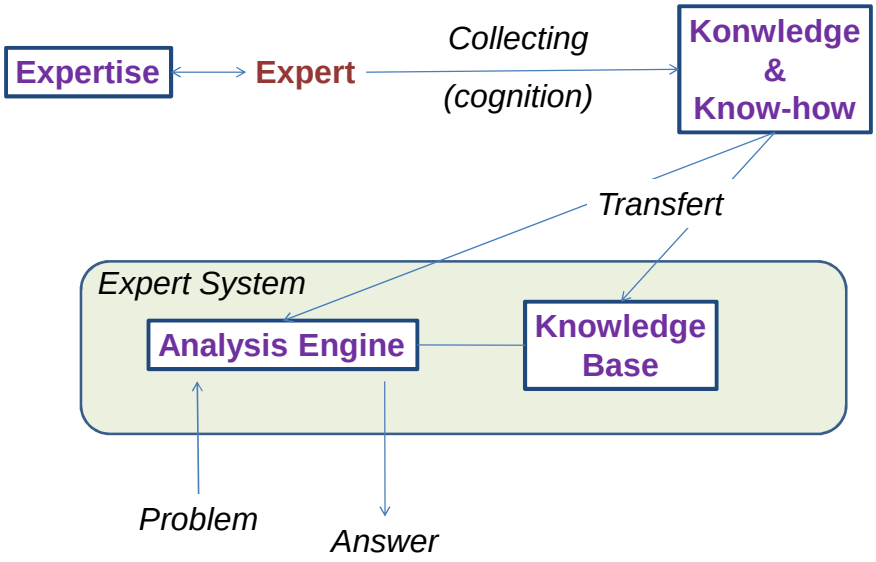
Artificial Intelligence

Logic and Expert Systems

Introduction



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System with Knowledge Base ?

- SBC (Système à Base de Connaissance)
  - Knowledge Base is related to a specific domain, a type of problem, …
  - Explicit representation of the knowledge
- Transfert of the knowledge
  - Implies a change of :
    - Media / support
    - Form
  - Linguistic modeling
    - Power of expression / statements
      - Is it possible to transfert the complete knowledge that the system shall take into account?
      - Is it possible to transfert all the knowledge that the expert owns?
    - Enables reasoning
      - Is the form well adapted to the processing that are required for solving a specific problem?
    - Efficient!

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Examples of knowledge base representation

- Triplets < object , attribute , value >
- Semantic networks
  - Nodes = concepts
  - Arcs = relations between concepts
- Logic – Predicates
  - Predicates represent facts, situations
  - Predicates can be defined based on conditions satisfied by other predicates
  - Equivalences are defined between logical expressions
  - A goal is defined by a predicate to satisfy
- Rules
  - Relations between:
    - Known information
    - Information to determine / verify / infer
  - Can include the execution of procedures

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Rules-based reasoning

- Components :
  - Set of rules
  - Set of facts
  - Infering engine
- Principle
  - Find among the set of rules the ones that can be « fired », or « applied »:

    If conditions are verified, then conclusions are applicable
  - Select one of these rules

    This may need conflict resolution
  - « Fire » / execute the rule

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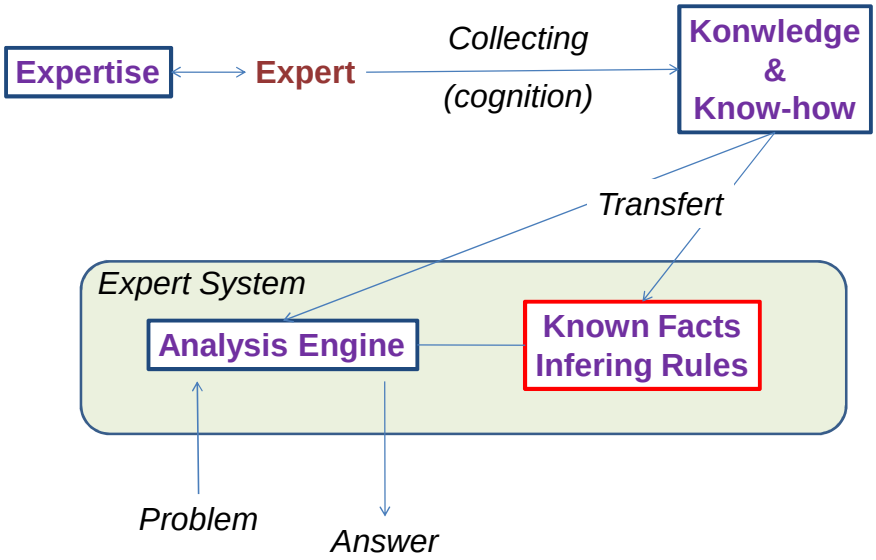

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Logic

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Introductory example

- Facts
  - on_top(C,A)
  - on_table(A) on_table(B)
  - free(B) free(C)

- Operations / Moving blocks:
  « remove » & « pile » actions
  - R1: free(x) ⇔ ¬ (∃ y, on_top(y,x))
  - R2: on_top(y,x) ∧ remove(y,x) ⇒ free(x) ∧ ¬ on_top(y,x)
  - R3: free(x) ∧ free(y) ∧ pile(x,y) ⇒ on_top(x,y)
- How to move 'A' on top of 'B'?
  i.e. how to obtain « on_top(A,B) »?

- Facts & Rules
  `on_top(C,A) on_table(A) on_table(B) free(B) free(C)`
  R1: `free(x) ⇔ ¬ ( ∃ y, on_top(y,x) )`
  R2: `on_top(y,x) ∧ remove(y,x) ⇒ free(x) ∧ ¬ on_top(y,x)`
  R3: `free(x) ∧ free(y) ∧ pile(x,y) ⇒ on_top(x,y)`
- « `on_top(A,B)` »?
  - R3 says: possible to obtain if we have
    « `free(A) ∧ free(B) ∧ pile(A,B)` »
  - free(B)=true ; pile(A,B) is an action to execute
  - « free(A) »=?
    R1 says: yes if `¬ ( ∃ y, on_top(y,A) )`
  - We have on_top(C,A)! … How to obtain ¬on_top(C,A)?
    Need to apply R2:
    `on_top(C,A) ∧ remove(C,A) ⇒ free(A) ∧ ¬ on_top(C,A)`
  - Thus: execute « remove(C,A) »:
    « `free(A) ∧ ¬ on_top(C,A)` » becomes true
  - Then execute « pile(A,B) »:
    the goal « `on_top(A,B)` » becomes true!

Logic

- « Language » / Formal way to represent the knowledge
  - Logics = formal languages used in order to represent/translate:
    - Information (known facts)
    - Reasoning mechanisms
      - i.e. the method used to make conclusions/ take decisions based on known facts

Syntax + semantic

- Syntax
  - Made of words and symbols
  - Words + symbols = sentences
- Semantic
  - Meaning of a particular sentence in a specific environment
    - Meaning = truth value

Types of logic

- Predicates - « ordre 0 »

  une suite de symboles séparés par des conjonctions (et), des disjonctions (ou) ou des négations (non)

  exemples:

  "Socrate est un homme" → HommeSocrate

  "Platon est un homme" → HommePlaton

  "Platon et Socrate sont des hommes"

  → HommeSocrate ∧ HommePlaton

- Propositions - « ordre 1 »

  une suite de symboles, de variables et de relations avec des quantificateurs universels et existentiels

  exemples:

  – Homme(Socrate) ∀x Homme(x) ⇒ Mortel(x)

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Propositions

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- Enable the representaton of:
  - Facts about the « world »: « Jean loves Marie »
  - Negations: « Marie does not love Jean »
  - Conjonctions & disjunctions
  - Sentences with logical consequenc… does not love Maris, she does not l… neither »

La logique des propositions permet
- des faits sur le monde: "Jean aime
- des négations: "Marie n'aime pas J
- des conjonctions et des disjonction
- des phrases avec "conséquence" l… l'aime pas non plus."

Une proposition est une expressior vraie soit fausse.

Éléments de base:
- symboles de propositions: P, Q, …
- phrases spéciales: Vrai, Faux

Syntaxe

- Propositions:
  « P » « Q » « R »
- Operators (symbols):
  ¬ ∧ ∨ not or and
  ⇒ IF … THEN …
  ⇔ … IF AND ONLY IF …
- Examples:
  ¬(P∧Q)∨(P⇒(Q⇒R))
  P∧Q ∧(Q⇒R)

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Truth table

P	¬P	Q	P ∧ Q	P ∨ Q	P ⇒ Q	P ⇔ Q
V	F	V	V	V	V	V
V	F	F	F	V	F	F
F	V	V	F	V	V	F
F	V	F	F	F	V	V

Inference

- To infer = to establish the truth value of a sentence by applying syntactical modifications to the sentence
  - The sentence is the fact to prove
  - The modifications are made based on the « infering rules »
    - Example

      Knowledge

      A=true B=true (A∧B)⇒C

      Infering 'C'

      yes because A and B are both true, and (A∧B)⇒C

Predicates

Syntax

- Au lieu des symboles propositionnels P_1 , P_2 , Q …, utiliser des prédicats et des termes:
- exemples

1) Personne (Marie) Aime(Roméo, Juliette)

constantes "prédicats" (ou simplement “prédicats”) sans signification prédéterminée

constantes individuelles (ou simplement “constantes”) sans signification prédéterminée

2) “Jean donne Fifi à Marie”
Donne(Jean, Marie, Fifi)

3) Égal(Plus(2,2), 4)

Constantes	RoiJean, 2, UniGE, ...
Prédicats	Frère, >, ...
Fonctions	Sqrt(.), JambeGaucheDe(.), ...
Variables	x, y, a, b, ...
Connecteurs	$\wedge, \vee, \neg, \Rightarrow, \Leftrightarrow$
Égalité	=
Quantificateurs	$\forall \ \exists$

Formula

Phrases atomiques = *prédicat(terme$_1$, ... , terme$_n$)*
ou *terme$_1$ = terme$_2$*

Terme = *fonction(terme$_1$, ... , terme$_n$)*
ou *constante* ou *variable*

Exemples
1) Frère(RoiJean, RichardCoeurDeLion)
2) > (Longueur(JambeGaucheDe(Richard)),15)

Phrases complexes = phrases atomiques réunies par des connecteurs

$\neg S$, $S_1 \wedge S_2$, $S_1 \vee S_2$, $S_1 \Rightarrow S_2$, $S_1 \Leftrightarrow S_2$

Exemples
1) Frère(RoiJean, Richard) $\Rightarrow$ Frère(Richard, RoiJean)
2) $>(1, 2) \vee \leq (1, 2)$
3) $>(1, 2) \wedge \neg > (1, 2)$

Truth table

my_predicate(A,B,C)

is true if and only if

A, B and C belong alltogether to the relationship defined by my_predicate

Quantification

- Used to define properties on sets of objects

  ∀x … whatever the value of x, … is true

  ∃x … there exist a value of x such that … is true

- ∃ <*variables*> <*sentence*>

  « There exist someone who is intelligent outside EPITECH »

  ∃ x human_being(x)∧intelligent(x)∧¬epitech(x)

∃x Chien(x) "il y a un chien"

variable liée par ∃

les variables désignent des emplacements possibles pour des constantes:

- x est une variable libre dans Chien(x)
- x est une variable liée dans ∃x Chien(x)

- ∀ *<variables> <sentence>*

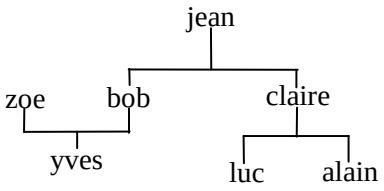
  Everyone at Epitech is intelligent

  ∀ x epitech(x) ⇒ intelligent(x)

Morgan law

…	*is the same as*	…
¬ ∃ x P		∀ x ¬ P
¬ ∀ x P		∃ x ¬ P
¬ (P ∨ Q)		¬ P ∧ ¬ Q
¬ (P ∧ Q)		¬ P ∨ ¬ Q

Example: genealogical tree



- Predicates:

  Father(x,y)

  father(yves,bob), father(claire,jean), …

  Mother(x,y)

  Allows a complete representation of the known facts

- Other relationships are derived from « father » and « mother » predicates by means of infering rules:

  $$father(x,y) \vee mother(x,y) \Rightarrow parent(x,y)$$

  Or

  $$father(x,y) \Rightarrow parent(x,y)$$
  $$mother(x,y) \Rightarrow parent(x,y)$$

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Summary

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Logic

- « Language » / Formal way to represent the knowledge
  - Logics = formal languages used in order to represent/translate:
    - Information: known facts
    - Reasoning mechanisms: know-how
      - i.e. the method used to make conclusions/ take decisions based on known facts

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Types of logic

- Predicates - « ordre 0 »
  - Sentences combined from symbols and operators 'and', 'or', 'not'
    - ManSocrate — *Socrate is a man*
    - ManSocrate $\wedge$ ManPlaton — *Socrate and Planton are men*

    with logical operators $\Rightarrow$, $\Leftrightarrow$
    - ManSocrate $\Rightarrow$ MortalSocrate

      If Socrate is a man, then Socrate is mortal
- Propositions - « ordre 1 »
  - Symboles, variables, quantifiers ($\exists$, $\forall$)
    - Man(Socrate)
    - $\forall$x Man(x) $\Rightarrow$Mortal(x) — *All men are mortal*

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Example with predicates

- Facts
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  - on_table(A) on_table(B)
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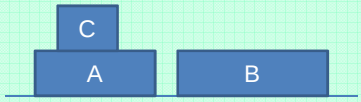

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  « remove » & « pile » actions
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- How to move 'A' on top of 'B'?
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- Facts & Rules
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Rules-based reasoning

- Components :
  - Set of rules — *if …conditions… then …conclusion/action…*
  - Set of facts — *what is kown*
  - Infering engine
- Principle
  - Find among the set of rules the ones that can be « fired », or « applied »:
    If conditions are verified, then conclusions are applicable
  - Select one of these rules
    This may need conflict resolution
  - « Fire » / execute the rule

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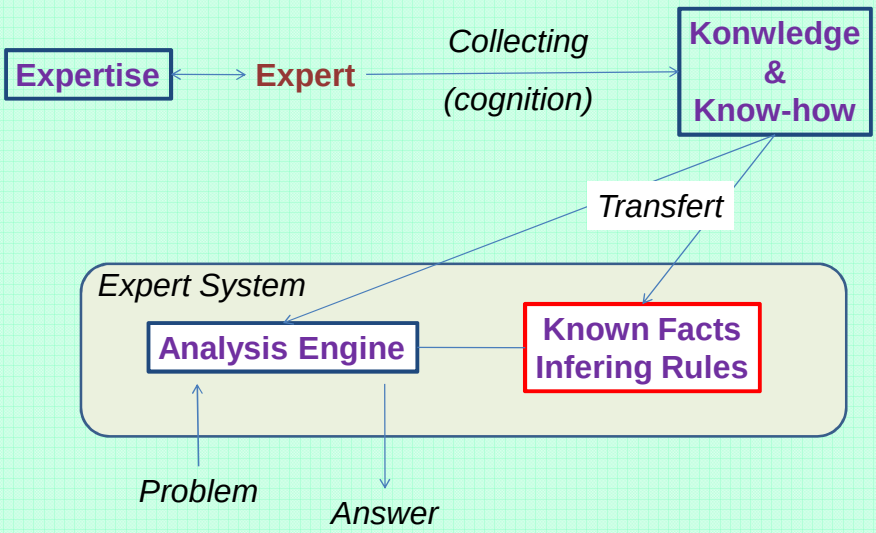
Rules-based expert system



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Hypothesis : rules such as

IF A and B and … THEN X

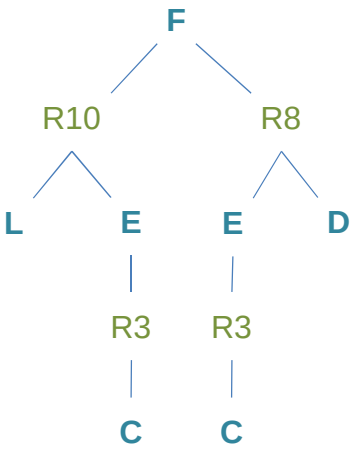
AND/OR Tree or Graph

Example

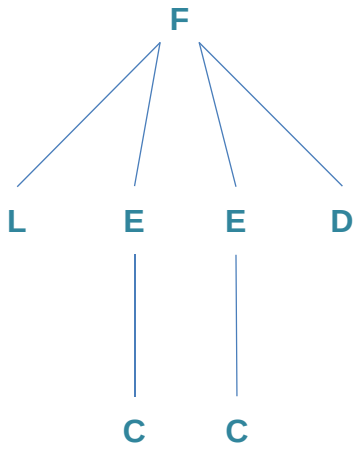
R1 : A -> B	R6 : M+L -> A
R2 : A -> C	R7 : I+B -> D
R3 : C -> E	R8 : E+D -> F
R4 : M -> C	R9 : K+F -> H
R5 : I+K -> A	R10 : L+E -> F

Graphical variations

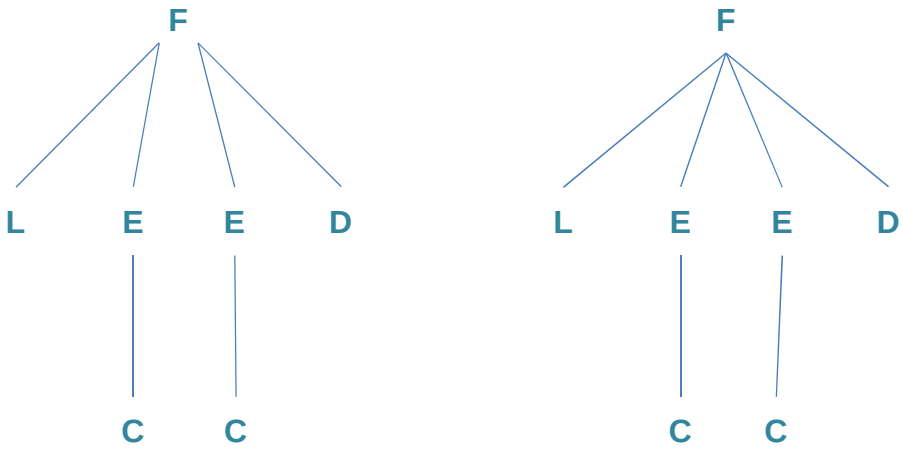
R3: C ⇒ E
R8: E∧D ⇒ F
R10: L ∧ E ⇒ F



Rules are explicitly shown



Rules are not shown



Is it the same?

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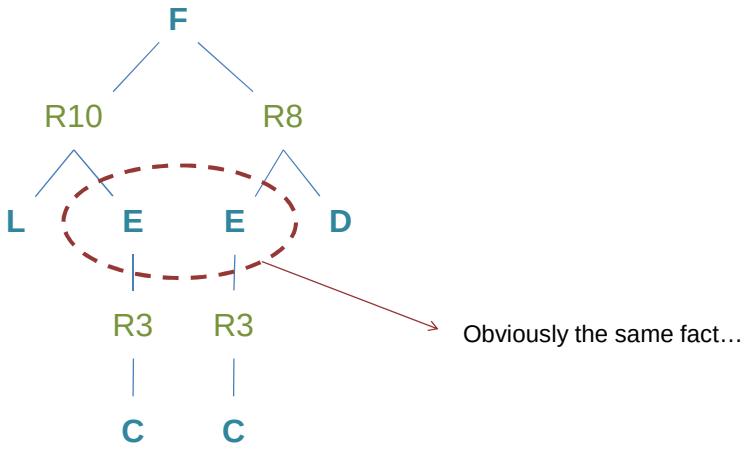

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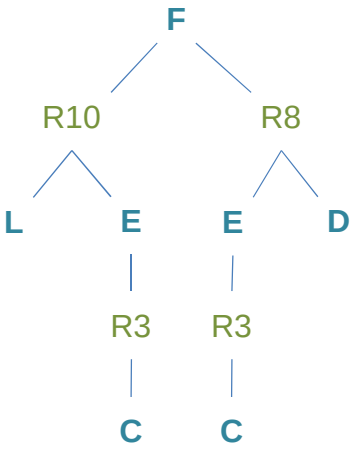

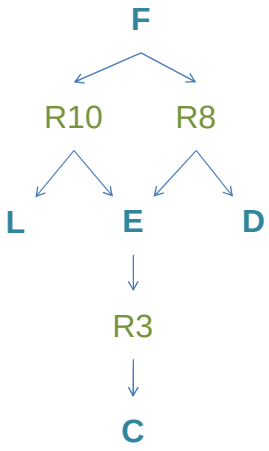

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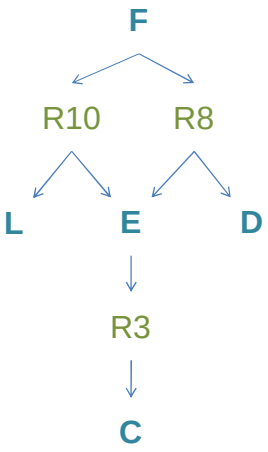

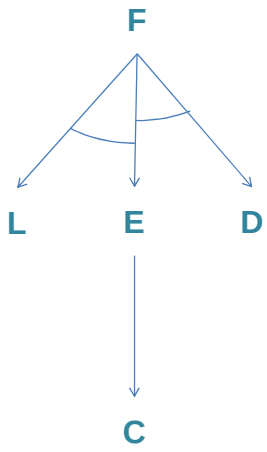

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Chaînage avant

Forward chaining

Infering rules:
R1: A→B
R2: A→C
R3: C→E
R4: M→C
R5: I&K→A
R6: M&L→A
R7: I&B→D
R8: E&D→F
R9: K&F→H
R10: L&E→F

Known facts:
I
L
M

Problem statement :

According to:

Facts that we know are true
representing the initial state of the search,
Representing the actual description of the world

Infering rules (they are true as well!...)
representing the know-how of the problem

What other facts can we determine as true?

Lorsqu'un nouveau fait *p* est ajouté à la base de connaissances:

pour chaque règle telle que *p* s'unifie avec un prémisse
et si les autres prémisses sont connus
alors ajouter la conclusion à la base de connaissances et
continuer le chaînage

- le chaînage avant est piloté par les données (*"data-driven"*)

càd, on infère des propriétés et des catégories à partir des séquences perceptives

- Iterate on:
  - Select a rule that is applicable
    - That is for which the « conditions » part is true
  - Apply the rule
    - That is: add the conclusion in the « known facts » set
- Stop when there is no more applicable rule

- Applying a rule adds known facts
  - Thus, a rule not applicable at one time may be aplicable later…

Infering rules:
R1: A→B
R2: A→C
R3: C→E
R4: M→C
R5: I&K→A
R6: M&L→A
R7: I&B→D
R8: E&D→F
R9: K&F→H
R10: L&E→F

Initial facts = {I,L,M}

Rule applied	Knowledge	
	ILM	
R4	ILMC	
R6	ILMCA	
R1	ILMCAB	
R2	ILMCAB	*no new fact added!*
R3	ILMCABE	
R7	ILMCABED	
R8	ILMCABEDF	
R10	ILMCABEDF	*no new fact added!*

Order may differ depending on the strategy to select a rule at each step!

But the result is the same…


```
facts_set forward_chaining(
              rules_set rules
              facts_set initial_facts)

rules_set to_fire ← rules
facts_set facts ← initial_facts

WHILE there_is_applicable_rule(to_fire,facts) DO

   rule r ← select_rule(to_fire,facts)
   to_fire ← to_fire – r
   facts ← facts + conclusion(r)

ENDWHILE

RETURN facts
```


- Variants
  - Each time a rule is selected, add its conclusions in the knowledge base and fire (new) rules accordingly

    See previous exemple and pseudo-code
  - Fire rules only based on the initial facts
    - Think about rules with actions as conclusions: allow to determine what could be done, but without taking the (final) decision)

Chaînage arrière

Backward chaining

Infering rules:
R1: A→B
R2: A→C
R3: C→E
R4: M→C
R5: I&K→A
R6: M&L→A
R7: I&B→D
R8: E&D→F
R9: K&F→H
R10: L&E→F

Known facts:
I
L
M

Problem statement :

According to:

Facts that we know are true
representing the initial state of the search,
Representing the actual description of the world

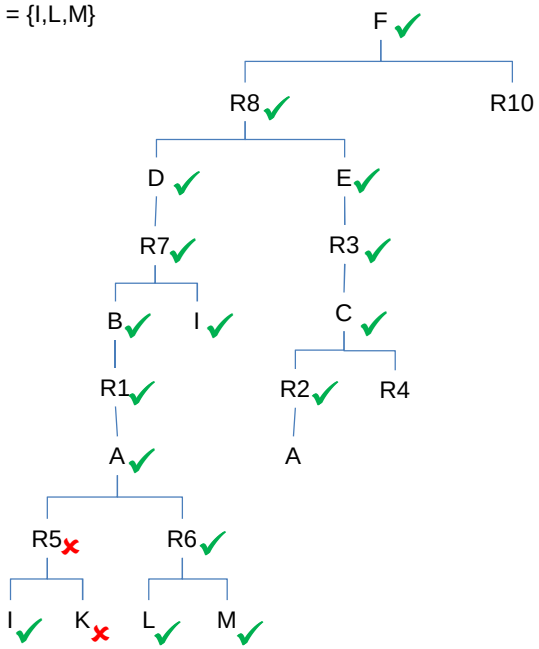
Infering rules (they are true as well!...)
representing the know-how of the problem

Is a given fact (e.g. F) true or not ?

- Iterate on all rules concluding to the fact:
  - Check if conditions are true
  - If yes, decide that the fact is true
- Checking if a condition is true is recursion!

Infering rules:
R1: A→B
R2: A→C
R3: C→E
R4: M→C
R5: I&K→A
R6: M&L→A
R7: I&B→D
R8: E&D→F
R9: K&F→H
R10: L&E→F

Initial facts = {I,L,M}
F ?



If all rules are of the form :

IF a set of facts that shall be true
THEN a set of facts that will be considered as true

- i.e. only the « and » operator is used

$$truth\_value(F) = OR_{R,\ F \in C(R)}\ fire\_ability(R)$$

$$fire\_ability(R) = AND_{F,\ F \in P(R)}\ truth\_value(F)$$

C(R)=set of facts as conclusion of a rule R
P(R)=set of facts in the condition part of rule R

```
bool truth_value: fact      F      IN
                  rules_set rules  IN/OUT
                  facts_set facts  IN/OUT

IF F ∈ facts THEN RETURN true

WHILE there_is_a_concluding_rule(rules,F) DO

   rule r ← select_a_concluding_rule(rules,F)
   rules ← rules - r
   IF fire_ability(r,rules,facts)
          THEN facts ← facts + F
               RETURN true

ENDWHILE

RETURN false
```

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```
bool fire_ability: rule      R          IN
                   rules_set rules      IN/OUT
                   facts_set facts      IN/OUT

facts_set facts_to_check ← condition(R)

WHILE facts_to_check ≠ ∅ DO

   fact F ← select_fact(facts_to_check)
   IF truth_value(F,rules,facts) = false
          THEN RETURN false
   facts_to_check ← facts_to_check - F

ENDWHILE

RETURN true
```

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After the « basic » rules and chaining algorithms…

Let's see more issues!

« OR » in conditions

- IF A OR B THEN C
- IF A THEN C
  IF B THEN C

« NOT »

- Domain of value :
  { true , undetermined }
  or
  { true , false , undetermined }

General boolean expressions

- IF <bool_expression> THEN A

```
bool fire_ability: rule R                IN
                       rules_set rules   IN/OUT
                       facts_set facts   IN/OUT

      Evaluate according to the semantic tree of the
      boolean expression

RETURN true
```

Multiple conclusions

- IF A THEN X AND Y AND Z
- IF A THEN X OR Y
  - At least one of 'X' and 'Y' shall be set to 'true'
  - How to do if we don't know that X or Y is false?
- IF A THEN X XOR Y
  - Exactly one shall be true
  - How to do if both are 'undetermined'?

Interactive backward chaining

- Idea:
  ask the user to help the system
- Principle 1:
  the system is an expert, and shall investigate as much as possible before requiring any help
- Principle 2:
  ask as few help as possible