AURA

Automated User-centered Reasoning and Acquisition System

BOEING

SRI International

THE UNIVERSITY OF TEXAS —AT AUSTIN—

Carnegie Mellon

PROJECT HALO

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Vulcan's Goals

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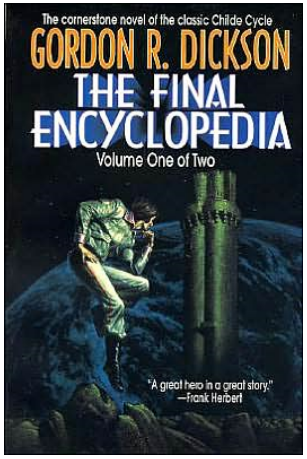
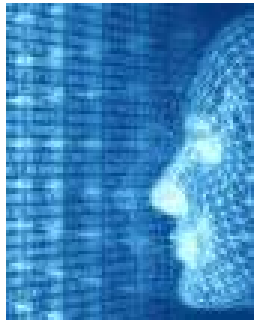
- Build a ``Digital Aristotle'' – a reasoning system capable of answering novel questions and solving advanced problems in a broad range of scientific disciplines



DIGITAL ARISTOTLE



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Some Uses of Digital Aristotle

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- Digital Research Assistant
  - Enable new biological discoveries (e.g., cure for diseases such as cancer, HIV), supporting analysis of the experimental data (e.g., micro array analysis) by relating it to bio-medical literature (18 million articles in PubMed)
  - Proposed as part of an NIH Center of Excellence
- Digital Tutor
  - Textbook of the future will be
    - Online, computable, adaptable, interactive
    - Help a student clarify misconceptions and enable deeper learning
  - Tool for teacher training

PROJECT HALO

Outline

AURA

- Project Overview
- Research Framework
- Requirement Analysis
- Implementation
  - Knowledge Formulation
  - Question Formulation
  - Question Answering
- Evaluation
- Future Work

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Towards Digital Aristotle

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General strategy for approaching the Final Encyclopedia
(for factual scientific knowledge)

Next Scaling Target

All Major Textbooks
+ Scientific Research

	Partial AP Syllabus	Single Textbook	Undergraduate Science Curriculum	All Major Textbooks + Scientific Research
Authors	Single Domain Expert	Small Team of Domain Experts and Knowledge Experts	Community of Scientists, Teachers, and Knowledge Experts	Web-based Scientific & Educational Communities
Uses	AP Question Answering	AP QA General QA Research Assistance Education	AP QA General QA Research Assistance Education	AP QA General QA Research Assistance Education Scientific Discovery
	2004-2008	2009-2011		

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Research Framework

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- ``Read a Chapter of a textbook and answer questions at the back of the chapter''
  - Raj Reddy on *Three Open Problems in AI, JACM'03*
- ``Build a Knowledge Base by Reading a Textbook''
  - Ed Feigenbaum on *Some Challenges for Computational Intelligence, JACM'03*

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Research Framework

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- Focus on fundamental hard sciences where knowledge is explicitly written down
  - Physics, Chemistry, and Biology
- Choose a widely accepted test for competence
  - Advanced Placement Test
    - The AP test is merely a metric. The system capability should be general enough to answer a broader set of questions
- Scope the problem to a manageable size
  - 50 pages of syllabus in each of the three domains

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Research Framework

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- Automatic reading was kept out of (initial) scope
  - Automatic techniques will not produce a fidelity of representation needed for AP question answering
  - Focus on the basic system and provide ways to incorporate automatically extracted information
  - Our focus is on ``book representation'' → Representation is essential for reading

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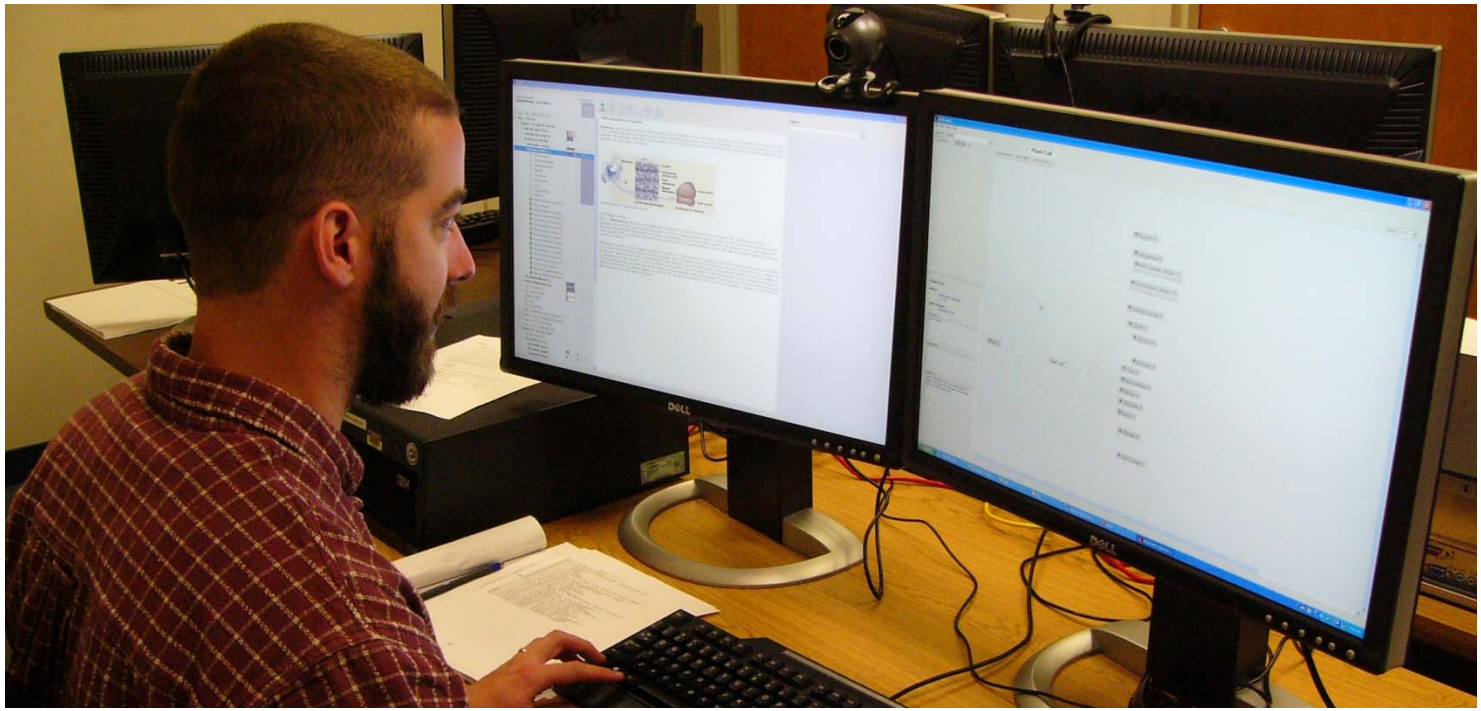
AURA

AURA

Automated User-Centered
Reasoning and Acquisition System



- Aura is a tool to help users formalize knowledge
- Aura can then reason with that knowledge
- So users can ask questions and understand the answers.

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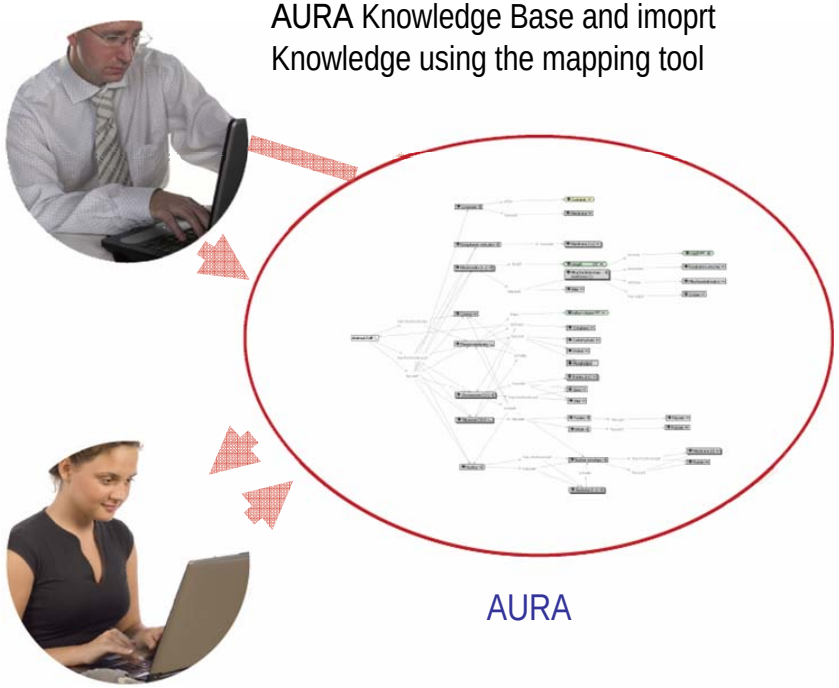
AURA Concept of Operations

Domain Experts Enter Knowledge

Domain Experts add knowledge to the AURA Knowledge Base and imoprt Knowledge using the mapping tool



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Users ask questions and get answers and explanations

AURA Answers Questions

Prior Work (Partial List)

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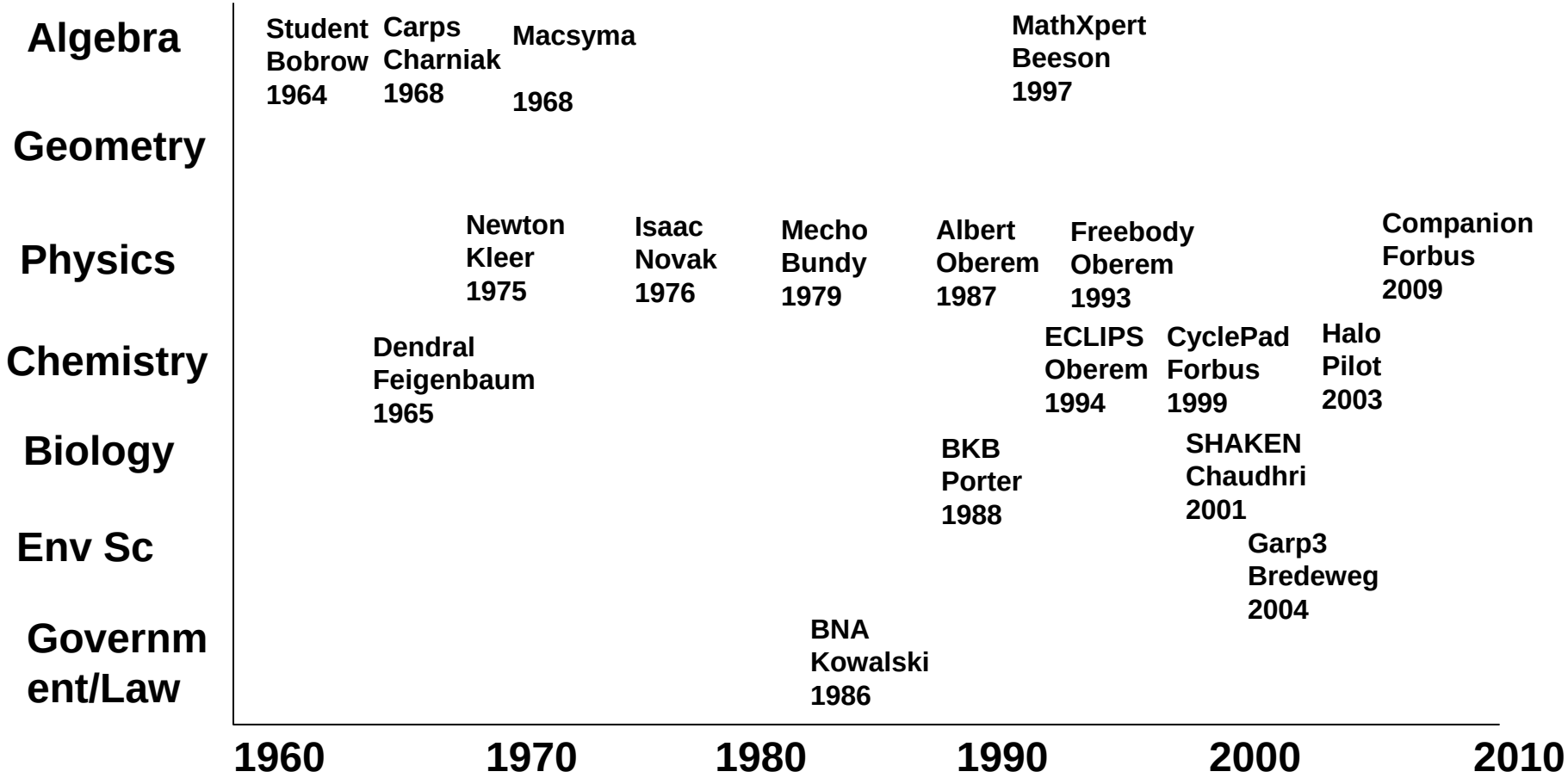

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How is AURA Different?

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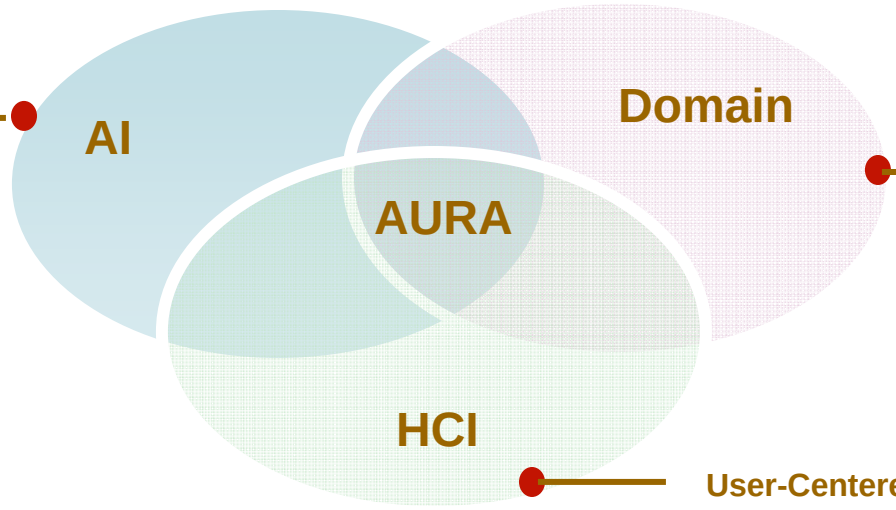

Knowledge Representation
Automated Reasoning
Natural Language Processing
Ontologies
Semantic Web

Physics
Chemistry
Biology
Environmental Science
Micro Economics
US Government & Politics

User-Centered Design
Usability testing
Natural Visualizations
Graphic Design

PROJECT HALO

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- Research Framework
- Requirement Analysis
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  - Knowledge Formulation
  - Question Formulation
  - Question Answering
- Evaluation
- Potential Application
- Future Work

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Requirement Analysis

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- Knowledge Representation and Reasoning (KR&R) Requirements
- Question Asking Requirements

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KR&R Requirements

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- We undertook a survey of the textbook knowledge and a sample of AP exams in the three domains
  - Systematically enumerated representation capabilities using a KR&R Ontology (Fikes 2008)
  - Most frequent KR&R types
    - Structured Objects
    - Rules
    - Mathematical equations
    - Tables
    - Diagrams
    - Computational Knowledge

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KR&R Requirements

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Combination and Decomposition Reactions

Table 3.1 ▼ summarizes two simple types of reactions, combination and decomposition reactions. In **combination reactions** two or more substances react to form one product. There are many examples of such reactions, especially those in which elements combine to form compounds. For example, magnesium metal burns in air with a dazzling brilliance to produce magnesium oxide, as shown in Figure 3.5 ▶:

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s) \qquad [3.6]$$

This reaction is used to produce the bright flame generated by flares.

When a combination reaction occurs between a metal and a nonmetal, as in Equation 3.6, the product is an ionic solid. Recall that the formula of an ionic compound can be determined from the charges of the ions involved. (Section 2.7) When magnesium reacts with oxygen, for example, the magnesium loses electrons and forms the magnesium ion, Mg^{2+}. The oxygen gains electrons and forms the oxide ion, O^{2-}. Thus, the reaction product is MgO. You should be able to recognize when a reaction is a combination reaction and to predict the products of a combination reaction in which the reactants are a metal and a nonmetal.

In a **decomposition reaction** one substance undergoes a reaction to produce two or more other substances. Many compounds undergo decomposition reactions when heated. For example, many metal carbonates decompose to form metal oxides and carbon dioxide when heated:

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g) \qquad [3.7]$$

The decomposition of $CaCO_3$ is an important commercial process. Limestone or seashells, which are both primarily $CaCO_3$, are heated to prepare CaO, which is known as lime or quicklime. Over 2.0×10^{10} kg (22 million tons) of CaO are used in the United States each year, principally in making glass, in obtaining iron from its ores, and in making mortar to bind bricks.

Structured Objects

Rules

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KR&R Requirements

AURA

- Mathematical equations

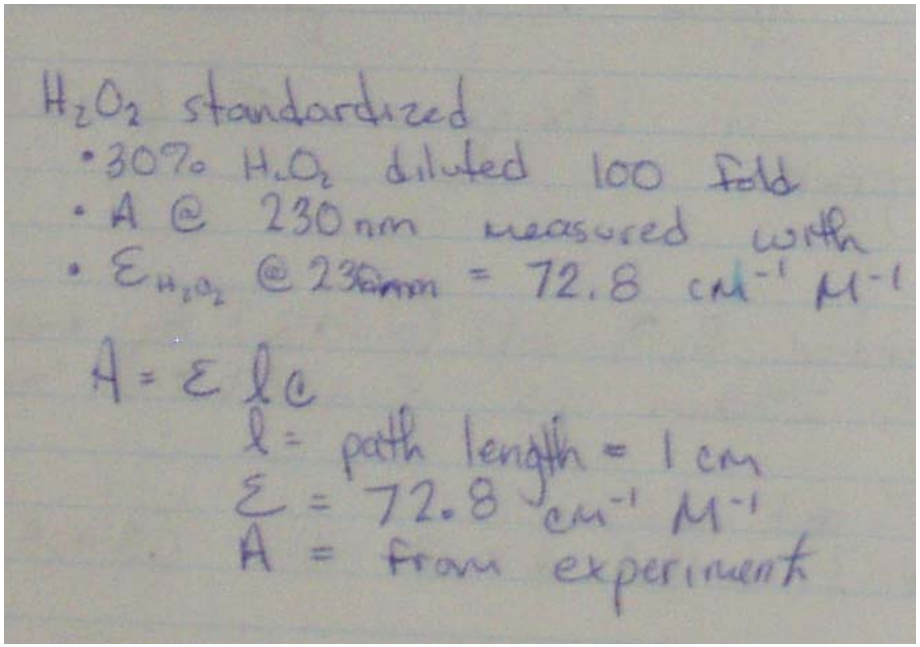
$$v = v_0 + at \qquad [a = \text{constant}] \quad \textbf{(2–11a)}$$

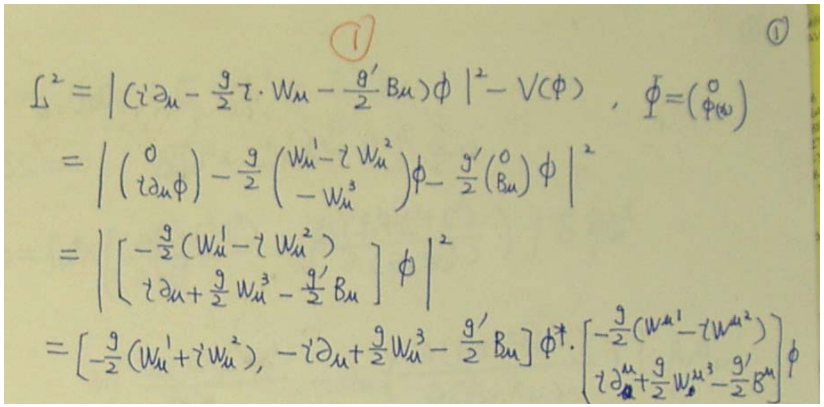
$$x = x_0 + v_0 t + \tfrac{1}{2}at^2 \qquad [a = \text{constant}] \quad \textbf{(2–11b)}$$

$$v^2 = v_0^2 + 2a(x - x_0) \qquad [a = \text{constant}] \quad \textbf{(2–11c)}$$

$$\bar{v} = \frac{v + v_0}{2}. \qquad [a = \text{constant}] \quad \textbf{(2–11d)}$$

Kinematic equations for constant acceleration (we'll use them a lot)





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KR&R Requirements

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- Tables

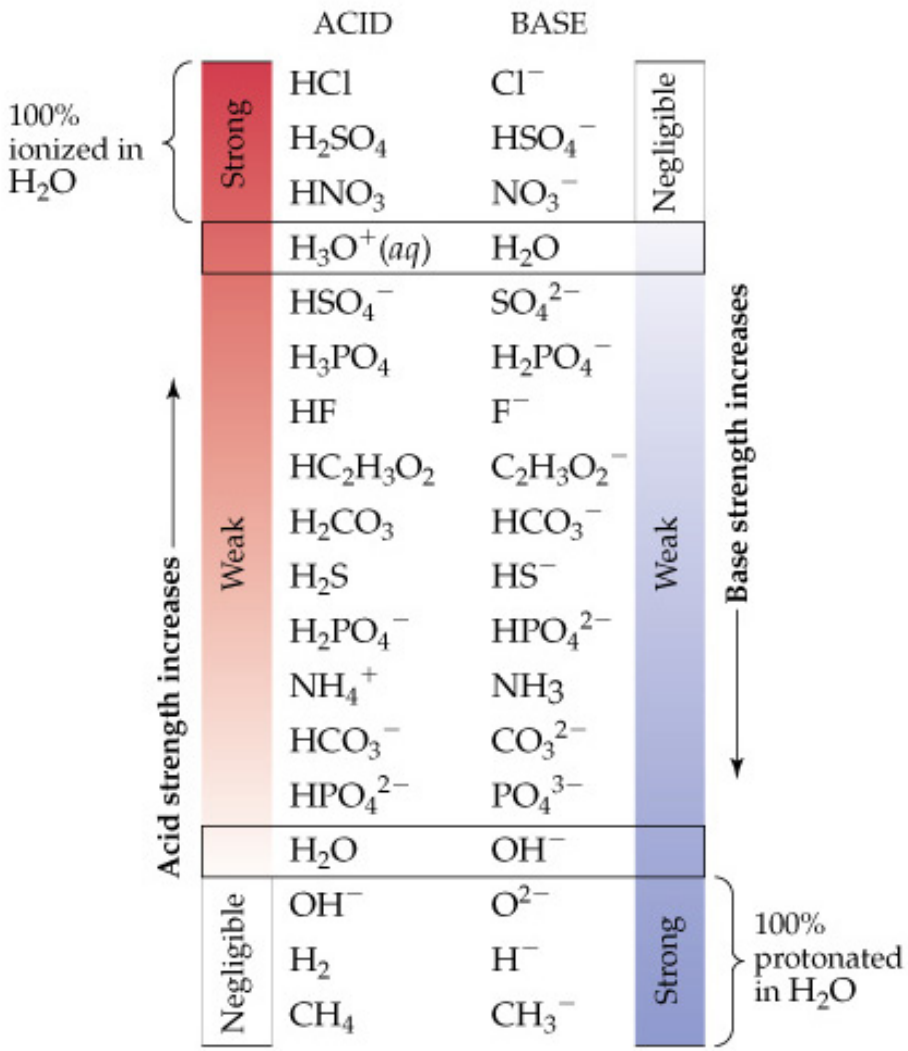

TABLE 4.1 Solubility Guidelines for Common Ionic Compounds in Water

Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	$C_2H_3O_2^-$	None
	Cl^-	Compounds of Ag^-, Hg_2^{2+}, and Pb^{2+}
	Br^-	Compounds of Ag^-, Hg_2^{2+}, and Pb^{2+}
	I^-	Compounds of Ag^-, Hg_2^{2+}, and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}
Insoluble Ionic Compounds		**Important Exceptions**
Compounds containing	S^{2-}	Compounds of NH_4^+, the alkali metal cations, and Ca^{2+}, Sr^{2+}, and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
	PO_4^{3-}	Compounds of NH_4^+ and the alkali metal cations
	OH^-	Compounds of the alkali metal cations, and Ca^{2-}, Sr^{2+}, and Ba^{2-}

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KR&R Requirements

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- Diagrams

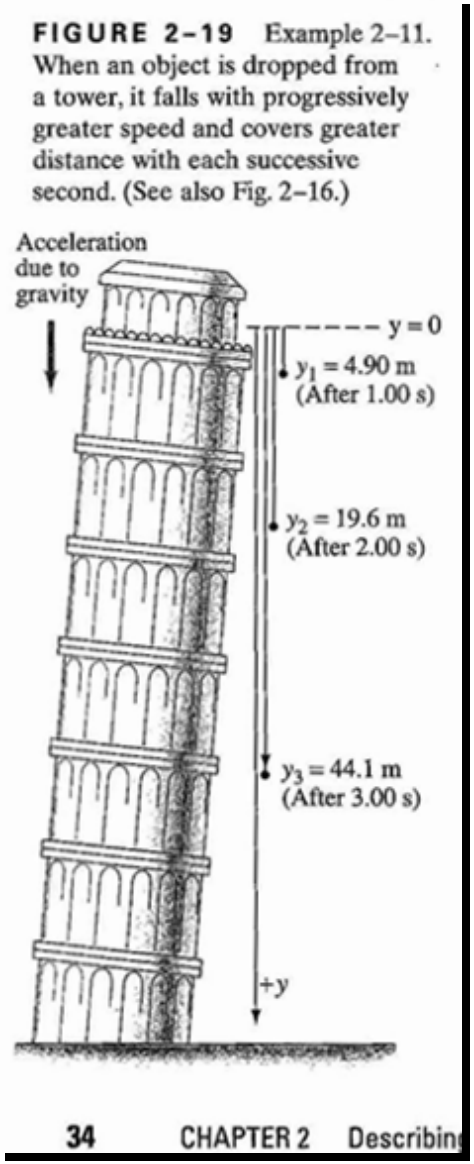


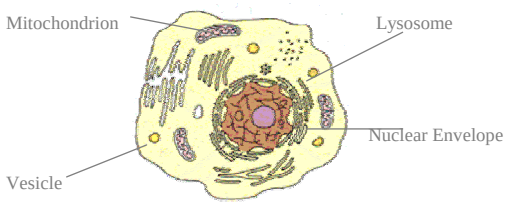
FIGURE 2–19 Example 2–11. When an object is dropped from a tower, it falls with progressively greater speed and covers greater distance with each successive second. (See also Fig. 2–16.)

34 CHAPTER 2 Describin

The lack of a rigid cell wall allowed animals to develop a greater diversity of cell types, tissues, and organs. Specialized cells that formed nerves and muscles -- tissues impossible for plants to evolve -- gave these organisms mobility. The ability to move about by the use of specialized muscle tissues is the hallmark of the animal world. (Protozoans locomote, but by nonmuscular means, i.e. cilia, flagella, pseudopodia.)

The animal kingdom is unique amongst eukaryotic organisms because animal tissues are bound together by a triple helix of protein, called collagen. Plant and fungal cells are bound together in tissues or aggregations by other molecules, such as pectin. The fact that no other organisms utilize collagen in this manner is one of the indications that all animals arose from a common unicellular ancestor.

Animals are a large and incredibly diverse group of organisms. Making up about three-quarters of the species on Earth, they run the gamut from sponges and jellyfish to ants, whales, elephants, and -- of course -- human beings. Being mobile has given animals the flexibility to adopt many different modes of feeding, defense, and reproduction.



The earliest fossil evidence of animals dates from the Vendian Period (650 to 544 million years ago), with coelenterate-type creatures that left traces of their soft bodies in shallow-water sediments. The first mass extinction ended that period, but during the Cambrian Period which followed, an explosion of new forms began the evolutionary radiation that produced most of the major groups, or phyla, known today. Vertebrates (animals with backbones) are not known to have occurred until the Ordovician Period (505 to 438 million years ago).

- **Centrioles** - Centrioles are self-replicating organelles made up of nine bundles of microtubules and are found only in animal cells. They appear to help in organizing cell division, but aren't essential to the process.
- **Cilia and Flagella** - For single-celled eukaryotes, cilia and flagella are essential for the locomotion of individual organisms. In multicellular organisms, cilia function to move fluid or materials past an immobile cell as well as moving a cell or group of cells.
- **Endoplasmic Reticulum** - The endoplasmic reticulum is a network of sacs that manufactures, processes, and transports chemical compounds for use inside and

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Knowledge Acquisition Design Approach

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- Structured Objects and Rules
  - Well-known type of knowledge
  - Prior experience with SHAKEN system
- Equations
  - Indispensable in Physics, and Chemistry
- Tables
  - Could be stated using a conceptual knowledge interface, but sometimes very tedious
- Diagrams
  - Very common, yet a very hard problem
  - Most often the same knowledge can be stated using text

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Question Asking Requirements

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- The training requirement needs to be kept low
- The question asker should not have to know about how the knowledge is represented
- The questions may contain scenarios

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- Research Framework
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Knowledge Formulation

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- The textbook is embedded in the software
  - Provides context, and starting point for formulation
- The users never begin from an empty KB
  - Knowledge Engineers provide a library of pre-built representations
    - The Component Library (CLIB) contains classes representing physical actions, *e.g.*, *Move, Attach, Penetrate*, and semantic relations, *e.g., agent, object, has-part (Barker, Clark, Porter, KCAP'01)*
  - Some domain-specific knowledge is *pump primed*
- User-centered Design for UI abstractions
  - Concept Maps
    - Based on extensive research in education
    - Present a collection of rules instead of one rule at a time (Clark, et. al., KCAP 2001, Chaudhri, EKAW 2003, KCAP 2007)
    - Use of four basic graph operations
      - Add, connect, specialize, equate

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Example Knowledge

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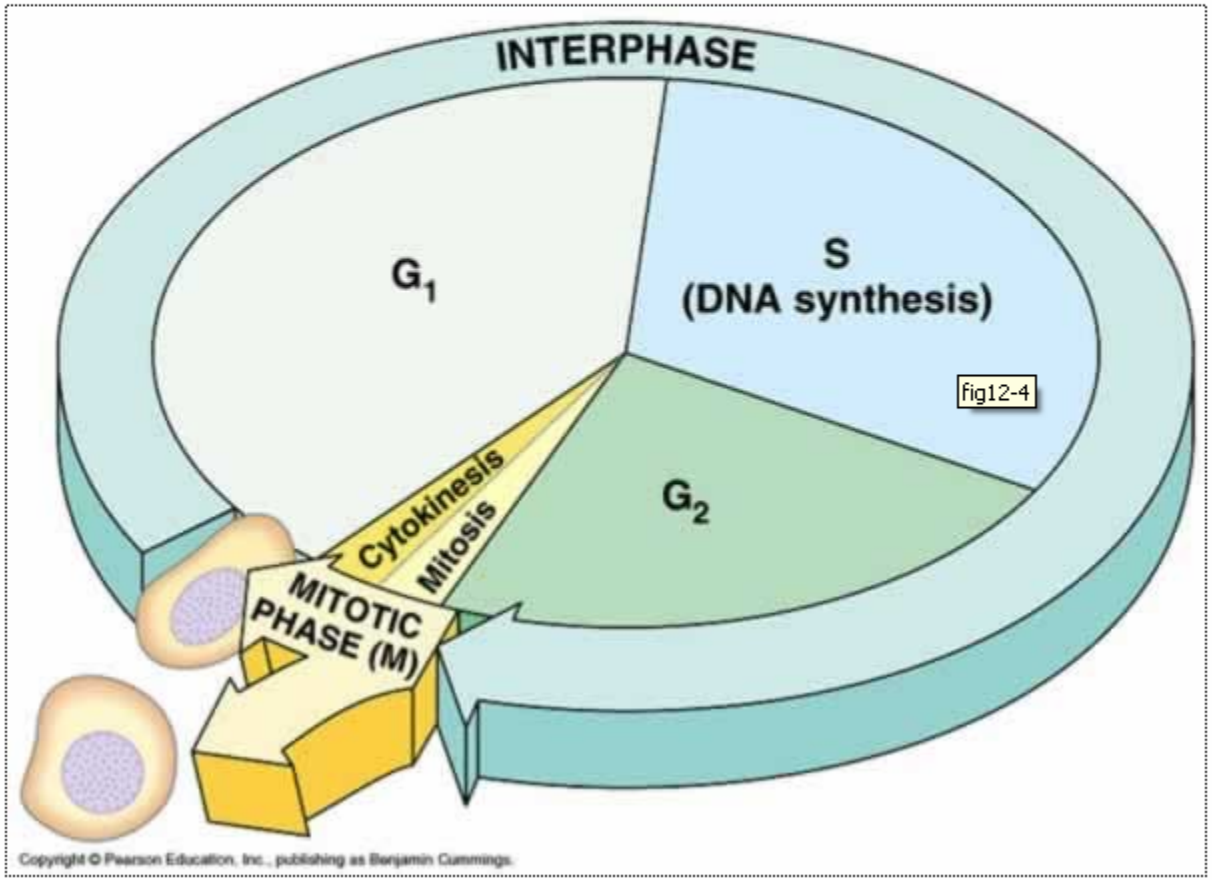
- **The mitotic phase alternates with interphase in the cell cycle:** ***an overview***

Mitosis is just one part of the cell cycle (FIGURE 12.4). In fact, the **mitotic (M) phase,** which includes both mitosis and cytokinesis, is usually the shortest part of the cell cycle. Mitotic cell division alternates with a much longer **interphase,** which often accounts for about 90% of the cycle. It is during interphase that the cell grows and copies its chromosomes in preparation for cell division. Interphase can be divided into subphases: the **G_1 phase** ("first gap"), the **S phase,** and the **G_2 phase** ("second gap"). During all three subphases, the cell grows by producing proteins and cytoplasmic organelles. However, chromosomes are duplicated only during the S phase (S stands for synthesis of DNA). Thus, a cell grows (G_1), continues to grow as it copies its chromosomes (S), grows more as it completes preparations for cell division (G_2), and divides (M). The daughter cells may then repeat the cycle.



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Knowledge Formulation

AURA

- **The mitotic phase alternates with interphase in the cell cycle: *an overview***

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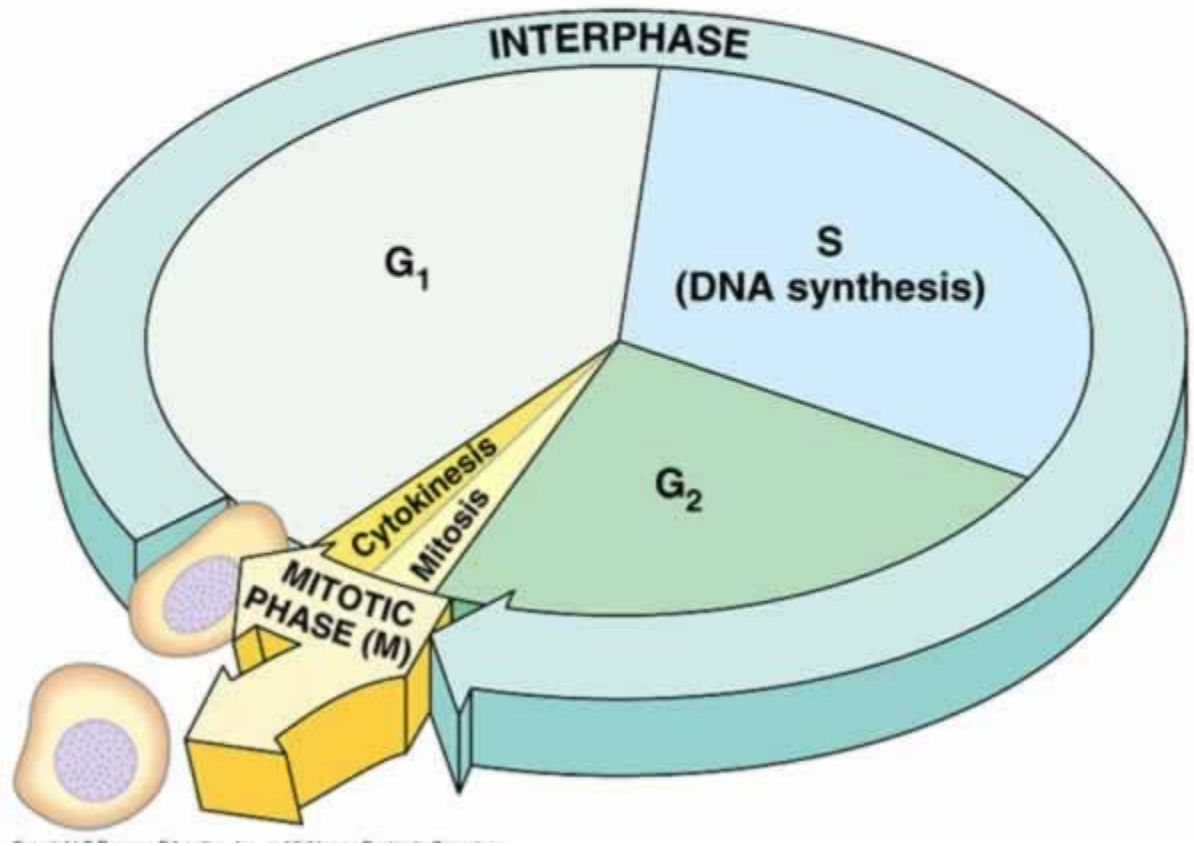

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Knowledge Formulation

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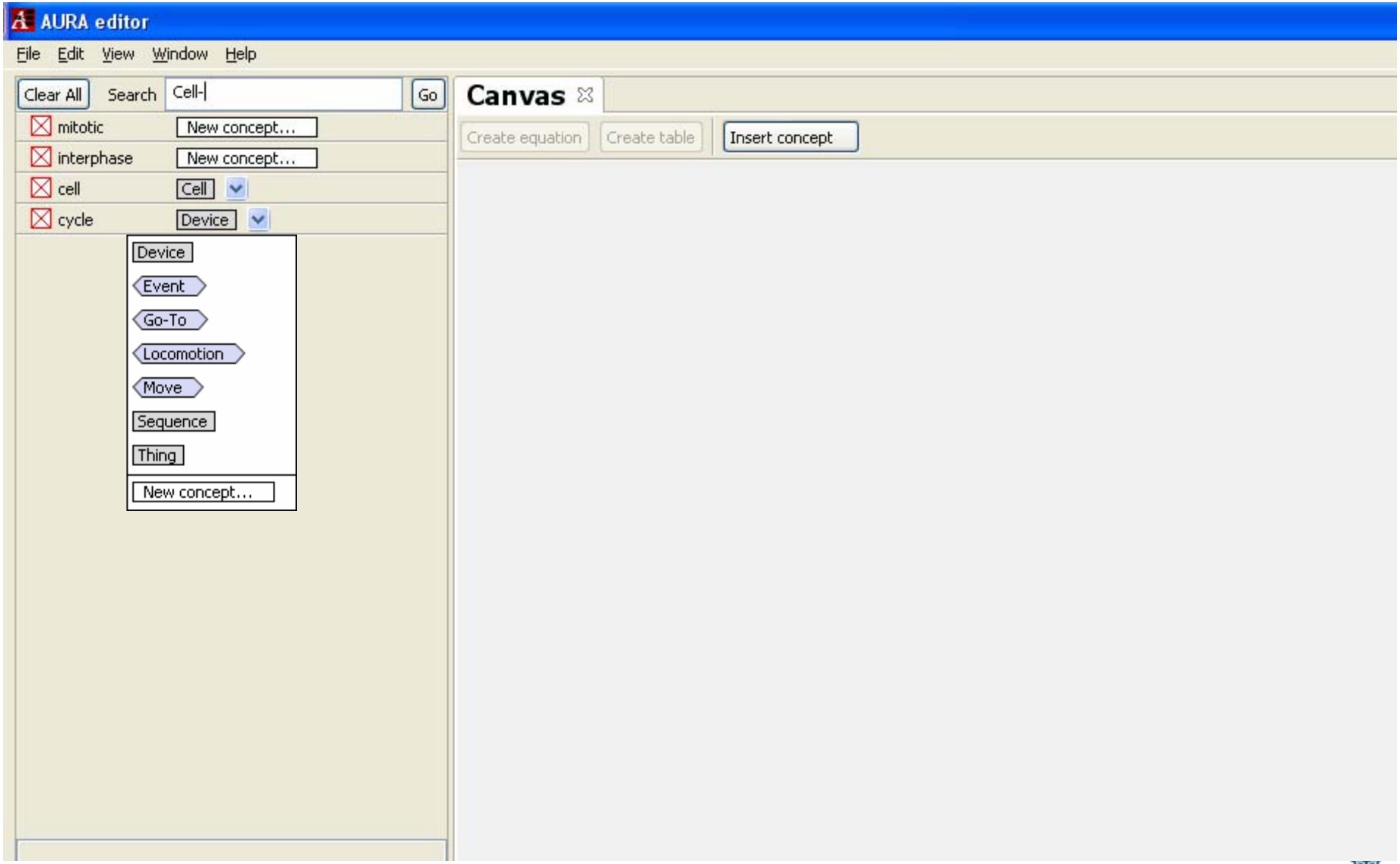

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Knowledge Formulation

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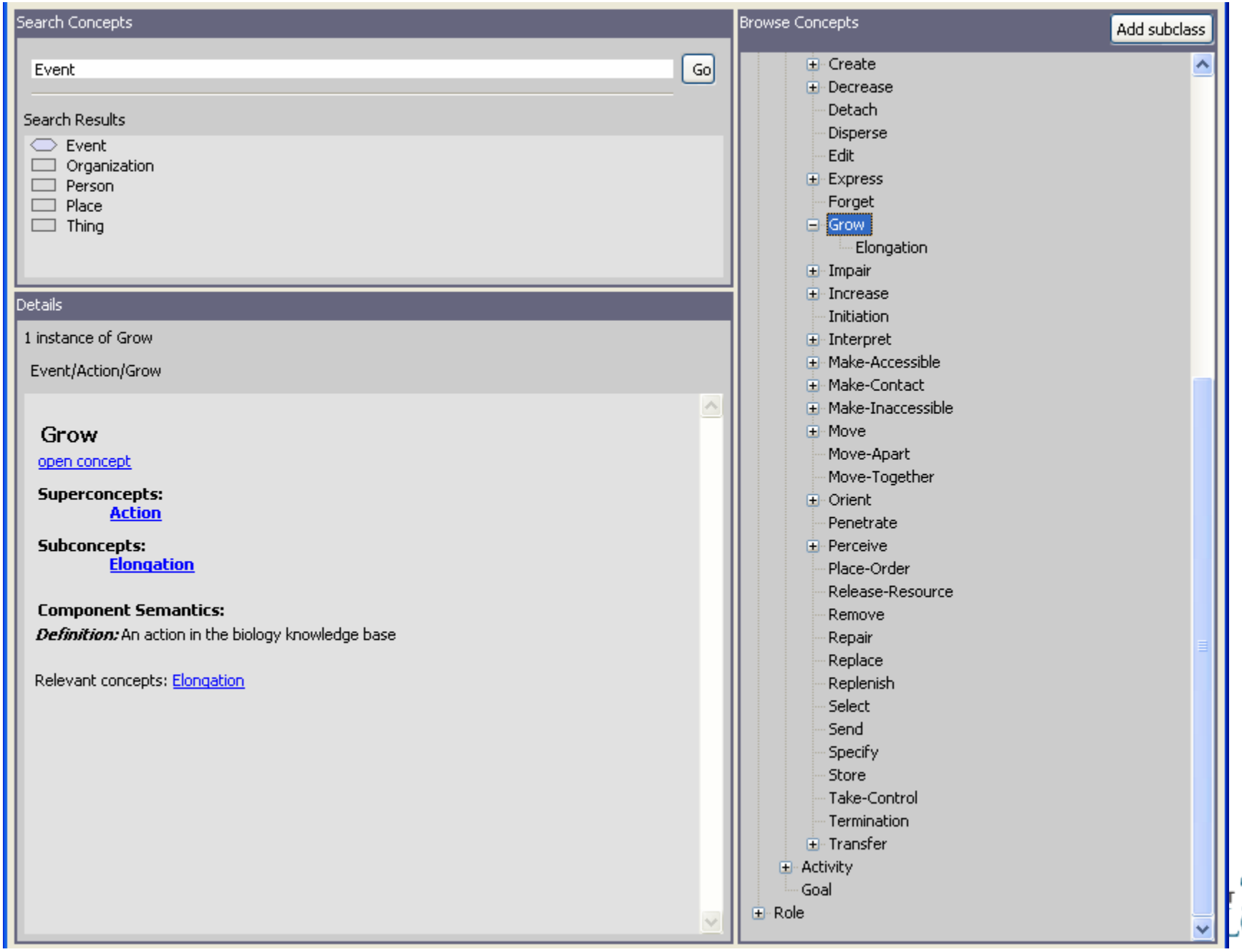

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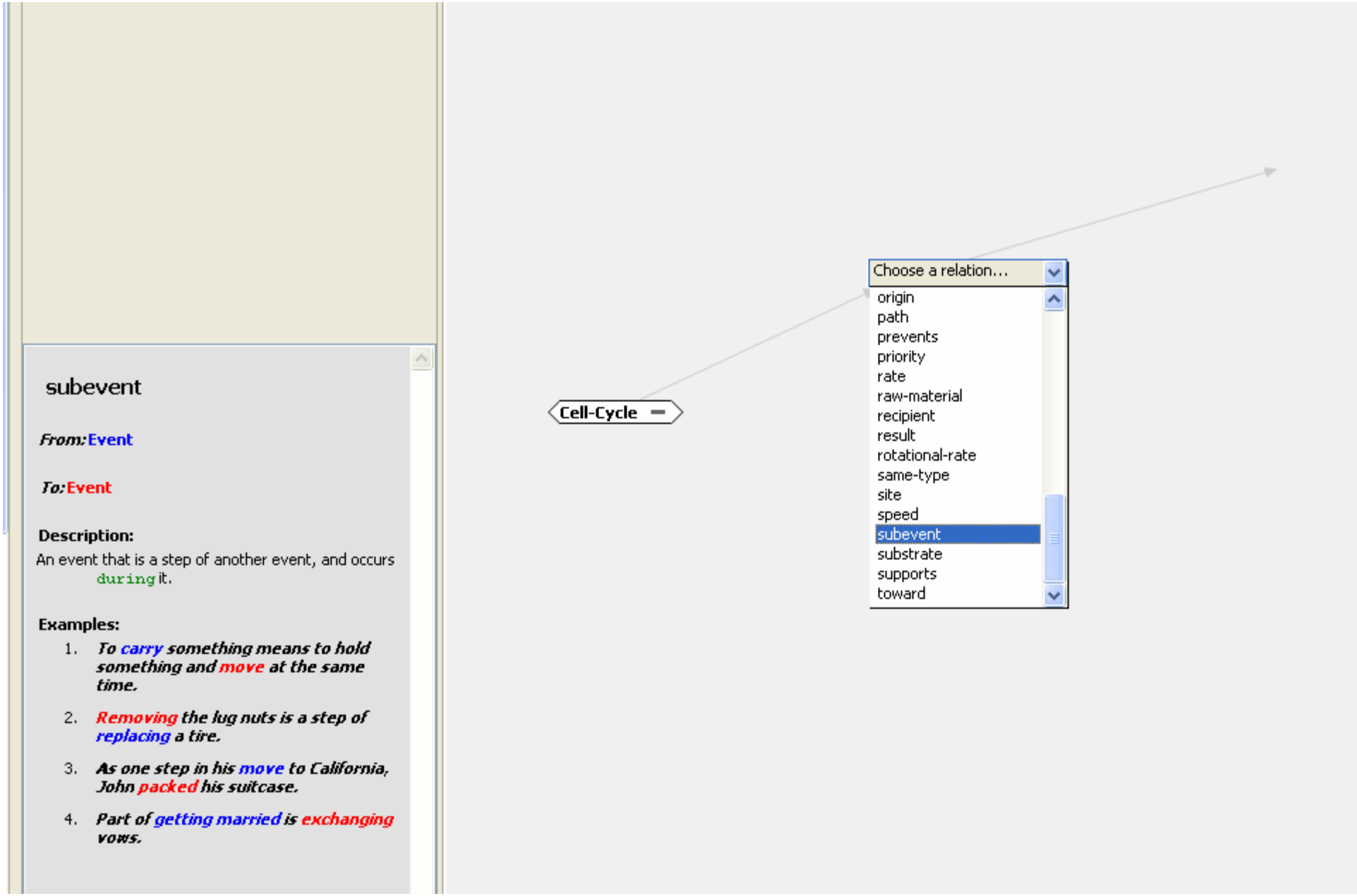

Knowledge Formulation

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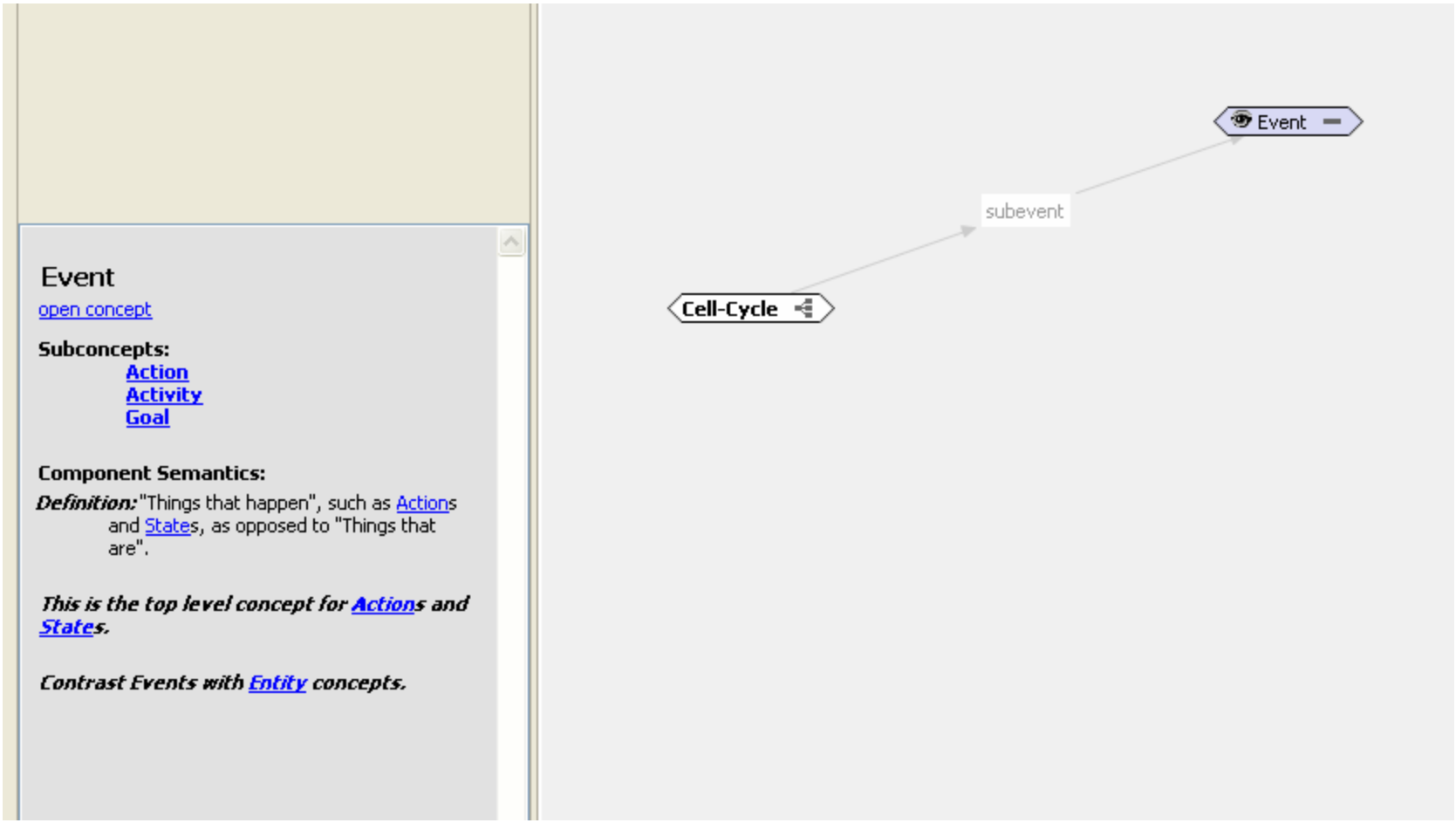

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Knowledge Formulation

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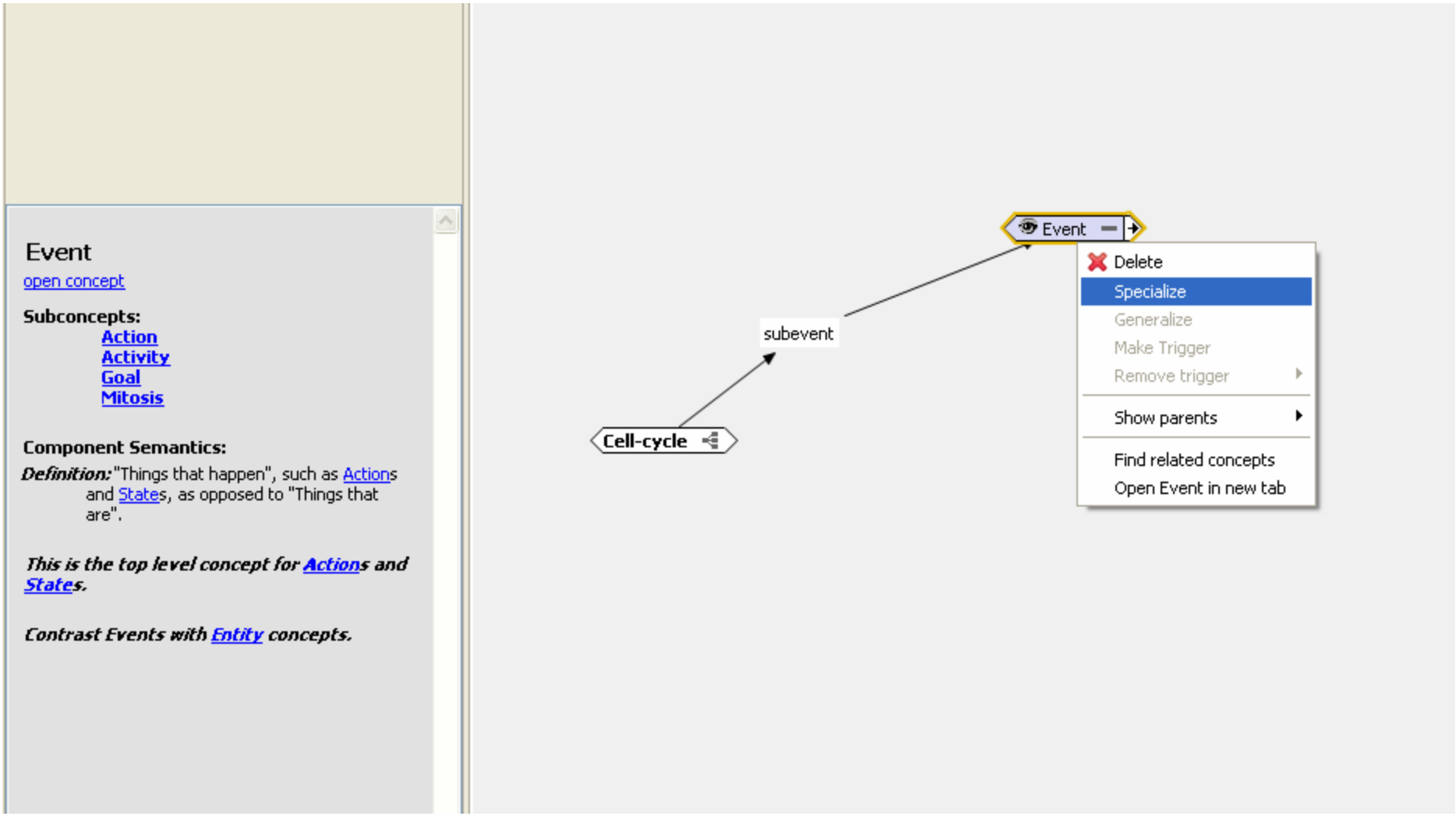

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Knowledge Formulation

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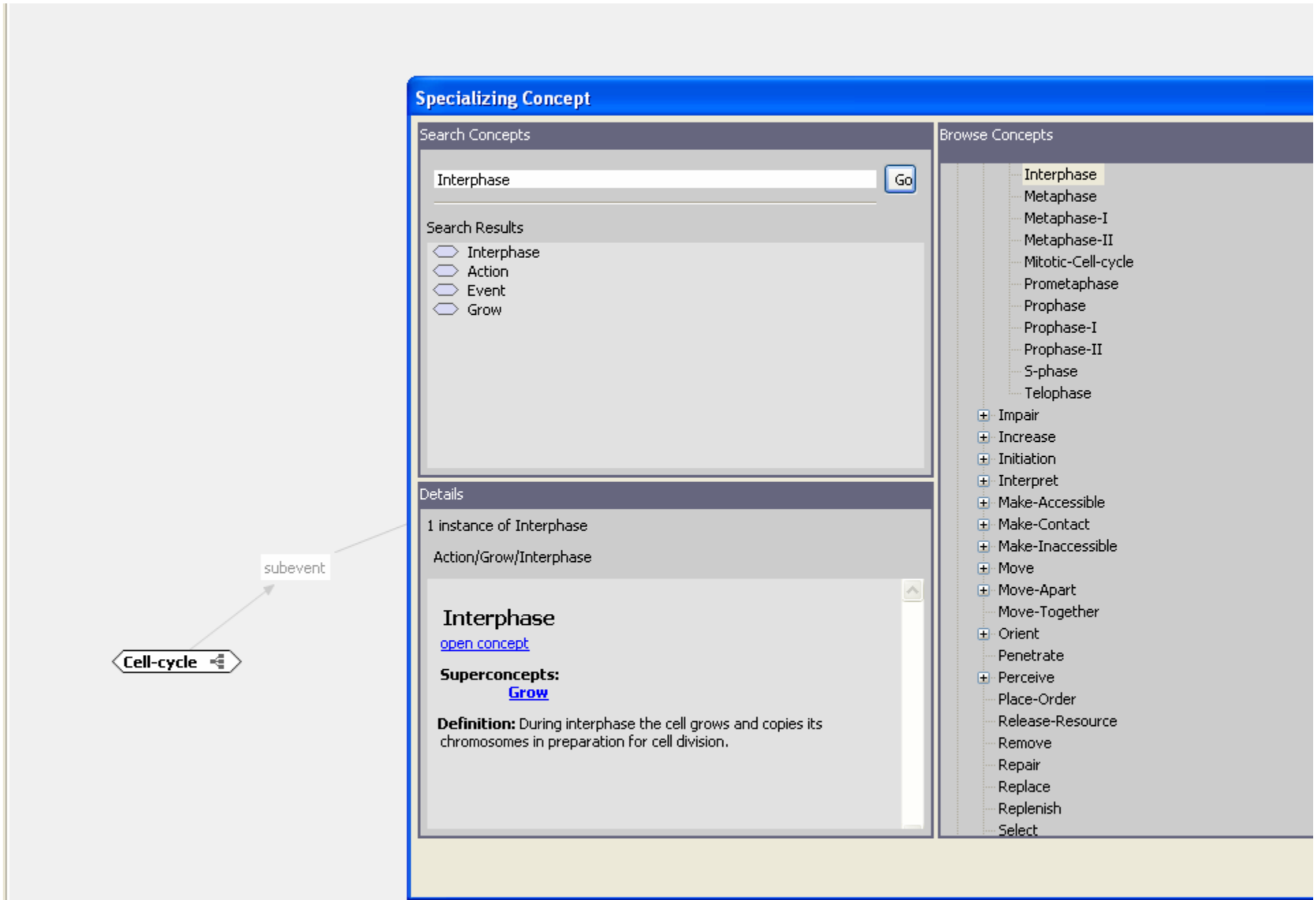

Knowledge Formulation

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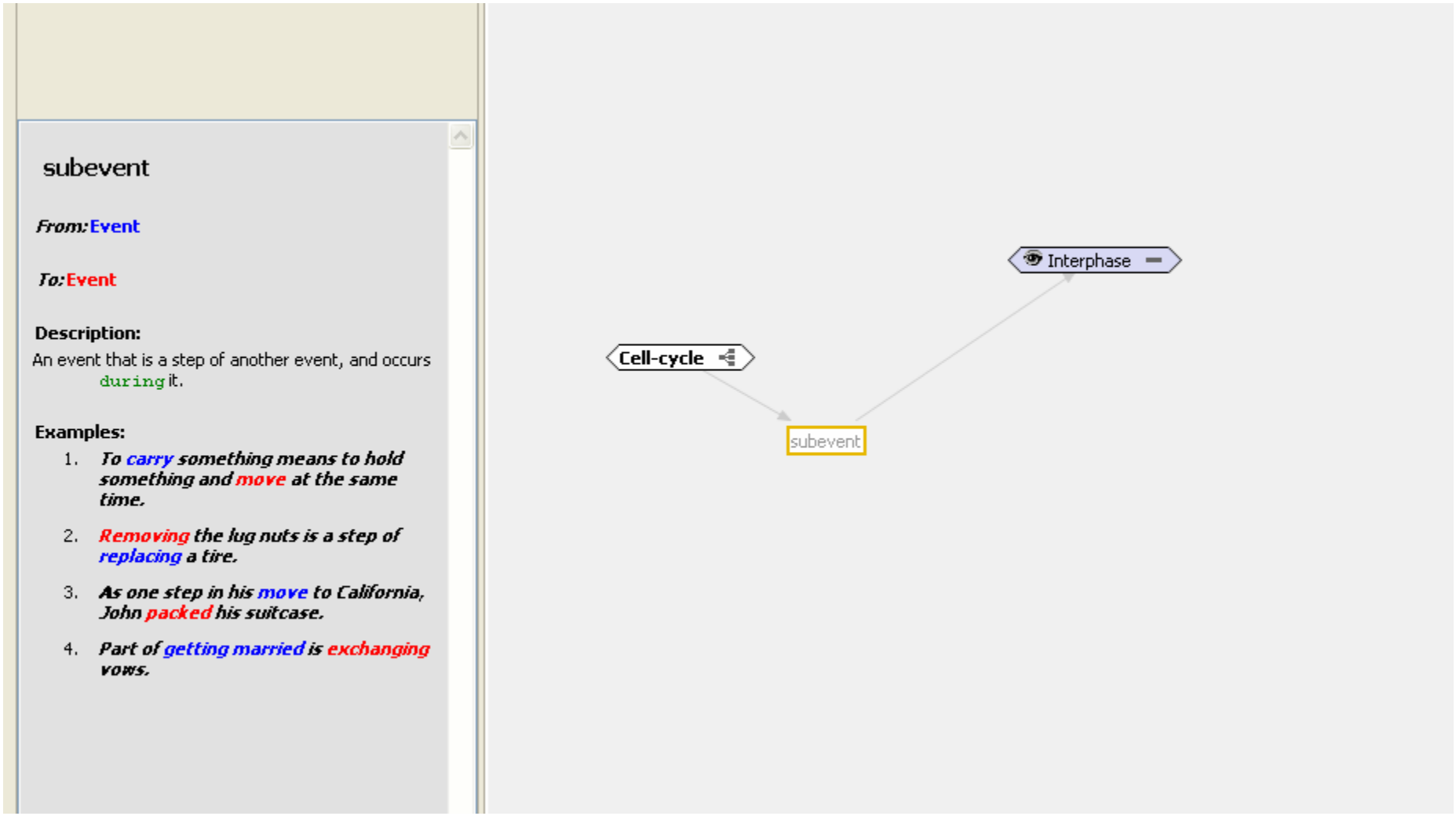

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Formulated Knowledge

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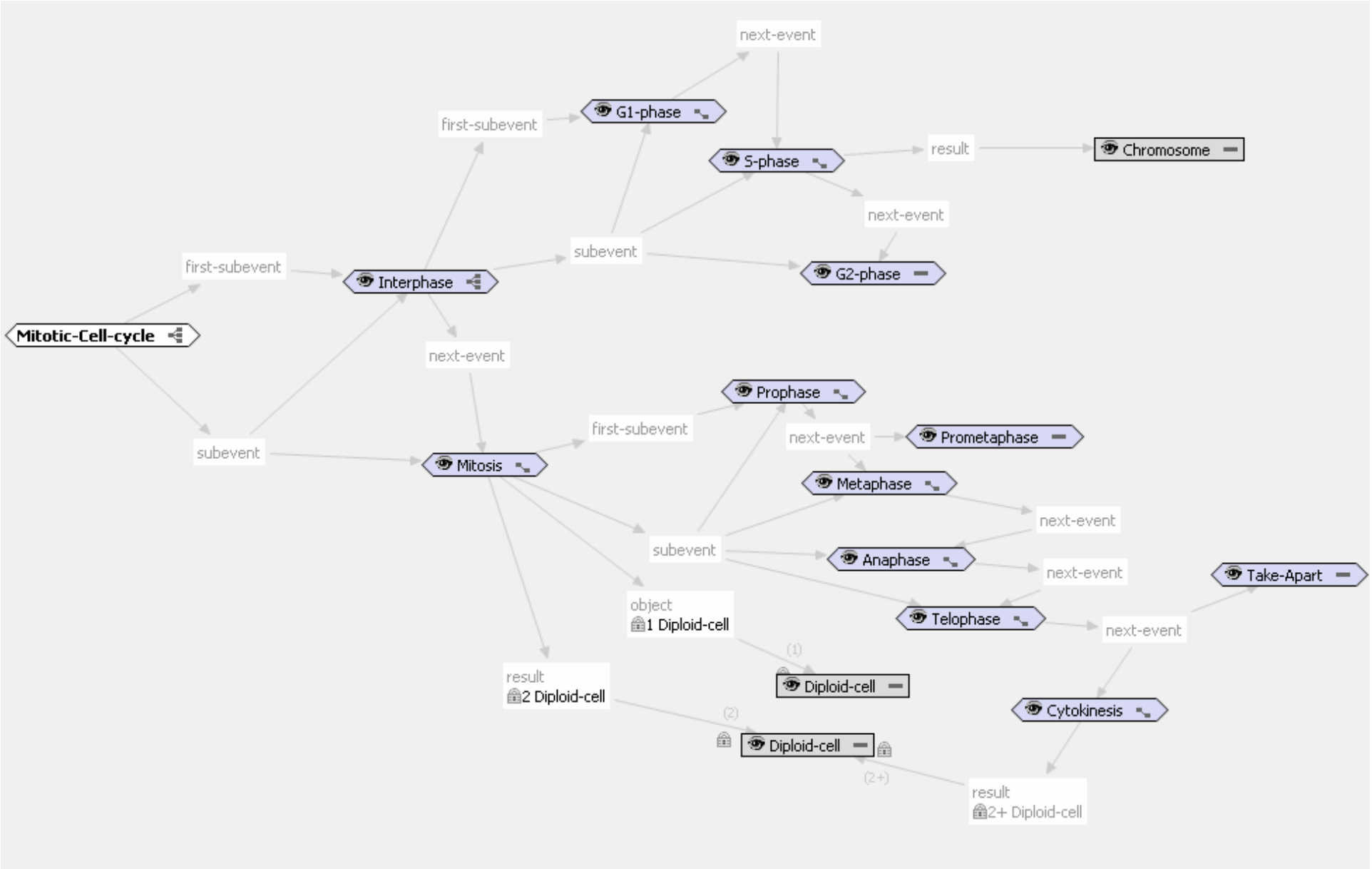

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Knowledge Formulation

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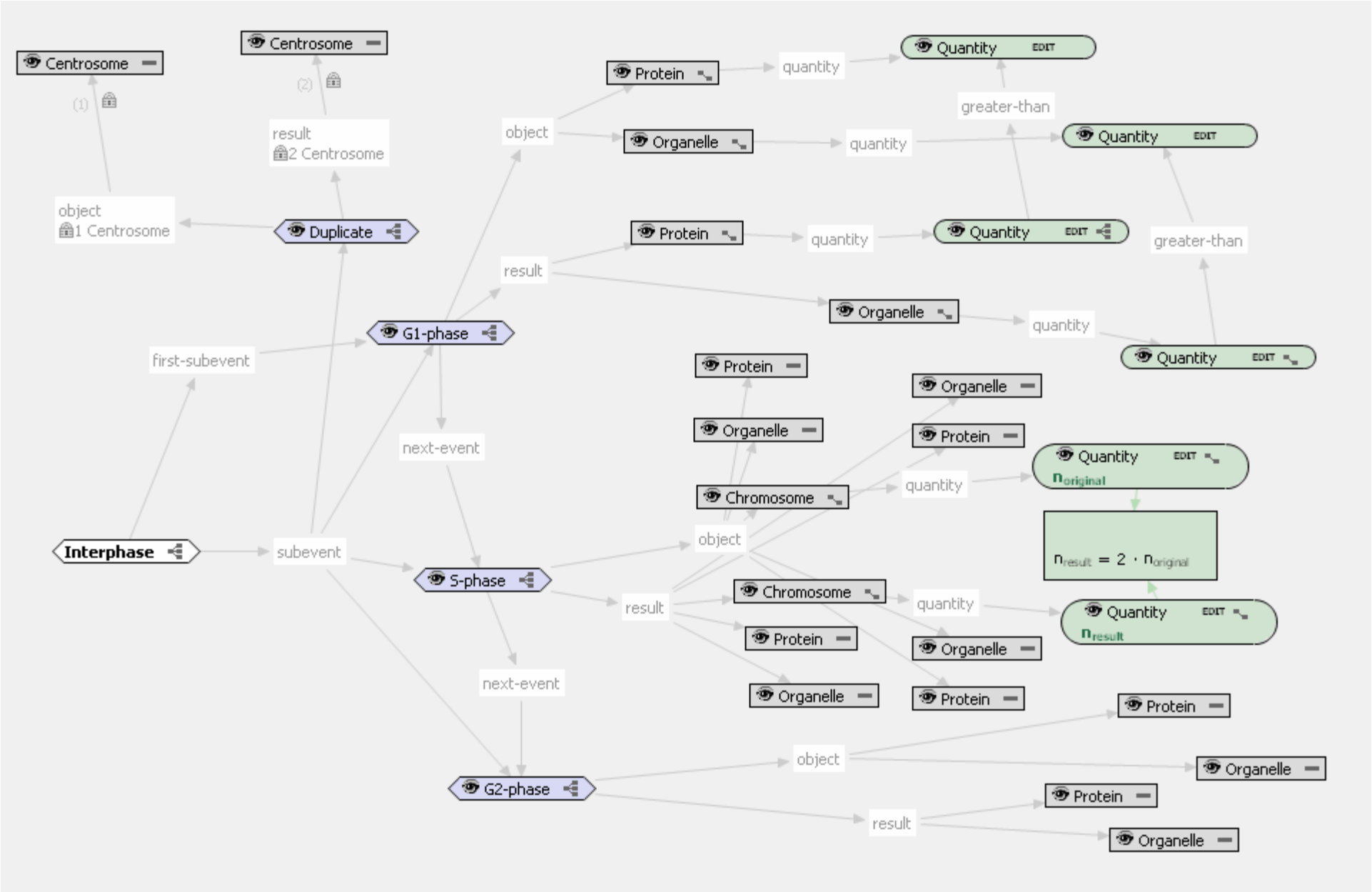

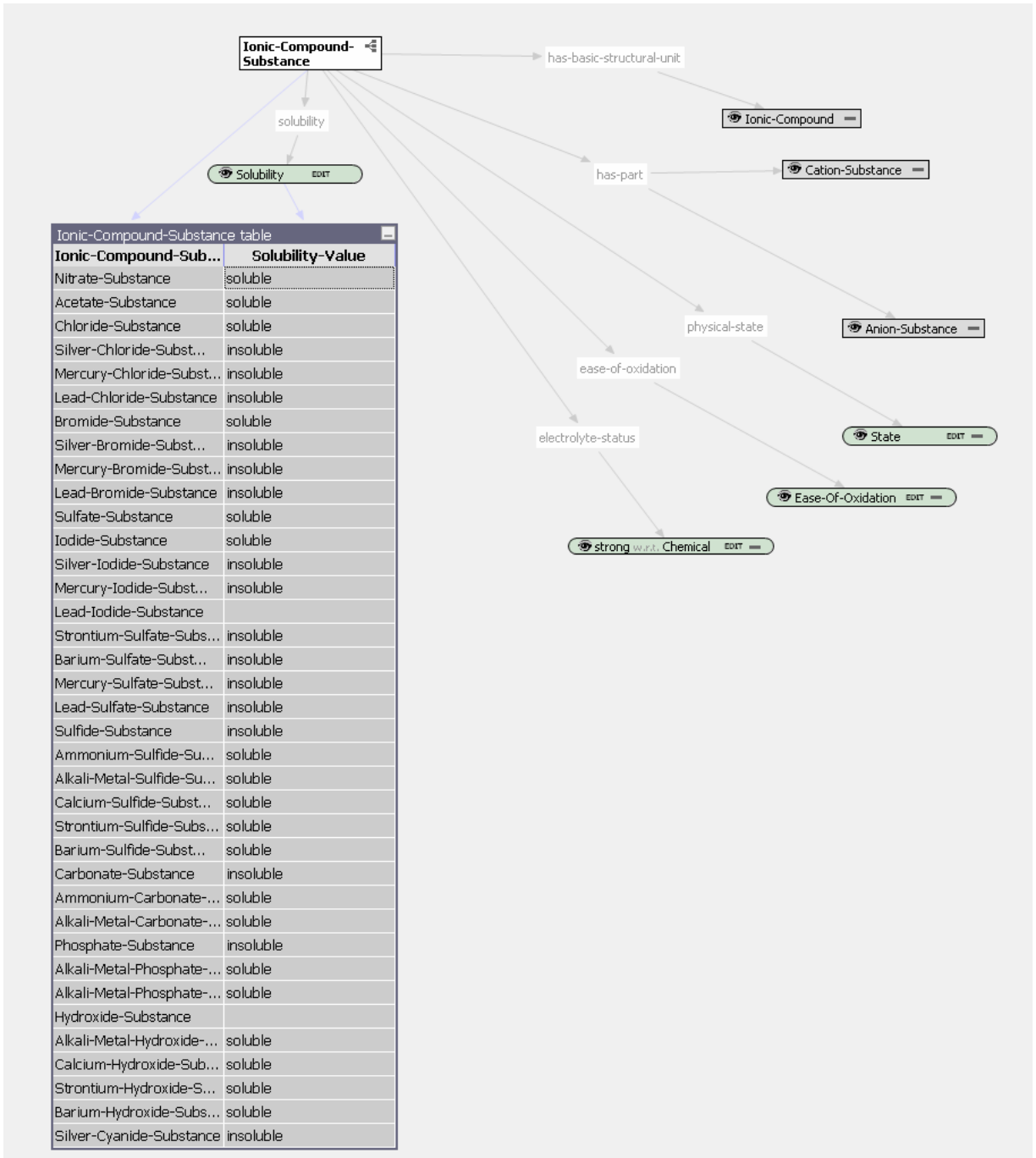

Ionic-Compound-Substance table

Ionic-Compound-Sub...	Solubility-Value
Nitrate-Substance	soluble
Acetate-Substance	soluble
Chloride-Substance	soluble
Silver-Chloride-Subst...	insoluble
Mercury-Chloride-Subst...	insoluble
Lead-Chloride-Substance	insoluble
Bromide-Substance	soluble
Silver-Bromide-Subst...	insoluble
Mercury-Bromide-Subst...	insoluble
Lead-Bromide-Substance	insoluble
Sulfate-Substance	soluble
Iodide-Substance	soluble
Silver-Iodide-Substance	insoluble
Mercury-Iodide-Subst...	insoluble
Lead-Iodide-Substance	
Strontium-Sulfate-Subs...	insoluble
Barium-Sulfate-Subst...	insoluble
Mercury-Sulfate-Subst...	insoluble
Lead-Sulfate-Substance	insoluble
Sulfide-Substance	insoluble
Ammonium-Sulfide-Su...	soluble
Alkali-Metal-Sulfide-Su...	soluble
Calcium-Sulfide-Subst...	soluble
Strontium-Sulfide-Subs...	soluble
Barium-Sulfide-Subst...	soluble
Carbonate-Substance	insoluble
Ammonium-Carbonate-...	soluble
Alkali-Metal-Carbonate-...	soluble
Phosphate-Substance	insoluble
Alkali-Metal-Phosphate-...	soluble
Alkali-Metal-Phosphate-...	soluble
Hydroxide-Substance	
Alkali-Metal-Hydroxide-...	soluble
Calcium-Hydroxide-Sub...	soluble
Strontium-Hydroxide-S...	soluble
Barium-Hydroxide-Subs...	soluble
Silver-Cyanide-Substance	insoluble

Mapping Graphs to Axioms

AURA

- Based on prior work with Shaken & CLIB
- A fragment of first order logic called prototypes
  - Clark et. al., KCAP'2001,
  - Chaudhri, et. al. EKAW, 2003
  - Fikes et. al., 2009

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Motivation for Prototypes

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- Support rule editing by
  - Grouping related axioms together
  - Providing a stable view of derived knowledge
- Provide a bridge to natural language processing systems
- Allow knowledge about a concept to be factored into multiple pieces

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What is a Prototype?

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- A set of axioms
  - A prototype identifies a root class, either by name or by a set of sufficient conditions for membership in the root class, and states necessary conditions on each member of that root class.
    - E.g., "Every car has a engine and a fuel tank''
    - A red car is red if and only if its color is red
  - In the form of a set of descriptions of individuals
    - Each description is said to describe a *prototype participant*
    - The participants include --
      - A "prototypical" member of the root class
        - Called the *root participant*

        E.g., a prototypical car
      - "Prototypical" slot values in other participants
        - Call *non-root participants*

        E.g., prototypical engine of a car, prototypical fuel tank of a car

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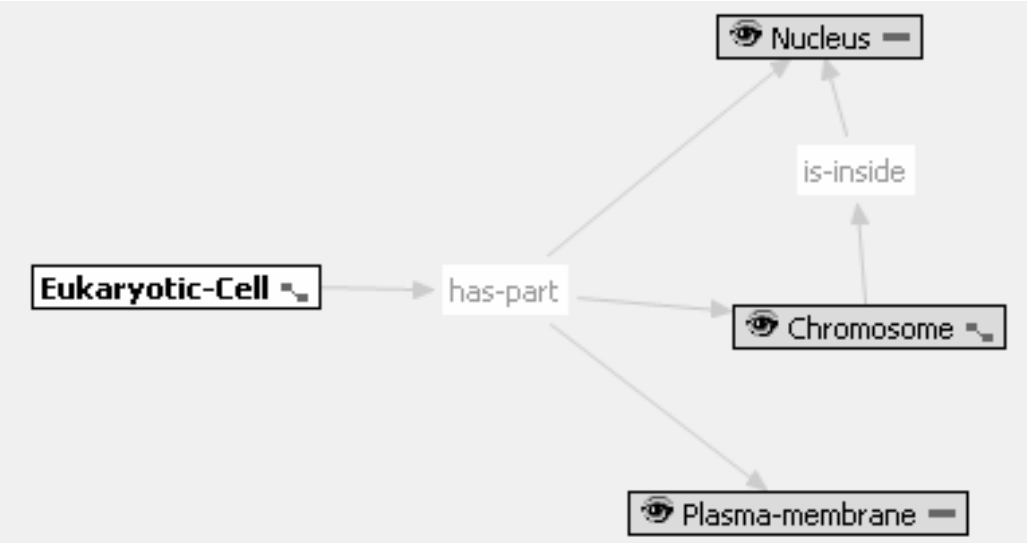
FOL Formalization of a Prototype

AURA

- A prototype is logically equivalent to the following axiom:

  If x satisfies the sufficient conditions specified in the prototype for membership in the prototype's root class, then there exist non-root participants satisfying the conditions specified in the prototype for each such participant such that the description of the root participant given in the prototype holds for x.

  E.g., A cell has parts Nucleus, Chromosome, Plasma-membrane, and the Chromosome is inside the Nucleus




```
(forall ?c
    (=> (instance-of ?c Eukaryotic-Cell)
        (exists ?x ?y ?z
        (and
        (instance-of ?x Nucleus)
        (instance-of ?y Chromosome)
        (instance-of ?z Plasma-Membrane)
        (has-part ?c ?x) (has-part ?c ?y)
        (has-part ?c ?z) (is-inside ?y ?x)))))
```

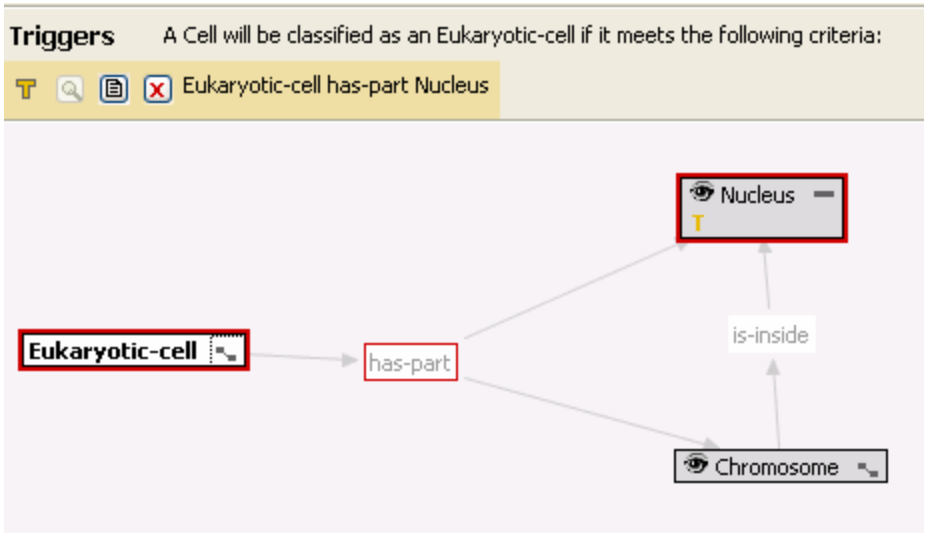
PROJECT HALO

Sufficient Properties

AURA

- A prototype is logically equivalent to the following axiom:

  If x satisfies the sufficient conditions specified in the prototype for membership in the prototype's root class, then there exist non-root participants satisfying the conditions specified in the prototype for each such participant such that the description of the root participant given in the prototype holds for x.




```
(forall ?c
    (=>  (or
           (instance-of ?c Eukaryotic-Cell)
           (and
             (instance-of ?c Cell)
             (exists ?n
               (instance-of ?n Nucleus)
               (has-part ?c ?n))))
           (exists ?x ?y ?z
           (and
           (instance-of ?x Nucleus)
           (instance-of ?y Chromosome)
           (instance-of ?z Plasma-Membrane)
           (has-part ?c ?x) (has-part ?c ?y)
           (has-part ?c ?z) (is-inside ?y ?x)))))
```

PROJECT HALO

Other Features

AURA

- Property values
  - E.g., 1 m, Tall Person, Red
- Constraints
- If-then-else conditions
- Mathematical equations, and their inheritance
  - V=u+at
- Tables and qualitative orders

PROJECT HALO

Expressiveness Analysis

AURA

- Following fragments of FOL are represented in the prototypes in relation to F-Logic/SILK
  - Frames
  - Equality
  - Monotonic Lloyd Topor
  - Aggregation
  - Constraint checking
  - Negation as Failure (NAF)
  - Skolemization
  - Prioritized default rules

PROJECT HALO

Motivation for Prototypes

AURA

- Support rule editing by
  - Grouping related axioms together
  - Providing a stable view of derived knowledge
- Provide a bridge to natural language processing systems
- Allow knowledge about a concept to be factored into multiple pieces

PROJECT HALO

Supporting Rule Editing

AURA

- Grouping related axioms together

```
(forall ?c
    (=> (instance-of ?c Eukaryotic-Cell)
        (exists ?x ?y ?z
        (and
        (instance-of ?x Nucleus)
        (instance-of ?y Chromosome)
        (instance-of ?z Plasma-Membrane)
        (has-part ?c ?x) (has-part ?c ?y)
        (has-part ?c ?z) (is-inside ?y ?x)))))
```

vs

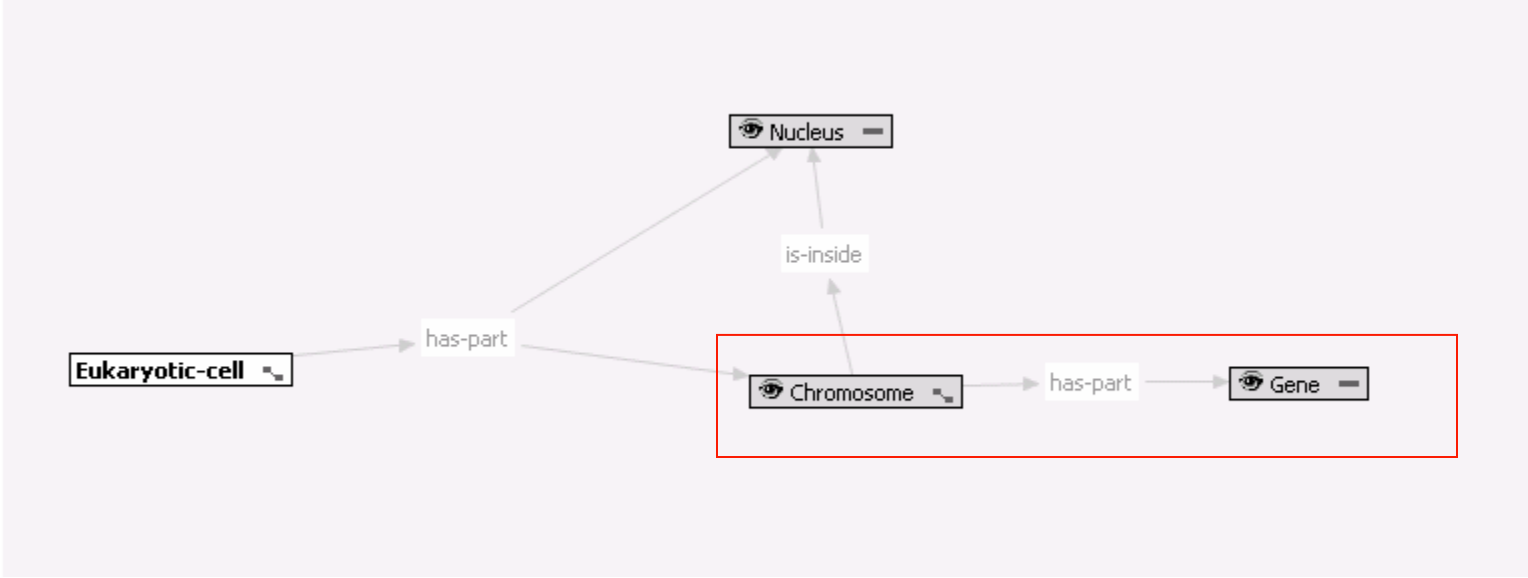
```
(forall ?c
    (=> (instance-of ?c Eukaryotic-Cell)
        (exists ?x
        (and
        (instance-of ?x Nucleus)
        (has-part ?c ?x)))))

(forall ?c
    (=> (instance-of ?c Eukaryotic-Cell)
        (exists ?y
        (and
        (instance-of ?y Chromosome)
        (has-part ?c ?y)))))

(forall ?c
    (=> (instance-of ?c Eukaryotic-Cell)
        (exists ?z
        (and
        (instance-of ?z Plasma-Membrane)
        (has-part ?c ?z)))))

(forall ?c ?y ?x
    (=>  (and
        (instance-of ?c Eukaryotic-Cell)
        (instance-of ?y Chromosome)
        (instance-of ?x Nucleus)
        (has-part ?c ?x) (has-part ?c ?y))
    (is-inside ?y ?x)
```

PROJECT HALO

Support Rule Editing

AURA

- Provide stable view of knowledge
  - Prototypes serve as views over derived knowledge



PROJECT HALO

Some Open Formalization Issues

AURA

- Formal analysis of reasoning properties of prototypes
  - Graph Equality
  - Multiple inheritance of rules
- Propagation of knowledge base updates
- How does prototype structure help in
  - Natural language processing
  - Factoring rules into multiple prototypes
  - Automated reasoning

PROJECT HALO

Outline

AURA

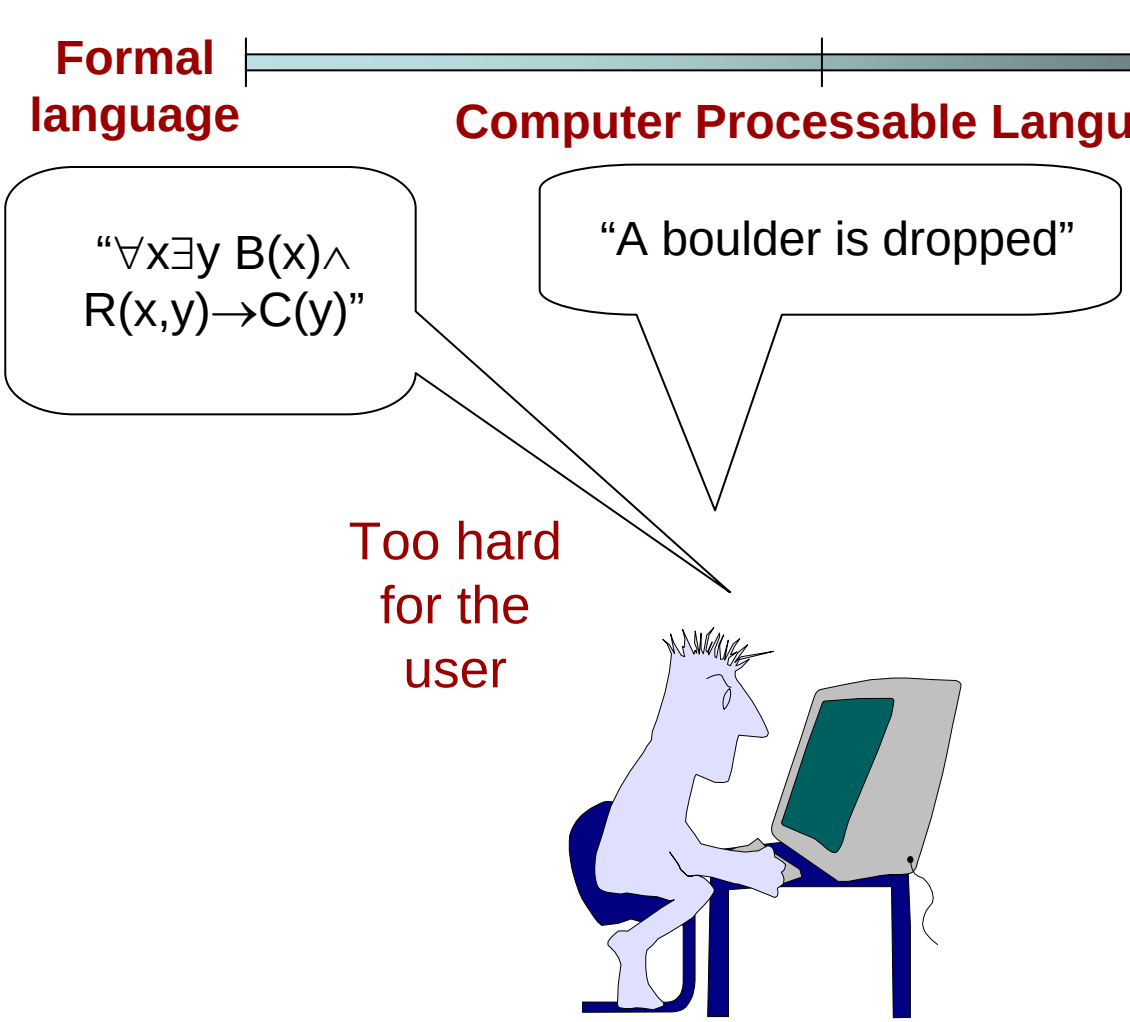
- Research Framework
- Requirement Analysis
- Implementation
  - Knowledge Formulation
  - Question Formulation
  - Question Answering
- Evaluation
- Potential Application
- Future Work

PROJECT HALO

Question Formulation

AURA

There lies a "sweet spot" between logic and full NL which is both human-usable and machine-understandable



"Consider the following possible situation in which a boulder first…"

PROJECT HALO

Question Formulation Cycle

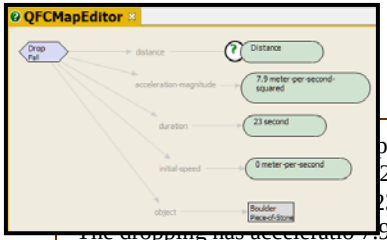
AURA

CPL (Controlled english)

Original text

A boulder is dropped.
The initial speed of the boulder is 0 m/s.
The duration of the drop is 23 seconds.
The acceleration of the drop is 7.9 m/s^2.
What is the distance of the drop?.

Rewriting advice



pping.
23 seconds.
23 seconds.
9 m/s^2.
The dropping has a distance of unknown
What is the distance?

Graph & paraphrase of system's understanding

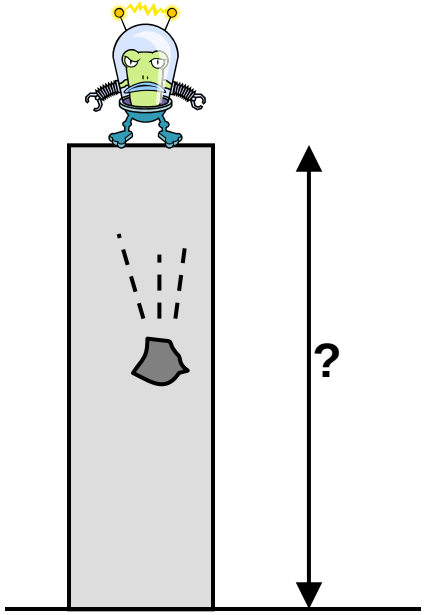
Question-Answering

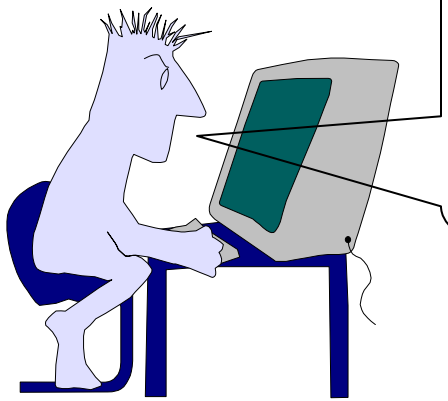
PROJECT HALO

Example of Question Formulation

AURA

An alien measures the height of a cliff by dropping a boulder from rest and measuring the time it takes to hit the ground below. The boulder fell for 23 seconds on a planet with an acceleration of gravity of 7.9 m/s^2. Assuming constant acceleration and ignoring air resistance, how high was the cliff?



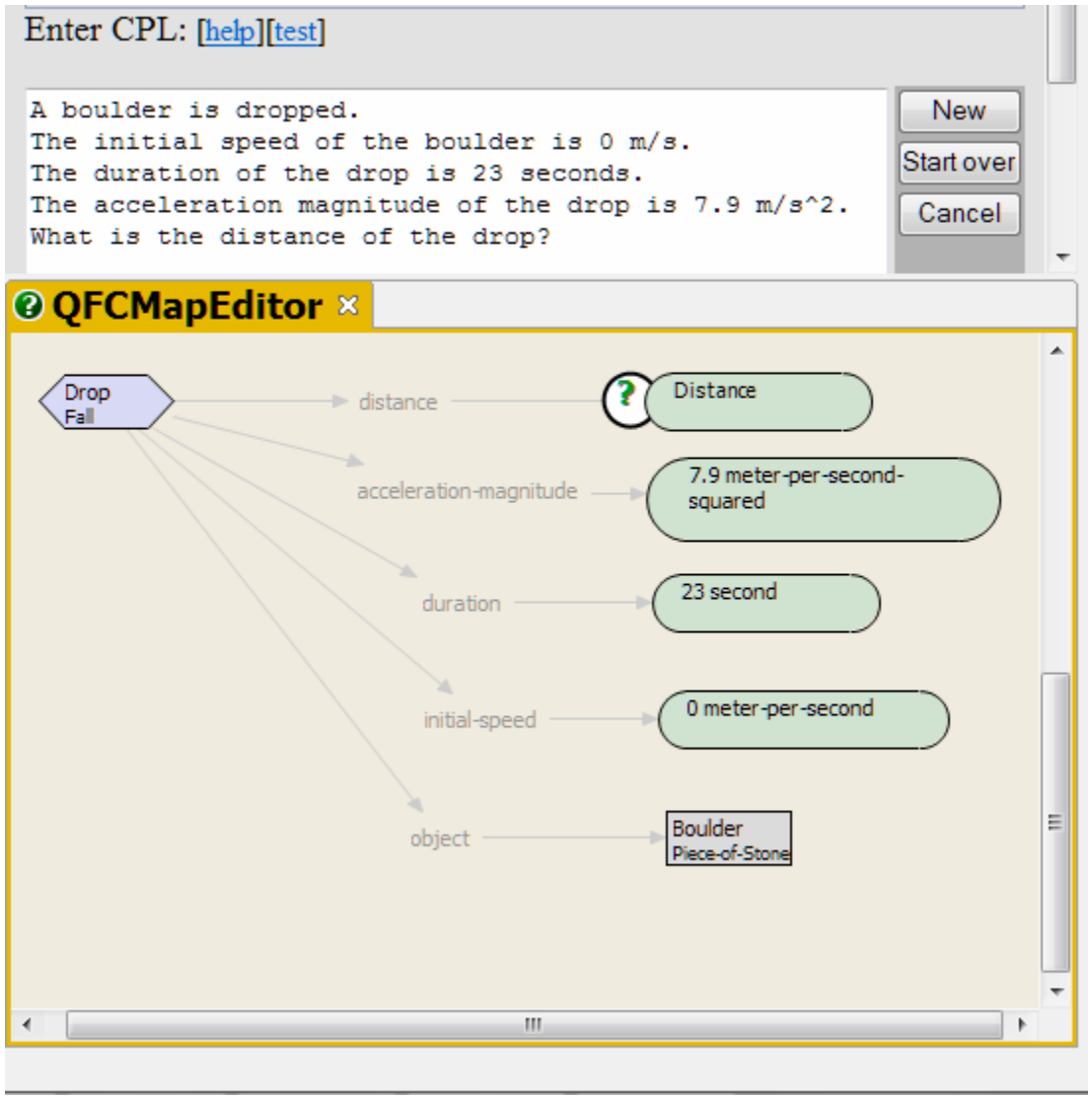


A boulder is dropped.
The initial speed of the boulder is 0 m/s.
The duration of the drop is 23 seconds.
The acceleration of the drop is 7.9 m/s^2.
What is the distance of the drop?

PROJECT HALO

Example Feedback from the System

AURA



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Question Understanding Pipeline

AURA

- Parsing
- Syntactic logic generation
- Reference resolution
- Transform verbs to relations
- Word sense disambiguation
- Semantic role labeling
- Metonymy resolution
- Question annotation
- Paraphrasing
- Query relaxation
- Abductive reasoning

PROJECT HALO

Outline

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PROJECT HALO

Question Answering

AURA

- Reasoning Control
- Reasoning Engine
  - Knowledge Machine (Clark, Porter, 1999)
  - Semantic Matching (Yeh, Porter, AAAI 2006)
- Specialized Reasoning Modules
  - Equation solving
  - Chemical compound recognition
- Explanation Generation
  - English generation from the knowledge base

PROJECT HALO

Example Answer

AURA

Answer

The distance of the fall = 2089.55 m

Explanation

free-fall :

Assumptions:

- Only for this concept consider downward positive.

Given the values

- t = 23 s
- u = 0 m/s
- g = 7.9 m/s^2

Given the equations

- $v^2 = u^2 + 2 \times g \times h$
- $h = u \times t + 1 \div 2 \times g \times t^2$
- $v = u + g \times t$

Evaluated v = u + g * t
giving v = 181.7 m/s

- h = 2089.55 m

PROJECT HALO

Example Answer

A solution that has a pH greater than 7 will result when this substance is dissolved in water.
a. sulfur dioxide
b. oxalic acid
c. phosphoric acid
d. carbonic acid
e. potassium nitrate

CPL
a. there is an aqueous solution of SO2.
what is the pH of the solution?
Answer
pH = 0

CPL
b. there is an aqueous solution of H_2C_2O_4.
what is the pH of the solution?
Answer
pH is less than 7

Example Answer

AURA

- What is the relationship between Caveolin and Muscle Cell?

  (Inspired by Larry Hunter's work on Biological Discovery)

PROJECT HALO

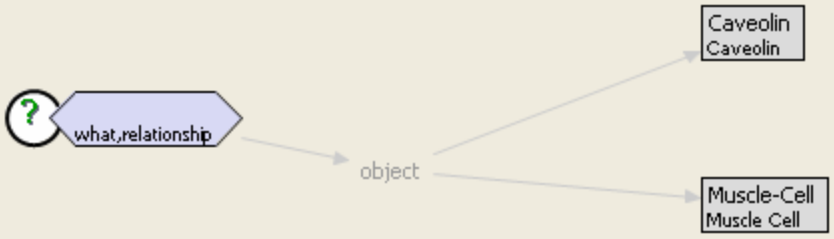
Example Answer

AURA

● What is the relationship between Caveolin and Muscle Cell?

Enter CPL: [help][vocabulary]

```
What is the relationship between Caveolin and Muscle Cell?
```



Answer

find more answers

The muscle-cell and the caveolin are related in the following ways:

- The caveolin is a basic structural unit of the caveola.
- The caveola does the transcytosis.
- The transcytosis has as subevent the carrying.
- The carrying is to the recyclingendosomes.
- The recyclingendosomes has the glucose-transporter.
- The glucose-transporter does the muscle-cell-glucose-uptake.
- The muscle-cell-glucose-uptake is done to the muscle-cell.

HALO

Outline

AURA

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- Future Work

PROJECT HALO

Evaluation

AURA

- Functional Evaluation
- Generality Evaluation

PROJECT HALO

Functional Evaluation

AURA

- How well does AURA support knowledge formulation by KFEs?
- How well does AURA support question formulation by the QFEs?
- How well does AURA support answers to novel questions?

PROJECT HALO

Independent Evaluation by BBN

AURA

- The evaluation employs a 2 x 2 design to test the effects of user experience on KF and QF
- In each cell users will author KBs for a section of an AP syllabus and other users will query the KBs to answer a set of AP questions in that domain

Question Formulation

(Scores on a test of newly generated AP questions)

Knowledge Formulation		SRI's Regression Test	SRI Domain Experts: With Partial Credit	SRI Domain Experts: Without Partial Credit	Cambridge Undergrads: With Partial Credit	Cambridge Undergrads: Without Partial Credit
SRI Domain Experts	Biology	Upper bound	Ideal Reference		Newly Trained Knowledge Formulators	
	Physics					
	Chemistry					
UC Denver SMEs	Biology 1	Initial Indicator of KB Quality	Newly Trained Question Formulators		Newly Trained Knowledge Formulators & Question Formulators	
	Biology 2					
	Biology 3					
	Physics 1					
	Physics 2					
	Physics 3					
	Chemistry 1					
	Chemistry 2					
	Chemistry 3					

Knowledge Formulation
20 hours of training
160 hours of knowledge entry

Question Formulation
4 hours of training
40 hours of question asking

PROJECT HALO

Independent Evaluation

AURA

- KF experiment
  - Held at UC Denver
  - 9 KFEs (3 in each domain)
- QF/QA Experiment
  - Held at BBN in Boston
  - 16 QFEs

Evaluation

AURA

- Functional Evaluation
- Generality Evaluation

PROJECT HALO

Take Away from 2008-2009 Evaluation

AURA

Domain	Known Question Set	Novel Question Set
Biology	71%	54%
Chemistry	73%	24%
Physics	79%	61%

- We had good results in Biology giving us confidence to propose encoding a full book as a good next scaling target
  - Scaling requires a knowledge factory
- We had some challenges in Chemistry and Physics suggesting need for further system improvement

PROJECT HALO

Implementing Knowledge Factory

AURA

EVALUESERVE
Your Global Knowledge Partner

Two performers selected after extensive search
- Evalueserve with IIT New Delhi as a consultant
- Kidosoft with IIIT Hyderabad as a consultant

We repeated a modified version of refinement phase evaluation experiment

After a two week training in Menlo Park, each team trained three biologists in India.

Each biologist team used AURA for five weeks to collaboratively construct a KB

The resulting KBs were tested on novel questions

Business Line
Financial Daily from THE HINDU group of publications
Wednesday, Jun 02, 2004

*because we're thir
discover Philips' innovat
www.philips.com/because

Info-Tech - Software

Kido Soft lab at IIIT

Our Bureau

HYDERABAD: Kido Software, a Hyderabad-based software company, plans to establish a Dynamic Software Lab in International Institute of Information Technology (IIIT), Hyderabad, to work on artificial intelligence (AI).

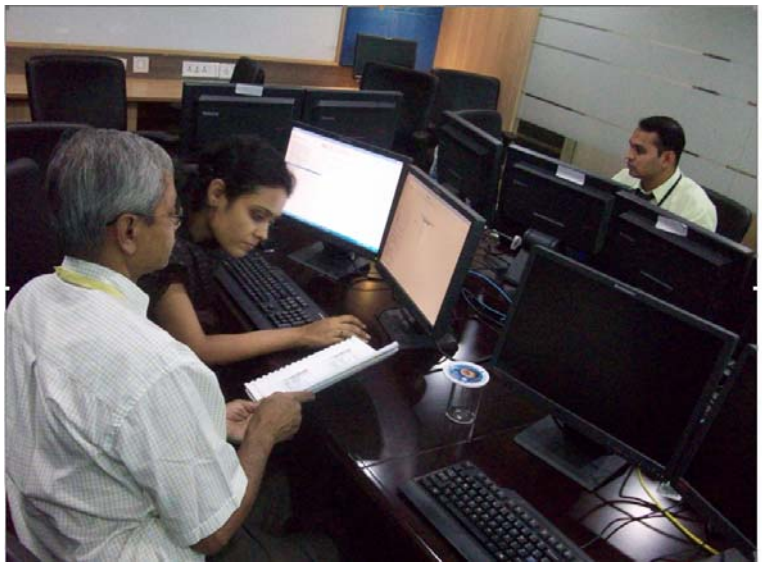
The Managing Director of Kido Software, Mr Prasad Yalamanchi, and Prof Rajiv Sangal, Director of IIIT-Hyderabad, on Monday, entered into a memorandum of understanding for setting up a Dynamic Software Lab in the IIIT-H Gachibowli campus. The focus will be on creating new technology platforms and an environment to train and develop software architecture.

Multi-User Knowledge Entry

AURA

- Two Knowledge Factory Locations in India

Kidosoft/IIIT Hyderabad



Evaluserve/IITD New Delhi

PROJECT HALO

Results

AURA

Single User Experiment	
SRI	45%
Multi-User Experiment	
Evalueserve	75%
KidoSoft	68%

EXPECTED RESULTS

- Teams were able to replicate the KB creation process
- KFEs were able to successfully collaborate

UNEXPECTED RESULTS

- We were expecting the scores in the range of 50%
- Breadth and depth of syllabus coverage is superior

PROJECT HALO

Generality Outside the Current Scope

AURA

- Even though we built the KB only for 50 pages of syllabus, our requirement analysis covered the whole syllabus
  - With the features currently implemented, we expect to be able to answer 50% of the questions on an AP Exam in the three Science domains
    - A preliminary exercise for encoding the whole Physics textbook required 36 specific extensions to CLIB
- We have analyzed three new domains
  - Micro Economics
    - Similar to Physics, but also more qualitative
  - US Government and Politics
    - Some similarities to Biology in the need for approximate matching of descriptions
  - Environmental Sciences
    - Similar to Physics and Biology, but requires qualitative reasoning
- The 50% coverage generalizes to the new domains

PROJECT HALO

Outline

AURA

- Research Framework
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- Implementation
  - Knowledge Formulation
  - Question Formulation
  - Question Answering
- Evaluation
- Future Work

PROJECT HALO

A Computer-Based Tutor

AURA

- Integrated into a Textbook
- Help a student
  - Read
  - Learn
  - Apply
  - Write

PROJECT HALO

Future Work

AURA

- Knowledge base for a full textbook
- Expand the expressiveness of the question formulation interface (Boeing)
  - Paraphrases, query relaxation, abduction
- Expand expressiveness of knowledge formulation
  - Computational knowledge, qualitative knowledge, and diagrams
- New Reasoning methods
  - Qualitative, symbolic, explanation
- Knowledge Debugging
- Applications
  - Bio discovery
  - Textbooks of the future

PROJECT HALO

Summary

AURA

- AURA is aimed to be a generic computational tool aimed at modeling knowledge in hard sciences
  - We have good results based on 50 pages of textbook syllabus and questions suite drawn from an advanced placement exam
  - We are set to mature the technology by scaling to one full book and put out an initial product protype

PROJECT HALO

For more information

http://www.ai.sri.com/project/aura

Thank You