Knowledge-Based Agents

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Agenda

Knowledge-Based Agents

Core Concepts

Propositional Logic

Debugging

Knowledge-Based Agents

Representations

- Atomic (Search)
- Factored (Constraints)
- **Structured** (TBD)

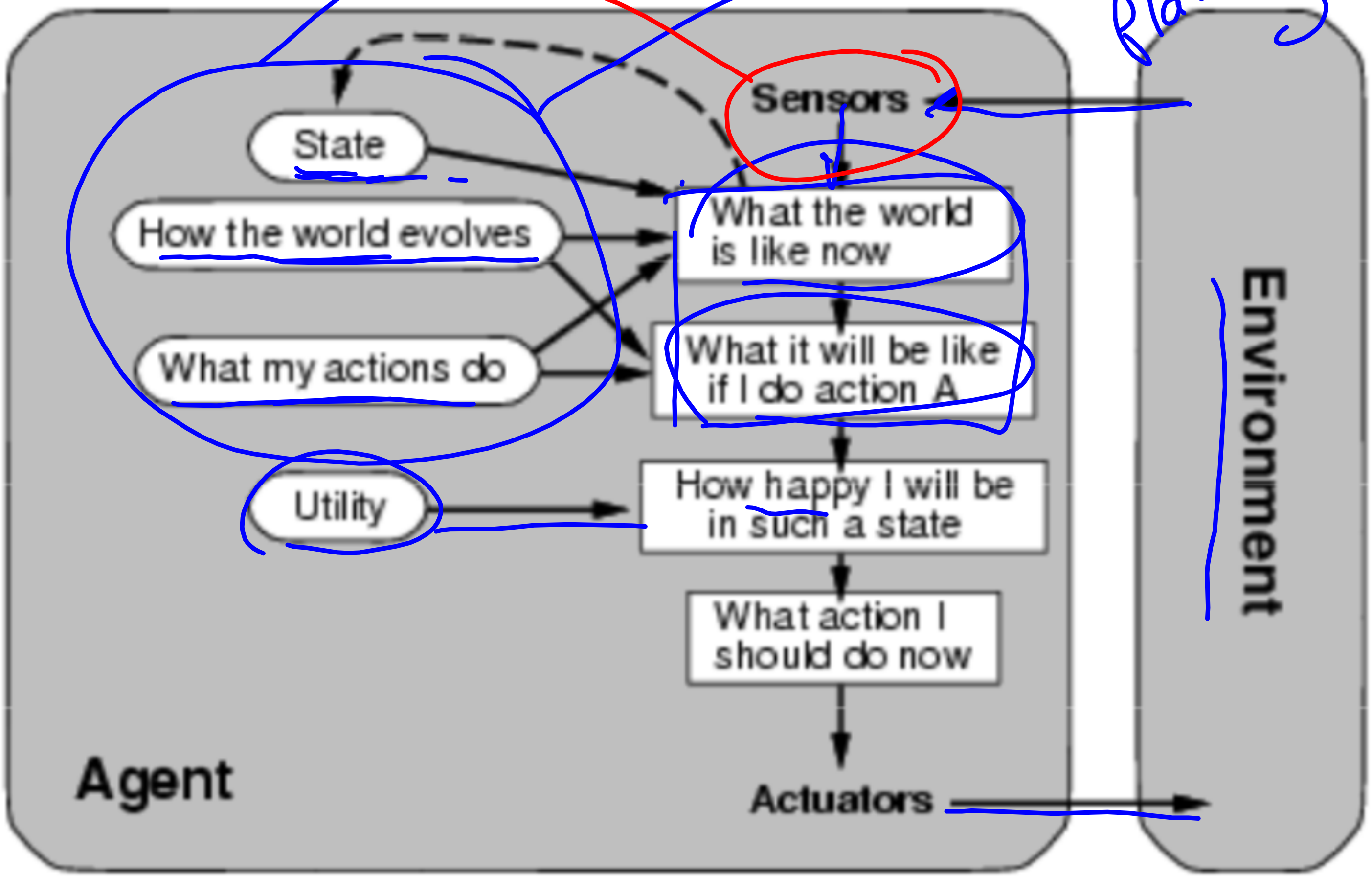
An Agent

Encoding
Translation

state update

Rules of the world

Consequences
planning



The Goal

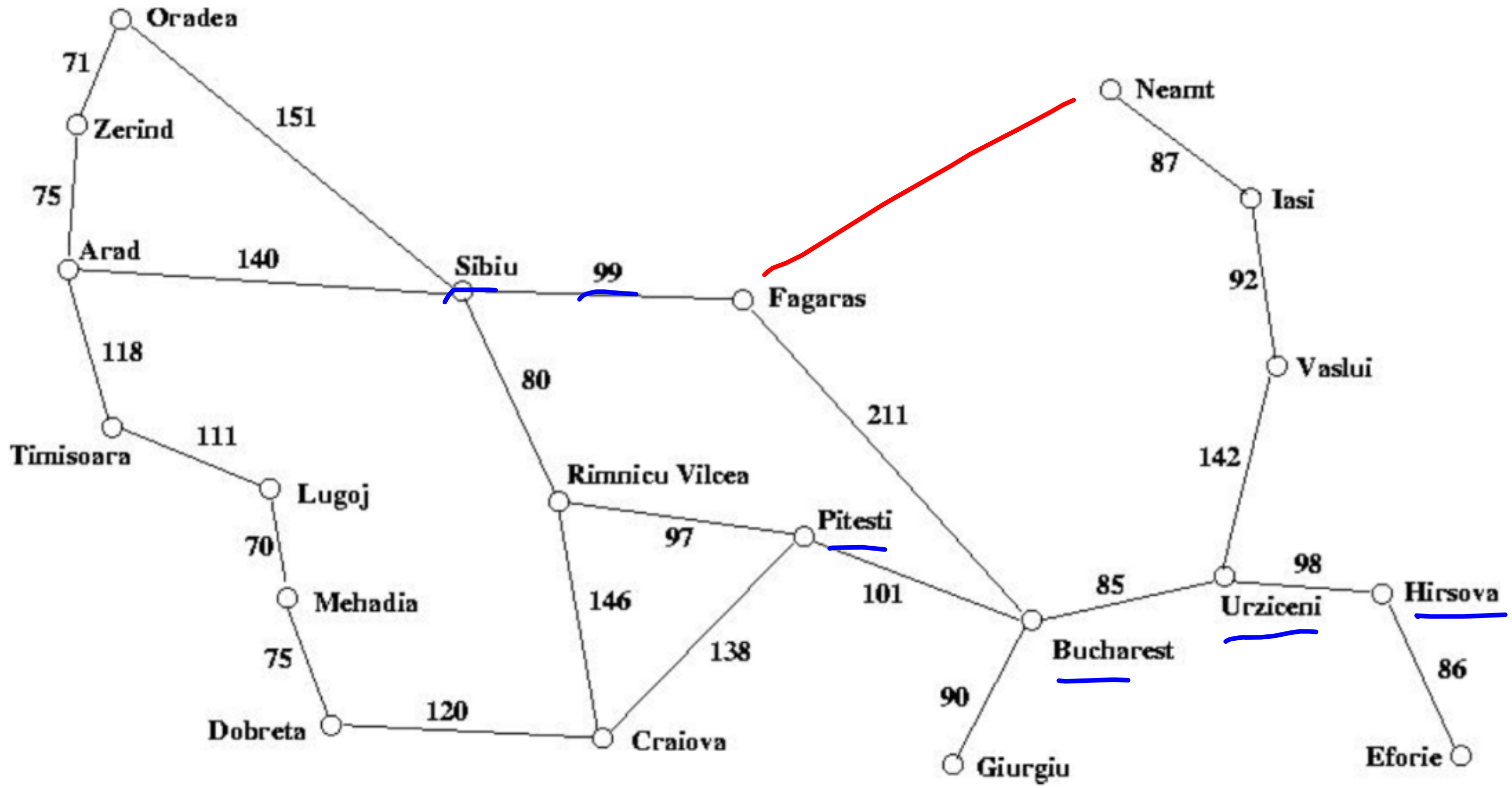
Standard Algorithms

- Domain-General *Reasoning*,
- Applied to Domain-Specific *Knowledge* - problem implementation.
- (In a Domain-General *Representation*)

Standard lang

Data structures

Implicit

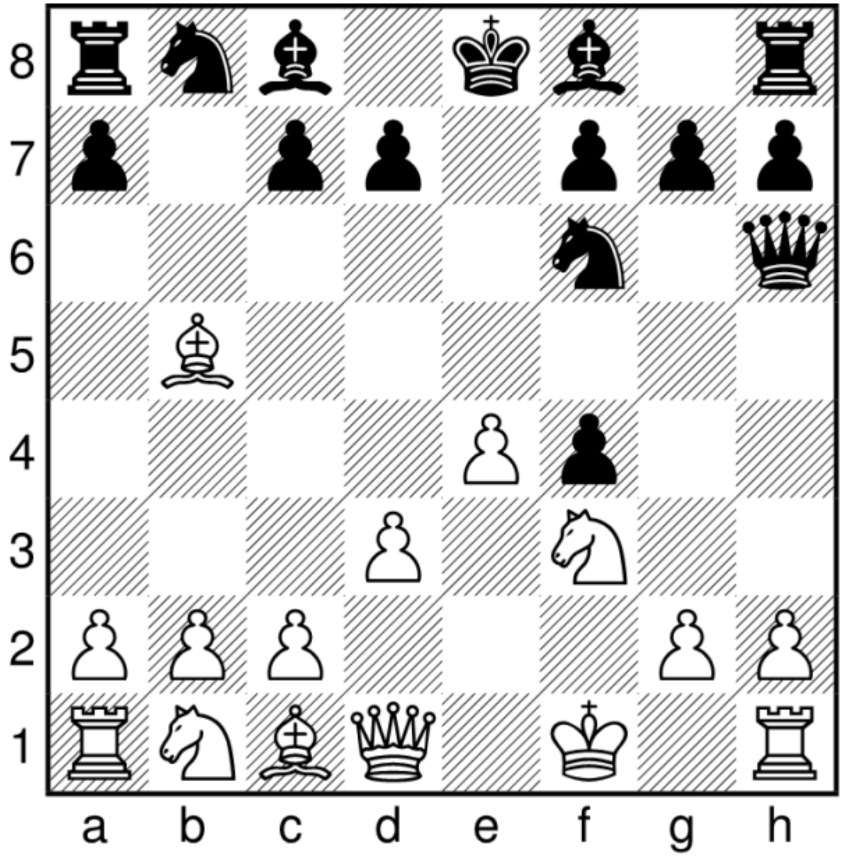

Oradea
71
Zerind
151
75
Arad
140
Sibiu
99
Fagaras
118
80
Timisoara
111
Lugoj
Rimnicu Vilcea
211
Neamt
87
Iasi
92
Vaslui
142
70
Mehadia
97
Pitesti
146
101
138
75
Dobreta
120
Craiova
85
Bucharest
90
Giurgiu
Urziceni
98
Hirsova
86
Eforie

~~Implicit~~ Explicit

```
road(oradea,     zerind,     71).
road(zerind,     arad,       75).

city(arad,       46.16667, 21.3).
city(bucharest, 44.41667, 26.1).

twoWayRoad(City1, City2, Distance):-
        road(City1, City2, Distance).
twoWayRoad(City1, City2, Distance):-
        road(City2, City1, Distance).

move(City1, City2):- twoWayRoad(City1, City2, _).

move(City1, City2, Distance):-
        twoWayRoad(City1, City2, Distance).
```

Prolog

Chess Examples



1. C3.is clear
2. B3.is clear
3. A3.is clear
4. WKn1 in b1
5. Can move WKn1 to C3
6. ¬ can move WQ to C3

Types of Reasoning

- Knowledge Representations:
  - Logic: propositional, predicate, temporal, fuzzy, probabilistic, etc. etc.
  - Networks of all kinds, including so-called Semantic Networks
  - Frames
  - Semantic Web: RDF, OWL, XML, etc.
  - English, Swahili, Urdu, etc. (for humans).
- Reasoning:
  - Logical inference
  - Temporal reasoning
  - Graph/subgraph matching
  - Analogical reasoning
  - Probabilistic inference

Assessment Criteria

- Assessment Criteria
  - **Representational Adequacy**: the ability to represent *sufficient* kinds of knowledge in the domain.
  - **Acquisitional Efficiency**: the ability to *easily* and *quickly* represent new knowledge in the formalism.
- Reasoning Methods
  - **Inferential Adequacy**: the ability to manipulate representational structures to derive sufficient new ones
  - **Inferential Efficiency**: the ability to derive new representational structures quickly

KB-Based Agent: Schema

```python
class KB_Agent:
    Knowledge_Base = {...}
    Curr_Time          = 0

    def get_action(Percept):
        Percept_Seq = make_percept_sequence(
            Percept, self.Curr_time)
        tell(self.Knowledge_Base, Percept_Seq)
        Query = make_action_query(self.Curr_Time)
        Act = ask(self.Knowledge_Base, Query)
        Act_Seq = make_action_sequence(
            Act, self.Curr_Time)
        tell(self.Knowledge_Base, Act_Seq)
        self.Curr_Time += 1
        return Act
```

DB Interface

Encoding/Decoding

Expert Systems

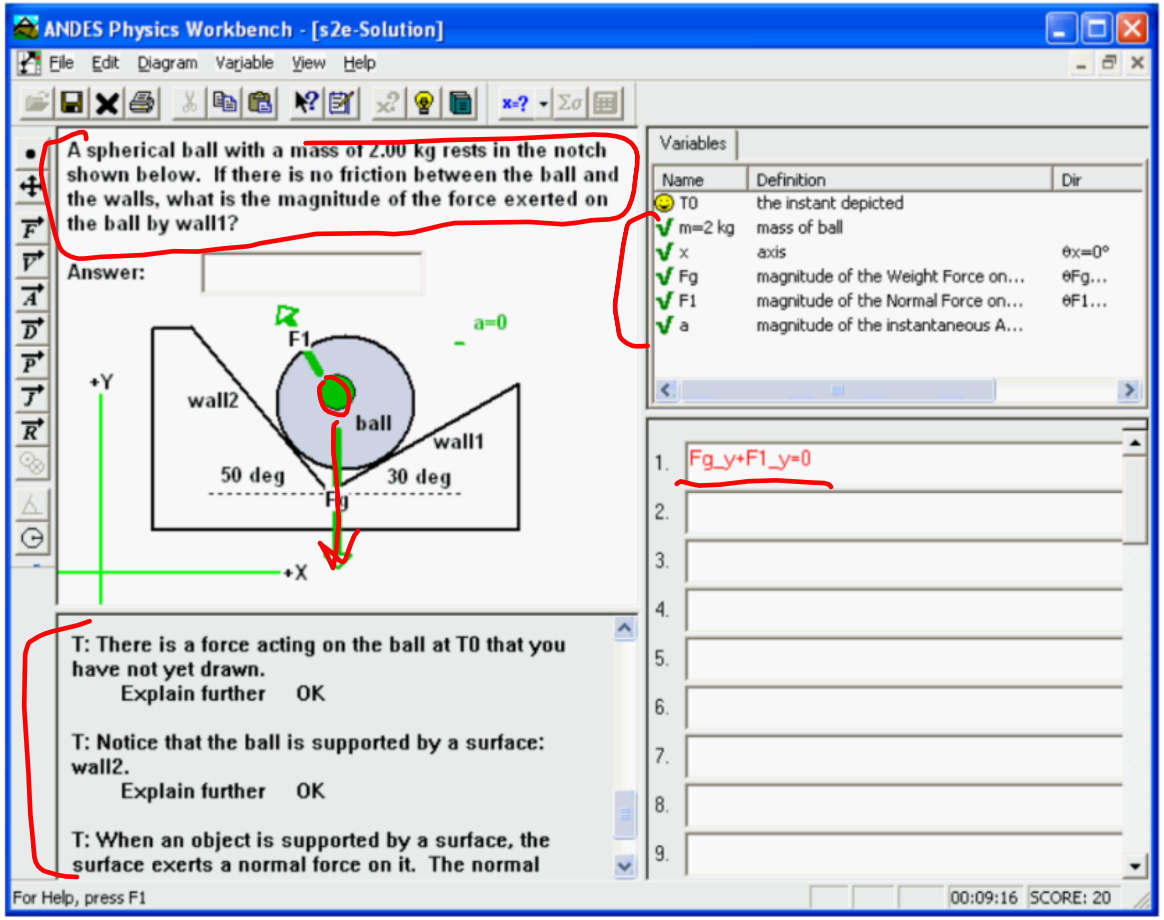


Image Credit: ubiquity.acm.org

Core Concepts

The basics

- *Statements* Individual facts, percepts, or information.
- *Knowledge* The *integration* of those statements to support reasoning.
- *Inference* The *induction* of new knowledge or *decisionmaking*.

Andes

ITB UI

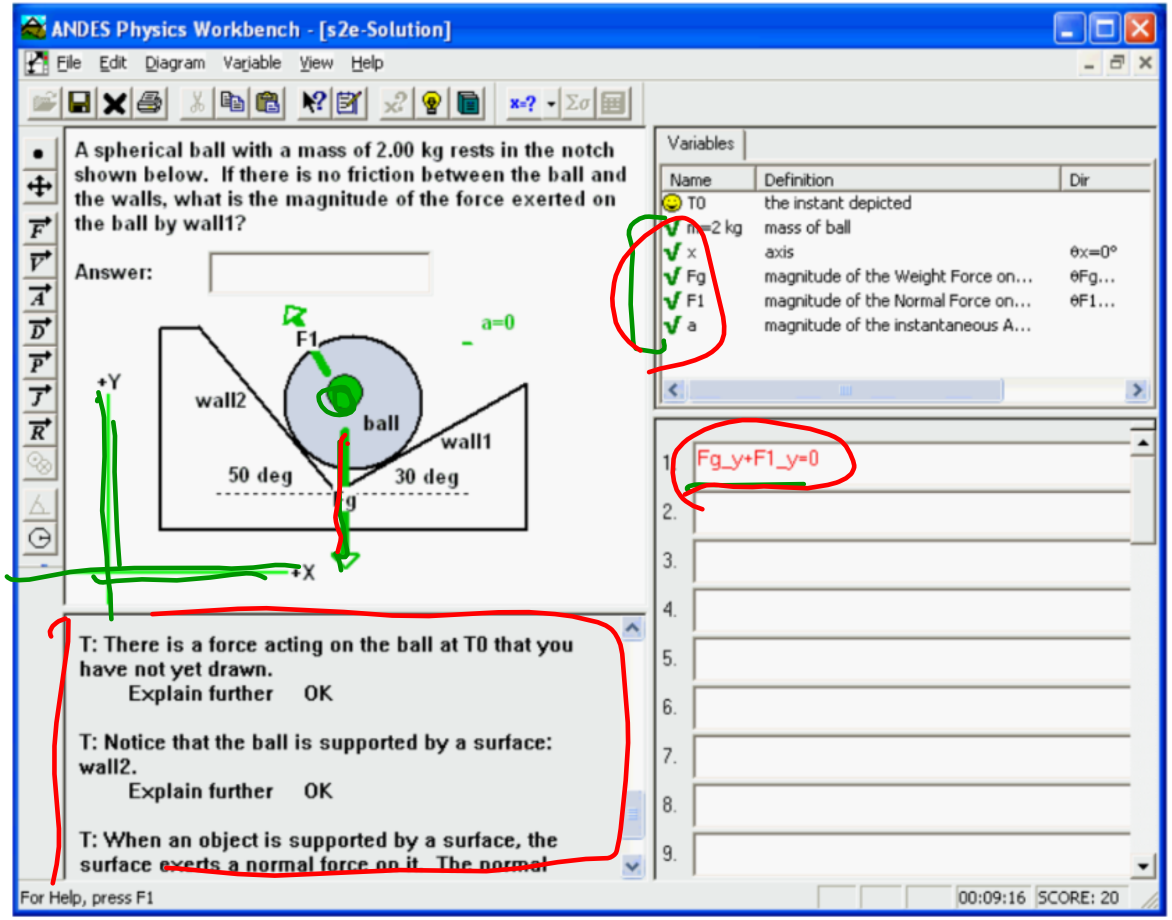


Image Credit: ubiquity.acm.org

Problem

A spherical ball with a mass of 2.00 kg rests in the notch shown below. If there is no friction between the ball and the walls, what is the magnitude of the force exerted on the ball by wall1?

KB

- (DRAW-AXES 40)
- (EQN (= |Yc_Fn_BALL_WALL2_1_40| 0))
- (IMPLICIT-EQN (= |OFn_BALL_WALL2_1| (DNUM 40 |deg|)))
- (VECTOR (FORCE BALL WALL2 NORMAL :TIME 1) (DNUM 40 |deg|))
- (DEFINE-VAR (MASS BALL))
- (EQN (= |Yc_Fw_BALL_EARTH_1_40| (* |Fw_BALL_EARTH_1| (SIN (- (DNUM 270 |deg|) (DNUM 40 |deg|))))))

The basics

- **Sentences** (*statements*) in the knowledge base.
- **Syntax**: rules for well formed sentences.
- **Semantics**: rules for the meaning of the sentence or *truth in each possible world*.
- Sentences must be true *XOR* false in each possible world.
- **Model**: A fixed assignment of values to all possible sentences (possible world).
- A sentence S **satisfies** a model if it is true in it.
- M **is a model of S** if S satisfies it.

Propositional Logic

Basic Elements

- Set P of *propositional symbols*: *p*, *q*, *r*, etc.
- Two *truth values*: true, false
- *Logical Symbols*: $\neg$, $\wedge$, $\vee$, $\Rightarrow$, $\Leftrightarrow$, $\square$
- *Punctuation*: ( ), [ ], { }.

if (IsRunning $\wedge$ Not Empty): continue

Propositions

- A symbol: a
- a negated proposition: $\neg P$
- Conjunction or Disjunction: $(P_1 \wedge P_2)$ $(P_1 \vee P_2)$
- An implication: $P_1 \Rightarrow P_2$ $\neg P_1 \vee P_2$
- A logical equivalence: $P_1 \Leftrightarrow P_2$. $(P_1 \rightarrow P_2) \wedge (P_2 \rightarrow P_1)$
- Note: Implication is not causation!

Semantics

- An *interpretation* is a specification of values (t—f) for all symbols:

$$m_i = \{s_0 = t, s_1 = f, \ldots\} \quad (1)$$

- Sentence values are constructed *recursively* from symbols up.

$(a \vee (\neg b \wedge c) \vee d)$

- Or stored in truth-tables.
- A model for a proposition (p) is an interpretation in which p is true.
- A proposition p is *valid* if for any interpretation I, $I \models p$ i.e., every interpretation is a model.

Model Checking

KB ⊕ p

- p is *satisfiable* if ∃ an I s.t. $I \models p$.
- p is *unsatisfiable* no valid model can be found.

logical consistency

- Theorem proving can be handled via DFS or rule algorithms.
- What is wrong with that?

Complex

Theorem Proving

- *Logical Equivalence* $a \equiv b$ iff $(a \models b) \wedge (b \models a)$.
- *Valid* (Tautology) $\forall m : m \models p$
- *Deduction Theorem*: $(a \models b)$ iff $(a \rightarrow b)$.
- Thus: $(a \models b)$ iff $(a \wedge \neg b)$ is unsatisfiable.

Resolution

- Convert all Knowledge to CNF $((a \vee b \vee \ldots) \wedge (c \vee \ldots) \wedge \ldots)$
- *Resolve* conflicting clauses to yield new information

$$\frac{(a \vee b \vee \neg c) \wedge (f \vee c \vee \neg q)}{(a \vee b \vee f \vee \neg q)}$$

$(\neg c) \wedge (c)$

- This process is sound and complete.

Definite & Horn Clauses

- Resolution is powerful but unnecessary with *Horn Clauses*
- At most one variable is positive: $(x \vee \neg y \vee \ldots)$
- These can be handled with implications $(p \wedge q) \rightarrow r$
- Can do Forward-chaining *data-driven* reasoning.
- And backward-chaining *goal-directed* reasoning.

Example: Chemistry

$$
\begin{aligned}
MgO + H2 &\rightarrow Mg + H2O && (2)\\
C + O2 &\rightarrow CO2 && (3)\\
CO2 + H2O &\rightarrow H2CO3 && (4)\\
& && (5)
\end{aligned}
$$

Assuming sufficient quantities of MgO, H2, C, and O2, prove that we can synthesize H2CO3.

Example: Chemistry (Propositional)

$$MgO \wedge H2 \Rightarrow Mg \wedge H2O \quad (6)$$
$$C \wedge O2 \Rightarrow CO2 \quad (7)$$
$$CO2 \wedge H2O \Rightarrow H2CO3 \quad (8)$$
$$MgO \quad (9)$$
$$H2 \quad (10)$$
$$C \quad (11)$$
$$O2 \quad (12)$$
$$\texttt{Conclusion} \quad H2CO3 \quad (13)$$

?

Example: Chemistry (CNF)

1. $\neg MgO \vee \neg H2 \vee Mg$
2. $\neg MgO \vee \neg H2 \vee H2O$
3. $\neg C \vee \neg O2 \vee CO2$
4. $\neg CO2 \vee \neg H2O \vee H2CO3$
5. MgO
6. $H2$
7. C
8. $O2$
9. $\neg H2CO3$ `Negated conclusion`

CNF

$(a \wedge \neg a)$ $\square$

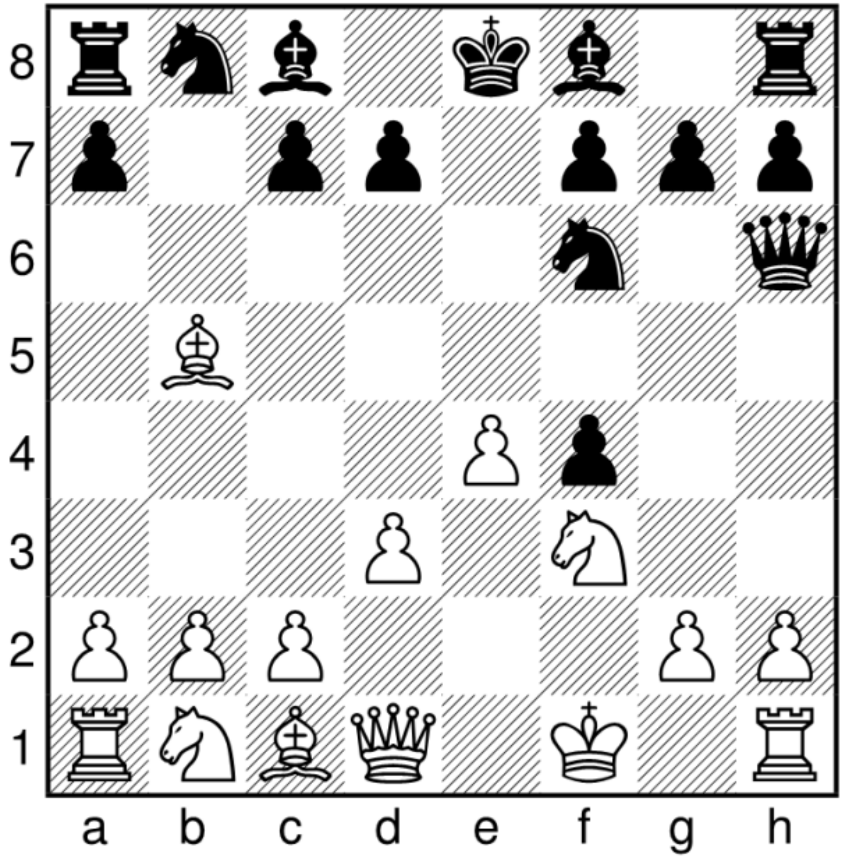
Law of the Excluded middle

Example: Chemistry (CNF)

10.	$\neg CO2 \vee \neg H2O$	$4 + 9$
11.	$\neg C \vee \neg O2 \vee \neg H2O$	$3 + 10$
12.	$\neg O2 \vee \neg H2O$	$7 + 11$
13.	$\neg H2O$	$8 + 12$
14.	$\neg MgO \vee \neg H2$	$2 + 13$
15.	$\neg H2$	$5 + 14$
16.	$\square$	$6 + 15$

Planning & Frames

We can even use this to do planning (sort of)



1. $clear^{t1}_{C3}$
2. $clear^{t1}_{B3}$
3. $clear^{t1}_{A3}$
4. $WKn1^{t1}_{b1}$
5. $Move_{Wkn1\,toc3} \Leftrightarrow (WKn1^{t1}_{b1} \wedge clear^{t1}_{C3})$

Debugging

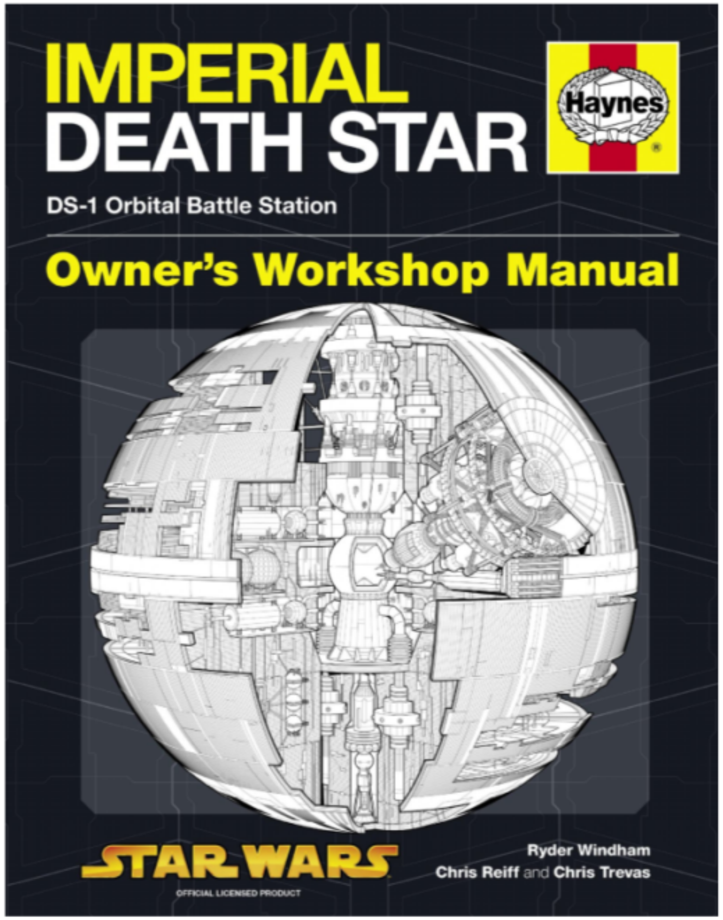
Real Problem: Sherlock

Digital Twin

logical model
Engine
Facing
codebase.

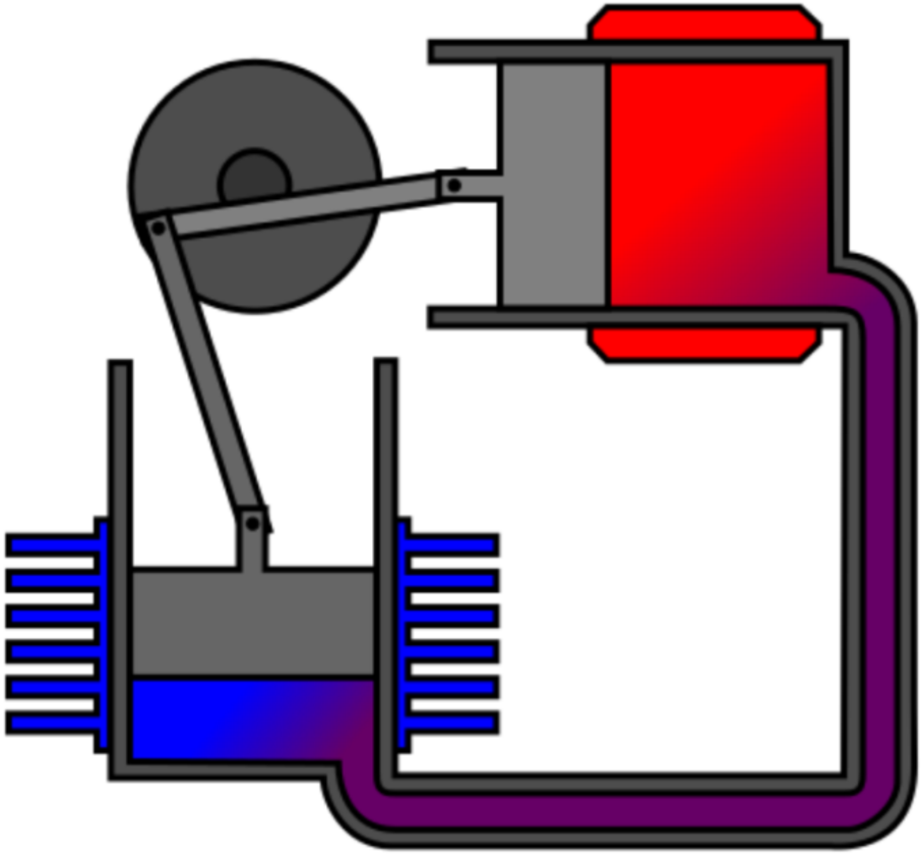
- The Sherlock system: Lesgold & Katz et al.
- Teaches basic diagnostic skills through modeling.
- Uses a logical model of student and system.
- Saved $>500k in one instance.

Service Debugging



Source: http://www.fine1steditions.co.uk

Basic Piston engine.



Source: https://en.wikipedia.org/wiki/File:Alpha_Stirling_frame_12.svg