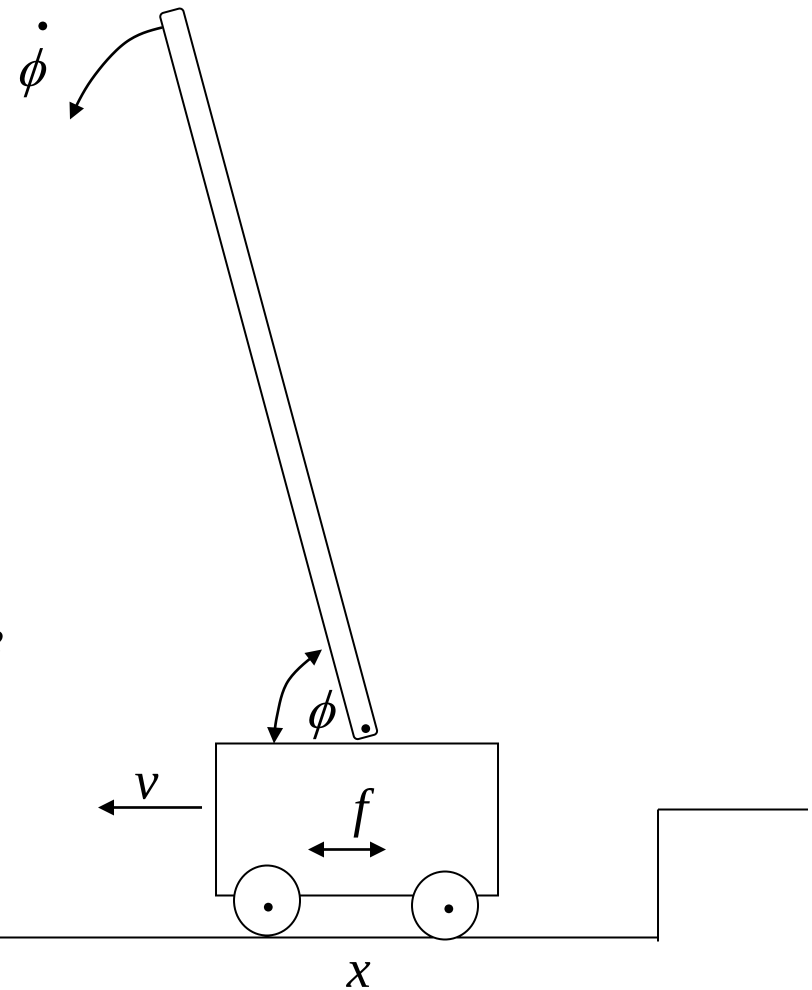
Pole-Balancing (Cart-Pole System)
(balancing an inverted pendulum)



Bang-Bang Control:

$$f = \begin{cases} f_{\text{forward}} \text{ if } \phi > \pi/2 + \varepsilon_1 \text{ AND } \dot{\phi} > \varepsilon_2 \\ \\ f_{\text{backward}} \text{ if } \phi < \pi/2 - \varepsilon_1 \text{ AND } \dot{\phi} < -\varepsilon_2 \end{cases}$$

"proportional controller"

linear mapping between *n* sensor values and *m* actor controls

$\mathbf{s} = (s_i)_{\ i=1..n}$ vector of sensor values (f.ex. light intensities)
$\mathbf{a} = (a_j)_{\ j=1..m}$ " " actor control values (f.ex. motor voltages)

$\mathbf{K} = (k_{i,j})_{i=1..m,\ j=1..n)}$ controller matrix

controller "logic":

$$\mathbf{a} = \mathbf{K} * \mathbf{s} + \mathbf{c} \quad \text{, i.e.} \quad \begin{pmatrix} a_1 \\ a_2 \\ \dots \\ a_m \end{pmatrix} = \begin{pmatrix} k_{11} & k_{12} & \dots & k_{1n} \\ k_{21} & k_{22} & \dots & k_{2n} \\ \dots & \dots & & \dots \\ k_{m1} & k_{m2} & \dots & k_{mn} \end{pmatrix} * \begin{pmatrix} s_1 \\ s_2 \\ \dots \\ s_n \end{pmatrix} + \begin{pmatrix} c_1 \\ c_2 \\ \dots \\ c_m \end{pmatrix}$$

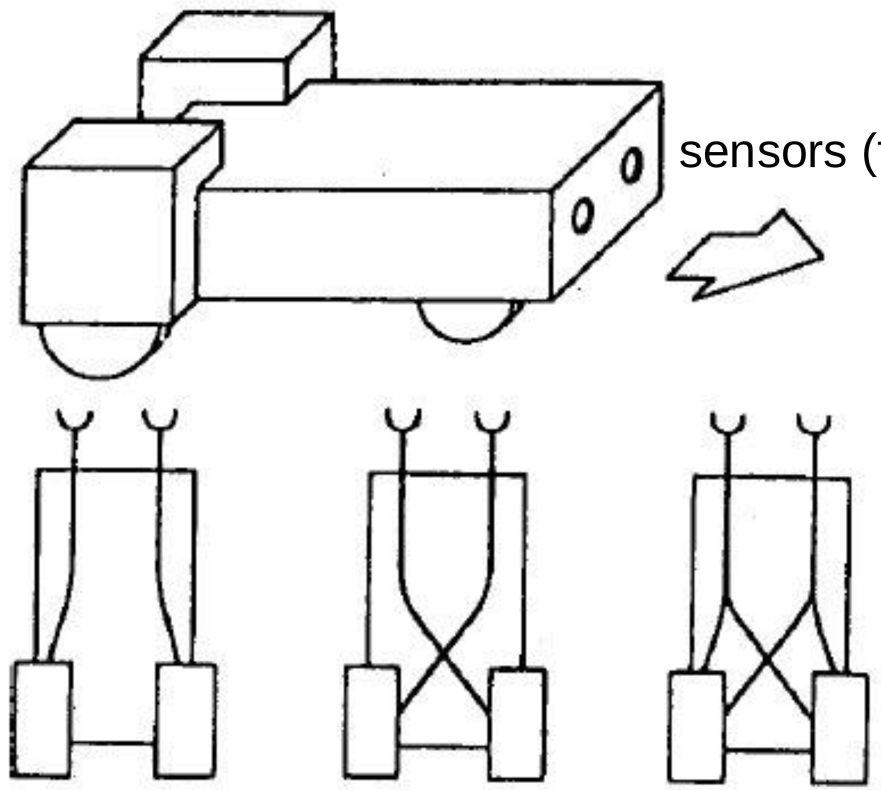
i.e. $a_j = k_{j1} \cdot s_1 + k_{j2} \cdot s_2 + \dots + k_{jn} \cdot s_n + c_j \quad , \quad j=1..m$

vector **s** may also represent deviations from target values of the sensors:

$\mathbf{s} - \mathbf{s}_{\mathbf{target}} \quad \Rightarrow \quad \mathbf{a} = \mathbf{0}$ when target value has been reached

Valentin Braitenberg: Vehicel - Experimente mit künstlichen Wesen

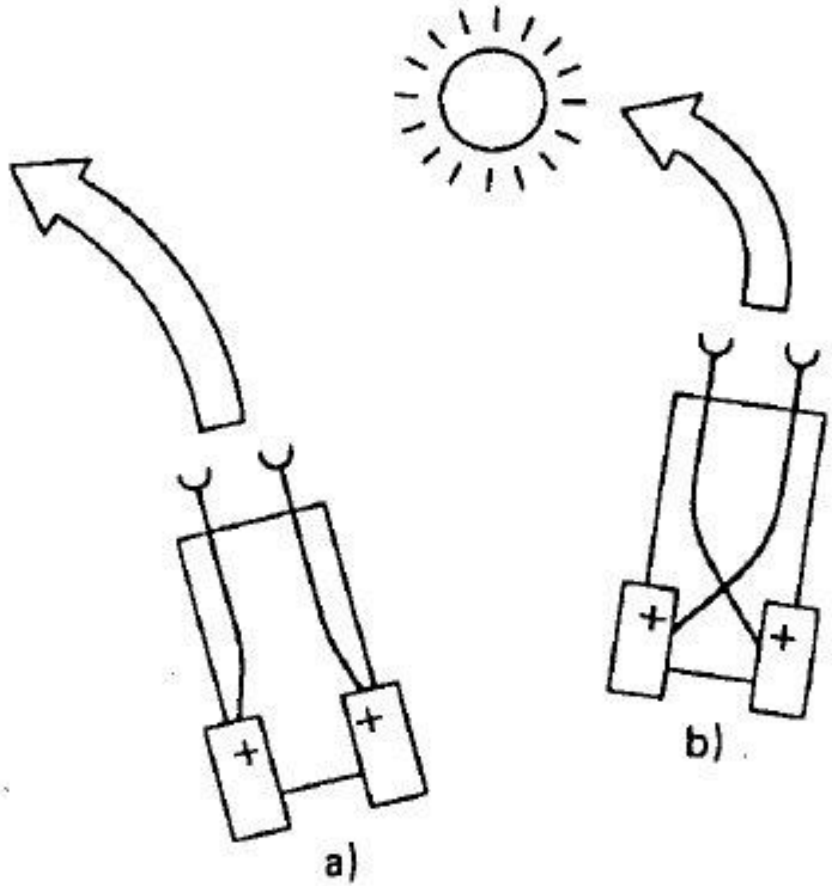
Wissenschaftliche Paperbacks Band 26, LIT Verlag 2004



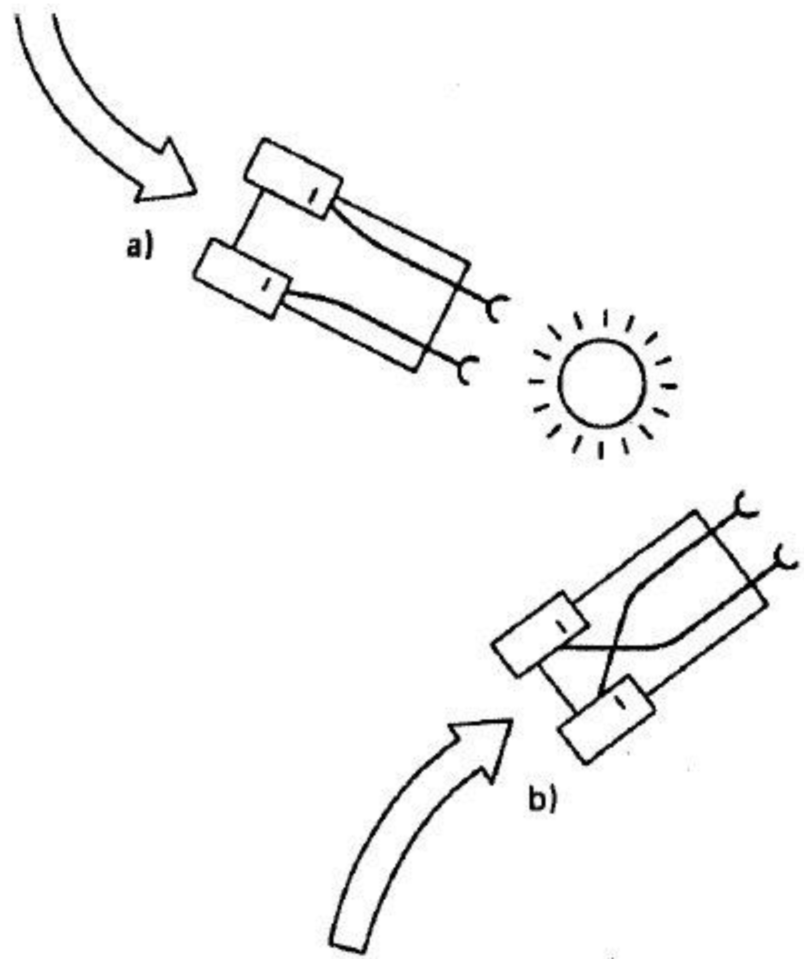
sensors (f.ex. light)

"proportional controller"
between sensors
and motors

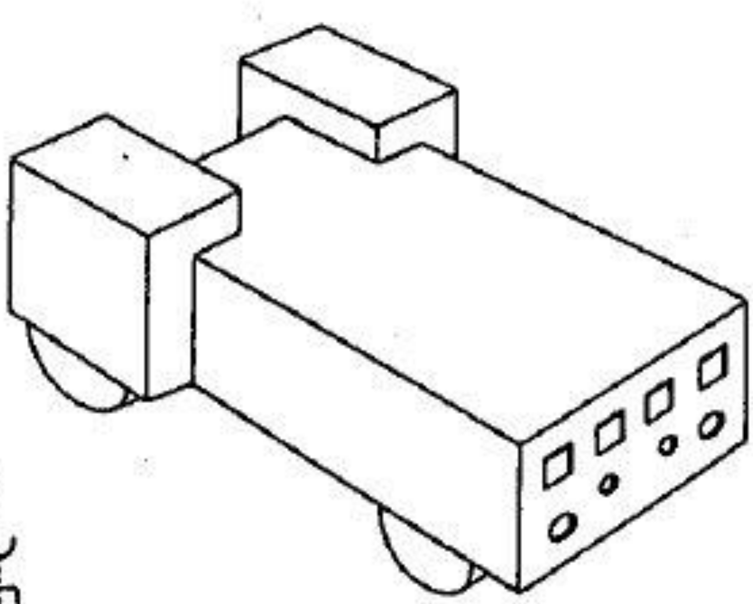
Braitenberg Vehikel: a) "fear" b) "aggression"

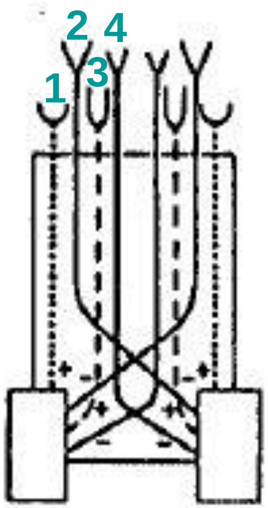


Braitenberg Vehicle: "love"



Braitenberg Vehicle: more complex, multisensorial vehicle





1. temperature: avoids the hot regions
2. light: destroys light sources
3. oxygen concentration: prefers places with high oxygen c.
4. concentration of organic material: stays at the pasture land, but looks for more fertile ones

fuzzy controller

starting point:

control based on logic (rules) is intuitive

problems:

- bang-bang control doesn‘t result in smooth control
- “ control is not robust under sensor uncertainty

a solution:

- use fuzzy logic and fuzzy control

the figures of the following slides refer to
http://en.wikipedia.org/wiki/Fuzzy_control_system

fuzzy controller

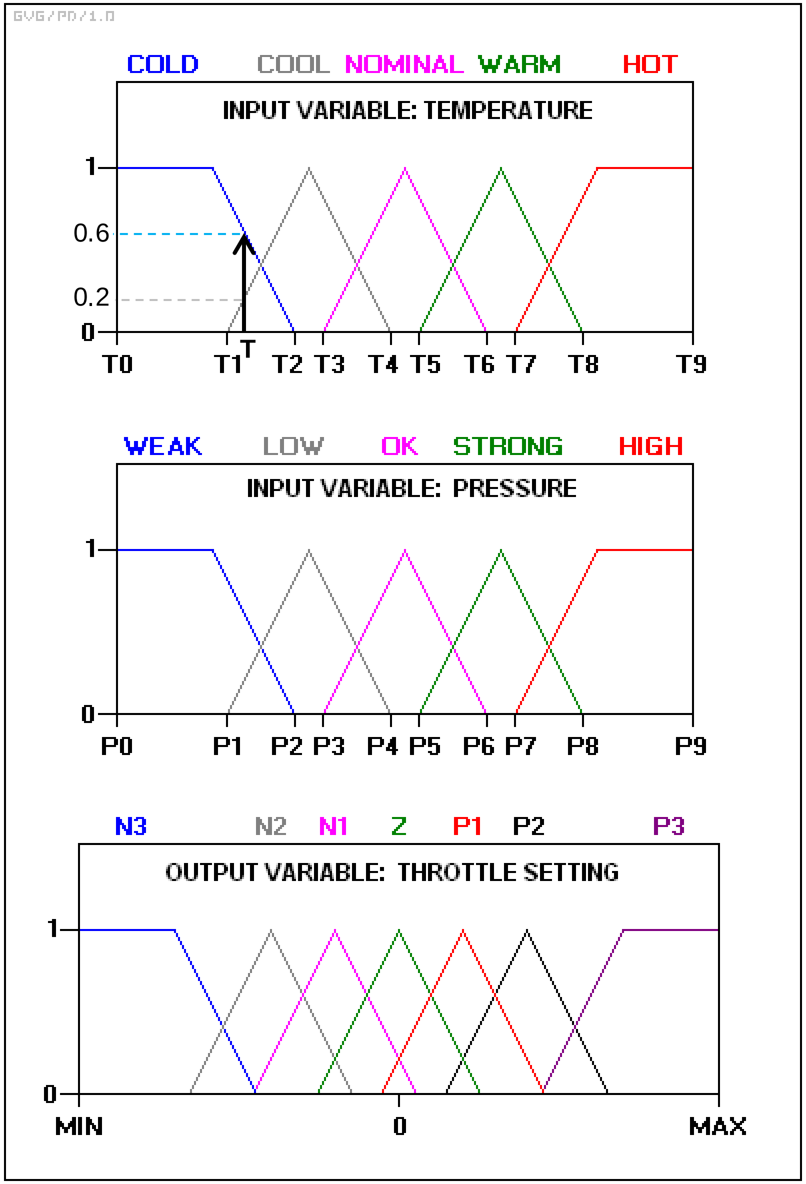
„fuzzification“ of continuous values (float, conceptually) to categories (enums):

- fuzzy description of input variables (from sensors)

T => cold(0.6) , cool(0.2)

- fuzzy description of control settings (to actuators)

N3: Large negative.
N2: Medium negative.
N1: Small negative.
Z: Zero.
P1: Small positive.
P2: Medium positive.
P3: Large positive.



fuzzy controller

Controller: in bang-bang style:

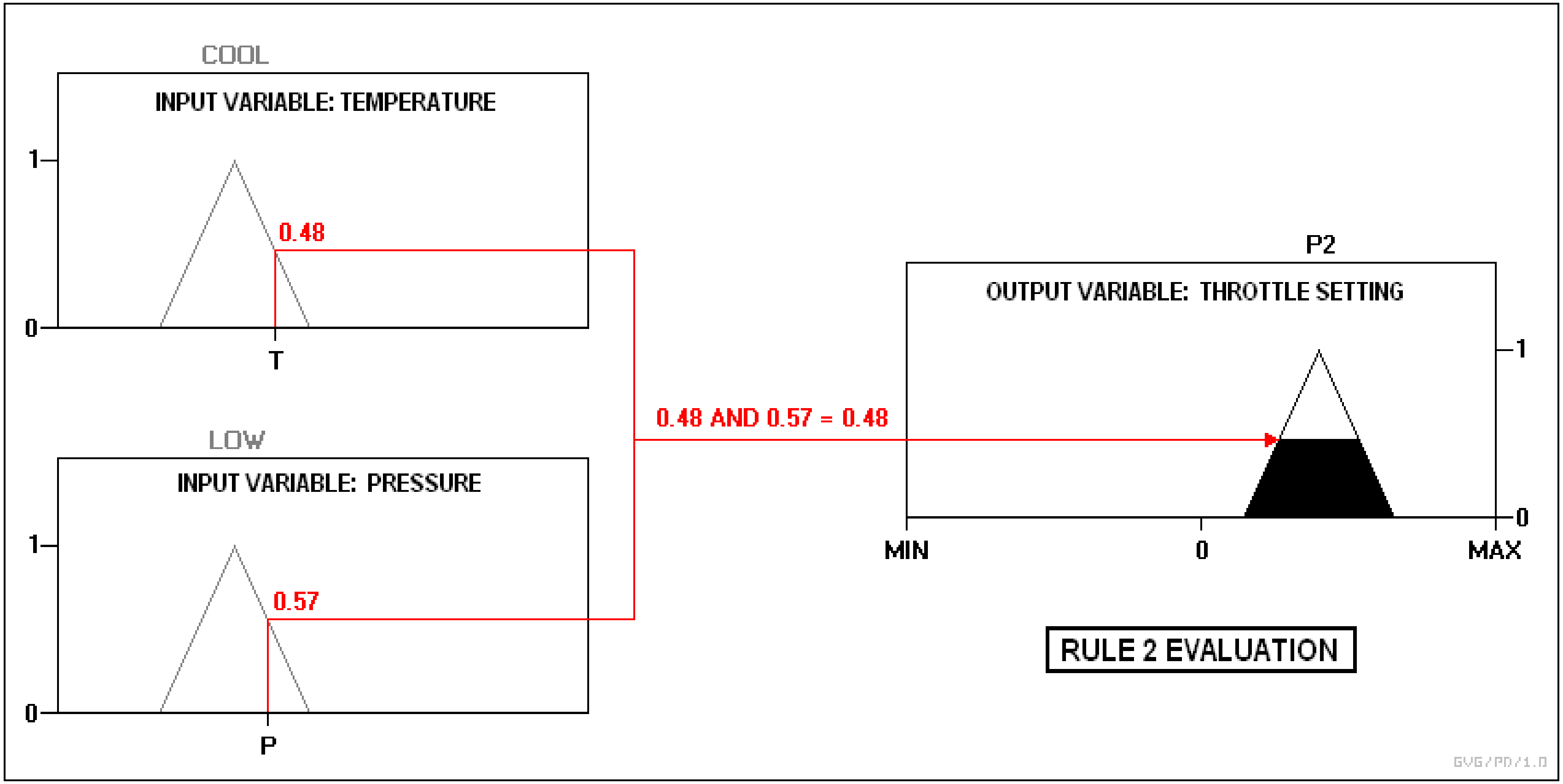
- rule 1: IF temperature IS cool AND pressure IS weak
  THEN throttle is large positive (P3)

- rule 2: IF temperature IS cool AND pressure IS low
  THEN throttle is medium positive (P2)

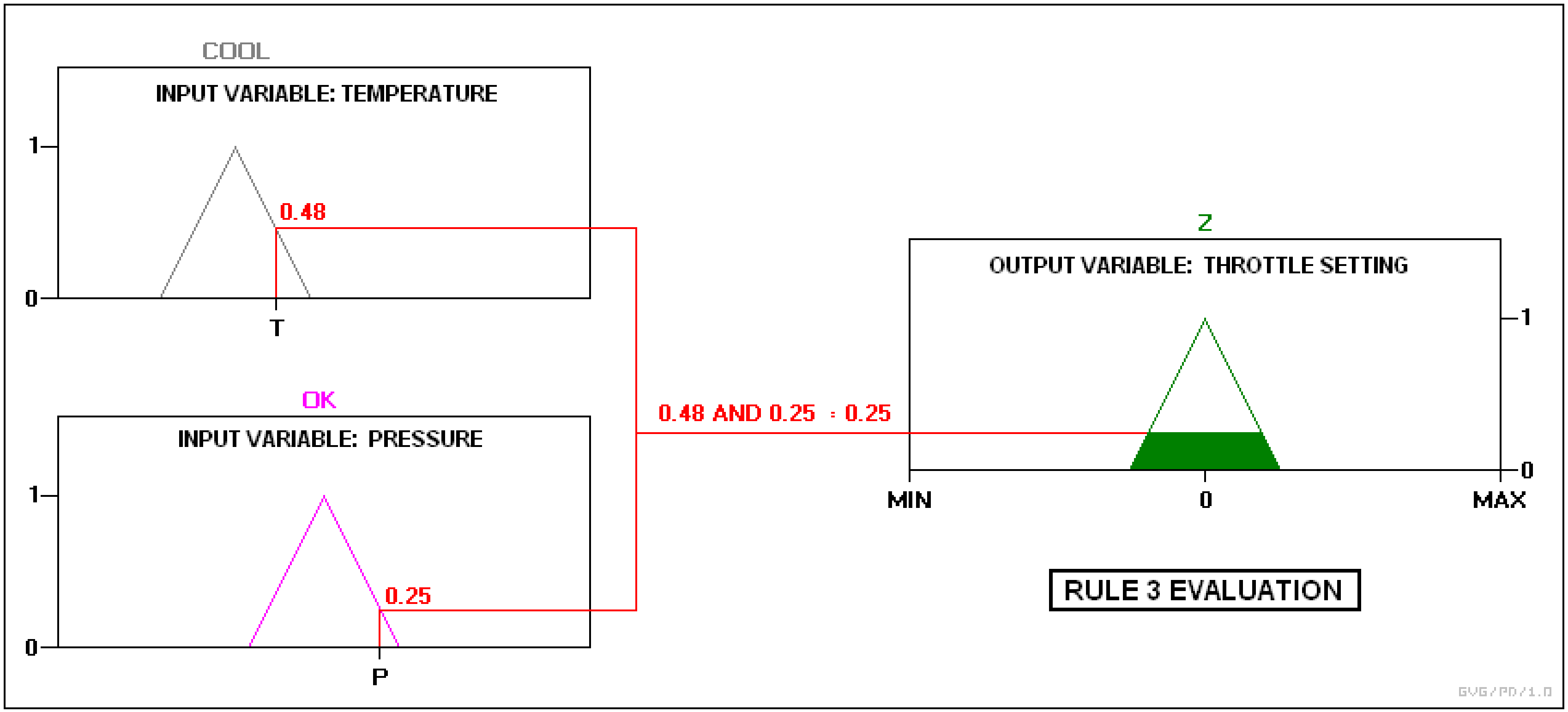
- rule 3: IF temperature IS cool AND pressure IS ok
  THEN throttle is zero (Z)

- rule 4: IF temperature IS cool AND pressure IS strong
  THEN throttle is medium negative (N2)
- …

fuzzy controller



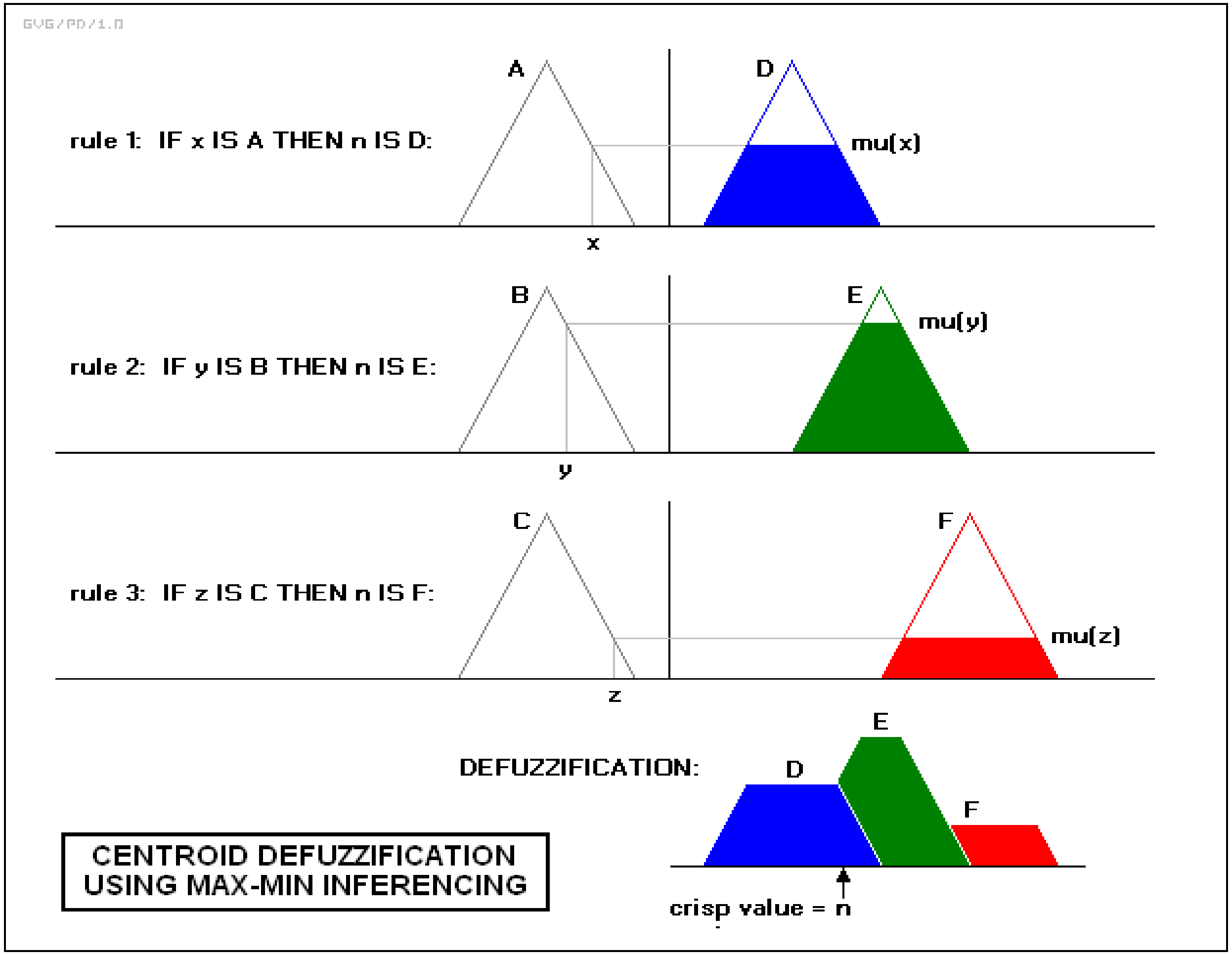
fuzzy controller



fuzzy controller

last step of a fuzzy control step: ***defuzzification***

- translate categorical values to real numbers (float)



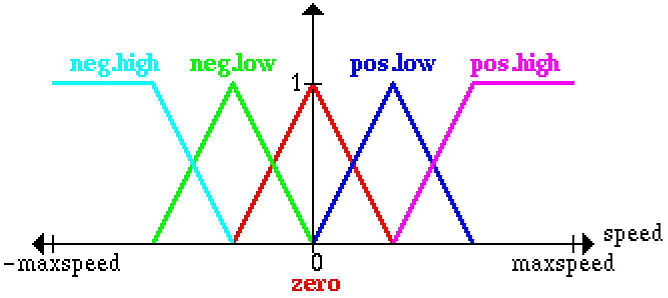
fuzzy controller

advantages of fuzzy control:

- robust under sensor value uncertainty (imprecision)
- continuous control because of defuzzification
- maintains the rule-based description: more intuitive than proportional controllers

Beispiel für das Inverted Pendulum:

http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol4/sbaa/report.fuzrules.html


neg.high
neg.low
pos.low
pos.high
1
speed
-maxspeed
0
maxspeed
zero