Rules based approaches

Where to find Knowledge and how to manage and use it?

Fuzzy Logic, CSP and Expert Systems

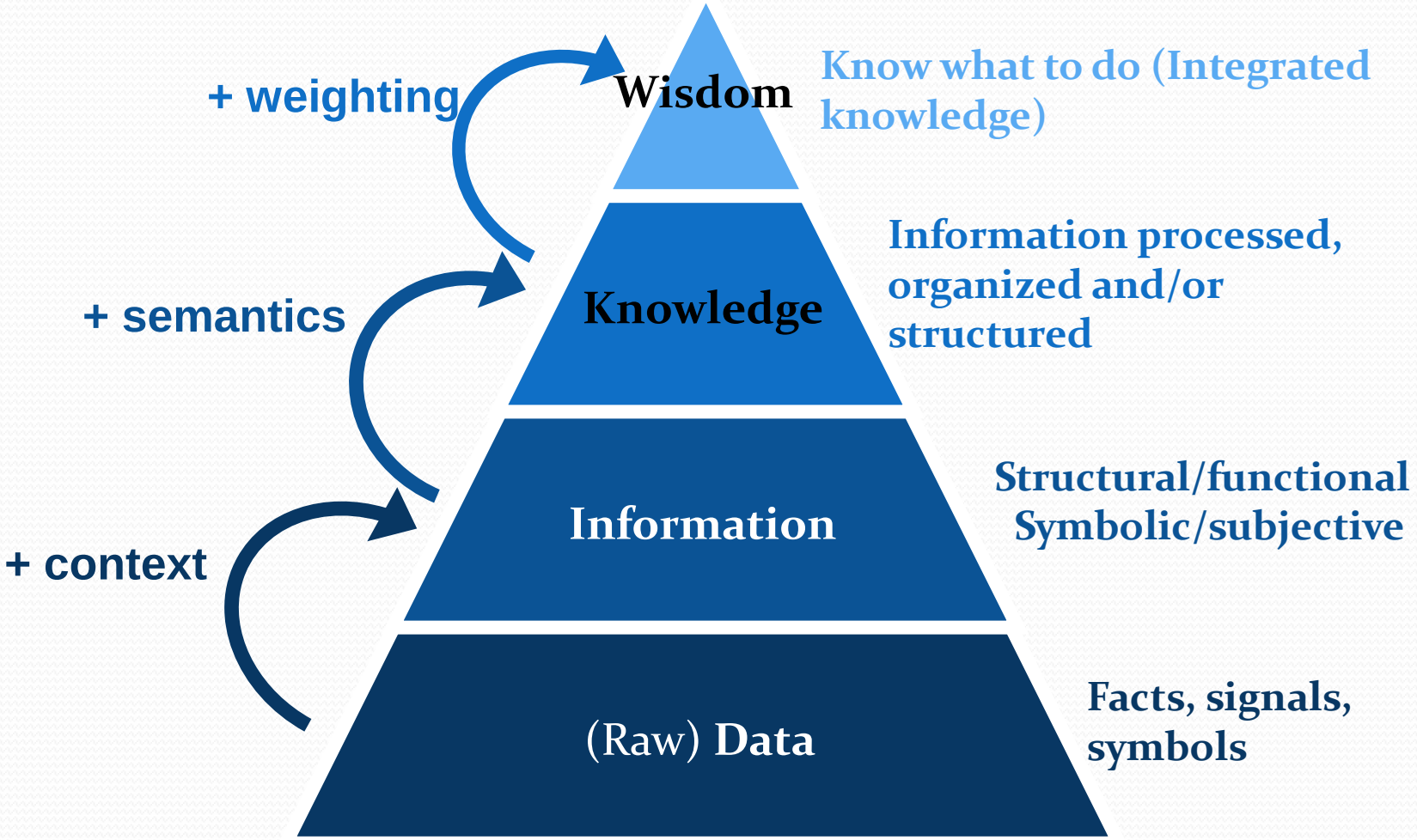
Why modeling Knowledge ?

This work is needed to:

- Secure the knowledge of one expert in case of its absence (retirement, illness…
- Spread its expertise to all company
  - To communicate with upstream activities
  - To train new colleagues
- Compare viewpoints of experts
- **Be able to automate part of the work of the expert in order to save his time and so to enable him to focus on more difficult/important issues.**

At this point, the object under study is not data nor information but **Knowledge**. Next sections explain several solutions used to express and store these habits in order to be able to re-use it.

From data to Knowledge



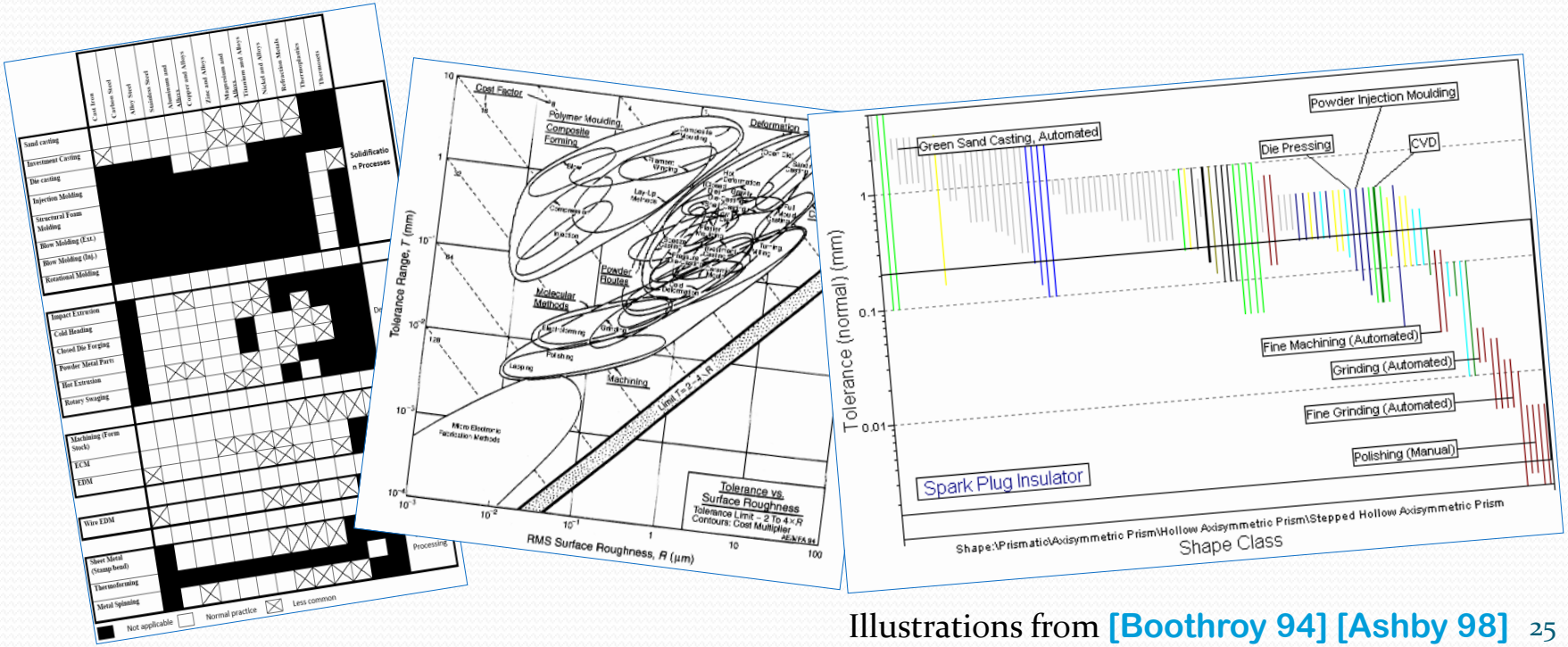
[Balmisse 2015]

Charts, abacus and graphs

A simple way to capitalize and formalize expertise or results from experiments (ReX) is the use of charts. Several tables or charts are available in the scientific literature, books or catalog of tools suppliers:

- Relationship between Process and Material
- Relationship between Process and expected Quality
- Relationship between Process and Geometry of the Product…

Easy to store and use, even more thanks to online databases and selection tools !



Illustrations from [Boothroy 94] [Ashby 98]

Charts example - Process / Material

Example of a chart (extracted from [Boothroy 94]) dealing with the compatibility of Processes and Materials, based on mainly experience and knowledge of the processes limits.

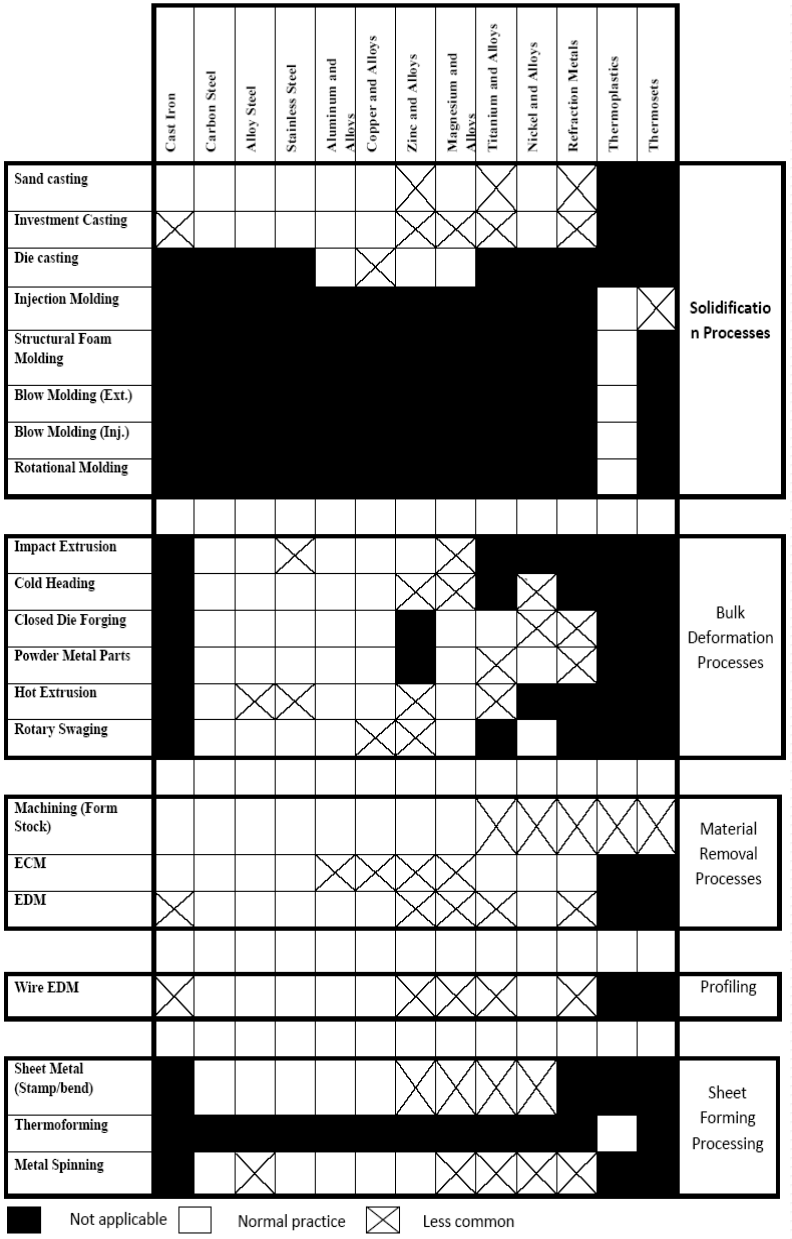


Chart example - Process / Material

For instance the operating range defined with Prof. LANGLOIS for Friction Stir Welding (FSW), based on several experiments.

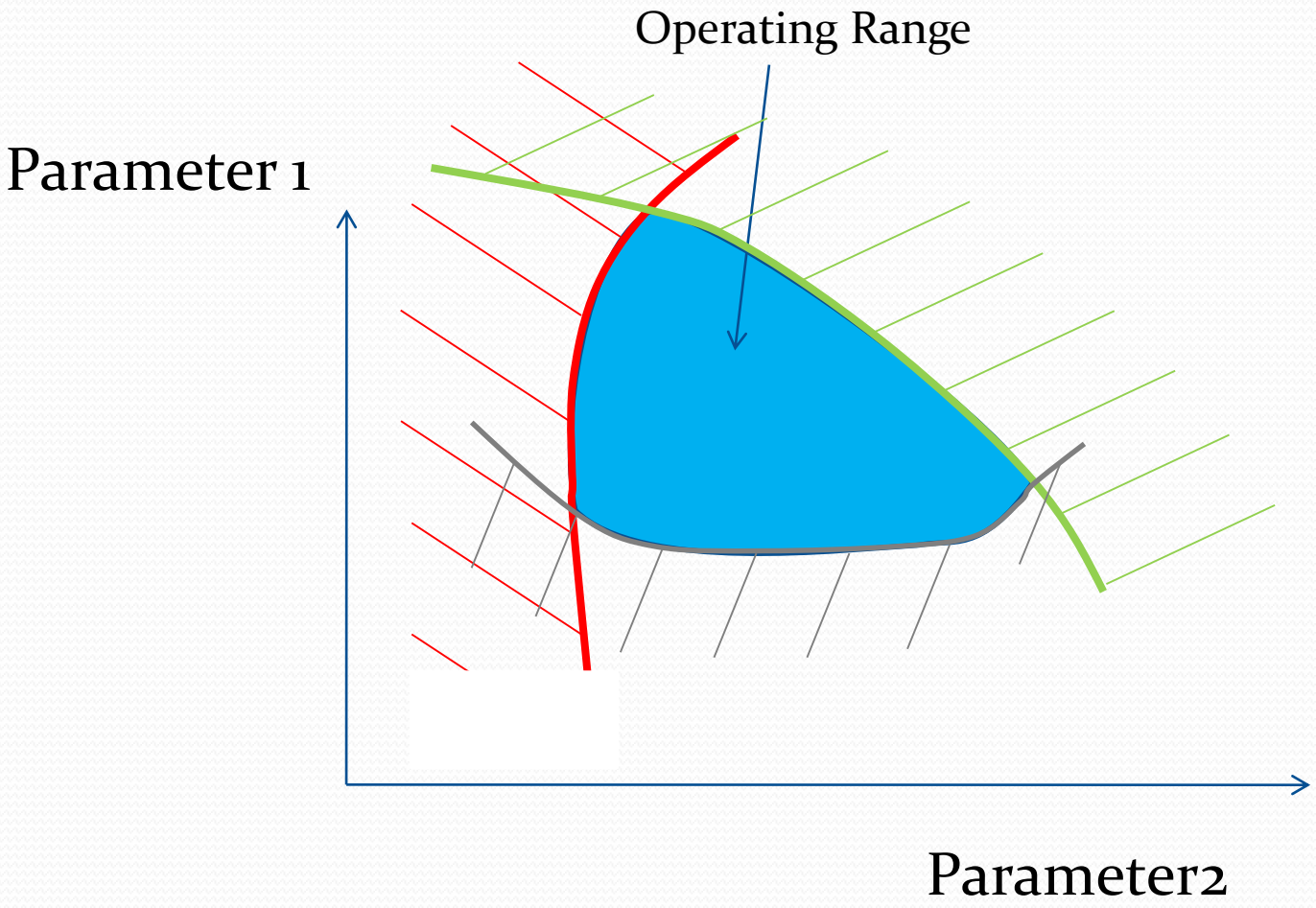


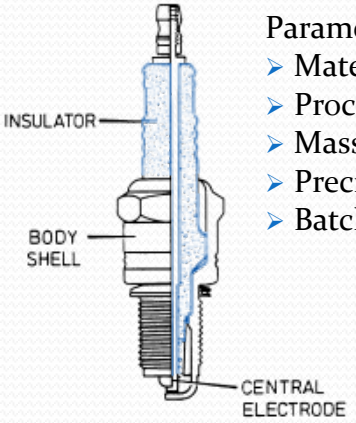
Chart example - Process / Quality

A lot of works were performed by M. Ashby and his teammates to propose graphs helping engineer to select both: Material and Manufacturing Process. From these works emerged one tool: CMS (Cambridge Material Selector), currently named CES.

This tools is a huge database where the user can define:

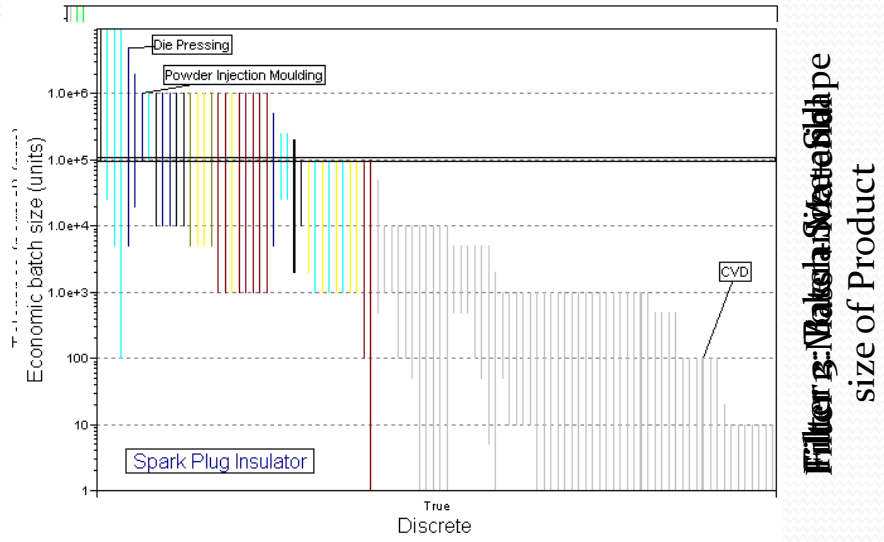
- What he is looking for(find a material or a process or both)
- The Product he aims to produce (Geometry class, weight…)
- The several constraints (roughness, geometrical tolerances…)

After these definitions, the tool applies these constraints and screens the resulting processes.



Parameters Definition:

- Material Class: **Ceramics**
- Process Class: **Primary**
- Mass: **0.05 kg**
- Precision: **0.2mm**
- Batch Size: **100 000**

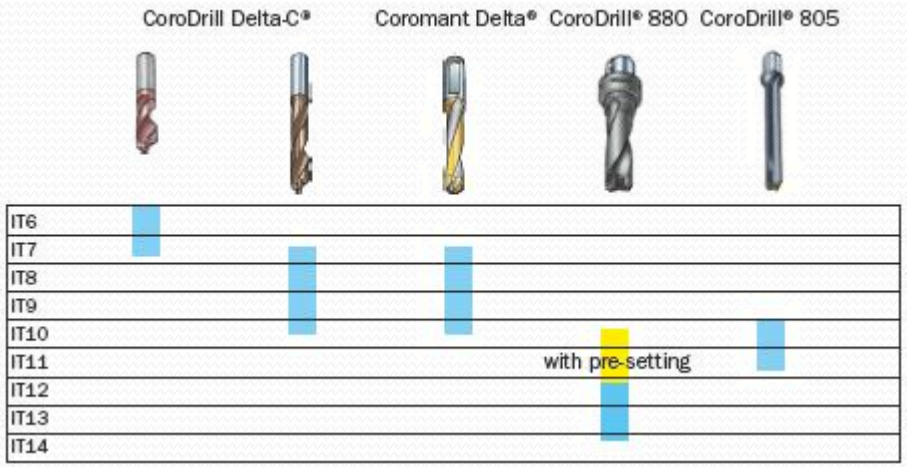


Example extracted from [Granta 12]

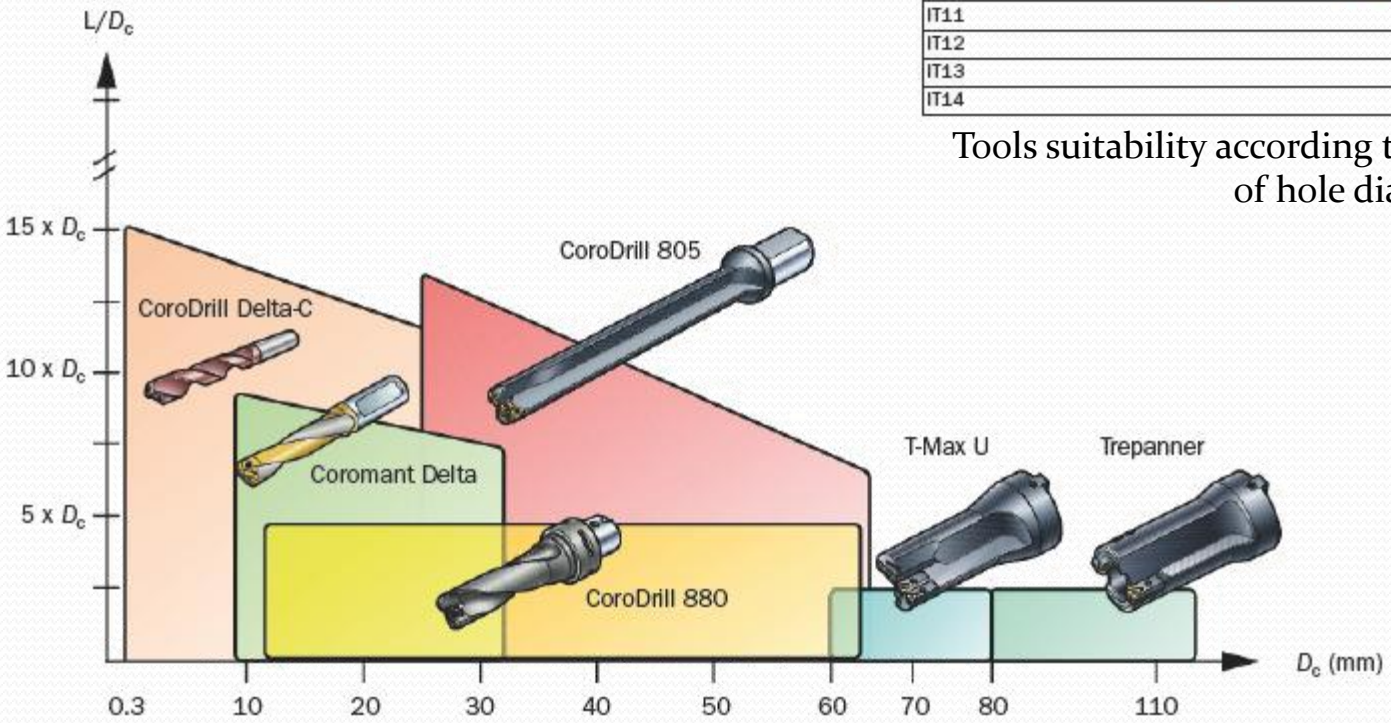
Chart example - Geometry / Tool

Several expertise can be found in supplier catalog where some process rules are formalized!

Here, two examples from the SandVik Coromant catalog [SandVik 12].



Tools suitability according to Geometrical tolerance of hole diameter



Tools suitability according to Geometrical parameters of hole feature (diameter and Length)

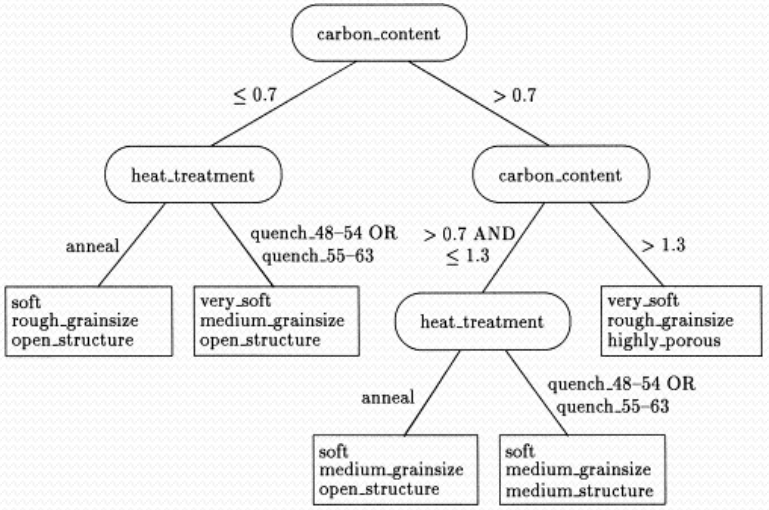
Production Rules

The most commonly used for the formalization of Knowledge (in the context of Process plan design) is the Production Rule. Its syntax is recognizable as:

If **<set of conditions to met>**
Then **<set of actions to perform>**
Else **<set of other actions to perform>**.

Several improvements of this approach were proposed such as:

- Ranking of these rules (mainly with weight parameters). Indeed, when several rules can be triggered in the same time it is needed to express a preference.
- Since these rules do not concern the same level of detail (some concern the choice of conceptual process plan some other one precise parameter of a tool for instance), a commonly solution is to structure them into a decision tree.



Decision tree extracted from **[Filipic 00]**

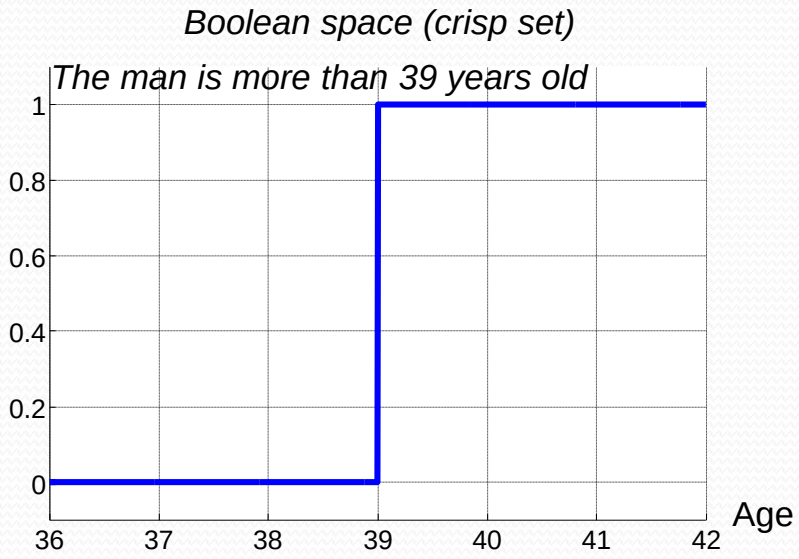
Production Rules - Drawbacks and Limits

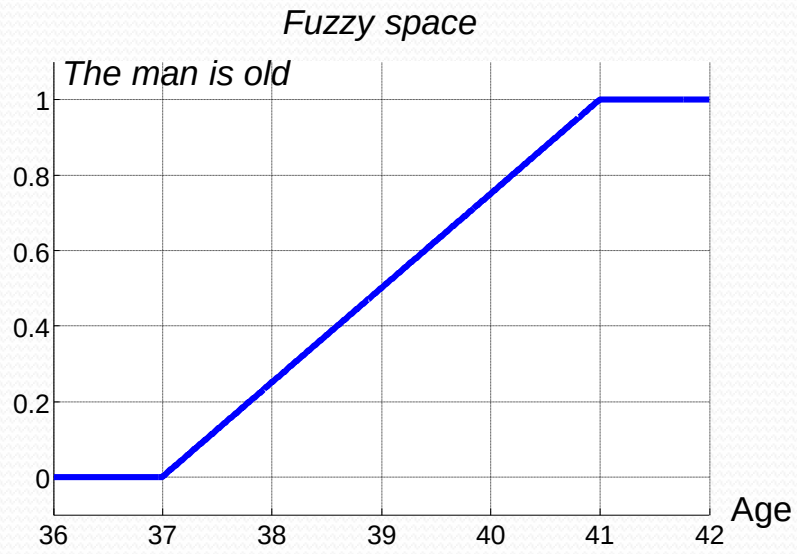
The drawbacks of this approach which is really easy to implement in simple algorithms are:

- The difficulty to identify and express rules:
  - It is difficult for expert to **identify and express how they work** and what is the different steps of their reasoning.
  - Experts of the domain (and so who are the most suitable to express rules) are not computer scientist: it is then difficult to **translate these rules into logical language** which are used to code rules.
  - The previous drawback can be solve thanks to the service of a Knowledge engineer. However adding an intermediate in the extraction flow decreases the quality of the Knowledge extracted.
  - How expert systems can manage rules based on **natural / Human expression** of Knowledge? Example: *If the hole is **large** then…* What *large* means, how to express it into rules? **[Derras 98]**
- The difficulty to manage these rules:
  - Difficulty of managing the **consistency** of hundreds of rules
  - Difficulty to perform the **maintenance** of rules base (to modify, add and remove rules)

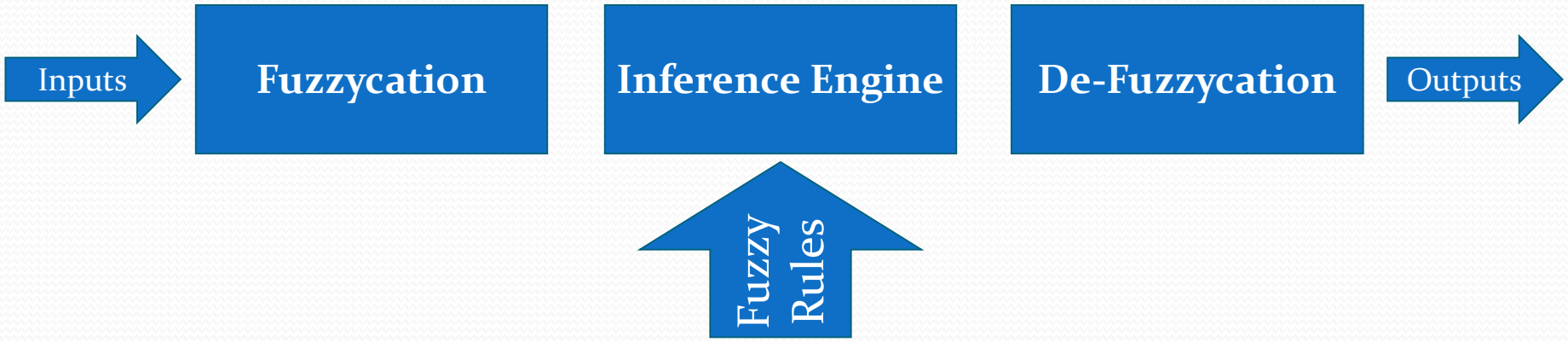
Fuzzy Logic Rules

As opposed to rules expressed with the structure *If… Then…* where conditions are Boolean (the conditions are fulfill or not), Fuzzy Logic adds **degree of membership (validity) of conditions** (conditions can be in more than 2 states). This flexibility is useful for the management of unclear rules and uncertainties.





Fuzzy Logic Process



Example of the evaluation of the waiter fee.

Inputs:

- The quality of the food
- The quality of the service

Output:

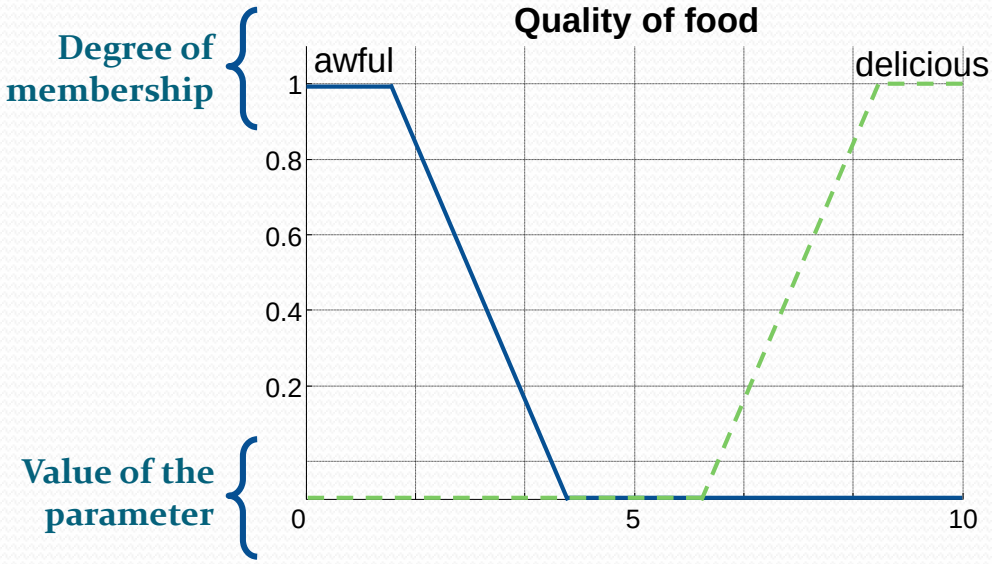
- The fee amount

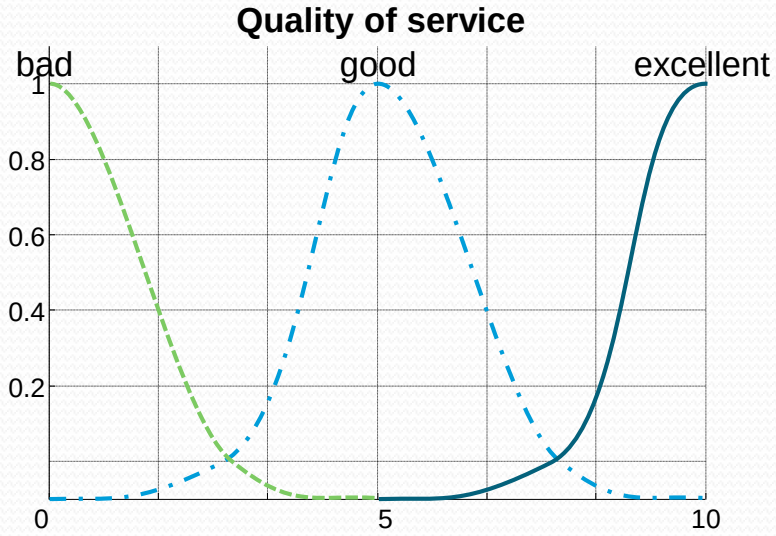
Rules:

- If the service is bad or food is awful then fee is low
- If the service is good then fee is ordinary
- If the service is excellent or food is delicious then fee is high

Fuzzy Logic - Parameters

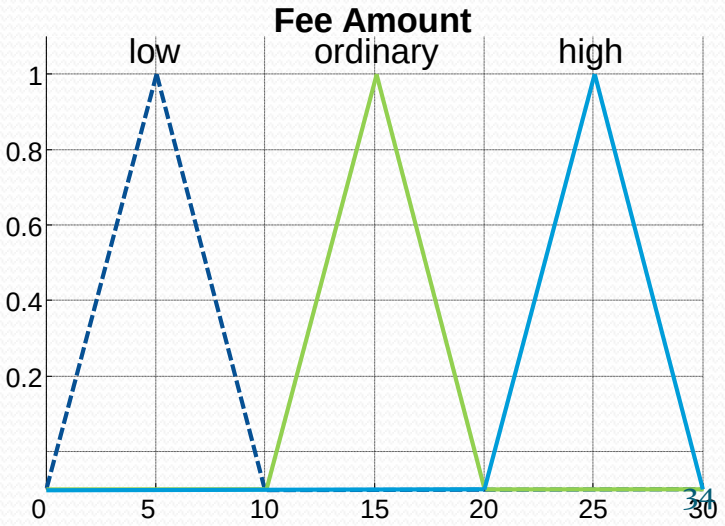
- Step one: Describes the variables in the fuzzy domain:





The aim is to quantify this fuzzy aspect by adding a law linking real numbers and fuzzy descriptions.

The fuzzy laws are not necessary linear. A part of the Knowledge is in the choice of these laws…



Fuzzy Logic - Rule definition

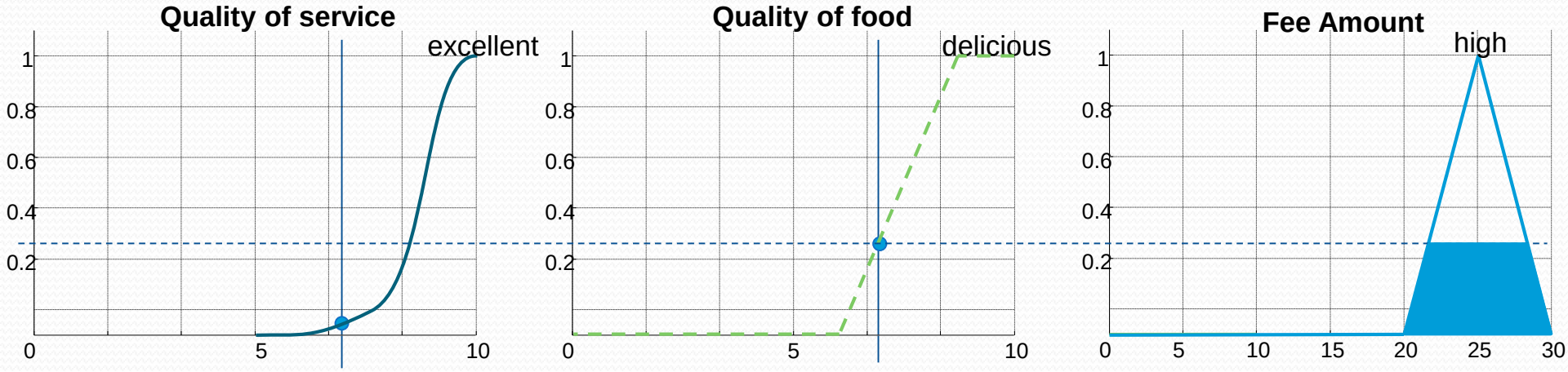
- Step two: Apply the rules.

  In the fuzzy world, the Boolean operators must be adapted [Mamdami 77]:

  - A **AND** B is transformed to $\boldsymbol{Min}(\boldsymbol{f_a}(\boldsymbol{x}), \boldsymbol{f_b}(\boldsymbol{x}))$
  - A **OR** B is transform to $\boldsymbol{Max}(\boldsymbol{f_a}(\boldsymbol{x}), \boldsymbol{f_b}(\boldsymbol{x}))$

  Consequently, the third rule is graphically represented as:

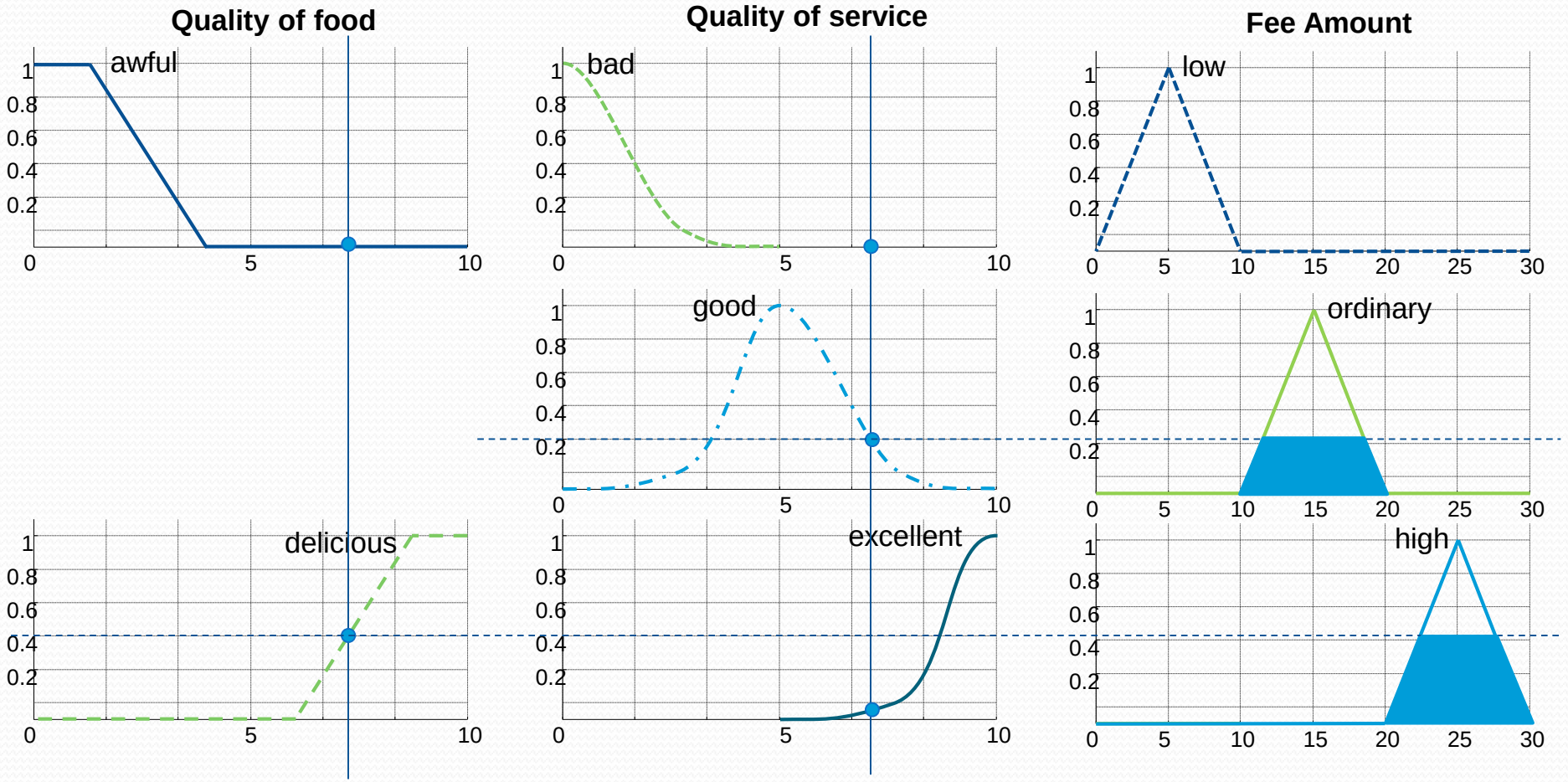
IF the service is excellent *OR* *food is delicious* *THEN* *fee is high*



And what append for this rule in the case of Quality of service is noted as 7/10 and Quality of food as 7/10 too?

Fuzzy Logic - Inference

Same question with the three rules and the case previously defined:



Fuzzy Logic - Inference

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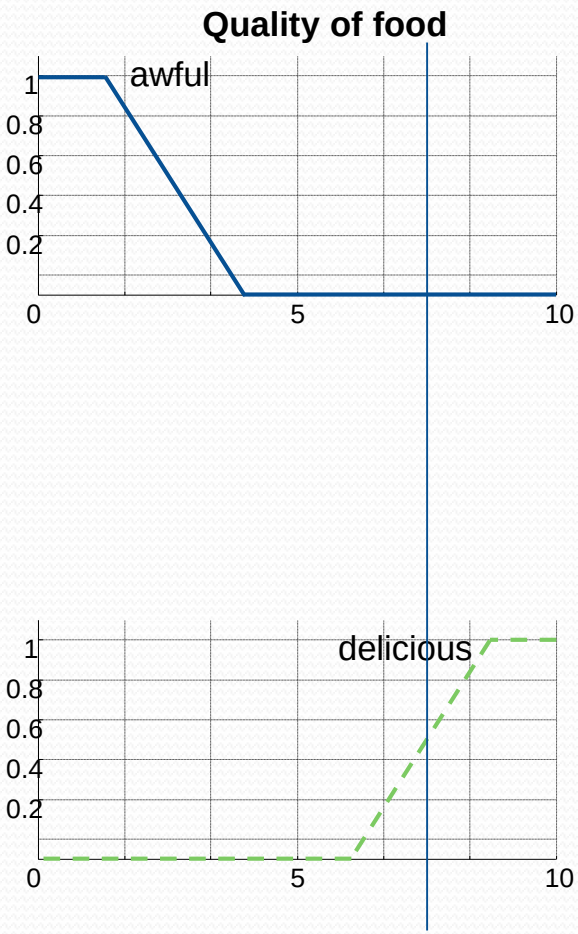
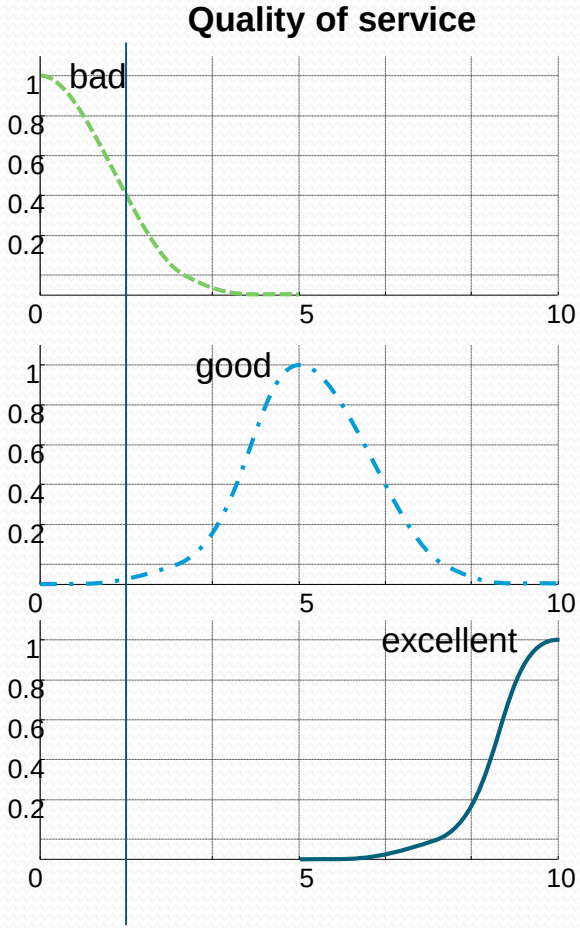
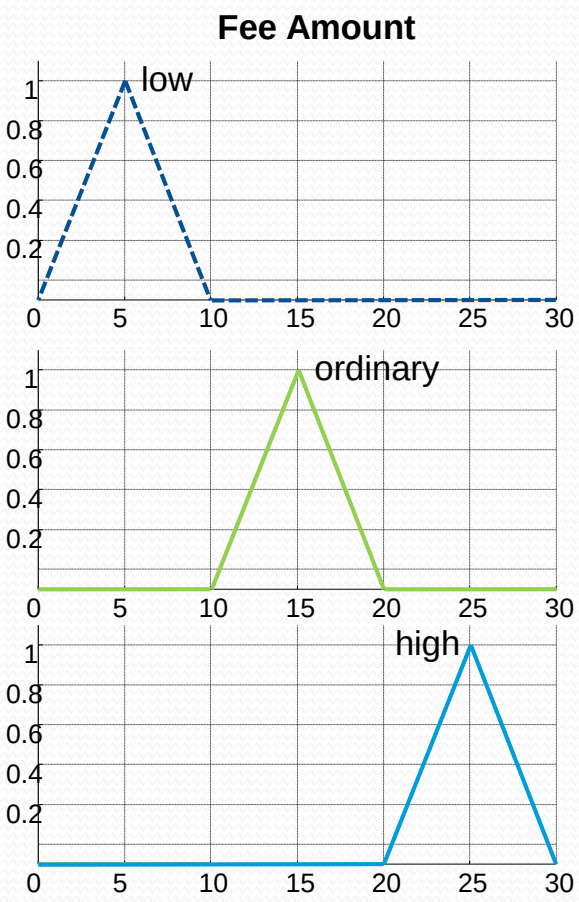




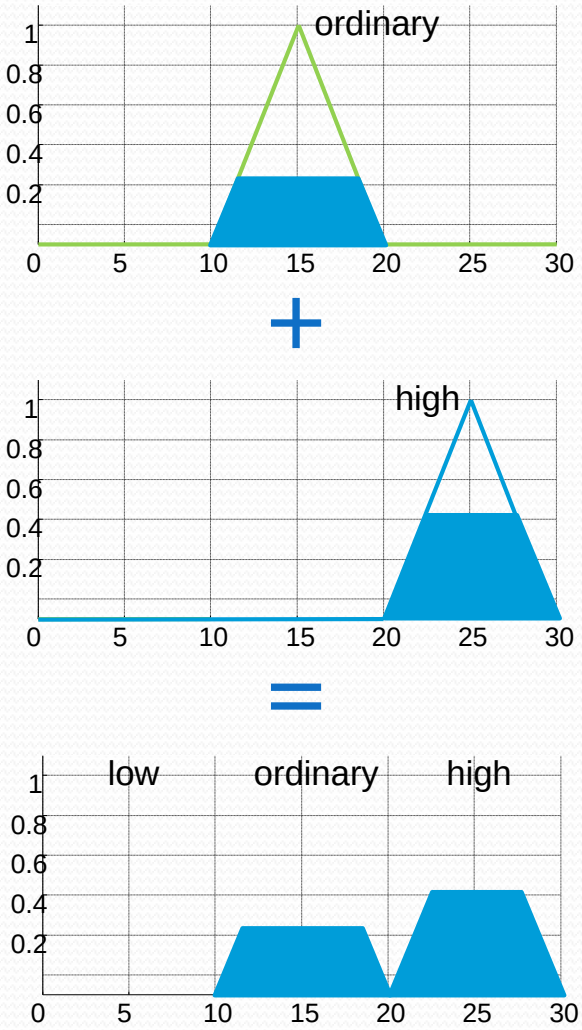


Fuzzy Logic - Aggregation

- Step two: Aggregate the result of the fired rules.

  This aggregation can be carried out by using several operators such as ***Sum*** or ***Max***.

  In this example, ***Sum*** operator is used:



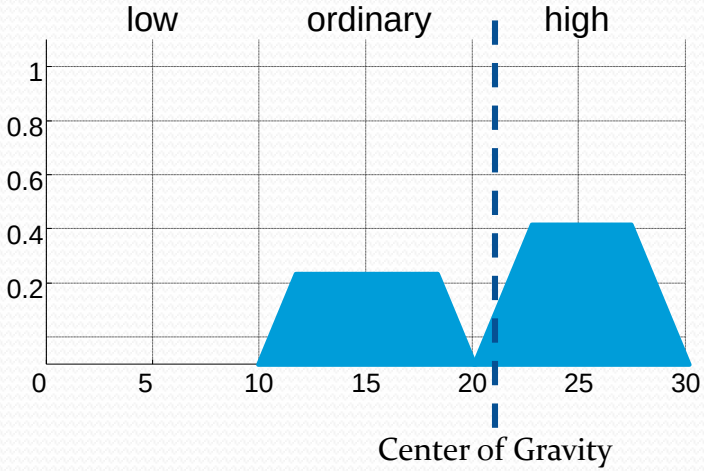
Fuzzy result: the fee is both ordinary and high.

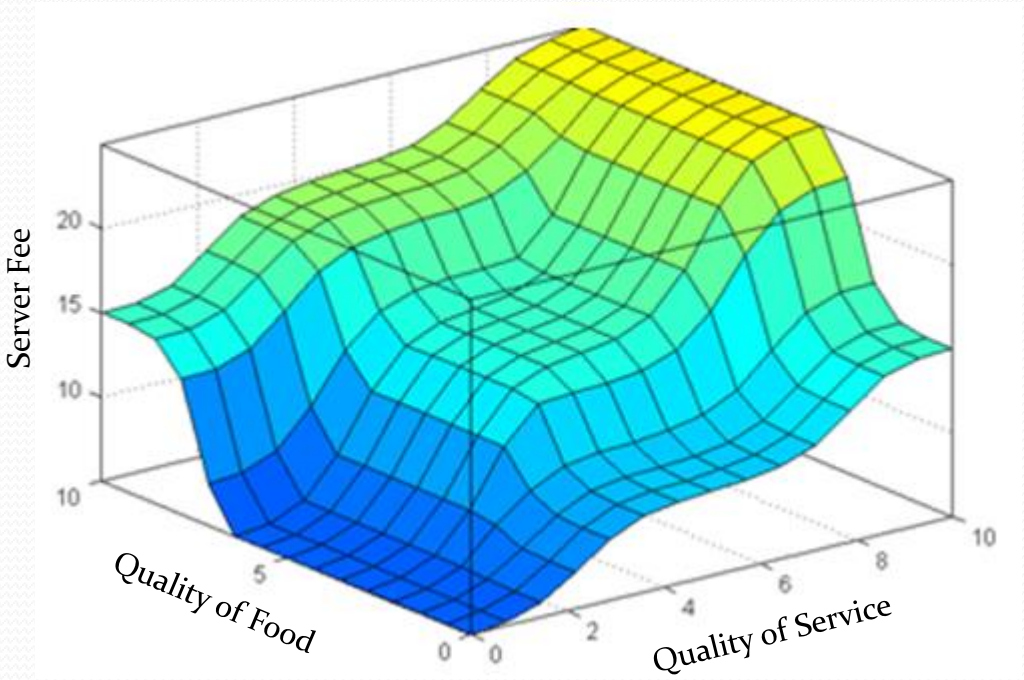
Next step: How to switch to the real world?

Fuzzy Logic - Defuzzication

- Step three: De-fuzzy

Since the previous calculus is still fuzzy (and so in two states which is not possible in real world) the next step is to find a criteria to choose only one value. Among the several solutions proposed in the literature, the center of gravity or the mean of maxima are commonly used.

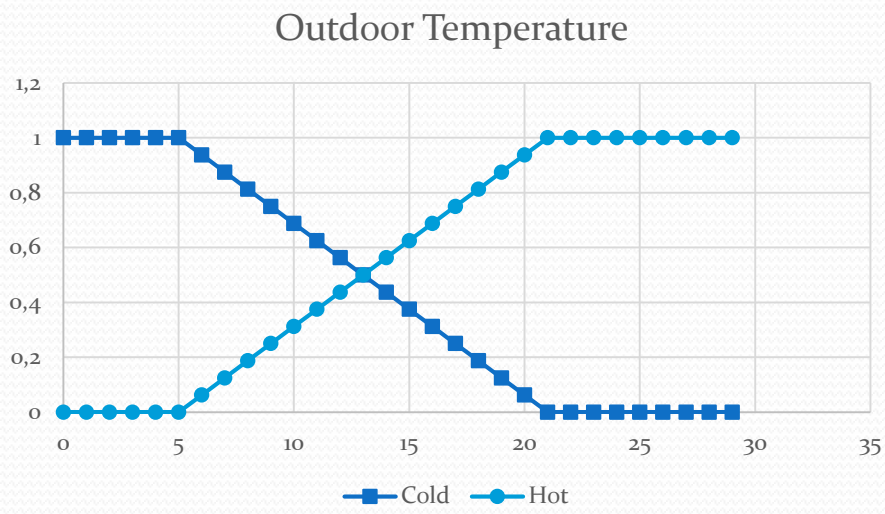


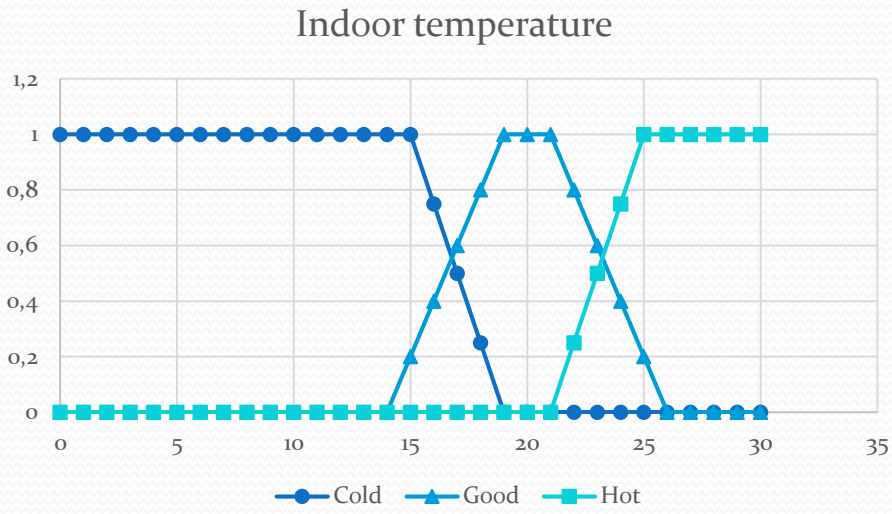


As a result of this problem, if we explore the definition domain of the two parameters (food and service qualities), the fuzzy tool gives the surface of the fee illustrated above.

Fuzzy Logic : Exercise 1 - Heating System

We want to control the heating system of ENSAM school thanks to 2 temperature probes and one fuzzy logic controller. The behavior of the fuzzy controller is based on the following parameters definitions:





The output Parameter (Heating Power), follows singleton fuzzy set:

- Null, for a heating power of 0%
- Poor, for a heating power of 33%
- Normal, for a heating power of 67%
- Maximum, for a heating power of 100%

Fuzzy Logic : Exercise 1 - Heating System

6 fuzzy rules are defined:

1. IF Outdoor T° is Cold AND Indoor T° is Cold THEN Power is Maximum
2. IF Outdoor T° is Cold AND Indoor T° is Good THEN Power is Normal
3. IF Outdoor T° is Cold AND Indoor T° is Hot THEN Power is Poor
4. IF Outdoor T° is Hot AND Indoor T° is Cold THEN Power is Normal
5. IF Outdoor T° is Hot AND Indoor T° is Good THEN Power is Poor
6. IF Outdoor T° is Hot AND Indoor T° is Hot THEN Power is Null

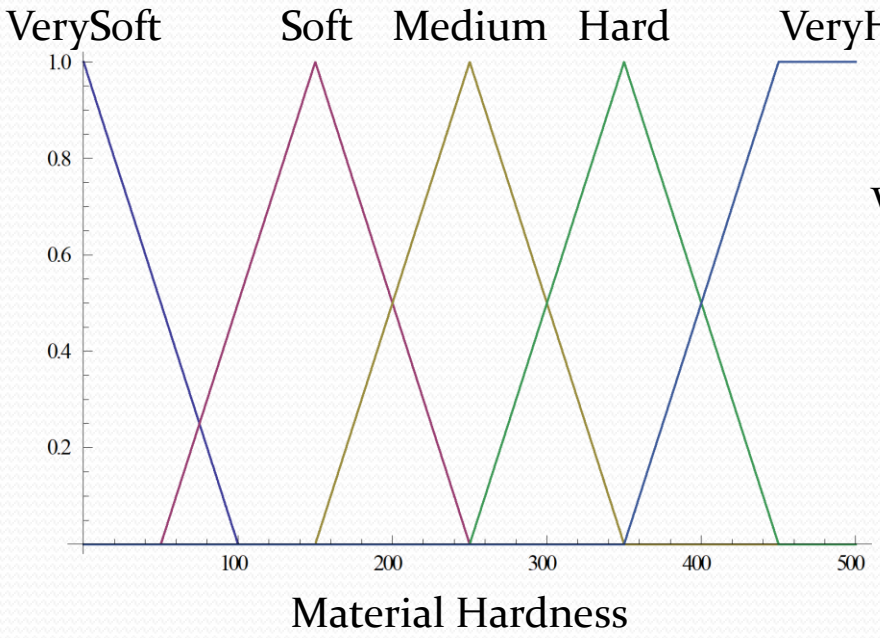
Aggregator operator: **Max**

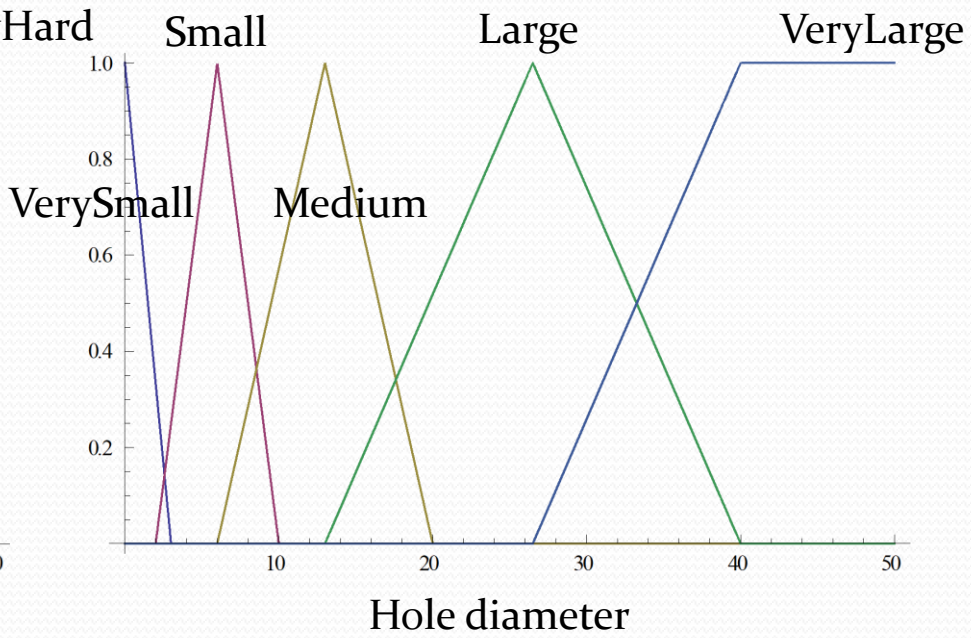
Defuzzycation operator: **CoG (Center of Gravity)**

Calculate the *Heating Power* in the case **Indoor T°= 15°C** and **Outdoor T°= 15°C**

Fuzzy Logic : Exercise 2 - Cutting conditions

The goal is to determine the cutting conditions (cutting speed and feed rate) of a drilling of a hole, regarding its diameter and the hardness of the material. **[Amaitik et al.]** proposes this model:



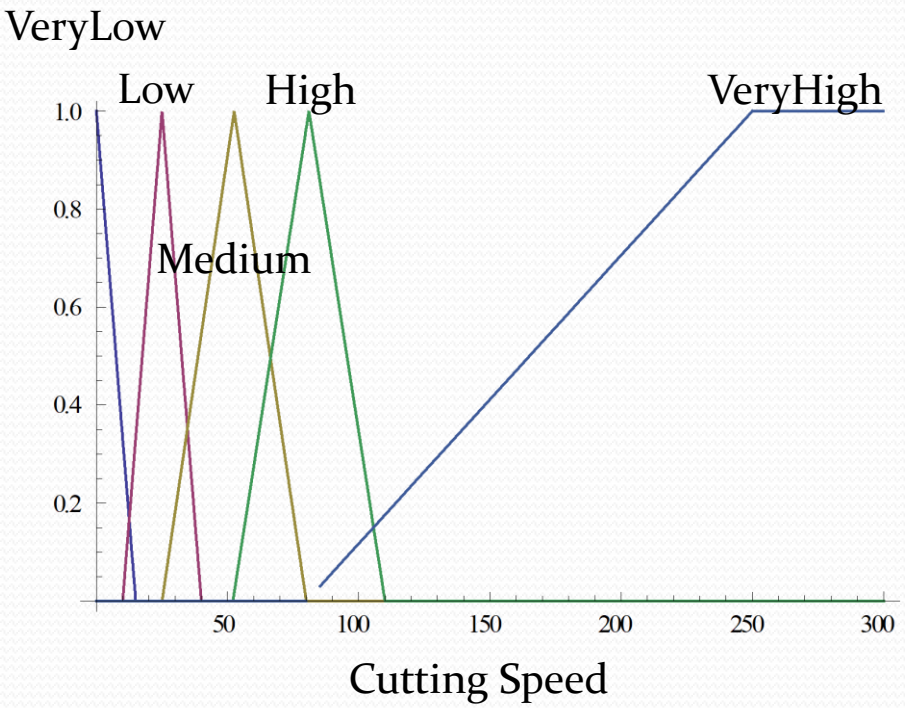


Fuzzy Logic : Exercise 2 - FuzzyRules

[Amaitik et al.] defines a set of rules expressed into a matrix to manage all combinations:

Table 3 Fuzzy rules for cutting speed and feed rate with high speed steel tool

Material Hardness	Hole Diameter					
		S	VS	M	L	VL
VS	V	M	M	M	M	M
	f	VS	S	M	F	F
S	V	L	L	L	L	L
	f	VS	S	M	F	F
M	V	L	L	L	L	L
	f	VS	S	M	M	F
H	V	VL	VL	VL	VL	VL
	f	VS	S	S	M	F
VH	V	VL	VL	VL	VL	VL
	f	VS	S	S	M	M



Fuzzy Logic : Exercise 2 - Cutting conditions

Using the data contained in the article of **[Amaitik et al.]**, apply the Fuzzy Logic approach to determine the value of the cutting speed for these two cases:

- Case 1: Hardness 300 BHL and diameter 6mm
- Case 2: Hardness 280 BHL and diameter 30mm

Use these fuzzy logic operators:

- Aggregation operator: **Max**
- De-fuzzy operator : **Center of gravity**