Outline

- Recapitulation
- Aggregation and value functions
- Combining data mining and decision support
- Two applications:
  - Academic
  - SMAC Advisor

Recap

Decision Making Disciplines

- Decision Making
  - Who or what is making decisions?
- Decision Sciences
  - Normative
  - Descriptive
  - Decision Support
  - decision theory
  - utility theory ...
  - cognitive sciences
  - social sciences ...

Central Decision Support Disciplines

- Decision Support
  - Operational Research
  - Decision Analysis
  - Decision Support Systems
  - mathematical formulation of the decision problem
  - searching for optimal solutions
  - decision process, stages
  - modeling
  - evaluation
  - finding 'sufficiently good' solutions
  - information systems
  - decision support

Evaluation Models

options

EVALUATION MODEL

ANALYSIS
Multi-Attribute Models

Quantitative Multi-Attribute Model for Car Selection

Qualitative Multi-Attribute Model for Car Selection

Hierarchical Multi-Attribute Model

Kepner-Tregoe Model

Job Offers

<table>
<thead>
<tr>
<th>Attribute</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salary</td>
<td>12</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Management experience</td>
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<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
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<tr>
<td>Education level</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

- what-if analysis
- sensitivity analysis
- charts
AHP: Analytic Hierarchy Process

- hierarchy of attributes
- assessing weights by a pairwise comparison of attributes
- assessing preferences by a pairwise comparison of alternatives
- consistency analysis

DEXi

Computer Program for Multi-Attribute Decision Making

A simple computer program for MADM that facilitates:
- Creation and editing of
  - model structure (tree of attributes)
  - value scales of attributes
  - decision rules (incl. using weights)
  - options and their descriptions (data)
- Evaluation of options (can handle missing values)
- Presentation of evaluation results with:
  - tables
  - charts
- Analyses: “what-if”, “±1”, selective explanation, comparison
- Preparing reports and charts

DEXi Model

Attribute Scale

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job</td>
<td>unacc; acc; good; acc</td>
</tr>
<tr>
<td>Location</td>
<td>unacc; acc; good</td>
</tr>
<tr>
<td>History</td>
<td>unacc; acc; good</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>unacc; acc; good</td>
</tr>
<tr>
<td>Long</td>
<td>unacc; acc; good</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tables</th>
<th>location</th>
<th>salary</th>
<th>satisfaction</th>
<th>Job</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50%</td>
<td>33%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 unacc</td>
<td>unacc</td>
<td>unacc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 *</td>
<td>unacc</td>
<td>unacc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 *</td>
<td>unacc</td>
<td>unacc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 acc</td>
<td>=acc</td>
<td>=acc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 acc</td>
<td>=acc</td>
<td>=acc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 =acc</td>
<td>=acc</td>
<td>=acc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 good</td>
<td>good</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 good</td>
<td>good</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9 good</td>
<td>good</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 good</td>
<td>good</td>
<td>good</td>
<td></td>
</tr>
</tbody>
</table>

Aggregation and Value Functions

Quantitative

Multi-Attribute Model for Car Selection

Value Function

\[ 50 \times P_1 + 20 \times P_2 + 30 \times P_3 \]

Options

1. 22.000 8 6 63
2. 26.000 6 9 72
3. 19.000 7 8 88

Qualitative

Multi-Attribute Model for Car Selection

Value Function (Decision Rules)

1. med high acc
2. high low good
3. low med acc

Options

1. med high acc
2. high low good
3. low med acc

Unacc

Unacc
Aggregation Functions in Math

\[ y = \text{aggreg}(x_1, x_2, \ldots, x_n) \]

1. Identify when unary:
   \[ \text{aggreg}(x) = x \]
2. Boundary conditions:
   \[ \text{aggreg}(0, \ldots, 0) = 0 \]
3. Non-decreasing:
   \[ \text{aggreg}(x_1, \ldots, x_n) \leq \text{aggreg}(y_1, \ldots, y_n) \text{ if } (x_1, \ldots, x_n) \leq (y_1, \ldots, y_n) \]

Value Functions

Value Function of a Single Attribute

\[ y = \text{value}(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i x_i \]

\[ y = \text{value}(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i x_i = 1 \]

Linear Aggregation Functions

\[ y = \text{min}(x_1, x_2) \]

\[ y = \text{max}(x_1, x_2) \]

Quantitative Multi-Attribute Model for Car Selection

Value Functions

Aggregation Functions in Math

Value Functions

Value Function of a Single Attribute

Linear Aggregation Functions

Minimum and Maximum
Multiplicative Aggregation Functions

\[ y = v(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} x_i^w \quad \sum_{i=1}^{n} w_i = 1 \]

Continuous Logic Functions

\[ y = v(x_1, x_2, \ldots, x_n) = \left( \sum_{i=1}^{n} w_i x_i^r \right)^{1/r} \quad \sum_{i=1}^{n} w_i = 1 \]

Value Function Defined Point-By-Point

Linear Aggregation of Partial Value Functions

\[ y = v(p_1(x_1), p_2(x_2), \ldots, p_n(x_n)) \]

Qualitative Multi-Attribute Model for Car Selection

Utility Function

<table>
<thead>
<tr>
<th>OPTION</th>
<th>PRICE</th>
<th>FUEL</th>
<th>SAFETY</th>
<th>CAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>med</td>
<td>high</td>
<td>acc</td>
<td>unacc</td>
</tr>
<tr>
<td>2.</td>
<td>high</td>
<td>low</td>
<td>good</td>
<td>acc</td>
</tr>
<tr>
<td>3.</td>
<td>low</td>
<td>med</td>
<td>good</td>
<td>acc</td>
</tr>
</tbody>
</table>

Utility

<table>
<thead>
<tr>
<th>SAFETY</th>
<th>PRICE</th>
<th>CAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>high</td>
<td>unacceptable</td>
</tr>
<tr>
<td>red</td>
<td>medium</td>
<td>unacceptable</td>
</tr>
<tr>
<td>red</td>
<td>low</td>
<td>unacceptable</td>
</tr>
<tr>
<td>acceptable</td>
<td>high</td>
<td>unacceptable</td>
</tr>
<tr>
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<td>medium</td>
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<td>good</td>
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<td>low</td>
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<td>excellent</td>
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<tr>
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<td>good</td>
</tr>
<tr>
<td>excellent</td>
<td>low</td>
<td>excellent</td>
</tr>
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</table>
SAFETY

Utility Function Defined Point-By-Point - Linearised

Combining Data Mining and Decision Support

Example: Cars

<table>
<thead>
<tr>
<th>Knowledge discovery from data</th>
<th>Data Mining</th>
<th>Use of models:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>- classification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- clustering</td>
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<tr>
<td></td>
<td></td>
<td>- evaluation</td>
</tr>
<tr>
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<td></td>
<td>- visualization</td>
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<tr>
<td></td>
<td></td>
<td>- explanation</td>
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<table>
<thead>
<tr>
<th>Multi-attribute modeling</th>
<th>Data Mining</th>
<th>Model:</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>- customers clustered</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- types of cars</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- customers analysed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- association rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- car evaluation model</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
DM + DS Integration?

Data Mining → Question → Decision Support

DM + DS Integration!

Decision Support for Data Mining

Meta-learning and multi-strategy learning

Incorporating DM methods into DSS, e.g.:
• MS OLE DB for DM
• MS Analysis Services
• Improving models by data analysis

Data Integrating DM and DS through Models

Sequential Application: DM, then DS

Parallel Applications: Multiple DM models, then DS

Data Mining

Model 1

Model Support

Model 2

Model 3

Problem:
Prediction of Academic Achievement

Primary School
High School

1
2
3
4
5

1: fails late
2: fails soon
3: prolonged
4: graduates: 2 or 3
5: graduates: 4 or 5

1
2
3
4
5

1: fails late
2: fails soon
3: prolonged
4: graduates: 2 or 3
5: graduates: 4 or 5

Data: Weka

DM: HINT

DS: DEXi

Prediction

Data Mining

DM + DS Integration: Academic

Data

LEGEND:

GA 1st grade - general achievement of the first high school grade
Slovene - mark of subject Slovene language
History - mark of subject History
Physics - mark of subject Physics
age enrol - age at enrolment (in months)
unex ab 3rd sem - unexcused absence in the third semester (hours)

SMAC Advisor

Decision Problem

Problem:
- Can GM maize be grown in coexistence with plants on other fields?

Criterion:
- Genetic interference (Adventitious Presence)
  Typical target AP: 0.9 %

Factors:
- pollen flow, volunteers, feral plants, mixing during harvesting, transport, storage and processing, human error, accidents, ...

SMAC Advisor

Decision support software that assesses the achievable AP given:
- relation between fields: distance, relative size, wind direction, etc.
- type and characteristics of used seeds
- environmental characteristics (e.g., background GM pollen pressure),
- use of machinery (e.g., sharing with other farmers)
- target AP

... and gives recommendations:
- farming allowed
- farming disallowed
- assess risks (coexistence is possibly achievable)
- assess additional measures (coexistence achievable by small changes)

SMAC Advisor Architecture

1. SMAC Advisor Wizard User Interface
2. Co-Existence Multi-Attribute DEXi Model
3. MAPOD® Simulation Results

SMAC Advisor Level 3: MAPOD® Simulator

Advanced simulator that assesses the rate of cross-pollination

SMAC Advisor Level 2: DEXi Model

Qualitative Multi-Attribute Model

Some MAPOD® Results

New case studies on the coexistence of GM and non-GM crops
in European agriculture
EUR 22102 EN
SMAC Advisor Level 2: DEXi Model

SMAC Advisor Level 2: Formulation of Rules

SMAC Advisor Level 1: User Interface

SMAC Advisor Level 1: User Interface

Machine Learning and DEX Models

"DM for DS": Model Revision


HINT: Learning DEXi Models From Data

Marko Bohanec

Introduction

- Multi-Attribute Decision Making: decompose the problem to less complex subproblems
- DEX: An Expert System Shell for MADM
  - qualitative attributes
  - decision rules

Problem

Development of hierarchical decision models is difficult

Given decision examples taken from
- existing database of past decisions or
- provided explicitly by decision-maker,
develop a corresponding model (hierarchy + functions)

Example

• What is the result of “traditional” decision-tree learning, such as See5?
• How does this table look in DEXi?
• How to create a hierarchical DEX model from this table?

Decision Tree (See5)

DEXi Table & Rules

Scales

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>lo, med, hi</td>
</tr>
<tr>
<td>X2</td>
<td>lo, med, hi</td>
</tr>
<tr>
<td>X3</td>
<td>lo, med, hi</td>
</tr>
<tr>
<td>Y</td>
<td>lo, med, hi</td>
</tr>
</tbody>
</table>

Tables

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>lo</td>
<td>lo</td>
<td>lo</td>
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<tr>
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<td>hi</td>
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</tbody>
</table>

Marko Bohanec
**Example**

- What is the result of “traditional” decision-tree learning, such as See5?
- How does this table look in DEXI?
- How to create a hierarchical DEXI model from this table?

<table>
<thead>
<tr>
<th>x1</th>
<th>x2</th>
<th>x3</th>
<th>y</th>
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<tbody>
<tr>
<td>lo</td>
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<td>lo</td>
<td>lo</td>
</tr>
<tr>
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</tr>
<tr>
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<td>hi</td>
<td>lo</td>
<td>lo</td>
</tr>
<tr>
<td>med</td>
<td>med</td>
<td>hi</td>
<td>hi</td>
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<td>hi</td>
</tr>
<tr>
<td>hi</td>
<td>hi</td>
<td>hi</td>
<td>hi</td>
</tr>
</tbody>
</table>

**Boolean Function Decomposition**

**Decomposition method HINT**

Extended Ashenhurst-Curtis decomposition of Boolean functions:
- adapted to development of multi-attribute decision models
- multi-valued attributes
- unsupervised and supervised decomposition
- partition selection measures
- generalization

Restriction:
- nominal attributes and utility

**Single-step decomposition**

**Partition matrix**

**Column compatibility**

Compatible columns

Incompatible columns