1 Introduction

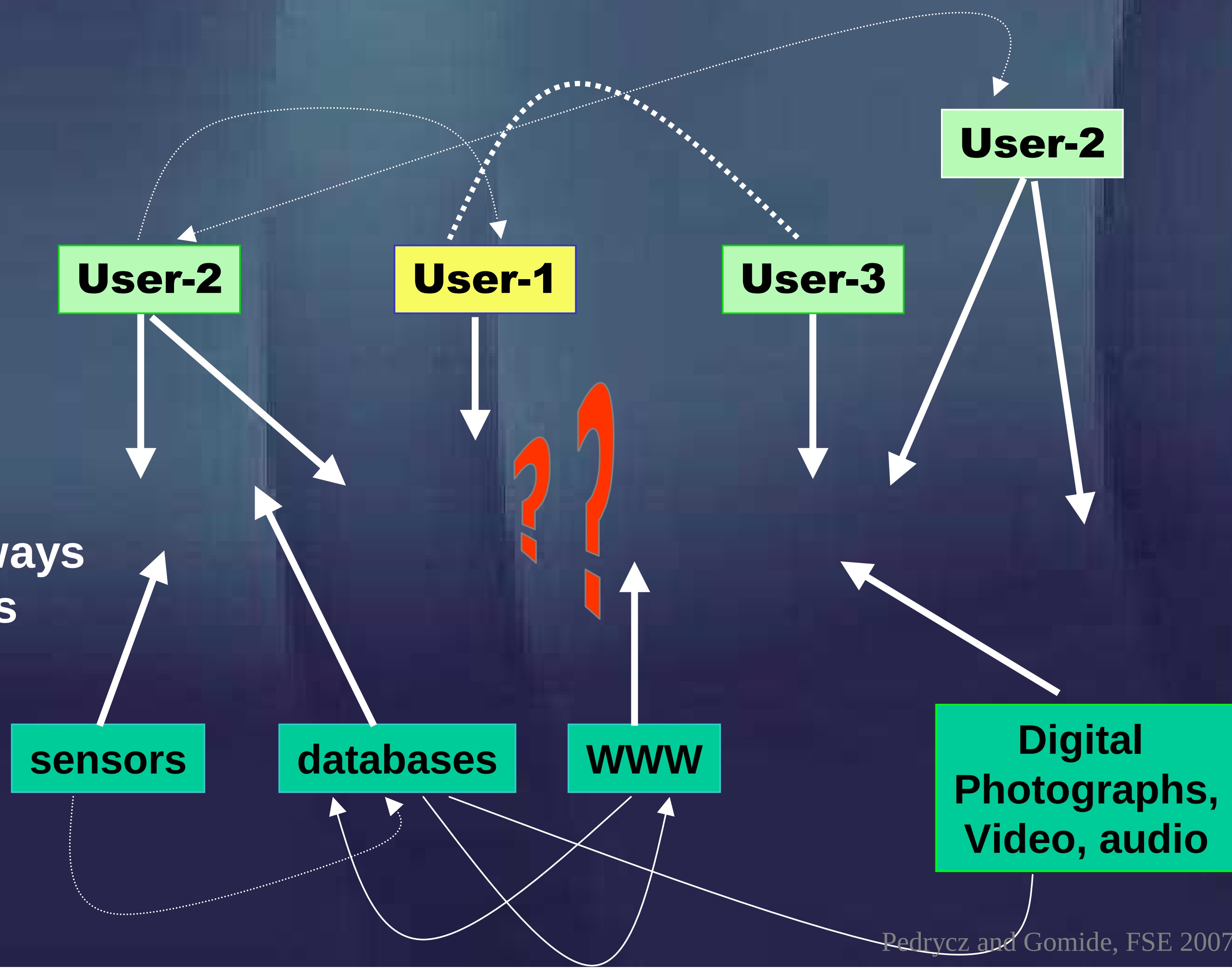
Fuzzy Systems Engineering
Toward Human-Centric Computing

Contents

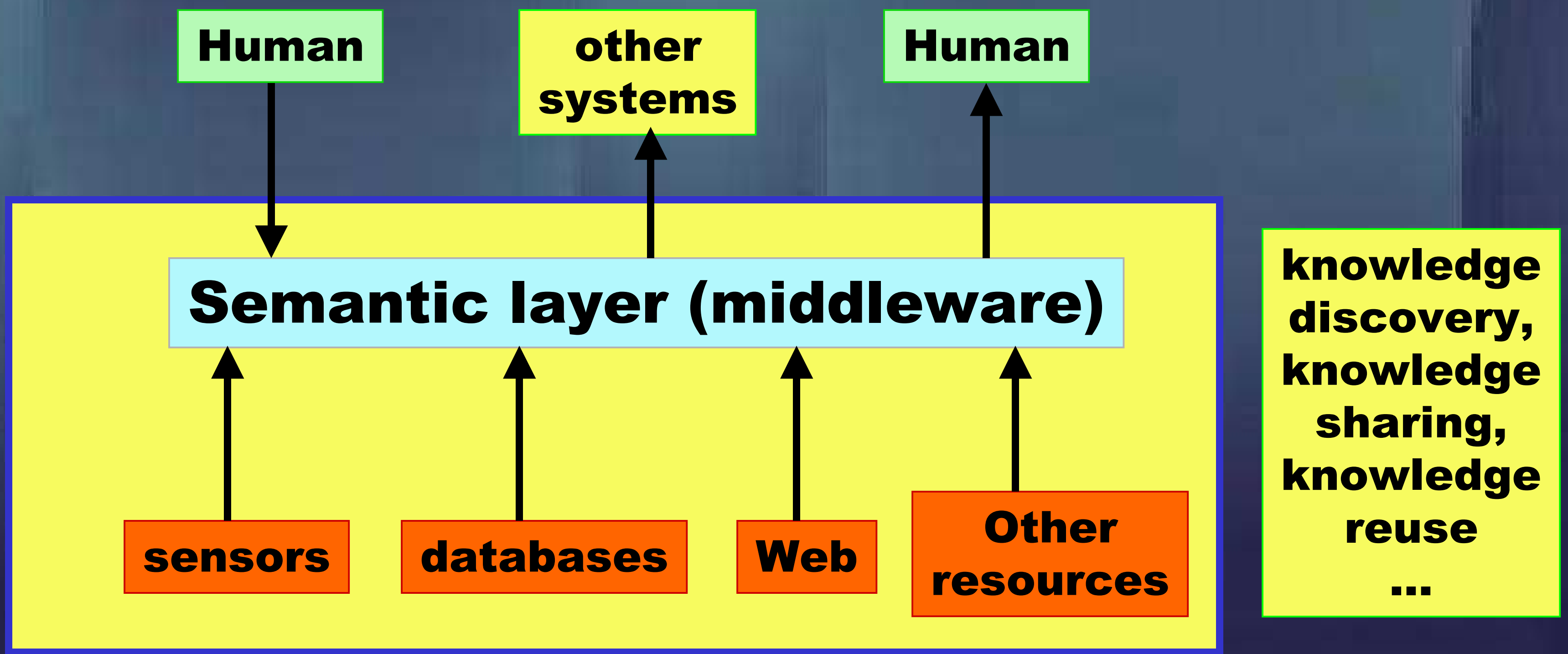
Digital communities and human-centric systems

Digital communities

Intelligent highways
Sensor networks
Smart housing
….



Human-centric systems



Human-centric systems

Human-centric computing (HC^2): main features

- User- and context –awareness, social interfaces
- Complexity
- Plasticity, learning and self-organization
- Predominant use of granular information (communication and processing)

Human-centric computing: selected examples

Area	*Key objectives, existing trends and solutions*
Intelligent data analysis	Effective explanatory analysis, delivery of findings at the level of information granules, effective mechanisms of summarization
System modeling	Building transparent models that could be easily interpreted and whose outcomes are readily understood. Models should help the user justify decisions taken
Adaptive hypermedia	Personalization of hypermedia to meet needs of individual users, development of specialized web services, building collaborative filtering, recommendation, content-based filtering, personalization of web engines, etc.
e-commerce	Expressing preferences of customers formulated at different levels of specificity (granularity)
Intelligent interfaces	Face expression, emotion recognition and tracking, formation and use of face-related features

Human-centric computing

“ the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it”

Weiser, 1991

Information granules and image processing

Images → perception and understanding

Meaningful entities (objects)

GRANULATION OF SPATIAL INFORMATION

Numeric information (pixels)

Images: from processing to understanding

User,
Decision-maker,
Designer,…

Symbols

UNDERSTANDING

Relevance
Feedback

SEMANTIC GAP

Numbers

Numeric information (pixels) and processing

Historical overview: A non-Aristotelian perspective

From two-valued to three-valued logic

- Lukasiewicz (~1920)
  true (0)
  false (1)
  don’t know (1/2)

- Three valued logic and databases (concept of null)

Dichotomy, two-valued logic and real world

true-false

yes-no → The underlying principle of excluded middle

black –white

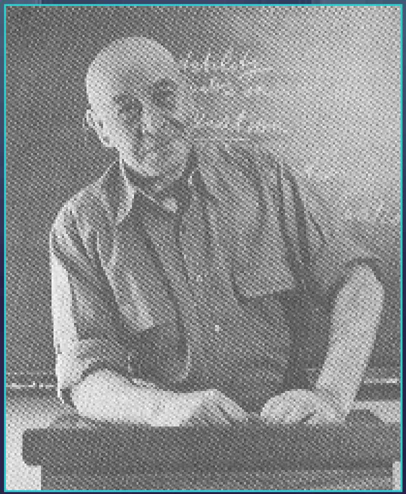
" … the law of excluded middle is true when precise symbols are employed, but it is not true when symbols are vague, as, in fact, all symbols are."

B. Russell, 1923

Non-Aristotelian view of the world

..in analyzing the Aristotelian codification, I had to deal with the two-valued, "either-or" type of orientation. In living, many issues are not so sharp, and therefore a system that posits the general sharpness of "either-or" and so objectifies "kind" , is unduly limited; it must be revised and more flexible in terms of "degree"…

A. Korzybski, 1933



Granular computing

Granular computing

regarded as a unifying platform aimed at

- representing,
- processing, and
- interpreting information granules

Information granules

- Individual entities drawn together with regard to its similarity, spatial or temporal closeness, or functional resemblance

- A fundamental mechanism of *abstraction*

- Information granules are *omnipresent* in human processes of perception and decision-making

Information granules

(a) information granules are the key components of knowledge representation and processing:

(b) the level of granularity of information granules (their size, to be more descriptive) becomes crucial to the problem description and an overall strategy of problem solving,

(c) there is no universal level of granularity of information; the size of granules is problem-oriented and is highly user dependent.

Fundamental formalisms

Sets and interval analysis (interval mathematics)

Fuzzy sets

Rough sets

…..

Interval analysis

algebraic operation	result
addition	[a+c, b+d]
subtraction	[a-d, b-c]
multiplication	[min(ac,ad, bc, bd), max(ac, ad, bc, bd)]
division	$[\min(\frac{a}{c},\frac{a}{d},\frac{b}{c},\frac{b}{d}),\max(\frac{a}{c},\frac{a}{d},\frac{b}{c},\frac{b}{d})]$ assumption: the interval [c, d] does not contain 0

Arithmetic operations on numeric intervals A and B

Interval analysis

BULLETIN DE L'ACADÉMIE
POLONAISE DES SCIENCES
Cl. III — Vol. IV, No. 5, 1956

MATHEMATICS

Calculus of Approximations

by
M. WARMUS

Presented by H. STEINHAUS on February 6, 1956

This paper presents a theory which lays down the foundations for numerical computations and makes it possible to formulate properly many numerical problems.

By the approximate number $[a, A]$ we shall indicate the interval $[a, A]$, i. e. the set of all real numbers x that satisfy the inequality $a \leqslant x \leqslant A$. The approximate number $[B-b, B+b]$ can also be denoted by $\overset{b}{B}$. Thus, the approximate number $[a, A]$ can be expressed in the form $\overset{\frac{1}{2}(A-a)}{\frac{1}{2}(A+a)}$. We shall omit initial zeros in the upper part, if they lie to the left of the last digit of the lower one. For example, we shall write $\overset{02}{3.1416}$ instead of $\overset{0.00002}{3.1416}$.

We say that the approximate numbers α and β are equal and we write $\alpha = \beta$ if, and only if, they are two identical intervals. Hence, we have $[a, A] = [b, B]$ if, and only if, $a = b$ and $A = B$, and similarly $\overset{a}{A} = \overset{b}{B}$ if, and only if, $A = B$ and $a = b$.

We say that the approximate number β approximates the approximate number α and we write $\alpha \Rightarrow \beta$ or $\beta \Leftarrow \alpha$, if, and only if, the interval β includes the interval α. Thus, we have $[a, A] \Rightarrow [b, B]$ if, and only if, $a \geqslant b$ and $A \leqslant B$, and similarly $\overset{a}{A} \Rightarrow \overset{b}{B}$ if, and only if, $b - a \geqslant |B - A|$. It is easy to prove that the approximations $\alpha \Rightarrow \beta$ and $\beta \Rightarrow \gamma$ imply $\alpha \Rightarrow \gamma$.

The relation $\alpha \Rightarrow \beta$ is a partial ordering of the set of all approximate numbers.

In practical computations it is convenient to use the following two rules:

$$\text{the rounding-off rule:} \quad \overset{a}{A} + c \Rightarrow \overset{a+|c|}{A};$$

$$\text{the extending rule:} \quad \overset{a}{A} \Rightarrow \overset{b}{A} \quad \text{if} \quad b \geqslant a.$$

Pedrycz and Gomide, FSE 2007

Fuzzy sets

Radical departure from Boolean (two-valued) information Granules

Fuzzy set as a descriptor of concepts with partial membership

Examples (1)

p. 65: *small* random errors in the measurement vector…

p. 70: The success of the method depends on whether the first initial guess is already *close enough* to the global minimum…

p. 72: Hence, the convergence region of a numerical optimizer will be *large*

F. van der Heijden et al., *Classification, Parameter Estimation and State Estimation*, J. Wiley, 2004, Chichester.

Examples (2)

p. 162: Comparison between bipolar and MOS technology (a part of the table)

	bipolar	MOS
integration	*low*	*very high*
power	*high*	*low*
cost	*low*	*low*

R.H. Katz, G. Borriello, *Contemporary Logic Design*, 2nd edition, Prentice Hall, Upper Saddle River, NJ, 2005

Examples (3)

p. 50: validation costs are *high* for *critical systems*

p. 660: …A *high* value for fan-in means that X is *highly coupled* to the rest of the design and changes to X will have extensive knock-on effect. A *high* value for fan-out suggests that the overall complexity of X may be *high* because of the complexity of control logic needed to coordinate the called components.

… Generally, the *larger* the size of the code of a component, the more *complex* and error-prone the component is likely to be…

… The *higher* the value of the Fog index, the more difficult the document is to understand

I. Sommerville, *Software Engineering*, 8th edition, Addison-Wesley, 2007, Harlow.

Explicit facet of fuzzy sets

typically pertains to some generic and fairly basic concepts we use in our communication and description of reality. There is a vast amount of examples as such concepts being commonly used every day, say

short waiting time, *large* dataset, *low* inflation, *high* speed, *long* delay, etc.

All of them are quite simple as we can easily capture their meaning. We can easily identify a universe of discourse over which such variable are defined. For instance, this could be time, number of records, velocity, and alike.

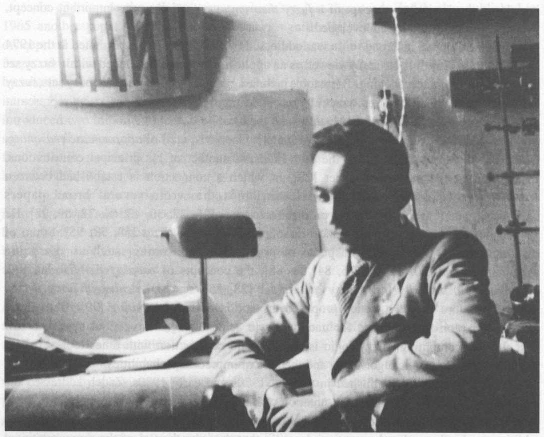
Implicit facet of fuzzy sets

Here we are concerned with more complex and inherently multifaceted concepts and notions where fuzzy sets could be incorporated into the formal description and quantification of such problems yet not in so instantaneous manner.

Some examples could include concepts such as "*preferred* car", "*stability* of the control system", "*high performance* computing architecture", "*good convergence* of the learning scheme", *strong* economy, etc.

"*preferred* car" -- evidently multifaceted and may involve a number of essential descriptors that when put together (speed, economy, reliability, depreciation, maintainability, …)

Fuzzy sets and the principle of incompatibility



Lotfi Zadeh during his student years in Tehran in the early 1940s (the large Russian sign ODIN, which means "alone," was his early proclamation of independence).

As the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics

Roles of fuzzy sets

as a enabling processing technology of some universal character and of profound human-centric character

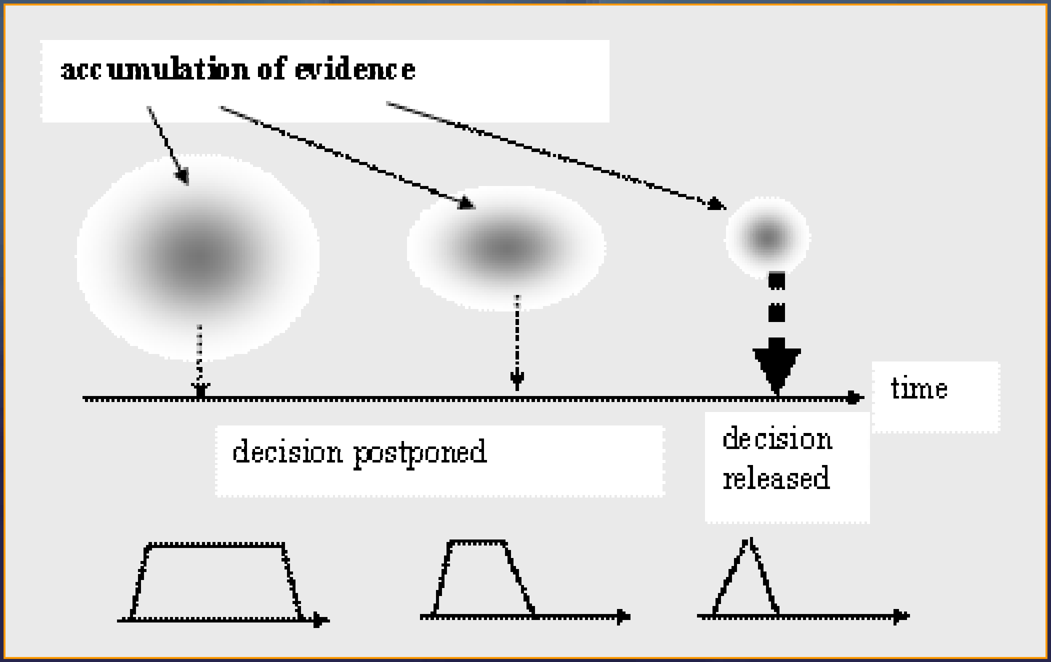
as an efficient computing framework of global character

as a vehicle of raising and quantifying awareness about granularity of outcomes

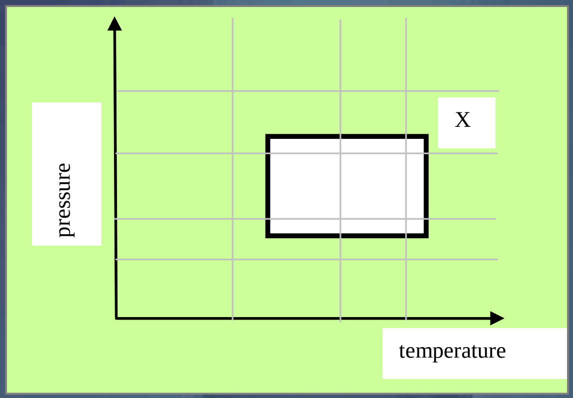
as a mechanism realizing a principle of the least commitment

Principle of the least commitment

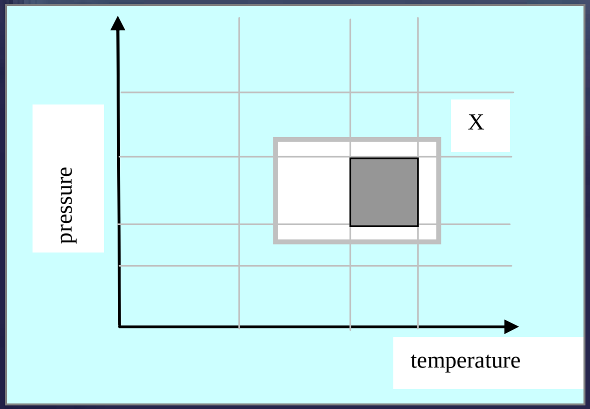
- Making decision realized in presence of sound evidence
- If not enough evidence available, postpone decision and actively accumulate more relevant findings

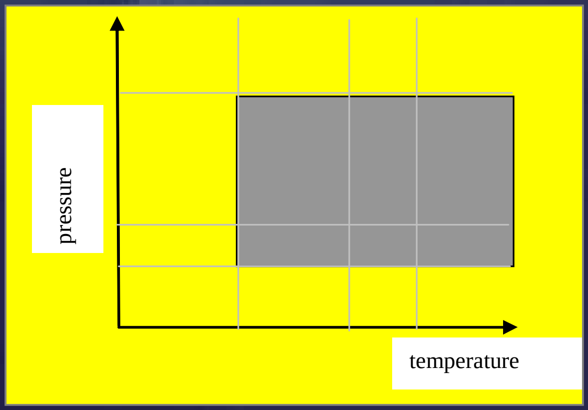


Rough sets

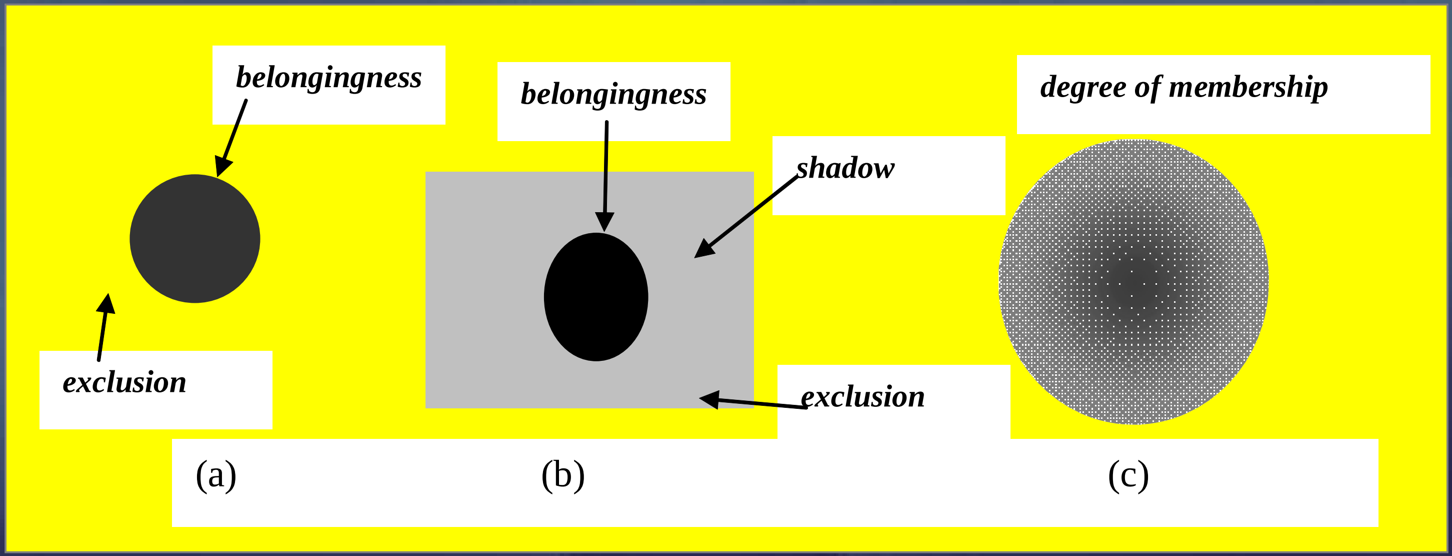


Description- lower and upper bound





Sets, fuzzy sets, shadowed sets



Computational Intelligence

Computational Intelligence (~1990)

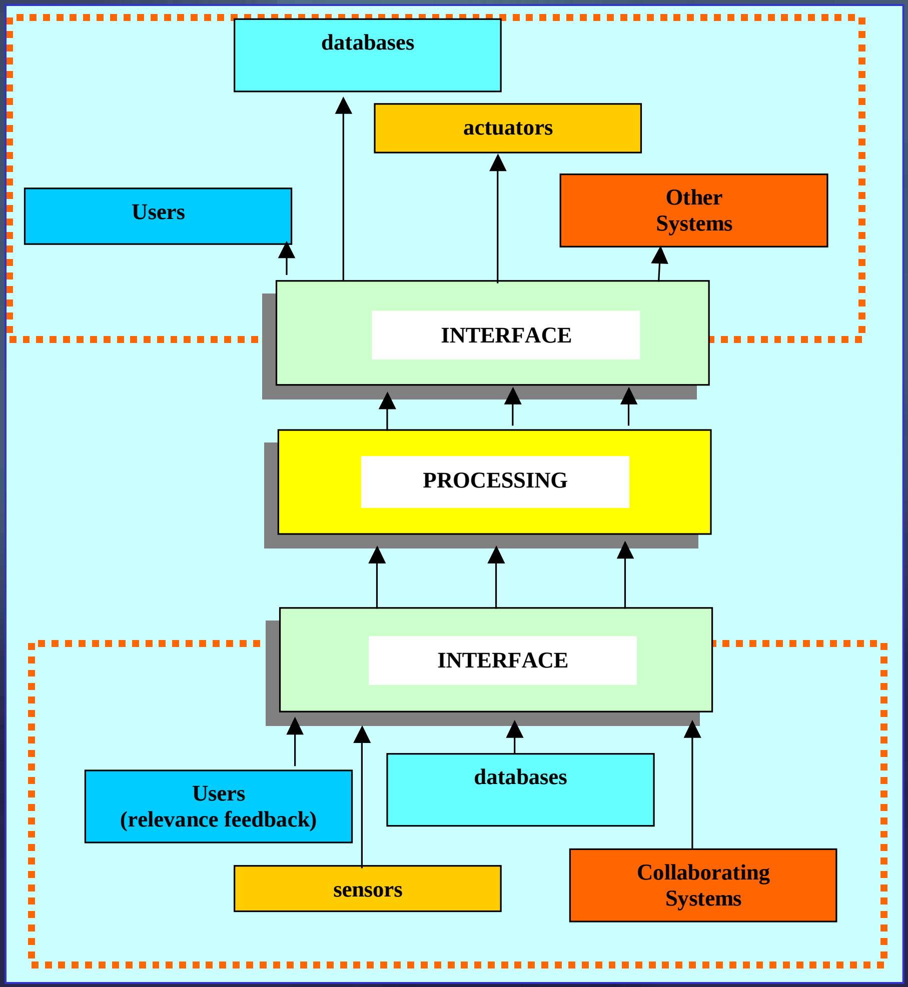
Multistrategy and multifaceted approach to design intelligent systems:

Granular computing

Neural networks

Evolutionary optimization (biologically-oriented computing)

Layered architectures of systems of computational intelligence



Pedrycz and Gomide, FSE 2007