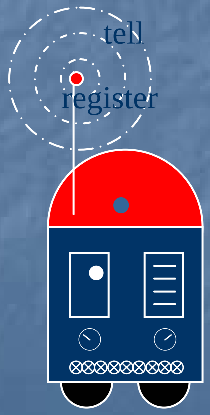
Overview of

Knowledge Representation and Reasoning



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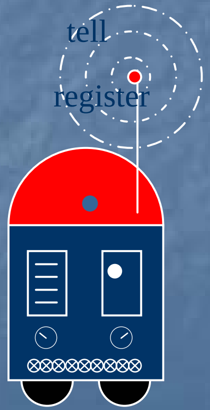
January 2004



Some material adapted from Richard Fikes, Stanford.

Questions

- What's the difference between data, information and knowledge?
  - Intensional vs. extensional information?
  - Particular vs. general information?
- What does it mean to **know** something?
  - Philosophers often define knowledge as "justified, true belief"
  - Early AI scientists considered appropriate use of knowledge to be a key
- How is knowledge created?
  - Via learning? By being told? By reasoning from exiting knowledge?
- How does our way of conceptualizing the world influence the way we think and act.

Knowledge Representation

"We base ourselves on the idea that in order for a program to be capable of learning something it must first be capable of being told it.

We shall therefore say that a program has common sense if it automatically deduces for itself a sufficiently wide class of immediate consequences of anything it is told and what it already knows."

John McCarthy, 1958, *"Programs with Common Sense"*, Teddington Conference on the Mechanization of Thought Processes, December 1958.

http://www-formal.stanford.edu/jmc/mcc59.html

Knowledge and reasoning

- Knowledge
  - The psychological result of cognition, i.e., of perception, learning and reasoning
  - That which is or can be understood
  - The wing wherewith we fly to heaven (Shakespeare)
  - Knowledge differs from data or information in that new knowledge may be created from existing knowledge using inference
- Reasoning
  - Thinking that is coherent and logical
  - Logical inference
  - The process of creating new knowledge from existing knowledge

Knowledge Representation

- Representation of knowledge
  - Description of world of interest
  - Usable by machine to make conclusions about that world
- Intelligent System
  - Computational system
  - Uses an explicitly represented store of knowledge
  - To reason about its goals, environment, other agents, itself
- Reasoning based on explicitly represented knowledge
- Working hypothesis
  - Knowledge of the world -
    - Can be articulated
    - Used as needed

Sample Issues in KR

- What form is the knowledge to be expressed?
- How can a reasoning mechanism generate implicit knowledge?
- How can knowledge by used to influence system behavior?
- How is incomplete or noisy information handled?
- How can we represent and reason
- How can practical results be obtained when reasoning is intractable?

KR&R – Knowledge Representation

- How information can be appropriately encoded and utilized in computational models of cognition
- Two primary areas of activity
  - Designing formats for expressing information
    - Mostly "general purpose" representation languages (e.g., first-order logic)
  - Encoding knowledge (knowledge engineering)
    - Mostly identifying and describing conceptual vocabularies (ontologies)
- Declarative representations are the focus of KR technology
  - Knowledge that is domain-specific but task-independent

KR&R – Reasoning

- Computations methods for creating new knowledge and information from exiting knowledge
  - Very general methods, e.g., modus ponens
  - Task-specific methods, e.g., algorithms for planning, scheduling, diagnosis, constraint satisfaction
  - Methods for managing reasoning, e.g., hybrid reasoning, parallel processing
- Analysis of reasoning
  - Soundness, completeness, complexity, …
- Methods for creating explanations of reasoning results

Expressiveness vs. tractability tradeoff

- How to express what we know
- How to reason with what we express
- "A Fundamental Tradeoff in Knowledge Representation and Reasoning"
  - H. Levesque, R. Brachman; in Readings in Knowledge Representation; R. Brachman and H. Levesque (eds); Morgan Kaufman; 1985.

KR and Data Base Research

- Both "represent" knowledge
- Data bases contain only "ground literals"
  - No disjunctions
  - No quantifiers
- Data base schema provide quantified information
- Deductive data bases include implications
- Data base concerns -
  - Efficient access and management of large data bases
  - Concurrent updating
- KR concerns -
  - Expressivity
  - Effective reasoning

Early History of KR ('60's - '70's)

- Origins
  - Problem solving work at CMU and MIT
  - Natural language understanding
- Many ad hoc formalisms
- "Procedural" vs. "declarative" knowledge
- No formal semantics
  - Problems:
    - How do we assign "meaning"
    - How can we say that a computer "understands"?

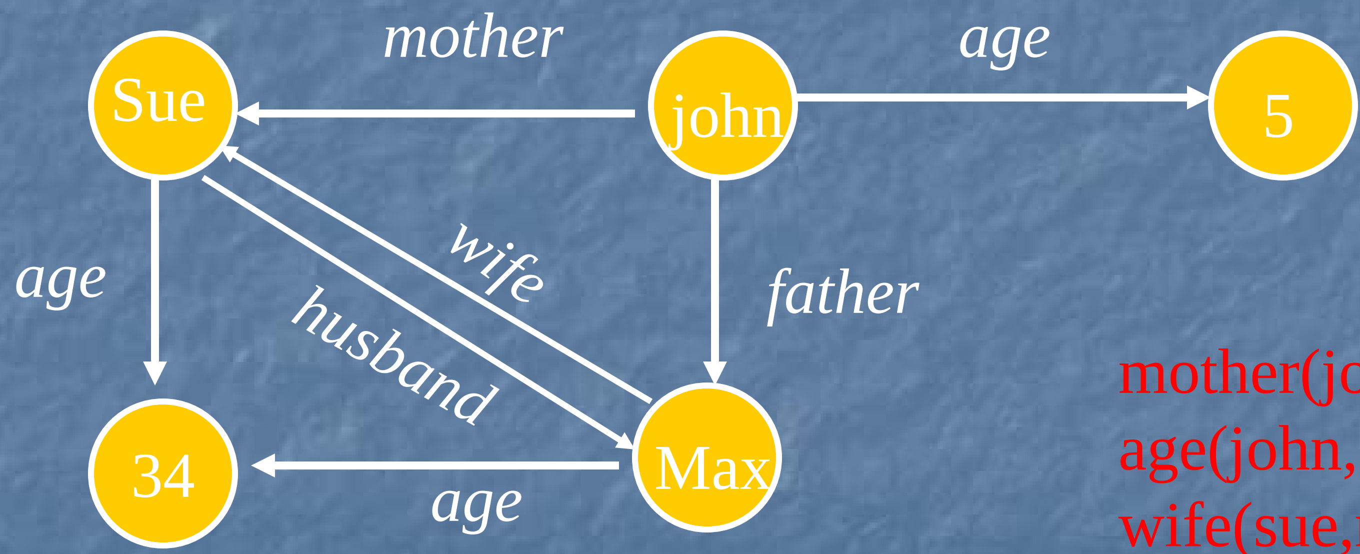
Emerging Paradigms ('70's - '80's)

- Semantic nets
  - Unstructured node-link graphs
  - No semantics to support interpretation
  - No axioms to support reasoning
  - "What's in a Link: Foundations for Semantic Nets"

    W. Woods, in Representation and Understanding: Studies in Cognitive Science; edited by D. Bobrow and A.Collins; Academic Press; 1975.
- Frames
- Production rules
- Predicate logic

Nodes and Arcs

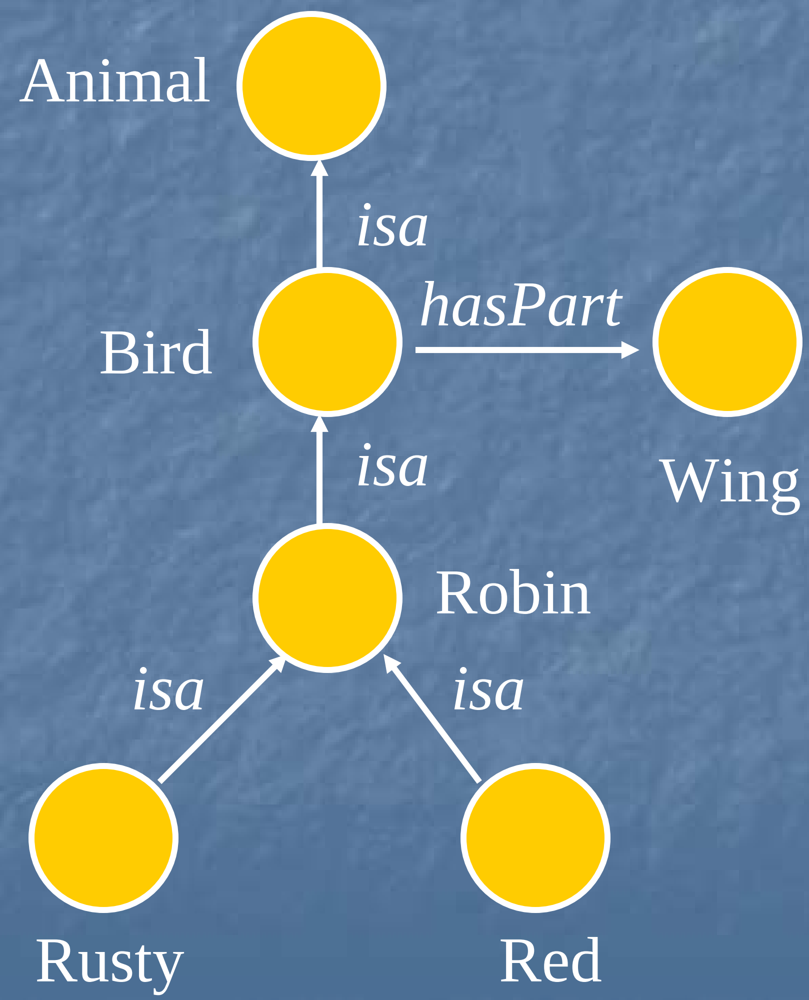
- arcs define binary relationships which hold between objects denoted by the nodes.



mother(john,sue)
age(john,5)
wife(sue,max)
age(max,34)
...

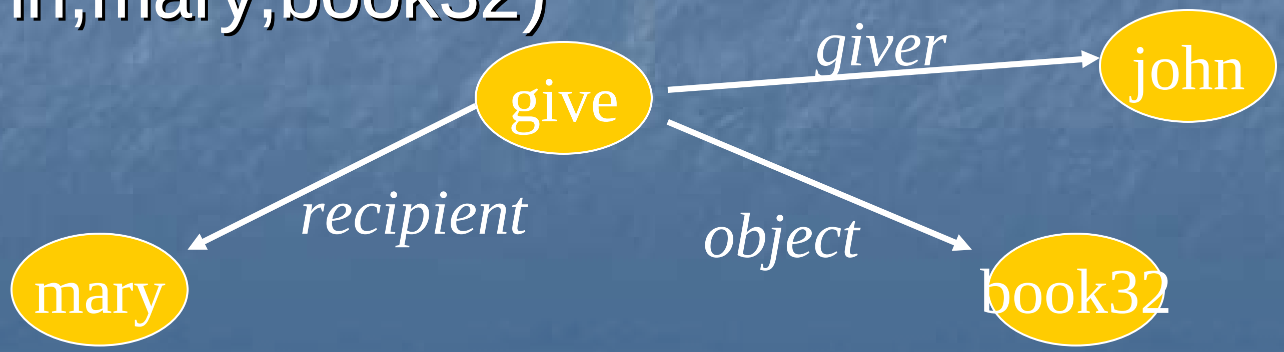
Semantic Networks

- The ISA (is a) or AKO (a kind of) relation is often used to link a class and its superclass.
- And sometimes an instance and it's class.
- Some links (e.g. haspart) are inherited along ISA paths.
- The semantics of a semantic net can be relatively informal or very formal
  - often defined at the implementation level



Reification

- Non-binary relationships can be represented by "turning the relationship into an object"
- This is an example of what logicians call "reification"
  - reify v : consider an abstract concept to be real
- We might want to represent the generic give event as a relation involving three things: a giver, a recipient and an object, give(john,mary,book32)



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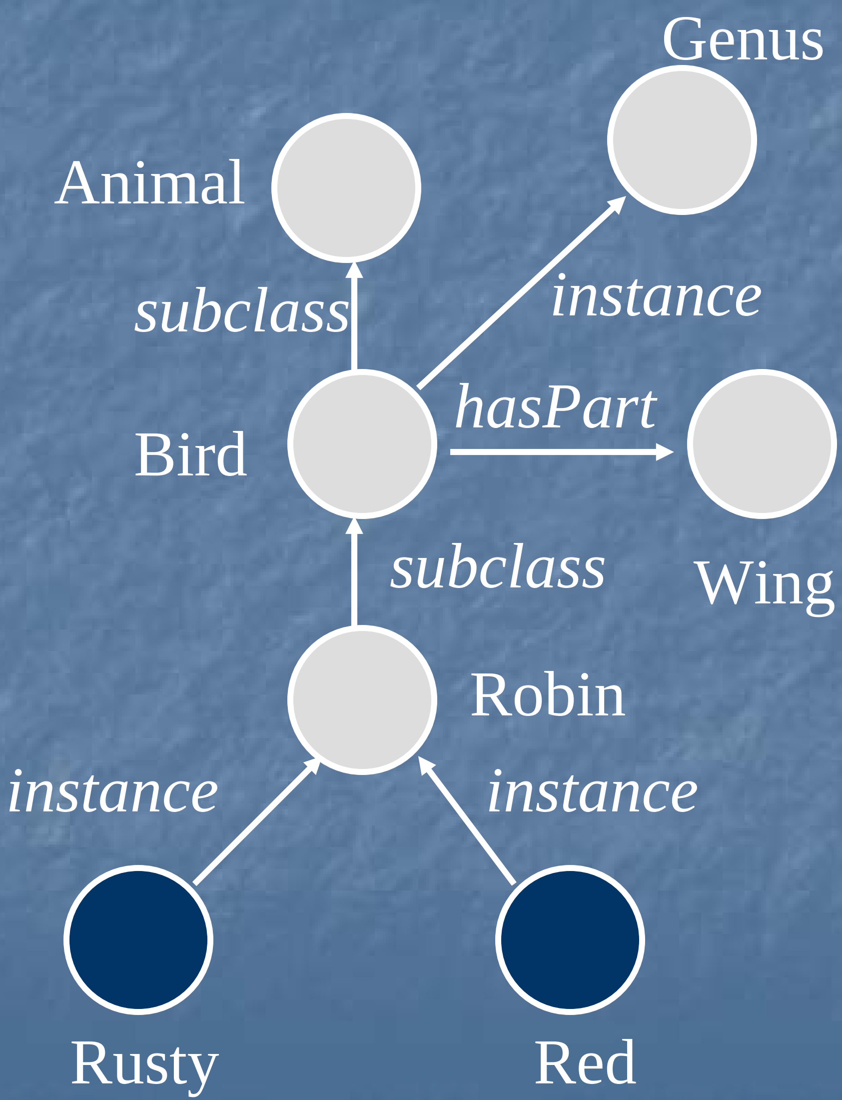
Individuals and Classes

- Many semantic networks distinguish
  - nodes representing individuals and those representing classes
  - the “subclass” relation from the “instance-of” relation



Emerging Paradigms ('70's - '80's)

- Semantic nets
- Frames
  - Structured semantic nets
  - Object-oriented descriptions
  - Prototypes
  - Class-subclass taxonomies
  - "A Framework for Representing Knowledge"
    - M. Minsky; in Mind Design; edited by J. Haugeland: MIT Press; 1981.
- Production rules
- Predicate logic

From Semantic Nets to Frames

- Semantic networks morphed into Frame Representation Languages in the 70's and 80's.
- A Frame is a lot like the notion of an object in OOP, but has more meta-data.
- A **frame** has a set of **slots**.
- A **slot** represents a relation to another frame (or value).
- A slot has one or more **facets.**
- A **facet** represents some aspect of the relation

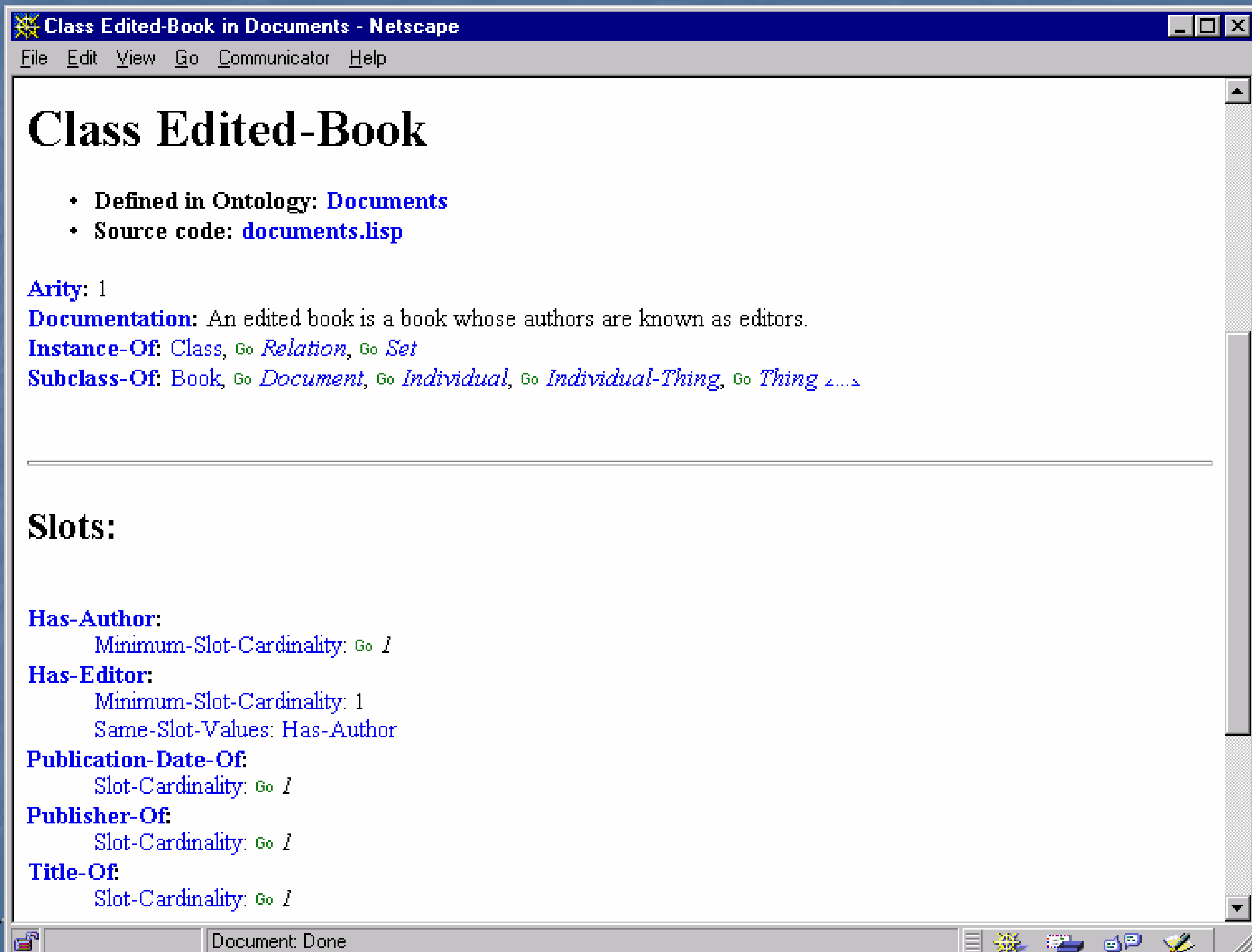
Facets

- A slot in a frame holds more than a value.
- Other facets might include:
  - current fillers (e.g., values)
  - default fillers
  - minimum and maximum number of fillers
  - type restriction on fillers (usually expressed as another frame object)
  - attached procedures (if-needed, if-added, if-removed)
  - salience measure
  - attached constraints or axioms
- In some systems, the slots themselves are instances of frames

Example Class-Subclass Taxonomy

- Author
- Document
  - Book
    - Edited-Book
  - Miscellaneous-Publication
    - Artwork
    - Cartographic-Map
    - Computer-Program
    - Multimedia-Document
    - Technical-Manual
  - Periodical-Publication
    - Journal
    - Magazine
    - Newspaper
  - Proceedings
  - Technical-Report
  - Thesis
    - Doctoral-Thesis
    - Masters-Thesis
- Title

Class Frame



Class Edited-Book in Documents - Netscape

File Edit View Go Communicator Help

Class Edited-Book

- **Defined in Ontology:** **Documents**
- **Source code:** **documents.lisp**

Arity: 1
Documentation: An edited book is a book whose authors are known as editors.
Instance-Of: Class, Go *Relation*, Go *Set*
Subclass-Of: Book, Go *Document*, Go *Individual*, Go *Individual-Thing*, Go *Thing* ...

Slots:

Has-Author:
Minimum-Slot-Cardinality: Go *1*
Has-Editor:
Minimum-Slot-Cardinality: 1
Same-Slot-Values: Has-Author
Publication-Date-Of:
Slot-Cardinality: Go *1*
Publisher-Of:
Slot-Cardinality: Go *1*
Title-Of:
Slot-Cardinality: Go *1*

Document: Done

Example Instance Frame

Instance Solving-Frame-Problem in My-Documents - Netscape

File Edit View Go Communicator Help

Instance Solving-Frame-Problem

- **Defined in Ontology: My-documents**
- **Source code: my-documents.lisp**

Documentation: Not supplied yet.

Has-Author:

    Minimum-Slot-Cardinality: Go *1*

Has-Editor: Murray-Shanahan

    Minimum-Slot-Cardinality: Go *1*
    Same-Slot-Values: Go *Has-Author*

Instance-Of: Edited-Book, Go *Book*, Go *Bounded*, Go *Document*, Go *Individual*, Go *Individual-Thing*, Go *Thing*

Number-Of-Pages-Of: 407

Publication-Date-Of: Year-1997

    Slot-Cardinality: Go *1*

Publisher-Of: Mit-Press

    Slot-Cardinality: Go *1*

Title-Of: Solving-The-Frame-Problem

    Slot-Cardinality: Go *1*

Document: Done

Description Logic

- There is a family of Frame-like KR systems with a formal semantics.
  - E.g., KL-ONE, LOOM, Classic, ...
- An additional kind of inference done by these systems is automatic **classification**
  - finding the right place in a hierarchy of objects for a new description
- Many current systems take care to keep the language simple, so that all inference can be done in polynomial time (in the number of objects)
  - ensuring tractability of inference

Emerging Paradigms ('70's - '80's)

- Semantic nets
- Frames
- Production rule systems
  - Situation-action rules
    - If (warning-light on) then (turn-off engine)
  - If-then inference rules
    - If (warning-light on) then (engine overheating)
    - If (warning-light on) then ((engine overheating) 0.95)
  - Hybrid procedural-declarative representation
  - Basis for expert systems
- Predicate logic

Production Systems

- The notion of a "production system" was invented in 1943 by Post
- Used as the basis for many rule-based expert systems
- Used as a model of human cognition in psychology
- A production is a rule of the form:

C1, C2, … Cn => A1 A2 …Am

Left hand side (LHS) *Right hand side (RHS)*

Condition which must hold before the rule can be applied

Actions to be performed or conclusions to be drawn when the rule is applied

Basic Components

- **Rules:** Unordered set of user-defined "if-then" rules.
  - Form: *if P1 ^ ... ^ Pm then A1, ..., An*
  - the *Pis* are facts that determine conditions when rule is applicable.
  - Actions can add or delete facts from the Working Memory.
- **Working Memory --** A set of "facts" consisting of positive literals defining what's known to be true about the world
  - Usually “flat tuples” like (age finin 45)
- **Inference Engine** -- Procedure for inferring changes (additions and deletions) to Working Memory.
  - Typically forward chaining

Typical CLIPS Rule

```
(defrule determine-gas-level ""
   (working-state engine does-not-
   start)
   (rotation-state engine rotates)
   (not (repair ?))
   =>
   (if (not (yes-or-no-p “Gas in
   tank?"))
       then (assert (repair "Add
   gas."))))
```

```
(defrule print-repair ""
  (declare (salience 10))
  (repair ?item)
  =>
  (printout t crlf crlf)
  (printout t "Suggested Repair:")
  (printout t crlf crlf)
  (format t " %s%n%n%n" ?item))
```

```
(defrule normal-engine-state-
  conclusions ""
   (declare (salience 10))
   (working-state engine normal)
   =>
   (assert (repair "No repair
  needed."))
   (assert (spark-state engine
  normal))
   (assert (charge-state battery
  charged))
   (assert (rotation-state engine
  rotates)))
```

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Typical CLIPS facts

- Facts in most production systems are basically flat tuples
- A simple extension supported by many is to allow simple templates using“slot-filler” pairs.

```
(deftemplate engine
   (slot horsepower)
   (slot displacement)
   (slot manufacturer)
   (slot year))
```

- Matching slots in a template is order insensitive, as in:

```
(engine (year 1998) (horsepower ?x))

(engine (horsepower 250)
   (displacement 500) (year 1998))
```

```
(initial-fact)
(working-state engine
  unsatisfactory)
(charge-state battery charged)
(rotation-state engine rotates)
(repair "Clean the fuel line.")
(engine (horsepower 250)
            (displacement 409)
            (manufacturer ford))
```

Basic Procedure

While changes are made to Working Memory do:

- **Match** -- Construct the Construct Conflict Set -- the set of all possible (rule, list-of-facts) pairs such that rule is one of the rules and list-of-facts is a subset of facts in WM that unify with the antecedent part (i.e., Left-hand side) of the given rule.
- **Conflict Resolution** -- Select one pair from the Conflict Set for execution.
- **Act --** Execute the actions associated with the consequent part of the selected rule, after making the substitutions used during unification of the antecedent part with the list-of-facts.

Rete Algorithm

- The ***Rete Algorithm*** (Greek for “net”) is the most widely efficient algorithm for the implementation of production systems.
- Developed by Charles Forgy at Carnegie Mellon University in 1979.
  - Charles L. Forgy, "Rete: A Fast Algorithm for the Many Pattern/Many Object Pattern Match Problem", Artificial Intelligence,19, pp 17-37, 1982.
- Rete is the only algorithm for production systems whose efficiency is asymptotically independent of the number of rules.
- The basis for a whole generation of fast expert system shells: OPS5, ART, CLIPS and Jess.

Soar

- Soar is a production system developed initially at CMU and now used in many places.
- Soar stood for State, Operator And Result because all problem solving in Soar is regarded as a search through a problem space in which you apply an operator to a state to get a result.
- It's also a general cognitive architecture for developing systems that exhibit intelligent behavior.
- See http://ai.eecs.umich.edu/soar/
- Example:

```
sp {hello-world
    (state <s> ^type state)
    -->
    (write |Hello World|) (halt)}
```

Emerging Paradigms ('70's - '80's)

- Semantic Nets
- Frames
- Production rule systems
- Predicate calculus
  - Primarily first order logic

    "Everybody loves somebody sometime."

    ```
    (forall ?p
          (implies (Person ?p1)
                   (exists (?p2 ?t) (and (Person ?p2)
                                         (Time ?t)
                                         (Loves ?p1 ?p2 ?t))))
    ```
  - Resolution theorem proving

KR in the '90's

- Declarative representations
  - Easier to change
  - Multi-use
  - Extendable by reasoning
  - Accessible for introspection
- Formal semantics
  - Defines what the representation means
  - Specifies correct reasoning
  - Allows comparison of representations/algorithms
- KR rooted in the study of logics
  - temporal, context, modal, default, nonmonotonic, …
- Rigorous theoretical analysis

Description Logic

- There is a family of Frame-like KR systems with a formal semantics.
  - E.g., KL-ONE, LOOM, Classic, ...
- An additional kind of inference done by these systems is automatic **classification**
  - finding the right place in a hierarchy of objects for a new description
- Current systems take care to keep the language simple, so that all inference can be done in polynomial time (in the number of objects)
  - ensuring tractability of inference

KR in the '00's ??

- Web based systems
  - embedding knowledge on web pages
  - languages based on XML: OIL, RDF, DAML, OWL
- Driven by new classes of applications
  - Electronic commerce (e.g, product catalogues)
  - Information retrieval on the web
  - Web services
- Integration with conventional software
  - e.g., OO modeling tools like UML
  - e.g., reflection in Java
- Business rules?
- Ontologies !
- ??

Summary

- Real knowledge representation and reasoning systems come in several major varieties.
- These differ in their intended use, degree of formal semantics, expressive power, practical considerations, features, limitations, etc.
- Some major families are
  - Logic programming languages
  - Theorem provers
  - Rule-based or production systems
  - Semantic networks
  - Frame-based representation languages
  - Databases (deductive, relational, object-oriented, etc.)
  - Constraint reasoning systems
  - Description logics