Multimodality and Vagueness in the Context of a Graphical, Object-Oriented Materials Information System

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Abstract

In the context of an extended understanding of information retrieval, multimodality and vagueness are discussed as key problems of materials information system development. The *WING-M2* prototype is presented which combines an object-oriented graphical interface with natural language feedback and correction functionality as well as additional components for graphical result querying and vague formulation of user needs. System development in *WING-IIR* is based on the rapid prototyping paradigm in combination with user tests in the application domain, materials information systems. Our design enhances traditional parallelized multimodal system structures by tailoring multimodality features to the respective advantages of different query modes. This approach seems to be of special importance for dealing with iterative retrieval strategies. Vagueness in user needs is addressed in different modalities: The graphical query module allows for visual specification of follow-up queries in line chart representations of factual data. It exploits the materials experts' visual interpretation of given data for graphical query formulation. The *fuzzy-logic* component of *WING-M2* applies vague concepts to query interpretation in different modalities (e.g. by modeling linguistic variables like high as fuzzy concepts).

1. Introduction

Recent publications in the Information Retrieval (IR) field mirror a significant change in research interests: The *classical* IR research paradigm focussing on evaluation and statistical methods is broadened by components like user modeling systems, knowledge-based query facilities or intelligent help systems (cf. INGWERSEN 1992:57ff). At the same time, system design is increasingly based upon results from software ergonomics and multimodality research.

In this context Belkin 1993:55 sees the standard model of IR as inappropriate and suggests a new approach in defining IR as *information-seeking behavior* in very general terms:

> The explicit consequences of this view are that: the goal of the IR system is to support the user in her/his entire range of information-seeking behaviors; the user must be considered the central component of the IR system; and interaction [...] is the central process of IR. (Belkin 1993:64)

Fox 1993:116 enlarges this viewpoint in including "networked multimedia information access" as typical IR research activities. Classical IR is thus seen as a phenomenon of past technical restrictions:

> [...] computerized information retrieval has been limited by many factors, such as storage capacities [...] costs of capturing data, and the practices of the publishing industry. With improvements in technology, we can break through these limitations, and manage large digital libraries of multimedia objects [...]. Yet to be successful and to have easily usable systems we urgently need better models.

The *WING-IIR* project of the Information Science Department at the University of Regensburg[*] (***W***erkstoff***I***nformationssystem mit ***N***atürlichsprachlicher/***G***raphischer Benutzerschnittstelle und ***I***ntelligentes ***I***nformation ***R***etrieval/*Materials Information System featuring Natural Language and GUI-based Database Access and Intelligent Information Retrieval)* is typical for that enlarged understanding of IR: Since 1988, we have been designing and implementing materials information systems combining an object-oriented graphical user interface with natural language query facilities and a graphical retrieval tool designed for query iterations based on a visual data presentation (i.e. line charts).

Our design is embedded in a toolbased, object-oriented structure which allows for adequate interpretation and usability for both, novice and expert users. Implementing contextsensitivity and transparency between query modalities and different levels of data granularity further help in solving materials problems (for a more detailed account see KRAUSE et al. 1993, 1994).

The term *modality* refers primarily to human perception; usage of different modalities (multimodality) may occur within a single *medium* as the technical carrier of information: In information systems like *WING-M2,* visual presentation of graphical and natural language information constitutes two *modalities* (visual perception of natural language and visual perception of images) using only one physical medium, the display screen (cf. MAYBURY 1993:2f). Multimodality has a threefold application in *WING-IIR*:

- GUI-based retrieval forms,
- natural language access and
- graphical result retrieval.

All modes may at any time be used for query build-up. In addition different modules of intelligent information retrieval (IIR) complement the basic database interface:

- the *WING-GRAPH* component allows for graphical retrieval of materials curves, i.e. users may manipulate graphical data representation in order to query the database (see ch. 3) and
- the *fuzzy-WING* component handles vagueness in queries and additionally provides vague interpretations of seemingly exact queries (see ch. 4),
- a stereotype-based user model reduces interface complexity by adapting to the users' actual interests (not to be discussed in this paper in further detail, see ROPPEL et al. 1993).

The industrial cooperation partner of *WING-IIR* is *MTU GmbH* (Motor and Engine Union), a major German manufacturer of aircraft engines and heavy Diesel motors. Since 1988, a department of MTU has been responsible for building up and servicing a relational database containing facts on relevant materials, especially steel, nickel and titanium alloys (cf. WOMSER-HACKER 1990).

For this database different access modes have been developed and tested with MTU-engineers; a first multimodal prototype *WING-M1* (cf. WOLFF & WOMSER-HACKER 1991) has subsequently been implemented and tested again. The results of these tests guide the development of an object-oriented, multimodal system *WING-M2,* based on the toolkit metaphor and eliminating the weaknesses of the previous systems. An overview concerning the manifold empirical investigations of our first-stage database access components the results of which justify the architecture of our *WING-M2* system prototype may be found in more detail in KRAUSE et al. 1993, 1994.

In this paper we concentrate on those aspects of our ongoing research which are essential for modeling vagueness in the context of a multimodal interface comprising a graphical user interface and natural language query access as well as graphical result

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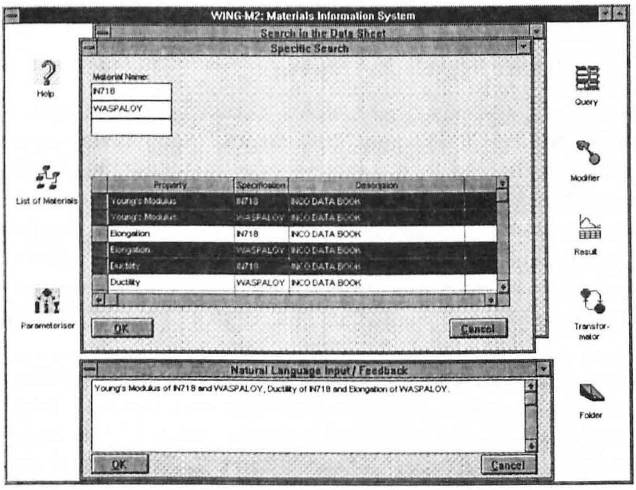
retrieval. Besides the well-known problem of vaguely defined user needs, a major reason for the importance of vagueness in the materials information domain is the inconsistent status of database contents. Due to external factors (esp. high costs for data acquisition) data are distributed very unevenly in the database and gaps occur frequently. These have to be compensated by derived similarity-relations between different database objects. Such problems have been widely ignored so far, as exactness and completeness on the side of the database were taken for granted. In reality however, gaps, uncertain or ambigue data are more a rule than an exception. It will become clear that the treatment and investigation of iterative retrieval is crucial for the model proposed in *WING-IIR*.

2. The Use of Natural Language as Correction Mode and Status Display

The traditional purpose of implementing natural language access to information systems is the replacement of hard-to-handle formal query languages. Another, somewhat advanced approach is the simple combination of GUI-based access with natural language querying where the user may at any time choose his preferred method of querying the database; thus multimodality is implemented as a parallelization of different query modes.

Both design variations have been implemented in *WING-IIR*, but have met with considerable problems in the *WING-IIR* user studies: Being confronted with the GUI/NL query alternative (in *one* interface), users very rarely made use of natural language querying (approx. 3 % of tasks solved); in test conditions where users had to use natural language access as the *only* mode of query formulation, this access type was judged to be inferior to GUI-based systems.

As a consequence, a design concept had to be found which avoided simply parallelizing modalities: The juxtaposition of different access modes had to be overcome in favor of exploiting the advantages of both database access modes, since parallelism does not support the strengths of natural language access in comparison to the graphical mode.



Material Name:
N718
WASPALOY

Property	Specification	Description
Young's Modulus	IN718	INCO DATA BOOK
Young's Modulus	WASPALOY	INCO DATA BOOK
Elongation	IN718	INCO DATA BOOK
Elongation	WASPALOY	INCO DATA BOOK
Ductility	IN718	INCO DATA BOOK
Ductility	WASPALOY	INCO DATA BOOK

Young's Modulus of IN718 and WASPALOY, Ductility of IN718 and Elongation of WASPALOY.

Figure 1: WING-M2 interface with a query example (materials comparison)

The graphical mode is preferred for its inherent presentational nature: Every action is explicitly offered by the system, only to be passively recognized by the user and subsequently selected with the mouse. The disadvantage of this method is that information has to be distributed over several screens for space restrictions. Thus users may have problems overseeing all the decisions that led to the actual situation, i.e. their query dialogue history.

The first step in avoiding this disadvantage is the introduction of explicit status information showing all parameters already set. In *WING-M2* the demand for status information is answered with a broadening of natural language functionality. Status information is generated stepwise from the user's graphical interaction as a natural language formulation and is presented in a window below the graphical input window (see fig. 1). Both windows present the same query by different means. They are context-sensitively and dynamically connected in both directions: For every parameter the user sets in the graphical mode the corresponding natural language statement is generated and vice versa.

The crucial enhancement of the natural language modality in *WING-M2* is that the natural language statement generated by the system may be edited. If the user wants to change a parameter in a complex query, for example the temperature value, the presentational character of the graphical mode does not help: The disadvantage of having to access the specific window or window part where the temperature parameter had been specified, remains. In this case the natural language correction mode is superior. This becomes obvious in the case of iterative retrieval: After studying the results of a complex query in most cases only details of the original query are modified.

At the same time *WING-M2* offers the possibility of switching modes any time even during the construction of a single query. Some parameters may be formulated in natural language without delay, while the user may at any time change to the graphical mode (if this promises an advantage). Recent user tests (as of June/September 1993 and June 1994) confirm this new solution for combining different modalities: Users accepted natural language as a post-query correction mode and rated this "partial query functionality" of natural language as positive.

It is clear that the empirical results concerning natural language queries from the first project stage might have been interpreted in way resulting in the complete elimination of this mode. But beside the above mentioned advantages of natural language as a status display and correction mode, other aspects have to be considered: Natural language offers a convenient way of expressing vague query concepts which may not otherwise be formulated in a typical GUI-interface (for a discussion of graphical formulation of vague queries, see ch. 3 below): Vague concepts like "*high* temperature" may be easily expressed in natural language. At the same time, empty result sets for precise queries allow for the iterative substitution of exact search conditions by vague query formulations in the natural language mode (cf. WOLFF 1992:246ff). Thus a precise query resulting in an empty set like *Young's modulus > 250 GPa* can be replaced by the vague concept ***high*** *Young's modulus* (for semantic interpretation of vague concepts see ch. 4).

3. Iterative Retrieval und Graphical Result Retrieval

An additional aspect of vagueness in IR systems, the complex notion of user needs, is mirrored by the inherently iterative nature of IR: Input and output, query formulation and result presentation are closely intertwined in interactive retrieval systems. In the *WING-IIR* research prototypes a phenomenon complicating this problem had to be modeled: In materials information systems - as in many application domains for fact retrieval - the user deals with large tables that are better to interpret in graphical form, i.e. as a chart. The abstract alphanumerical representation in this case is no appropriate means of communication. Therefore visual representation is a central part of WING-GRAPH system functionality.

In modeling retrieval iteration, this restriction of query formulation to the textual mode (even in a GUI-context) creates a severe problem: Figuring out possible query dialogue continuations, users often refer to the graphical representation of the result data (e.g. *I am looking for materials with a* ***steeper*** *elasticity* ***curve***). Traditional systems force users back into the query modality proposed for the initial query, while at the same time they have already applied "graphical thinking" based on the preferred *result presentation modality*. In order to avoid this modality switching in iterative retrieval, the *WING-GRAPH* system exploits graphical techniques for the query formulation process itself.

The basic hypothesis of *graphical result retrieval* is that materials experts' visual capabilities may be employed for query build-up. Especially for comparative queries in large databases it may be easier to formulate a query graphically in the adequate modality of representation, i.e. graphics (for a comprehensive research overview see DESANCTIS 1984, LOHSE 1991, and WOLFF 1994:ch.5.1) than trying to develop a complex query abstractly describing a comparison with a given data item (e.g. a measurement series). A transfer of knowledge gained from the interpretation of a materials curve (i.e. from the graphical representation) into the abstract numerical modality can thus be avoided - a fully graphical retrieval cycle is accomplished.

The starting point is the empirically validated hypothesis that for the evaluation of large amounts of data, esp. for judging trends and tendencies, graphical representations are easier to interpret than alphanumerical representations. On the basis of these findings a modified version of PINKER's cognitive model of graph representation and computation in the mind (PINKER 1990) is used for modeling the graphical retrieval process: This is seen as a three-component cyclic process comprising

a) the user's interpretation of visualized data
b) graphical query formulation using direct manipulation and
c) the system's query transactions and iterative result display.

Analyzing graphical displays on the basis of Kosslyn's structural framework for graphical data displays (KOSSLYN 1989), it becomes clear that there are three major types of graphical queries: *Abstract query types* defining search conditions in a graphical way without referring to given data (e.g. materials property curves), *relational query types*, defined in direct correlation to the data presented in the display and *user-authored data entities as query basis*, i.e. (materials) curves drawn by the user for defining a query in the form of a graphical curve shape hypotheses.

While this is yet a mere theoretical analysis of graphical query types, the gap between the materials experts' interpretation capabilities and production possibilities in the given context (interaction tool, screen resolution, interaction techniques provided etc.) has to be taken into account: The interpretation of a given curve as a comparison with mentally represented "ideal" materials curves may be much more detailed than the materials expert's actual output in graphically formulating a query. Thus the important role of mental imagery (cf. WEBER & KOSSLYN 1986) in the interpretation and query formulation process is influenced by a great number of external factors.

Taking these factors into account and at the same time localizing graphical retrieval as an add-on component for retrieval iterations *after* a first result presentation, it becomes clear that *relational query types* offer the greatest potential for implementing cyclic retrieval in the user-preferred modality. Within this framework for graphical retrieval, the two major aspects of materials information system design, vagueness and multimodality, are addressed on different levels:

The possibility of formulating queries graphically can narrow the gap between vague user needs and the system-imposed requirement of exact query definition: Since the user is allowed to use the preferred modality of data visualization and interpretation for query definition, no "translation problem" between graphical interpretation and alphanumerical representation occurs. At the same time the *WING-GRAPH* component is required to provide for vague query interpretation mechanisms, since most graphical queries can not be interpreted *literally*, e.g. when the user draws a meaningful curve sketch which cannot be exactly matched in the database.

Obviously, adding graphical result retrieval to *WING-M2* introduces an additional aspect of multimodality as well: *Graphical* retrieval as a search modality is introduced in an interpretation fairly different from the design features of standard graphical user interfaces which merely provide the user with a graphical *environment* but do not influence the final modality of query definition: In standard GUIs there is a strong alphanumerical aspect in query formulation even if the user selects items from "graphical" dialogue elements or navigates by way of direct manipulation.

3.1. The Design of *WING-GRAPH*

Based upon the query type categorization mentioned above a prototype with six different graphical query types has been implemented and tested (see fig. 2 and ch. 3.2 below). The functional focus lies on *relational search types* allowing for iterative graphical retrieval as the main entry point in graphical result retrieval.

The interface of the *WING-GRAPH* component has the following elements: Central part of the display is the graphics window, where materials data is displayed as line graphs using the typical display characteristics for each material property (scaling, labeling, value ranges displayed etc.). This graphical data display is also used for formulating the graphical queries. In order to do so, the user may select one of six query types from a toolbox containing the respective interaction type selectors (presently symbol-defined push buttons).

Abstract query types:
- Definition of search points and (rectangular) search areas

Relational query types:
- Definition of search areas in relation to a given curve (stray value range)
- Better-/worse-condition in relation to a given curve
- Comparison of two given data sets (materials curves)
- Modification of a given curve

User-authored query hypotheses:
- Drawing of a curve sketch as query formulation

Table 1: Query types in WING-GRAPH

Having selected a query type, the user can define his query in the main graphical window and then iterate this process combining different search types, until the desired query formulation is completed. This query may then be matched against the database, possibly resulting in a new graphical display of the result set (i.e. those materials curves found in the query process).

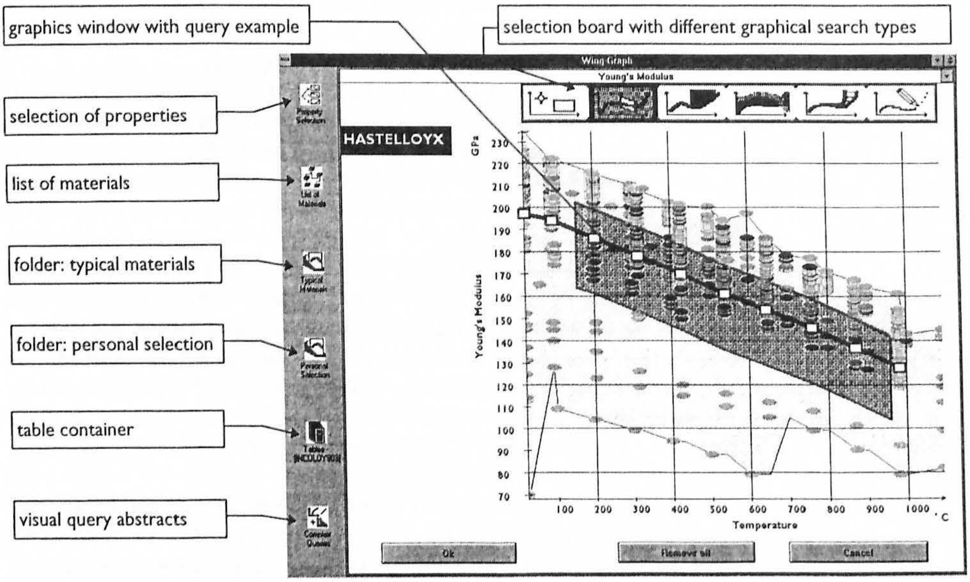


Figure 2: Interface of the WING-GRAPH module showing a graphical query definition

While graphical data interpretation is thought to be advantageous for some situations, a multimodal system requires the presence of both relevant modes of information display. Therefore, the user may at any time choose to view the data table for any curve displayed by opening the table folder.

Additionally, *WING-GRAPH* module offers a direct entry-facility: The user may select a curve from folders containing iconized materials curves (as data entities), on the basis of which he may start a new retrieval cycle. The folders can be adapted by the user to contain the selection of materials of highest relevance to his query interests. Just as query entry, query construction and feedback are likewise aided by a simple *iconic visual language* (cf. CHANG 1990): Joining graphical queries concerning different materials properties together, the user may construct a complex graphical query formulation (fig. 3) which itself is reflected in a natural language feedback summary satisfying the multimodality framework laid out in ch. 2.

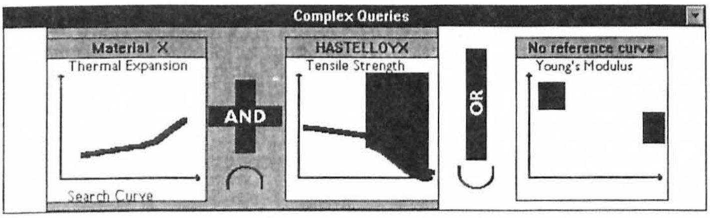


Figure 3: Example of a complex query using visual query abstracts

Summing up, *WING-GRAPH* as a visual query mode should be seen within the recent visualization efforts in IR (cf. CROUCH & KORFHAGE 1990, OLSEN et al. 1993) and database research (*visual query systems*, cf. BATINI et al. 1992).

3.2. Empirical Validation of Graphical Retrieval

The *WING-GRAPH* component has been tested by 9 materials experts of our cooperation partner, MTU; in the test, the subjects were asked to solve eight typical materials database problems using the different query types provided by *WING-GRAPH.* While they were not only able to pick out the correct search type in 77% of the tasks solved, they also arrived a at meaningful task solution in almost any case using alternative (graphical) search strategies (see WOLFF 1994:ch. 7 for details).

The test validated the theoretical assumption that *relational* search types are the most important improvement offered by graphical retrieval since they allow for detailed materials comparison queries otherwise difficult to handle. At the same time they are the essential connection between the *WING-M2* kernel system as the retrieval *iteration entry point* and the add-on graphical retrieval facility. The test also showed that the different query types might be reduced to fewer but more powerful search tools oriented more closely at the basic three-type categorization mentioned above. Finally, the importance of allowing for a flexible combination of different query types was stressed, as users frequently applied different query types consecutively in the definition of their search goal.

Certainly the main result of testing *WING-GRAPH* is that for some typical, esp. comparative database search problems graphical result retrieval is a valuable enhancement of query functionality and interaction design in the context of a multimodal materials information system.

3.3. Graphical Query Processing

Not much has been said so far concerning the semantic interpretation of graphical query constructs. While for the simpler query types there seems to be a straightforward translation into formal query languages (e.g. SQL), the more complex types require a multi-layered interpretation scheme. In those cases where the user either draws a curve sketch himself or modifies a given materials curve, the system has to provide for a "vague" interpretation of the users' query. In these cases the query is constructed by

a) reducing the user defined graphical construct to meaningful hypotheses about a possible conjunction of measurement values.

b) Where different typical series of reference points exist (e.g. measurements at 50°C, 150°C, 250°C ... vs. 100° C, 200° C, 300° C) the system provides for automatic interpolation between the different series

c) The system decides on vague interpretation ranges laid around every single search condition depending on the user's typical interests, the contents of the database (measurement density) and the overall complexity of the query (the higher the number of conditions, the broader any local interpretation may become)

d) Finally, the system decides on the semantics of condition conjunctions which vary with respect to the different search types (inclusive vs. exclusive conjunctions).

Query processing (esp. c) and d)) makes use of a simple user model specifying the typical search interests of different user types which are used in determining the interpretation ranges in query evaluation. A construction engineer, for example, has far broader search interests than a materials analysis engineer; queries formulated by the former are therefore to be interpreted more vague than those posed by the latter. While the system at the present stage works with fixed attributes for the different user types, it is clear that the evaluation process may be considerably improved by implementing fuzzy evaluation functions for graphical retrieval as well. These are described in more detail in the following chapter.

4. Handling Vague Queries in *WING-IIR*

Just as user-system interactions often refer to vague concepts concerning the graphical properties of curve shapes, a phenomenon addressed in *WING-GRAPH*, it has become obvious that users often think in vague categories in other contexts as well. For example, engineers search for materials with *high* Young's modulus, *low* thermal expansion or *good* corrosion resistancy. They want to find materials or property values that are *similar* or *characteristic* with respect to what is already known to them. User tests in the *WING-IIR* project have shown that users spontaneously employ vague concepts while formulating natural language queries.

The users' problem of defining exact search boundaries and their preference for vague formulations in certain search contexts has been the reason for integrating a fuzzy logic module into the *WING-M2* prototype allowing for the use of vague query conditions. Replacing exact search conditions with vague queries also counteracts the consequences of inconsistent or incomplete database contents, especially data or measurement gaps typical of high-cost data like those in the materials domain.

4.1. Theoretical Background of Fuzzy Set Theory

There is a variety of alternative approaches to modeling vagueness in IR, e.g. fuzzy set or fuzzy logic theory, probabilistic and possibilistic approaches, certainty factors. The fuzzy logic approach chosen here provides a way to model vague expressions using so-called linguistic variables (see examples above). Whether a particular temperature is estimated as *high*, depends on several contextual factors. In the materials domain, these linguistic variables cannot be mapped onto standardized value ranges with general validity. Human intuition does not agree with exact boundaries that might for example associate a value of 21 degree Celsius completely with the category *low* while excluding a value of 22 degree.

Fuzzy logic as a means to knowledge representation and manipulation has been set out in the sixties and early seventies by L. ZADEH (cf. ZADEH 1965 and 1971) and has gained new momentum in numerous practical applications in recent years. The relevant aspects of fuzzy set theory shall be briefly summarized in the following.

In contrast to classical set theory or logic, fuzzy sets depend on the idea that there are different degrees of membership of an element with respect to some set, i.e. a

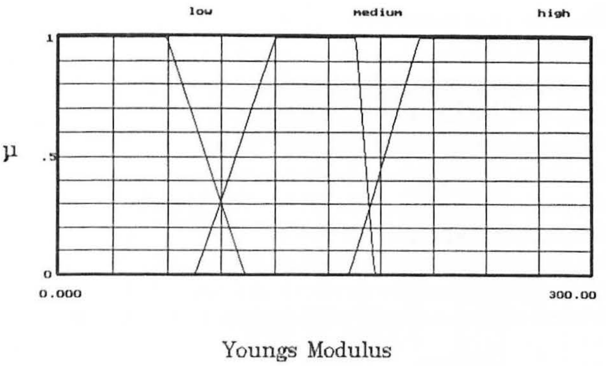


*Figure 3: Young's Modulus: Fuzzy Concepts **low**, **medium**, and **high***

proposition is not either true or false but possesses intermediate truth values like *very true* or *mostly false*. These degrees of membership may be described by a characteristic membership function μ, The values of μ, typically represented by a value in the interval [0,1], indicate to which degree a concrete value belongs to some fuzzy concept with 0 denoting „no membership", and 1 a membership of 100 percent (cf. KLIR & FOLGER 1988, 27f.). Within this theory, exact thresholds are not necessary, since vague concepts may overlap each other (see fig. 4). Like in crisp sets there are also methods of relating fuzzy sets. In analogy to ordinary set operations like union, intersection and complement, fuzzy set theory gives corresponding techniques at hand. The standard operations are the *minimum* and *maximum* operators: *Minimum* provides a fuzzy intersection, *maximum* a fuzzy union. Since intersection and union are analogous to logical AND and OR, the intersection operator demands simultaneous satisfaction of all operands, whereas union is already satisfied with only one condition being fulfilled. To combine two fuzzy sets on the basis of the *minimum* operator, the lower degree of satisfaction is taken into account, while the *maximum* operator demands the maximum of satisfaction. Both operators have been criticized for different reasons (cf. MAYER et al. 1993, 40f.). Therefore a lot of empirical work has to be done to evaluate the results gained with these operators. The following table shows how the minimum operator may be applied in a materials example:

	membership in set of high corrosion resistancy	*membership in set of great hardness*
material A	0.4	0.4
material B	0.9	0.3
material C	0.7	0.3

Table 2: Minimum Operator

If the minimum operator is applied for intersecting two or more vague sets (e.g. *high corrosion resistancy AND great hardness*), the membership to the resulting vague set is 0.4 for material A and 0.3 for material B. Material B's high membership value of 0.9 for the set of high corrosion resistancy is not taken into account at all. In natural language and in human cognitive processes the AND concept has no crisp definition: Humans normally apply compensation techniques when combining concepts which are satisfied to different degrees. In most cases, the degree of compensation is determined by contextual factors. *Compensating operators* work on the basis of this assumption: A very high value concerning one condition can make up for the lack of satisfaction of the other (cf. MAYER et al. 1993:45).

A more demanding approach leading to a rule-based expert system would go beyond the combination of vague concepts by deriving knowledge on the basis of inferences. A set of production rules describing fixed situations is necessary to formulate the relation between several vague concepts (e.g. *IF Young's modulus is high AND thermal expansion is low THEN solidity is good*). User studies have proved the need as well as the potential for such inference mechanisms, but a lot of work with respect to knowledge engineering is necessary to acquire and formalize the appropriate rules. This remains to be done in future work.

4.2. The Design of *fuzzy-WING*

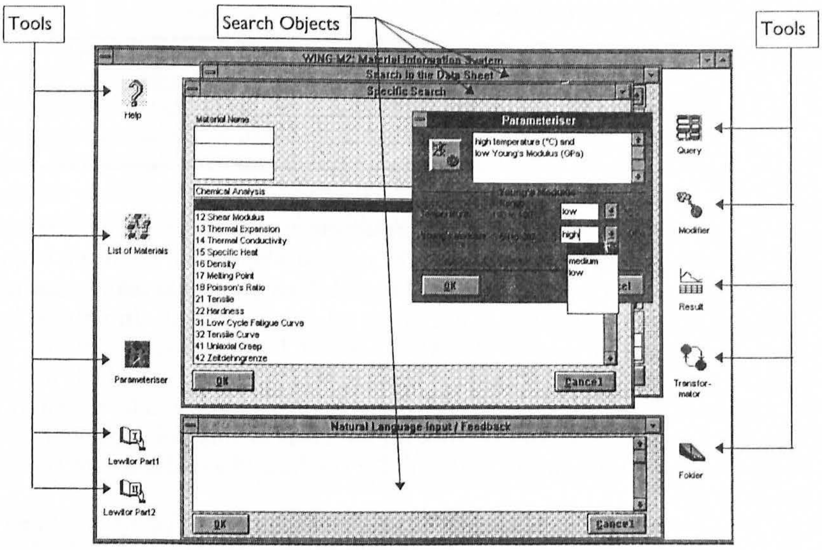
Fuzzy-WING is the component of *WING-M2* that handles vague queries. As a tool of the kernel system, it conforms to the principles of contextsensitivity and the twofold usage of natural language expressions as described in ch. 2. Vague queries may be employed in two different ways: Users may either express vague concepts directly in their input to all search modalities, or they can force a vague interpretation of query conditions by activating and adjusting the fuzzy tool themselves. The *WING-IIR* knowledge base has been expanded by a *fuzzyfication* of materials properties and parameters, i.e. a linguistic assessment was performed so that the measurement values in the database are mapped onto corresponding fuzzy sets which model linguistic concepts like *low*, *medium*, or *high*. The following example shows the three vague concepts with respect to Young's modulus:

4.2.1 User Input Containing Vague Concepts

In WING-M2 search parameters are specified by the user in the *Parametrizer* tool which accepts exact values, value ranges (e.g. *temperature 700-750 C*), vague terms (*hot, low, good*) and their synonyms *(at extreme temperature)* as well as modifiers *(very* hot*)*. The system presents the possible vague concepts for each attribute in a list (see fig. 5). User tests and interviews showed that for most of the material properties commonly agreed search preferences exist (e.g. *high* Young's-modulus), so these can be highlighted.

Since interpretation of vagueness in the materials domain is context dependent, a *high* temperature means something different for aluminum than for titanium alloys. Therefore, the *fuzzy* module has to be activated with parameters appropriate for each particular context.

In the current system, this contextual dependency is realized by information represented by additional columns in the SQL tables having vague concepts as attributes and membership function values of the special measurement values as items.



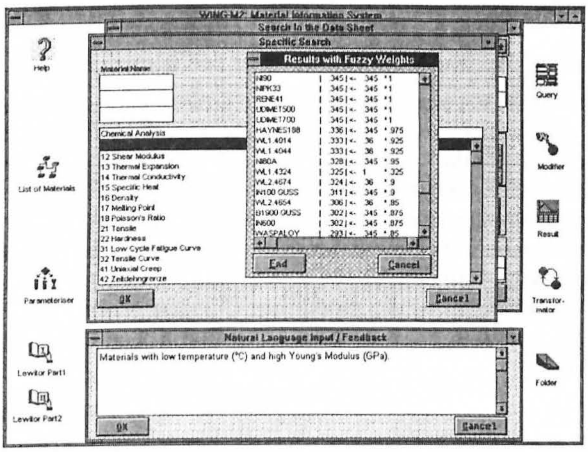
high temperature (°C) and
low Young's Modulus (GPa)

low

high

Figure 5: WING-M2: Searching for materials using fuzzy concepts

As a first solution, results are presented in a ranked list showing the items in descending order of their membership-function values. In the case of intersection of two or more vague criteria (e.g. **high** *Young's modulus AND* **low** *thermal expansion*) a visualization problem of complex fuzzy sets arises. *Fuzzy-WING* presently calculates the product of different membership function values as a single value to be ranked in the result list. In a later stage, weights of special properties may be included to vary the ranking order of the result list (see fig. 6).



Chemical Analysis
12 Shear Modulus
13 Thermal Expansion
14 Thermal Conductivity
15 Specific Heat
16 Density
17 Melting Point
18 Poisson's Ratio
21 Tensile
22 Hardness
31 Low Cycle Fatigue Curve
32 Tensile Curve
41 Uniaxial Creep
42 Zeitdehngrenze

```
NI90         | .345 |<-  .345  *1
NIPK33       | .345 |<-  .345  *1
RENE41       | .345 |<-  .345  *1
UDIMET500    | .345 |<-  .345  *1
UDIMET700    | .345 |<-  .345  *1
HAYNES188    | .336 |<-  .345  *.975
WL1.4014     | .333 |<-  .36   *.925
WL1.4044     | .333 |<-  .36   *.925
NI80A        | .328 |<-  .345  *.95
WL1.4324     | .325 |<-  1     *.325
WL2.4674     | .324 |<-  .36   *.9
IN100 GUSS   | .311 |<-  .345  *.9
WL2.4654     | .306 |<-  .36   *.85
B1900 GUSS   | .302 |<-  .345  *.875
IN600        | .302 |<-  .345  *.875
WASPALOY     | .293 |<-  .345  *.85
```

Materials with low temperature (°C) and high Young's Modulus (GPa).

Fig. 6: Materials as result of a search ranked by fuzzy weights

According to empirical evidence cut-off points that limit the number of items in the result set (e.g. at the point of intersection of two vague concepts) may be determined.

WING-M2's natural language mode offers another way of directly expressing vague query concepts. The system's parser has to recognize linguistic variables in the input string and to associate them with the adequate vague concepts.

The additional function of natural language as a status display that can be manipulated allows the broadening of unsatisfactory query results by the introduction of vague terms into the conditions (*Young's modulus of 250 GPa* ↔ ***high*** *Young's modulus*).

The graphical query mode (see ch. 3 above) always operates with such a vague interpretation of user input. E.g. the position of a mouse click is interpreted as a certain range around that point, drawing on the same knowledge base and vague concepts as the *fuzzy* tool.

4.2.2 Determining Vague Query Interpretation

Experienced users can parametrize the *fuzzy* component just as the other *WING-M2* tools. This means that the user can pre-determine a modification of search conditions by accessing the underlying vague models. Similar approaches have already been employed in the materials domain by the use of standard tolerances (e.g. 5% variation) in the case of data gaps and have been criticized for their fixed ranges. A fuzzy manipulation of these ranges, depending on the application context, seems to be a viable approach. Experienced users can set the vague concept of a particular property, modify membership values, or make settings for activations or de-activations of the fuzzy tool. To make this possible, the vague concepts are presented in tables or a co-ordinate system with graphical manipulation devices. Thus users have the possibility to integrate their own individual and context dependent interpretation of vague concepts. If the fuzzy tool is activated for all properties, even exact query conditions are interpreted within a vague range.

This option is available in all query objects and a status display signals if and for which properties the fuzzy tool is activated. Currently, in each active property parametrizer an icon indicating the status of fuzzy processing fulfills this function (cf. fig 5).

5 Implementation

All *WING-IIR*-components have been implemented in the *MS-Windows* environment and are connected to our SQL-based materials database by the *Gupta SQLBase Database API for Windows*. The kernel system *WING-M2* has been designed using *Gupta's SQLWindows* application generator. The *WING-GRAPH* component has been implemented in *MS Visual C++*. *Fuzzy-WING* makes use of the *Fuzzy-Tech* function library for the development of fuzzy-logic-based applications. The database is a structurally complete subset of our cooperation partner's in-house database system comprising nineteen tables with detailed measurement data as well as overview data and additional tables for solving denominator problems.

6. Conclusion

The *WING-IIR* approach to designing a multimodal materials information system stresses the importance of an adequate treatment of multimodality and vagueness for accessing complex factual databases. User tests with different system prototypes have led to the design and implementation of an object-oriented query system offering a graphical interface as well as natural language functionality for query modification and correction. Additionally, the problem of vague queries is handled on different levels: A result query mode allows for querying with visualized data sets (i.e. materials property curves) while a fuzzy-logic-based component offers the possibility of interpreting vague queries. Both, multimodal design and handling of vagueness are of special importance for conducting iterative retrieval strategies.

7. References

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