DRONACHARYA
College of Engineering

INTELLIGENT SYSTEMS (CSE-303-F)

Section C

Knowledge Representation & Reasoning

AI and KR

- A description of **Artificial Intelligence** is:
  - The study and development of systems that demonstrate intelligent behavior
- Based on the above, a description of **Knowledge Representation & Reasoning** is:
  - The study of ways to represent and reason with information in order to achieve intelligent behavior

KR&R is the part of AI that is concerned with thinking and how thinking contributes to intelligent behavior

What is KR&R?

- There are many ways to approach the topic of intelligence and intelligent behavior
  - *neuroscience*, *psychology*, *evolution*, *philosophy*
- KR suggests an approach to understanding intelligent behavior that is radically different
  - Instead of studying humans very carefully (biology, nervous systems, psychology, sociology, etc.), it argues that what we need to study is ***what humans know***.
  - It is taken as a given that what allows humans to behave intelligently is that they know a lot of things about a lot of things and are able to apply this knowledge as appropriate to adapt to their environment and achieve their goals.

- KR&R focuses on the knowledge, not on the knower. We ask what *any* agent—human, animal, electronic, mechanical—would need to know to behave intelligently, and what sorts of computational mechanisms might allow its knowledge to be manipulated.

Knowledge

- **What is knowledge?** This is a question that has been discussed by philosophers since the ancient times, and it is still not totally clarified.
  - Will not attempt to define it formally…
- Observe that when we say something like "John knows that …," we fill in the blank with a simple
  - "John knows that Mary will come to the party,"
  - "John knows that Spain won the Euro"
- Among other things, **knowledge is a relation between a knower and a *proposition***
  - **knower :** John
  - **proposition:** the idea expressed by a simple declarative sentence, like "Mary will come to the party."
- What can we say about propositions? For KR&R, what matters about propositions is that they are abstract entities that can be *true* or *false*, *right* or *wrong*.
  - When we say, "John knows that *p*," we can just as well say, "John knows that it is true that *p*."

Representation

- Roughly, **representation** is a relationship between two domains, where the first is meant to "stand for" or take the place of the second.
  - Usually, the first domain, the representor, is more concrete, immediate, or accessible in some way than the second.
    - For example, a drawing of a hamburger on a sign might stand for a less immediately visible fast food restaurant;
    - an elected member of parliament might stand for his or her constituency.
  - The type of representor that we will be most concerned with here is the formal *symbol*, that is, a character or group of characters taken from some predetermined alphabet.
    - The digit "7," for example, stands for the number 7, as does the group of letters "VII"
  - ***Knowledge representation*, then, is the field of study concerned with using formal symbols to represent a collection of propositions believed by some agent**.

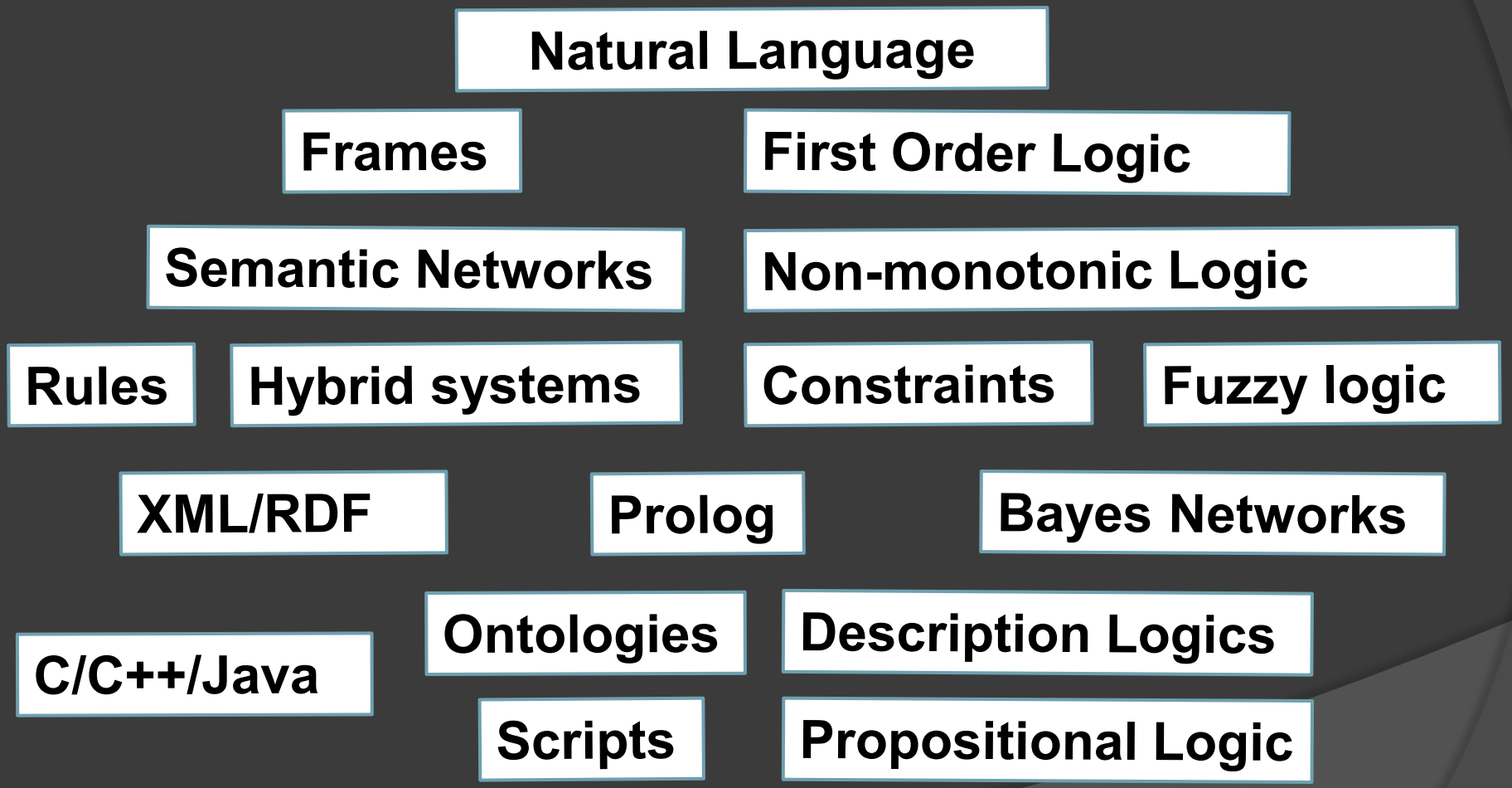
& Reasoning

- What is **reasoning**? In general, it is the formal manipulation of the symbols representing a collection of believed propositions to produce representations of new ones.
  - Here that we use the fact that symbols are more accessible than the propositions they represent: They must be concrete enough that we can manipulate them (move them around, take them apart, copy them, string them together) in such a way as to construct representations of new propositions.
    - We might start with the sentences "*John loves Mary*" and "*Mary is coming to the party*" and after a certain amount of manipulation produce the sentence, "*Someone John loves is coming to the party*"
    - We would call this form of reasoning ***logical inference*** because the final sentence represents a logical conclusion of the propositions represented by the initial ones
- Reasoning is a form of calculation, not unlike arithmetic, but over symbols standing for propositions rather than numbers

How can knowledge be represented ?

- **Symbolic methods**
  - Declarative Languages (Logic)
  - Imperative Languages (C, C++, Java, etc.)
  - Hybrid Languages (Prolog)
  - Rules
  - Frames
  - Semantic Networks
  - …
- **Non – symbolic methods**
  - Neural Networks
  - Genetic Algorithms

Symbolic Methods of Knowledge Representation



What does Knowledge Representation include ?

- Exception Tolerant and Inconsistency-Tolerant Reasoning, Default Logics, Conditional Logics, Paraconsistent Logics, Argumentation
- Temporal Reasoning, Spatial reasoning, Causal Reasoning, Abduction, Explanations, Extrapolation, Model-based diagnosis
- Reasoning about Actions, Situation Calculus, Action Languages, Dynamic Logic
- Reasoning, Planning, and Decision Making under Uncertainty, Probabilistic and Possibilistic approaches, Belief Functions and Imprecise Probabilities
- Representations of Vagueness, Many-valued and Fuzzy Logics,
- Concept Formation, Similarity-based reasoning
- Information Change, Belief Revision, Update
- Information Fusion, Ontologies, Ontology Methodology, and Ontologies themselves
- Qualitative reasoning and decision theory, Preference modelling, Reasoning about preference, reasoning about physical systems

What does Knowledge Representation include ?

- Intelligent agents, negotiation, group decision making, cooperation, interaction, game theory, common knowledge, cognitive robotics
- Algebraic foundations of knowledge representations, graphical representations
- Modal logics and reasoning, belief, preference networks, constraints
- Knowledge representation languages, Description logics, Logic programming, SAT, constraint programming, inductive logic programming, complexity analysis
- Natural language processing, learning, discovering and acquiring knowledge, belief networks, summarization, categorization
- Applications of KR&R, Knowledge-based Scheduling, WWW querying languages, Information retrieval and web mining, Website selection and configuration, Electronic commerce and auctions
- Philosophical foundations and psychological evidence

Types of Knowledge

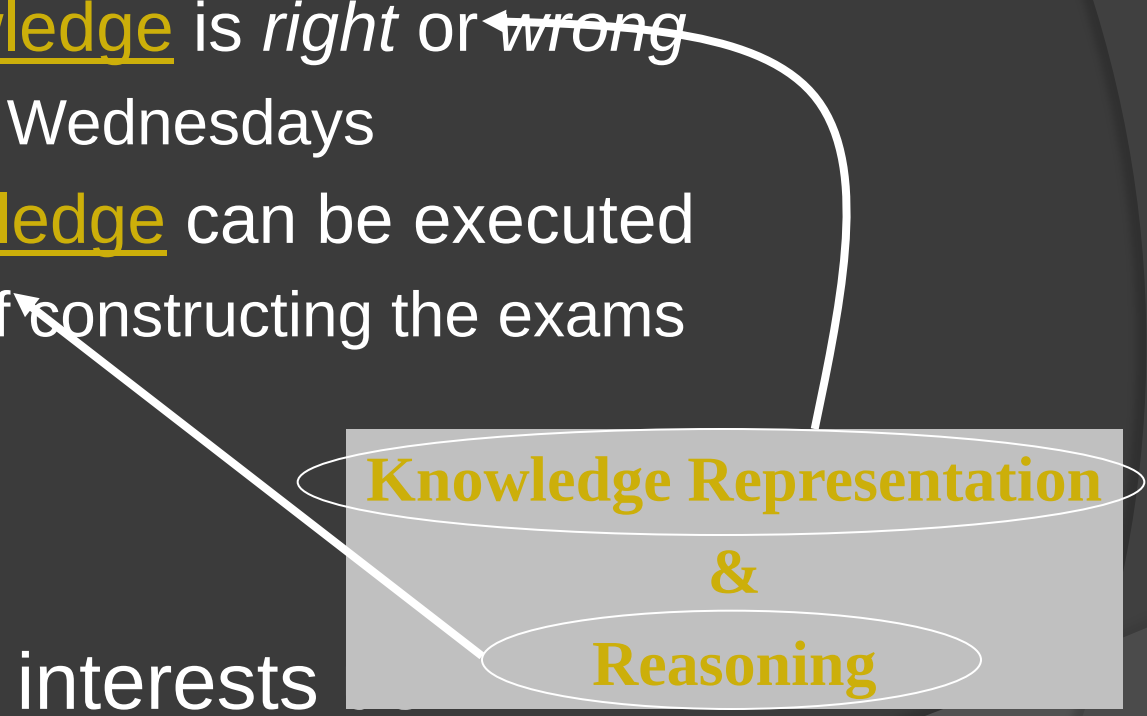
- **Declarative Knowledge**
  - Description of notions, facts, and rules of the world
- E.g.
  - For each lecture there is a specific time and place
  - Only one lecture can take place at each time and place
- Descriptional knowledge, non procedural, independent of targets and problem solving

Types of Knowledge

- **Procedural Knowledge**
  - Description of procedures required to achieve targets
  - Knowledge of the order in which actions must be performed
  - Heuristic knowledge
- E.g.
  - To construct the exams timetable, assign first the classes of the first year
  - To reach Athens faster, take the airplane
- It depends on the targets and problems

Types of Knowledge

- **Basic Difference**
  - declarative knowledge is *right* or ~~*wrong*~~
    - Lectures are on Wednesdays
  - procedural knowledge can be executed
    - the procedure of constructing the exams timetable



- Which of the two interests
  - Both of course

The Language of Propositional Logic

- Before any system aspiring to intelligence can even begin to reason, learn, plan, or explain its behavior, it must be able to formulate the ideas involved.
  - You will not be able to learn something about the world around you, for example, if it is beyond you to even express what that thing is.
- So we need to start with a *language*, in terms of which knowledge can be formulated. We will examine in detail one specific language that can be used for this purpose: the language of ***propositional logic***
  - Propositional logic is not the only choice, of course, but is a simple and convenient one to begin with.
- What does it mean to "have" a language? Once we have a set of words or a set of symbols of some sort, what more is needed? As far as we are concerned, there are two main things:
  - A KR language is defined by its **syntax** and its **semantics**

Syntax of a KR language

- We need to specify which groups of symbols, arranged in what way, are to be considered properly formed.
  - In English, for example, the string of words "*the cat my mother loves*" is a well-formed phrase, but "*the my loves mother cat*" is not.

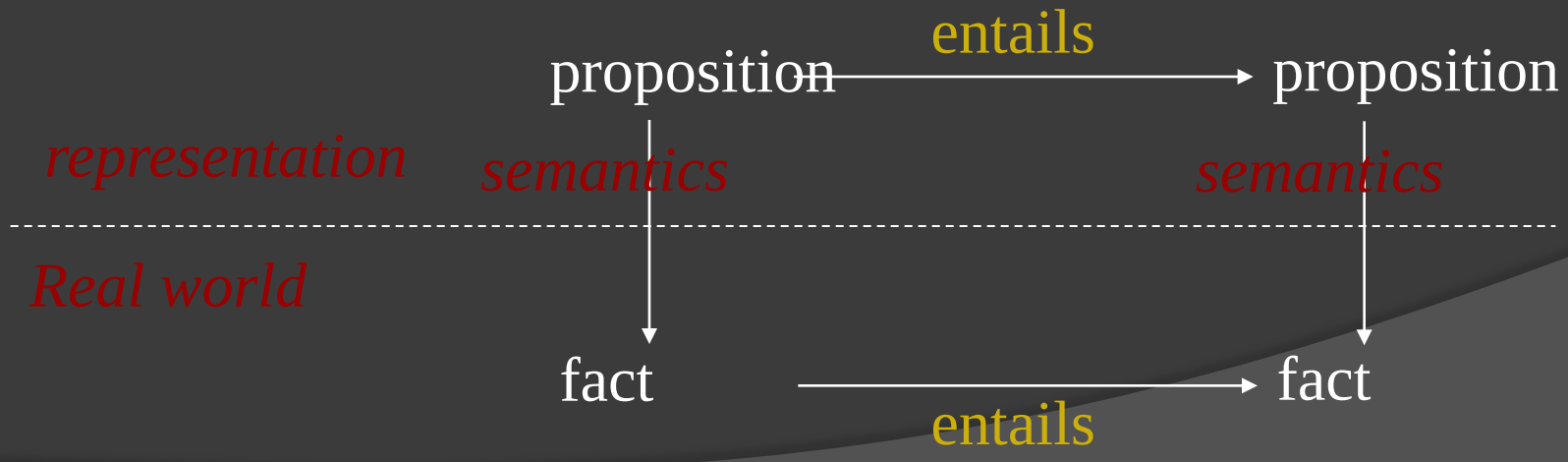
- The **syntax** consists of a set of symbols used by the language and a set of rules according to which the symbols can be combined to form proper sentences

Semantics of a KR language

- We need to specify what the well-formed expressions are supposed to mean.
  - Some well-formed expressions like "*the recently divorced decimal holiday*" might not mean anything. We need to be clear about what idea about the world is being expressed.
- The **semantics** determine a mapping between symbols, combinations of symbols, propositions of the language and concepts of the world to which they refer
- A proposition in a KR language does not mean anything on its own
  - The semantics (i.e. the meaning) of the proposition must be defined by the language author through an **interpretation**

Knowledge Representation Languages

- An expression is **true** under a certain interpretation if the facts of the real world that it represents are valid
- We say that a proposition *α* **is entailed** by a set of propositions s when whenever the set of propositions s is true then *α* is true
  - entailment is usually notated by *s* |= *α*



Desired Features of KR languages

- **Epistemological Level**
  - Clarity
  - Expressiveness
- **Logical Level**
  - Elegant syntax & semantics
  - Decidability / Tractability
  - Sound and complete inference mechanism
- **Implementation Level**
  - Space & Time efficiency
  - Extensibility

Expressiveness vs. Tractability

- Assume you are requested to describe a painting. You can use either of the following languages
  1. The Greek language. I.e. all syntactically and semantically correct statements in Greek
  2. The tiny subset of the Greek language that only includes words "*ωραίος*", "*άσχημος*"
- Your descriptions are:
  1. "*Ο πίνακας αυτός είναι διανθισμένος με εξαίσιες πινελιές χρωμάτων που τονίζουν την ομορφιά του τοπίου που απεικονίζει ο καλλιτέχνης. Από την άλλη εύκολα εντοπίζει κανείς και συγκεκριμένες ατέλειες που κυρίως αφορούν την προοπτική*...."
  2. "*ωραίος*"
- Which description is more accurate/expressive?
- Which description allows you to answer the query "είναι ο πίνακας ωραίος?" faster?

Logic for KR

- Historically logic is the first KR language
  - 1959-1965: First Order Logic is **the** KR language for AI
  - 1965: **Resolution** (*Robinson*) means real hope for universally applicable proof method
    - computational & representational problems
  - 1970s: **Rivals emerge** (semantic networks, rules, frames)
    - unclear semantics & inference
  - 1975: **Logic Programming** (*Kowalski*)
    - decrease expressivity to increase efficiency
    - declarative & procedural knowledge in one language
  - 1980…: **Non-monotonic reasoning** (*McCarthy,Reiter*)
    - common sense knowledge

Advantages of Logic for KR

- Like all declarative languages:
  - compact
  - task-independent
  - modular representation
  - resusable, flexible, maintainable
- Logic has formal well defined semantics
- Logic is expressive
  - incomplete knowledge
  - temporal logics
  - second order logic
  - …

Disadvantages of Logic for KR

- Inefficiency !!!
  - implementation level
- Difficulty in describing procedural knowledge

- Expressivity vs. Tractability
  - the more expressive the less tractable
  - "*Problem solving based on expressive logics is impossible*"

  - Why ?
    - expressiveness

In the worst case !

broader problems => harder problems

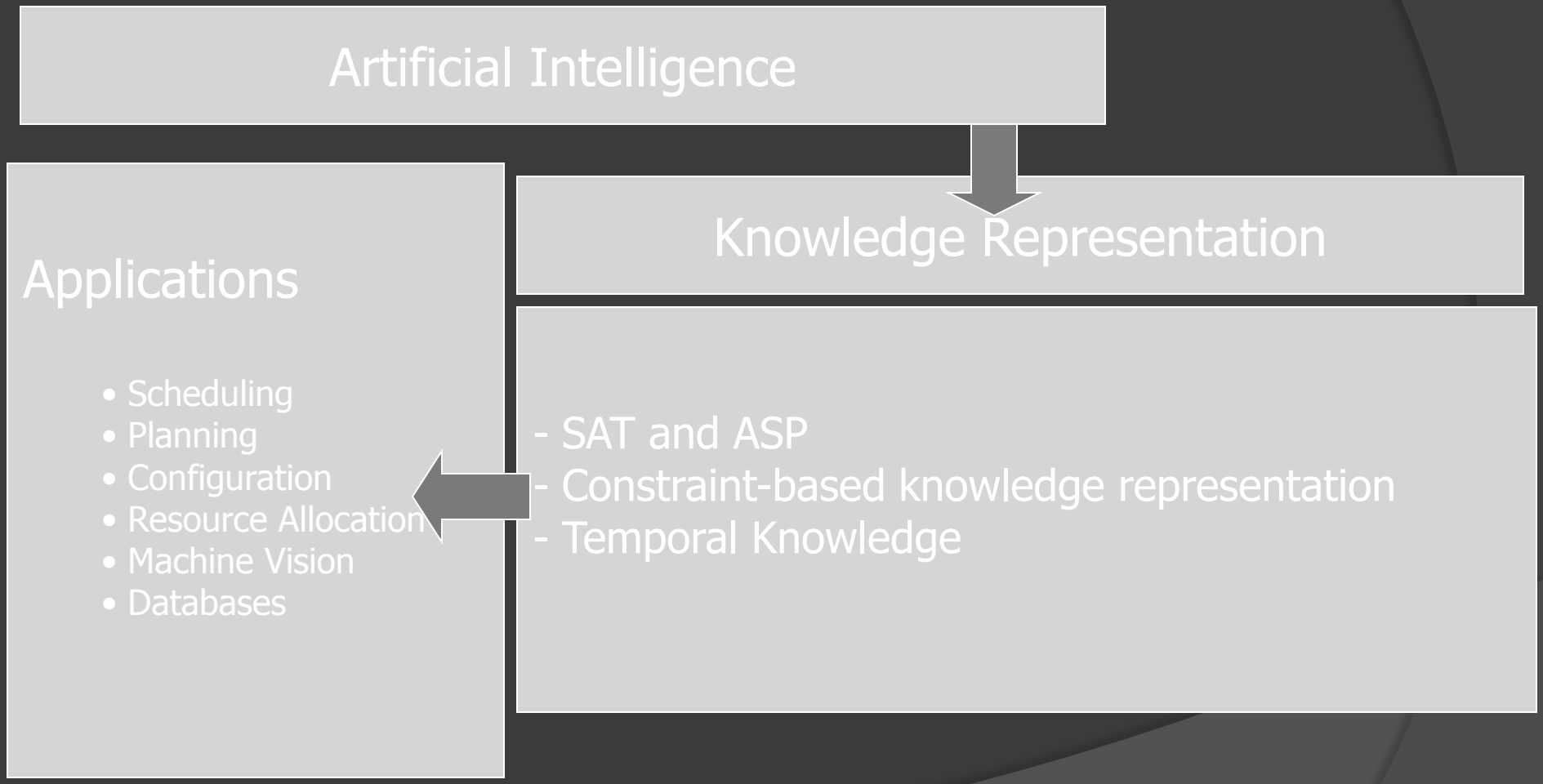
Disadvantages of Logic for KR

- Solutions:
  - restricting expressivity
    - **SAT**
  - augmenting declarative statements with procedural information
    - **logic programming**
  - new more powerful inference techniques
    - **constraint solving**
  - heuristics
    - **incomplete reasoning mechanisms** (local search)

What is this course about ?

* **Propositional Satisfiability (SAT)**
  - Reasoning Techniques
  - Modeling Real Problems
* **Actions, Situations, Events, Default Information**
  - Stable Models and Answer Set Programs
* **Constraint-based KR**
  - The CSP formalism
  - Reasoning Algorithms
  - Applications
* **Temporal Knowledge & Reasoning**
  - Qualitative and Quantitative

Course Flow


Artificial Intelligence
Knowledge Representation
Applications
• Scheduling
• Planning
• Configuration
• Resource Allocation
• Machine Vision
• Databases
- SAT and ASP
- Constraint-based knowledge representation
- Temporal Knowledge

Propositional Satisfiability (SAT)

- Propositional Logic in *Conjunctive Normal Form* (CNF)
  - Checking the satisfiability (and finding a model) of PL sentences in CNF is called SAT

- **Representation**

  Literals, Clauses

- **Reasoning**

  Propagation (UP, BinRes, etc.)
  Complete Search (DPLL)
  Local Search (GSAT, WalkSat)

- **Applications**

  planning verification circuit design
  model checking cryptography
  games and puzzles

Actions, Situations, and Events

- **Situation Calculus**
- **Describing Actions in Situation Calculus**
  - The Frame Problem
- **Time and Event Calculus**

- **Reasoning with Default Information**
  - Open and Closed Worlds
- **Negation as Failure and Stable Models**
  - ***Answer Set Programming*** **(ASP)**

Knowledge Representation with Constraints

- **Constraint Satisfaction Problems (CSPs)**
  - Representation
  - Reasoning
  - Applications

Variables, Values, Constraints, Models
Global Constraints, Uncertainty

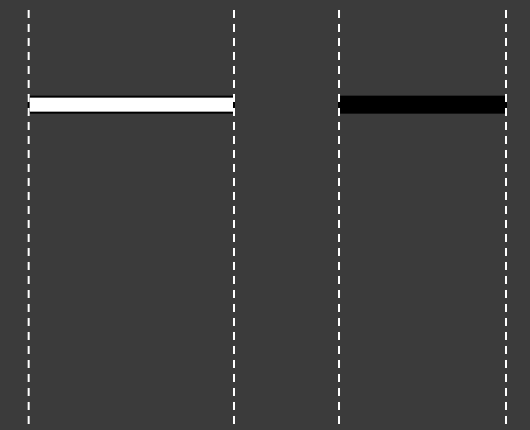
Constraint Propagation (AC, PC, etc.)
Complete Search (BT, FC, CBJ, MAC)
Local Search (Min_Confs, Breakout)

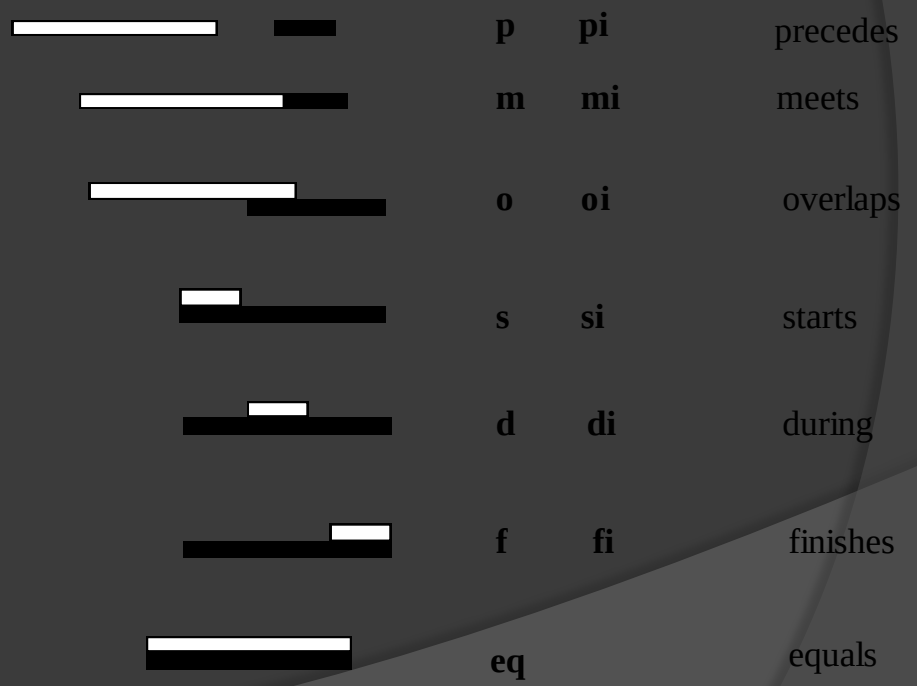
scheduling design and cofiguration
bin packing and partitioning frequency assignment
combinatorial mathematics games and puzzles
bioinformatics planning vehicle routing

Temporal KR&R

- Representation & Reasoning with Temporal Information

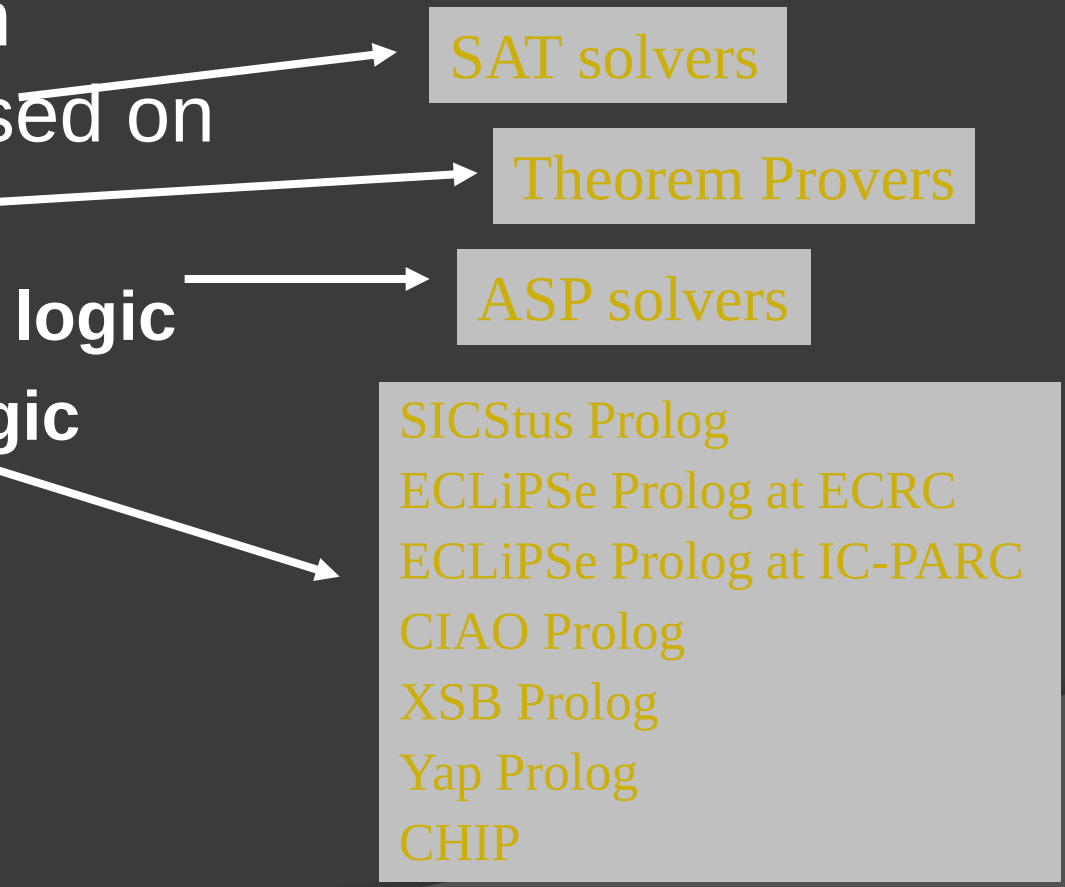
  quantitative (Allen's algebra, etc.) **qualitative** (STP,TCSP, etc.)





Logic-based Reasoners

- Knowledge Representation Languages based on Logic
  - **Propositional logic**
  - **First order logic**
  - **Answer set programming**
  - **Prolog**



Constraint-based Reasoners

- **Imperative, Functional, Concurrent Languages and Sy**
  - C/C++
  - Java
  - functional languages
  - concurrent lan

ILOG Solver
Choko
ECLiPSe

Java Constraint Library (JCL)
GECODE
AbsCon

Claire
Michel Lemaitre's Lisp library
Screamer (Lisp)
FaCiLE

Mozart / Oz
AKL