Fuzzy logic

Traditional logic is bivalent, which means that only two truth values are allowed: every proposition must be either true or false. But the inherent vagueness of many terms, apparent in the sorites paradox, suggests that this requirement is too rigid if logic is to encompass the full scope and complexity of natural language.

Fuzzy logic has been developed, initially by the computer scientist Lofti Zadeh, to allow for imprecision and degrees of truth. Truth is presented as a continuum between true (1) and false (0). So, for instance, a particular proposition that is 'partly true' or 'more or less true' might be represented as true to degree 0.8 and false to degree 0.2. Fuzzy logic has been particularly important in AI (artificial intelligence) research, where 'intelligent' control systems need to be responsive to the imprecisions and nuances of natural language.

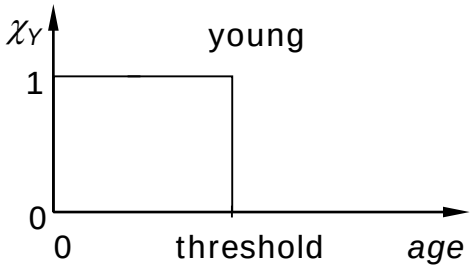
From: Dupré, B. The sorites paradox. In Dupré B. (2007) *50 philosophy ideas you really need to know*. Quercus Publishing PLc, London, p. 122.

Fuzzy Arden Syntax: Modelling uncertainty in medicine

- linguistic uncertainty
  - due to the unsharpness (fuzziness) of boundaries in linguistic concepts; gradual transition from one concept to another
  - modeled by fuzzy sets (e.g., fever, increased glucose level, hypoxemia)

- propositional uncertainty
  - due to the incompleteness of medical conclusions; uncertainty in definitional, causal, statistical, and heuristic relationships
  - here: modeled by truth values between zero and one (e.g., 0.6, 0.9)

Crisp sets vs. fuzzy sets



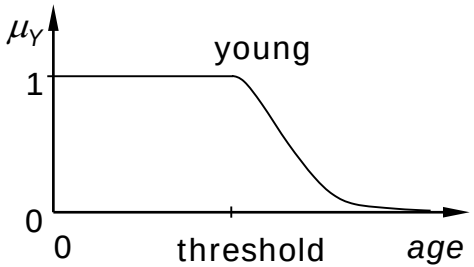
yes/no decision

$U = [0, 120]$

$Y \subseteq U$ with $Y = \{(\chi_Y(x)/\ x) \mid x \in U\}$

$\chi_Y: U \rightarrow \{0, 1\}$

$$\chi_Y(x) = \begin{cases} 0 & x > \text{threshold} \\ 1 & x \leq \text{threshold} \end{cases} \quad \forall\ x \in U$$



gradual transition

$U = [0, 120]$

$Y \subseteq U$ with $Y = \{(\mu_Y(x)/\ x) \mid x \in U\}$

$\mu_Y: U \rightarrow [0, 1]$

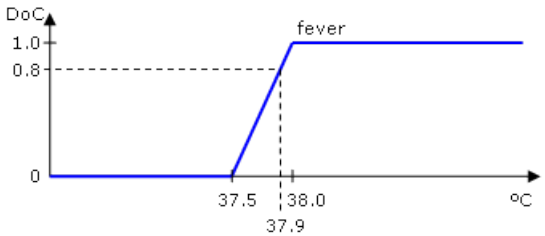
$$\mu_Y(x) = \begin{cases} \dfrac{1}{1 + (0.04\ x)^2} & x > \text{threshold} \\ 1 & x \leq \text{threshold} \end{cases} \quad \forall\ x \in U$$

Clinical concepts and relationships between them

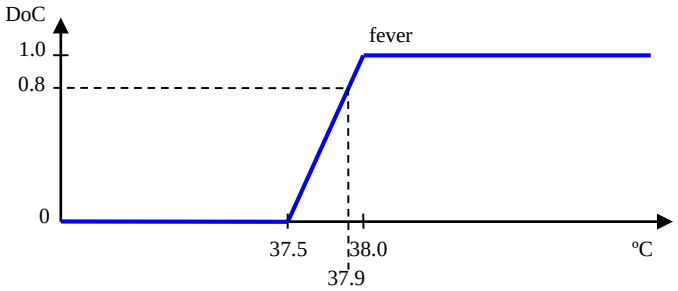
truth value

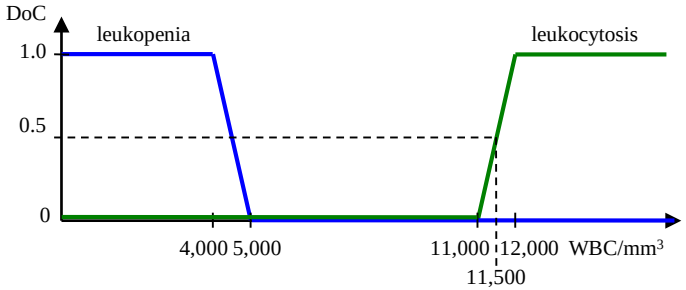
$$(S_1 \wedge S_2) \vee \neg S_3 \xrightarrow{t} D$$

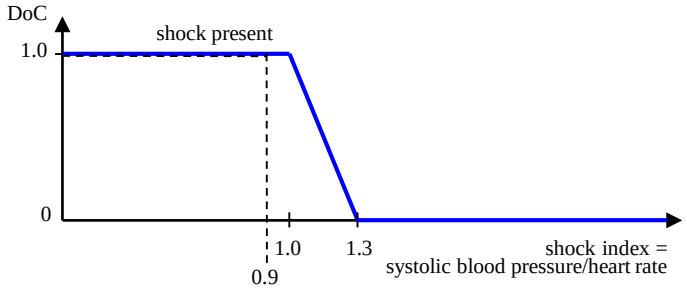
DoC



Examples of fuzzy sets as they are applied in Moni-ICU



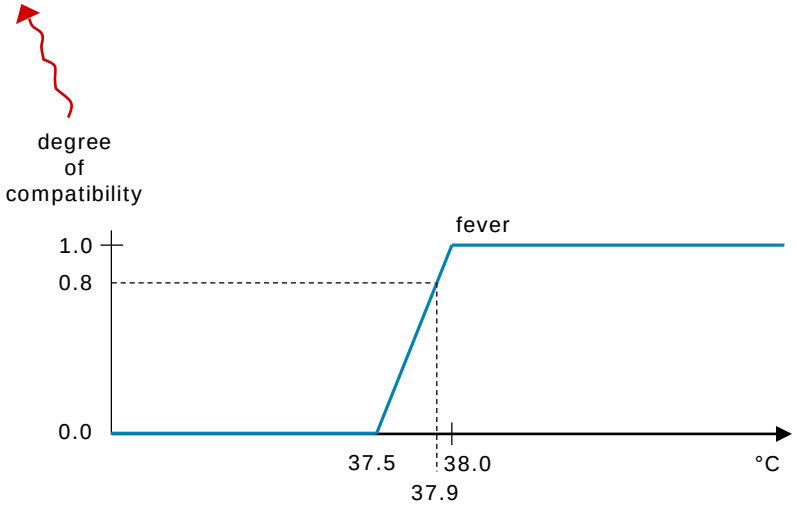




Uncertainty in conclusions I: through linguistic uncertainty in premises

Example:

$S_1 \vee S_2 \vee S_3 \vee S_4 \vee S_5 \xrightarrow{1.0} S_6$ is true is 0.8.



S_1: fever
S_2: hypotension
S_3: leukopenia
S_4: leukocytosis
S_5: increased CRP

S_6: inflammatory signs (with sepsis)

Uncertainty in conclusions II: through uncertainty in propositions

Example 1:

$S_1 \xrightarrow{0.8} D_1$

S_1 : highly increased amylase

D_1: acute pancreatitis

Example 2:

$I_1 \xrightarrow{0.8} S_1$

I_1 : thermoregulation (cooling)

S_1: fever

Example 3:

at least 4/11: $S_1 \ldots S_{11} \xrightarrow{0.75} D_1$

S_1: morning stiffness lasting at least one hour

$\vdots$

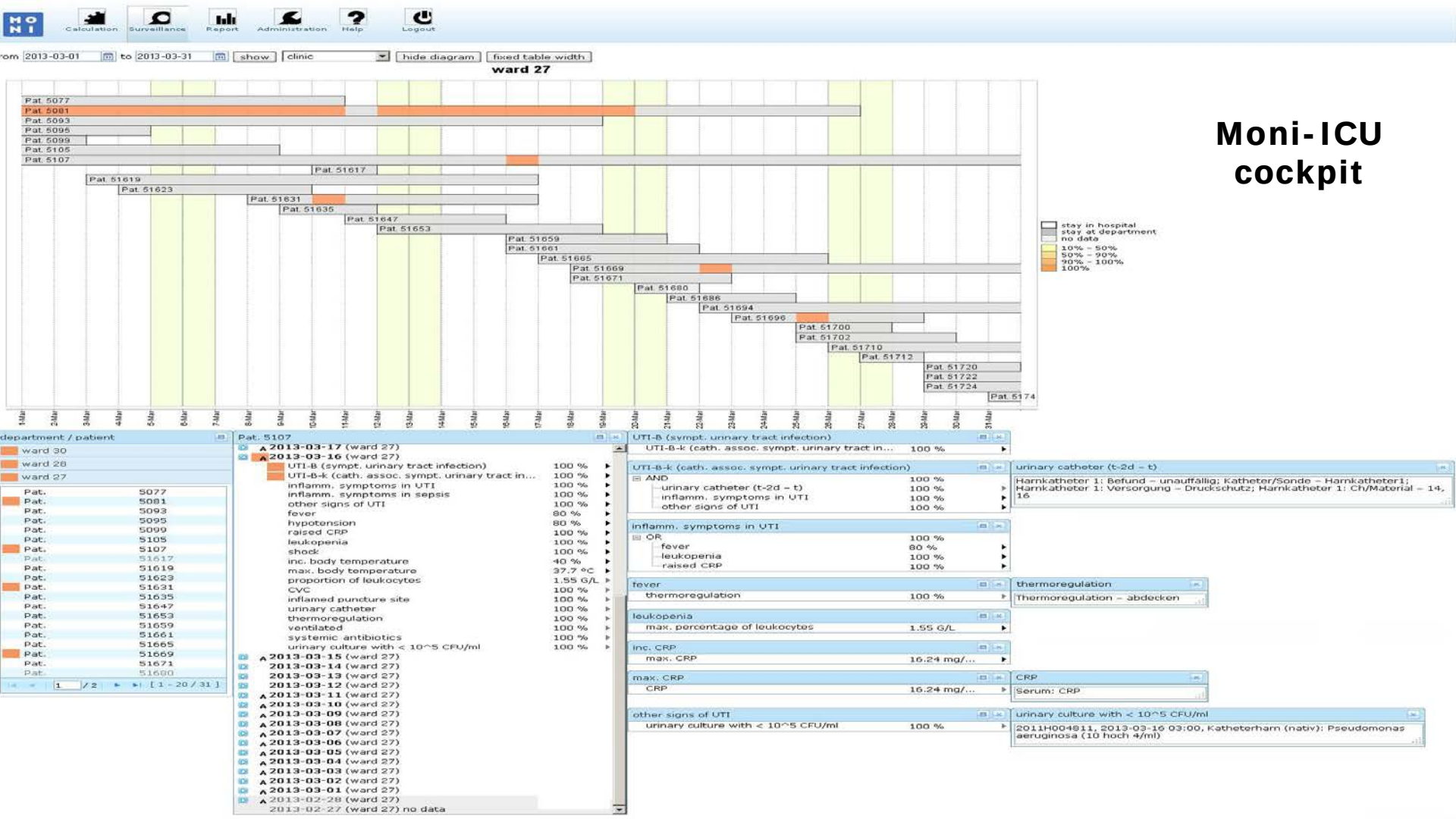
S_5: symmetric joint involvement

$\vdots$

S_9: positive serum rheumatoid factor

$\vdots$

D_1: rheumatoid arthritis



Moni-ICU cockpit

Four clinical concepts in Moni-ICU

Clinical Concept (Unit)	Fuzzy Set		
	Normal Range	Borderline Range	Pathological Range
Increased body temperature (fever) (°C)	< 37.5	37.5 – 38.0 [1)]	> 38.0 [2)]
Increased C-reactive protein (CRP) (mg/dl)	< 1.0	1.0 – 6.0 [3)]	> 6.0 [3)]
Leukopenia (WBC/mm^3)	> 5,000	4,000 – 5,000 [4)]	< 4,000 [2)]
Leukocytosis (WBC/mm^3)	< 11,000	11,000 – 12,000 [4)]	> 12,000 [2)]

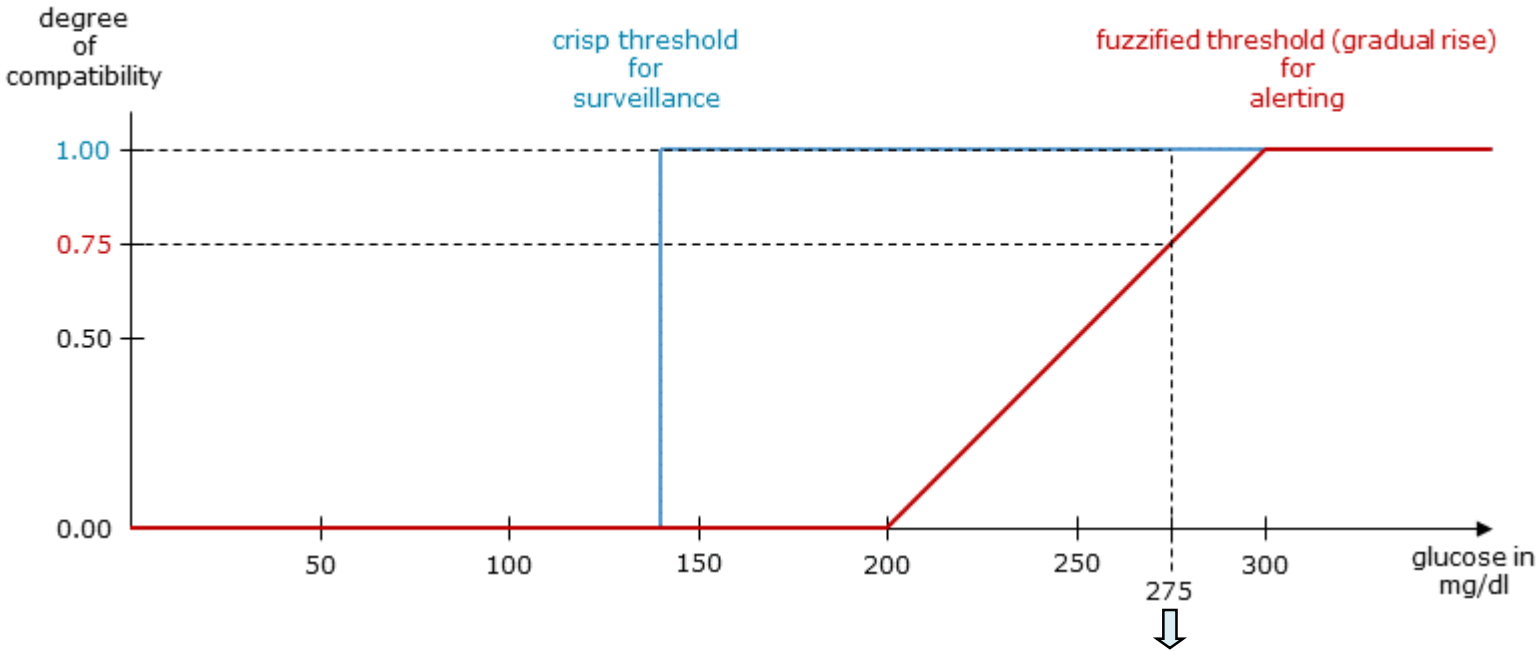
[1)] as defined by clinicians
[2)] as defined by CDC/NHSN, ECDC, and KISS for retrospective surveillance purposes
[3)] as defined by clinicians; CRP is an early phase protein, useful as an “infection radar” for prospective purposes
[4)] as defined by clinicians; white blood cell count (WBC) is a slowly reacting indicator, important for surveillance purposes

Frequency distributions: four clinical concepts as well as the topmost HAI definitions (24,325 patient days)

Clinical Concept	Absent n (%)	Borderline n (%)	Present n (%)
Increased body temperature (fever)	16,074 (66.1)	3,421 (14.0)	4,830 (19.9)
Increased C-reactive protein (CRP)	4,383 (18.0)	5,841 (24.0)	14,101 (58.0)
Leukopenia	22,991 (94.5)	668 (2.8)	666 (2.7)
Leukocytosis	15,169 (62.4)	1,544 (6.3)	7,612 (31.3)
BSI or[1)] CRI2 or UTI-A or UTI-B	20,687 (85.0)	606 (2.5)	3,032 (12.5)

[1)] inclusive disjunction with precedence of “present” over “borderline” over “absent”

Two different hyperglycemia definitions



Hyperglycemia (surveillance) is true is 1.00.
Hyperglycemia (alerting) is true is 0.75.

Modelling other forms of uncertainty

- artificial neural network
  - put calculated equations into MLMs
- Bayesian networks
  - put necessary formulas into MLMs
  - use an API to external Bayesian network software
- **...**

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