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Notes on designing Fuzzy Systems

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Steps for fuzzy system design

- Problem definition
- Parametrization of the model: concepts
- Mapping definition: rules
- Implementation
- Testing

Problem definition

Analogous to what done in classical model design

- Selection of the input variables
- Selection of the output variables
- Selection of the goals of the model

Selection of input variables

In principle, input variables are numerical or ordinal variables so that it is possible to define fuzzy sets on them.

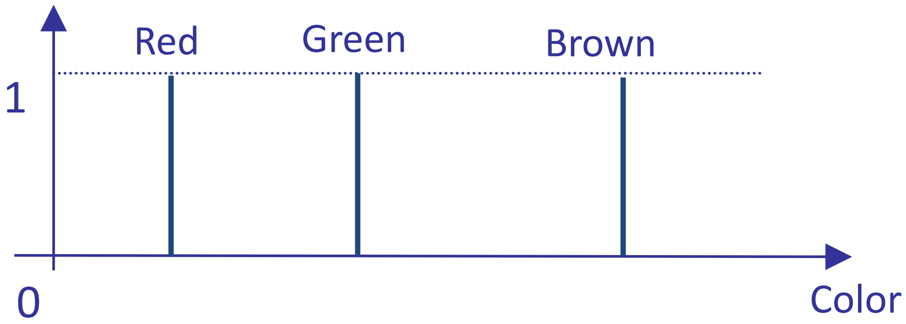
Variables that can be either

- "perceived", coming directly from sensors, data, or users
- computed from perceived variables (error, derivatives, composition of variables)

In general, there are no a priori preclusions to select variables: it depends on the problem and the designer sensibility

Very special cases

If really needed, also non ordinal variables could be integrated, in a fuzzy system, for instance because their values are available from a source.



Notice that we do not have base values for Color, but we could have a degree of membership provided in input

E.g.: Green 0.8

Of course, if we have, and would like to use, the correct information for a color, we could identify it by defining its components, e.g., Red , Green, and Blue, in a multidimensional space.

Selection of output variables

Output variables are the results of the model, so come directly from the modeler needs.

For instance:

- for a control application, we might either have the control variables, or the respective increments
- for a decision support system we might have the decision to be taken

Selection of the goals of the fuzzy model

The goals of the fuzzy models depend on the specifications.

For instance, a control system may reach the set point as soon as possible, with the least overshooting, as robustly as possible, etc.

The goals should always be stated in advance, and guide the design.

System parametrization

Selection of membership functions for all variables

Selection of the inferential mechanism (which T- norms…)

Selection of eventual fuzzyfication and defuzzyfication

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How are MFs defined?

Single expert

- Objective evaluation (e.g.: error wrt a set point)
- Interview (e.g.: operator of a control room)

Multiple experts

- Probabilistic elaboration, possibly weighted by the expert reliability

Automatic systems (NN, GA, …) working on data

How many MFs?

It depends on the application.

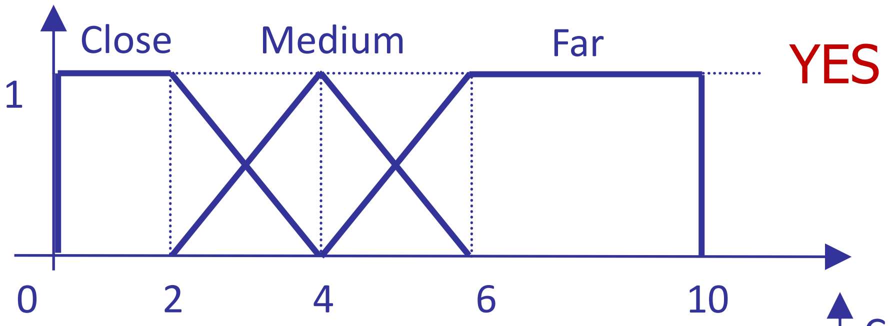
In general from 3 to 7.

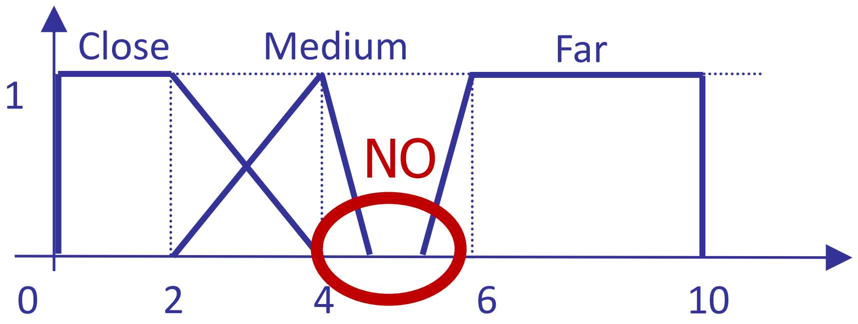
Why?

The “magic” number 7: people usually cannot manage more than 7 2 concepts at a time

An output for each input

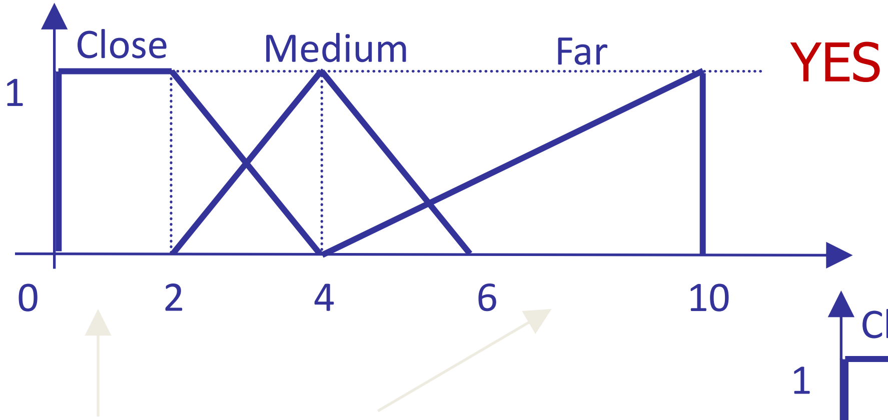
Any point in the range of input variables has to be covered by at least one fuzzy set participating to at least one rule



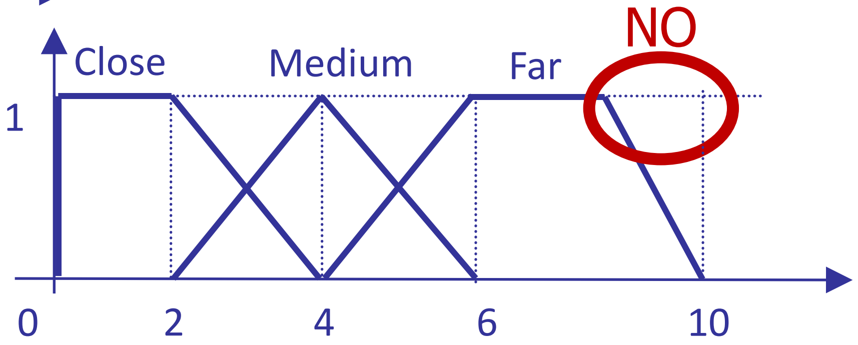


Boundary considerations

Boundary should be covered with maximum value

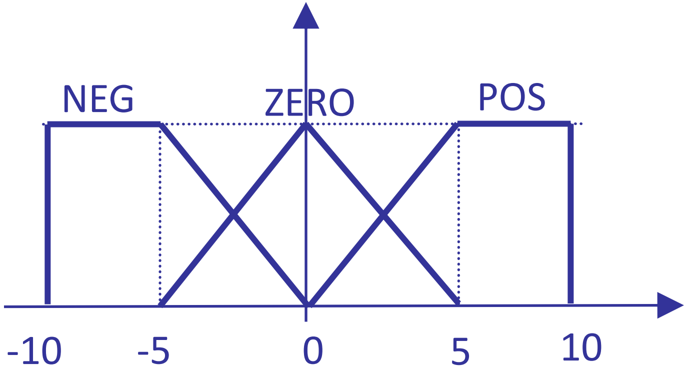


Saturation or not?



How to reach equilibrium

A mediating MF

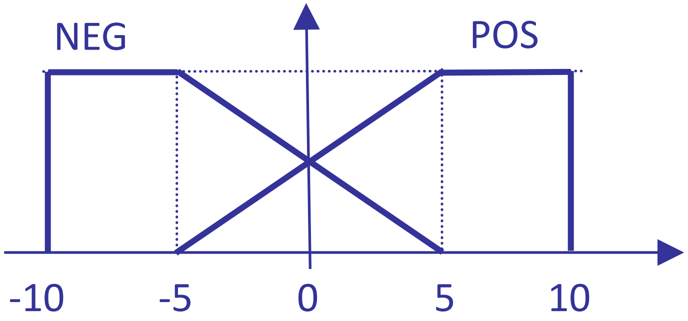


IF (X is POS) THEN (U is NEG)

IF (X is NEG) THEN (U is POS)

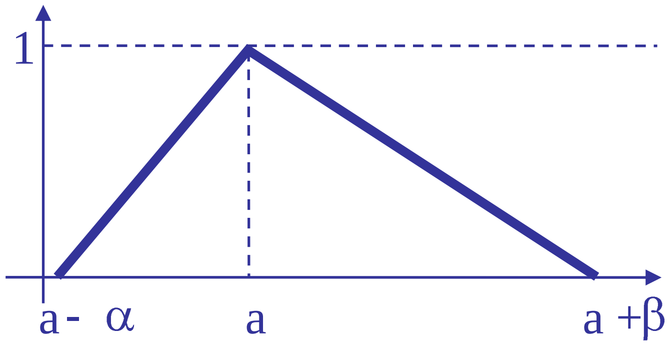
IF (X is ZERO) THEN (U is ZERO)

Just pushing…

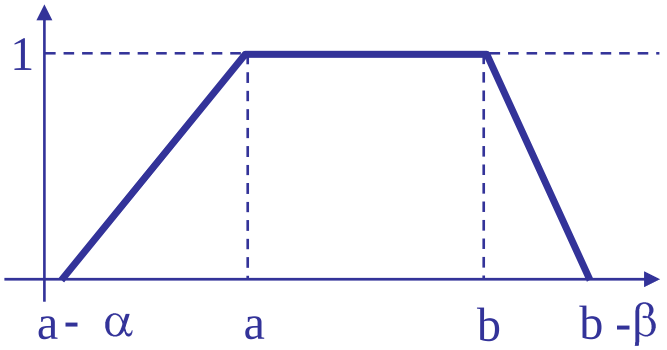


Some conceptual differences

A fuzzy set with only one member with the maximum membership

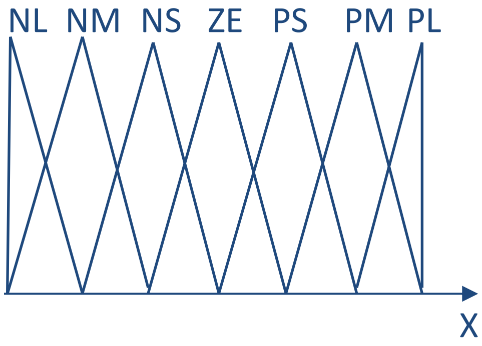


A fuzzy set with a set of members with the maximum membership



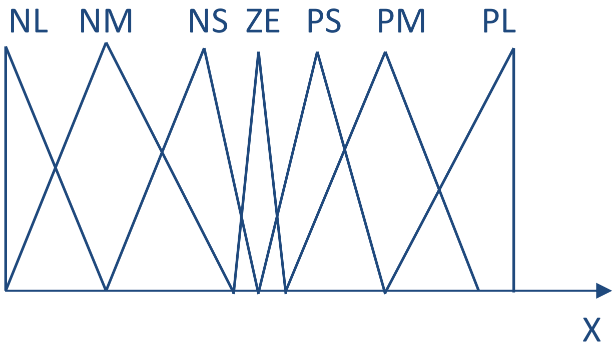
How to distribute the MFs

Evenly distributed



Max robustness to noise

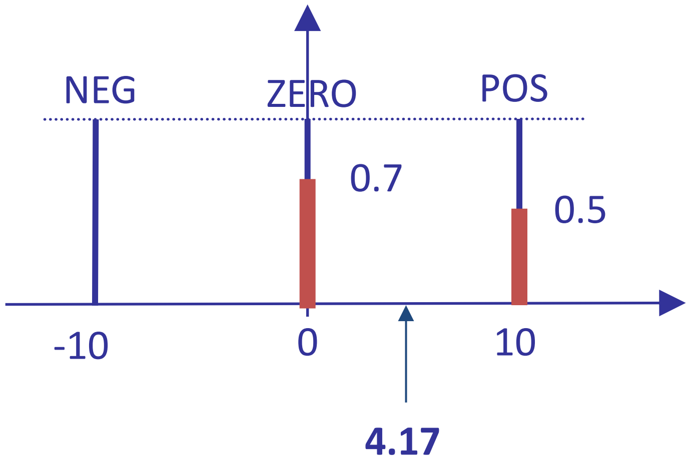
Unevenly distributed



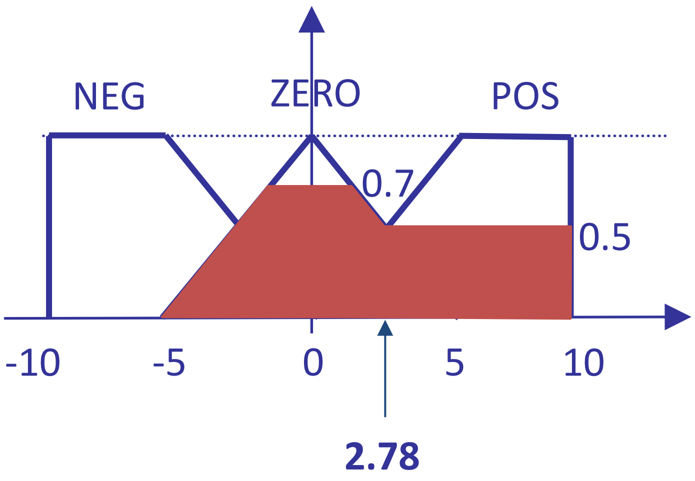
More precision where needed

Singletons or other for the output

Singletons: the weight of any cut
is proportional to the cut level



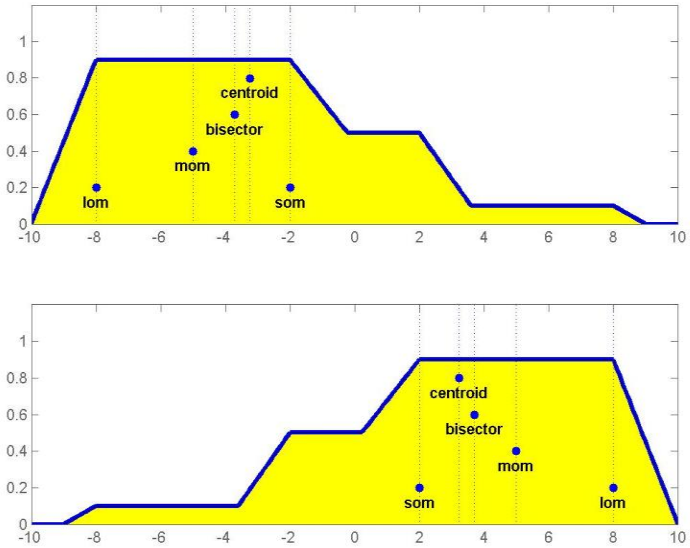
Generic shapes: the weight of
the lower parts counts more:
is this desired?



Defuzzyfication

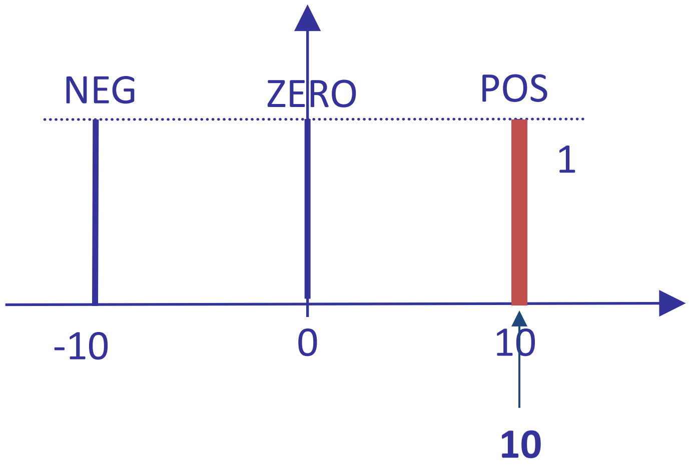
Many different possibilities:

- Centroid
- Bisector
- Average of maxima
- Lowest maximum
- Highest maximum
- Center of the highest area
- ...

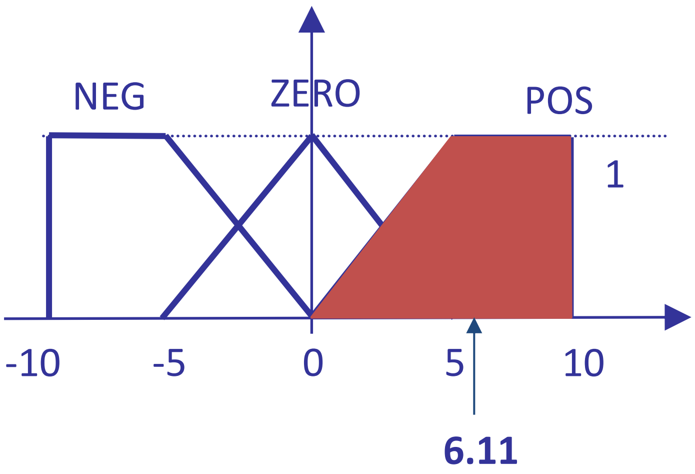


Singletons or other for the output (again)

Singletons: the defuzzyfication with center of mass can bring to the extreme



Defuzzyfication with center of mass cannot reach the extreme



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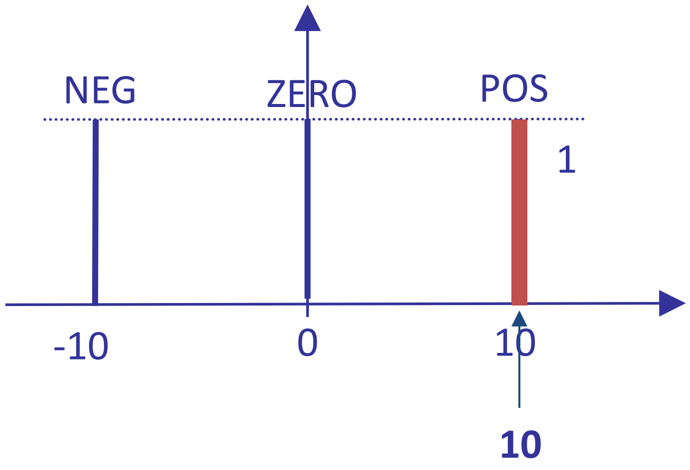

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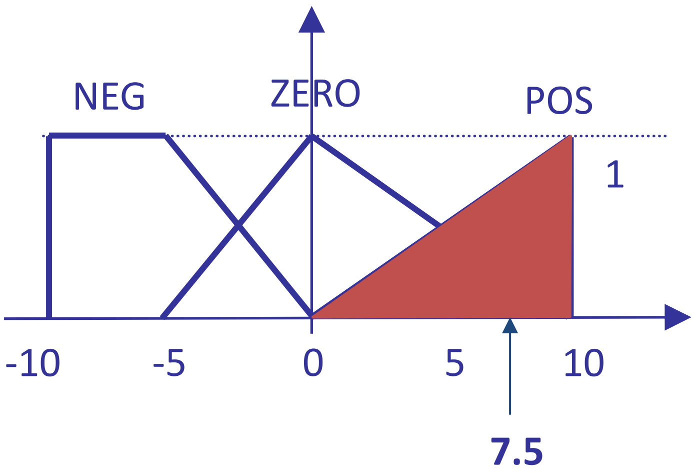


Rule definition

From experience

- Introspective analysis
- Structured interview

From another model (e.g., from a mathematical model, to improve robustness)

By using machine learning, or self-tuning techniques (NN, GA, ...)

Selection of inferential engine

The inferential engine depends on the operators selected for:

- AND of antecedent clauses
  - min: the worst degree of matching is the most relevant
  - product: all the degrees of matching are relevant

- Detachment: combination with the rule weight
  - min
  - product

- Aggregation of degrees of the same consequent
  - max: the best degree is the most relevant
  - probabilistic sum: all the collected knowledge is taken into account

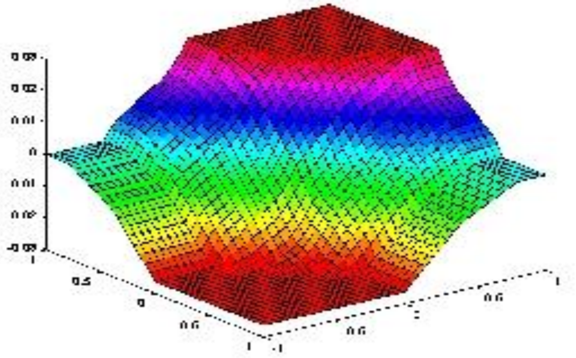
It is important to be coherent in the choice.

Testing

Aim: verify the design goals

Possible activity

- Dynamic simulation, if the model of the subject is available
  - E.g., if the model of the controlled system is available
- “Static” simulation (single I/O check, output (control) surface study)
- Test on the process, possibly under safe conditions



Available development tools

Many tools, mainly for fuzzy control (including Matlab)

Common features:

- guided definition of rules and MF
- visualization of control surfaces
- suite of MFs, operators and defuzzification methods
- support to testing
- support to learning
- optimized code production, for many processors

Some tools for the development of generic fuzzy rule systems: FOOL, Fuzzy Clips, FLIP, FCL, …

FCL: an IEEE standard

IEEE-IEC document 61131-7

An example: model the aggressiveness of a character in a videogame

```
FUNCTION_BLOCK

\* VAR definition *\

 VAR_INPUT
   Our_Health      REAL; (* RANGE(0 .. 100) *)
   Enemy_Health    REAL; (* RANGE(0 .. 100) *)
 END_VAR

 VAR_OUTPUT
   Aggressiveness  REAL; (* RANGE(0 .. 4) *)
 END_VAR
```

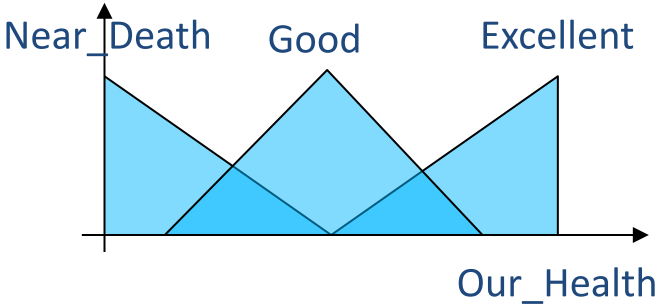
FCL Example (2): MF definition

```
\* MF definition *\

FUZZIFY Our_Health
   TERM Near_Death := (0, 0) (0, 1) (50, 0) ;
   TERM Good := (14, 0) (50, 1) (83, 0) ;
   TERM Excellent := (50, 0) (100, 1) (100, 0) ;
END_FUZZIFY

FUZZIFY Enemy_Health
   TERM Near_Death := (0, 0) (0, 1) (50, 0) ;
   TERM Good := (14, 0) (50, 1) (83, 0) ;
   TERM Excellent := (50, 0) (100, 1) (100, 0) ;
END_FUZZIFY

FUZZIFY Aggressiveness
   TERM Run_Away := 1 ;
   TERM Fight_Defensively := 2 ;
   TERM All_Out_Attack := 3 ;
END_FUZZIFY
```



FCL Example (3): defuzzyfication

```
\* Definition of the defuzzyfication method *\

DEFUZZIFY Aggressiveness
   METHOD: MoM; \\Media of Maxima
END_DEFUZZIFY
```

FCL Example (4): rule definition

```
RULEBLOCK first
 AND:MIN;
 ACCU:MAX;
 RULE 0: IF (Our_Health IS Near_Death) AND (Enemy_Health IS Near_Death)
         THEN (Aggressiveness IS Fight_Defensively);
 RULE 1: IF (Our_Health IS Near_Death) AND (Enemy_Health IS Good)
         THEN (Aggressiveness IS Run_Away);
 RULE 2: IF (Our_Health IS Near_Death) AND (Enemy_Health IS Excellent)
         THEN (Aggressiveness IS Run_Away);
 RULE 3: IF (Our_Health IS Good) AND (Enemy_Health IS Near_Death)
         THEN (Aggressiveness IS All_Out_Attack);
 RULE 4: IF (Our_Health IS Good) AND (Enemy_Health IS Good)
         THEN (Aggressiveness IS Fight_Defensively);
 RULE 5: IF (Our_Health IS Good) AND (Enemy_Health IS Excellent)
         THEN (Aggressiveness IS Fight_Defensively);
 RULE 6: IF (Our_Health IS Excellent) AND (Enemy_Health IS Near_Death)
         THEN (Aggressiveness IS All_Out_Attack);
 RULE 7: IF (Our_Health IS Excellent) AND (Enemy_Health IS Good)
         THEN (Aggressiveness IS All_Out_Attack);
 RULE 8: IF (Our_Health IS Excellent) AND (Enemy_Health IS Excellent)
         THEN (Aggressiveness IS Fight_Defensively);
END_RULEBLOCK
END_FUNCTION_BLOCK
```

What to remember from these slides?

- General design principles
- Why selecting a set of operators or another?
- How to select a set of MFs (distribution, shape)?