# Production Systems

## Rule base Systems

(Busse book handout)

CSE 352

(Lecture Notes 4)

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# Production Systems
# (Rule Based Systems)

A production system consists of:

1. A **knowledge base**, also called a **rule base** containing production **rules**, or productions.
2. A **database**, contains **facts**
3. A **rule interpreter**, also called a rule application module to control the entire production system.

# Production Rules
# (Expert System Rules)

Production rules are the **units** of knowledge of the form:

**IF conditions**

**THEN actions**

**Condition part** of the rule is also called the **IF** part, premise, antecedent or left side of the rule.

# Production Rules
# (Expert System Rules)

**Action part** is also called **THEN** part, conclusion, consequent, succeedent, or the right side of the rule.

**Actions** are **executed** when **conditions** are **true** and the **rule** is **fired**.

Rules Format:

$$\mathbf{C_1 \ \& \ C_2 \ \& \ \ldots \ \& \ C_n \ => A}$$

$C_1, \ldots, C_n, A$ are atomic formulas

# Production Rule
# (Expert System Rule)

1. **Propositional logic conceptualization:** rules are propositional logic formulas i.e.

Rules are:

$$C_1 \,\&\, C_2 \,\&\, \dots \,\&\, C_n \;\Rightarrow\; A$$

where $C_1$, … , $C_n$, A are atomic formulas

In this case atomic formulas are propositional variables or sometimes propositional variables and their negations

**All our book examples use propositional logic conceptualization!**

# Production Rules

## 2. Predicate Form conceptualization

**(knowledge representation)**

Rules are:

**$C_1$ & $C_2$ & … & $C_n$ => A**

where $C_1$, … , $C_n$, A are atomic formulas

**Atomic formulas** now represent **records** in the **database** and are written in a **triple form**:

**(x, attribute, value of the attribute) , or**

**(ID, attribute, value of the attribute)**

or in a **predicate form**

**attribute (x, value of the attribute ) ,**

**attribute (ID, value of the attribute )**

# Production System ES

**ES = (R, RI, DBF)**

**R** - is a finite set of **production rules**

**RI** – is an **inference engine** called **rule interpreter**

**DBF** – is a **database** of **facts** (changing dynamically)

Rules are always

$$C_1 \,\&\, \dots \,\&\, C_n \Rightarrow A$$

For $n >= 1$ and

$C_1, \dots, C_n$, $A$ are atomic formulas in a Knowledge Representation we work with

# Propositional Rule of Inference in ES

## Rules Interpreter RI

**Rule of inference of the Rule Interpreter is:**

$$\frac{C_1 \& C_2 \& \ldots \& C_n \Rightarrow A ; \quad C_1, \ldots, C_n}{A}$$

for $C_1, \ldots, C_n$ belonging to **DBF**

**APPLICATION** of the **Rule of Inference** means that

for a given **rule** of the production (**expert) system ES**

$C_1 \& \ldots \& C_n \to A$

the **rule interpreter RI** will **check database of facts DBF** and

**if all** $C_1, \ldots, C_n$ **belong to DBF**, the interpreter will **deduce A** and **add A** to the **database of facts DBF.**

We also say that the interpreter **"Fire the rule"** and **add** new **fact A** to the **database of facts**.

# Conceptualizations

**In Predicate Form Conceptualization**

**Facts** are certain **atomic formulas**

attribute (x, value of the attribute )

where the variable x is replaced (**unified** ) with record identifier ID

**In Propositional conceptualizations**

**Facts** are **propositional** **atomic formulas** i.e. propositional variables or

(sometimes) negations of propositional variables

# DBF – Database of Facts

The **content** of **DBF** (database of facts) is **changed cyclically** by the **rules interpreter RI**

**Facts** may have **time tags** so that the time of their insertion by **RI** in to **DBF** can be determined

**Example:** (propositional)
**DBF** = {A, B} and our ES has a rule
**A &B => C**

The interpreter **RI** matches A &B with **facts** A,B and **fires** rule and **adds C** to the DBF and new get
**NEW DBF = {A, B, C}**

# RI Rule Interpreter

**RI** works iteratively in **recognize-and-act** cycles

In a **ONE CYCLE**

1. **RI matches** the condition part of the rules against **facts (current state of DBF)**
2. **Recognizes** **all** applicable rules
3. **Selects** **one** of them and **applies it** **(fires, executes)**
4. **Adds** the **action part** of the applied rule (fired rule) to the current **DBF.**

**RI stops** when goal is reached (problem solved) or there are no more applicable rules.

# Predicate Form Conceptualization: Example

| Records | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|
| $O_1$ | 1 | 2 | 0 | 1 | 1 |
| $O_2$ | 0 | 0 | 1 | a | b |
| $O_3$ | 0 | 1 | 2 | 1 | a |

Constants: (key attributes) o1, o2, o3

Values of a1 are: 1, 0, values of a2 are: 2, 0, 1

values of a3 are: 0, 1, 2, values of a4 are: 1, a, and values of a5 are: 1, a, b

**TRIPLE PREDICATE FORM CONCEPTUALIZATION**

**Some Atomic Formulas that are NOT FACTS** are:

**$(x\ , a_1, 1)$, (x, a1, 0) , (x, a2, 2), (x, a5, a),** where x is a variable!

**Some Atomic Formulas that ARE FACTS in our data table** are:

**$(O_2, a_2, 0)$, $(O_2, a_3, 1)$, $(O_3, a_5, a)$,**

**Rule example:**

**$(x, a_1, 0)$ & $(x, a_5, a)$ => $(x, a_3, 1)$**

# Different Forms of Atomic Formulas

**Atomic formula** that is a **FACT** written in a **triple form**:

**($o_1$, $a_1$, 1)**

The same formula written in **predicate form** is: **$a_1$ ($o_1$, 1)**

**Atomic formula** that is **NOT a FACT** written in a triple form is

**(x , $a_3$, 1)**

The same formula written in **predicate form** is: **$a_3$ (x, 1)**

**In Busse Handout** the form of atomic formulas is:
(Entity, Attribute, Value), (person, Attribute, Value),

where Entity **represents a variable x,** person **represents a constant (like John):**

(x, Attribute, Value) , (John, Attribute, Value),

Where John **is a constant** and atomic formula becomes a FACT

**We will use x to denote variables** and we use the

**predicate form**: **attribute(x, value)**

# Different Forms of Atomic Formulas

| Name | a1 | Valuehouse | |
|---|---|---|---|
| John | yes | 100,000 | |

**Atomic Formula** that is a **FACT** written in a **predicate form**:

Valuehouse(John, 100,000)

**Atomic Formula** that is **NOT a FACT** written in a **predicate form:**

Valuehouse(x, 100,00)

x is a variable

In our Data Table: John is the key attribute

# Two Forms of Atomic Formulas

| ID | Eyes | Shoe Size | Children | House | Salary |
|---|---|---|---|---|---|
| John | Blue | 10 | 2 | Big | 100,000 |
| Mary | Green | 9 | 0 | Small | 5,000 |
| Anita | Green | 9 | 1 | Small | 3,000 |

1. Some **atomic formulas** from our database that are **facts** written in Busse's handout **triple form are**

   (John, Eyes, Blue), (Mary, Children, 0)

   (Mary, House, Small), (Anita, Eyes, Green)

2. Some atomic formulas that are not facts written in a **predicate form are** Eyes(x, Blue), House(x, Small)

Observe that the above formulas become **FACTS** when x becomes John or Mary. We say that **we MATCH** x in Eyes(x, Blue), with the record John, or with the record Mary in House(x, Small)

**We write it: Eyes(x, Blue){x/John) = Eyes(John, Blue),**

**House(x, Small){x/Mary} = House(Mary, Small)**

# Rule Interpreter RI

The **RI** works iteratively in **Recognize-And-Act** cycles. In such a cycle, RI:

1. **Matches** the condition part of the rules against the **facts** and **recognizes** all applicable rules
2. **Selects** one of the applicable rules and applies the rule i.e. **fires** or **executes** it : **adds fact (action part) to the database**

Rules have names, many have **time tag**.

**RI stops** when problem solved or **no rules are applicable**.

# Pattern Matching: **Unification**

**ES RULES** with atomic formulas that are **not FACTS** written in a **triples form:**

**(x, attribute, value)**

where a **variable** x is also called an **entity**

**Atomic formulas** that are **NOT FACTS** are:

**(x, attribute, value)**

**FACTS** are represented by similar triples, with entity as a **constant**. i.e. they are:

**(ID, attribute, value)**

# Pattern Matching: **Unification**

**Pattern matching –** is **matching** the variable x in the triple

**(x, attribute, value)**

with a **proper record** in the **database** identified by the key attribute ID, i.e. It **matching** with the **fact**

**(ID, attribute, value)**

**We write it as**

**(x, attribute, value) {x/ID} = (ID, attribute, value)**

**or**

**attribute(x, value) {x/ID} = attribute(ID, value)**

# Example

Lets look at a RULE in a predicate triple form representation

(person, yearlyincome, >$15,000) &

(person, valuehouse, >$30,000) **=>** (person, loantoget, <$3,000)

Person: variable x

**Rule Format is:** $C_1\ (x)\ \&\ C_2\ (x) \rightarrow A(x)$

(x, yearlyincome, >$15,000) &

(x, valuehouse, >$30,000) => (x, loantoget, <$3,000)

In "Plain English": If somebody has an yearly income greater the $15,000 and his/hers house has a value greater the n$30,000, then bank approves any loan smaller than $3,000.

Given Facts:

F1: (John, yearlyincome, >$15,000)

F2: (John, valuehouse, >$30,000)

PATTERN MATCHING

We assign (**UNIFY**) **x/John** (person/John)

We use the inference rule $C_1$ (x)**&**$C_2$ (x) → A(x) and matching $C_1$ (x)**&**$C_2$ (x) with $F_1$ & $F_1$ for x =John, where

A(x): (x, loantoget, <$3,000) i.e. we write

**$C_1$(x) &$C_2$ (x) → A(x) {x/John} ;** $F_1$ & $F_1$

**RI adds** new fact

**(John, loantoget, <$3,000)**

to the **DBF**

During a cycle of RI, most of the time is spent on **pattern matching = unification**

First the most popular efficient **pattern matching algorithm** was **RETE algorithm** (Forgy 1982)

It is used in a **rule-based** language OPS5, a language still being used for programming expert systems

**Fogy** gave a TALK in CS Stony Brook in Spring 2019 on the newest version of the language OPS5

and improvements of the **RETE algorithm**

Both still going strong

There also are many excellent new **unification techniques** and **algotithms**

They are mainly developed by researchers working in **Automated Theorem Proving** field of **AI**

It is still a large and vibrant area of **AI** reasearch

**Prolog** is based on the **predicate resolution** and

They are used for **Prolog** improvements

**Prolog** is the most natural, efficient and modern language to use in many **AI** applications

We will cover **Propositional Resolution** as the next subject

# ES Conflict Resolution

**RI recognition – part of the cycle** is divided into two parts

1. **Selection**: **identification of applicable rules** based on pattern matching and
2. **Conflict resolution**: **choice** of **which** rule to **fire** (apply, execute)

**There are many choice possibilities and we decide what we want to use while designing the system**

# Conflict Resolution Heuristics

Here are some **conflict resolution heuristics** (**choices**)

**Most specific rule**

- **Example:** rules P => R, P & Q => S are both applicable,
- we **choose** P & Q => S as it is **more specific** (contains more detailed information)
- **The rule using the most recent facts** : facts must have **time tags**
- **Highest Priority rule:** rules must have assigned priority
- **The first rule:** rules are linearly ordered
- **Principle: No rule** is allowed to **fire** more then once on basis of the same contents of **DBF**
- **We eliminate** firing the same rule all the time

# Production Rules and Expert System Rules

**Production rules** are the rules in which **actions** are **restricted exclusively** to **ADD FACTS to the DBF**

**Expert Systems** might contain also different rules; like rules about rules **(METARULES)**, **DOMAIN-FREE** rules, **DOMAIN specific** rules, or others.

**Rules** can have names (can be numbers, like R1, R2, … etc)

**Rules** often have **time tags** or other indicators, depending of **heuristics** used by RI module.

# Metarules

Metarules – are rules about rules.

Metarules may be **domain-specific**, such as:

**IF** the car does not start

**THEN** first check the set of rules about the fuel system

Metarules may be **Domain-free** (not connected with DBF) such as

**IF** the rules given by manual apply

**AND** textbook rules apply

**THEN**: check first manual rules

# Advantages and Disadvantages of Rules Based Expert systems

**Advantage**: modularity. Rules are independent pieces of knowledge so may be added or deleted.

They are easy to understand (should be)

**Disadvantages**: inefficiency of big production systems with non-organized rules

**Rules based expert systems are the most popular**

# Forward Chaining

Data -> Rules -> Goal

Also called DATA DRIVEN, BOTTOM UP, or ANTECEDENT chaining

During the SELECTION step of each cycle, the RI is looking for applicable rules by MATCHING (unifying) condition part of a rule with the CURRENT CONTENT of the DB;

Forward chaining is applied, i.e. the proper rule is FIRED and a new FACT (action part) is added to the DB.

Process TERMINATES when the GOAL is reached, or when all possible FACTS are already inferred from the INITIAL database.

# Backward Chaining

Also called GOAL-DRIVEN consequent chaining

- The production system ESTABLISHES whether a goal is supported by a given database

**Start with the goal**

-Applicable RULES are found by matching ACTION parts with the GOAL

$\mathbf{C_1 \wedge \ldots \wedge C_n \Rightarrow GOAL}$

Now the conditional part:

$\mathbf{C_1 \wedge \ldots \wedge C_n}$ is checked against the DB.

If all are (after matching) in DB, the solution is reached.

**If $C_i$ is not in DB**, we treat it as a **SUBGOAL** and **repeat.**

# Backward Chaining (re-captured )

GOAL = Fact F

Selected rule (by matching action parts with F)

(R) $C_1 \wedge \ldots \wedge C_n \rightarrow F$

1. **If all $C_1 \wedge \ldots \wedge C_n$ are in DB –** End
2. Let **C** be any of $C_1 \wedge \ldots \wedge C_n$ after unification and substitution, if needed.

**CASE when Propositional ATOMIC Include negation**

**If ~C is in DB, (R) can't be used and another rule should be selected**

3. **Neither C (nor ~C ) is in DB**, then **C is a SUBGOAL** and **we start over again as with F.**
4. **If no applicable rules exist, GOAL F is not established.** System may need new rules.

Usually, backward chaining is executed as depth-first search.

Backward chaining is used in applications with large data.

Forward chaining might produce too much.

Usually, mixed strategies are used.

# Example (Busse book)

Knowledge representation = propositional logic

CASE WHEN ATOMIC: VARIABLES OR NEGATION OF VARIABLES

RULES:

R1: IF the ignition key is on
AND the engine won't start
THEN the starting system (including battery) is faulty

R1 $A \wedge B \rightarrow E$

R2: IF E AND the headlights work
THEN the starter is faulty

R2 $E \wedge C \rightarrow G$

R3: IF E AND ~C
THEN the battery is dead

R3 $E \wedge \sim C \rightarrow I$

# Example (continued)

R4: IF the voltage test on the ignition switch shows 1 to 6 volts,
THEN the wiring between the ignition and the solenoid is OK

R4 D➔F

R5: IF F
THEN replace the ignition switch

R5 F➔H

**FACTS in the INITIAL DATABASE:**

A: The ignition key is on

B: The engine won't start

C: The headlights work

D: The voltage test on the solenoid shows 1 to 6 volts

^ |--------------------semantics--------------------------|

|

Syntax (in propositional logic representation): A, B, C, D

Initial DB

IDB = {A, B, C, D}

**Rules**

R1 A∧B ➔ E

R2 E∧C ➔ G

R3 E∧~C ➔ I

R4 D ➔ F

R5 F ➔ H

GOAL:

**Infer all possible facts from IDB**

1. **Rules are ordered by number**
   $R_1 < R_2 < R_3 < R_4 < R_5$

2. **And they are scanned by RI in this order and inserted into a queue**

**Conflict Resolution: ORDER (1) and**
**Fire a rule from the front of the queue (and remove it)**

**STEP 1: Applicable: R1, R4** Queue (front to rear): R1, R4

**Fire: R1 and add E to the IDB**

**NEWDB = {A, B, C, D, E}**

**STEP 2: (second cycle)** **E:** The starting system is faulty is added

- R1 is no longer applicable, since its action would add E, which is already in (new) DB (last in C.R.)
- R2 is applicable Queue (front to rear): R4, R2

Step2: R3 is not applicable; R4 is applicable (and is in queue); R5 is not applicable.

**R4 is FIRED** from the FRONT of the queue, removed from the queue and new fact

**F:** The wiring between the ignition and the solenoid is OK

Is added to the DB , now **DBF= { A, B, C, D, E, F}**

**STEP 3 (third cycle)** Queue: R2, R5

R5 is inserted, R2 is FIRED (and removed) and new fact

**G:** The starter is faulty

Is added to the DB, now **DBF = {A, B, C, D, E, F, G}**

**STEP 4 (fourth cycle)** Queue: R5

No new rules are applicable, so R5 is fired and new fact

**H:** Replace the ignition switch

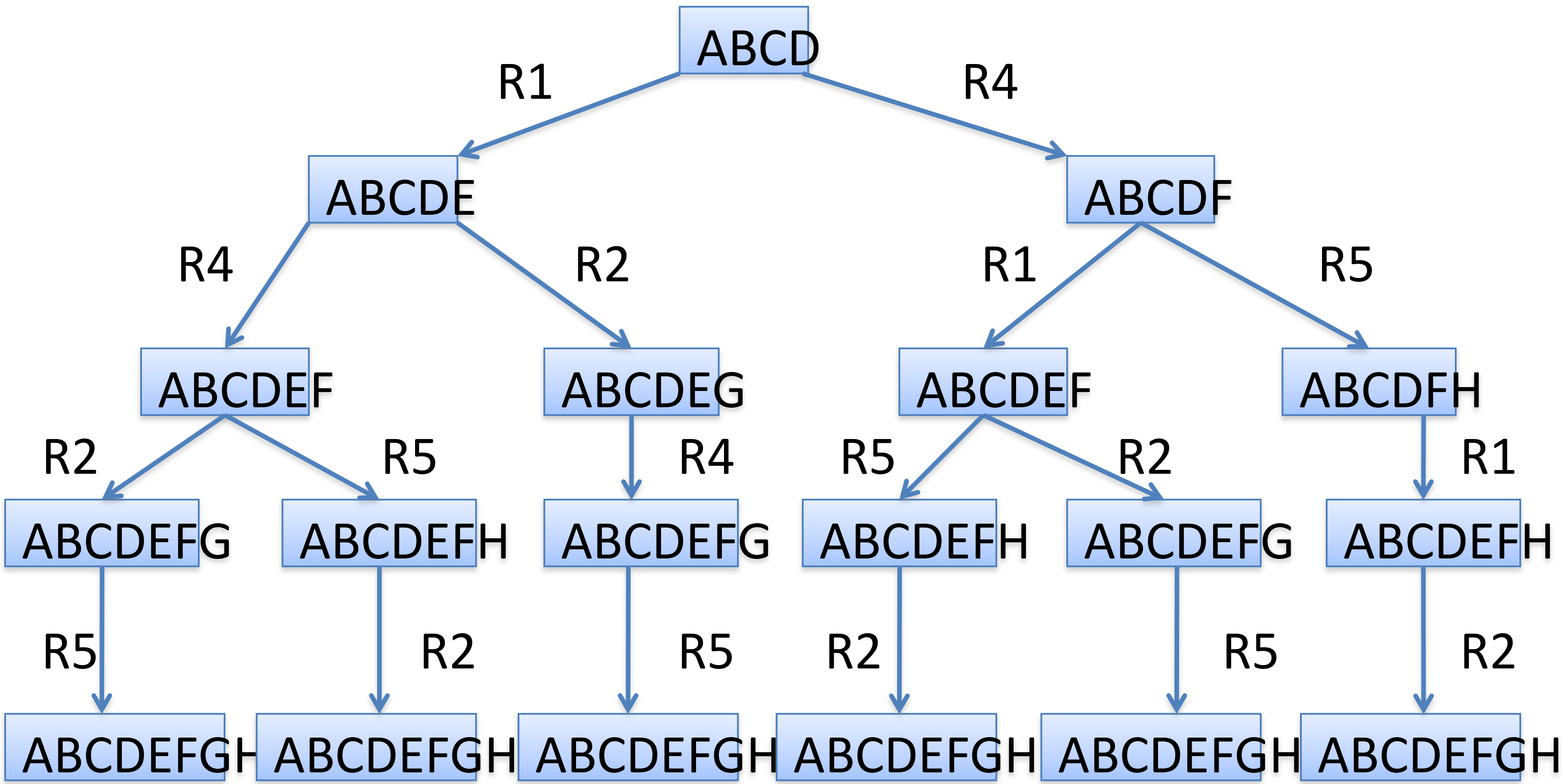
**Is added to the DB**

**STEP 5** No applicable rules (all are used!)

**DBF = { A, B, C, D, E, F, G, H}**

**RI STOPS COMPUTATION**

# Search Space




Goal: All possible facts deduced

# EXAMPLE 2

**Initial DB**

**IDB= {A, B, C, D}**

**GOAL**

**Use backward chaining to infer/reject**

**H∧I**

**Rules**

**R1** A∧B➔E; **R2** E∧C➔G; **R3** E∧~C➔I;

**R4** D➔F; **R5** F➔H

**First: Consider H. H is not in the DB**. The only rule that matches **H** (action) is

R5: F➔H

**Look at F;** It is not in the IDB, so **it is a SUBGOAL**. Applicable:

R4 D➔F, and D is in the IDB.

So, **F is SUPPORTED** and hence **H is supported.**

**Next: Consider I.** I is not in the DB, applicable rule is

R3 E∧~C➔I

**C is in the DB**, hence **R3 cannot be used**. R3 is the ONLY rule, hence **I is not supported** and

**GOAL H∧I is rejected**.

# Example 2 re-captured

Initial Database: DBF= {A, B, C, D}

**Rules**

**R1: A & B => E**

**R2: E &C => G**

**R3: E & ¬ C => I**

**R4: D =>F**

**R5: F => H**

**Backward Chaining Goal : H & I**

**First**: Consider H.

H is not in DBF only rule that matches H ( as action) is R5.

**R5: F => H**

**Look at F;** F is not in DB, so F becomes a **subgoal**

**Applicable: R4: D =>F,** and D is in DBF so

F is **supported** and hence **H is supported.**

# Example 2 continued

**Next:** check I.

I is not in DBF, only applicable rule is **R3: E & ¬ C => I**

C is in DB, hence R3 can't be used.

R3 is the only applicable rule, hence **I is not supported** and **GOAL H & I is rejected.**

# Propositional Logic Conceptualization

## Example 3

R1: If you are hot, then turn thermostat down

R2: If you are not hot and window is open, then close the window

R3: If the thermostat is turned down and you are cold, then open the window

1. **Conceptualize this system in propositional logic**
2. **Design questions the program has to ask the user to achieve the goal: "open the window" by backward chaining and conflict resolution**

# Example 3 Rules revisited

**R1:** hot => turn down termostat

**R2:** ¬ hot & window open => close window

**R3:** thermostat down & cold => open window

**GOAL:** open window

The GOAL has to be reached by use of conflict resolution and rules R1, R2, R3 from **a certain database of fact.**

We need to build our **DBF** by asking user some questions

ATOMIC: variables, negations of variables

# Propositional Logic Conceptualization 1

CASE WHEN ATOMIC: VARIABLES OR NEGATION OF VARIABLES

**H** – you are hot **¬ H** – you are not hot

**O** – window open (open window)

**D** – Thermostat down

**W**- close window (closed window)

**C**- you are cold

**R1: H => D**

**R2: ¬ H & O => W**

**R3: D & C => O**

**Goal: reach O** by backward chaining

- **You need to build your DBF by asking questions**.

# Example 3

In order to reach the goal  we have only one rule applicable:

**R3: D & C => O**

We have two **subgoals**: **D, C**

We  get **D** by  **R1: H => D**  and **D** becomes a **subgoal**.

**No applicable rule, so we need ask a question about H.**

**Question:**  Are you hot (**H**) ?

**If answer   is YES**:  we ADD **H** into DBF , i.e.

DBF = {H}  and we apply (fire ) **R1: H => D**   and get **D.**

**D is supported**

We look now for **C**, **no applicable  rule, so we need ask a question  about**  **C**

# Example 3 continued

**Question:** Are you cold (**C**)?

**If answer is YES,** we ADD **C** into DBF, and **C is supported ,**

and the **GOAL O is SUPPORTED.**

**If answer to the question:** Are you hot (**H**) ?

**is NO,** we added ¬ H to DBF, i.e DBF = {¬ H} .

No applicable rule, we STOP,

**GOAL O IS REJECTED**.

# Propositional Logic Conceptualization 2

CASE WHEN ATOMIC: VARIABLES OR NEGATION OF VARIABLES

**H** – you are hot

**WO**– window open

**OW –** open the window

**D** – Thermostat down

**CW**- close the window

**WC**- window closed

**C**- you are cold

**R1: H => D**

**R2: ¬ H & WO => CW**

**R3: D & C => OW**

**Goal: reach OW** by backward chaining

- **You need to build your DBF by asking questions**.

# Propositional Logic Conceptualization 3

CASE WHEN ATOMIC: VARIABLES (no negation)

**H** – you are hot **NH** – you are not hot

**WO**– window open

**OW –** open the window

**D** – Thermostat down

**CW**- close the window

**WC**- window closed

**C**- you are cold

**R1: H => D**

**R2: NH& WO => CW**

**R3: D & C => OW**

**Goal: reach OW** by backward chaining

- **You need to build your DBF by asking questions**.

# PREDICATE FORM Conceptualization

**OBSERVATION:**

**FACTS are always true in ES Database**

For example a Fact:

**(car#42, battery, weak), or battery(car#42,weak)**

means that in our database we have a record

| Key | Other attribute | Other attribute | Battery | | |
|---|---|---|---|---|---|
| Car#42 | | | weak | | |

# Example 4:  Predicate Conceptualization

| Key | Other attribute | Other attribute | Battery | | |
|---|---|---|---|---|---|
| car#42 | | | weak | | |

Another way of writing the fact **(car#42, Battery, weak)** is:

**Battery(ar#42, weak)**

This is called a **predicate form**

**Atomic formula** written in a **triple form** is:

**(x, Battery, weak)** , or **(ID, Battery, weak)**

**First is not a FACT, second is a FACT.**

**Atomic formula** written in a **predicate form** is:

**Battery(x, weak)**

**Atomic formula that is a fact is**

**Battery(c#42, weak)**

# Example 5: given a **DB**

| Cars | Battery | Color | Buy | PutGarage |
|---|---|---|---|---|
| $C_1$ | good | red | no | |
| $C_2$ | weak | black | no | |

The **DB** represents the following **FACTS**: (in triple form)

F1. **($C_1$, Bbttery, good)**

F2. **($C_1$, color, red)**

F3. **($C_1$, buy, no)**

F4. **($C_2$, battery, weak)**

F5. **($C_2$, color, black)**

F6. **($C_2$, buy, no)**

We want to use the expert system rules to PUT cars into proper garages, i.e. to fill missing values of the attribute PutGarage. We assume that we have two garages: G1, G2.

**WHAT IS WRONG WITH THIS PROBLEM???**

# WHAT IS WRONG WITH THIS PROBLEM???

| Cars | Battery | Color | Buy | PutGarage |
|---|---|---|---|---|
| $C_1$ | good | red | no | |
| $C_2$ | weak | black | no | |

The **DB** represents the following **FACTS**: (in triple form)

F1. **($C_1$, battery, good)**

F2. **($C_1$, color, red)**

F3. **($C_1$, buy, no)**

F4. **($C_2$, battery, weak)**

F5. **($C_2$, color, black)**

F6. **($C_2$, buy, no)**

We want to use the expert system rules to PUT cars into proper garages, i.e. to fill missing values of the attribute PutGarage. We assume that we have two garages: G1, G2.

**NONE OF LISTED FACTS** F1, F2, ...F6 **BELONGS to the DB!!!**

**ATTRIBUTES are: Battery, Color,Buy – NOT- battery,color, buy**

# Example 6: CORRECTED

| Cars | Battery | Color | Buy | PutGarage |
|---|---|---|---|---|
| $C_1$ | good | red | no | |
| $C_2$ | weak | black | no | |

The CORRECT **DB** representing **FACTS**: in **PREDICATE Form is**

F1. **Battery($C_1$, good)**

F2. **Color($C_1$, red)**

F3. **Buy($C_1$, no)**

F4. **Battery($C_2$, weak)**

F5. **Color($C_2$, black)**

F6. **Buy($C_2$, no)**

Use the expert system rules (next slide) to PUT cars into proper garages, i.e. to fill missing values of the attribute PutGarage. We assume that we have two garages: G1, G2.

# Predicate Rules Interpreter RI

A Predicate Rule of inference of the Rule Interpreter is:

$$\frac{C_1(x) \& \ldots \& C_n(x) \Rightarrow A(x)\ \{x/ID\};\ C_1(ID) \ldots C_n(ID)}{A(ID)}$$

**APPLICATION** of the **Predicate Rule of Inference** means that

for a given **rule** of the production (**expert) system ES**

$C_1 \& \ldots \& C_n \rightarrow A$ i.e. $C_1(x) \& \ldots \& C_n(x) \rightarrow A(x)$

the **rule interpreter RI** will check **database** (or database of facts) and **match** (unify) $x$ with a proper **record identifier** ID (constant ID), if possible and evaluate

$C_1(x) \& \ldots \& C_n(x)\{x/ID\} = C_1(ID) \& \ldots \& C_n(ID)$

**if all $C_1(ID), \ldots C_n(ID)$ belong to DBF**, the **Interpreter RI** will **deduce**

$A(x)\{x/ID\} = A(ID)$ and **add** $A(ID)$ to the **database of facts DBF.**

# Example 5

Some Rules in our ES (in a triple form) are:

**R1. (x, Battery, good) & (x, Color, red) =>**

**(x, PutGarage, 2)**

**R2. (x, Battery, weak) & (x, Buy, no) =>**

**(x, PutGarage, 1)**

- **Matching (**Unification): we unify x in the **R1** with C1 and we get

**(x, Battery, good) & (x, Color, red) ){x/C1} = F1&F2**

**(x, PutGarage, 2){x/C1}= (C1, PutGarage, 2)**

# Example 5

Rules in **our ES** (in a triple form) are:

**R1. (x, Battery, good) & (x, Color, red) =>**

**(x, PutGarage, 2)**

**R2. (x, Battery, weak) & (x, Buy, no) =>**

**(x, PutGarage, 1)**

- Matching (Unification): we unify x in the rule **R2** with C2 and we get

**(x, Battery, weak ) & (x, Buy, no) ){x/C2} = F4&F6**

**(x, PutGarage, 1){x/C2}= (C2, PutGarage, 1)**

# Example 5: Extended Data Base

| Cars | Battery | Color | Buy | PutGarage |
|---|---|---|---|---|
| $C_1$ | good | red | no | 2 |
| $C_2$ | weak | black | no | 1 |

We used the expert system rules **to PUT cars into proper garages,** and
As a consequence we filled the
missing values of the attribute PutGarage.

**EXERCISE:** Repeat it all writing rules in **PREDICATE Form**