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Qualitative Multiple Criteria Models with Cycles: A Preliminary Study with Method DEX

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Objectives

A preliminary study
of introducing cycles
into DEX models

DEX (Decision EXpert):
Hierarchical qualitative (rule-based) multi-criteria method
https://en.wikipedia.org/wiki/Decision_EXpert

Outline

DEX Method:

- Principles
- Some applications

Motivation: Why introducing cycles in DEX?

- Applications in agriculture
- Cycles in other methods, e.g., ANP
- Computational power of the Conway's Game of Life

Case Study: Evaluation of Researchers

Conclusions

What is DEX?

Decision EXpert
Originates in 1980's

DEX

Multi-Criteria Decision Analysis
- modeling using criteria and utility functions
- problem decomposition and structuring
- evaluation and analysis of decision alternatives

Artificial Intelligence
Expert Systems
- qualitative (symbolic) variables
- "if-then" rules
- decision model = knowledge base
- handling imprecision and uncertainty
- transparent models, explanation

Machine Learning

Fuzzy sets
- verbal measures
- fuzzy operators

Multiattribute De
a Fuzzy Heu

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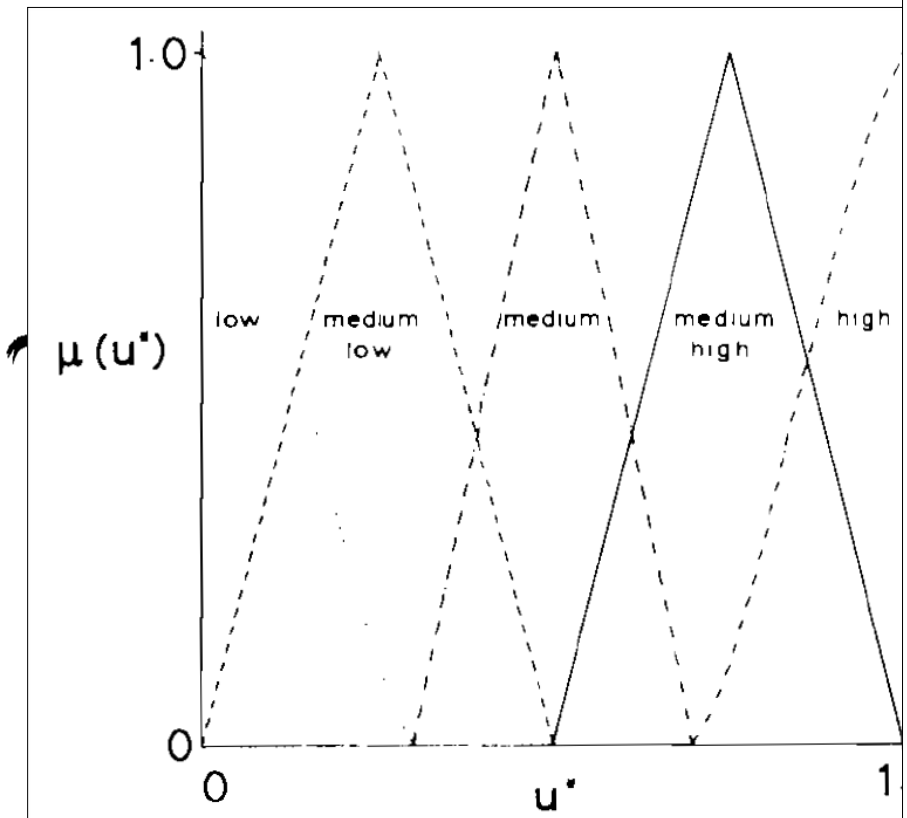


Fig. 1. Definitions of verbal utility values on U^*, [0, 1].

TABLE I
PARENTS

D1 Nature	D2 Performance	D3 Size	D4 Price	Utility
sc, non-sc	good	S	cheap	v^3 high
"	"	"	reas.	v high
"	"	"		
"	"	"	dear	low
sc, non-sc	good	med. small	cheap	v^2 high
"	"	"	reas.	high
"	"	"	dear	low
sc, non-sc	good	med. large	cheap	med.
"	"	"	reas.	med. low
"	"	"	cheap	low
sc, non-sc	med.	small	cheap	v^3 high
"	"	"	reas.	high
"	"	"	dear	v low
sc, non-sc	med.	med. small	cheap	high
"	"	"	reas.	med. high
"	"	"	dear	v low
sc, non-sc	med.	med. large	reas.	low
sc, non-sc	poor	small	reas.	med. high
sc, non-sc	good, med, poor	large	cheap, reas, dear	v^3 low

Acta Psychologica 68 (1988) 271–286
North-Holland

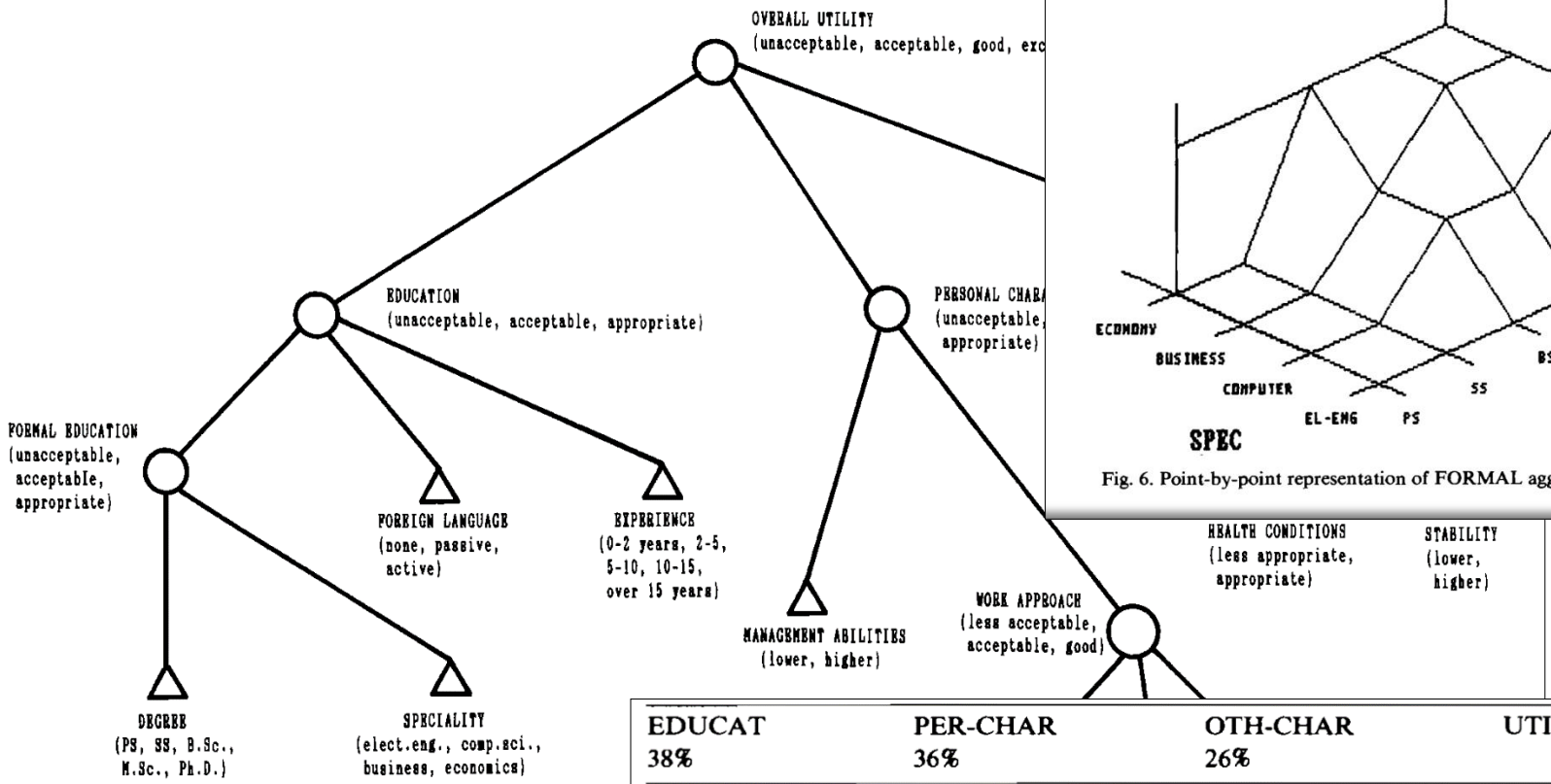


Fig. 8. An example of tree of attributes f

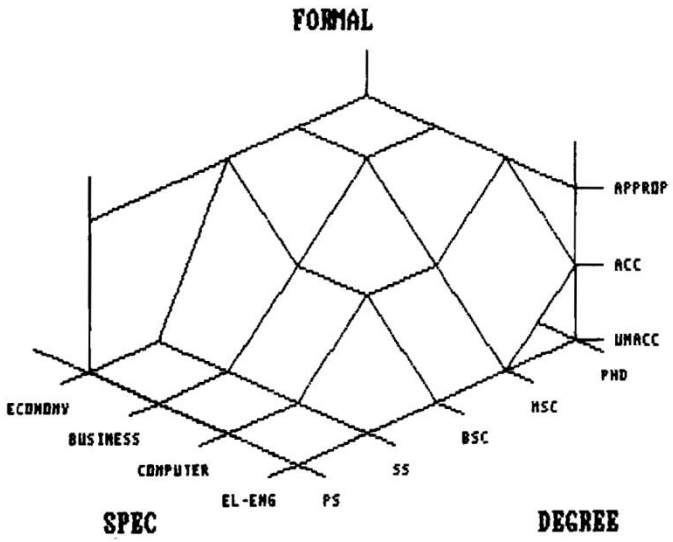


Fig. 6. Point-by-point representation of FORMAL aggregate utility function.

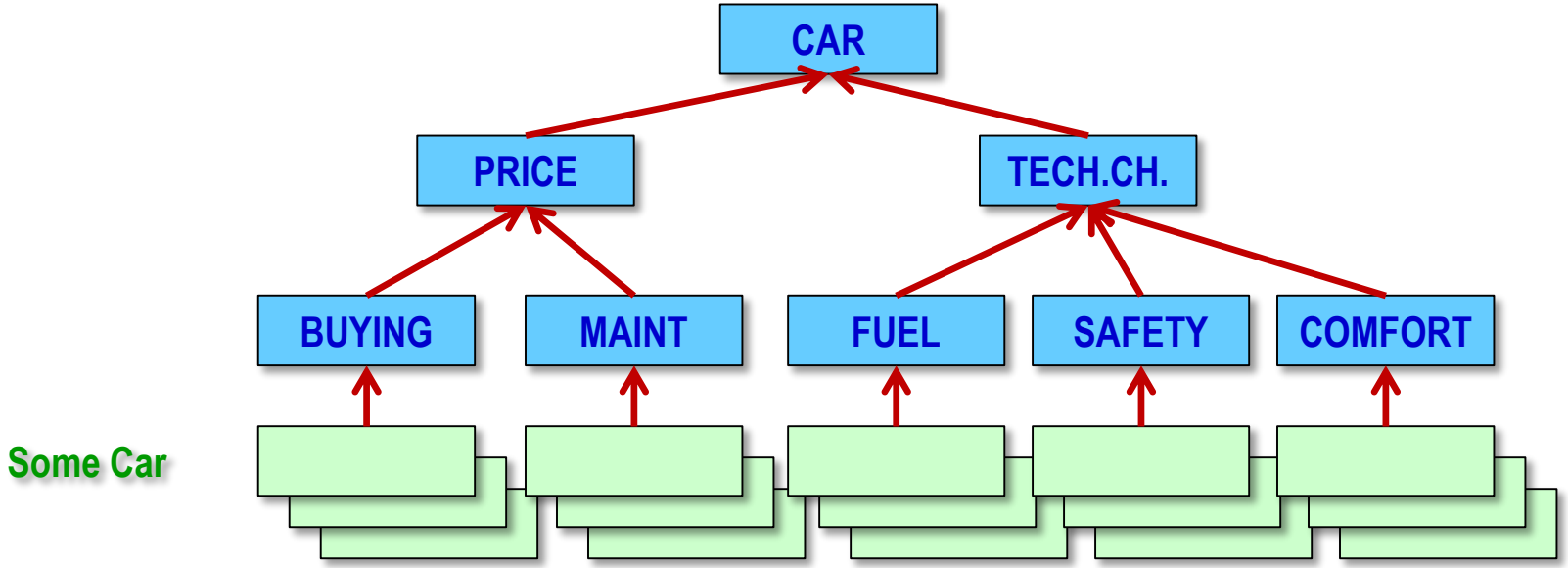
EDUCAT 38%	PER-CHAR 36%	OTH-CHAR 26%	UTILITY
< = acc	< = acc	–	unacc
–	–	unacc	unacc
unacc	–	–	unacc
–	unacc	–	unacc
acc	approp	> = acc	acc
approp	acc	> = acc	acc
approp	approp	acc	good
approp	approp	approp	exc

DEX

Method for qualitative multi-attribute modeling

DEX is similar to other multi-attribute methods:

1. Multiple attributes, hierarchically structured
2. Evaluation of alternatives: bottom-up aggregation

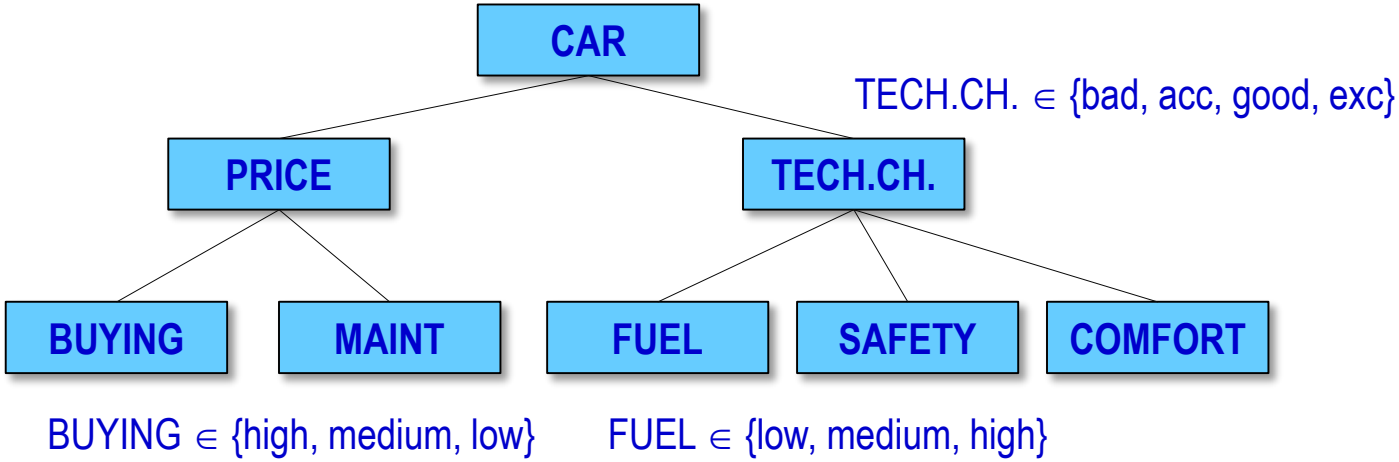


DEX

Method for <u>qualitative</u> multi-attribute modeling

DEX is different from the majority of multi-attribute methods:

1. Attributes are discrete, symbolic, qualitative

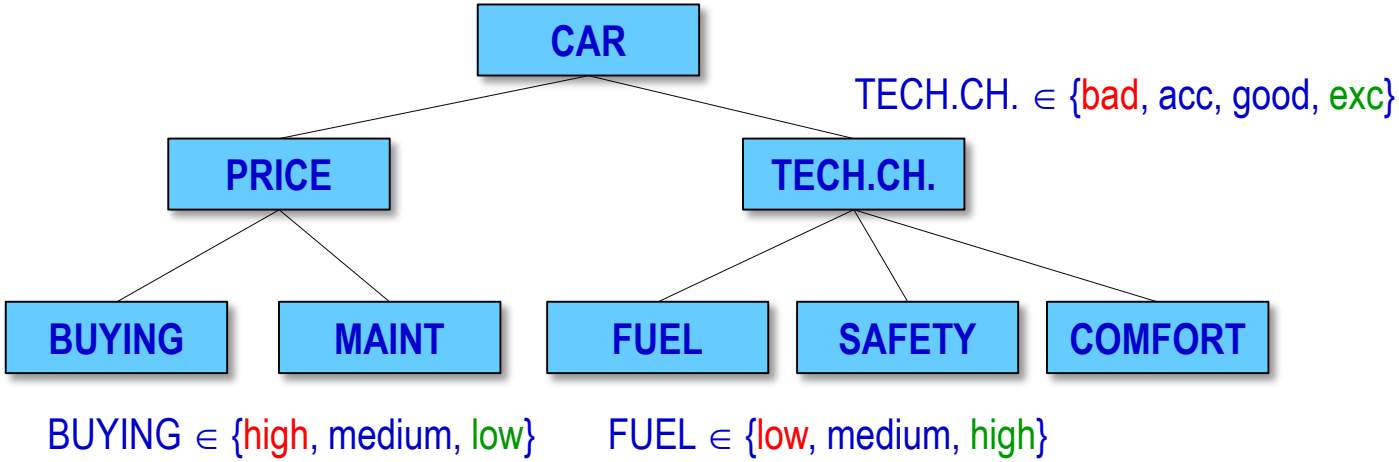


DEX

Method for qualitative multi-attribute modeling

DEX is different from the majority of multi-attribute methods:

1. Attributes are discrete, symbolic, qualitative
   Attribute scales can be unordered (categorical),
   but are typically preferentially ordered (increasing or decreasing)

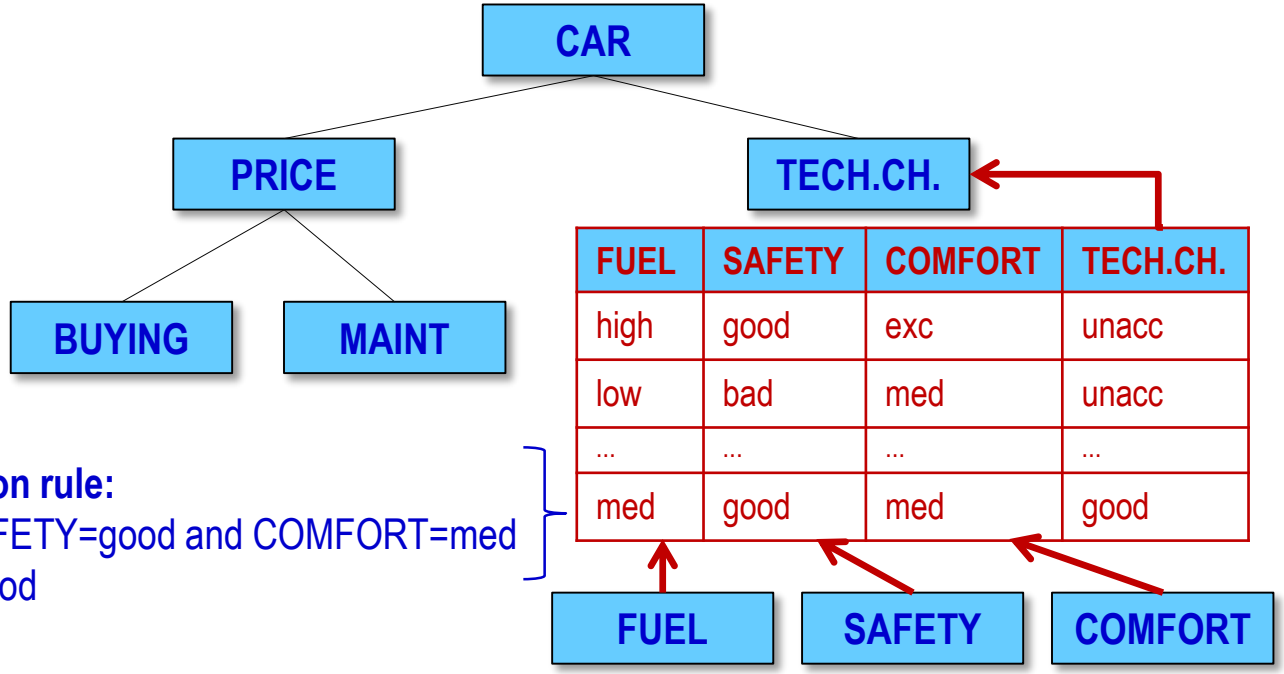


DEX

Method for <u>qualitative</u> multi-attribute modeling

DEX is different from other multi-attribute methods:

2. Evaluation of alternatives (aggregation) is defined by *decision tables*



FUEL	SAFETY	COMFORT	TECH.CH.
high	good	exc	unacc
low	bad	med	unacc
...	...	...	...
med	good	med	good

Elementary decision rule:
if FUEL=med & SAFETY=good and COMFORT=med
then TECH.CH.=good

MCDM Methods Classification

- by Decision Task ("Problematic")
  - Choosing
  - Sorting
  - Classification
  - Ranking
- by Approach ("School")
  - Value system
    Full aggregation
    "American school" — AHP, Kepner-Tregoe, MAUT, MACBETH, DEX
  - Outranking
    "French school" — ELECTRE, PROMETHEE
  - Disaggregation/Aggregation — UTA
  - Goal/Aspiration/Reference — TOPSIS
  - Rule preference model — DRSA, DEX
  - Multiobjective optimization
- by Information Type
  - Quantitative — most of the others
  - Qualitative — DEX
- by Acquisition of Preferences
  - Direct — Kepner-Tregoe, MAUT, DEX
  - Indirect
    - pairwise comparison — AHP, outranking methods
    - weight elicitation — AHP, SMART, SWING
    - questioning

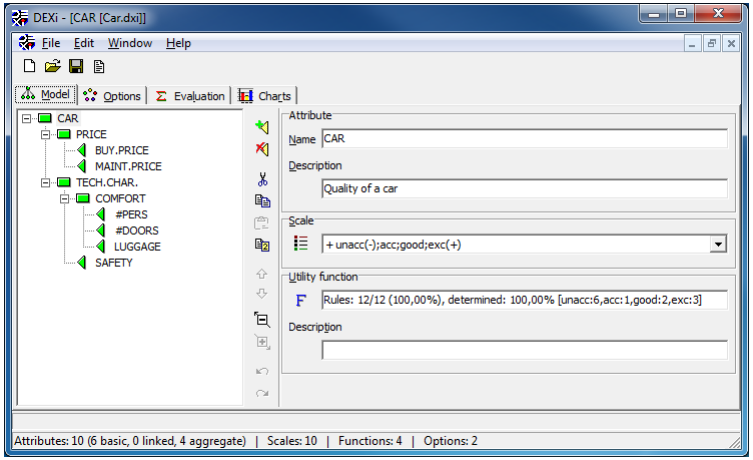
DEXi:

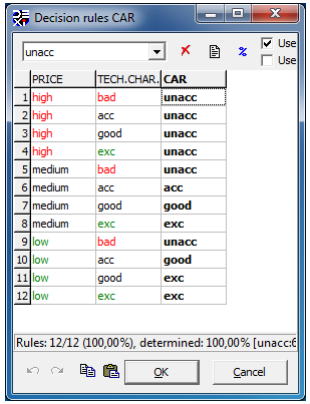
Program for Multi-Attribute Decision Making

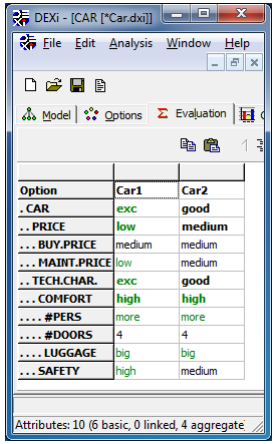
http://kt.ijs.si/MarkoBohanec/dexi.html

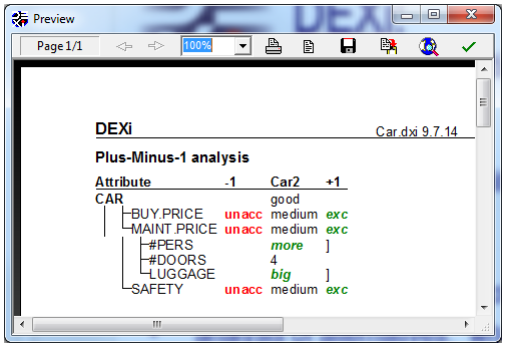
Functionality

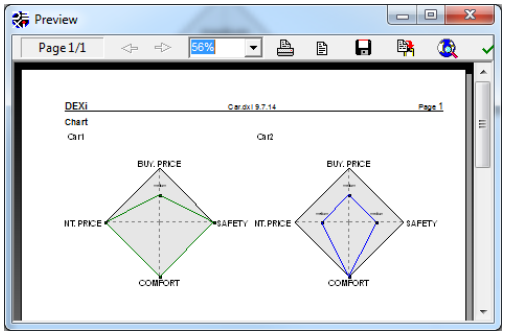
- creation and editing of qualitative DEX models:
  - model structure
  - decision tables
- acquisition and evaluation of alternatives
- analysis of alternatives: “what-if”, “±1 analysis”, comparison of alternatives, selective explanation
- tabular and graphical reports











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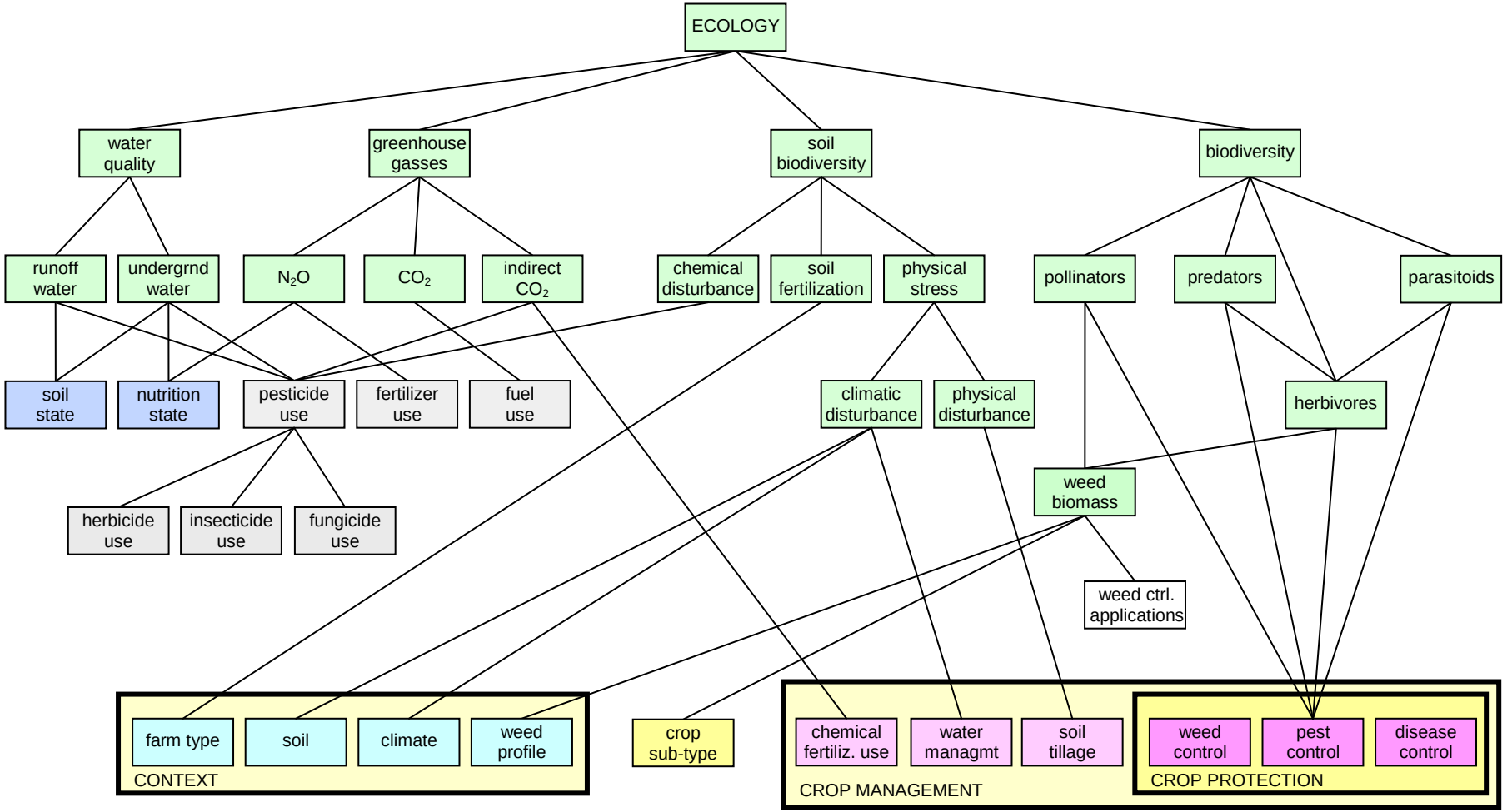
Cropping Systems: Ecology Part



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A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops.
Ecological Modelling 215, 247-261, 2008.

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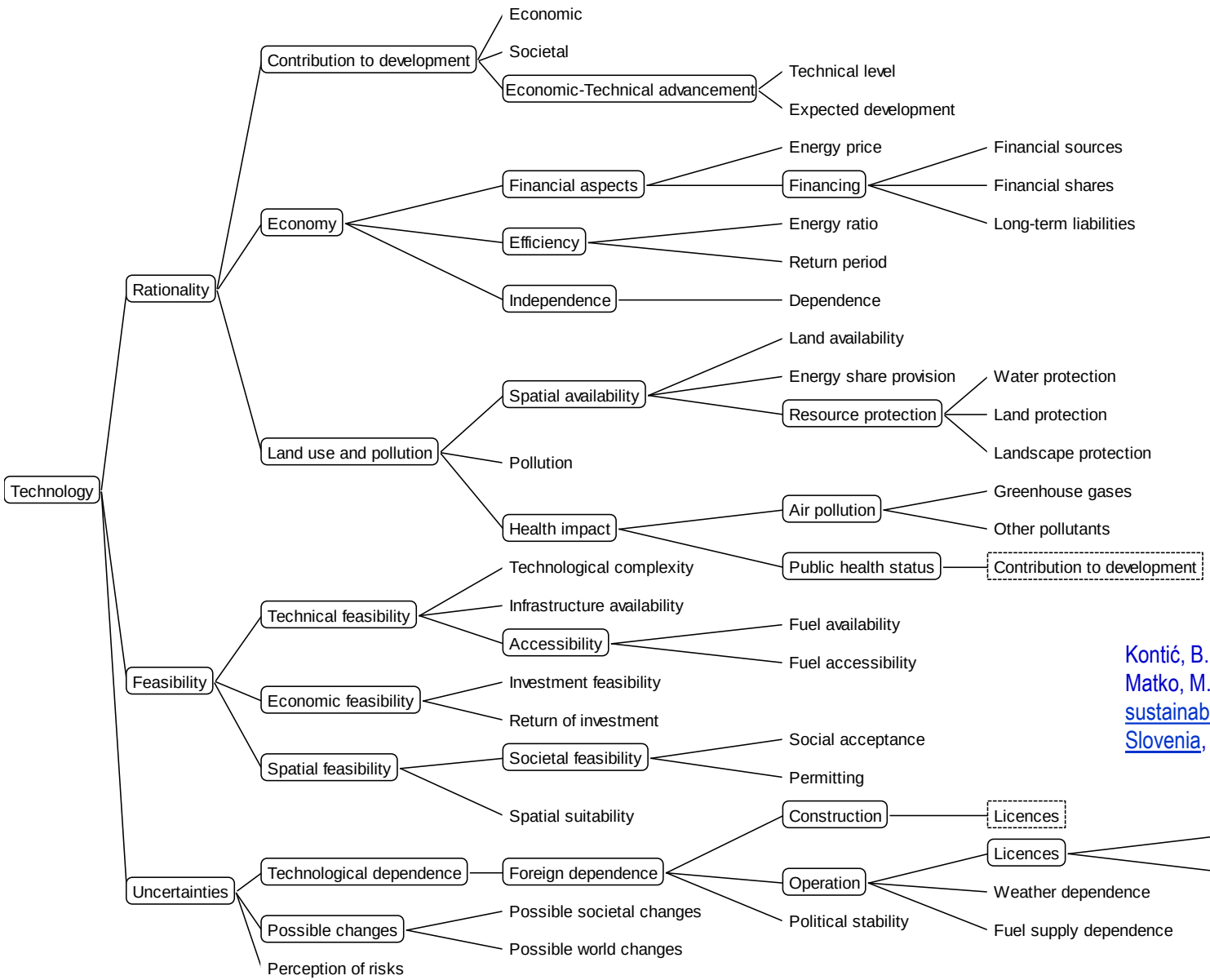
Electric Energy Production Technologies



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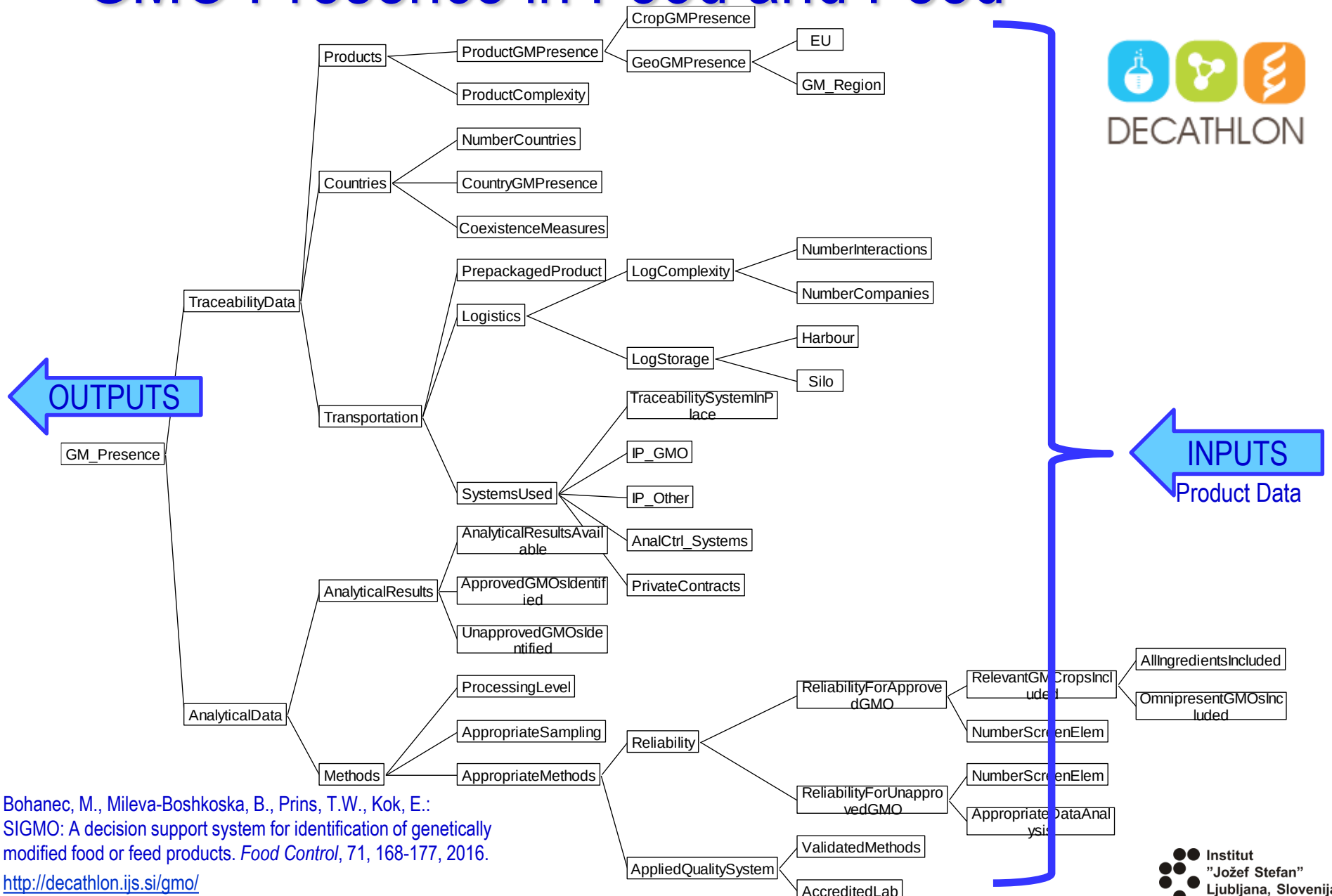
GMO Presence in Food and Feed



Bohanec, M., Mileva-Boshkoska, B., Prins, T.W., Kok, E.: SIGMO: A decision support system for identification of genetically modified food or feed products. *Food Control*, 71, 168-177, 2016.

http://decathlon.ijs.si/gmo/

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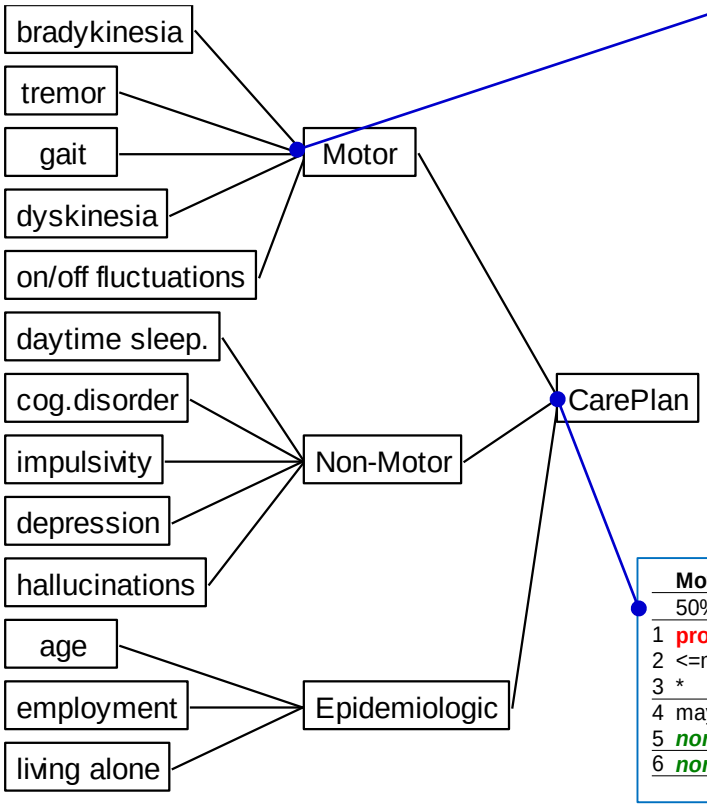
Parkinson's Disease: Medication Change

Structure



Decision rules

	bradykinesia	tremor	gait	dyskinesia	on/off fluctuations	Epidemiologic	Motor
	19%	19%	24%	13%	15%	10%	
1	problematic	problematic	*	*	*	*	problematic
2	problematic	*	*	<=problematic	*	*	problematic
3	problematic	*	*	*	problematic	*	problematic
4	problematic	*	*	*	*	active	problematic
5	*	problematic	*	<=problematic	*	*	problematic
6	*	problematic	*	*	problematic	*	problematic
7	*	problematic	*	*	*	active	problematic
8	*	*	problematic	*	*	*	problematic
9	*	*	*	severe	*	*	problematic
10	*	*	*	*	problematic	active	problematic
11	problematic	normal	normal	normal	normal	passive	maybe
12	normal	problematic	normal	normal	normal	passive	maybe
13	normal	normal	normal	problematic	*	passive	maybe
14	normal	normal	normal	>=problematic	problematic	passive	maybe
15	normal	normal	normal	problematic	normal	*	maybe
16	normal	normal	normal	normal	normal	*	normal

	Motor	Non-Motor	Epidemiologic	CarePlan
	50%	50%	0%	
1	problematic	*	*	change
2	<=maybe	<=maybe	*	change
3	*	problematic	*	change
4	maybe	normal	*	maybe
5	normal	maybe	*	maybe
6	normal	normal	*	no_change

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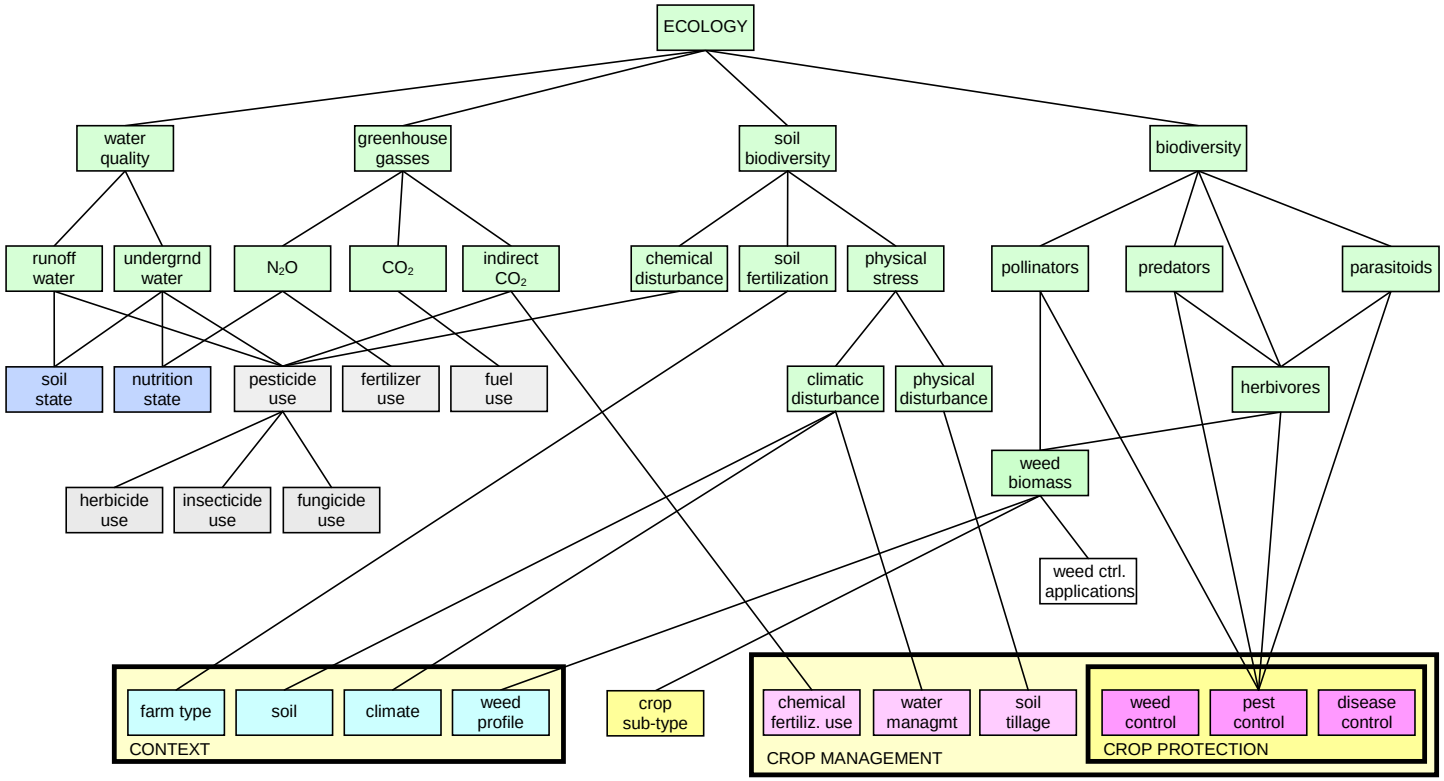
Motivation for “DEX with Cycles”

Most MCDM methods employ:

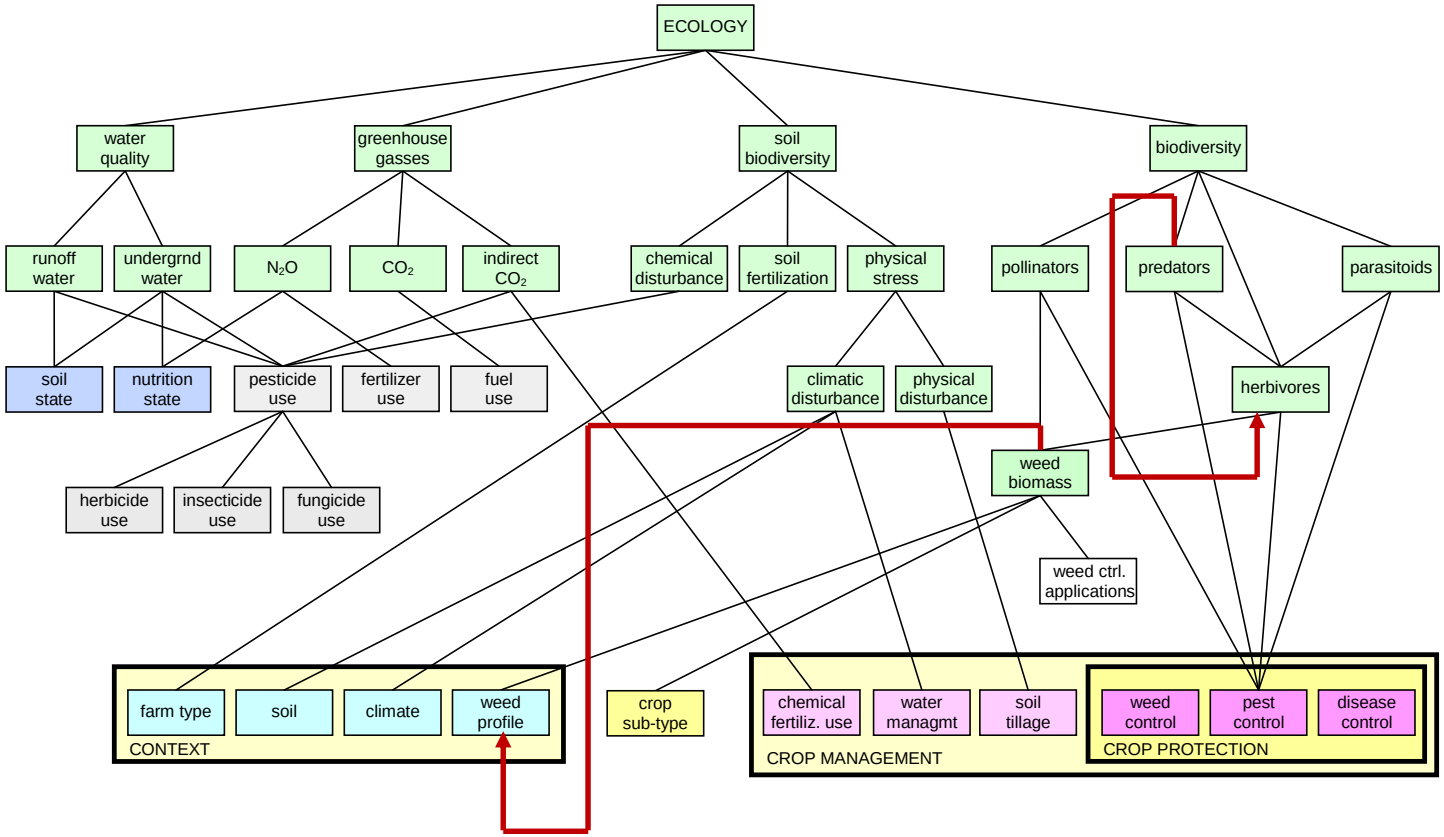
- an inputs → output(s) structure: tree or directed graph without cycles
- a step-by-step aggregation of inputs into the output(s)



Motivation for “DEX with Cycles”

However, sometimes we do need cycles in order to represent:

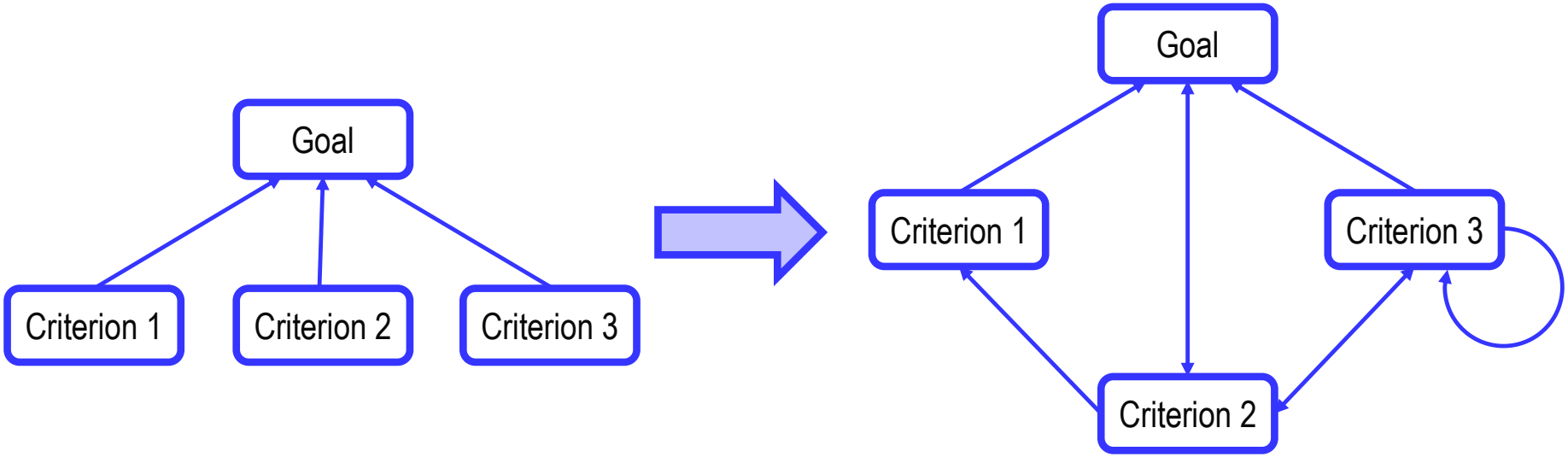
- criteria inter-dependence
- dynamic properties of the alternatives



Motivation for “DEX with Cycles”

Some MCDM methods do employ cycles:

- ANP: Analytic Network Process (Saaty, 1996)
- WINGS: Weighted Influence Non-linear Gauge System (Michnik, 2013)
- DEMATEL: Decision Making Trial and Evaluation Laboratory (Gabus & Fontela, 1972)

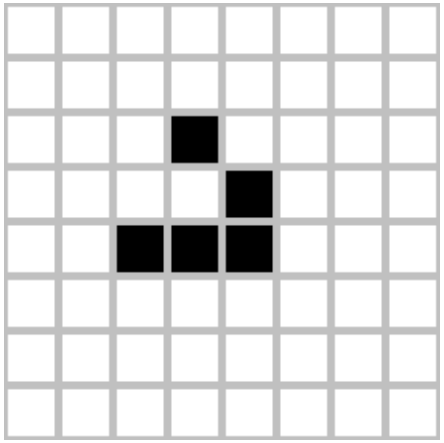


Motivation for “DEX with Cycles”

CGL: Conway’s Game of Life (Conway, 1970)

Rules (“"B3/S23"”):

	Cell Status	# Neighbours	New Status
1	live	< 2	**dead**
2	live	2 or 3	**live**
3	live	> 3	**dead**
4	dead	3	**live**
5	dead	not 3	**dead**

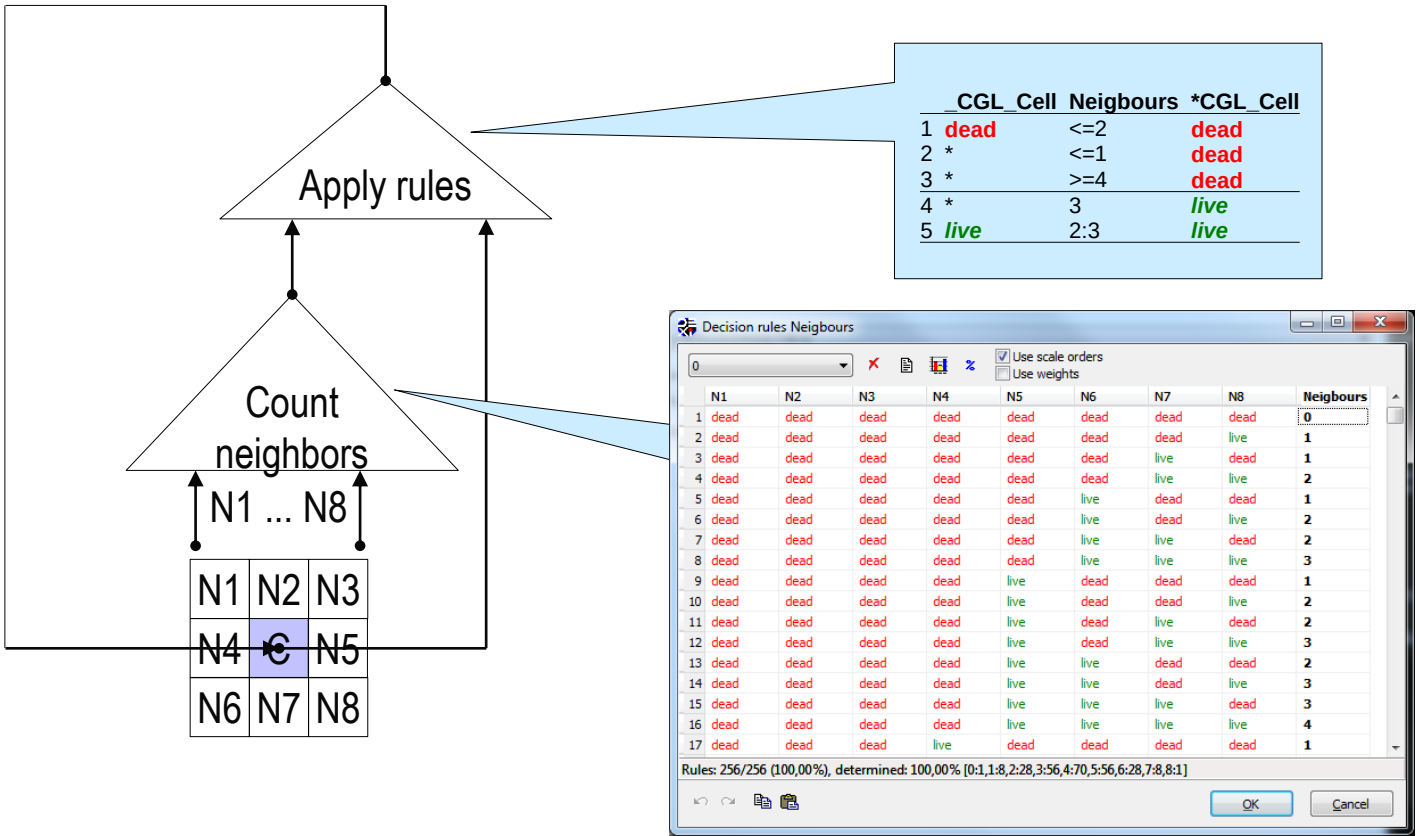


Wikipedia: (Camargo, 2008)

https://en.wikipedia.org/wiki/File:Gospers_glider_gun.gif

Motivation for “DEX with Cycles”

1. CGL is Turing complete: As powerful as any computer with unlimited memory and no time constraints (Berlekamp et al., 1982)
2. CGL can be implemented with DEX models with cycles



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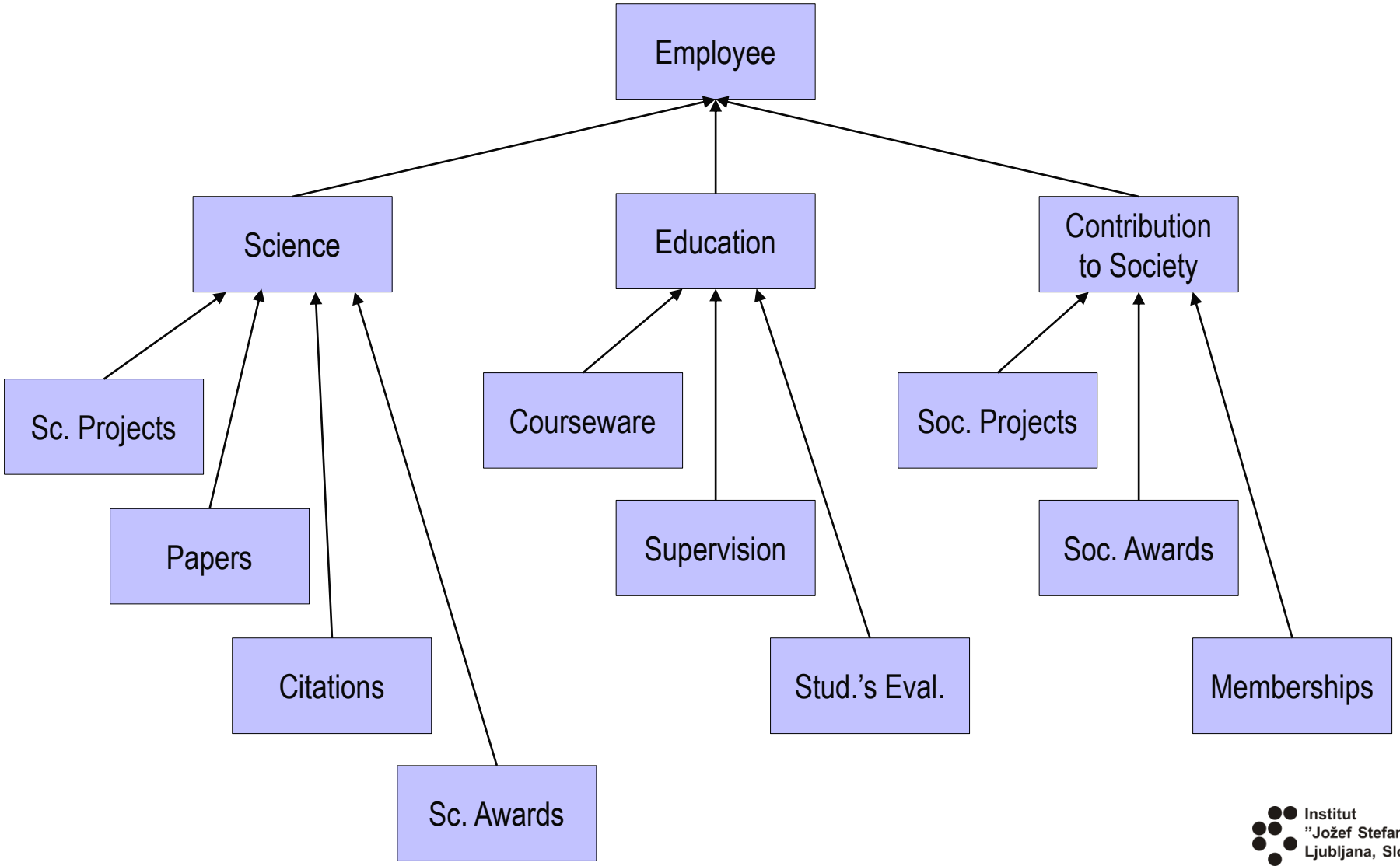
Case Study: Evaluating Researchers

Goal: Assess the quality and perspective of seven university researchers

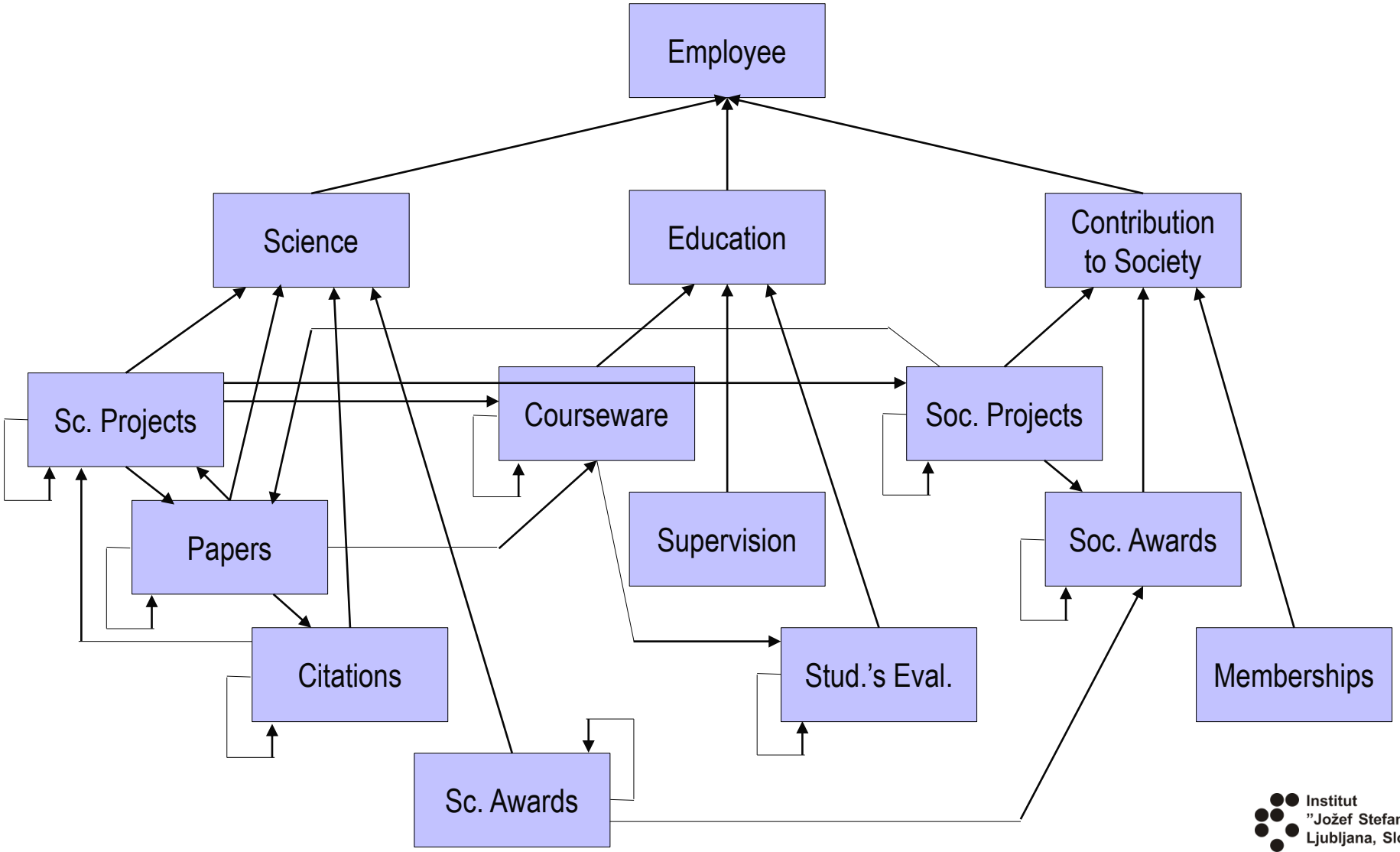
Methods: “DEX with Cycles” and ANP

	E1	E2	E3	E4	E5	E6	E7
ScienceProjects	2 (univ, national), associate	2 (univ, national), associate 1 (univ), leader	2 (univ, national), associate	3 (univ, national, international), associate	3 (2 univ + national)	4 (univ + national)	1 (univ)
Papers	1 wos, 3 journals, 18 conferences	40 conference papers, 5 journal	2 wos, 20 papers on conferences, 5 journal	10 conferences, 1 journal	17 conference papers, 5 journal papers, 2 WOS, 1 CC	43 conference papers + 10 journal papers	5 conference and 1 journal paper
Citations	55 (google)	152 (google)	16 (google)	21 (google)	70 (google)	260	26
ScientificAwards	No	5 best paper awards on conferences	No	No	Yes, 2 prizes	Yes, 1	Yes, 1
Courseware	Presentations for laboratory exercises	Presentations for laboratory exercises	Presentations for seminars	Notes for laboratory exercises, 1 book	Teaching materials for seminars	Presentations for laboratory exercises	Teaching materials for seminars and e-course
StudentEvaluation	3.5	3	4.6	4	4.6	4.4	4.6
Supervision	9 bachelor	12 bachelor	14 bachelor	6 bachelor, 1 master	10 bachelor, 2 master, 2 candidates for rector’s award (1 win)	10 bachelor	3 bachelor
Membership	3 scientific, 2 social	3 scientific, 2 social	3 scientific, 5 social	2 scientific, 0 social	3 scientific, 3 social	3 scientific	2 scientific, 2 social
SocialProjects	No	Yes, 2	Yes, 1	No	Yes, 3	No	1
SocialAwards	No	Yes, 1	No	No	No	Yes, 2	Yes, 1

DEX Model Structure



DEX Model Structure with Cycles



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Implementation

Indirectly in DEXi software (http://kt.ijs.si/MarkoBohanec/dexi.html):

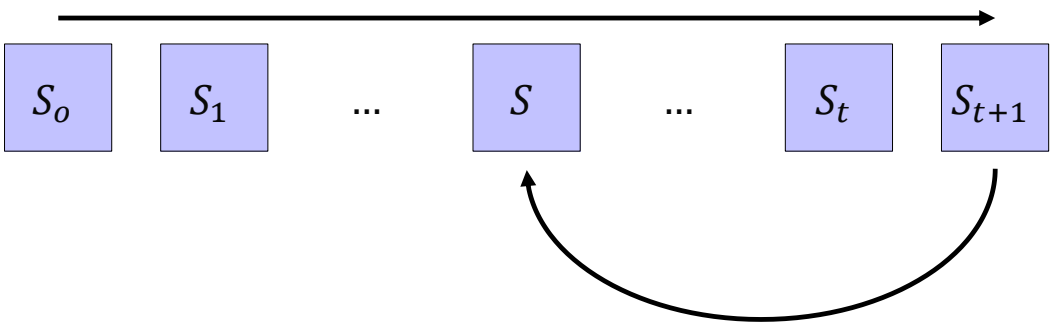
- Converting models with cycles to hierarchies:
  splitting a dynamic attribute "Name" to: "_Name" (input) and "*Name" (output)
- Implementing an evaluation algorithm similar to CGL:

set initial values to all input variables → S_0

repeat

$S_{t+1} \leftarrow$ Evaluate(S_t)

until $\exists S \in \{S_0, \dots, S_t\}$: $S_{t+1} = S$



Model in DEXi

Model structure and scales

Attribute	Scale
Employee	very_low; low; med; high; *very_high*
├**Science**	very_low; low; med; high; *very_high*
│├***ScientificProjects**	none; low; average; good; *exc*
│└*_ScientificProjects*	none; low; average; good; *exc*
│└*_Papers*	low; acc; *exc*
│└*_Citations*	low; med; *high*
│├***Papers**	low; acc; *exc*
│└*_Papers*	low; acc; *exc*
│└*_ScientificProjects*	none; low; average; good; *exc*
│└*_SocialProjects*	none; low; average; good; *exc*
│└***Citations**	low; med; *high*
│└_Citations	low; med; *high*
│└*_Papers*	low; acc; *exc*
│└***ScientificAwards**	none; low; *high*
│└*_ScientificAwards*	none; low; *high*
├**Education**	very_low; low; med; high; *very_high*
│├***Courseware**	none; low; average; good; *exc*
│└*_Courseware*	none; low; average; good; *exc*
│└*_ScientificProjects*	none; low; average; good; *exc*
│└_Papers	low; acc; *exc*
│└***StudentsEvaluation**	low; med; *high*
│└_StudentsEvaluation	low; med; *high*
│└_Courseware	none; low; average; good; *exc*
│└Supervision	none; average; *exceptional*
└**ContributionToSociety**	very_low; low; med; high; *very_high*
│├Memberships	low; med; *high*
│├***SocialProjects**	none; low; average; good; *exc*
│└*_SocialProjects*	none; low; average; good; *exc*
│└_ScientificProjects	none; low; average; good; *exc*
│└***SocialAwards**	none; low; *high*
│└_SocialAwards	none; low; *high*
│└_SocialProjects	none; low; average; good; *exc*
│└_ScientificAwards	none; low; *high*

Some rules

	_Citations	_Papers	*Citations
1	low	<=acc	low
2	<=med	low	low
3	low	*exc*	med
4	med	acc	med
5	*high*	low	med
6	>=med	*exc*	*high*
7	*high*	>=acc	*high*

	_StudentsEvaluation	_Courseware	*StudentsEvaluation
1	low	<=average	low
2	<=med	none	low
3	low	>=good	med
4	<=med	good	med
5	med	low:good	med
6	>=med	low	med
7	*high*	<=low	med
8	>=med	*exc*	*high*
9	*high*	>=average	*high*

Evaluation: Employee E1

Attribute	[0] E1	[1]*E1
Employee	**very_low**	**very_low**
Science	med	med
***ScientificProjects**	average	average
_ScientificProjects	average	average
_Papers	acc	acc
_Citations	**low**	**low**
***Papers**	acc	acc
_Papers	acc	acc
_ScientificProjects	average	average
_SocialProjects	**none**	**none**
***Citations**	**low**	**low**
_Citations	**low**	**low**
_Papers	acc	acc
***ScientificAwards**	**none**	**none**
_ScientificAwards	**none**	**none**
Education	low	low
***Courseware**	low	low
_Courseware	low	low
_ScientificProjects	average	average
_Papers	acc	acc
***StudentsEvaluation**	med	med
_StudentsEvaluation	med	med
_Courseware	low	low
Supervision	average	average
ContributionToSociety	**very_low**	**very_low**
Memberships	med	med
***SocialProjects**	**none**	**none**
_SocialProjects	**none**	**none**
_ScientificProjects	average	average
***SocialAwards**	**none**	**none**
_SocialAwards	**none**	**none**
_SocialProjects	**none**	**none**
_ScientificAwards	**none**	**none**

Evaluation: Employee E2

Attribute	[0] E2	[1] E2	[2] E2	[3] E2	[4] E2	[5] E2	[6] E2	[7]*E2
Employee	med	med	med	high	*very_high*	*very_high*	*very_high*	*very_high*
├─**Science**	high	high	high	*very_high*	*very_high*	*very_high*	*very_high*	*very_high*
│ ├─***ScientificProjects**	good	good	good	*exc*	*exc*	*exc*	*exc*	*exc*
│ │ ├─***_ScientificProjects***	good	good	good	good	*exc*	*exc*	*exc*	*exc*
│ │ ├─***_Papers***	acc	acc	acc	*exc*	*exc*	*exc*	*exc*	*exc*
│ │ └─***_Citations***	med	med	med	med	*high*	*high*	*high*	*high*
│ ├─***Papers**	acc	acc	*exc*	*exc*	*exc*	*exc*	*exc*	*exc*
│ │ ├─***_Papers***	acc	acc	acc	*exc*	*exc*	*exc*	*exc*	*exc*
│ │ ├─***_ScientificProjects***	good	good	good	good	*exc*	*exc*	*exc*	*exc*
│ │ └─***_SocialProjects***	average	good	*exc*	*exc*	*exc*	*exc*	*exc*	*exc*
│ ├─***Citations**	med	med	med	*high*	*high*	*high*	*high*	*high*
│ │ ├─_Citations	med	med	med	med	*high*	*high*	*high*	*high*
│ │ └─***_Papers***	acc	acc	acc	*exc*	*exc*	*exc*	*exc*	*exc*
│ └─***ScientificAwards**	*high*	*high*	*high*	*high*	*high*	*high*	*high*	*high*
│ └─***_ScientificAwards***	*high*	*high*	*high*	*high*	*high*	*high*	*high*	*high*
├─**Education**	low	low	low	low	*very_high*	*very_high*	*very_high*	*very_high*
│ ├─***Courseware**	average	average	average	good	*exc*	*exc*	*exc*	*exc*
│ │ ├─***_Courseware***	low	average	average	average	good	*exc*	*exc*	*exc*
│ │ ├─***_ScientificProjects***	good	good	good	good	*exc*	*exc*	*exc*	*exc*
│ │ └─_Papers	acc	acc	acc	*exc*	*exc*	*exc*	*exc*	*exc*
│ ├─***StudentsEvaluation**	low	low	low	low	med	*high*	*high*	*high*
│ │ ├─_StudentsEvaluation	low	low	low	low	low	med	*high*	*high*
│ │ └─_Courseware	low	average	average	average	good	*exc*	*exc*	*exc*
│ └─Supervision	average	average	average	average	average	average	average	average
└─**ContributionToSociety**	high	*very_high*	*very_high*	*very_high*	*very_high*	*very_high*	*very_high*	*very_high*
├─Memberships	med	med	med	med	med	med	med	med
├─***SocialProjects**	good	*exc*	*exc*	*exc*	*exc*	*exc*	*exc*	*exc*
│ ├─***_SocialProjects***	average	good	*exc*	*exc*	*exc*	*exc*	*exc*	*exc*
│ └─_ScientificProjects	good	good	good	good	*exc*	*exc*	*exc*	*exc*
└─***SocialAwards**	*high*	*high*	*high*	*high*	*high*	*high*	*high*	*high*
├─_SocialAwards	low	*high*	*high*	*high*	*high*	*high*	*high*	*high*
├─_SocialProjects	average	good	*exc*	*exc*	*exc*	*exc*	*exc*	*exc*
└─_ScientificAwards	*high*	*high*	*high*	*high*	*high*	*high*	*high*	*high*

Evaluation: Employee E7

Attribute	[0] E7	[1] E7	[2] E7	[3] E7	[4] E7	[5]*E7
Employee	very_low	very_low	very_low	very_low	very_low	very_low
├**Science**	very_low	very_low	very_low	very_low	very_low	very_low
│├***ScientificProjects**	none	none	none	none	none	none
││├***_ScientificProjects***	low	none	none	none	none	none
││├***_Papers***	low	low	low	low	low	low
││└***_Citations***	low	low	low	low	low	low
│├***Papers**	low	low	low	low	low	low
││├***_Papers***	low	low	low	low	low	low
││├***_ScientificProjects***	low	none	none	none	none	none
││└***_SocialProjects***	low	low	low	low	low	low
│├***Citations**	low	low	low	low	low	low
││├_Citations	low	low	low	low	low	low
││└***_Papers***	low	low	low	low	low	low
│└***ScientificAwards**	low	low	low	low	low	low
│└***_ScientificAwards***	low	low	low	low	low	low
├**Education**	high	med	low	very_low	very_low	very_low
│├***Courseware**	average	low	none	none	none	none
││├***_Courseware***	good	average	low	none	none	none
││├***_ScientificProjects***	low	none	none	none	none	none
││└_Papers	low	low	low	low	low	low
│├***StudentsEvaluation**	***high***	***high***	med	low	low	low
││├_StudentsEvaluation	***high***	***high***	***high***	med	low	low
││└_Courseware	good	average	low	none	none	none
│└Supervision	average	average	average	average	average	average
└**ContributionToSociety**	low	low	low	low	low	low
├Memberships	med	med	med	med	med	med
├***SocialProjects**	low	low	low	low	low	low
│├***_SocialProjects***	low	low	low	low	low	low
│└_ScientificProjects	low	none	none	none	none	none
└***SocialAwards**	low	low	low	low	low	low
├_SocialAwards	low	low	low	low	low	low
├_SocialProjects	low	low	low	low	low	low
└_ScientificAwards	low	low	low	low	low	low

Conclusions

Idea:

- Introduce cycles to qualitative DEX models
- in order to model criteria inter-dependence and dynamic properties of alternatives.

Findings:

- Introducing cycles to DEX is feasible
- and promises to boost their theoretical computational power.
- Cycles break the convenient input → output structure of MCDM models,
- and there are several possible approaches to the evaluation.
- Current implementation: hierarchies of input-output pairs and a CGL-like iteration

Further work:

- Learning on real-life use cases, comparing with other methods, e.g. ANP
- Studying theoretical properties, e.g. convergence, oscillations

2018 Open Conference of the IFIP WG 8.3 on Decision Support Systems (IFIP 2018 DSS)

to be held during 13-15 June 2018 in Ljubljana, Slovenia.

The theme of the conference is ***"DSS Research Delivering High Impacts to Business and Society"***

http://ifip2018dss.ijs.si/

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Thank you

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