

# **The Formal Representation of Scientific Knowledge with Prolog**

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# Overview

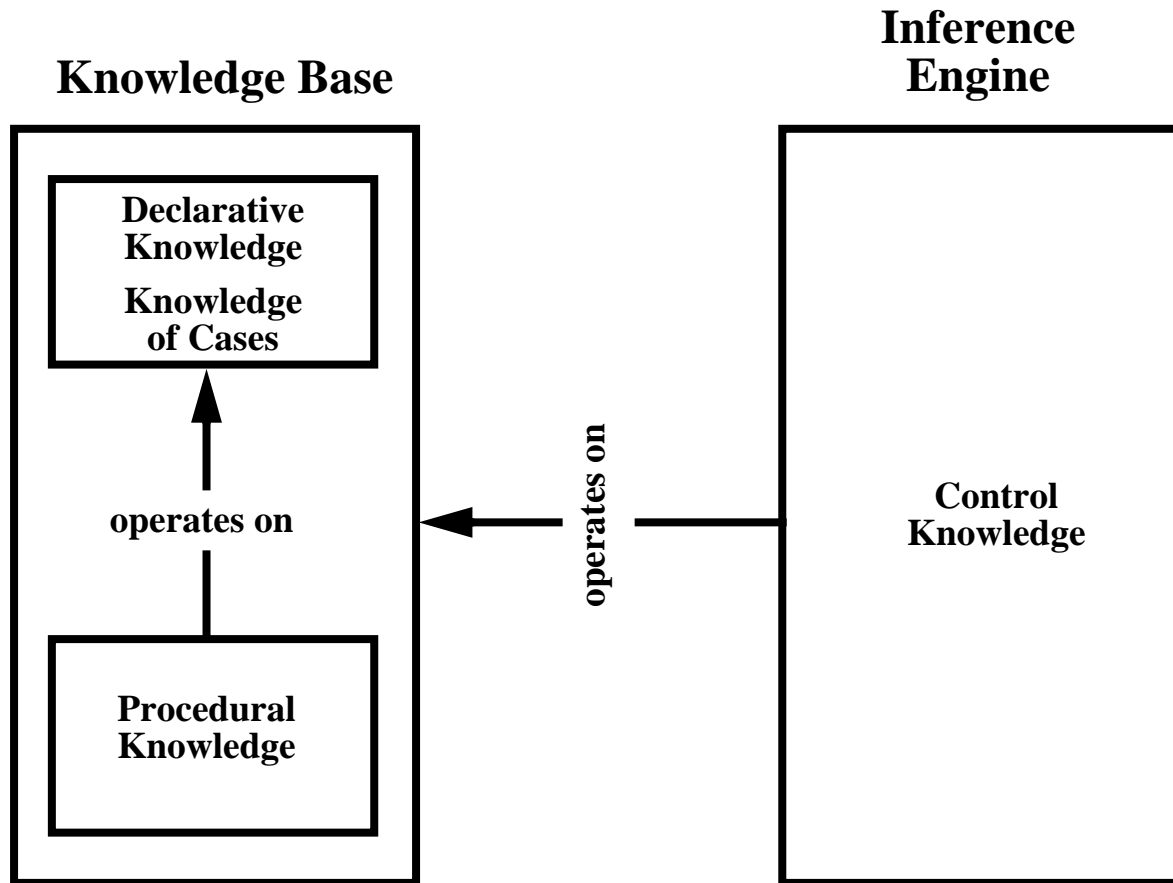
- 1. Theoretical foundations of knowledge-based systems**
- 2. Design of knowledge-based systems**
- 3. Knowledge representation formats**
- 4. Representing knowledge with Prolog**
- 5. An example: A model of knowledge about qualitative and quantitative aspects of classical mechanics**
- 6. Some problems of logic-based knowledge representation formats**

# 1. Theoretical Foundations of Knowledge-Based Systems

- **The physical symbol system hypothesis (Newell, 1980)**
- **The knowledge representation hypothesis (Smith, 1982)**

## 2. Design of Knowledge-Based Systems

### Architecture



# Types of Models

- **Theoretical scope:**
  - **Competence models**
  - **Performance models**
  
- **Empirical scope:**
  - **General models**
  - **Prototypical models**
  - **Individualized models**
  - **Idiosyncratic models**

# 3. Knowledge Representation Formats

## Analogical Knowledge

- Representation of mental images

**Basic relations:**

**spatial relations**

**Basic processes:**

**scanning, zooming, rotating**

**Example:**

**Mental image of a block resting on an  
inclined plane**

# Propositional Knowledge

- **Representation of factual knowledge about abstract concepts as well as specific instances and their properties**
- **Examples:**
  - **Semantic networks: Abstraction hierarchies**

## **Basic relations:**

**superclass-subclass-relation,**

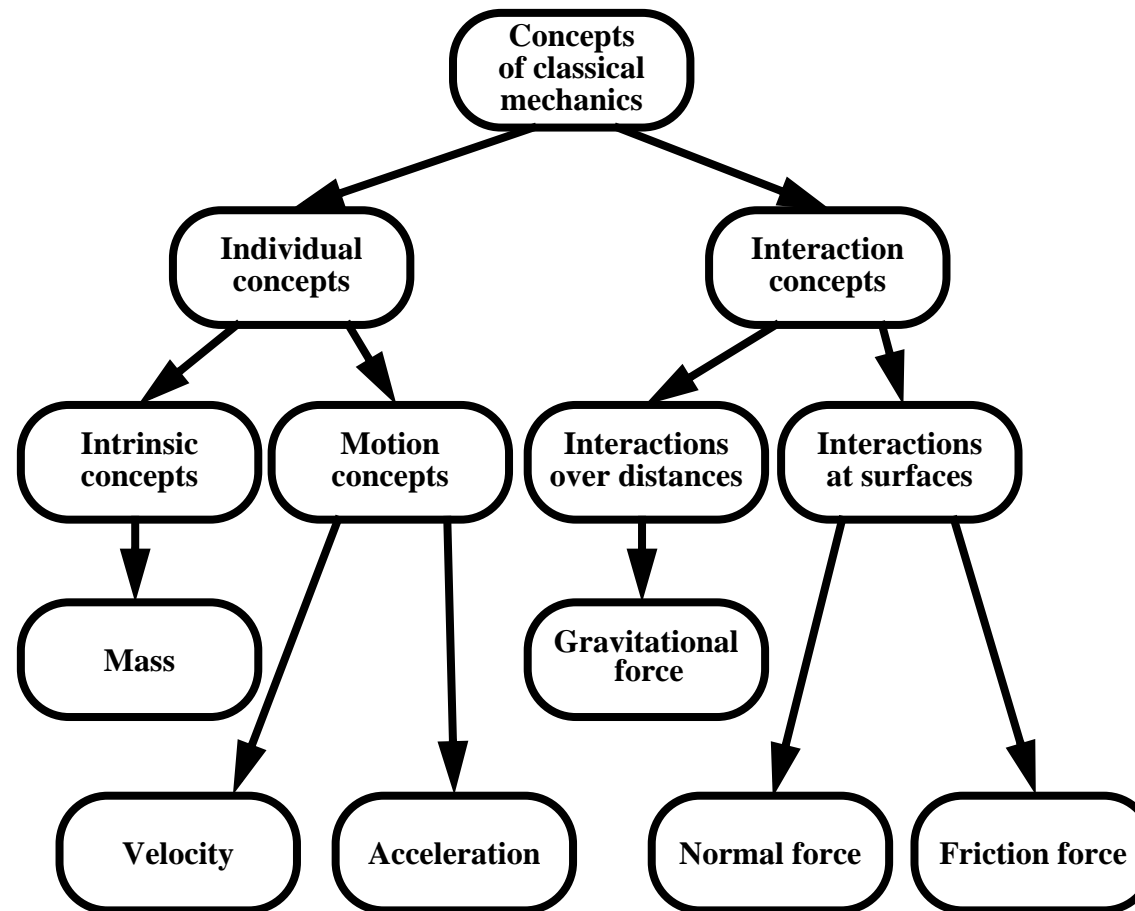
**instance-relation**

## **Basic processes:**

**inheritance, spread of activation**

## Example:

### Hierarchy of concepts in classical mechanics



- **Frames: Structured descriptions of abstract concepts as well as specific instances and their properties**

**Basic relations:**

**superclass-subclass-relation,**

**part-whole-relation, instance-relation**

**Basic processes:**

**inheritance, procedural demons**

**Example:**

**Structured description of the concept  
weight**

**(weight (subclass of (value, gravitational force))  
(variable (value,  $F_G$ ))  
(source (value, earth))  
(recipient (value, body of mass  $m$ ))  
(direction (value, towards the center of the earth))  
(magnitude (if needed,  $F_G = m g$ )))**

- **Scripts: Hierarchies of abstracted sequences of events**

**Basic relations:**

**superclass-subclass-relation,**

**part-whole-relation,**

**predecessor-/successor-relation**

**Basic processes:**

**inheritance, temporal reasoning**

# Rule-Based Knowledge

- **Representation of operational knowledge and control knowledge**

**Basic relations:**

**if-then-rules**

**Basic processes:**

**selection of rules,**

**application of rules**

**Example:**

**Describing the conditions under which a  
normal force acts on body**

**If**

**there is a body and  
there acts a gravitational force on the body  
due to the earth and  
the body rests or moves on a surface**

**then**

**there acts a normal force on the body  
due to the surface**

# Knowledge of Cases

- **Representation of specific situations or events**

**Basic relations:**

**similarity relation**

**Basic processes:**

**selection of cases,**

**adaptation of cases,**

**mapping of cases to new problems**

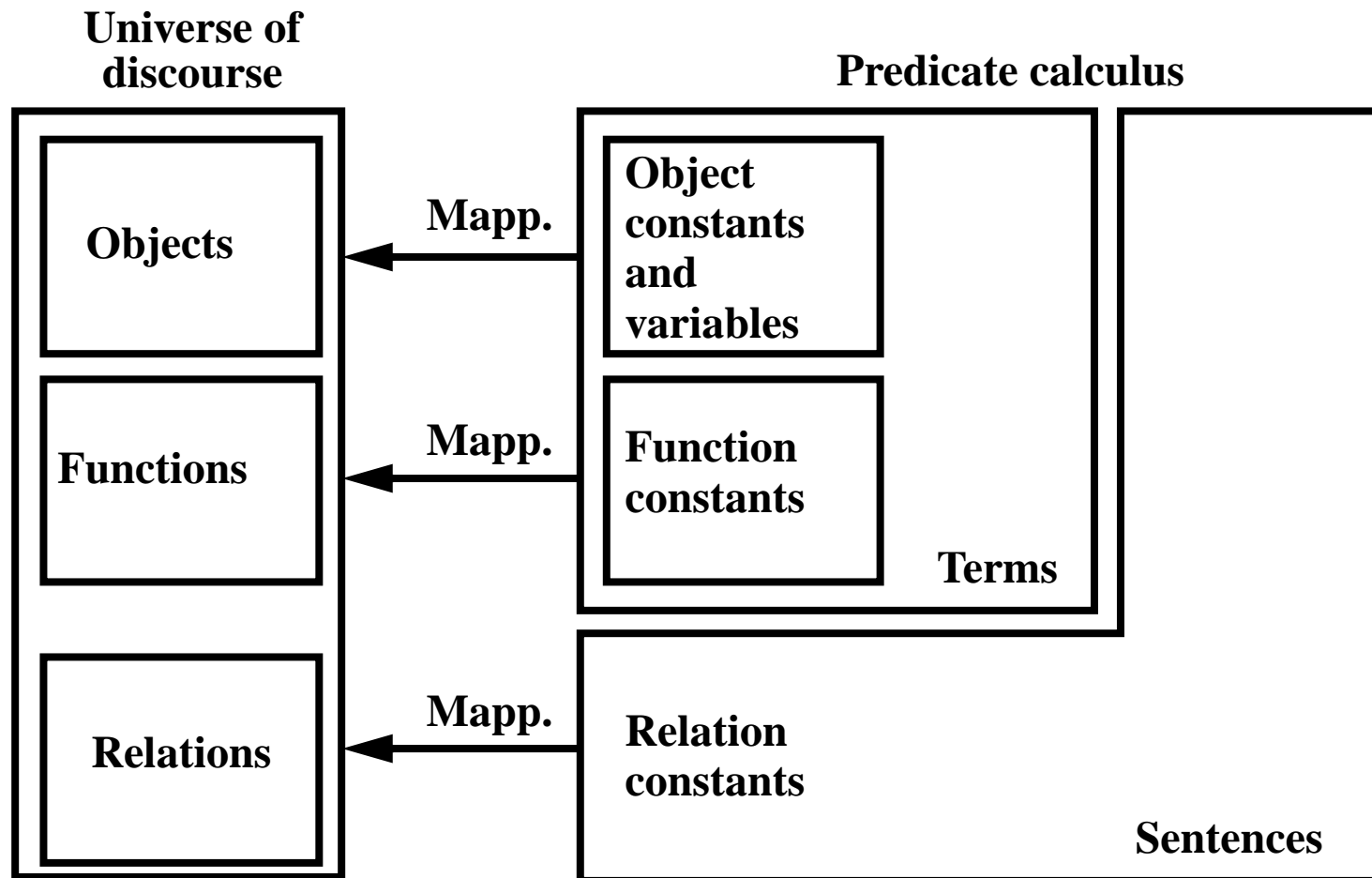
**Example:**

**A specific solution to a problem**

**in classical mechanics**

## 4. Representing Knowledge with Prolog

- Logical foundations: First-order predicate calculus



○ **Prolog = Logic + Control**

- **Logic: Horn Clauses**

**Clauses: Disjunction of literals**

$$\mathbf{A \vee \neg B \vee C \vee D}$$

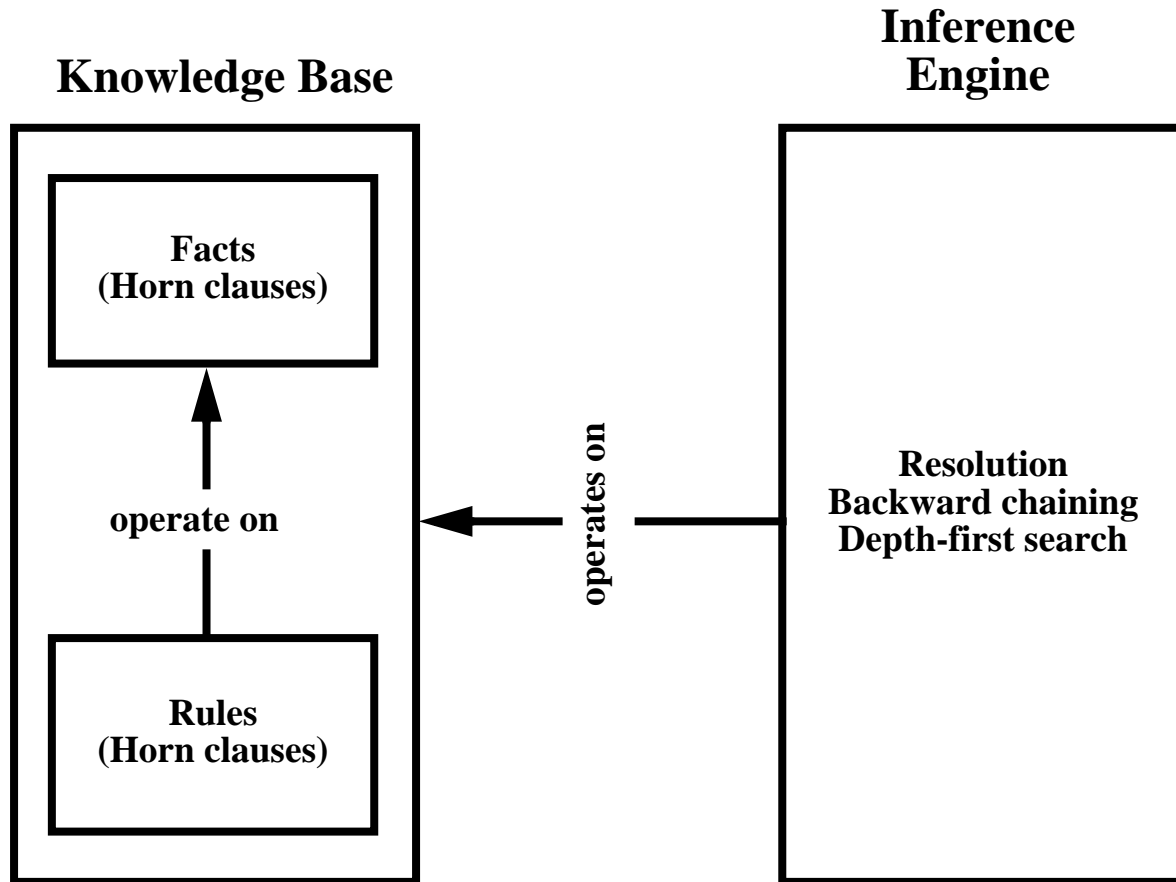
**Horn Clauses: Clauses with at most one positive literal**

$$\mathbf{A \vee \neg B \vee \neg C \vee \neg D}$$

$$\mathbf{A \Leftarrow B \wedge C \wedge D}$$

- **Control: Resolution + Backward chaining,  
depth-first search**

○ **The Prolog-system as a knowledge-based system**



## **5. An Example: A Model of Knowledge About Qualitative and Quantitative Aspects of Classical Mechanics**

### **Modeling Goal**

- **Reconstruction of characteristic differences in the problem solving behavior of novice and advanced problem solvers in classical mechanics**

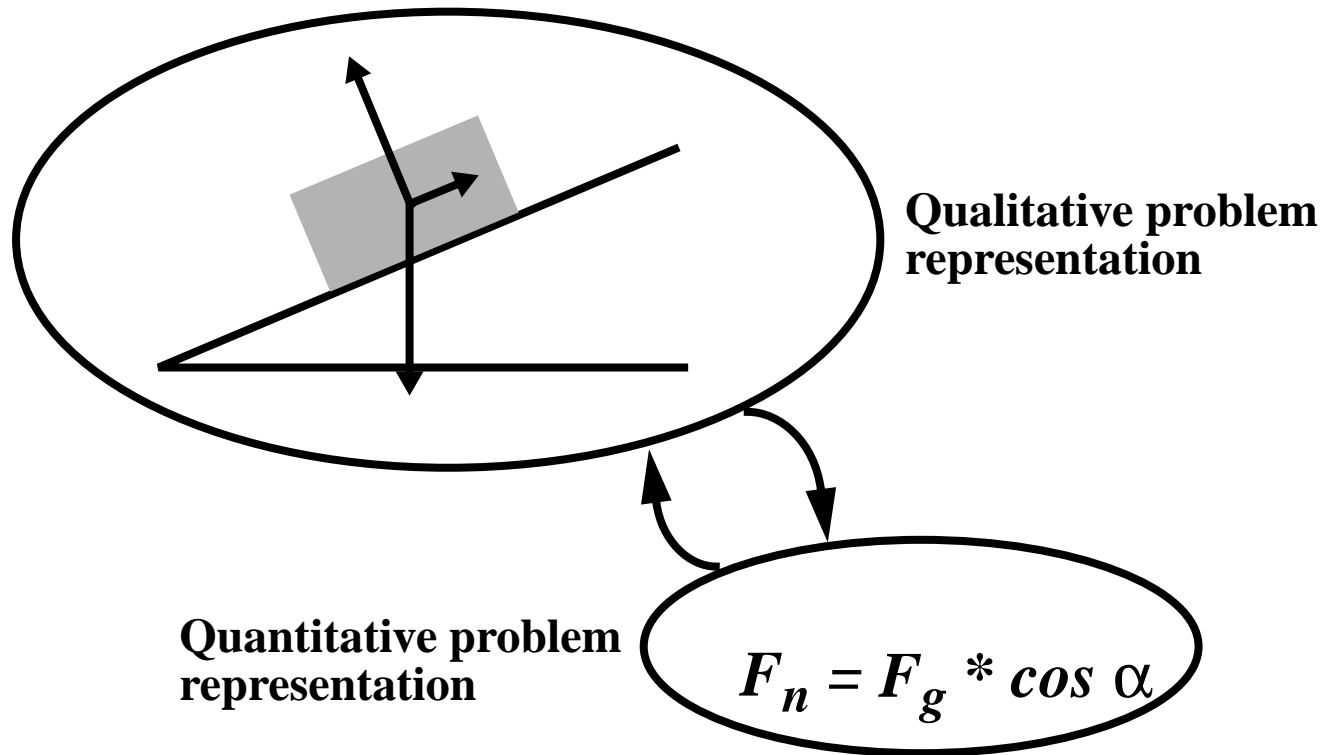
# Application Domain

- **Standard textbook physics problems which address one-dimensional motion with constant acceleration**
- **Example:**

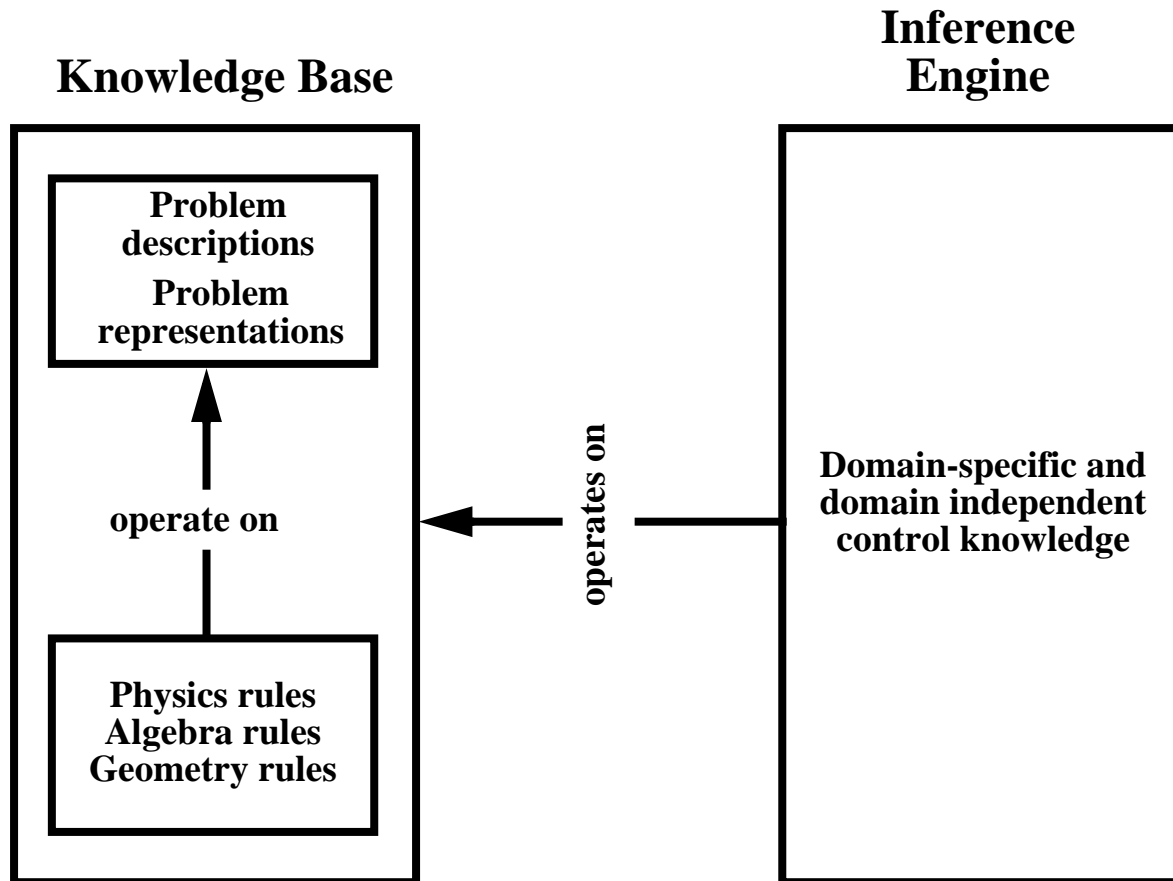
**What is the minimum stopping distance for a car of mass  $m = 820$  kg travelling along a flat horizontal road with the velocity  $v = 12$  m/s, if the coefficient of friction  $f$  between tires and road equals 0.8?**

# Conceptual Idea

- Problem solving as the construction, application and coordination of qualitative and quantitative problem representations



# Architecture



# Knowledge Representation

- **Basic modeling component: Equations**

**value(Situation, Parameter) = Value**

- **Knowledge about qualitative aspects of the normal force:**

**if**

**value(S, instance( $O_1$ , body)) = true and**

**not(value(S, massless( $O_1$ )) = true) and**

**value(S, instance( $O_2$ , plane)) = true and**

**value(S, on( $O_1$ ,  $O_2$ )) = true**

**then**

**value(S, instance(force( $O_1$ ,  $O_2$ , fn), normal\_force)) = true.**

**if**

**value(S, instance(force( $O_1$ ,  $O_2$ , fn), normal\_force)) = true and**

**value(S, instance( $O_2$ , plane)) = true**

**then**

**value(S, inclination(force( $O_1$ ,  $O_2$ , fn))) =**

**perpendicular(value(S, inclination( $O_2$ ))).**

**if**

**value(S, instance(force( $O_1$ ,  $O_2$ , fn), normal\_force)) = true and**

**value(S, instance( $O_2$ , plane)) = true**

**then**

**value(S, sense(force( $O_1$ ,  $O_2$ , fn))) =**

**value(S, relative\_position( $O_1$ ,  $O_2$ )).**

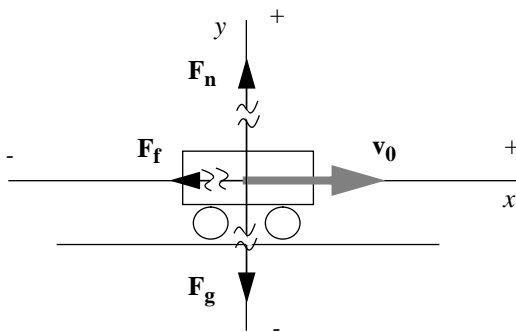
- **Knowledge about quantitative aspects of the normal force:**

$$\begin{aligned} & \text{value}(S, \text{magnitude}(\text{force}(O_1, O_2, \text{fn}))) = \\ & \text{value}(S, \text{magnitude}(\text{force}(O_1, \text{earth}, \text{fg}))) * \\ & \cos(\text{value}(S, \text{inclination}(O_2))). \end{aligned}$$

# Performance

## Qualitative reasoning:

the object whose motion has to be analyzed is the car  
 the forces on the car are  $\mathbf{F}_g$ ,  $\mathbf{F}_n$  and  $\mathbf{F}_f$



direction of  $\mathbf{F}_f$  is opposite to direction of  $\mathbf{v}_0$   
 magnitude of  $\mathbf{F}_x$  equals negative magnitude of  $\mathbf{F}_f$

## Quantitative reasoning:

$$F_x = -F_f = m * a_x$$

direction of  $\mathbf{F}_g$  is opposite to direction of  $\mathbf{F}_n$   
 magnitude of  $\mathbf{F}_y$  equals difference between  
 magnitude of  $\mathbf{F}_n$  and magnitude of  $\mathbf{F}_g$

$$F_y = F_n - F_g = m * a_y$$

motion with constant acceleration and with initial  
 velocity

$$v^2 = v_0^2 + 2 * a * \Delta r$$

direction of  $\mathbf{a}$  is opposite to direction of  $\mathbf{v}_0$   
 magnitude of final velocity  $\mathbf{v}$  equals zero

$$v = 0 \text{ m/s}$$

magnitude of  $\mathbf{a}_y$  equals zero

$$\begin{aligned} a_y &= 0 \text{ m/s}^2 \\ a_x &= a \\ &= -F_f / m \\ &= -(F_n * f) / m \\ &= -(m * g * \cos \alpha * f) / m \\ &= -g * \cos \alpha * f \end{aligned}$$

$$\Delta r = -v_0^2 / (-2 * g * \cos \alpha * f)$$

## **6. Some Problems of Logic-Based Knowledge**

### **Representation Formats**

- Limits of theoretical and practical computability**
- Correspondence between conceptualization and formalization**
- Closed world assumption**
- Non-monotonic aspects in reasoning**
- Brittleness**
- Uncertainty in reasoning**
- Learning**