Knowledge support for Modeling and Simulation intermediate results of a dissertation project

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the KSMSA project

Outline

1. Motivation, project goals, relation to the Semantic Web
2. Basic components of the system
   a. System Architecture
   b. Documentation Framework
   c. Ontology Framework
3. Experiments
   a. Automatic Classification of Documents
   b. Higher-order Inference

Motivation – State of the Art

Current situation of work with scientific documentation

- **Many tools for authoring and management of scientific documents, often need for combining several tools.**
- **Presentation of documents on WWW using purely presentation formats like HTML, PDF, MS Word.**
- **Global search engines see only these presentation-oriented documents → inaccurate search.**

Motivation – Current Development

Developing areas:

- **XML-based formats: Semantic Web (RDF, OWL, . . .), document representation (DocBook, MathML, SVG, . . .)**
- **Development of ontologies for various domains.**
- **New generation of WWW (Semantic web) promises significant improvement of services, esp. search services.**

Motivation – Bottlenecks of the Semantic Web

- **Standards are very complicated, low-level, lack of integrating applications.**
- **Decentralistic approach: “Let's not develop any upper, centrally accepted ontologies”.**
- **So far tool for researchers rather than for general public.**

Motivation – Project Goals

Project KSMSA: Knowledge Support for Modeling and Simulation

The goal of the project is

- **to create methodology for management of knowledge base in the form of large collection of scientific documents**
- **validate the methodology using prototype implementation of knowledge-based system**

Methodology

The methodology is based on the idea of integration of the following processes:

- **authoring documents**
- **connecting documents to the knowledge base (annotation)**
- **searching the knowledge base**
- **evolution of the semantic model of the knowledge**

KSMSA System Architecture

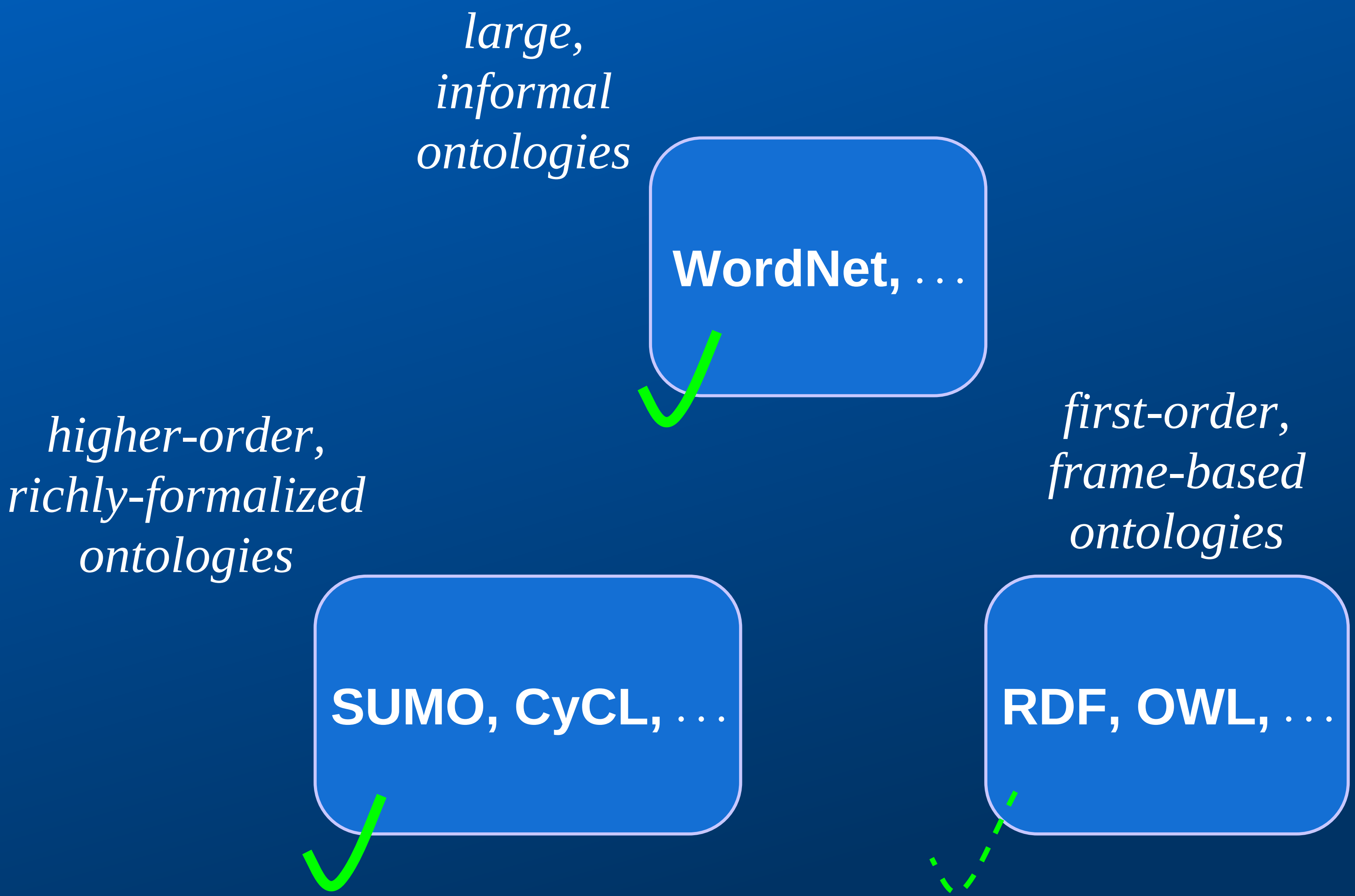
Knowledge System – Ontology

The heart of the knowledge model is *ontology* – formal description of concepts in certain domain of interest. There are different degrees of formalization of ontology concepts:

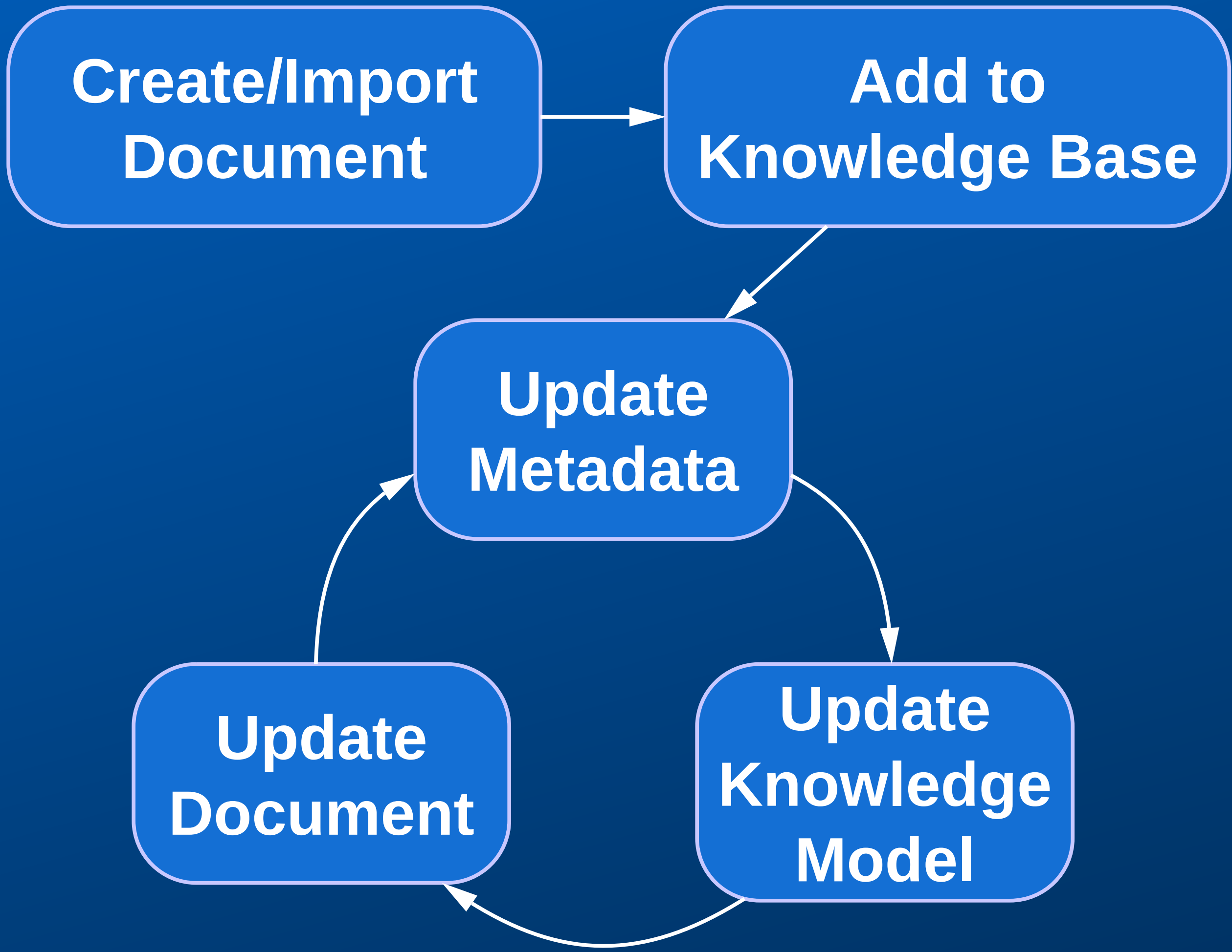
1. **Concepts provide fixed points for associating further structures (sense disambiguation).**
2. **Organization into taxonomies: navigation aid, simple inference (generalization & specialization).**
3. **More complex formalizations – more sophisticated inference such as problem solving – problematic.**

Our knowledge model should support all degrees of formalization.

What is Ontology?



Document Life Cycle



Software Tools

Tools needed for realization of our knowledge system:

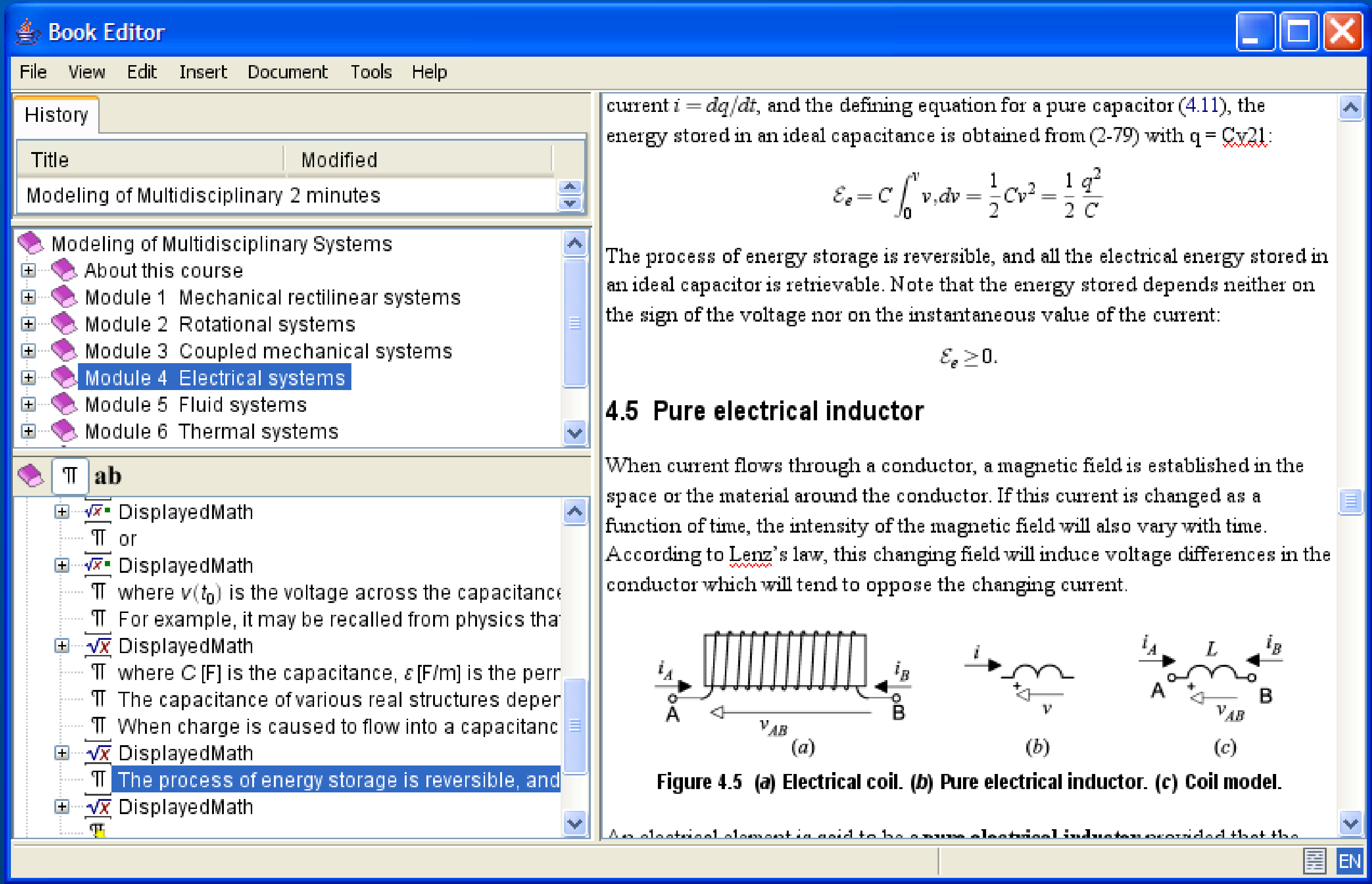
- **Document management tools**
- **New knowledge modeling language**
- **Ontology authoring and browsing tools**
- **Knowledge base management tools**
- **Search of the knowledge base**

$\Rightarrow$ **need for integration of these tools**

Tools – Documentation Framework: RichDoc

- Support for basic documentation structures (sections, lists, tables)
- Support for advanced structures (figures, animations, mathematic typesetting)
- Independence of a document on its presentation (like HTML–CSS)
- Compact, extensible XML-based representation
- Scalability – supports large documents
- Possibility of embedding small documentation fragments into superordinate units
- Possibility of custom data integration, (metadata, ontology-based concepts)

Tools – Documentation Framework



Knowledge Modeling Language

SUO-KIF

+ Expressive Power
+ Legible Syntax

OWL

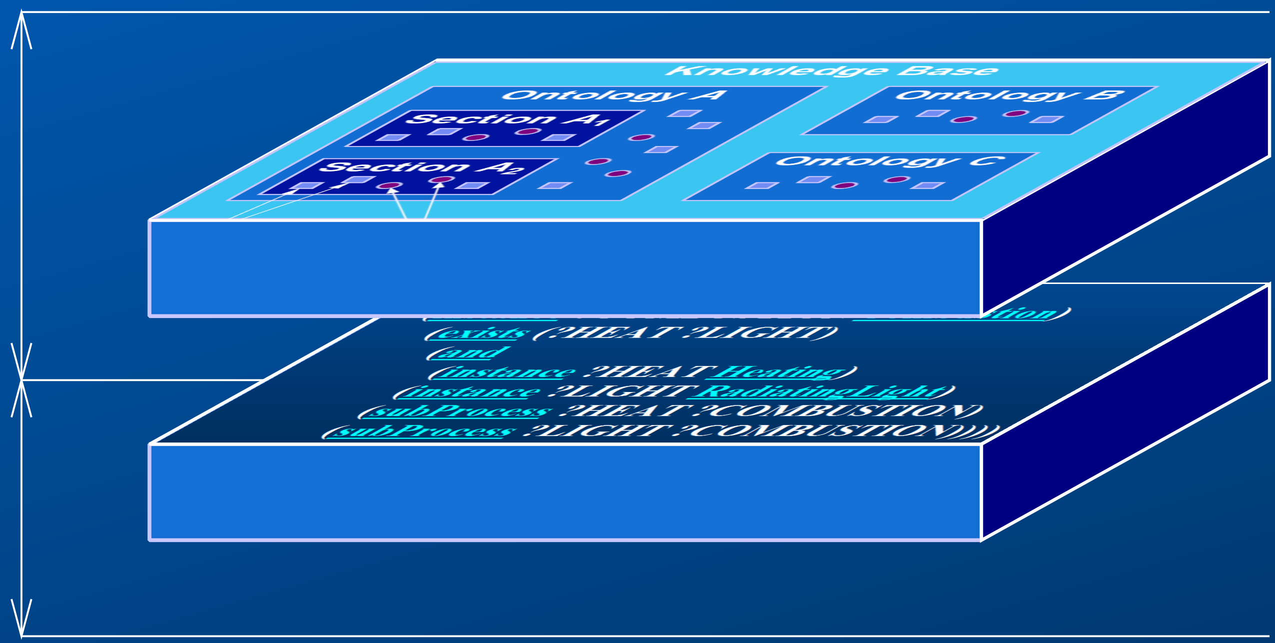
+ Namespace Support
+ Modularity

New Knowledge Modeling Language

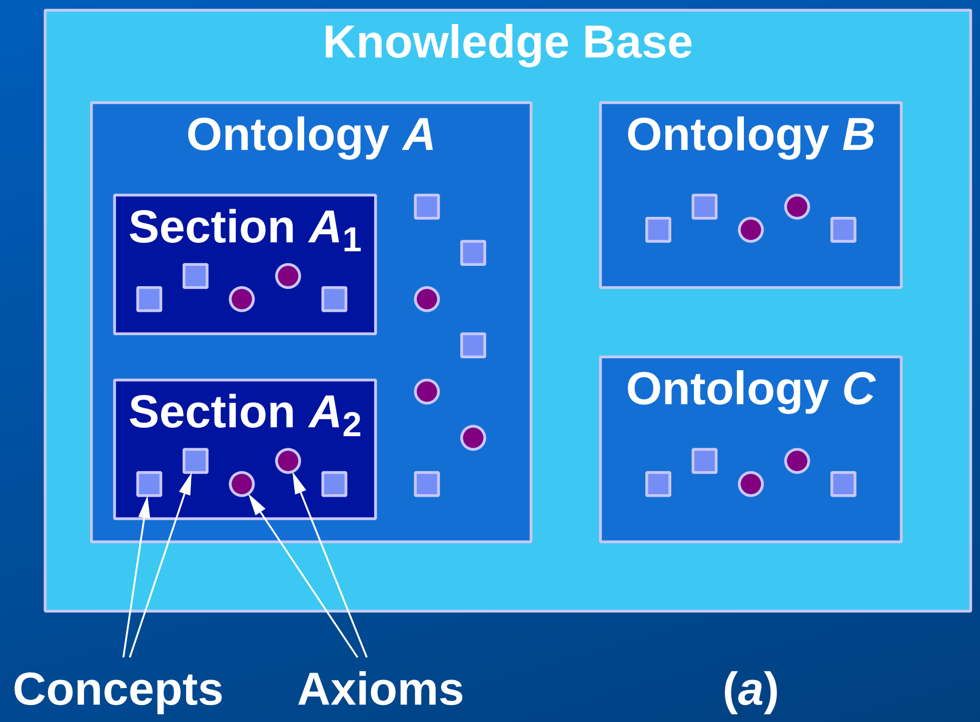
Knowledge Modeling Language

meta-level
(ontologies, sections, namespaces)
SUO-KIF extension

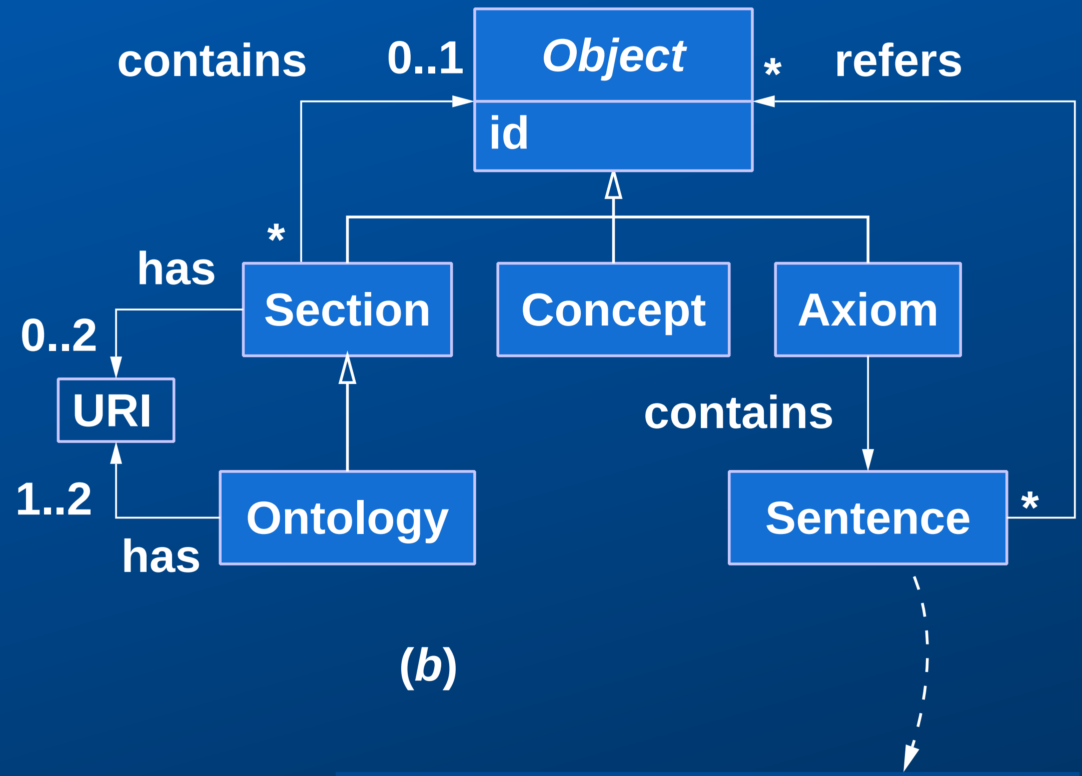
axiomatic level
(first-order sentences)
equivalent to SUO-KIF



Knowledge Modeling Language – Meta-level



(*a*)



(*b*)

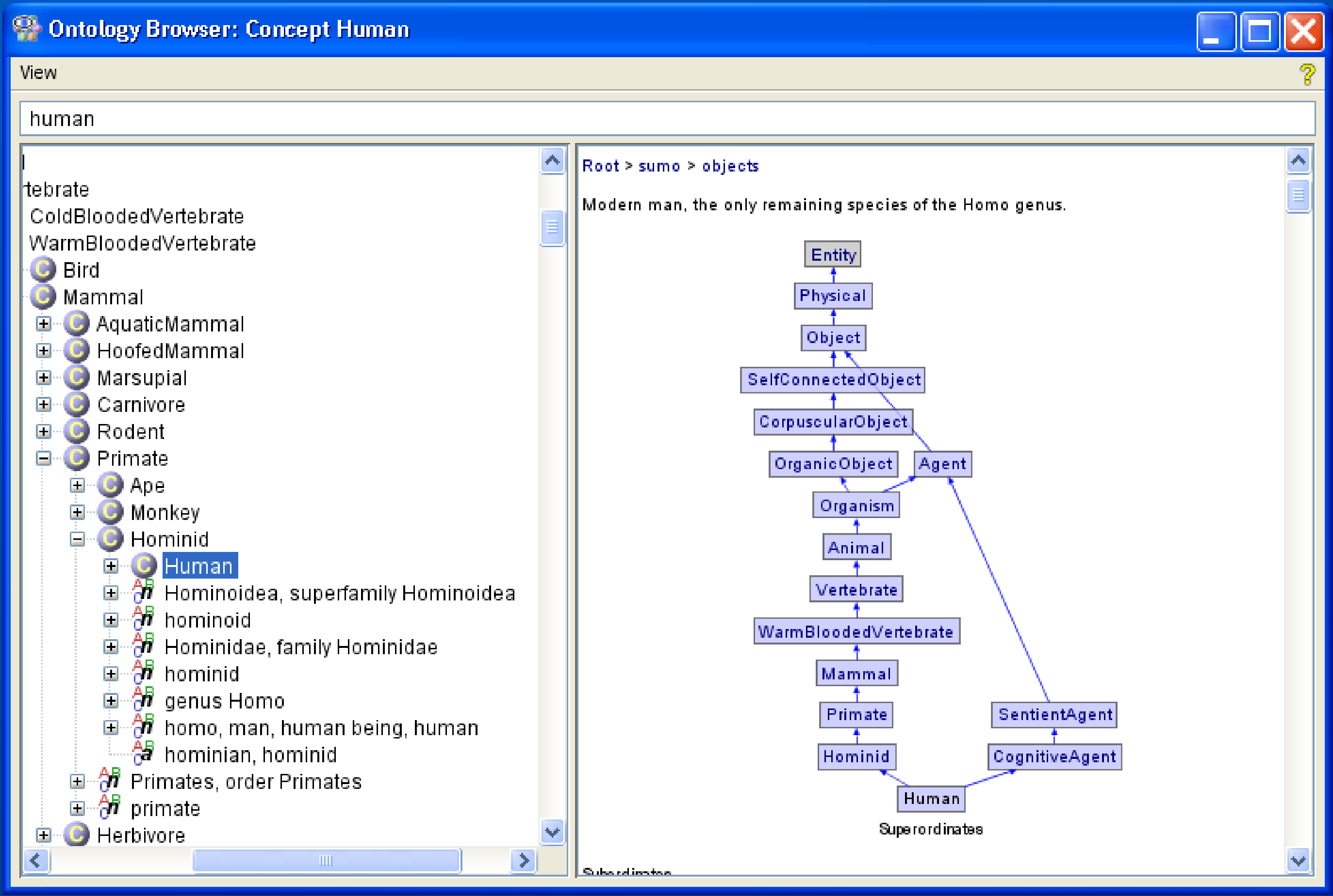
SUO-KIF sentences

```
(=>
  (instance ?COMBUSTION Combustion)
    (exists (?HEAT ?LIGHT)
      (and
        (instance ?HEAT Heating)
        (instance ?LIGHT RadiatingLight)
        (subProcess ?HEAT ?COMBUSTION)
        (subProcess ?LIGHT ?COMBUSTION))))
```

Tools – Ontology Management

- Support for management of large ontologies
- Uniform representation of simple axioms (facts) as well as complex logical formulas in first-order or higher-order logic
- Special support for authoring particular axioms (subclass or instance relations, etc)
- Compact XML-based representation
- Extensible plugin architecture – advanced users may provide GUI support for certain types of axioms
- Supports importing (SUMO, WordNet) and exporting (KIF, OWL) of various formats.

Tools – Ontology Management



Experiments

- **Automatic Document Classification**
  classify documents into thematic topics according to their full text
- **Higher-order semantics and inference**
  construct proofs for higher-order theories

Automatic Document Classification

- **Uses large database of English words, classified into topics**
- **Database was created using the full text of the Wikipedia encyclopedia**

Automatic Document Classification

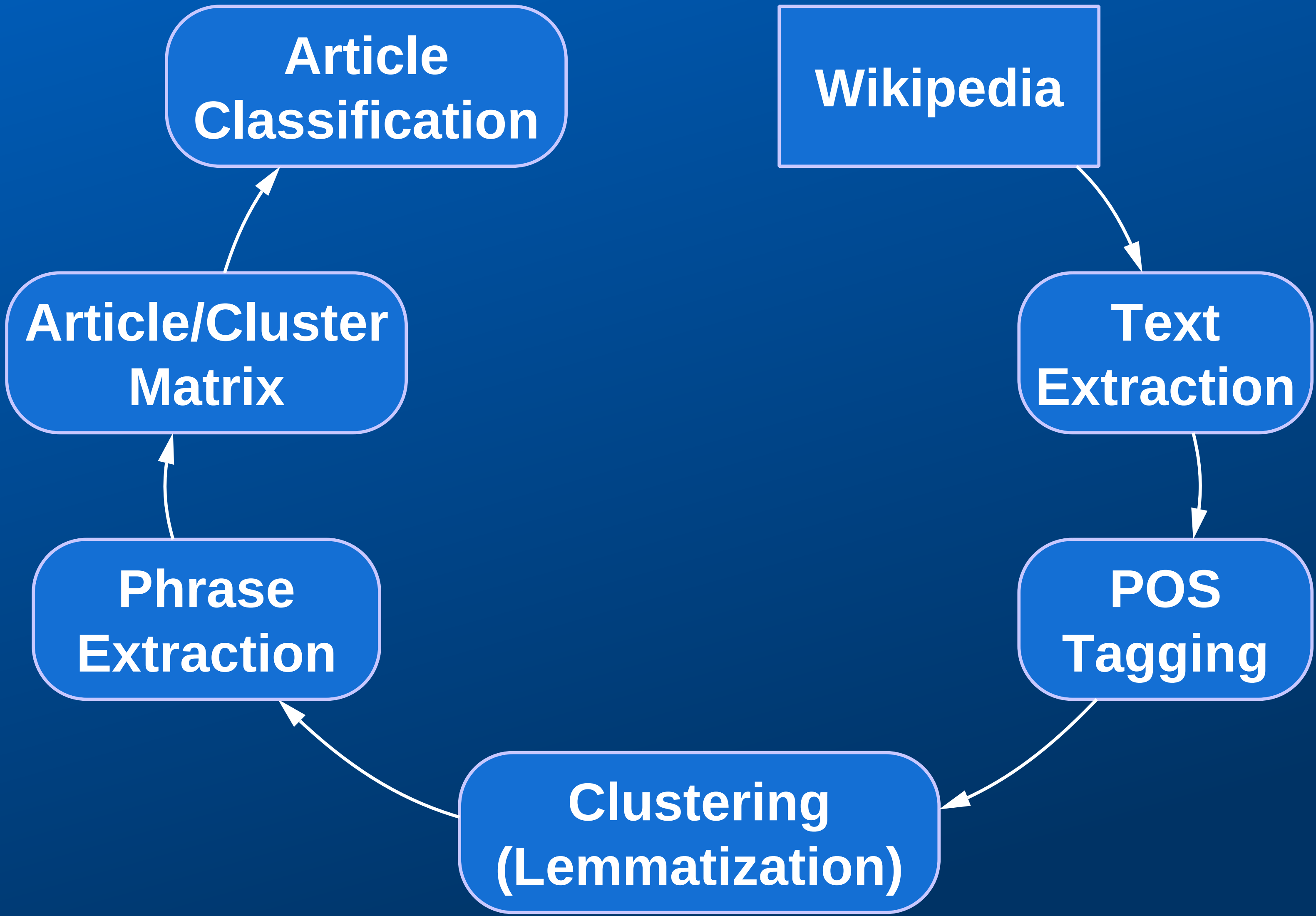
What information the corpus analysis provide?

- **List of concepts that do not contribute to topic classification (“‘Semantic Stop List’’ – common words like *read*, *accept*, *computer* etc.**
- **For each category, list of concepts with high entropy gain.**
- **For each concept, list of categories with high entropy gain.**

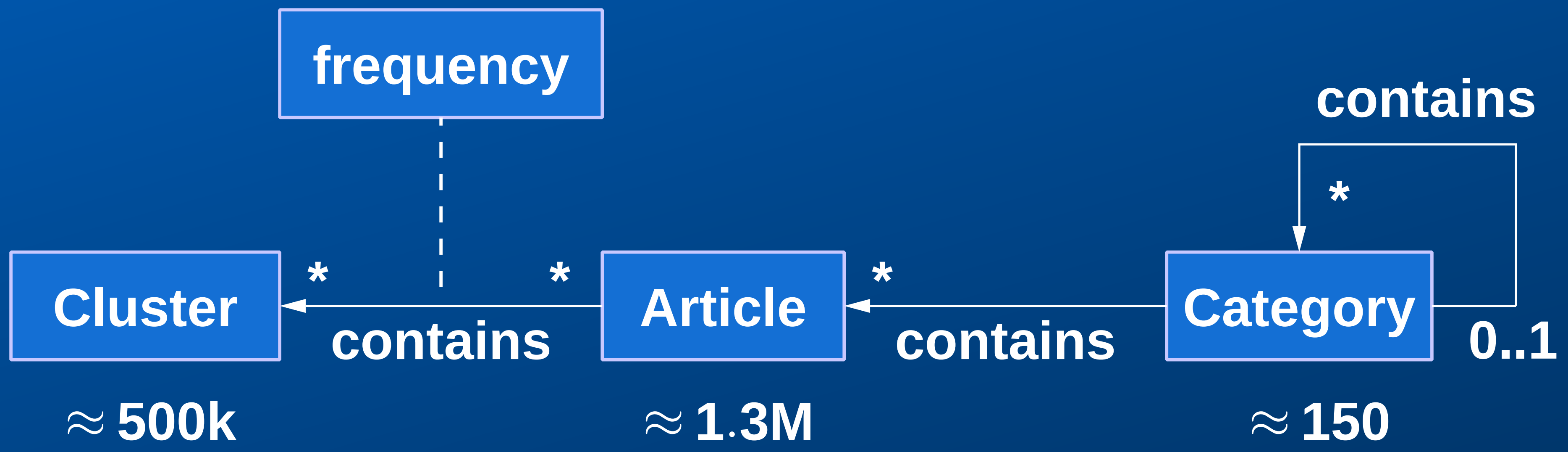
Why Wikipedia?

- **Easily accessible large body of English text**
- **Relatively well-weighted content**
- **Relatively good classification into topical categories; *but*: category system is too dense and inaccurate, must be “distilled” into much smaller number of categories**

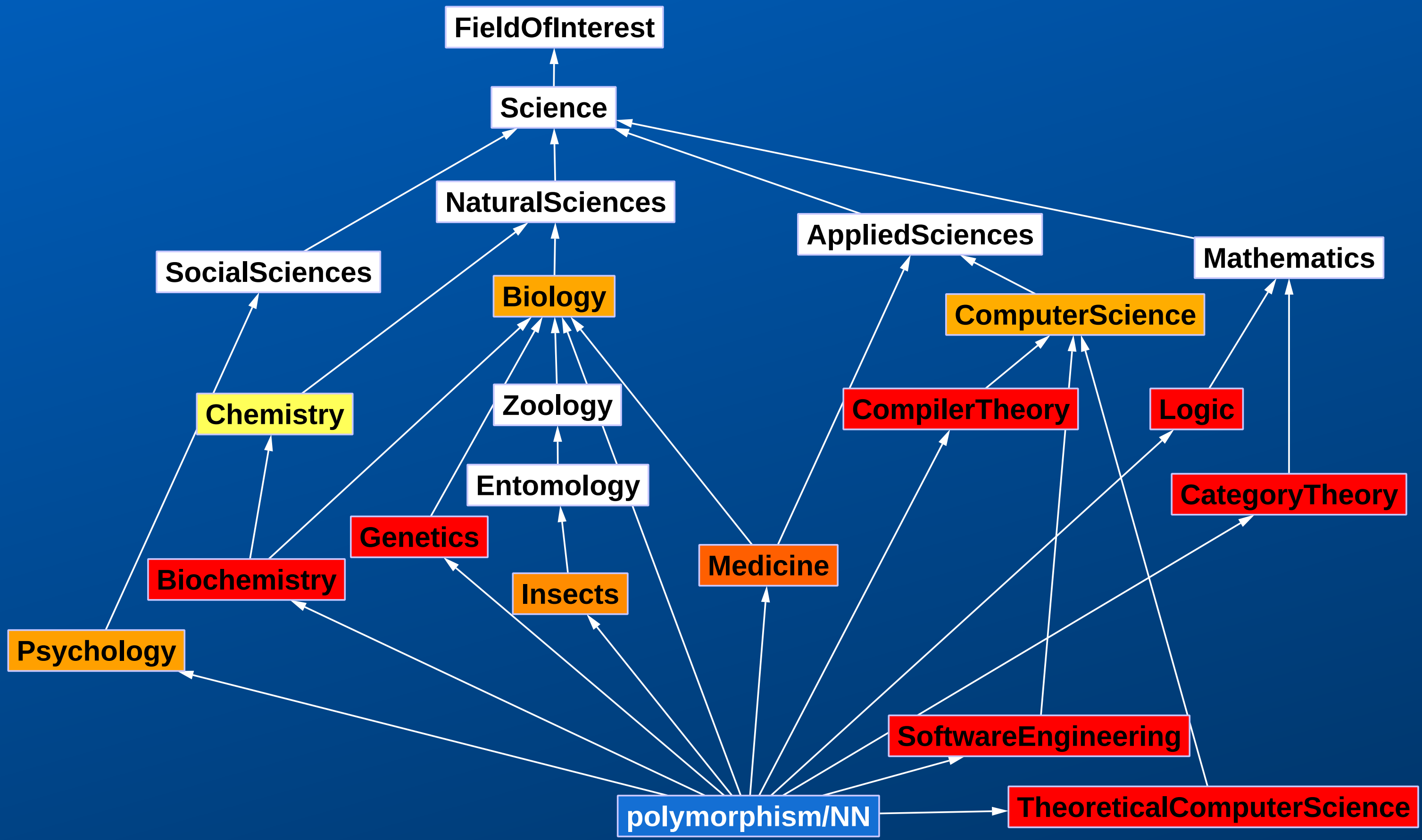
Wikipedia Corpus Analysis



Wikipedia Corpus Database



Wikipedia Corpus – Classification Example



Cluster "Polymorphism"

Significant topics:	**88 of 1.34M**
Entropy:	**13.90**

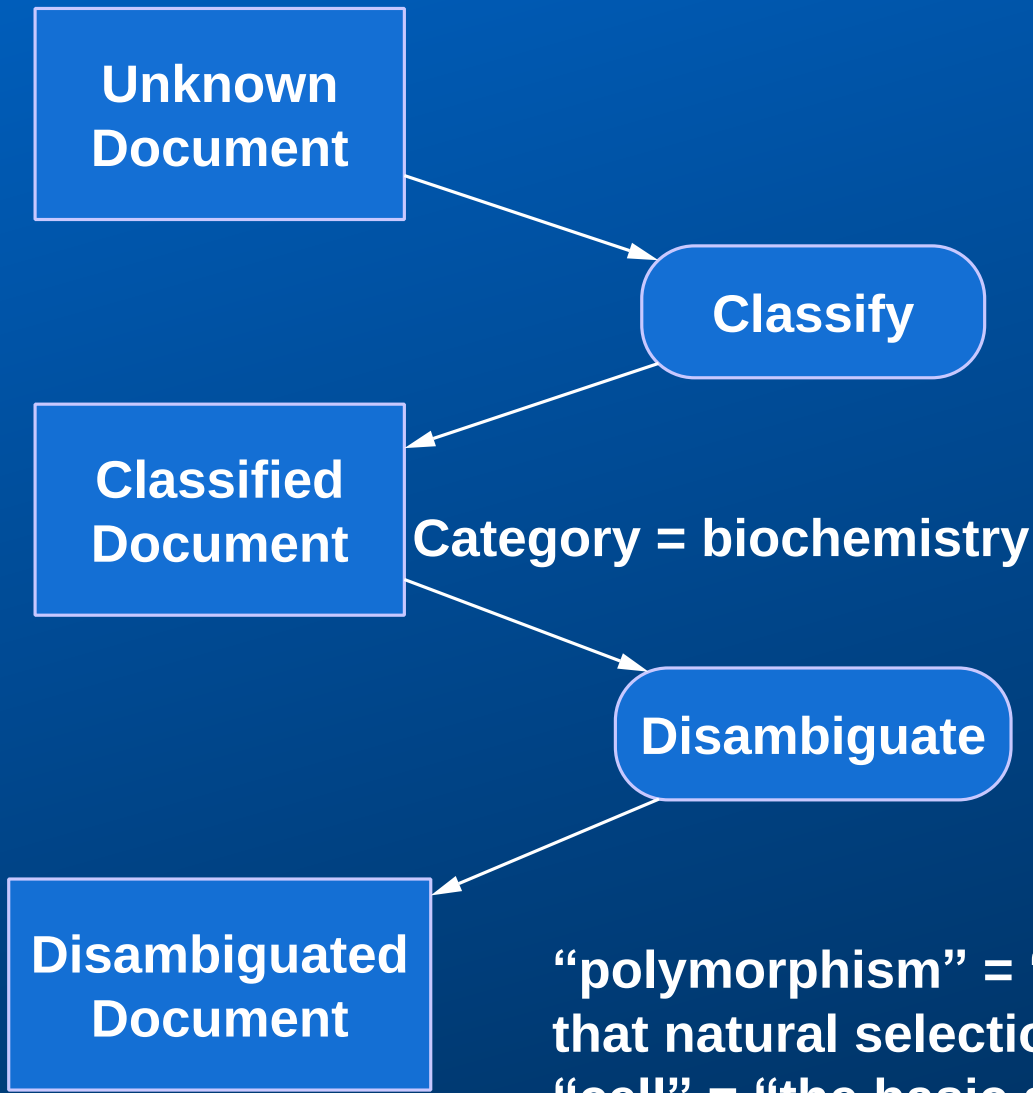
Category "Biochemistry"

Significant topics:	**7 of 2.26k**
Entropy:	**8.34**

Topics

5	**Restriction fragment length polymorphism**
3	**Amplified fragment length polymorphism**
3	**Single nucleotide polymorphism**
2	**Polymerase chain reaction**
2	**Biochip**
2	**Perilipin**
2	**RAGE**

Wikipedia Corpus – Topic-based disambiguation



"polymorphism" = "the genetic variation within a population that natural selection can operate on"
"cell" = "the basic structural and functional unit of all organisms"   etc.

Wikipedia Corpus – Problems

- Topic classification sometimes does not work. Example: Wikipedia's category "Submarines" is mapped to category "Sports" according to shortest category path Submarines → Ships by type → Sailing → Olympic sports → Sports. More appropriate would be e.g. "Security".
- The frequency–based phrase extraction extracts frequently-used collocations that are not concepts. For instance, the phrase "said to have been" appears in about 3000 articles, and is therefore identified as concept.

Higher-order Semantics

- The SUO-KIF language supports higher-order sentences, such as
  $\text{believes}(\text{Mary}, \text{teacher}(\text{John}))$, or
  $\text{holdsDuring}(\text{Monday}, \text{located}(\text{John}, \text{Prague}))$,

  but does not provide any semantics or inference support for them
- We propose an extension of common first-order semantics, and an inference system that can construct proofs in higher-order theories

Higher-order Semantics

- **Higher order atom: $P(\ldots,\varphi,\ldots)$, P is predicate, φ is sentence**
- **First order interpretation $\mathcal{M}:\Lambda\to\{\text{true},\text{false}\}$, Λ is set of well-formed formulas; $\mathcal{M}$ satisfies first-order consistency requirements, such as $\mathcal{M}(\varphi)\neq\mathcal{M}(\neg\varphi)$, etc.**
- **Higher order interpretation $\mathcal{H}$ must fulfill those requirements of $\mathcal{M}$ and**

  1. **if $\mathcal{H}\models P(\ldots,\varphi,\ldots)$, then $\mathcal{H}\not\models P(\ldots,\neg\varphi,\ldots)$**
  2. **if $\mathcal{H}\models P(\ldots,\varphi,\ldots)$, and $\varphi\models\psi$, then $\mathcal{H}\models P(\ldots,\psi,\ldots)$**

Higher-order Resolution

This yields, besides standard resolution rule:

- $\{\varphi \vee A, \psi \vee \neg B\} \vdash (\varphi \vee \psi)\theta$, **$A$ and B are atoms, and θ is the most general unifier of A and B.**

two additional resolution rules:

1. $\{\varphi \vee P(\ldots, \alpha, \ldots), \psi \vee \neg P(\ldots, \beta, \ldots)\} \vdash (\varphi \vee \psi)\theta$, **if $\alpha\theta \vdash \beta\theta$; α and β are sentences, $\alpha\theta$ and $\beta\theta$ must be closed sentences (not containing free variables)**
2. $\varphi \vee P(\ldots, \psi, \ldots) \vdash \varphi \vee \neg P(\ldots, \neg\psi, \ldots)$

Higher-order Resolution: Example 1

(1) Mary is in Prague during Tuesday, (2) Prague does not overlap with Berlin, (3) Tuesday Afternoon is part of Tuesday, (4) If someone is in l_1 and l_1 does not overlap with l_2, then someone is not in l_2, and (5) If something is true during t and t' is part of t, then something is true during t'. We want to prove that (q) Mary is not in Berlin during Tuesday Afternoon.

(1)	$\text{holdsDuring}(\text{Tuesday}, \text{located}(\text{Mary}, \text{Prague}))$
(2)	$\neg\text{overlaps}(\text{Prague}, \text{Berlin})$
(3)	$\text{partOf}(\text{TuesdayAfternoon}, \text{Tuesday})$
(4)	$\text{located}(x, l_1) \wedge \text{located}(x, l_2) \Rightarrow \text{overlaps}(l_1, l_2)$
(5)	$\text{holdsDuring}(t, p) \wedge \text{partOf}(t', t) \Rightarrow \text{holdsDuring}(t', p)$
($\neg q$)	$\text{holdsDuring}(\text{TuesdayAfternoon}, \text{located}(\text{Mary}, \text{Berlin}))$

Proof:

$(t_1) = (3) \times (5)$	$\text{holdsDuring}(\text{Tuesday}, p) \Rightarrow \text{holdsDuring}(\text{TuesdayAfternoon}, p)$
$(t_2) = (t_1) \times (1)$	$\text{holdsDuring}(\text{TuesdayAfternoon}, \text{located}(\text{Mary}, \text{Prague}))$
$(t_3) = (t_2)^*$	$\neg\text{holdsDuring}(\text{TuesdayAfternoon}, \neg\text{located}(\text{Mary}, \text{Prague}))$
$(t_4) = (t_3) \times (\neg q)$	$\Box$ if $(a)\text{located}(\text{Mary}, \text{Berlin}) \vdash (b)\neg\text{located}(\text{Mary}, \text{Prague})$
$(t'_1) = (a) \times (4)$	$\text{located}(\text{Mary}, l_1) \Rightarrow \text{overlaps}(l_1, \text{Berlin})$
$(t'_2) = (t'_1) \times (2)$	$\neg\text{located}(\text{Mary}, \text{Prague})$
$(t'_3) = (t'_2) \times (\neg b)$	$\Box$

Higher-order Resolution: Example 2

(1) Everyone knows whether he is a teacher or not. (2) Everyone believes what he knows. (3) What someone knows must be true. (4) Mary believes that John is a teacher. (5) John doubts he is a teacher. (q) There is a person that believes that some false proposition is true.

$$(1a) \quad \text{teacher}(x) \Rightarrow \text{knows}(x, \text{teacher}(x))$$
$$(1b) \quad \neg\text{teacher}(x) \Rightarrow \text{knows}(x, \neg\text{teacher}(x))$$
$$(2) \quad \text{knows}(x, p) \Rightarrow \text{believes}(x, p)$$
$$(3) \quad \text{knows}(x, p) \Rightarrow p$$
$$(4) \quad \text{believes}(\text{Mary}, \text{teacher}(\text{John}))$$
$$(5) \quad \text{believes}(\text{John}, \neg\text{teacher}(\text{John}))$$
$$(\neg q) \quad \text{believes}(x, p) \Rightarrow p$$

Proof:

$$(t_1) = (5)^* \quad \neg\text{believes}(\text{John}, \text{teacher}(\text{John}))$$
$$(t_2) = (t_1) \times (2) \quad \neg\text{knows}(\text{John}, \text{teacher}(\text{John}))$$
$$(t_3) = (t_2) \times (1a) \quad \neg\text{teacher}(\text{John})$$
$$(t_4) = (4) \times (\neg q) \quad \text{teacher}(\text{John})$$
$$(t_5) = (t_4) \times (t_3) \quad \Box$$

The End...

Project KSMSA

http://virtual.cvut.cz/ksmsaWeb/main

RichDoc Framework

http://richdoc.sourceforge.net