

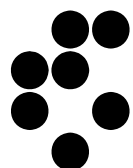
IJS delovno poročilo  
DP-10707  
March 2011

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**DEXi: Program for Multi-Attribute Decision Making  
User's Manual**

Version 3.03

**Institut "Jožef Stefan", Ljubljana, Slovenija**



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**DEXi**

Version 3.03

**Program for multiattribute decision making**

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Developed in collaboration:  
Jožef Stefan Institute, Ljubljana  
Faculty of Organisational Sciences, Kranj  
Ministry of Education, Science and Sport  
of the Republic of Slovenia

## 1 Introduction

DEXi is an educational computer program for multi-attribute decision making. It is aimed at interactive development of qualitative multi-attribute decision models and the evaluation of options. This is useful for supporting complex decision-making tasks, where there is a need to select a particular option from a set of possible ones so as to satisfy the goals of the decision maker. A multi-attribute model is a hierarchical structure that represents the decomposition of the decision problem into sub-problems, which are smaller, less complex and possibly easier to solve than the complete problem.

### 1.1 Availability

DEXi is implemented in Borland Delphi and runs on Microsoft Windows platforms. The latest version can be downloaded from:

<http://kt.ijs.si/MarkoBohanec/dexi.html>

DEXi can be used free of charge for non-commercial applications. For information on commercial applications and for any other questions, please contact [Marko Bohanec \(marko.bohanec@ijs.si\)](mailto:marko.bohanec@ijs.si). Any feedback on your experience with DEXi will be greatly appreciated.

### 1.2 Functionality

DEXi supports two basic tasks:

1. development of [qualitative multi-attribute models](#);
2. application of these models for the [evaluation](#) and [analysis](#) of options.

The models are developed by defining:

- [attributes](#): qualitative variables that represent decision sub-problems,
- [scales](#): ordered or unordered sets of symbolic values that can be assigned to attributes,
- [tree of attributes](#): a hierarchical structure representing the decomposition of the decision problem,
- [utility functions](#): rules that define the aggregation of attributes from bottom to the top of the tree of attributes.

In the evaluation and analysis stage, DEXi facilitates:

- [description of options](#): defining the values of basic attributes (terminal nodes of the tree),
- [evaluation](#) of options: a bottom up aggregation of option values based on utility functions,

- [analysis](#): what-if analysis, "plus-minus-1" analysis, selective explanation and comparison of options,
- reporting: graphical and textual presentation of models, options and evaluation results.

DEXi differs from most conventional multi-attribute decision modeling tools in that it uses qualitative (symbolic) attributes instead of quantitative (numeric) ones. Also, aggregation (utility) functions in DEXi are defined by *if-then* decision rules rather numerically by weights or some other kind of formula. (However, DEXi does support [weights](#) indirectly.)

In comparison with its predecessor [DEX](#), DEXi has a more modern and more convenient user interface. Also, it has better graphical and reporting capabilities, and facilitates the use of weights to represent and assess qualitative utility functions. On the other hand, DEXi is somewhat less powerful than DEX in dealing with incomplete option descriptions: DEX employs probabilistic and fuzzy distribution of values, while DEXi facilitates only the use of crisp or unknown option values.

### 1.3 Applications

[DEXi](#) is particularly suitable for solving complex [decision problems](#), which typically involve:

- many (say, 15 or more) [attributes](#),
- many [options](#) (10 or more),
- judgment, which prevalently requires [qualitative](#) reasoning rather than numerical evaluation,
- inaccurate and/or missing data,
- group decision making, which requires communication and explanation.

For successful application, DEXi requires sufficient resources, in particular expertise and time for developing a [DEXi model](#).

Some typical application areas and decision problems, in which DEX and DEXi have been used so far, are the following:

1. Information technology
  - evaluation of computers
  - evaluation of software
  - evaluation of Web portals
2. Projects
  - evaluation of projects
  - evaluation of proposals and investments
  - product portfolio evaluation
3. Companies
  - business partner selection
  - performance evaluation of companies
4. Personnel Management
  - personnel evaluation
  - selection and composition of expert groups
  - evaluation of personal applications for jobs
5. Medicine and Health-Care
  - risk assessment
  - diagnosis and prognosis
6. Other Areas
  - granting personal/corporate loans
  - assessment of technologies
  - assessments in ecology and environment
  - assessments in agronomy

## 1.4 Development and history

DEXi has been developed in collaboration of the:

- [Department of Knowledge Technologies, Jožef Stefan Institute](#), Ljubljana, Slovenia, and
- [University of Maribor, Faculty of Organizational Sciences](#), Kranj, Slovenia.

The initial development was financially supported by the Ministry of Education, Science and Sport of the Republic of Slovenia within the *Ro (Computer Literacy) Programme* (1999–2000).

The development of DEXi started in 1999. The motivation was twofold. First, it was conceived as a successor to [DEX](#), a successful program for multi-attribute modeling. Until 1999, DEX had been used in several tens of real-life decision situations (see publications on the [DEX](#) web page). However, as a MS-DOS program, DEX was becoming outdated and less convenient for its users. Second, in that time in Slovenia, the DEX methodology was taught in several university courses, and there were ideas to introduce it into secondary schools as well. Thus, there was a strong need for a simple computer program to be used in decision-modeling courses in secondary schools and universities.

Consequently, DEXi's design is a trade-off between these two requirements. It has a convenient MS Windows user interface, which has been kept as simple as possible. Some advanced DEX features have been deliberately dropped, such as: probability and fuzzy distributions of values, chain attributes, advanced transformations of utility functions, some settings and reports. In order to deal with missing, incomplete or uncertain data, DEXi employs value sets instead of more complex value distributions of DEX. On the other hand, more emphasis has been put on graphical and reporting capabilities in DEXi. Also, DEXi adds a new functionality for the treatment of attribute weights.

In subsequent years, DEXi was increasingly used not only in education, but also in more and more advanced decision-support projects. Some extremely complex decision models were developed in international projects, proving – somewhat surprisingly – that DEXi is suitable not only for education, but also for supporting difficult real-life decision problems. Inevitably, in order to address these requirements, DEXi was gradually upgraded with new advanced features, such as new methods for option analysis, import/export features and undo/redo functionality.

## 1.5 Versions

DEXi version 1.00 was released in 2000, with Slovenian user interface only.

DEXi versions 1.01 through 1.04 were gradually released in the period 2001-2006. They addressed only bug fixes and the addition of Slovenian help. There were no major functional additions or improvements.

DEXi version 1.02 with English user interface was released in 2001.

DEXi version [2.00](#) was released in 2007, introducing a number of additions and improvements:

- Slovenian and English user interface for the same functionality,
- editing options,
- editing utility functions,
- importing/exporting options,
- exporting utility functions,
- report and report settings,
- improved DEXi file format,
- English help,
- installation package,
- improved DEXi web page,
- bug fixes.

DEXi version [3.00](#) was released in 2008:

- undo/redo functionality,
- option analysis functionality,
- improved option data entry,
- updated English help and DEXi web page,
- bug fixes.

DEXi version [3.01](#) was released in May 2009:

- added exporting of attribute tree (two formats: tab-delimited and GML),
- bug fixes.

DEXi version [3.02](#) was released in October 2009:

- added model description editor,
- added a new operation to join attributes,
- added searching functionality,
- improved status displays,
- bug fixes.

DEXi version [3.03](#) was released in March 2011:

- added descriptions, summary displays and rounding control of utility functions,
- added import and copy/paste functionality for utility functions,
- new report: Function summary,
- exporting reports to tab-delimited files,
- extended searching functionality,
- bug fixes.

Section 0 provides a more detailed description of different versions of DEXi.

## 1.6 Credits

Marko Bohanec: Design and programming, English help, Web pages  
Vladislav Rajkovič: Initial design and management, educational aspects  
Eva Jereb: Slovenian help  
Uroš Rajkovič: English translation of version 1.02  
Zarja Vintar: DEXi logo

## 1.7 Acknowledgments

David Berneda, <http://www.teemach.com/>, TeeChart Pro V4  
Jordan Russell, <http://www.jrsoftware.org/>, Inno Setup 5.1.11



## 2 Basic concepts

### 2.1 Decision Analysis

*Decision Analysis* is a discipline popularly known as "*Applied Decision Theory*". It provides a framework for analyzing [decision problems](#) by:

- structuring and breaking them down into more manageable parts,
- explicitly considering the possible options (alternatives), available information, involved uncertainties, and relevant preferences of the decision maker(s),
- combining these in order to arrive at optimal or at least 'sufficiently good' decisions.

Decision Analysis, and the [DEXi](#) program as well, are aimed at *supporting* people in making decisions rather than *making* decisions themselves. For this purpose, they provide methods and tools for developing [decision models](#) and using them for the [evaluation](#) and [analysis](#) of options.

### 2.2 Decision Problem

In [Decision Analysis](#), a *decision problem* is understood primarily as a *problem of choice*, which is defined as follows:

- Given a set of options (also called alternatives), which typically represent some object or actions, either
- *choose* an option that best satisfies the goals (objectives) of the decision maker, or
- *rank* the options according to these goals.

Making a choice usually occurs as part of a [decision process](#).

Decision Analysis and [DEXi](#) are particularly interested in *complex* decision problems, that is problems which are for some reason considered difficult by the decision maker and require careful elaboration and analysis. Complex decision problems are usually characterized by:

- **Novelty:** the decision maker is confronted with the problem for the first time and has insufficient knowledge or skills to address the problem;
- **Unclearness:** unclear understanding of the problem and its goals, unknown or incompletely defined options;
- **Uncertainty:** existence of possible events that cannot be controlled by the decision maker, but can affect the decision or its consequences (for example: competition response, weather);
- **Multiple and possibly conflicting goals;**
- **Group decision-making:** involvement of different decision-makers or groups that have different and possibly conflicting goals;
- **Important consequences of the decision** (such as possible big financial losses or environmental impacts);
- **Limited resources to conduct the decision process** (most often: available time and expertise).

### 2.3 Decision Process

The ultimate goal of a *decision process* is to solve a [decision problem](#), that is, to make a decision. In [Decision Analysis](#), the decision process is understood as a process of careful and in-depth analysis of the decision problem. It involves a systematic acquisition and organization of knowledge about the decision problem, which is done by [participants of the decision process](#) and typically includes:

- assessing the problem,
- collecting and verifying information,
- identifying options (alternatives),
- anticipating consequences of decisions,

- making the choice using sound and logical judgment based on available information,
- justification and informing others of the decision and its rationale,
- evaluating decisions and their consequences.

In general, such a process should:

- provide all the information needed for a 'sufficiently good' decision,
- reduce the chance of overlooking important information and making other errors,
- improve the effectiveness and efficiency of the decision-making, and
- improve the quality of the decision itself.

Usually, the decision process involves at least the following steps:

1. [Problem identification](#)
2. Modeling: developing a [decision model](#)
3. [Evaluation](#) and [analysis of options](#)
4. Choice: making the decision
5. Implementation of the decision

The decision-support tool [DEXi](#) is primarily used in the steps 2 and 3.

### 2.3.1 Participants of the Decision Process

In general, a typical [decision process](#) involves up to four types of participants, either individuals or groups:

1. *Stakeholders* (also called *decision problem owners*): individuals or organizations that have a legitimate interest in the decision-making problem. Usually, these are the ones that need to make the final decision, and are also responsible for that decision.
2. *Experts*: People knowledgeable in the field so that they can provide information and advice relevant for the decision. They may contribute to the overall [decision problem identification](#), to the definition of options, goals and criteria, and to the [decision model](#) development.
3. *Decision analyst(s)* : Methodologists with experience in [Decision Analysis](#), that is, the underlying methodology and tools. Often, they take the role of moderators or mediators of the decision-making team.
4. *Users*: People affected by the decision.

### 2.3.2 Decision Problem Identification

The identification of decision problem occurs at the beginning of a [decision process](#). At this stage, the objective is to understand the decision problem and its components. Some typical questions asked in this stage are:

- What is the decision problem about? Is it difficult and important? Why?
- Who is the stakeholder (decision owner)? Who is responsible, and who will be affected by the decision? Who are other possible [participants](#) in the decision process?
- What in general are the options (alternatives) in this case? Can we define some specific ones?
- Which goals (objectives) should be achieved by the decision? Which are the criteria to be met by the decision?
- What are the uncertainties involved?
- What are the goals of the decision process? Should we select a single option, or evaluate or rank more of them?
- What are the expected consequences of this decision process?
- Do we need to justify the decision? To whom and how?

To be suitable for [multi-attribute modeling](#), a decision problem must have some specific properties. Primarily, it should deal with options, which need to be evaluated, analyzed and compared with each other. It is important that the decision problem can be decomposed into smaller, less complex sub-problems, and that the options can be described by their basic features that correspond to the problem decomposition. Thus, we should also ask questions such as:

- Can we think of decomposing the problem into sub-problems? Can we define the relationship between factors that affect the decision?
- Can we think about representing options with their basic features? Which are these features?

## 2.4 Decision Model

The [Decision Analysis](#) approach is characterized by the use of decision models. In general, a *decision model* encodes knowledge and information that is relevant for solving the [decision problem](#) at hand. Decision models are usually developed by [participants](#) of the [decision process](#) using tools such as [DEXi](#). Typical models used in Decision Analysis are:

- decision trees,
- influence diagrams,
- [multi-attribute models](#).

Among these, [DEXi](#) employs [qualitative multi-attribute models](#).

Once developed, the decision model is used to:

- [evaluate options](#) and
- perform various [analyses](#), such as what-if or sensitivity analysis.

The obtained evaluation and analysis results provide the basis for decision maker's assessment of options and possible choice of the best one.

## 2.5 Multi-Attribute Model

*Multi-attribute models* (also called *multi-criteria models*) represent a class of models used in [Decision Analysis](#) that evaluate options according to several, possibly conflicting, goals or objectives. In principle, a multi-attribute model represents a decomposition of a decision problem into smaller and less complex sub-problems. A model consists of:

- [attributes](#) and
- [utility functions](#).

Attributes are organized hierarchically into a [tree of attributes](#). Each attribute takes values from the corresponding [scale](#).

Multi-attribute models are used for option [evaluation](#) and [analysis](#).

Multi-attribute models used in [DEXi](#) are [qualitative](#).

## 2.6 Qualitative Multi-Attribute Model

[DEXi](#)'s [multi-attribute models](#) are called *qualitative*. They are characterized by:

- using qualitative (symbolic) [attributes](#), whose [scales](#) are discrete and typically consist of words rather than numbers,

- employing [utility functions](#) that are represented by (tables of) decision rules rather than numerical formulae.

Here, the word "qualitative" is used for contrast with more traditional "quantitative" [decision models](#), which are characterized by:

- using continuous numerical attributes, which typically represent the decision-maker's preferences, and
- using numerical utility functions, such as the weighted sum.

## 2.7 Attribute

*Attributes* are variables that occur in [multi-attribute models](#). They are organized into a hierarchical structure called [tree of attributes](#). According to their position in the tree, the attributes are either:

- *basic attributes*: terminal nodes ("leaves") of the tree, or
- *aggregate attributes*: internal nodes in the tree.

Basic attributes represent inputs of the [multi-attribute model](#). [Options](#) are described by the values of basic attributes.

Aggregate attributes represent option [evaluations](#). They include are the one or more *roots* of the tree, which represent the overall evaluation of options.

In [DEXi](#), each attribute is defined by its:

- *Name*: main identification of the attribute, which is typically a short string used in printouts, table headings, etc.;
- *Description*: usually a longer string providing further documentation about the attribute;
- [Scale](#).

Aggregate attributes also have a [utility function](#).

## 2.8 Tree of Attributes

In a [multi-attribute](#) model, [attributes](#) are organized hierarchically into a *tree of attributes*. A model can have one or more *root attributes*. Each attribute can be 'decomposed' into one or more descendant attributes that appear one level below that attribute in the tree. 'Decomposed' attributes are called *aggregate attributes*. Attributes that do not have descendants and appear as leaves of the tree, are called *basic attributes*.

### 2.8.1 Interpretation

A tree of attributes can be interpreted in three ways:

1. *Decomposition*: It represents a decomposition of a decision problem into sub-problems. To solve 'a problem', which is represented by a higher-level attribute, one has to solve sub-problems represented by its lower-level descendants.
2. *Dependency*: A higher-level attribute depends on its immediate descendants in the tree. This dependency is modeled by a [utility function](#) that corresponds to the higher-level attribute.
3. *Aggregation*: Tree structure defines the bottom-up aggregation of option values. The value of a higher-level attribute is calculated as an aggregation of the values of its immediate descendants in the tree. Again, this aggregation is defined by the corresponding [utility function](#).


The interpretation of attribute types is as follows:

- *basic attributes* represent inputs of the model,
- *root attributes* represent its main outputs, and
- other *aggregate attributes* represent intermediate results of [option evaluation](#).

### 2.8.2 Linked Attributes

In principle, [DEXi's multi-attribute models](#) have a strict [tree](#) structure: [attributes](#) are structured so that there is exactly one path from each aggregate attribute to the root of the tree. This means that each attribute (other than the root) influences exactly one parent in the tree. Sometimes, this is not enough and we wish to introduce attributes that influence more than one parent. In other words, we wish to create attribute *hierarchies* (directed acyclic graphs) rather than simple trees.

For this purpose, [DEXi version 2.0](#) introduced the concept of *linked attributes*. The idea is that whenever there are two [attributes](#) in the tree that have equal names and equal [scales](#), and at least one of them is basic, they are declared 'linked' and they 'logically' represent a single attribute. Attribute linking is done automatically by [DEXi](#), but only when explicitly enabled in [Settings/Advanced](#). By default, linking is disabled and equally named attributes are considered different.

This concept allows that [DEXi's trees](#) still retain their basic tree structure. In tree displays, linked attributes appear separately, so the tree structure is preserved - it is only that linked attributes are represented by special symbols:  in [Tree Views](#) and with italic letters in [reports](#). On the [Options Page](#), however, any 'chain' of linked attributes appears only once, so there is no need for duplicate data entry. Linked attributes are also properly handled during the [evaluation](#) and on the [Evaluation Page](#).

### 2.8.3 Recommendations

1. Before editing a tree in [DEXi](#), sketch it on paper.
2. Before making a real tree, create an unstructured list of attributes. Brainstorm! At this stage, try not to overlook important attributes, but do not bother about their structure or redundancy.
3. When making a structure of attributes, create meaningful subtrees that contain related attributes. Try structuring your unstructured list in two directions:
  - Bottom-up: Group similar attributes together into a single higher-level attribute. It is usually a good indication if you can find a meaningful name for it.
  - Top-down: Decompose complex attributes into simpler ones.
4. Avoid meaningless, redundant, duplicate, inessential and unoperational attributes. In other words, check each basic attribute that:
  - it has a well defined meaning,
  - it does not duplicate or overlap with some other attributes,
  - it does affect the decision (and you know how, at least approximately),
  - it can be measured or assessed with sufficient accuracy.
5. Avoid aggregate attributes that have more than three descendants. Too many descendants cause a [combinatorial explosion](#) on the size of corresponding [utility functions](#), making them extremely difficult to handle. In this case, try to [restructure](#) the tree below that attribute.

Attribute linking works only when enabled in [Settings](#). In that case, it is done automatically while you edit your model on the [Model Page](#). As this may appear confusing, you may temporarily disable linking. When enabled again, your links will be restored automatically.

## 2.9 Scale

*Scale* represents a set of values that can be assigned to an [attribute](#).

In [DEXi](#), scales are qualitative and discrete. They consist of a set of words, such as: 'excellent', 'acceptable', 'inappropriate', etc.

Scales can be *ordered* or *unordered*, and ordered scales can be either *increasing* or *decreasing*. An unordered scale is just a collection of values, whose relation with each other is unknown or undefined. In contrast, the values of an ordered scale are ordered *preferentially*, that is, according to their contribution to the quality of options. The values of increasing scales are ordered from 'bad' to 'good' values, and the value of a decreasing scales are ordered from 'good' to 'bad' values. In both cases, 'bad' represents a value that is disadvantageous for the option and is least preferred by the decision maker. Analogously, 'good' represents an advantageous and most preferred value. The ordering of scales plays an important role in the definition of [utility functions](#), where it simplifies the definition of decision rules and facilitates checking of their consistency.

With ordered scales, the lowest value is considered 'bad' and the highest 'good' by default. This can be changed in [Scale Editor](#), where you can individually declare the status of each value. In this way, not only a single value, but a whole subsequence of values can be declared as 'bad' or 'good'.

For emphasis and better visualization, extreme values of ordered scales are printed in different fonts and colors. By default, 'bad' values appear in **bold-red** and 'good' values appear in *italic-green*. These can be changed in [Settings/Report](#).

### 2.9.1 Example scales

**no**, *yes*

**low**, medium, *high* (e.g., for "Quality")

**high**, medium, *low* (e.g., for "Price")

**unacceptable**, acceptable, good, *excellent*

### 2.9.2 Recommendations

On scale size (number of values):

- For basic attributes: Use the least number of values that is still sufficient to distinguish between importantly different characteristics of [options](#). Usually, this means two to four values.
- For aggregate attributes: The number of values should gradually increase from basic attributes towards the root of [tree of attributes](#). For example, three four-valued attributes might be aggregated into a five-valued attribute. Five-valued root attributes usually work quite well.

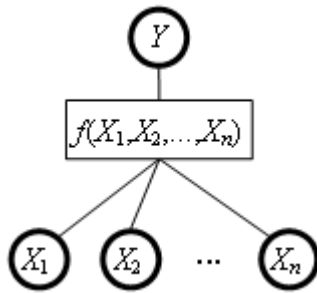
On scale ordering:

- Use increasing scales whenever possible, they really help in the definition of [utility functions](#).
- Avoid decreasing scales. They are much less comprehensible than increasing scales. Increasing and decreasing scales do not work when mixed together in a single utility function.

## 2.10 Utility Function

*Utility functions* are the components of [multi-attribute models](#) that define the aggregation aspect of [option evaluation](#). For each aggregate [attribute](#)  $Y$ , whose descendants in the [tree of attributes](#) are  $X_1, X_2, \dots, X_n$ , the corresponding utility function  $f$  defines the mapping:

$$f: X_1 \times X_2 \times \dots \times X_n \rightarrow Y$$



In [DEXi](#), a utility function maps all the *combinations* of the lower-level attribute values into the values of  $Y$ . The mapping is represented in a table, where each row gives the value of  $f$  for one combination of the lower-level attribute values. Rows are also called *decision rules*, because each row can be interpreted as an *if-then* rule of the form:

if  $X_1 = \text{value}_1$  and  $X_2 = \text{value}_2$  and ... and  $X_n = \text{value}_n$ , then  $Y = \text{value}$  (or value [interval](#))

In the context of representation, such rules are also called *elementary rules*. This name is used for contrast with [complex rules](#).

### 2.10.1 Intervals

An *interval* is a subset of consecutive [scale](#) values. [DEXi](#) often uses intervals in connection with [utility functions](#), particularly when they are [edited](#) or represented by [complex rules](#).

An interval of values is denoted in one of the following ways:

- '\*': the asterisk denotes any value of the corresponding attribute;
- '>=value': stands for 'better than or equal to' *value* (alternative interpretation: 'at least as good as' *value*);
- '<=value': 'worse than or equal to' *value*;
- 'value1:value2': denotes the interval between and including the two values.

### 2.10.2 Complex Rules

[DEXi](#) uses *complex rules* in order to represent its [utility functions](#) in a more compact and possibly more comprehensible way than with elementary rules (table rows). Complex rules are obtained by joining several elementary rules which have the same function value. In other words, a complex rule represents one or more elementary rules. In tables, complex rules are characterized by the use of [intervals](#).

**Example:** This is the CAR utility function from the [Car Evaluation Model](#), represented with *elementary rules*:

	PRICE	TECH.CHAR.	CAR
1	high	bad	unacc
2	high	acc	unacc
3	high	good	unacc
4	high	exc	unacc
5	medium	bad	unacc
6	medium	acc	acc
7	medium	good	good
8	medium	exc	exc
9	low	bad	unacc
10	low	acc	good
11	low	good	exc
12	low	exc	exc

This is the same function represented with *complex rules*:

	PRICE	TECH.CHAR.	CAR
1	high	*	unacc
2	*	bad	unacc
3	medium	acc	acc
4	medium	good	good
5	low	acc	good
6	>=medium	exc	exc
7	low	>=good	exc

Notice the decreased number of rows from 12 to 7 and the use of symbols '\*' and '>='. For example, the complex rule 1 says that if PRICE is 'high', and regardless on the value of TECH.CHAR., the value of CAR is 'unacc'. This complex rule is a compact representation of the first four elementary rules.

### 2.10.3 Weights

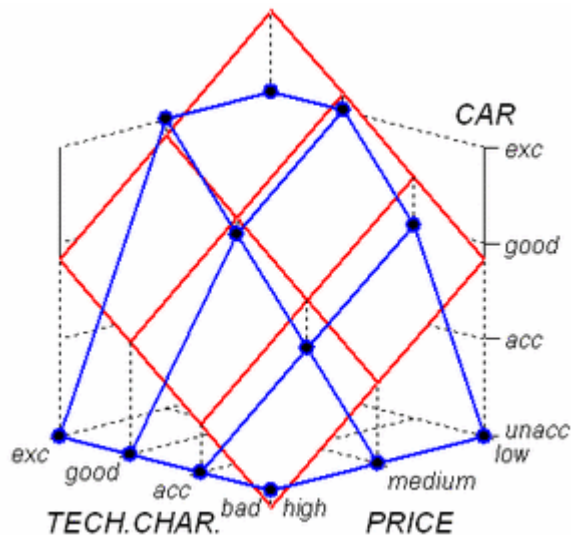
*Weights* are commonly used in [Decision Analysis](#) to model the importance of [attributes](#). Weights are numbers, usually normalized to the sum or maximum of 100, which define the contribution of the corresponding attribute to the final [evaluation](#). In Decision Analysis, [utility functions](#) are commonly defined using some form of the weighted sum, for example:

$$f(X_1, X_2, \dots, X_n) = w_1 \times X_1 + w_2 \times X_2 + \dots + w_n \times X_n$$

Here,  $w_i$  denote weights and  $X_i$  denote attributes.

In [qualitative multi-attribute models](#), there is natively no room for weights: attributes are symbolic and utility functions are defined by decision rules. However, to bridge the gap between qualitative and quantitative models, it is possible to introduce weights - in a very approximate and imprecise way - also into the qualitative models.

#### 2.10.3.1 Principle



The figure above illustrates the basic approach. It shows the [CAR utility function](#), represented by points (blue dots) in a three-dimensional space. Each point represents one defined decision rule. To find out the weights, DEXi places a (hyper)plane (shown in red) into this space so that it matches the points as closely as possible (using the least squares measure). Once done, weights can be approximated directly from the slopes of the hyperplane: the higher the slope in the direction of an attribute, the higher the corresponding relative weight. In the above figure, the weights of PRICE and TECH.CHAR. are almost identical, 53 and 47, respectively. These are *local normalized* weights (see the definition below).



DEXi uses weights for two purposes:

- as an approximate representation of utility functions, used primarily for verification and overview (see [examples](#) from the [Car Evaluation](#) model), and
- for defining utility functions or their parts (see the [weight-based](#) strategy of handling [non-entered](#) function values).

### 2.10.3.2 Weight Types

Actually, DEXi uses four types of weights, as illustrated with the following weights from the [Car Evaluation](#) model:

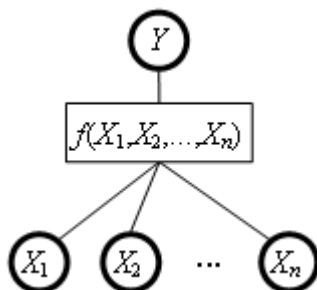
Attribute	Local	Global	Loc.norm.	Glob.norm.
CAR				
PRICE	60	60	53	53
BUY.PRICE	50	30	50	26
MAINT.PRICE	50	30	50	26
TECH.CHAR.	40	40	47	47
COMFORT	50	20	50	24
#PERS	39	8	36	9
#DOORS	22	4	27	6
LUGGAGE	39	8	36	9
SAFETY	50	20	50	24

The difference between *local* and *global* is due to the [tree of attributes](#). *Local* weights always refer to a single aggregate attribute and a single corresponding utility function, so that the sum of weights of the attribute's immediate descendants (function arguments) is 100%. *Global* weights, on the other hand, take into account the structure of the tree and relative importance of its sub-trees. A global weight of an attribute is calculated as a product of the local weight and the global weight of the attribute that lies one level above. A global weight of the root attribute is 100%. For example: the global normalized weight of BUY.PRICE is 50% (its local normalized weight) × 53% (global normalized weight of PRICE), which gives 26%.

Weights can also be *normalized* or not. This is because some [scales](#) can have more values than the others. Geometrically, larger scales appear longer, they have lower slopes and, consequently, smaller weights. *Normalization* refers to the procedure in which all scales are adjusted to the same length (unit interval) before determining the weights. Usually, this is the better method of weight assessment and comparison of attributes.

### 2.10.4 Combinatorial Explosion

Consider a [utility function](#)  $f$  that maps the values of the attributes  $X_1, X_2, \dots, X_n$  into the value of the aggregate attribute  $Y$ .



In [DEXi](#), a utility function maps all the *combinations* of the lower-level attribute values into the values of  $Y$ . Suppose that each  $X_i$  has a [scale](#) consisting of  $s_i$  values. Then, the number of combinations and thus the size of  $f$  is equal to

$$S = s_1 \times s_2 \times \dots \times s_n$$

In other words, when defining  $f$ , you should define  $S$  decision rules.

#### 2.10.4.1 Example

Let all the  $n$  lower-level attributes have  $s$ -valued scales. In this case, the size of  $f$  equals to

$$S = s^n$$

The following table shows how fast  $S$  grows with the increasing  $n$  and  $s$ .

$S = s^n$	Number of lower-level attributes $n$			
Scale size $s$	2	3	4	5
2	4	8	16	32
3	9	27	81	243
4	16	64	256	1024
5	25	125	625	3125

#### 2.10.4.2 Recommendations

Experience shows that utility functions of size up to 25 are small and usually quite easy to define. The difficulty grows towards the size of about 100, which is already quite difficult. Everything above 100 is very difficult, and everything above 500 is extremely hard if not impossible to define.

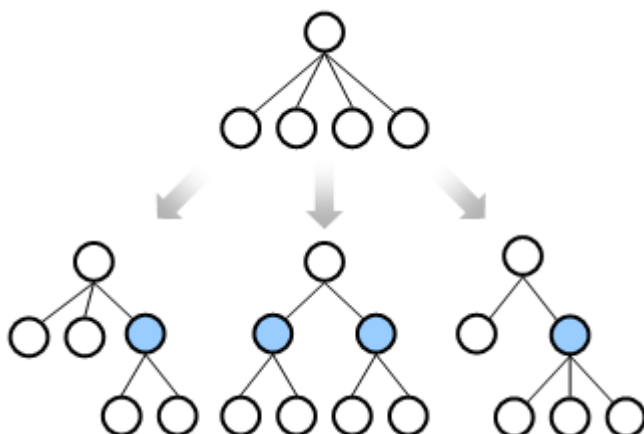
Also, it is not only the size that matters. The more the attributes, the more difficult the function to define, even if the size of the functions is comparable. Combining four attributes together usually appears quite a hard task for human brain.


For these reasons, the DEXi method strongly advises to limit the number of aggregate attributes' descendants to three, and to [restructure](#) the [tree of attributes](#) whenever this condition has not been met.

To prevent the combinatorial explosion, the [DEXi](#) program issues a warning before creating a function of size 200 or more, and disallows the creation of functions larger than 1000.

#### 2.10.4.3 Restructure Tree of Attributes

In order to avoid [combinatorial explosion](#) in [DEXi models](#), it is strongly advised to structure the [tree of attributes](#) so that each aggregate [attribute](#) has only two or three immediate descendants. Whenever you encounter an aggregate attribute with four descendants, you may want to consider restructuring the tree below that attribute. Usually, there are several ways to do this:



In all cases, you should regroup the lower-level attributes and introduce one or two new aggregate attributes, denoted by .

Usually, the 'right' structure is the one that appears the most 'logical' so that:

- it groups together similar or related attributes, and
- it is easy to give names to the newly created attributes.

## 2.11 Options

*Options* (also called *alternatives*) are basic entities studied in a [decision problem](#). Depending on the problem, they can represent different objects, solutions, courses of action, etc., which are [evaluated](#) and [analyzed](#) by a [multi-attribute model](#).

In [DEXi](#), each option is represented by its *name* (not necessarily unique) and a set of *values*, so that one value is assigned to each [attribute](#) in the [tree of attributes](#). These values are further distinguished into:

- *option description*: vector of values assigned to basic attributes;
- *intermediate evaluation results*: values assigned to aggregate attributes other than the roots of the tree;
- *final (or overall) evaluation results*: values assigned to the root(s) of the tree.

Values assigned to basic attributes can be either defined or undefined:

- *Defined* means that a single qualitative value from the corresponding [scale](#) has been assigned to that attribute.
- *Undefined* means that the value is unknown or unspecified. In [DEXi](#), this is denoted by an asterisk '\*' and is interpreted as a *set of all values* that can be assigned to the corresponding attribute.

## 2.12 Evaluation of Options

With [multi-attribute models](#), [options](#) are *evaluated* in the following way:

1. Each option is represented by a vector of basic [attribute](#) values.
2. The values of each option are aggregated in a bottom-up way according to the defined [structure](#) of the model and corresponding [utility functions](#).
3. The overall evaluation of an option is finally obtained as the value of one or more root [attributes](#) of the model.

On this basis, the decision maker can compare and rank the options, and possibly identify and select the best one.

In the evaluation, undefined values of basic attributes, denoted '\*', are interpreted as sets of all possible values that can be assigned to corresponding attributes. There, [DEXi](#) evaluates options trying all these values and keeps track of the evaluation results in these cases. Therefore, an evaluation result is not necessarily represented by a single attribute value, but can also be a *set of values*.

In [DEXi](#), results of option evaluation are shown on its [Evaluation Page](#), as well as in [charts](#) and [reports](#).

## 2.13 Analysis

*Analysis* is one of the key concepts in [Decision Analysis](#). In contrast with [evaluation](#), which is merely a calculation directed from inputs ([option](#) descriptions) to outputs (evaluation results), analysis is

understood as an active involvement of [participants](#) who are trying to find answers to questions such as:

- Are option evaluations in accordance with expectations? Are they 'correct'? If not, why?
- How do the options compare with each other? Which one is the best and why?
- Can we explain and justify the evaluations? What are the most important strong and weak points of individual options?
- What if something changes: What if we try a new option? What if an option becomes unavailable? What if some option characteristics change?
- How sensitive is the evaluation to small changes of the model (such as addition or deletion of an attribute, modification of some decision rules)?

In other words, analysis is a creative and possibly repetitive application of [decision models](#) aimed at better understanding of the decision problem, better understanding of options, their characteristics and consequences, and better justification of the decision. In general, this involves techniques such as: *what-if* analysis, *sensitivity* analysis, *stability analysis*, etc.

In [DEXi](#), analyses are mostly carried out on the [Evaluation Page](#), where you can:

- Review intermediate and overall results of option evaluation. In order to clarify and justify the results, you may focus on particularly bad or good evaluations.
- Change individual option values and immediately see the effects on evaluation results.
- Employ commands on the [Analysis Menu](#) (or corresponding toolbar buttons) to perform the [analyses](#): Plus-minus-1 analysis, Selective explanation and Comparison of options.

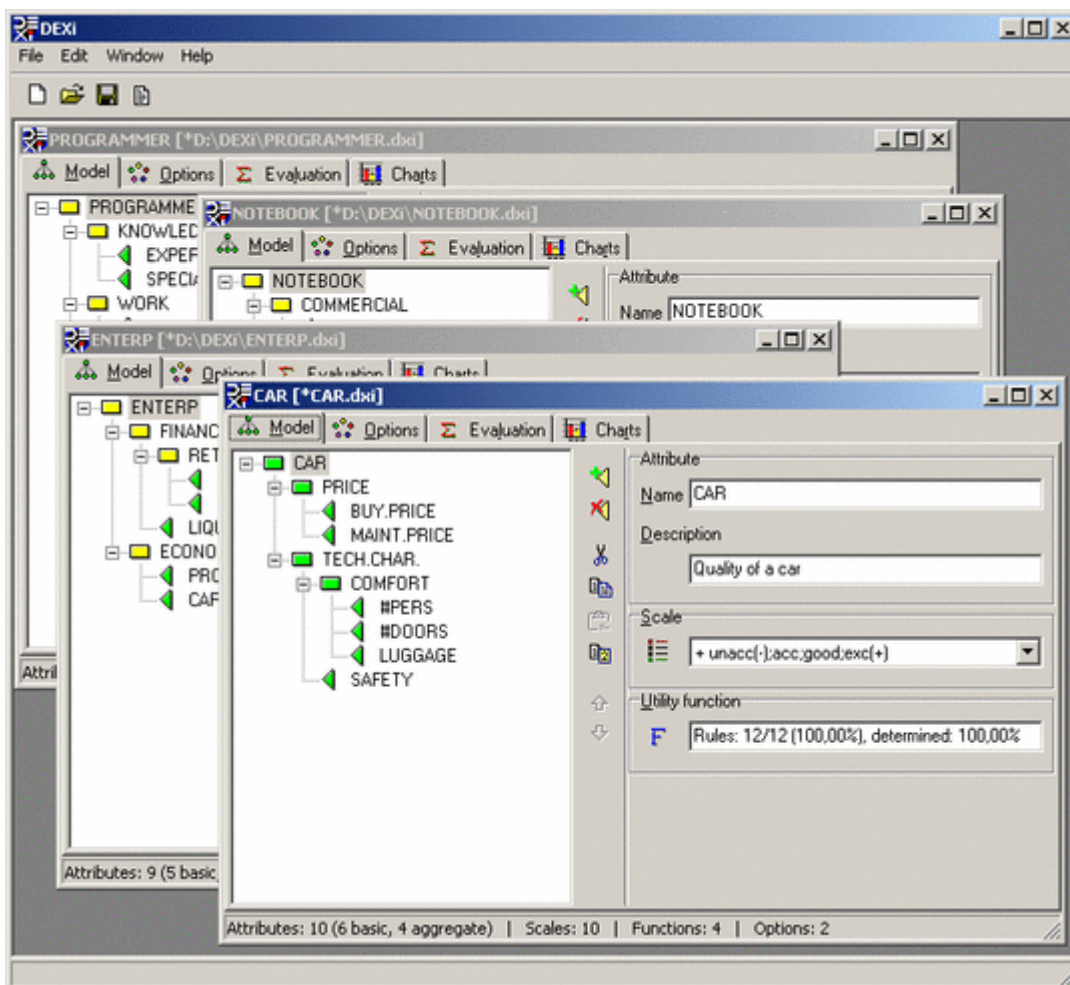
Some analyses can also take place elsewhere:

- On the [Options Page](#), you can duplicate an option description and prepare it for 'what-if' analysis.
- On the [Model Page](#), you can change any model component and retry the evaluation by opening the [Evaluation Page](#).
- Various [charts](#) and [reports](#) may provide further insight into the evaluation process and achieved results.

### 3 DEXi components and commands

At the top level, [DEXi](#) provides a standard Windows MDI (Multi-Document User Interface). In this case, a 'document' is a [DEXi model](#). You can work with one or more models at the same time using the following windows and commands:

- [Main Toolbar](#)
- Menus:
  - [File Menu](#)
  - [Edit Menu](#)
  - [Analysis Menu](#)
  - [Window Menu](#)
  - [Help Menu](#)
- [Model Window](#)



#### 3.1 DEXi Model

The term *DEXi Model* refers to the 'document' that is created and edited in [DEXi's Model Window](#), and stored externally on a [DEXi File](#).

A DEXi model contains the data on:

- a [qualitative multi-attribute model](#),
- [options](#), and
- [program settings](#).

## 3.2 DEXi File

Each [DEXi model](#), which is created and/or edited in [DEXi](#), can be stored on a [DEXi File](#). You can load and save files using the [File menu](#) commands. DEXi supports three file formats:

**.dxi** This is the native DEXi file format, which stores a single [model](#), the corresponding [option data](#) and [program settings](#).

**.dax** File format used by the older program [DEX](#).

**.xml** File format used by yet another old program, jDEX.

Normally, you should only use the default **.dxi** file format. The formats **.dax** and **.xml** are obsolete and do not support all DEXi's features. They are implemented only for compatibility with DEX and jDEX.

The **.dxi** files are composed as XML documents, so you may use other XML tools to process them.

In order to conform to the XML standard and fully support UTF-8 strings, the format of **.dxi** files has changed from DEXi 1.04 to 2.0. DEXi versions prior to 2.0 cannot process the new files and refuse to load them. DEXi 2.0 and above support both formats as follows:

- Loading: File format is recognized automatically.
- Saving: By default, files are saved using the new format. For the old format, select "DEXi version 1" in the **Save file** dialogue.

For versions 2.0 and above, DEXi files are in principle backward compatible for reading, but not for writing. This means that any previous version of DEXi can read a file that was created by a more recent version, however attempting to save this file by the previous version may result in data loss. Regular updating of DEXi to new versions is therefore strongly advised.


## 3.3 Main Toolbar

The main toolbar of [DEXi](#) provides four buttons for fast activation of top-level [DEXi model](#) commands.

 **New:** Create a new DEXi model and show it in a new [window](#).


 **Open:** Load an existing DEXi model from a [DEXi file](#) and show it in a new [window](#).

 **Save:** Save the current DEXi model on a [DEXi file](#). File name is requested only when the model is saved for the first time.

 **Report:** Create and preview a [report](#).


## 3.4 File Menu

The [DEXi File Menu](#) is available at all times for working with the currently active [DEXi model window](#). Mainly, it provides commands for creating, loading and saving [DEXi files](#), but there are also commands for importing and exporting other data, making reports, changing program settings and exiting DEXi.

 **New:** Create a new [DEXi model](#) and open a corresponding [window](#). Initially, the model is almost empty, containing only one root [attribute](#) and no [options](#).

 **Open:** Open and load an existing [DEXi file](#) through a standard **Open a file** dialogue.

**Close:** Close the currently active [DEXi model window](#). Before closing, DEXi checks whether the model has been saved on a [DEXi file](#), and if not, asks you whether to: save the model (**Yes**), discard the model (**No**), or to **Cancel** closing the window.

 **Save:** Save the currently edited model on a [DEXi file](#). This is a 'quick' save that normally rewrites the output file without confirmation. However, it does ask you to provide a file name for a newly created and yet unsaved model.

**Save as:** Save the currently edited model on a [DEXi file](#). In this case, a **Save file** dialogue appears before saving and always lets you to define or redefine the name (and possibly format) of the file.

**Import.../Import function:** Open a [function file](#) and load its decision rules into the currently selected [utility function](#). The function is created if necessary. Imported are only those rules whose argument values in the file are matched with the ones in DEXi. Even though DEXi tries to recognize the data format used in the [function file](#), it is strongly recommended that function data is exported and imported using the same [Import-Export Settings](#).

**Import.../Import options:** Open an [option file](#) and load its data into the current [model](#). Existing options that have same names as imported options are overwritten by imported data. Otherwise, imported options are inserted into the model.


**Export.../Export tree:** Export the current [tree of attributes](#) to an external file. Two data formats are supported:

- *Tab-delimited:* textual format with columns containing attribute names, scales and descriptions;
- *GML (Portable Graph File Format):* for creating tree graphs by programs such as [yEd Graph Editor](#).

**Export.../Export function:** Save the [utility function](#) that is currently selected in the current [window](#). Data is written to a [function file](#). Before saving, you are asked to define the name and format of this file.

**Export.../Export options:** Extract [option](#) data from the current [model](#) and save it on an [option file](#). Only options that are selected ('checked') on the Options sub-page of the [Charts Page](#) are actually exported. Before saving, you are asked to specify the name and format of the file.

**Model description...:** View and edit a description of the current model. The entered text is used only for documentation and can be displayed in a [report](#).

 **Report:** Create and preview a [report](#).

**Settings:** View and edit DEXi [program settings](#).

**Exit:** Close all windows and terminate the execution of DEXi.

### 3.4.1 Option Data File

Option data files contain [option](#) data, which is imported and exported through [File Menu](#) commands. In [DEXi](#), the contents and format of option files are controlled at three points:

- On [Charts Page/Options Sub-page](#), where you can select options to be actually exported (all options are selected by default).
- In 'Import options' and 'Export options' dialogues that are used to specify file names and basic file format, which is either 'Tab-delimited' or 'Comma-separated (CSV)'.
- In [Settings/Import-Export](#), where you can specify further details of 'Option data format'.

### 3.4.1.1 Examples

1. Tab-delimited option data file containing both options from the [Car Evaluation](#) model and exported using the default [Settings](#): using 'base 1' values, displaying all attributes using indentation, normal orientation. The TAB character is denoted '↵'.

```
↵Car1↵Car2
CAR↵4↵3
. PRICE↵3↵2
. . BUY.PRICE↵2↵2
. . MAINT.PRICE↵3↵2
. TECH.CHAR.↵4↵3
. . COMFORT↵3↵3
. . . #PERS↵3↵3
. . . #DOORS↵3↵3
. . . LUGGAGE↵3↵3
. . SAFETY↵3↵2
```

2. The same data as above but using comma-separated format, 'base 0' values and including only non-indented basic attributes in normal orientation.

```
"", "Car1", "Car2"
"BUY.PRICE", "1", "1"
"MAINT.PRICE", "2", "1"
"#PERS", "2", "2"
"#DOORS", "2", "2"
"LUGGAGE", "2", "2"
"SAFETY", "2", "1"
```

3. The same as above, but with text values and transposed orientation.

```
"", "BUY.PRICE", "MAINT.PRICE", "#PERS", "#DOORS", "LUGGAGE", "SAFETY"
"Car1", "medium", "low", "more", "4", "big", "high"
"Car2", "medium", "medium", "more", "4", "big", "medium"
```

## 3.4.2 Function Data File

Function data files are tab-delimited text files for storing [utility functions](#), which are exported and imported through 'Export function' and 'Import function' [File Menu](#) commands, respectively. One file contains one utility function, whose format can be specified with [Settings/Import-Export](#).

### 3.4.2.1 Examples

1. TECH.CHAR. function from the [Car Evaluation](#) model, exported in tab-delimited format, using 'base 1' values and exporting all rules. The character '+' represents an entered rule. The TAB character is denoted '↵'.

```
↵COMFORT↵SAFETY↵TECH.CHAR.
1↵1↵1↵1↵+
2↵2↵1↵1↵+
3↵3↵1↵1↵+
4↵1↵1↵1↵+
5↵2↵2↵2↵+
6↵3↵3↵3↵+
7↵1↵1↵1↵+
8↵2↵3↵3↵+
9↵3↵4↵4↵+
```




2. The same function exported using text values and exporting only entered rules (in this case there is no need to display the '+' or '-' entered status).

```
↵COMFORT↵SAFETY↵TECH.CHAR.
1↵bad↵bad↵bad
2↵acc↵bad↵bad
3↵good↵bad↵bad
```



4- bad-bad-bad  
5- acc-acc-acc  
6- good-good-good  
7- bad-bad-bad  
8- acc-good-good  
9- good-exc-exc


### 3.5 Edit Menu


The [DEXi Edit Menu](#) provides commands for editing the [DEXi model](#) that is shown in the currently active [model window](#). The available editing commands depend on the currently edited model component, that is, on the page that is currently open in the model window:  [Model](#),  [Options](#),  [Evaluation](#).


There is no Edit Menu associated with the  [Charts](#) page.

### 3.6 Window Menu

The [DEXi Window Menu](#) is available at all times and provides commands for working with [DEXi model windows](#). These commands are particularly useful when there are multiple model windows loaded simultaneously and shown in the [main window](#) of DEXi.

 **Cascade:** Stack currently open windows so that each window title bar is visible. This facilitates an easy selection of each window.

 **Tile Horizontally:** Resize and move all currently open windows so that they are shown above each other, occupying the full width of the main window.

 **Tile Vertically:** Resize and move all currently open windows so that they are shown behind each other, occupying the full height of the main window.

**Minimize All:** Minimize all currently open windows so that they are shown only as small bars ('icons') in the main window.

**Arrange icons:** Neatly arrange all currently minimized window 'icons'.

### 3.7 Help Menu

The *Help Menu* commands provide help on [DEXi](#).

 **Help:** Show this help.

 **About:** Show DEXi version and copyright information.

For further information and latest news, see the [DEXi Web Page](#).


### 3.8 Model Window

A *DEXi Model Window* provides workspace for editing and using one [DEXi model](#). It consists of four pages ('tabs'):

 [Model:](#) Edit the current [DEXi model](#): its structure and components.

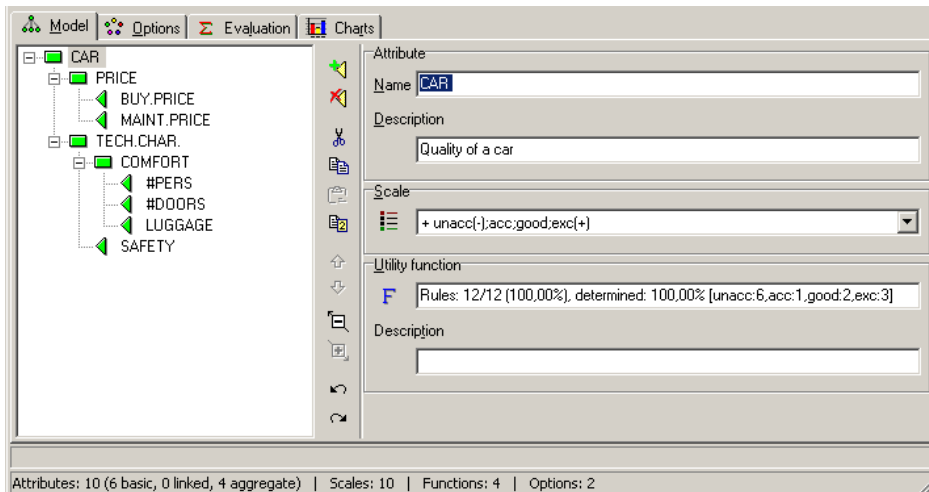
 [Options:](#) Edit [option](#) descriptions.

 [Evaluation](#): [Evaluate](#) and [analyze options](#).

 [Charts](#): Compose and view charts.


### 3.9 Model Page

The *Model Page* of [DEXi model window](#) provides workspace and commands for editing a [DEXi model](#): its structure, attributes, scales and utility functions, but excluding options and program settings.



#### 3.9.1 Workspace

The workspace consists of four main areas that correspond to the following model components:


1. [Tree of attributes](#): On the left, there is an "Explorer-like" [Tree View](#) that displays the structure of the edited model. It has an associated vertical toolbar. All toolbar buttons and most of the corresponding Edit Menu [commands](#) refer to the currently selected attribute in the tree.
2. [Attribute](#): There are two entry fields in which you can name (or rename) the currently selected attribute and optionally provide its description.
3. [Scale](#) of the currently selected attribute: You can either select an existing scale from a pull-down list, or press  to open the [Scale Editor](#). Whenever the attribute's scale has been already defined, the list of scales contains only 'compatible' scales - the ones having the same number of values.
4. [Utility function](#) of the currently selected aggregate attribute. There are three parts: a read-only field showing the current [status](#) of the function, the button **F** to invoke the [Function Editor](#), and a field for entering an optional description of the function. The utility function area is not available for basic attributes.

#### 3.9.2 Commands

To invoke a command, you may either:

- press a button shown in the window,
- select an item from the Edit Menu, or
- select an item from the pop-up menu that appears after right-clicking the mouse button.

The Model Page provides the following commands:


 **Add attribute:** This command creates a new attribute and inserts it into the tree as a descendant ('child') of the currently selected attribute. The new attribute is automatically called "New", so you should consider giving it a more meaningful name.


 **Delete subtree or item:** This command depends on the type of the currently selected attribute:


- For an aggregate attribute: it discards all its descendants and its utility function, effectively converting it into a basic attribute.
- For a basic attribute: it deletes that attribute


Thus, to completely delete a sub-tree of attributes, you should "delete it twice".


 **Cut:** Equivalent to **Copy** followed by **Delete subtree or item**.


 **Copy:** Copies the currently selected sub-tree into the clipboard for further use.


 **Paste:** Inserts previously **Cut** or **Copied** sub-tree into the model, positioning it as a descendant ('child') of the currently selected attribute.


 **Duplicate:** Makes a copy of the currently selected sub-tree and inserts it as a new top-level tree in the model, so that it can be easily moved around.

 **Find...:** Opens a window in which you can define a text to be searched for in the model. You can also select components in which to search: attribute names, attribute descriptions, and/or scales. The search can be case sensitive or not.


 **Find next:** Continues searching from the current position in the model.

 **Move up:** Moves the currently selected attribute one place up according to what is shown in the tree view.


 **Move down:** Moves the currently selected attribute one place down according to what is shown in the tree view.

 **Shrink tree:** Shrinks the display of the tree by one level.


 **Expand tree:** Extends the display of the tree by expanding the inner-most collapsed sub-trees.


 **Undo:** Undo the last tree-editing operation.

 **Redo:** Redo the last undone tree-editing operation.

 **Scale:** Invokes the [Scale Editor](#) to create or edit the [scale](#) of the currently selected attribute.

 **Delete scale:** Deletes the scale of the currently selected attribute.

 **Utility function:** Invokes the [Function Editor](#) to create or edit the [utility function](#) of the currently selected aggregate attribute.

 **Delete function:** Deletes the utility function of the currently selected aggregate attribute.

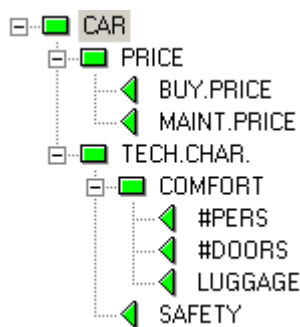
### 3.9.3 Remarks

Changing the structure and scales of attributes can severely affect previously defined [utility functions](#). In some cases, for example when adding or deleting an attribute value, DEXi tries to adapt the affected function so that its 'meaning' is preserved as much as possible. Unfortunately, such adaptation is impossible with more extensive changes, particularly when adding or deleting function arguments. In these cases, the function must be deleted and defined anew. Before deleting a function, DEXi issues a warning and asks for your confirmation.



Consequently, you might want to develop your tree structure as completely as possible before attempting to define utility functions.

### 3.9.4 Tree View

*Tree View* is an important part of the [DEXi model window](#) and its [Model Page](#). It shows the [structure](#) of the currently edited [DEXi model](#).









In Tree View, you can:

- Select a single attribute by clicking it or using keyboard arrows.
- Invoke [Model Page commands](#). Most of these commands refer to the currently selected attribute.
- Move attributes and subtrees shown in the Tree View using standard drag-and-drop mouse commands.
- Expand and collapse the display of sub-trees by clicking the symbols  and , respectively.



#### 3.9.4.1 Status

While editing the model, the status of its [attributes](#) is shown in Tree View using the following symbols:

-  Incomplete basic attribute: an attribute having an undefined [scale](#).
-  Completely defined basic attribute.
-  Aggregate attribute whose [utility function](#) cannot be constructed due to undefined [scales](#) of its own and/or its descendants.
-  Aggregate attribute with an undefined [utility function](#) (but everything is ready for its construction).
-  Aggregate attribute with a partially or incompletely defined [utility function](#).
-  Aggregate attribute with a fully defined (100% [determined](#)) [utility function](#).

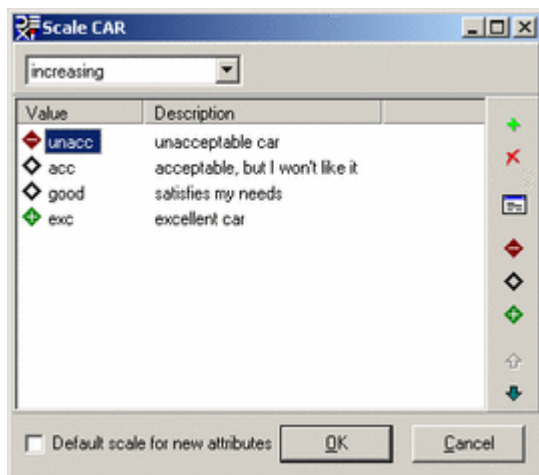
 [Linked attribute](#).

### 3.9.4.2 Remark

Usually, the goal is to completely define all [DEXi model](#) components. In Tree View, this is indicated by "all green" status symbols. Occasionally and only with a good reason, it is acceptable to leave a partially defined utility function  and/or to have a linked attribute .

## 3.10 Scale Editor

*Scale Editor* is a window in which you can create and edit one attribute [scale](#). Basically, a scale is just an ordered or unordered list of values; you can add and delete these values, give them names and optional descriptions, change their order and define their **bad** or **good** class.



### 3.10.1 Workspace

Scale Editor consists of:


- *Value list*: each value has a name (usually a short string) and an optional description (used only for documentation).
- *Scale order* entry field at the top: here you can define scale ordering: *unordered*, *increasing* (recommended) and *decreasing*.
- *Toolbar* at the right: provides [command](#) buttons.
- The field *Default scale for new attributes*: when checked, this scale will be automatically assigned to all attributes created hereafter in the [Model Page](#).


### 3.10.2 Commands

To invoke a command, you may either:


- press a button shown in the toolbar, or
- select an item from the pop-up menu that appears after right-clicking the mouse button.


Scale Editor provides the following commands:


 **Add value**: Inserts a new value into the list. The default name of this value is 'new value', and you may change this name immediately after insertion.


 **Delete value**: Deletes the value that is currently selected in the value list.


**F2 (keyboard): Rename value:** Opens a small in-line field in which you can quickly rename the currently selected value.

 **Edit value:** Opens a dialogue in which you can edit both the name and description of the currently selected value.

 **Set bad:** Set the class of the currently selected value to **bad**.

 **Set neutral:** Set the class of the currently selected value to 'neutral' (nor **bad** nor *good*).

 **Set good:** Set the class of the currently selected value to *good*.




 **Move up:** Moves the currently selected value one place up in the list.

 **Move down:** Moves the currently selected value one place down along the list.

### 3.10.3 Remarks

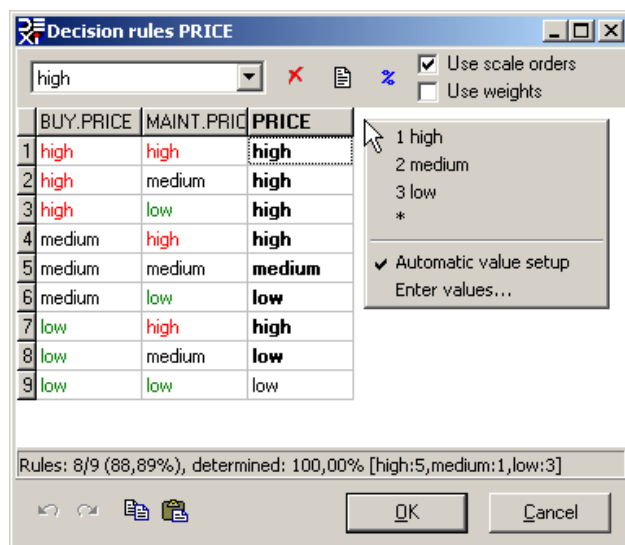
Editing a scale (especially adding and deleting values) may affect already defined [utility functions](#). DEXi tries to adapt the affected functions so that their 'meaning' is preserved as much as possible, but you should be careful and verify all affected functions after making such changes.

*Increasing* scales are strongly recommended: they improve the comprehensibility of [models](#) and simplify the definition of [utility functions](#).

The concept of value 'class' (**bad**, neutral, *good*) is meaningful only with ordered scales. Thus, the commands    do not work with *unordered* scales. For *ordered* scales, classes must be ordered, too. Therefore, classes can be assigned only so that zero or more **bad** values are followed by zero or more neutral values, which are then followed by zero or more *good* values.

## 3.11 Function Editor

*Function Editor* is a window in which you can create and edit one [utility function](#). Its workspace consists of a table, two toolbars, pop-up menu, and status bar.



### 3.11.1 Table


The central part displays a table of *decision rules*. Table rows contain all the possible combinations of values of function's arguments (lower-level attributes in the [tree](#)). The rightmost column (such as PRICE above) represents the output function value. This is the only editable column in the table. It contains *cells* into each of which you can assign:

- a single value taken from the corresponding [scale](#) (for example: 'high'), or
- an unknown value, denoted '\*' (this is the initial value set to all rows of a newly created table).

The values *entered* by you appear in **bold**. Other values are called [non-entered](#) and are shown in normal typeface. By default, non-entered values are handled by [DEXi](#) and recalculated each time the table has changed. In general, non-entered values are [intervals](#).

You can enter a cell value in one of the following ways:

- selecting an item from the *Rule values* field, which appears above the table;
- right-clicking and selecting an item from the pop-up menu; or
- pressing one of the keys **1**, **2**, ..., on the keyboard, which represent consecutive scale values, or the key **\***, which represents an unknown value.

To delete the currently selected cell value, press the **Delete** key or the  button. Deleting changes cell status to [non-entered](#).

### 3.11.2 Toolbars

The horizontal toolbar, which is shown above the table, consists of:

**Rule values** field: used to select a value and assign it to the current cell.

 **Delete value**: Deletes the contents of the currently selected cell.

 **Complex rules**: Makes and [previews complex rules](#) of the current function.


**% Weights**: Open [Weight Editor](#) to define attribute [weights](#).


**Use scale orders** and **Use weights** are two check boxes that define how to [handle non-entered values](#).

The horizontal toolbar below the table contains:

 **Undo**: Undo the last function-editing operation.

 **Redo**: Repeat the last undone function-editing operation.

 **Copy**: Copies the current utility function into the clipboard for further use. The copied data format is the same as used in a [function file](#).

 **Paste**: Imports previously **Copied** function into the current function. After the operation, it reports the number of imported rules (rules whose values matched between the clipboard and the current functions) and the number of rules whose values actually changed.

The buttons  **Undo** and  **Redo** appear only if activated in [Settings](#).

It is strongly recommended not to change [Import-Export Settings](#) between copying and pasting a function.

### 3.11.3 Pop-up Menu

This menu appears after right-clicking your mouse. It has two parts: the first one lists values that can be assigned to the current cell, and the second part contains two items:

**Automatic value setup:** Controls table recalculation after each change. When checked, DEXi does recalculate all [non-entered](#) function values. Otherwise, there is no recalculation and the two toolbar checkboxes are disabled.

**Enter values:** Changes the status of table cells from non-entered to entered. Entered cells are never recalculated by DEXi and can be only changed by you. After issuing this command, you can specify whether to change the status of all non-entered cells, or only those having a single (non-interval) value.

### 3.11.4 Status bar

Status bar displays the [status](#) of the edited function.

### 3.11.5 Utility Function Status

When a [utility function](#) is created in [DEXi](#), it is completely *undefined* at first: all cells in [Function Editor](#) contain the undefined value '\*'. When you edit the function, you usually assign values to more and more cells and the function becomes more and more defined. Usually, the goal is to completely define the function, that is, to precisely specify all cell values.

[DEXi](#) uses two measures of function definition, which are both displayed as status/progress indicators on [Model Page](#) and in [Function Editor](#).

The first measure is called *entered rules ratio*. This is a ratio between the number of entered rules (that is, cell values defined by you) and the total number of rules (function [size](#)).

The second measure, *determination*, is somewhat more complex, but better. It takes into the account that, in general, cell values are [intervals](#) rather than single values. A cell is 100% determined if it is assigned a single value, and is 0% determined if it is completely undefined, that is, it contains the complete interval of values (denoted '\*'). For smaller intervals, intermediate values are calculated proportionally.

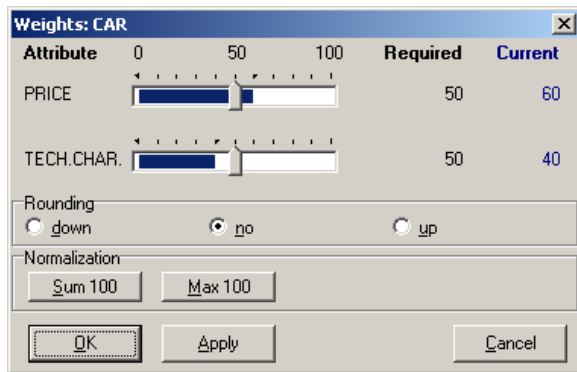
A function is fully determined when all its cells - both entered and non-entered - are 100% determined. This is in general achievable with less than 100% entered rules due to DEXi's [handling of non-entered values](#). Therefore, when editing a function, the primary aim is to make it 100% determined, regardless on the ratio of entered rules.

The display of utility function status also includes a frequency distribution of function values, shown in square brackets. For instance, '[high:5,medium:1,low:3]' denotes that five decision rules map to the value 'high', one rule to 'medium' and three to 'low'. For functions that contain [intervals](#), the sum of frequencies is greater than the total number of rules.

### 3.11.6 Weight Editor

In *Weight Editor* you can view and define [weights](#) of the [utility function](#) that is currently edited in [Function Editor](#). Primarily, these weights are intended for [weight-based](#) calculation of [non-entered](#) function values.





In this editor, you can set your required weights by moving the sliders of the corresponding [attributes](#). The numerical values of these settings are shown under 'Required'. In addition, you can *normalize* these weights using the buttons:

**Sum 100:** The weights are proportionally scaled, so that their sum is 100.

**Max 100:** The weights are proportionally scaled, so that the maximal weight is equal to 100.

The blue bars and blue numbers show the actual 'Current' weights. These are [determined](#) from the utility function currently edited in [Function Editor](#).

'Rounding' specifies how to calculate the values of [non-entered rules](#) that fall just between two ordinal values. For example, let ordinal numbers of 'acc' and 'good' be 2 and 3, respectively. For some non-entered rule, the linear approximation formula using [weights](#) can calculate the value 2.5. In this case, 'Rounding' specifies whether this value is rounded 'down' to 2 (meaning 'acc') or 'up' ('good'). The default setting of 'no' does not favor any specific direction and leaves the rounding to the underlying arithmetic software.

### 3.11.6.1 Remarks

Absolute values of weights are not really important in DEXi; only their relative proportions with each other do matter. Both normalizations preserve this property.

It is important to understand that 'Current' weights represent the closest possible match with your 'Required' weights *and* the rules already entered in the table. In general, thus, 'Current' weights differ from the 'Required' weights, and there are two main reasons for this:

- [Utility function](#) space in DEXi is discrete, not continuous. The functions are discrete, too. In general, it is impossible to exactly match continuous 'Required' weights to a discrete 'Current' utility function.
- A [hyperplane](#) constructed from 'Required' weights depends on already entered function values. The more the entered values, the less the freedom for the hyperplane, and the lower the chance to match the 'Required' weights.

For example, there is no freedom left with a fully defined utility function. In this case, 'Required' weights have no effect.

The default setting of 'Rounding' is 'no' for compatibility with DEXi versions prior to 3.03. However, it is recommended to explicitly set 'Rounding' to 'down' or 'up' for better stability of numerical calculations.

### 3.11.7 Handling Non-Entered Function Values

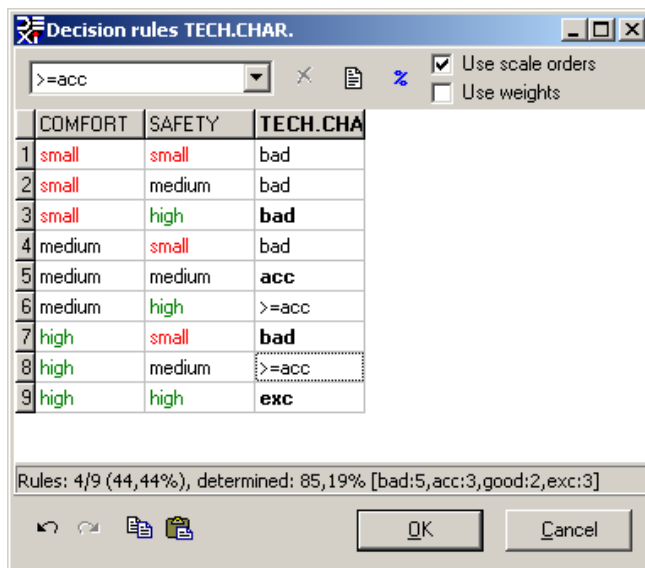
In [Function Editor](#), [utility function](#) values are either *entered* by the user or *non-entered*. Entered values are shown in **bold** and are never changed by DEXi during the editing session. This is, however, not

the case with non-entered values, which are handled by DEXi with the purpose to aid and simplify the function editing process, and maintain the consistency of function definitions. Non-entered values are shown in normal typeface and, by default, they are recalculated whenever the table changes. The calculation is based on already entered values and other available information (particularly [weights](#)).

DEXi uses two strategies for calculating non-entered values, which can be individually activated or deactivated using the two corresponding checkboxes on the [Function Editor toolbar](#): **Use scale orders** and **Use weights**.

### 3.11.7.1 Scale orders

This strategy takes into account the ordering of [scales](#). Consider the function  $y=f(x)$ , where both  $y$  and  $x$  have increasingly ordered scales. Then, whenever  $x$  increases, it is clear that  $f(x)$  should also increase or remain constant. This function property is known as *monotonicity*.

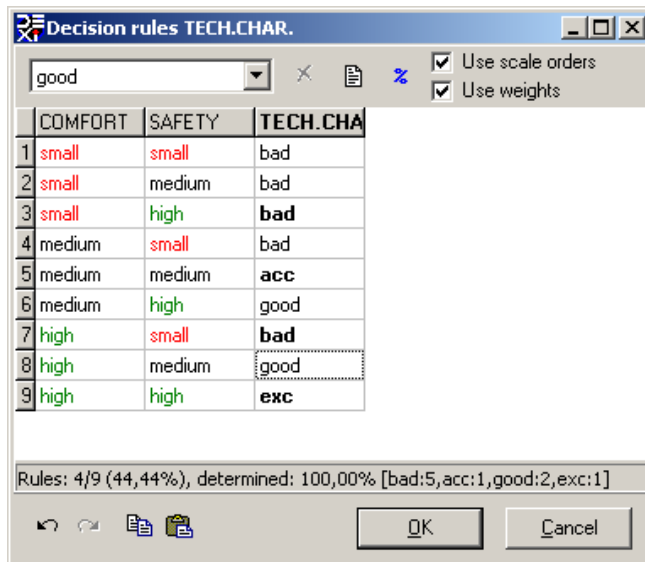


It is easy to see that, in general, monotonicity narrows the [intervals](#) of values that can be assigned to non-entered cells. For example, the rule 5 above assigns **acc** to the combination COMFORT=medium and SAFETY=medium. From this, it immediately follows that for any rules having COMFORT or SAFETY better than medium, the TECH.CHAR. value should be **acc** or better - this is exactly what is shown with rules 6 and 8 above. Similarly, the entered **bad** value of rule 7 implies that the value of non-entered rules 4 and 1 is bad, too.

This strategy fails whenever the user themselves enters values so that they violate monotonicity. In this case, DEXi deactivates this strategy and disables the **Use scale orders** checkbox.

### 3.11.7.2 Weights

This strategy calculates the values of non-entered rules using a *hyperplane* (linear function), which is constructed using [weights](#), as defined in the [Weight Editor](#), and other already entered rules. The hyperplane is constructed so that its slopes correspond to weights required by the user, and that its surface lies as close as possible (in the least squares sense) to the already entered values.

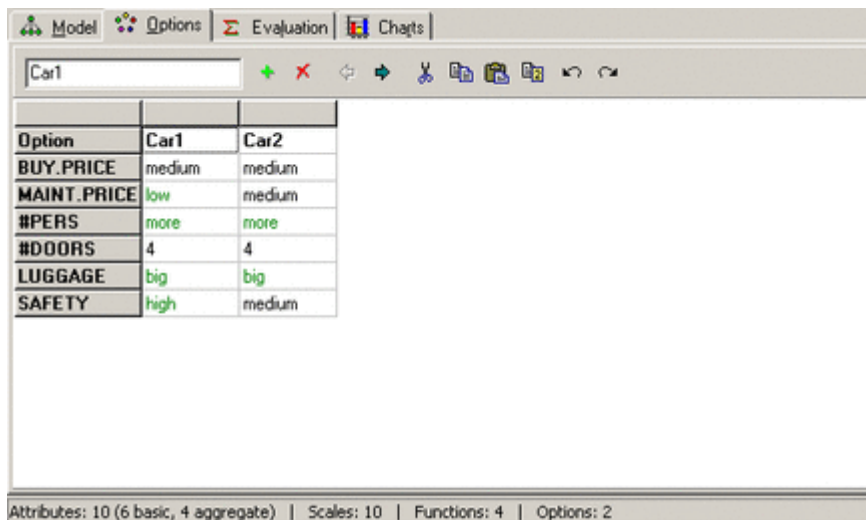


As long as your function is '100% determined', the proportion of actually entered rules is not that important and can be less than 100%. However, even in this case you should be aware that non-entered rules are more volatile than entered ones. Entered values are never changed by DEXi, but non-entered values may be unintentionally changed later, for example, by changing weights in [Weight Editor](#). To protect your completed function from such changes, you may want to run the [Enter values](#) command.

For final verification of your function, you may also want to review its [complex rules](#) and [weights](#).

### 3.12 Options Page

The *Options Page* of [DEXi model window](#) provides workspace and commands for editing [option](#) descriptions: option names and option values assigned to basic [attributes](#) of the currently edited [DEXi model](#).



#### 3.12.1 Workspace

The workspace provides a table for editing option data. Each column represents an [option](#). The first row displays options' names and each of the remaining rows corresponds to one basic [attribute](#).

Above the table, there is a toolbar consisting of:

- a data-entry field, used to edit the value of a single cell in the table, and
- command buttons.

To enter an option name, select a corresponding name cell in the table and edit its contents in the data-entry field.

To enter a cell value other than name, you can:


- select an item from the data-entry field,
- right-click and select an item from the pop-up menu; or
- press one of the keys **1**, **2**, ..., on the keyboard, which represent consecutive scale values, or press the key **\***, which denotes an undefined value.


#### 3.12.2 Commands


To invoke a command, you may either:


- press a button shown in the toolbar,
- select an item from the Edit Menu.

All commands refer to the option (column) whose cell is currently selected in the table.


 **Add option:** Inserts a new column to the right of the currently selected option. The new option is named 'New' and all its value cells are set to '\*' ('undefined').


 **Delete option:** Deletes the currently selected option.

 **Move left:** Moves the currently selected column one place to the left.


 **Move right:** Moves the currently selected column one place to the right.

 **Cut:** Equivalent to **Copy** followed by **Delete option**.

 **Copy:** Copies the currently selected option (column of cells) into the clipboard for further use.

 **Paste:** Inserts previously **Cut** or **Copied** column into the table, positioning it to the right of the currently selected column.

 **Duplicate:** Duplicates the currently selected column.

 **Undo:** Undo the last option-editing operation.

 **Redo:** Repeat the last undone options-editing operation.

### 3.12.3 Remarks

Duplicating columns is very useful for 'what-if' [analysis](#): duplicate an option, then leave the original intact and modify only its copy. In this way, you can easily compare the effects of changes on [evaluation](#) results.

## 3.13 Evaluation Page

The *Evaluation Page* of [DEXi model window](#) displays [evaluation](#) results. Each [option](#) created previously in the [Options Page](#), is evaluated by the [model](#) created in the [Model Page](#). You can change option descriptions (values of basic attributes) and see the effects of changes, and copy and paste all option data. In addition, the [Analysis Menu](#) and corresponding toolbar buttons provide commands for option [analyses](#): Plus-minus-1 analysis, Selective explanation and Compare options.

Option	Car1	Car2
. CAR	exc	good
. . PRICE	low	medium
. . . BUY.PRICE	medium	medium
. . . MAINT.PRICE	low	medium
. . TECH.CHAR.	exc	good
. . . COMFORT	high	high
. . . . #PERS	more	more
. . . . #DOORS	4	4
. . . . LUGGAGE	big	big
. . . . SAFETY	high	medium

Attributes: 10 (6 basic, 4 aggregate) | Scales: 10 | Functions: 4 | Options: 2

### 3.13.1 Workspace

The workspace is similar to [Options Page's](#) one in that it provides a table showing option data. The difference is that all option data is shown here, including the values of both basic and aggregate attributes. Rows of the table correspond to all [attributes](#) and are displayed so as to indicate the [tree](#) structure of the current model.


You can move along the cells and select each of them. When you select a cell that corresponds to a basic attribute, a data-entry field appears in the toolbar, so that you can change the value of that cell in the same way as on the [Options Page](#). The effects of any change are immediately shown in the table.


### 3.13.2 Commands

To invoke a command, you may either:

- press a button shown in the toolbar,
- select an item from the Edit Menu.

The following commands are available on this page:

 **Copy options:** Copies data of all the options into the clipboard for further use.

 **Paste options:** Copies or inserts previously **Copied** option data back into the table. The position where each option's data is pasted into the table is determined from option names. Suppose an option named "Opt" has been previously copied into the clipboard. If "Opt" exists in the current table, then the paste command replaces all its data. Otherwise, a new option "Opt" is created.

 **Find...:** Opens the same window as on the [Model Page](#) in which you can define a text to be searched for in the data table.

 **Find next:** Continues searching from the current position in the data table.

 **Undo:** Undo the last option-editing operation.

 **Redo:** Redo the last undone option-editing operation.

**Analysis of options:** The following three buttons provide shortcuts to option analysis commands available in the [Analysis Menu](#):

**±1 Plus-minus-1 analysis:** Investigating the effects of changing basic option values by one step up and down.

**≡+ Selective explanation:** Identifying particular advantages and disadvantages of an option.

**△ Compare options...:** Comparing an option with some other options.

### 3.14 Analysis Menu

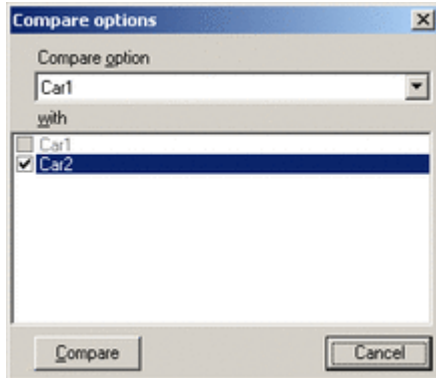
The [DEXi Analysis Menu](#) is available only from the [Evaluation Page](#). This menu provides commands for the analysis of options. Each command creates and previews an option analysis report.

#### 3.14.1 Option analyses

**±1 Plus-minus-1 analysis:** This analysis investigates the effects of changing each basic attribute by one value down and up (if possible), independently of other attributes. The analysis is carried out for the currently selected option and displays the effects of changes on the currently selected aggregate attribute.

**≡+ Selective explanation:** Displays particularly strong and weak values of the currently selected option. This method finds and displays all connected subtrees of attributes whose values are either all **good** (for strong points) or **bad** (for weaknesses).

**△ Compare options...:** This command creates a report that is similar to the common [Evaluation results](#) report, but highlights differences between options. First, DEXi opens a dialogue in which you can choose a primary option and a list of secondary options:



After selection, DEXi makes a report in which it compares the primary option with each secondary one. The primary option values are displayed in full, whereas the secondary options' values are displayed only when they differ from the primary option.

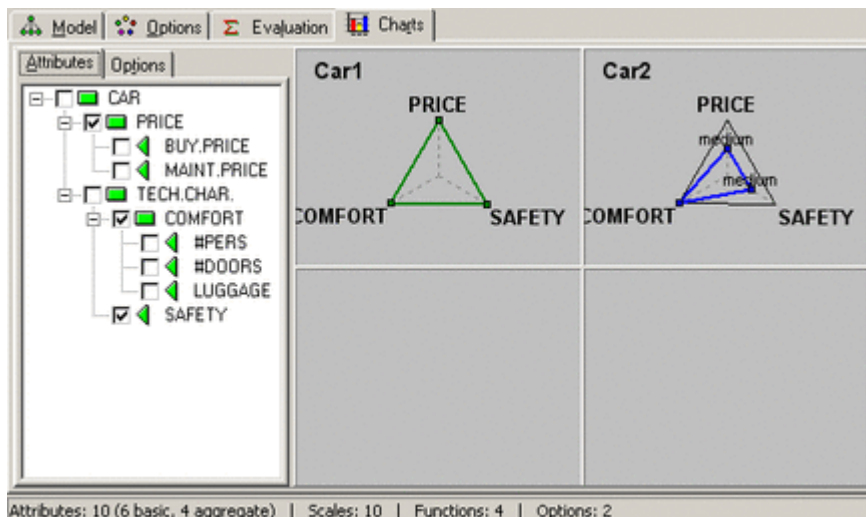
When selecting options on the *Compare options* dialogue, you can right-click on the list of options, which gives you two additional commands:

**Select all options:** Select all options other than the primary one.

**Unselect all options:** Exclude all options from comparison.

### 3.15 Charts Page

The *Charts Page* of [DEXi model window](#) provides workspace and commands to create graphical displays of [evaluation](#) results.



### 3.15.1 Workspace

The workspace consists of a *selection area* on the left and *chart display* on the right. The selection area consists of two sub-pages ('tabs'):

- **Attributes:** This page shows the [tree](#) structure of the current [DEXi model](#). There, you can check attributes that constitute chart's dimensions.
- **Options:** This page shows the list of currently defined [options](#). You can check individual options to be displayed in the current chart. This selection also determines which options are displayed in [reports](#) or exported to [files](#).

The chart type is determined according to the number of checked attributes (see [chart examples](#)):

- No attributes: No chart is displayed
- One attribute: Bar chart
- Two attribute: Scatter chart
- Three to six attributes: Radar chart

Radar charts can display only one option at the same time. To choose which option is displayed, select it ('highlight' its name) on the *Options* sub-page.

### 3.15.2 Commands

To invoke a command, you may either:

- select an item from the Chart Menu,
- right-click and select an item from the pop-up menu.

**Show all options:** Select all options for display.


**Hide all options:** Hide all options from display. [Usually, this is followed by selecting individual options from the *Options* sub-page.]

**Show values:** When this item is checked, full [scale](#) value names are shown in charts. Otherwise, only their ordinal numbers are displayed. [This is typically used to save space or to avoid overlapping text.]

**Show option names:** This item controls whether option names are displayed in charts or not. [This may also save space or avoid overlapping text.]

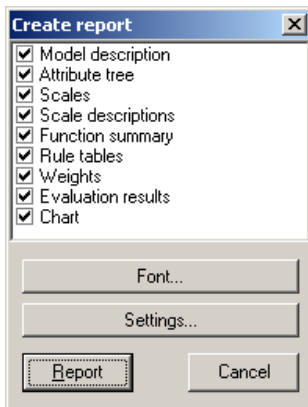


**Four options:** This item is available only for radar charts. When it is checked, four radar charts and thus four options are shown simultaneously. Otherwise, there is only one large chart that displays one option.

 **Copy chart:** Copies the current chart into the clipboard so that it can be pasted into other documents. Available formats for pasting are 'Windows Metafile' and 'Enhanced Metafile'.

## 3.16 Report

*Report* provides a formatted and mostly textual presentation of key components of your current [DEXi model](#). After invoking this command, a small window appears in which you can select [elements](#) to be included in the report:



In addition to element selection, you can press one of the buttons:

**Font:** Specify font to be used in the report (the default is Arial, 10pt).

**Settings:** Open [Settings/Report](#) in order to specify the format of report and its [elements](#).

**Report:** Create a report consisting of selected elements and [preview](#) it on the screen.

**Cancel:** Close this window without creating a report.

Also, you can right-click on the list and select one of the menu items:

**Select all reports:** Select all report elements

**Unselect all reports** all current selections

### 3.16.1 Report elements

**Model description:** Textual description of the current model, which is optional and used only for documentation.

**Attribute tree:** Displays [attribute](#) names and descriptions. [Tree structure](#) is indicated by indenting and connecting attribute names. [See an [example](#).]

**Scales:** Similar to 'Attribute tree', but displays [scales](#). [See an [example](#).]

**Scale descriptions:** A long printout of [scales](#). For each scale in your [model](#), it prints out the scale name, corresponding attribute description, and all scale values together with their own descriptions, if any. [This report element is rarely needed.]

**Function summary:** Displays the [tree structure](#) along with the [status of utility functions](#).

**Rule tables:** Prints out all [utility functions](#) defined in your [model](#). Display format is determined in [Settings/Report](#). [See some [examples](#)].

**Weights:** Similar to 'Attribute tree', but displays attribute [weights](#). You can explicitly select displayed weight types in [Settings/Report](#). [See an [example](#)].

**Evaluation results:** Similar to 'Attribute tree', but displays [evaluation](#) results. Only options that are selected on the [Charts Page](#) are included into this report element. Again, its format can be determined through [Settings/Report](#).

**Chart:** Prints out the chart that is currently displayed on the [Charts Page](#).

### 3.17 Preview

*Preview* displays [reports](#) created by [DEXi](#). You can view these reports and optionally print them, save on files or copy individual pages for transfer to other applications (such as Microsoft Word).

The toolbar, which is displayed at the top of Preview, provides the following buttons and controls:


**Page status:** Displays the current page number and total number of pages.


 and **PgUp:** Shows the previous page.


 and **PgDn:** Shows the next page.

**Zoom:** Controls the magnification of display.

 **Print:** Prints the report.

 **Page setup:** Opens a dialog to define page size, orientation, and margins.

 **Save:** Save the current report on file. The available formats are: 'Text File (\*.txt)', 'Tab-delimited File (\*.tab)', 'Enhanced Metafile (\*.emf)', and 'Bitmap (\*.bmp)'. The former two save the entire report, while the latter two save only the current page.

 **Copy:** Copies the current page to clipboard for its transfer to other applications. The page is saved in two formats, 'Windows Metafile' and 'Enhanced Metafile'.

 **Close:** Closes the current preview and returns back to [DEXi](#).

### 3.18 Settings

*Settings* is a dialogue in which you can specify how [DEXi](#) handles reports, external files and other advanced features. For this purpose, it provides three pages: Report, Import/Export and Advanced.

#### 3.18.1 Report Page

Use this page to specify various aspects of [report](#) formatting.

**Each section on new page:** When checked, each report [element](#) is strictly started on a new page. Otherwise, multiple elements may appear on a single page.

**Bad values** and **Good values**: Use these controls to specify the appearance of 'bad' and 'good' [scale](#) values.

**Functions**: These controls specify the display of [utility functions](#):

- *weights*: specifies whether [weights](#) are displayed or not;
- *rule numbers*: include or exclude row numbers;
- *complex rules*: when checked, represent the function with [complex rules](#), otherwise use elementary rules;
- *entered rules only*: when checked, display only rules entered by the user, otherwise also show [non-entered rules](#).

**Weights**: These controls specify the display of [weights](#). Use these controls to specify the number of decimal places and to select individual [weight types](#).

**Evaluation**: These controls specify the display of [evaluation](#) results:

- *Number of columns* refers to the number of options shown together on the right hand side of the 'Evaluation results' [report element](#).
- *Trim characters* specifies the maximum number of characters that can be used to display option values in this report element [the shorter the strings, the more options can be displayed together].

### 3.18.2 Import/Export Page

This Settings page specifies the format of external data files. which are imported and exported through [File Menu](#) commands.

**Option data format**: These controls specify the format and contents of imported and exported [option data files](#).

- *Option values*: specifies the format of values, which can be either *text* strings or ordinal numbers starting at 0 (*base 0*) or 1 (*base 1*).
- *Attributes*: import/export the values of *all* or only *basic* [attributes](#).
- *Orientation* specifies whether data file rows correspond to attributes (*normal*) or options (*transposed*).
- *Indent* specifies whether attribute names are *indented* or *not*. Indentation adds whitespace to outline the [tree](#) structure of attributes.

**Function data format**: These controls specify the format and contents of exported [function data files](#).

- *Attribute values*: specifies the format of attribute values, which can be either *text* strings or ordinal numbers starting at 0 (*base 0*) or 1 (*base 1*).
- *Rules*: export *all* or only *entered* decision rules.
- *Interval format* specifies the format of function values, which are in general [intervals](#). Possible formats are:
  - *from:to*,
  - *from* and *to* separated by the TAB character, or
  - using interval symbols '\*', '>=', '<=' and '!':.

### 3.18.3 Advanced Page

This page contains two controls:

**Link equal attributes**: specifies whether DEXi performs automatic [linking of attributes](#) or not.

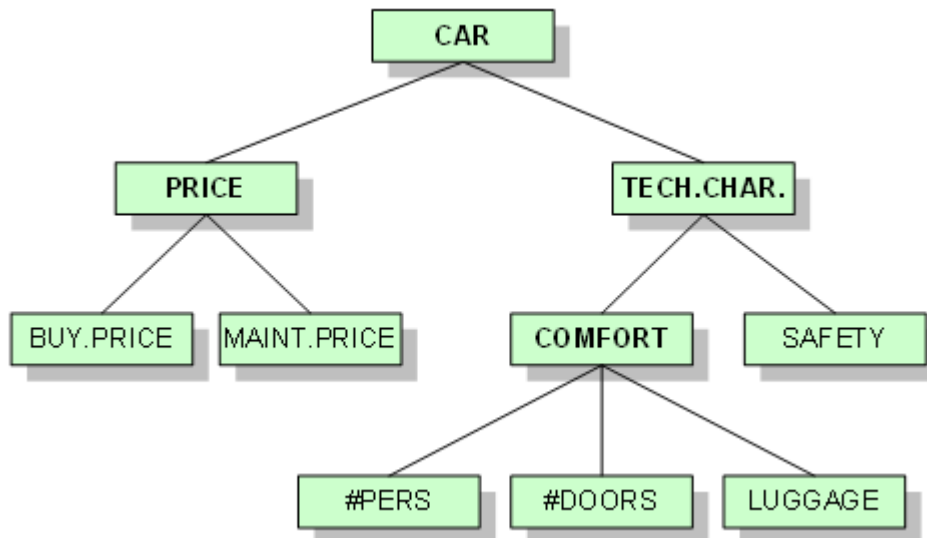
**Undo/Redo:** to activate or deactivate the Undo/Redo functionality when editing models, options and utility functions.

## 4 Example: Car Evaluation Model

This is an example of a [DEXi multi-attribute](#) model for the evaluation of cars. This is a very small and simple model used to illustrate main concepts of multi-attribute modeling and DEXi, and is not meant to address the problem of car evaluation at any realistic level. This model has been traditionally handed out together with all previous versions of the programs [DEX](#) and [DEXi](#). For this reason, it is shown here without change, in spite of its age.

### 4.1 Tree of Attributes for Car Evaluation

The [Car Evaluation Model](#) has the following [tree structure](#) of attributes:



#### 4.1.1 Interpretation

This structure can be interpreted as follows:

1. *Decomposition*: In order to evaluate a CAR, we consider its PRICE and TECHNICAL CHARACTERISTICS. PRICE is further decomposed into BUYING PRICE and MAINTENANCE PRICE. Similarly, TECH.CHAR. are decomposed into COMFORT and SAFETY, and COMFORT is further decomposed into the number of PERSONS (passengers), number of DOORS and size of the LUGGAGE boot.
2. *Dependency*: The attribute CAR depends on PRICE and TECH.CHAR. Similarly, COMFORT depends on #PERS, #DOORS and LUGGAGE. Etc.
3. *Aggregation*: The values of #PERS, #DOORS and LUGGAGE are aggregated into a value of COMFORT. Then, in the following order, BUY.PRICE and MAINT.PRICE are aggregated into PRICE, COMFORT and SAFETY are aggregated into TECH.CHAR., and PRICE and TECH.CHAR. are aggregated into CAR.

#### 4.1.2 Attribute Types

The attributes in this tree are of the following types:

- Basic attributes are: BUY.PRICE, MAINT.PRICE, #PERS, #DOORS, LUGGAGE and SAFETY
- Aggregate attributes are: CAR, PRICE, TECH.CHAR. and COMFORT.
- The root attribute is CAR.

### 4.1.3 Attribute Descriptions

In [DEXi](#)'s reports, this tree is printed together with attributes' descriptions and appears as follows:

Attribute	Description
CAR	Quality of a car
PRICE	Price of a car
BUY.PRICE	Buying price
MAINT.PRICE	Maintenance price
TECH.CHAR.	Technical characteristics
COMFORT	Comfort
#PERS	Maximum number of passengers
#DOORS	Number of doors
LUGGAGE	Size of the luggage boot
SAFETY	Car's safety

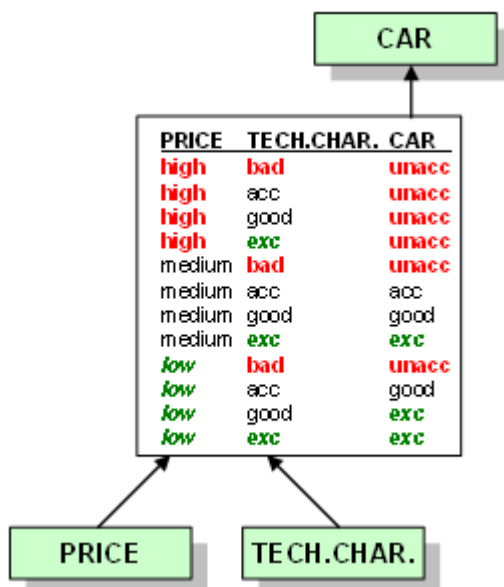
### 4.2 Scales for Car Evaluation

The [scales](#) of attributes in the [Car Evaluation Model](#) are defined as follows:

Attribute	Scale
CAR	<b>unacc</b> ; acc; good; <b>exc</b>
PRICE	<b>high</b> ; medium; <b>low</b>
BUY.PRICE	<b>high</b> ; medium; <b>low</b>
MAINT.PRICE	<b>high</b> ; medium; <b>low</b>
TECH.CHAR.	<b>bad</b> ; acc; good; <b>exc</b>
COMFORT	<b>small</b> ; medium; <b>high</b>
#PERS	<b>to_2</b> ; 3-4; <b>more</b>
#DOORS	<b>2</b> ; 3; 4; <b>more</b>
LUGGAGE	<b>small</b> ; medium; <b>big</b>
SAFETY	<b>small</b> ; medium; <b>high</b>

### 4.3 Utility Functions for Car Evaluation

Consider the root [attribute](#) of the [Car Evaluation Model](#). According to the [tree of attributes](#), the root attribute CAR depends on two lower-level attributes: PRICE and TECH.CHAR. Thus, the utility function that corresponds to CAR maps all the combinations of values of PRICE and TECH.CHAR. into the values of CAR (see the [scales](#) of these attributes). The function is defined by the table shown below.



### 4.3.1 Interpretation

The attributes PRICE and TECH.CHAR. have three and four values, respectively, so the number of rows in the table is  $3 \times 4 = 12$ . Each row provides a value of CAR for one combination of the values of PRICE and TECH.CHAR. Interpreted as an *elementary decision rule*, the fourth row, for example, means the following:

if PRICE=medium and TECH.CHAR.=bad then CAR=unacc.

### 4.3.2 Elementary decision rules

The [Car Evaluation Model](#) has four aggregate attributes and, consequently, four utility functions. These are defined by the following tables of elementary decision rules:

PRICE	TECH.CHAR.	CAR	#PERS	#DOORS	LUGGAGE	COMFORT
1 high	bad	unacc	1 to_2	2	small	small
2 high	acc	unacc	2 to_2	2	medium	small
3 high	good	unacc	3 to_2	2	big	small
4 high	exc	unacc	4 to_2	3	small	small
5 medium	bad	unacc	5 to_2	3	medium	small
6 medium	acc	acc	6 to_2	3	big	small
7 medium	good	good	7 to_2	4	small	small
8 medium	exc	exc	8 to_2	4	medium	small
9 low	bad	unacc	9 to_2	4	big	small
10 low	acc	good	10 to_2	more	small	small
11 low	good	exc	11 to_2	more	medium	small
12 low	exc	exc	12 to_2	more	big	small
13			3-4	2	small	small
14			3-4	2	medium	small
15			3-4	2	big	small
16			3-4	3	small	small
17			3-4	3	medium	medium
18			3-4	3	big	medium
19			3-4	4	small	small
20			3-4	4	medium	medium
21			3-4	4	big	high
22			3-4	more	small	small
23			3-4	more	medium	medium
24			3-4	more	big	high
25			more	2	small	small
26			more	2	medium	small
27			more	2	big	small
28			more	3	small	small
29			more	3	medium	medium
30			more	3	big	high
31			more	4	small	small
32			more	4	medium	high
33			more	4	big	high
34			more	more	small	small
35			more	more	medium	high
36			more	more	big	high

BUY.PRICE	MAINT.PRICE	PRICE	COMFORT	SAFETY	TECH.CHAR.
1 high	high	high	small	small	bad
2 high	medium	high	small	medium	bad
3 high	low	high	small	high	bad
4 medium	high	high	medium	small	bad
5 medium	medium	medium	medium	medium	acc
6 medium	low	low	medium	high	good
7 low	high	high	low	small	bad
8 low	medium	low	low	medium	good
9 low	low	low	low	high	exc

### 4.3.3 Complex rules and weights

This example shows all the [utility functions](#), defined in the [Car Evaluation Model](#). They are represented in terms of local [weights](#) and [complex rules](#).

	PRICE	TECH.CHAR.	CAR
	60%		40%
1	<b>high</b>	*	<b>unacc</b>
2	*	<b>bad</b>	<b>unacc</b>
3	medium	acc	acc
4	medium	good	good
5	<b>low</b>	acc	good
6	>=medium	<b>exc</b>	<b>exc</b>
7	<b>low</b>	>=good	<b>exc</b>

	BUY.PRICE	MAINT.PRICE	PRICE
	50%		50%
1	<b>high</b>	*	<b>high</b>
2	*	<b>high</b>	<b>high</b>
3	medium	medium	medium
4	>=medium	<b>low</b>	<b>low</b>
5	<b>low</b>	>=medium	<b>low</b>

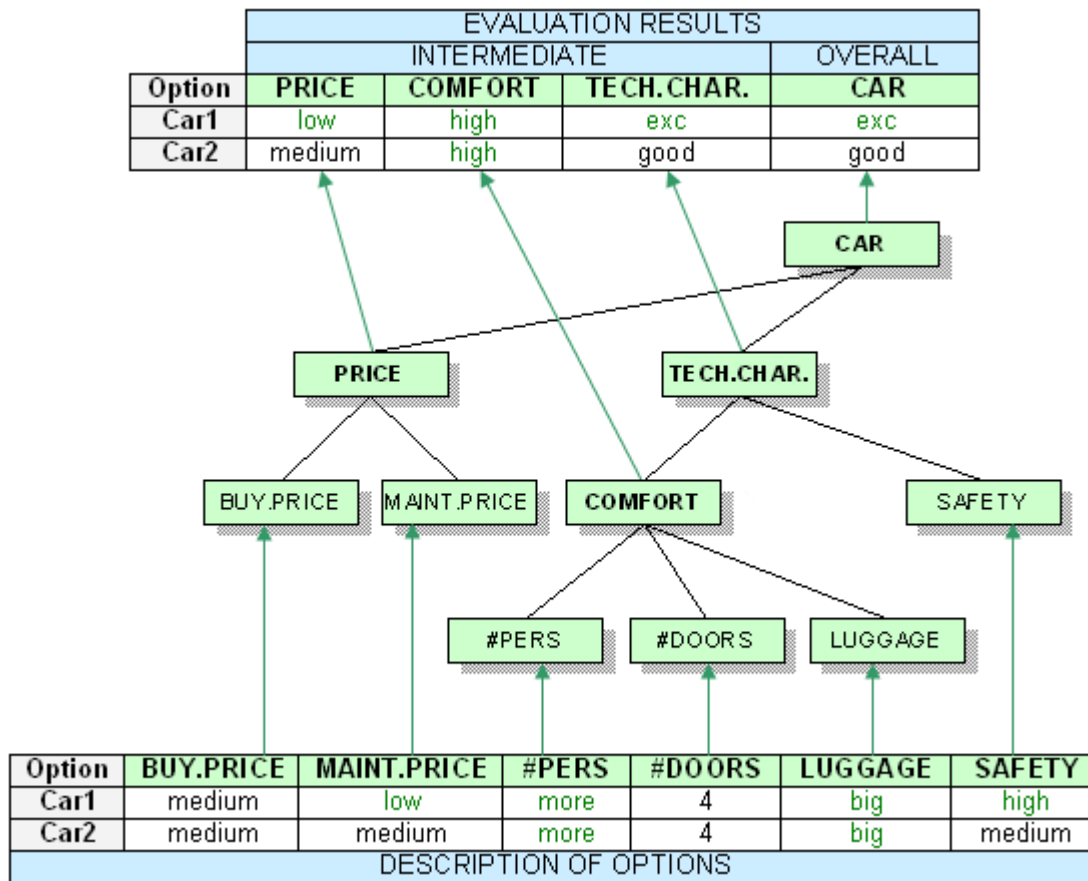
	COMFORT	SAFETY	TECH.CHAR.
	50%		50%
1	<b>small</b>	*	<b>bad</b>
2	*	<b>small</b>	<b>bad</b>
3	medium	medium	acc
4	medium	<b>high</b>	good
5	<b>high</b>	medium	good
6	<b>high</b>	<b>high</b>	<b>exc</b>

	#PERS	#DOORS	LUGGAGE	COMFORT
	39%	22%		39%
1	<b>to_2</b>	*	*	<b>small</b>
2	*	<b>2</b>	*	<b>small</b>
3	*	*	<b>small</b>	<b>small</b>
4	3-4	3	>=medium	medium
5	3-4	>=3	medium	medium
6	>=3-4	3	medium	medium
7	>=3-4	>=4	<b>big</b>	<b>high</b>
8	<b>more</b>	>=3	<b>big</b>	<b>high</b>
9	<b>more</b>	>=4	>=medium	<b>high</b>

#### 4.4 Description and Evaluation of Cars

Options evaluated by the [Car Evaluation](#) models are, obviously, cars. This example illustrates two basic concepts: [description of options](#) and [evaluation of options](#).





#### 4.4.1 Interpretation

At the bottom, the table shows two options, *Car1* and *Car2*, described by the qualitative values assigned to the six basic attributes of the tree.

These values then aggregated from bottom to the top of the [tree of attributes](#) according to the structure of the tree and defined [utility functions](#). In this way, *intermediate evaluation results* are first obtained and assigned to the attributes PRICE, COMFORT and TECH.CHAR. (see the table at the top). Finally, the values of PRICE and TECH.CHAR. are aggregated into CAR, giving the *overall evaluation* of both cars.

### 4.5 Some Car Option Analyses

These examples show some option analysis reports obtained from the [Car Evaluation Model](#). These reports can be created by commands of the [Analysis Menu](#) or corresponding buttons on the [Evaluation Page](#).

#### 4.5.1 Plus-minus-1 analysis

The first example shows results of [Plus-minus-1 analysis](#) for the option *Car2* and the aggregate attribute CAR. The column **Car2** displays the current values of *Car2*. The column **-1** displays the values of the attribute CAR when each corresponding lower-level attribute's value changes by one step down (independently of other attributes). Similarly, the column **+1** shows the effects of increasing the value by one step up. Empty fields denote no effect, and the brackets '[' and ']' indicate that the attribute value cannot be decreased or increased, respectively.

Attribute	-1	Car2	+1
CAR		good	
├BUY.PRICE	<b>unacc</b>	medium	<b>exc</b>
├MAINT.PRICE	<b>unacc</b>	medium	<b>exc</b>
├├#PERS		<b>more</b>	]
├├#DOORS		4	
├├LUGGAGE		<b>big</b>	]
└SAFETY	<b>unacc</b>	medium	<b>exc</b>

The above display shows, for example, that BUY. PRICE considerably affects the evaluation of Car2. When BUY. PRICE decreases by one step (from 'medium' to 'high'; the latter value is not shown), the overall value of CAR becomes 'unacc'. In the other direction (from 'medium' to 'low'), the overall evaluation improves to 'exc'.

The two brackets ']' indicate that the values of corresponding attributes, #PERS and LUGGAGE, cannot be increased any more, preventing the +1 part of the analysis.

#### 4.5.2 Selective explanation

[Selective explanation](#) highlights particular advantages and disadvantages of an option. The method finds and displays only those connected sub-trees of attributes for which the option has been evaluated as particularly good or bad.

##### Strong points

Attribute	Car1
CAR	<b>exc</b>
├PRICE	<b>low</b>
├└MAINT.PRICE	<b>low</b>
├COMFORT	<b>high</b>
├├#PERS	<b>more</b>
├├LUGGAGE	<b>big</b>
└SAFETY	<b>high</b>

This example shows that Car2 has three particularly strong parts (two sub-trees and one single attribute):

1. overall evaluation, which is strongly influenced by low MAINT. PRICE,
2. COMFORT due to very good #PERS and LUGGAGE, and
3. high SAFETY.

#### 4.5.3 Compare options

This analysis compares one (primary) option with some other selected (secondary) options, displaying all values of the primary option and only those values of the secondary options that differ from the primary's ones.

Attribute	Car1	Car2
CAR	<b>exc</b>	good
├PRICE	<b>low</b>	medium
├├BUY.PRICE	medium	
├├MAINT.PRICE	<b>low</b>	medium
└TECH.CHAR.	good	<b>exc</b>
├COMFORT	<b>high</b>	
├├#PERS	<b>more</b>	
├├#DOORS	4	
├├LUGGAGE	<b>big</b>	
└SAFETY	<b>high</b>	medium

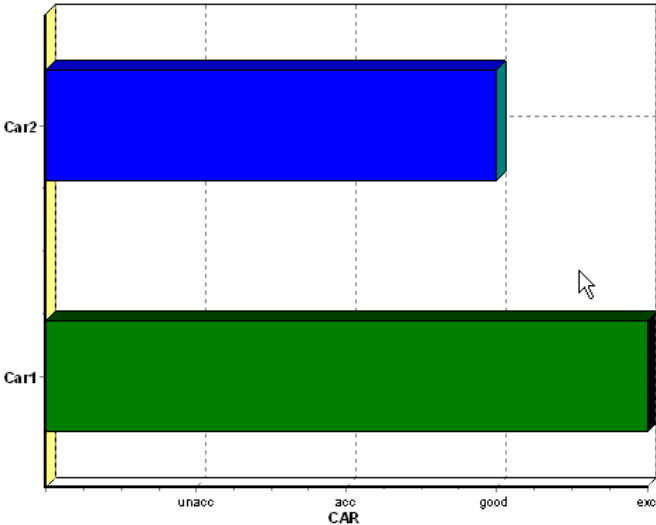
This example compares *Car1* (primary option) with *Car2* (secondary option). *Car2* differs from *Car1* in the values of basic attributes MAINT. PRICE and SAFETY, which cause different evaluations of TECH. CHAR, PRICE and CAR.

### 4.6 Some Car Evaluation Charts

The following examples show some charts that can be obtained in [DEXi](#) from the [evaluation of cars](#) using the [Car Evaluation Model](#). The charts differ in the number of evaluation dimensions (actually [attributes](#)) selected for presentation in [DEXi's Chart Page](#).

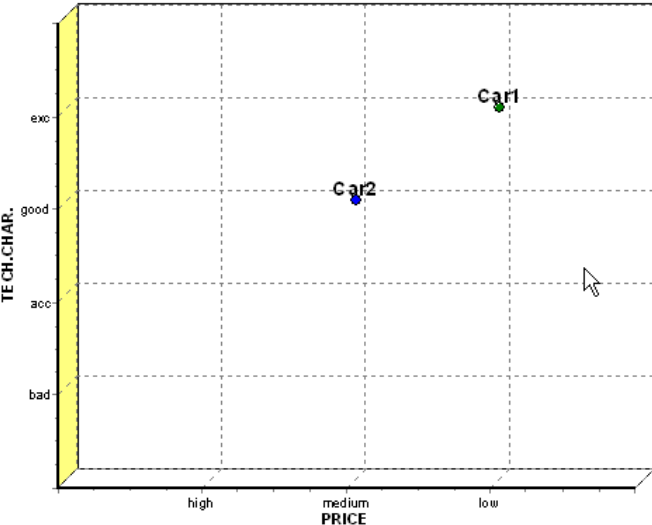
#### 4.6.1 Bar Chart

This chart displays evaluation results according to one evaluation dimension. In this case, this is the root attribute CAR, so the chart shows the overall evaluation of two cars.



#### 4.6.2 Scatter Chart

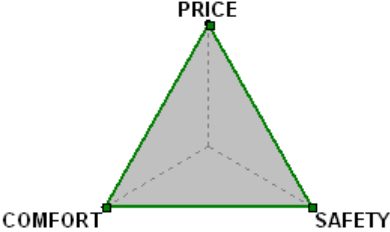
A scatter chart displays evaluation results according to two selected evaluation dimensions. In this case, the selected dimensions are PRICE and TECH.CHAR., that is, the two attributes that occur just below the root attribute CAR (see the [tree structure](#)).



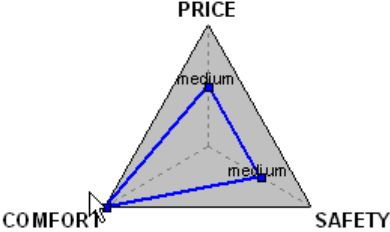
**4.6.3 Radar Chart**

Radar chart displays evaluation results according to three or more dimensions (the maximum is six). The next chart shows the evaluation of cars using the three attributes PRICE, COMFORT and SAFETY.

**Car1**



**Car2**



## 5 Further reading

### 5.1 Documentation in Slovene

The DEXi User's Manual is available as:

Jereb, E., Bohanec, M., Rajkovič, V.: *DEXi: Računalniški program za večparametrsko odločanje*, Moderna organizacija, Kranj, 2003.

Further information on decision analysis, multi-attribute modeling, fundamental DEXi concepts and underlying methods is available in:

Bohanec, M.: *Odločanje in modeli*. DMFA - založništvo, 2006.

### 5.2 Selected Publications

Bohanec, M., Rajkovič, V.: Večparametrski odločitveni modeli. *Organizacija* 28(7), 427–438, 1995. [<http://kt.ijs.si/MarkoBohanec/org95/index.html>]

Bohanec, M., Rajkovič, V.: Multi-attribute decision modeling: Industrial applications of DEX. *Informatica* 23, 487–491, 1999.

Bohanec, M., Zupan, B., Rajkovič, V.: Applications of qualitative multi-attribute decision models in health care, *International Journal of Medical Informatics* 58-59, 191–205, 2000.

Cestnik, B., Bohanec, M.: Decision support in housing loan allocation: A case study, *IDDM-2001: ECML/PKDD-2001 Workshop Integrating Aspects of Data Mining, Decision Support and Meta-Learning: Positions, Developments and Future Directions* (eds. Giraud-Carrier, C., Lavrač, N., Moyle, S., Kavšek, B.), Freiburg, 21–30, 2001.

Leben, A., Bohanec, M.: Evaluation of life-event portals: Multi-attribute model and case study, *Knowledge management in electronic government* (ed. Wimmer, M.A.), 4th IFIP International Working Conference KMGov 2003, Rhodes, Greece, 25–36, 2003.

Mladenčić, D., Lavrač, N., Bohanec, M., Moyle, S. (eds.): *Data mining and decision support: Integration and collaboration*. Kluwer Academic Publishers, 2003. Chapters:

- Bohanec, M.: Decision support. 23–35.
- Bohanec, M., Rajkovič, V., Cestnik, B.: Five decision support applications. 177–189.
- Moyle, S., Bohanec, M., Ostrowski, E.: Large and tall buildings: A case study in the application of decision support and data mining. 191–202.

Moyle, S., Ostrowski, E., Bohanec, M.: Knowledge development using data mining: A specific application in the construction industry. *Leveraging corporate knowledge* (ed. Truch, E.), Gower, pp. 181–197, 2004.

Vintar, M., Grad, J. (ur.): *E-uprava: Izbrane razvojne perspektive*, Univerza v Ljubljani, Fakulteta za upravo, 2004.:

- Leben, A., Bohanec, M.: Vrednotenje portalov življenjskih situacij, 123–140.
- Bohanec, M.: Odločanje in večparametrsko modeliranje, 205–219.

Bohanec, M., Messéan, A., Angevin, F., Žnidaršič, M.: SMAC Advisor: A decision-support tool on coexistence of genetically-modified and conventional maize. *Proc. Information Society IS 2006*, Ljubljana, 9–12, 2006.

Verdev. M., Bohanec, M., Džeroski, S.: Decision support for a waste electrical and electronic equipment treatment system. *Proc. Information Society IS 2006*, Ljubljana, 89–92, 2006.

Bohanec, M., Cortet, J., Griffiths, B., Žnidaršič, M., Debeljak, M., Caul, S., Thompson, J., Krogh, P.H.: A qualitative multi-attribute model for assessing the impact of cropping systems on soil quality. *Pedobiologia* 51(3), 239–250, 2007.

Taškova, K., Stojanova, D., Bohanec, M., Džeroski, S.: A qualitative decision-support model for evaluating researchers. *Informatika* 31(4), 479–486, 2007.

Žnidaršič, M., Bohanec, M., Zupan, B.: Modelling impacts of cropping systems: Demands and solutions for DEX methodology. *European Journal of Operational Research* 189, 594–608, 2008.

Bohanec, M., Messéan, A., Scatasta, S., Angevin, F., Griffiths, B., Krogh, P.H., Žnidaršič, M., Džeroski, S.: A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops. *Ecological Modelling* 215, 247–261, 2008.

Rozman, Č., Potočnik, M., Pažek, K., Borec, A., Majkovič, D., Bohanec, M.: A multi-criteria assessment of tourist farm service quality. *Tourism Management* 30, 629–637, 2009.

Žnidaršič, M., Bohanec, M., Lavrač, N., Cestnik, B.: Project self-evaluation methodology: The Healththreats project case study. *Proc. Information Society IS 2009*, Ljubljana, 85–88, 2009.

Bohanec, M., Žnidaršič, M.: Izkušnje z večparametrskimi odločitvenimi modeli pri podpori odločanja o gensko spremenjenih organizmih. DAES 2010: Sodobni izzivi menedžmenta v agroživilstvu (ur. Č. Rozman, S. Kavčič), Pivola, 18.–19.3.2010, 29–37, 2010.

Stubelj Ars, M., Bohanec, M.: Towards the ecotourism: A decision support model for the assessment of sustainability of mountain huts in the Alps. *Journal of Environmental Management* 91(12), 2554–2564, 2010.

Žnidaršič, M., Bohanec, M.: Handling uncertainty in DEX methodology. URPDM 2010: Uncertainty and robustness in planning and decision making (eds. C.H. Antunes, D.R. Insua, L.C. Dias), *Proceedings of the 25th Mini-EURO Conference*, University of Coimbra - Portugal, 15–17 April 2010.

Pavlovič, M., Čerenak, A., Pavlovič, V., Rozman, Č., Pažek, K., Bohanec, M.: Development of DEX-HOP multi-attribute decision model for preliminary hop hybrids assessment. *Computers and Electronics in Agriculture* 75, 181–189, 2011.

## DEXi Versions

This is a detailed summary of additions and improvements in different versions of DEXi.

### 5.3 Version 2.0

#### 5.3.1 New components

- Installation package
- English help
- Reconstructed [DEXi Web Page](#)

#### 5.3.2 New program features

- Program [settings](#), which control various aspects of DEXi, particularly [reports](#) and data import/export.
- Importing and exporting [option data](#) through [File Menu](#) commands and Copy/Paste operations on the [Evaluation Page](#).
- Exporting [utility functions](#) through a [File Menu](#) command.
- Moving option data on the [Options Page](#).
- [Attribute linking](#).
- Slovene and English user interface.

#### 5.3.3 Changed program features

- Modified [DEXi file](#) format:
  - full conformance with XML UTF-8 standard;
  - saving [program settings](#) in DEXi files;
  - saving DEXi files in "version 1" and "version 2" formats.
- [Scale Editor](#):
  - improved handling of the ENTER key.
- [Function Editor](#):
  - consistent implementation of the two [non-entered value-handling](#) strategies: 'Use scale orders' and 'Use weights';
  - added pop-up menu for improved data entry;
  - added 'Enter values' command.
- [Options Page](#):
  - required confirmation before deleting an option.

#### 5.3.4 Bug fixes

- [Model Page](#): Function transformations when moving attributes up and down.
- Display of [Evaluation Page](#) when there are no options.
- Displaying button glyphs and icons.
- Avoiding initial crash (hopefully) when there are no printers installed.

### 5.4 Version 3.0

#### 5.4.1 New program features

- Added Undo/Redo functionality when editing [models](#), [options](#) and [utility functions](#).
- Added option analysis functionality:
  - added [Analysis Menu](#) and toolbar buttons on the [Evaluation Page](#),
  - implemented three [analysis](#) methods: Plus-minus-1 analysis, Selective explanation and Compare options.

- Improved option data entry: right-click menus are now available also on the [Options](#) and [Evaluation](#) Pages.
- Added Shrink/Expand commands to alter the display of attribute trees on the [Model Page](#).

#### 5.4.2 Changed program features

- Added Undo/Redo selection to [Settings/Advanced](#).
- Added file name on report headings.

#### 5.4.3 Changed documentation

- Updated English help.
- Updated [DEXi Web Page](#).
- New URL of the DEXi Web page: <http://kt.ijs.si/MarkoBohanec/dexi.html>

#### 5.4.4 Bug fixes

- [Function Editor](#): The right-click menu now correctly enters function values.
- Corrected calculation of weights of underspecified utility functions.

### 5.5 Version 3.01

#### 5.5.1 New program features

- Slightly changed [File Menu](#): added "Import..." and "Export..." submenus.
- Added "File/Export.../Export tree..." menu item, for exporting trees of attributes, using two data formats:
  - Tab-delimited: textual format with columns containing attribute names, scales and descriptions;
  - GML ([Portable Graph File Format](#)): for creating tree graphs by programs such as [yEd Graph Editor](#).

#### 5.5.2 Bug fixes

- Generation of decision rules of incompletely specified utility functions, correctly interpreting the setting "entered rules only".
- Treatment of linked attributes in "Plus-minus-1 Analysis".

### 5.6 Version 3.02

#### 5.6.1 New program features

- Added Model Description functionality:
  - Added "File/Model Description..." [File Menu](#) item,
  - Added "Model description" [report](#) item.
- Added functionality to search attribute names, descriptions, and scales, for text strings:
  - Added [Edit Menu](#) items "Edit/Find..." and "Edit/Find next".
- Added a drag-and-drop operation to join two father/son attributes into a single attribute (provided they have compatible scales).
- Improved information displayed in status bars.

#### 5.6.2 Bug fixes

- Activation of "Export function".
- Proper counting of attributes of different types in status messages.



## 5.7 Version 3.03

### 5.7.1 New program features

- Improved handling and display of [utility functions](#):
  - Added ability to describe individual functions ([Model Page](#): Description),
  - Extended display of function characteristics: added distributions of class values ([Model Page](#), [Function Editor](#) and Function summary [report](#)),
  - Added value rounding control for functions defined by weights ([Weight Editor](#): Rounding),
  - Added menu item "File/Import.../Import function..." for importing utility function from tab-delimited files,
  - Added copying and pasting of utility functions ([Function Editor](#): Copy and Paste buttons).
- Reports:
  - Added new [report](#) type: "Function summary",
  - Added ability to save [reports](#) on tab-delimited files (as additional means of exporting data).
- Search functionality extended to the [Evaluation Page](#):
  - Added menu items "Edit/Find..." and "Edit/Find next".

### 5.7.2 Bug fixes

- Report preview does not require an installed printer any more.
- [Model Page](#): Timely refreshing of [Tree View](#).
- Proper positioning of windows on systems with multiple monitors.

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