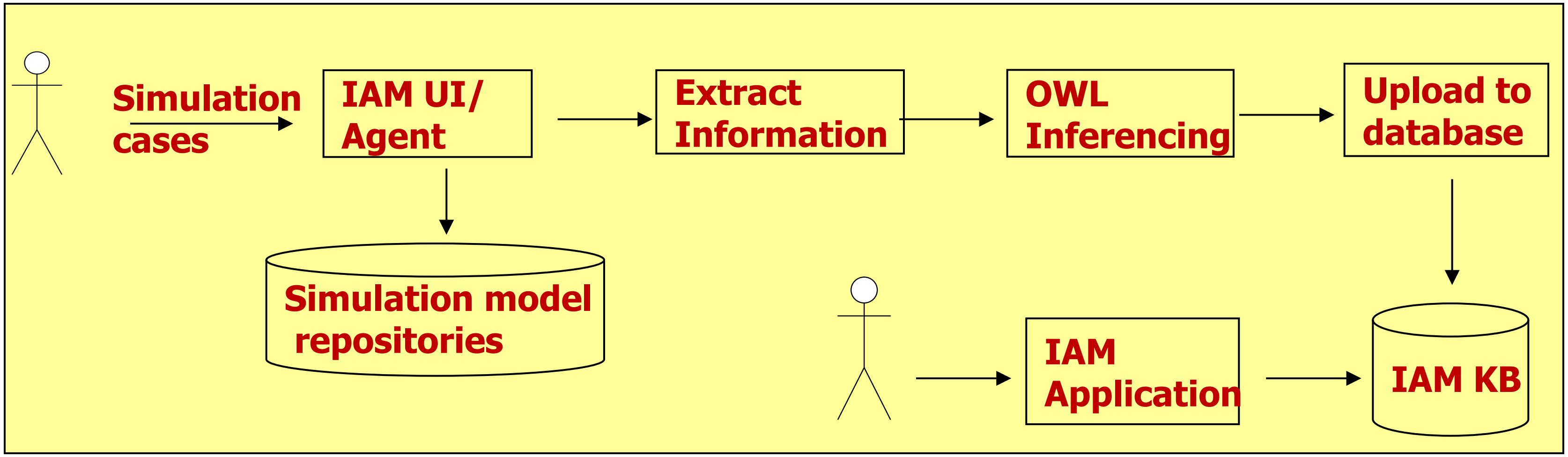
Populating the Metacatalog

- Most of the metadata is captured offline
- Metadata extraction by custom built parsers



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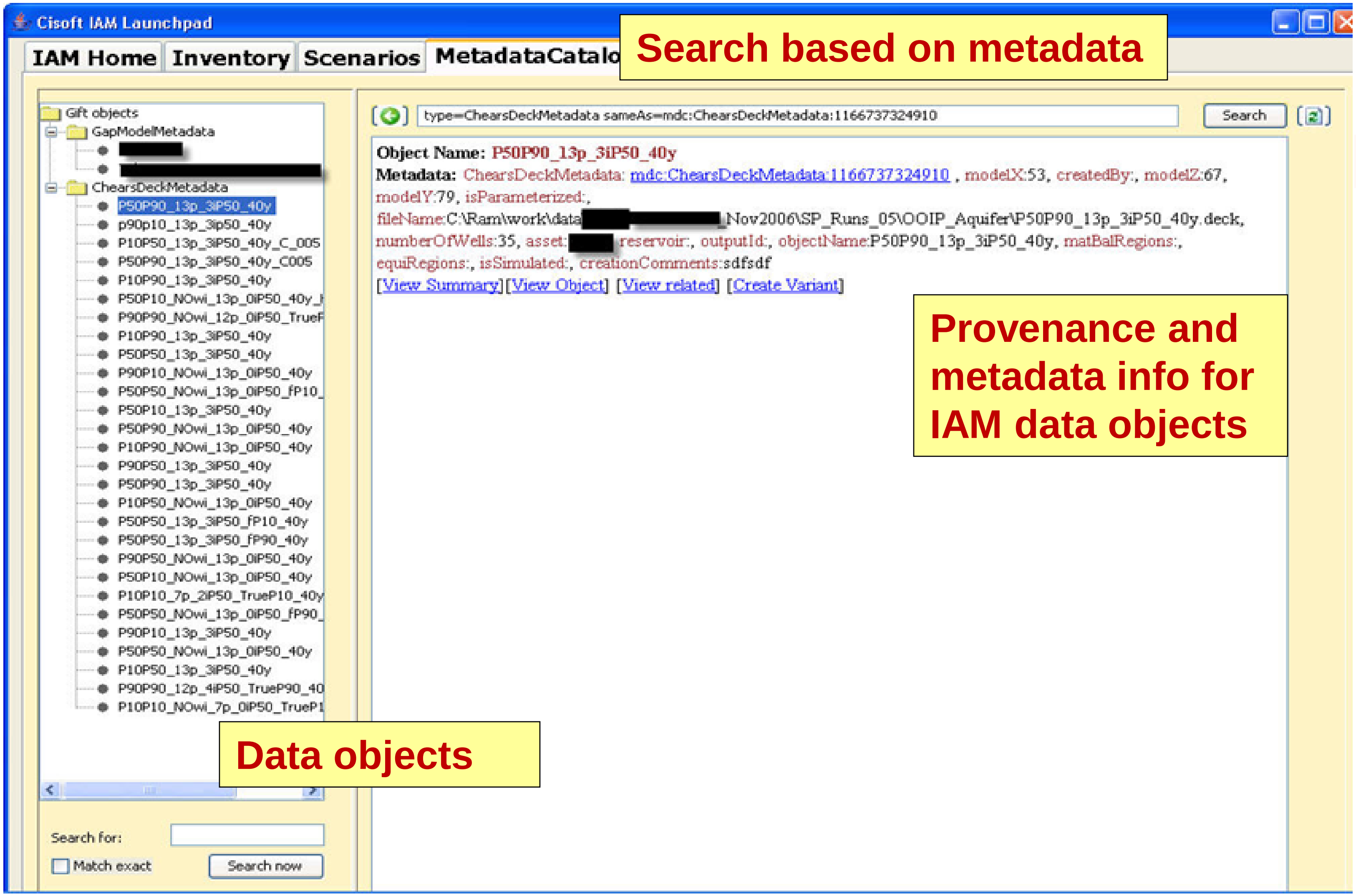
Example 1: Browse And Search



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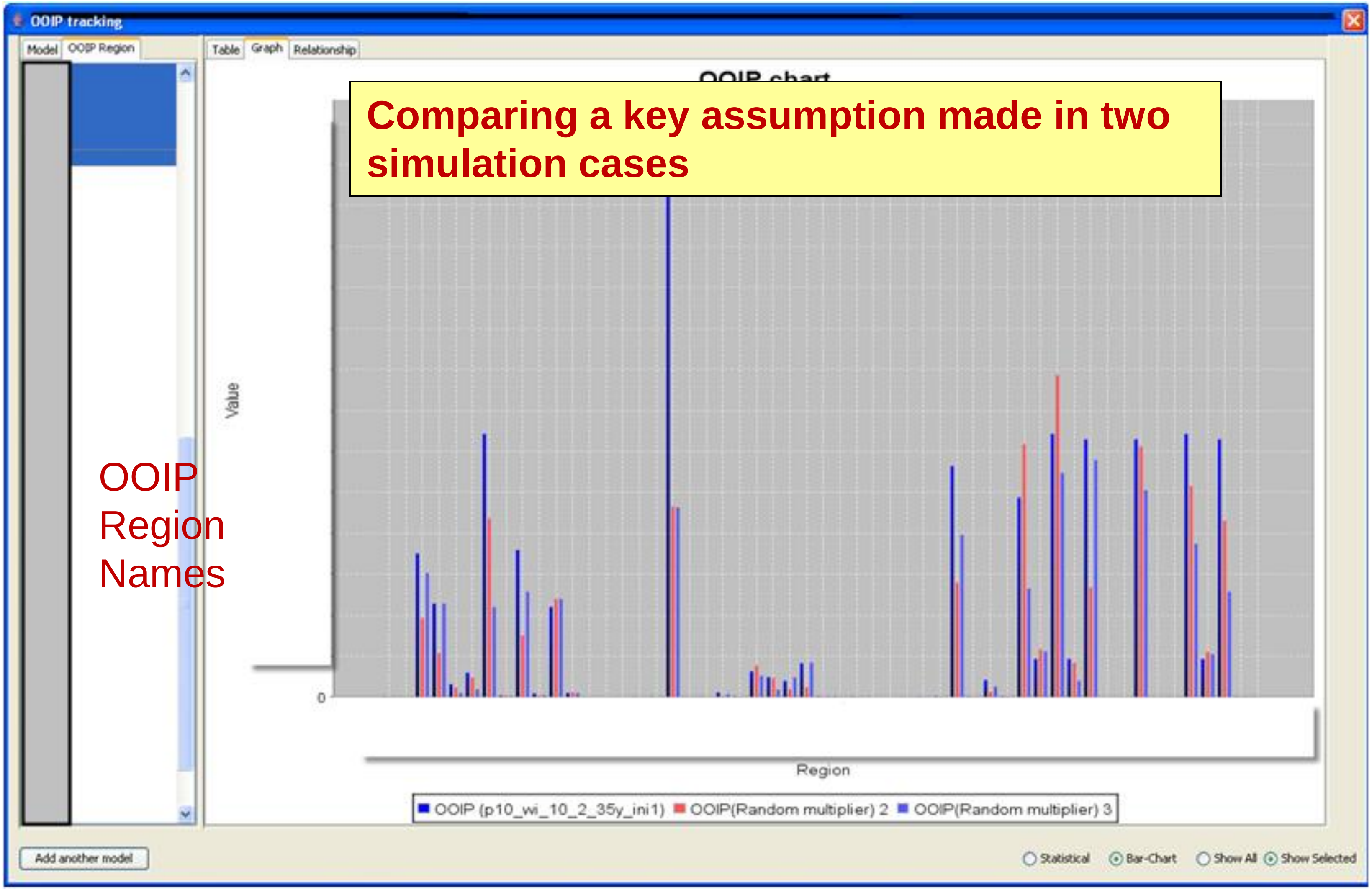
Example 2: Comparing Assumptions



Comparing a key assumption made in two simulation cases

OOIP Region Names

Software Development Methodology

- Agile development using Scrum
  - Iterative software development in “Sprints”
  - Close collaboration with customer
    - Reviews/demos after each sprint
    - Flexible prioritization at sprint boundaries
    - “Product Owner” role represents the stakeholders
  - Less focus on formal documentation

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Phases

- Development in sprints

Requirements → Planning → Ontology Spec/ Refactoring ⇄ Review → Application Dev

- Observation: Ontology frequently modified
  - Techniques for change management make methodology more successful

CiSoft Miscellaneous

- Addressed key risks of an OWL-based solution
  - Performance - Benchmarking
  - Limited tool support – Web service interfaces for KB
  - Ongoing evaluation of alternatives
- Tech transfer to software developers
  - Code and documentation
  - Demos and training
- Development
  - Ontology design was done with the assistance of domain experts and end users
  - CiSoft researcher acting as “Product Owner” for Scrum team moved research into deployment

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Ontology Design

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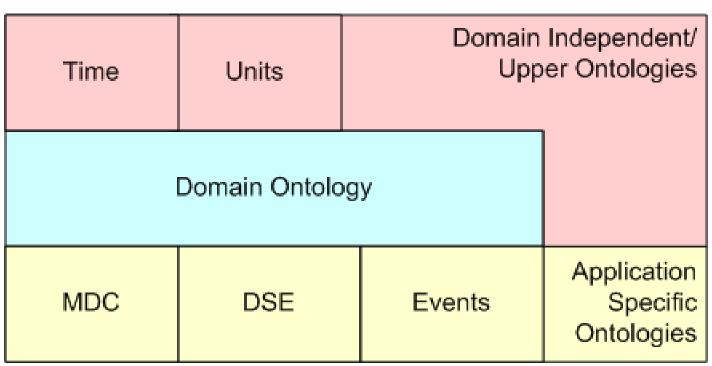
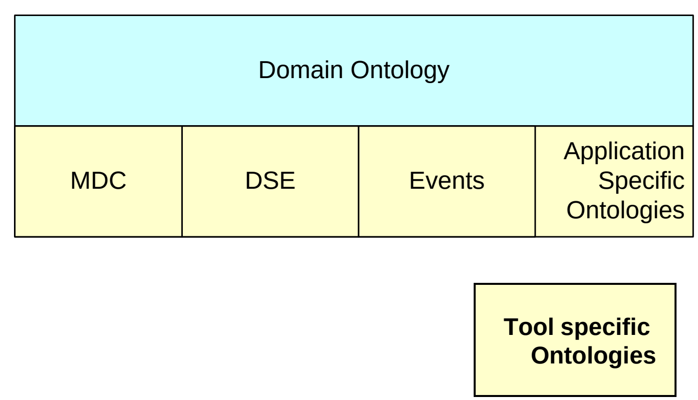
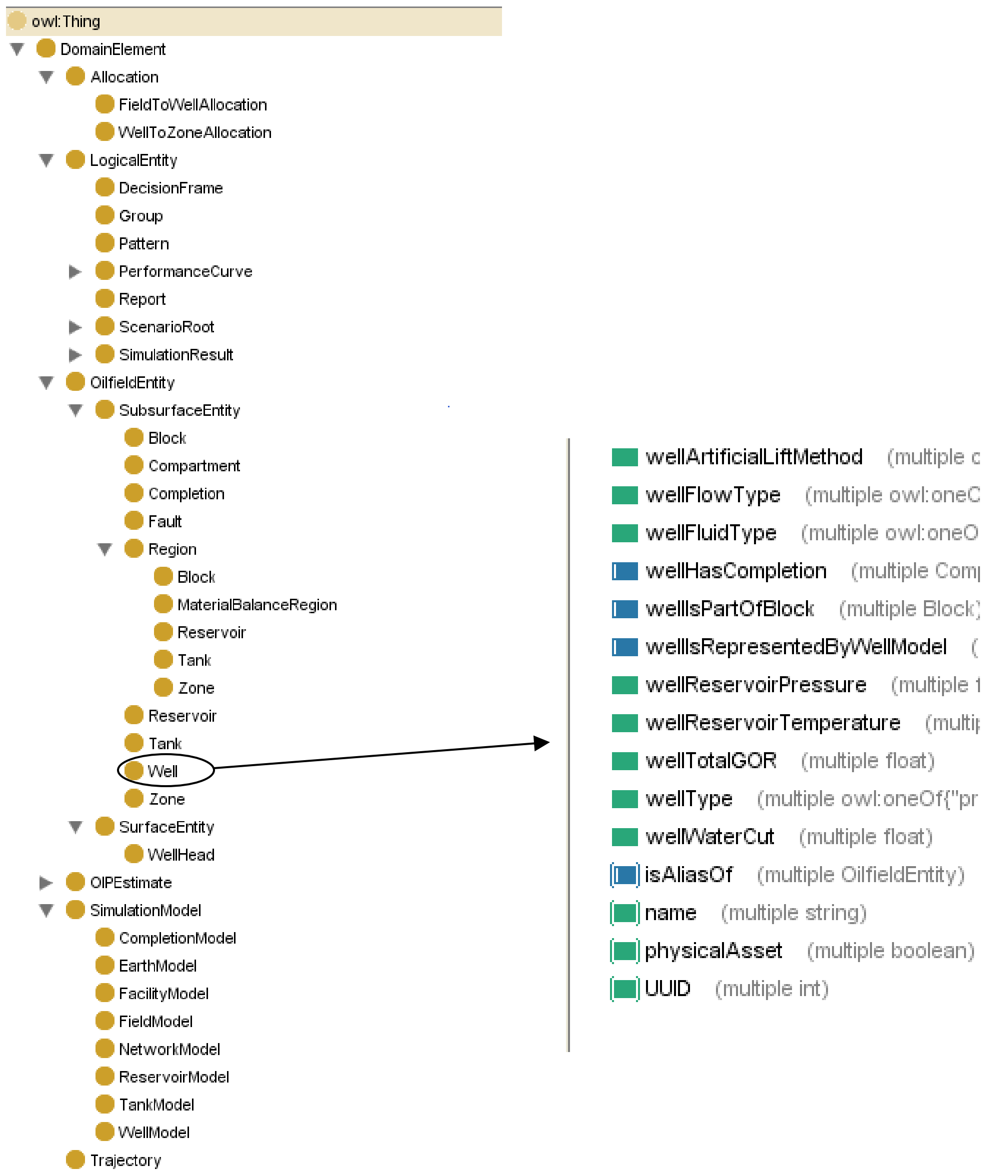
- Ontology design divided into three levels to improve modularity
- Domain independent/Upper ontologies
  - Concepts common to all ontologies like time, units etc.
- Domain ontology
  - Model of the elements in the asset
  - Uses elements from upper ontologies
- Application specific ontologies:
  - Elements specific to a given application or workflow
  - Uses elements from upper and domain ontologies





CiSoft IAM Ontologies: Domain Ontology



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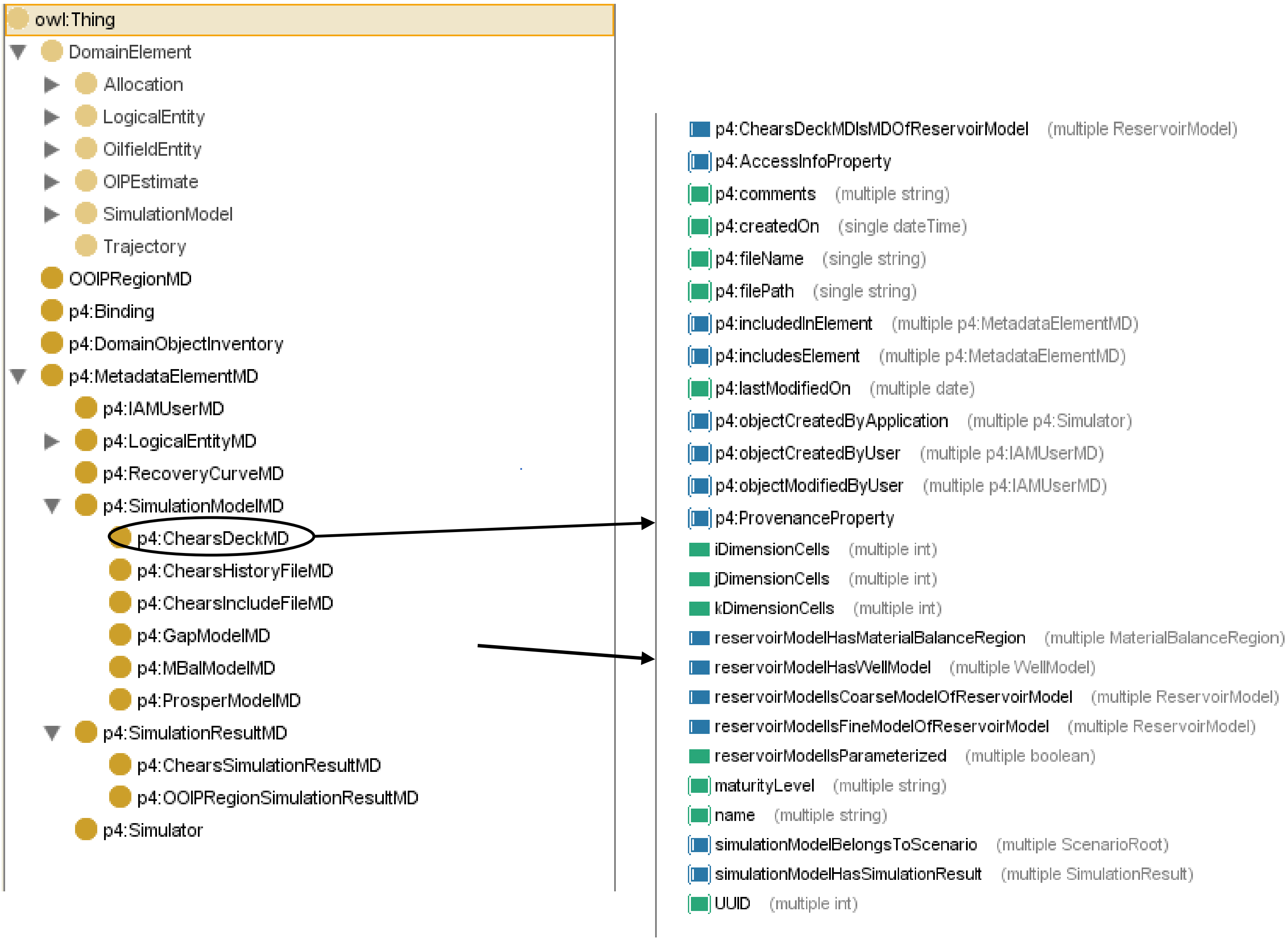
CiSoft IAM Ontologies: Metadata ontology



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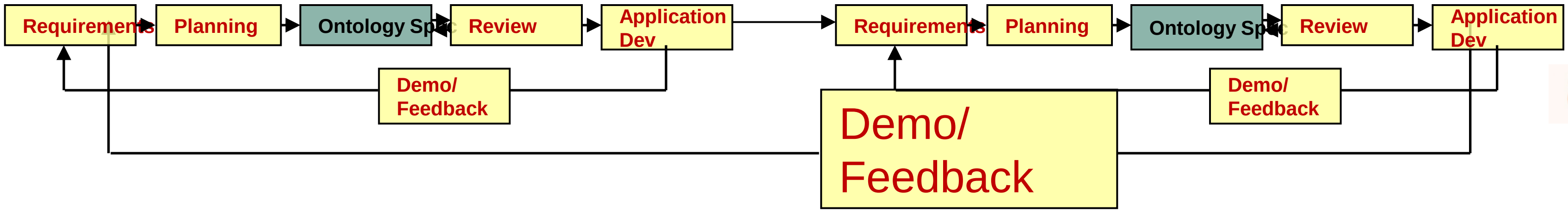
Implementation

- OWL data store + SPARQL querying
- Current implementation uses Jena OWL API
  - Two reasoners
    - Rule based reasoner (Jena)
    - Tableaux reasoner (Pellet)
  - OWL data stored in Jena RDBMS, file system
- Web service API to abstract data store (Apache Axis2)
- Various applications that use MDC

Supporting Iterative Development



- Ontologies are modified in every sprint

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Change Management Problem

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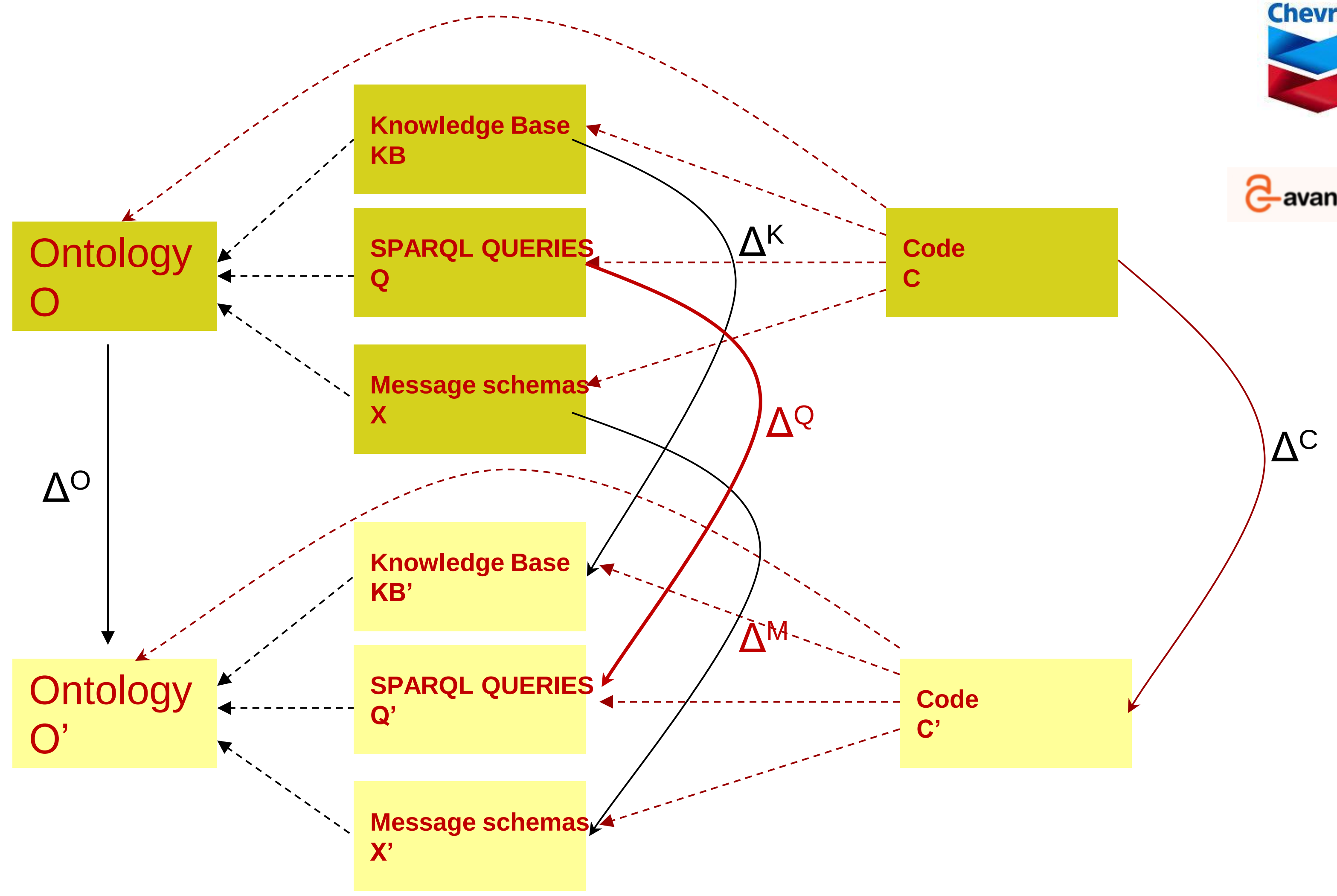
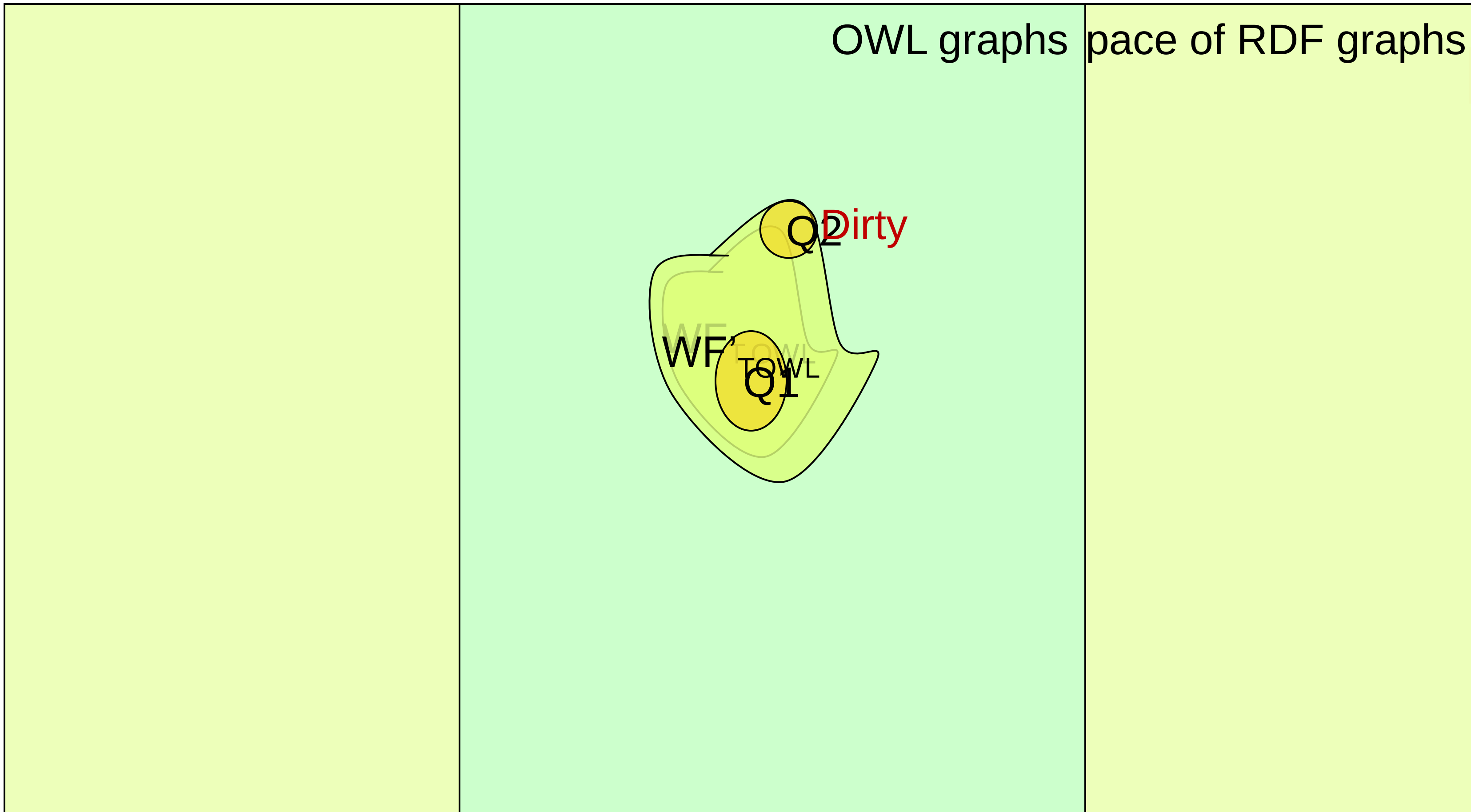


Detect **dirty queries** that are invalidated when an ontology is modified

Dirty Queries



$$\mathrm{EXT}_{T'}(Q) \cap (WF'_{T,OWL} \setminus WF_{T,OWL}) != \Phi$$

$$\vee\ \mathrm{EXT}_{T}(Q) \cap (WF_{T,OWL} \setminus WF'_{T,OWL}) != \Phi$$

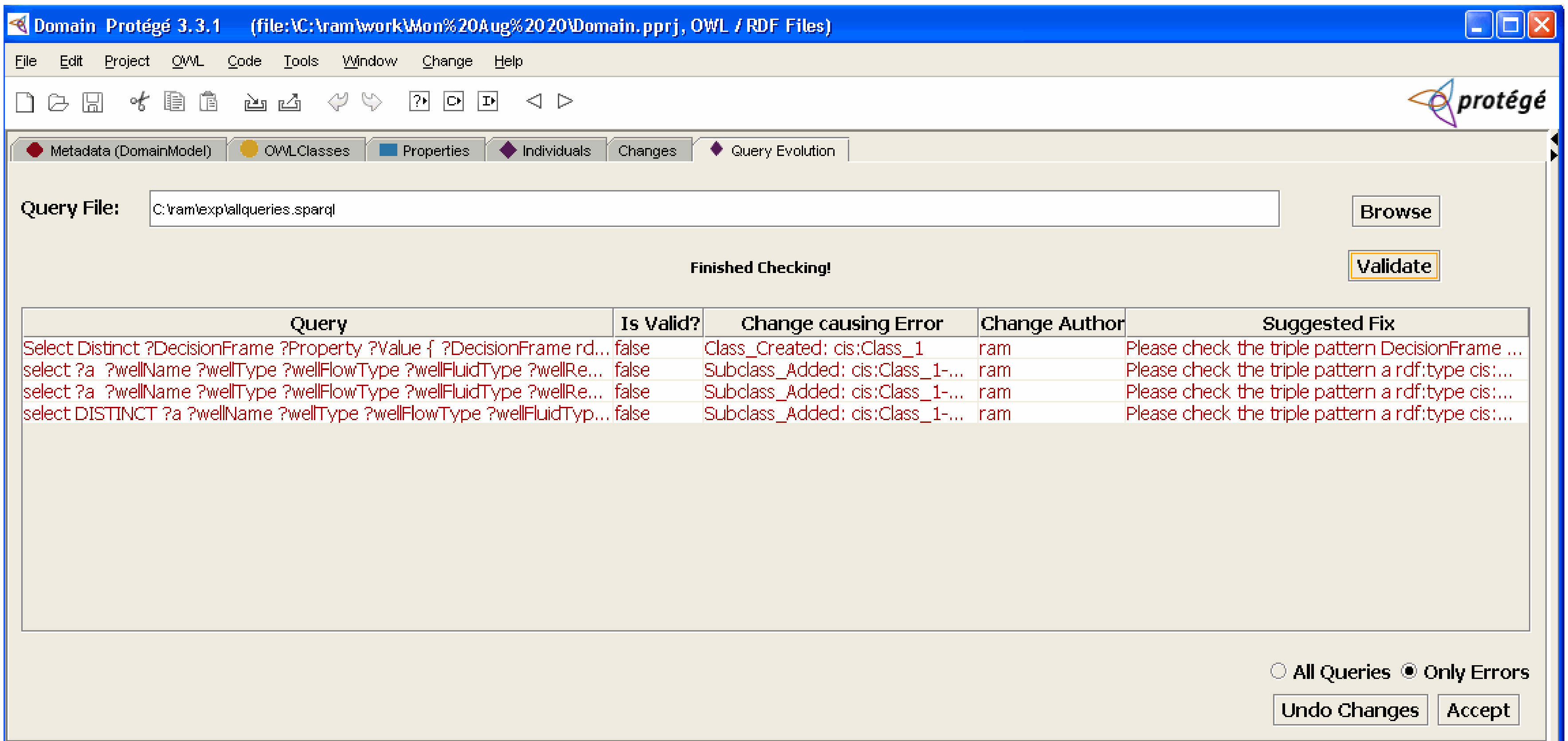
Change handling

- Detect ontology changes
- Evaluate Query, EXT(Q)
- Compute the impact/semantics of changes, $WF'_{T,OWL} \setminus WF_{T,OWL}$
- Match query and changes

Capture Change → Query Evaluation → Semantics of Change → Detect Dirty Queries

Implementation

- Protégé plugin
  - Jena, Pellet, SPARQL parser



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Lessons learnt

- Ontology design
  - Plan schema changes carefully and do not change schema often
  - Keep OWL ontology small and modular; use OWL imports
- Performance
  - Track performance through product development cycle
  - Consider performance enhancing components (caching) in architecture
- Be cognizant of OWL features your tool supports
  - Very few are fully compliant with standards
- Design for change
  - Use SPARQL querying
  - Separate KB querying components from business logic and UI
  - Active area of work- expect big improvements soon

Features we missed

- SPARQL
  - Rollup/aggregation queries. E.g. get the aggregate of OOIP for region as sum of OOIPs of contained regions
  - Results as triples
  - XPath like expressions. E.g. get sub-tree under X
- Updating materialized OWL knowledge bases
  - *Solved problem* in research
- Better XML-OWL/RDF interoperability
  - SPARQL-XML (?)
  - OWL/RDF- XML (Gloze)

Areas of interest

- Ontology extension
  - Modeling events
  - Capturing data provenance
- Performance improvements
  - Developing representative benchmarks
  - Evaluating various RDF triple stores
  - Algorithms for parallel OWL inferencing
- Change management
  - Managing evolution of schema and instance data
  - Efficient techniques to track changes to OWL KBs

Some of our publications

- R. Soma, Viktor Prasanna, Detecting dirty queries during iterative development of OWL-based applications, 7th International Conference on Ontologies, DataBases, and Applications of Semantics (ODBASE 2008), Monterrey, Mexico, Nov 11 - 13, 2008.
- R. Soma, Viktor Prasanna, Parallel Inferencing for OWL Knowledge Bases, International Conference on Parallel Processing (ICPP-2008), September 2008.
- R. Soma, Viktor Prasanna, A Data Partitioning Approach for Parallelizing Rule Based Inferencing for Materialized OWL Knowledge Bases, International Conference on Parallel and Distributed Computing and Communication Systems (PDCCS), September 2008.
- R. Soma, Amol Bakshi, Viktor Prasanna, W. DaSie and B. Bourgeois, Semantic-web technologies for Oil-field Management, SPE Intelligent Energy Conference and Exhibition, April 2008.
- R. Soma, Amol Bakshi, Viktor Prasanna, A Semantic Framework for Integrated Asset Management, Proceedings of The Seventh IEEE International Symposium on Cluster Computing and the Grid (CCGrid), 2007
- R. Soma , A. Bakshi, V. K. Prasanna, and W. Da Sie, A Model-Based Framework for Developing and Deploying Data Aggregation Workflows, 4th International Conference on Service Oriented Computing (ICSOC), December 2006.

Backup

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Change capture

- Well studied problem
  - All changes to OWL, representation, capture..
- Use Protégé plugin

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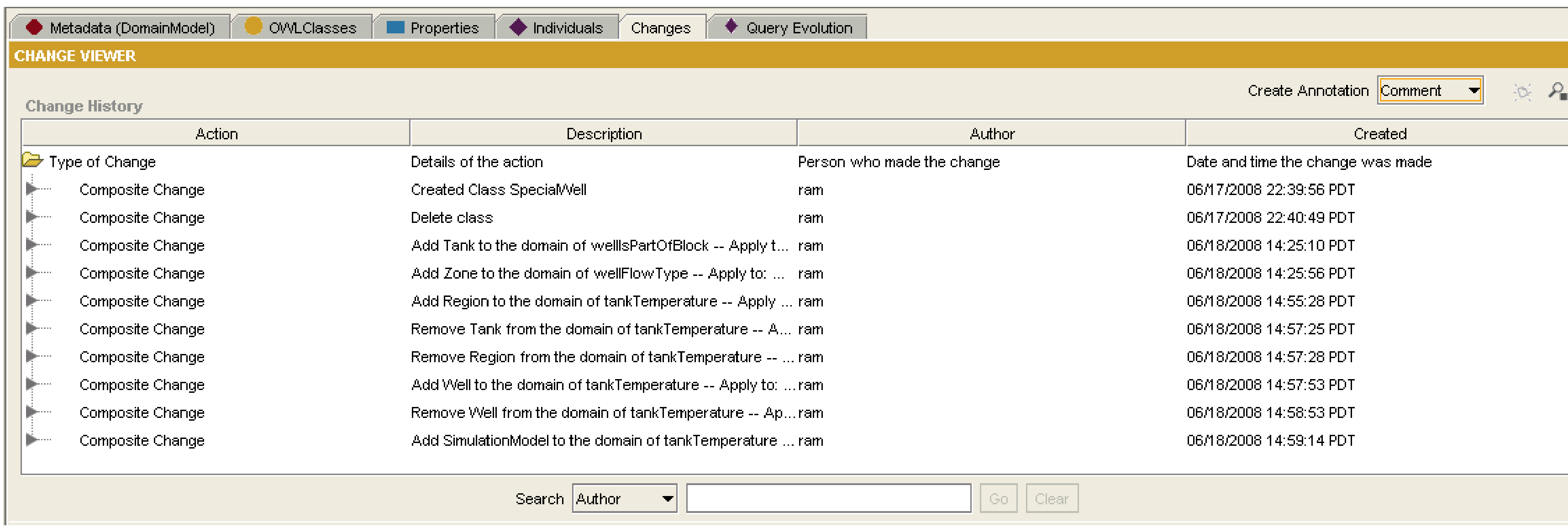

Action	Description	Author	Created
Type of Change	Details of the action	Person who made the change	Date and time the change was made
Composite Change	Created Class SpecialWell	ram	06/17/2008 22:39:56 PDT
Composite Change	Delete class	ram	06/17/2008 22:40:49 PDT
Composite Change	Add Tank to the domain of wellIsPartOfBlock -- Apply t...	ram	06/18/2008 14:25:10 PDT
Composite Change	Add Zone to the domain of wellFlowType -- Apply to: ...	ram	06/18/2008 14:25:56 PDT
Composite Change	Add Region to the domain of tankTemperature -- Apply ...	ram	06/18/2008 14:55:28 PDT
Composite Change	Remove Tank from the domain of tankTemperature -- A...	ram	06/18/2008 14:57:25 PDT
Composite Change	Remove Region from the domain of tankTemperature -- ...	ram	06/18/2008 14:57:28 PDT
Composite Change	Add Well to the domain of tankTemperature -- Apply to: ...	ram	06/18/2008 14:57:53 PDT
Composite Change	Remove Well from the domain of tankTemperature -- Ap...	ram	06/18/2008 14:58:53 PDT
Composite Change	Add SimulationModel to the domain of tankTemperature ...	ram	06/18/2008 14:59:14 PDT

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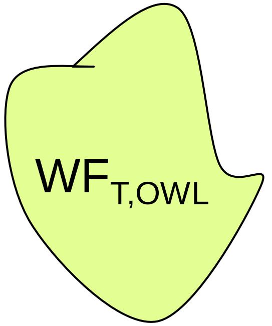
Query evaluation

- Evaluate triple patterns (TP)
  - "Projecting" TP to $WF_{T,OWL}$
  - Observations:
    - All OWL statements are either *type*, *property* or *identity* assertions
    - Triple pattern can have variable or constant in each of its 3 places: 2*2*2= 8 types of triple patterns
- Evaluate graph pattern
  - Based on semantics of connectors

CiSoft Semantics of change

- Not all changes modify WF
  - Lexical Changes: Names of entities, properties, easy to handle
  - Extensional: Modifies WF
  - Assertional: Does not change WF but adds rules
  - Cardinality: Does not change WF but adds/removes constraints
- Determine $WF'_{OWL} \setminus WF_{OWL}$ from changes
  - About 50 kinds of changes to OWL ontology



Object	Operation	Argument(s)	Semantics of Change
Ontology	Add_Class	Class definition (C)	$IOC \neq IOC'$
Ontology	Remove_Class	Class ID (C)	$IOC \neq IOC'$, $CEXT(SC) \neq CEXT'(SC)$ $CEXT(Dom(P)) \neq CEXT'(Dom(P))$, $CEXT \neq CEXT'(Ran(P)) \forall P \mid C \in Dom(P)$ or $Ran(P)$
Class (C)	Add_SuperClass	Class ID (SC)	$CEXT(SC) \neq CEXT'(SC)$
Class(C)	Remove_SuperClass	Class ID (SC)	$CEXT(SC) \neq CEXT'(SC)$
Property (P)	Set_Transitivity	Property ID	- (Assertional Change)
Property (P)	UnSet_Transitivity	Property ID	- (Assertional Change)

Matching

- Aggregate changes
- Handle Lexical change: String search/replace
- Compare extension of query with semantics of change
  - If they have some element in common ➔ dirty
  - E.g. EXT(Q) = P (ALL_Persons X rdf:type X Person) U P(ALL_Persons X IOP X I U L)
  - Sem(ch) = {ALL_Persons’ != ALL_Persons}