

Using spatial analysis in decision making

Techniques for spatial data analysis

Last week

- We looked at **processing errors** that resulted from errors in outputs
- For **uncorrelated errors and local functions** we saw how **simple error analysis** could estimate absolute (and thus relative errors) in a given output
- For more complex processes, and **focal or global functions**, we used **Monte Carlo Simulation** to estimate uncertainty, for example as a result of DEM uncertainty
- I demonstrated the importance of considering **spatially correlated error** in such MCS
- Finally, we looked at the use of **fuzzy sets** as a means of reasoning with **vague or uncertain information**

Learning objectives

You will:

- **know**, and **can illustrate**, the **differences** between **multi-criteria** and **multi-objective approaches** to spatial planning;
- for a given problem, **be able** to **suggest an MCE approach to finding optimal locations**;
and
- will be able to **illustrate** how GIS can be integrated as **a part** of the **spatial decision making process**.

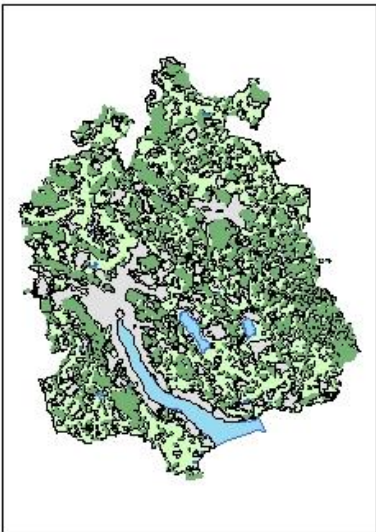
Outline

- We are going to look at how GIS can be used to help us make **decisions**
- Introduce a range of **multi-criteria evaluation** techniques and look at their use through a very simple example – this material reinforces what you saw in GITTA suitability lesson (**GEO243**) – you should revisit it...
- Examine how these techniques can be used to aid decision making through a **real-world example...**

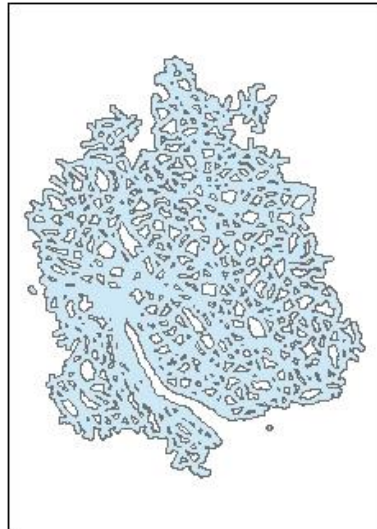
Simple Boolean suitability analysis

- We want to find potential locations for learning to ski in Canton Zurich
- We need to meet the following criteria
 - Land cover must be “open”
 - Must be within 400m of a road (access)
 - Slope must be between 10° and 20° (steep enough to ski, but not too steep)
- If **any one** of these rules is not met the site is **not suitable**
- We overlay the three datasets and then perform an AND operation on the attributes of the new polygons to find a suitable area

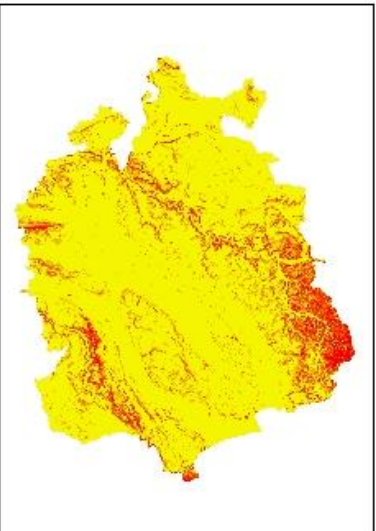
These criteria are made up 😊!



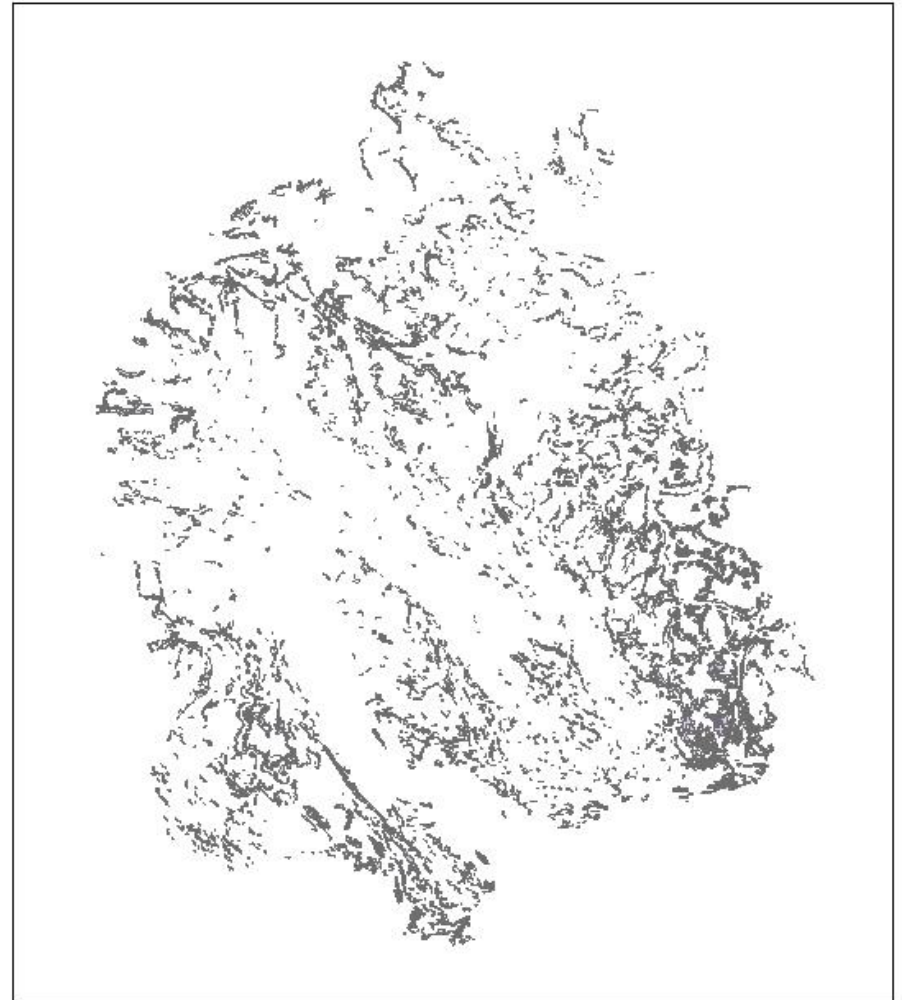
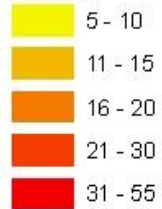
Landcover



Within 400m of roads



Slope



Areas within 400m of roads, which are open and between 10 and 20 degrees

Multi-criteria evaluation

- This example identifies areas that **simultaneously** meet all specified criteria (through a Boolean rule)
- It **does not suggest** which of those areas are most likely to be the best sites for skiing

Multi-criteria evaluation (MCE) techniques are required to evaluate the suitability of sites falling within the feasible areas identified using standard GIS overlay procedures.

Carver, 1991

What is MCE?

- MCE are a suite of techniques used in analysing the **trade-offs** between **choice alternatives** with different impacts
- MCE aims to identify the **best compromise sites** from a set of possible alternatives
- MCE techniques developed in environmental economics and were used **aspatially**
- They have been adapted for use in GIS to provide a **more formal basis** for aiding decision making

Basic ideas of MCE

"investigate a number of choice possibilities in the light of multiple criteria and conflicting objectives"

Voogd, 1983, p.21

Criterion: *"... a rule to test the desirability of alternative decisions"*

Attribute *"... properties of elements of a real-world geographical system"*

Objective: *"... a statement about the desired state of a spatial system"*

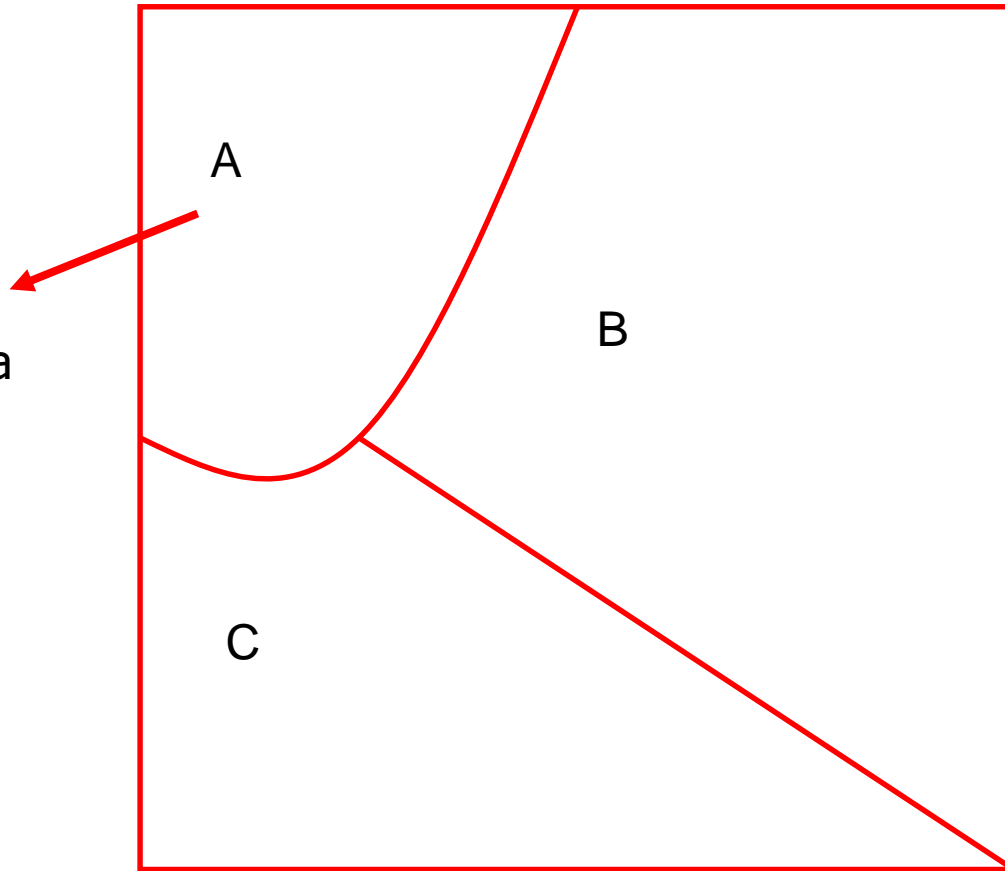
Malczewski, 1999

So what does this mean?

- MCE uses **criteria** to identify the sites described by their **attributes** which best meet an **objective**
- For example:
 - **Objective:** I need a plot to build a housing estate (and I am a developer)
 - **Criteria:** The houses must be near cinemas, far from main roads and near public transport
 - **Attributes:** The data I will use to describe these criteria at different sites (e.g. distance from road)
- In this case the criteria **clearly conflict** – somewhere **far** from main roads is less likely to be **near** public transport

Site A

NearCinema
NearBus
FarRoad



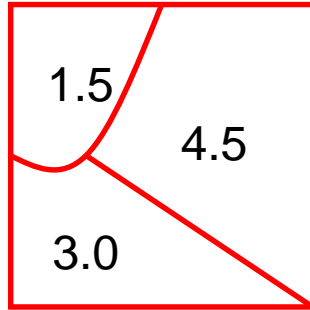
The following examples all use the same data – we have three possible sites each of which have attributes describing nearness to cinemas and public transport and distance from major roads

Which site is most suitable?

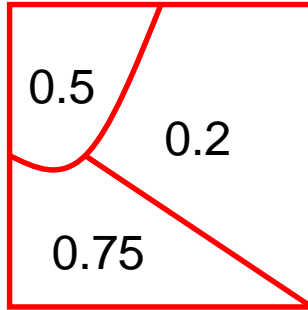
Boolean overlay

- **Criteria** – a place is either suitable or not, e.g. must be $< 1\text{km}$ from a cinema
- **Solution** is the area which meets all our criteria
- Can often leave a very small sub-set of data, but **doesn't provide any ranking**
- Useful when we have very many sites to screen to do an **initial screening** (get rid of the places that are unfeasible) and have **legal constraints**

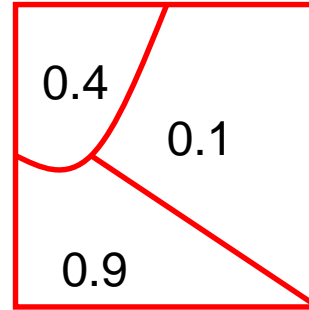
Distance from
cinema (km)



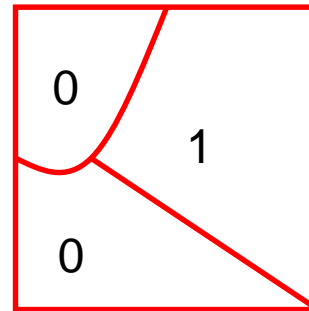
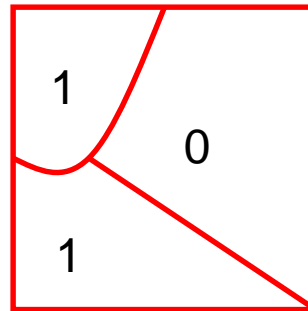
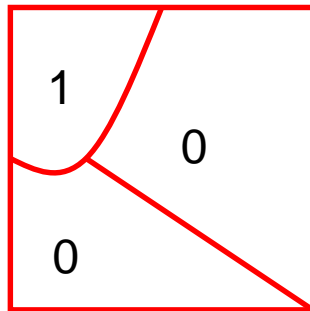
Distance from
road (km)



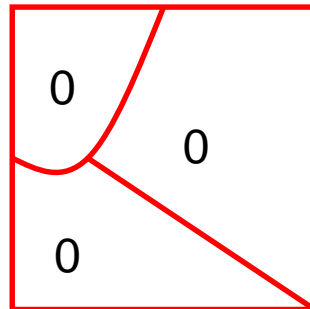
Distance from
public transport (km)



Houses must be
less than 2km from cinema **and**
more than 300m from road **and**
within 200m of public transport



Boolean
layers



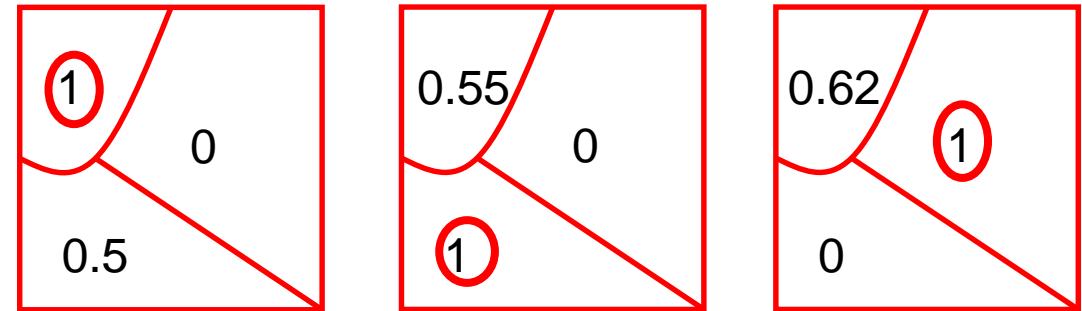
Intersection

Weighted linear combination

- **Standardise** the range of all our variables (note that highest value is assumed most suitable)
- **Weight** them according to **perceived importance**
- **Add the layers** and derive a map of nominal suitability
- The location with the **highest score** is the **most suitable**
- Assume that **suitability is linear** with respect to scores and that **variables are independent**

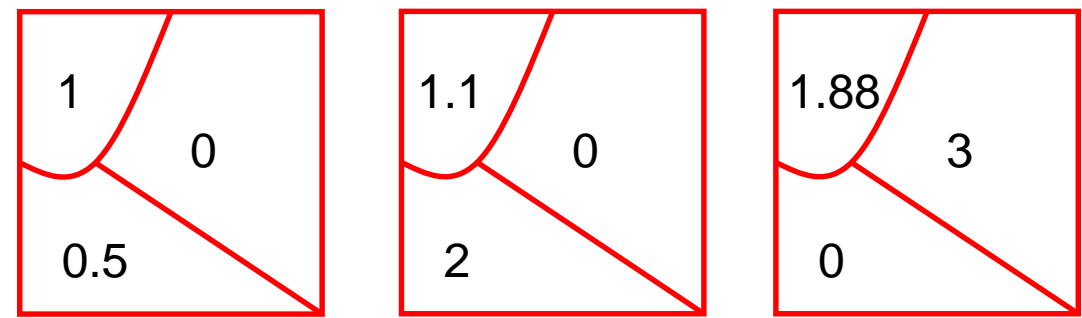


Layers have values between 0 and 1, 1 is most suitable, 0 least

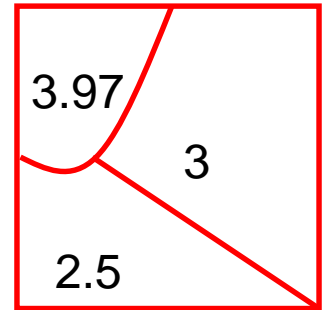


Standardised layers

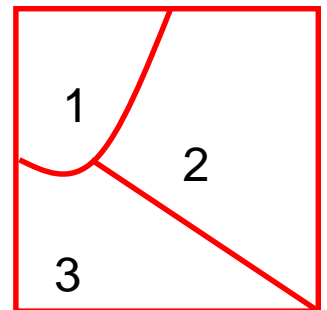
Weights are 1 for cinema, 2 for roads and 3 for public transport



Weighted



Sum of layers
→




Ranking

Note, standardising between 0 and 1 has a different effect to standardising between 1 and 2. Why?

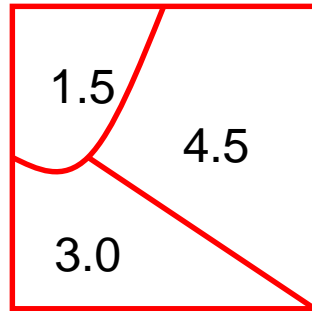
Analytic hierarchy process

- Provides a **more formal basis** for assigning the weights – take values for relative importance between 1 and 9
- 1 means variables have same importance, 9 one variable is absolutely more important than another
- We take the reciprocal if a variable is less important
- Weights are **$1/(\Sigma \text{column})$** and sum to 1
- Here, public transport is **absolutely more important** than cinemas

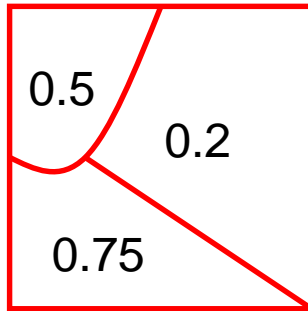
	<u>Cinema</u>	<u>Road</u>	<u>Public transport</u>		Weights
Cinema	1	1/2	1/9		Cinema 0.083 (i.e. $1/(1 + 2 + 9)$)
Roads	2	1	1/3		Roads 0.222
Public transport	9	3	1		Public transport 0.692

 Only need this side... See Jones for more on this...

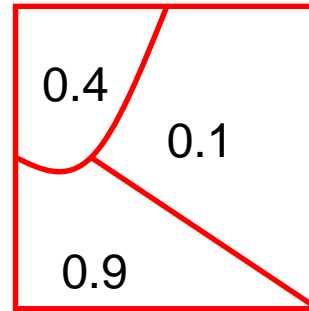
Distance from
cinema



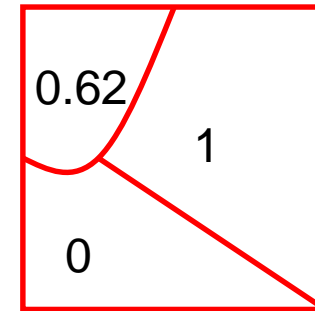
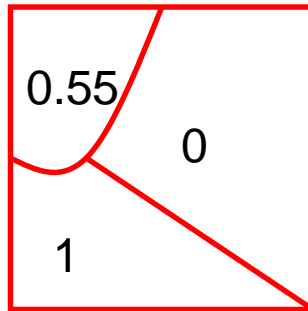
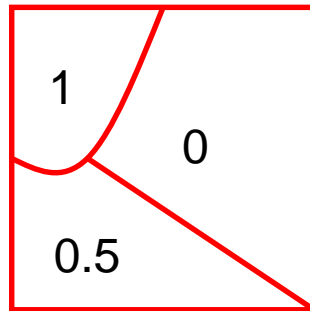
Distance from
road



Distance from
public transport

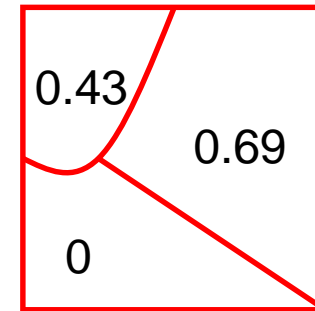
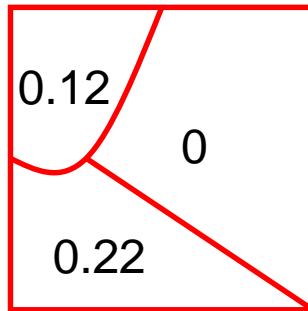
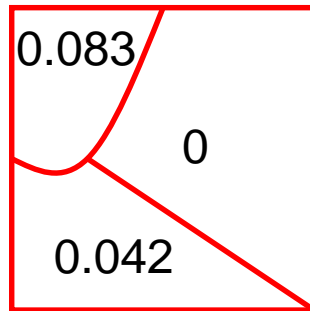


Layers have
values between
0 and 1, 1 is
most suitable,
0 least



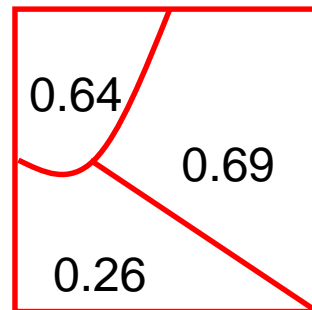
Standardised
layers

Weights are as
calculated on
last slide

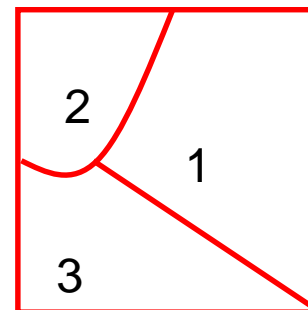


Weighted

Sum of
layers



Ranking



Ideal point methods

- These methods consider the **distance** of a solution from an ideal solution
- We **identify an ideal solution** and then calculate the distance of our alternatives from it using a distance metric

$$s_{i+} = \left[\sum_j w_j^p (v_{ij} - v_{+j})^p \right]^{1/p}$$

where s_{i+} is the separation of the i th alternative from the ideal point

w_j^p is the weight of attribute j

v_{ij} is the standardised value of attribute j for site i

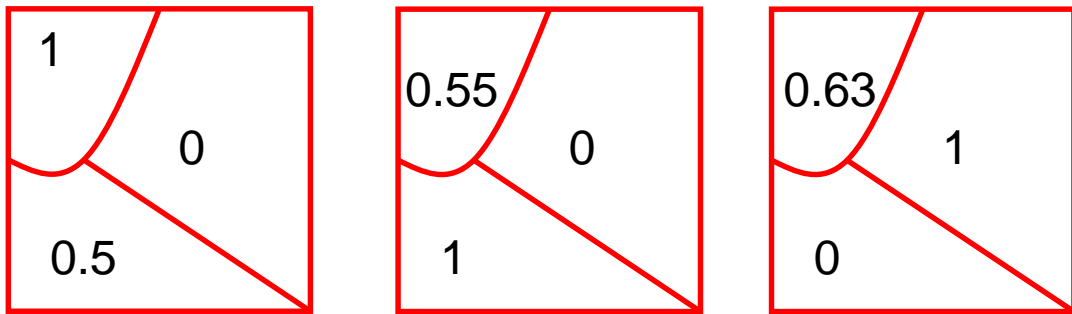
v_{+j} is the ideal value of attribute j

p is a power parameter between 1 and ∞

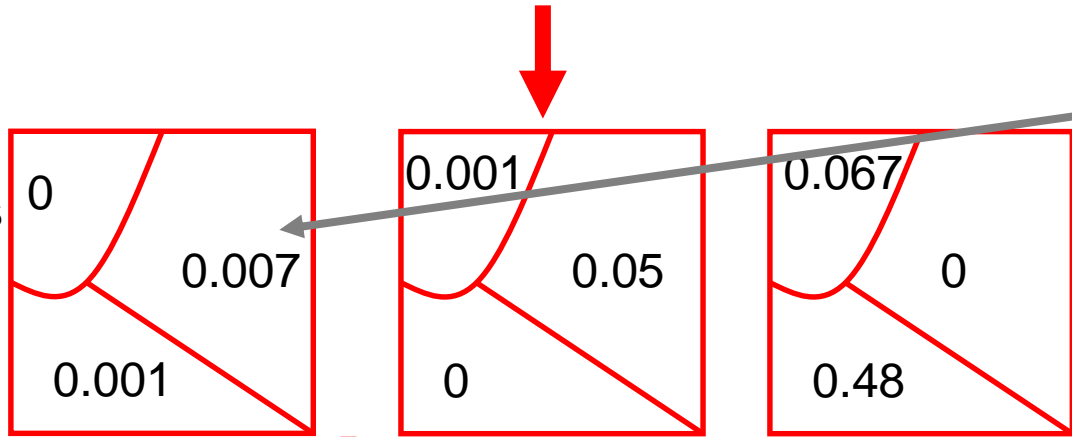
More on the ideal point method

- The power parameter p determines how we **measure distance** – $p=1$ - Manhattan distance and $p=2$ - Euclidean distance in **criteria space**
- As p increases the importance of small differences increases
- There are different ways to implement the method – one of these takes the **standardised layers** and says that the *ideal solution* is the **maximum value**¹
- The **best solution** is the one that is **nearest the ideal in m-dimensions** (where m is the number of attributes)

¹Or vice-versa if the orders are reversed



Standardised values (Here 1 is the **ideal** value)

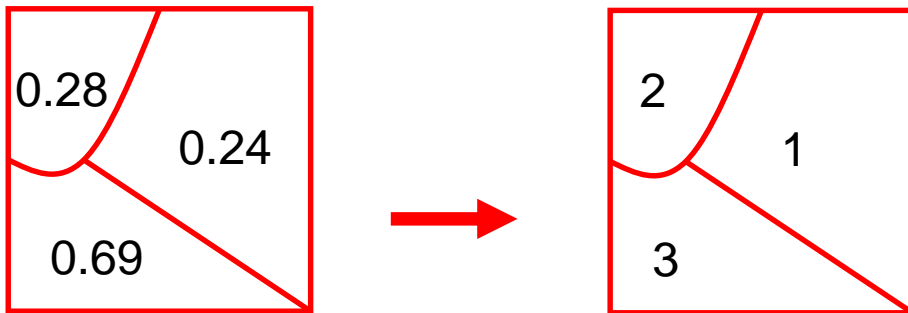


Weights as in AHP

$$(0.083)^2 \times (0 - 1)^2 = 0.007$$

$$S_{i+} = w^p (v_{ij} - v_{+j})^p$$

p=2 here



Ranking

$$\sqrt{[\sum S_{i+}]}$$

Concordance methods

- This method attempts to rank sites according to a **pairwise comparison** of alternatives
- Each criteria is compared for two sites (e.g. are cinemas nearer the house at Site A or B)
- An entry is put in the **concordance matrix** which is equivalent to the **sum of the weights** for the **criteria which are better** for the site (weights *again* from AHP)
- The **final matrix** is used to **generate rankings** (which may be partial – sites can tie)

	Cinema	Roads	Public transport
Site A	1	0.55	0.63
Site B	0	0	1
Site C	0.5	1	0
Weights	0.083	0.222	0.692

These values are the raw values for the layers

	Site A	Site B	Site C	Sum	Ranking
Site A	-	0.305	0.775	1	2
Site B	0.692	-	0.692	1.384	1
Site C	0.222	0.305	-	0.527	3

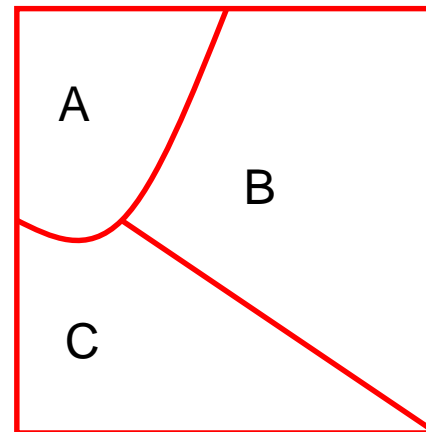
Site A is better than **Site B** for **cinema** and **roads** – so value is $0.083+0.222$

Site A is better than **Site C** for **cinema** and **public transport** – so value is $0.083+0.692$

Site B is better than **Site A** for **public transport** – so value is 0.692

Summary of results

Method	Site A	Site B	Site C	
Boolean	0	0	0	} <i>Site rankings, 1 is best...</i>
Weighted	1	2	3	
AHP	2	1	3	
Ideal point	2	1	3	
Concordance	2	1	3	



What about multiple objectives?

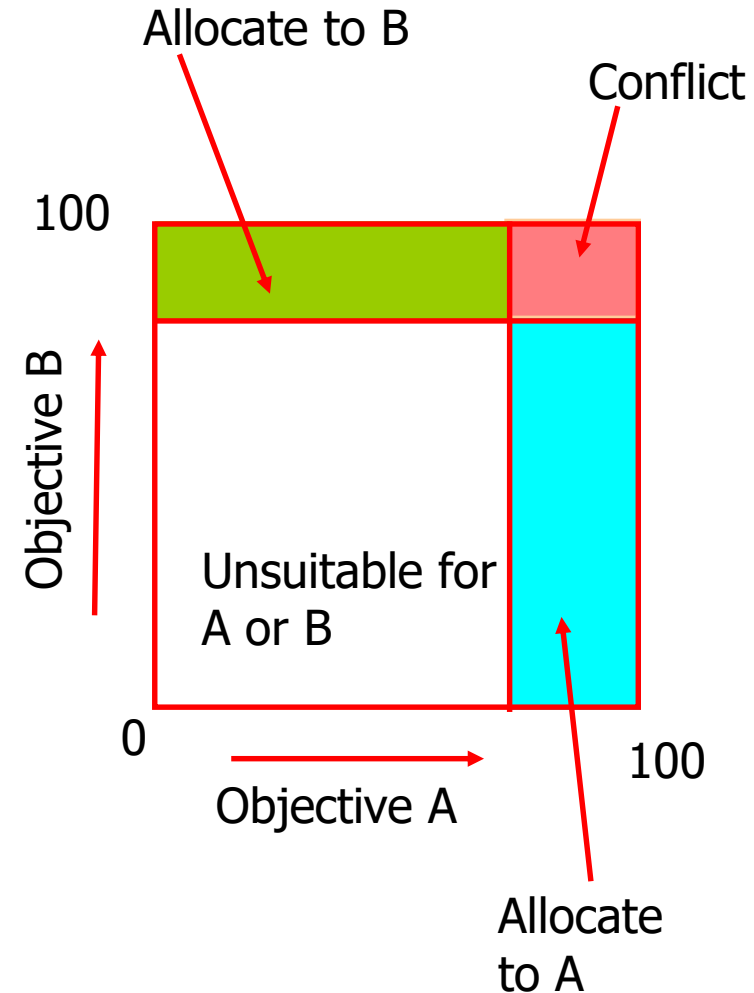
- So far we have talked about multiple criteria – we wanted to optimise a site according to a **range of criterion**
- Often, we also have a **range of objectives** – so for example a builder might wish to choose the cheapest land, whilst an environmentalist might prefer building to take place on sites which damage the environment least
- These sites **may not be the same** – so we try to find the **best compromise site**
- This is **multi-objective analysis**

Multi-objective analysis

- I will briefly describe a **conceptually simple** idea here – you can read more in Jones (1997)
- **Multiple Objective Land Allocation (MOLA)** assumes that we have performed **multi-criteria analysis** for a number of different objectives and have suitability layers for **each objective**
- Our task is then to **allocate locations** according to the differing objectives (which may or may not conflict)

Multiple Objective Land Allocation

- Iterate through all the solution sets and find the **highest ranked sites** in each
- If a **cell is highly ranked** for only a **single objective**, it can be allocated to that
- If a cell is highly ranked with respect to several objectives, it is in conflict **or** meets both objectives
- We may decide which objective is nearer, and allocate it to that
- Sites are **iteratively allocated** until **sufficient sites (area)** for all the objectives have been found



N.B: Here we assume objectives A and B are equally important

Summary

- MCE techniques allow us to **categorise** and **rank** a location's **suitability** using a range of techniques
- Here we looked at a range of different MCE techniques including boolean overlay, weighted linear combination, analytical hierarchy process, ideal point method and concordance techniques
- They can all be applied to raster or vector data – defining the attributes and extracting them is the important thing
- Different techniques may give **different answers**
- MOLA allows us to also consider **multiple objectives**

SDSS revisited

- In the introduction to the practicals I briefly introduced the idea of Spatial Decision Support Systems
- I want to **briefly revisit** what I said then – these, ideas are **central to implementing** your projects
- I've seen lots of project plans, and been sent more
- If you haven't spoken to me, then please make sure you do this week

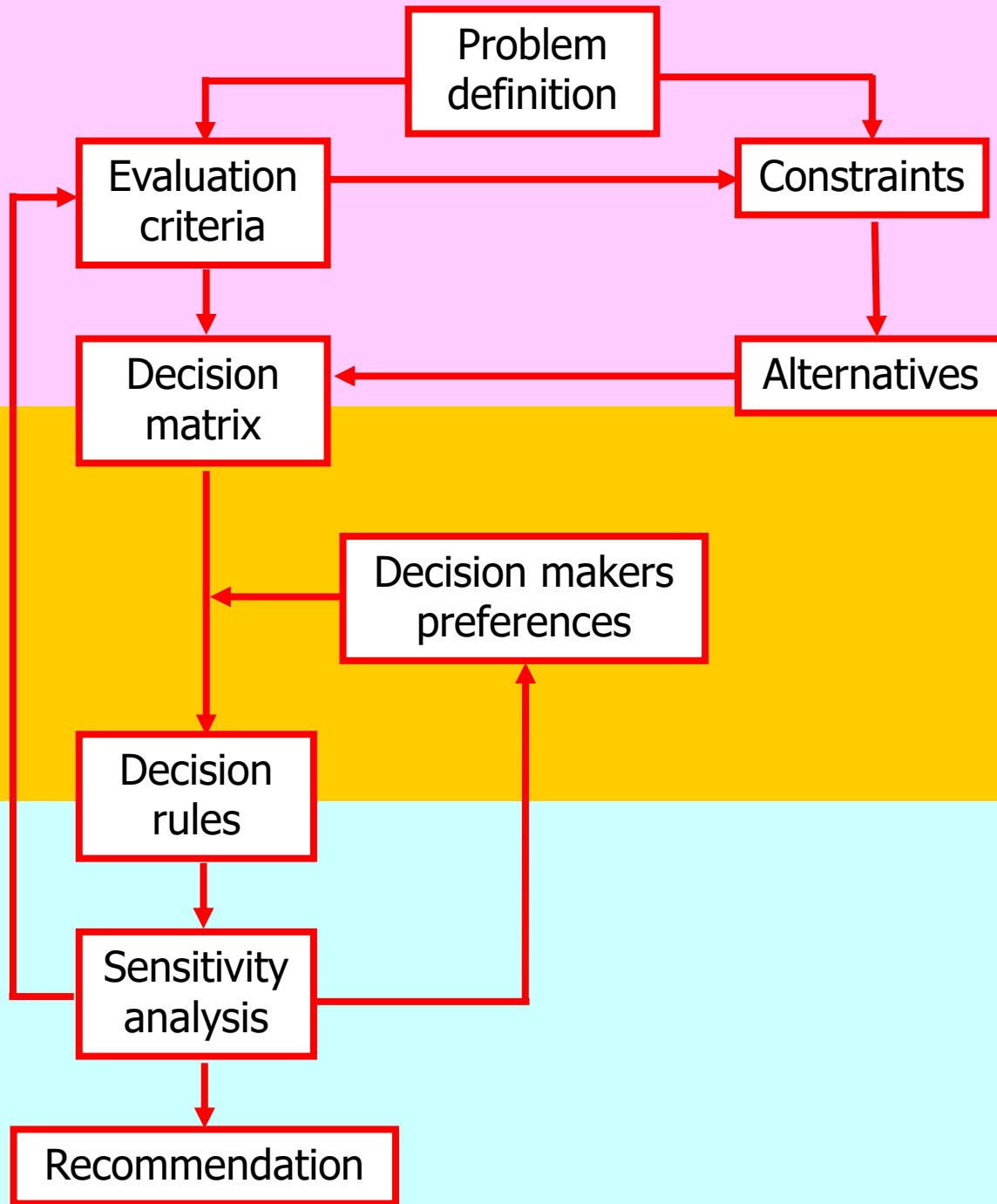
Using GIS for making decisions

- So far we have looked at a set of techniques for ranking based on attributes, criteria and objectives
- These techniques assume some very important things:
 - We know **what the question is**
 - We know **what attributes are related** to the question
 - We know how to form **rules to compare** attributes
 - We know how **important different factors are**

Computers can't do these things!!!

Spatial Decision Support Systems(SDSS)

- People make decisions (either rationally or irrationally!)
- **SDSS** can be thought of as the **tools** or **process** that decision makers can use to **help them** in making decisions through:
 - **visualising** the problem
 - **defining relationships** between factors
 - **predicting outcomes** through modelling
 - **evaluating** how sensitive decisions are to changes in individual factors (and also to uncertainty)
 - visualising **spatial relationships** between potential sites
- The following diagram visualises a framework for SDSS



Intelligence phase
GIS

Design phase
MCE

Choice phase
MCE/GIS

What does it all mean!!

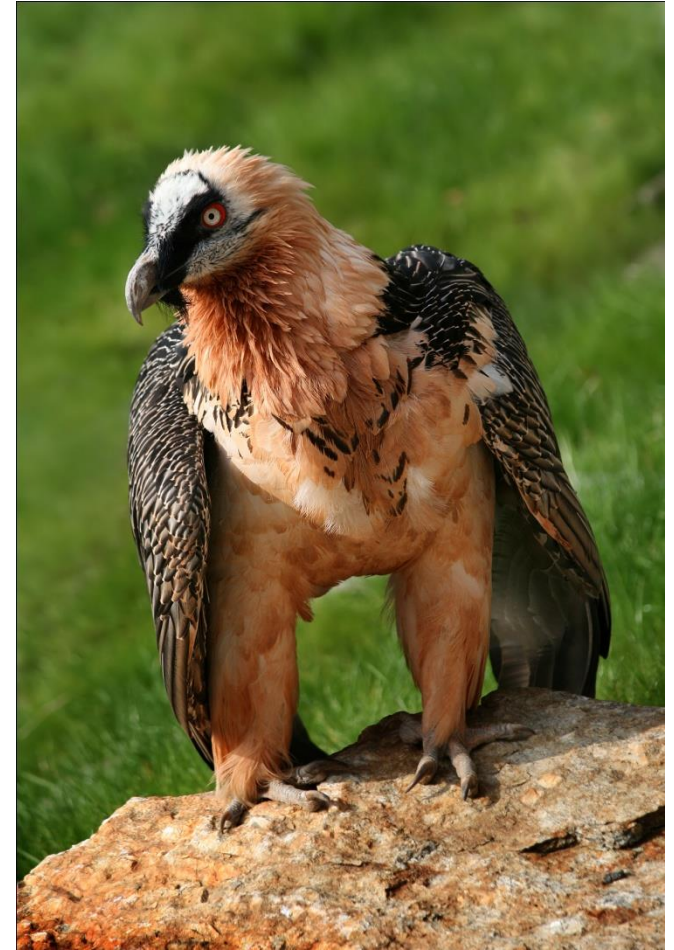
- The previous diagram is very pretty – but what does it mean!
- It tries to show the steps in the process of SDSS and divides them up into three phases:
 - The **intelligence phase** – here **raw data** are collected, processed and visualised. The decision maker can utilise exploratory spatial analysis techniques to clearly identify the problem
 - The **design phase** – here a set of possible alternatives are identified through use of a range of techniques
 - The **choice phase** – finally we evaluate the alternatives – perhaps one is chosen, or a range are delivered to decision makers

An example

- We are going to explore the flowchart using an example
- It is based on a Masters thesis carried out in the Department
- Many complex issues which we will explore
- The question – where is available **habitat and nesting potential for Bartgeier**
- Who might care about this question?

[News report 1](#)

[News report 2](#)



From:http://de.academic.ru/pictures/dewiki/66/Bartgeier_Gypaetus_barbatus_front_Richard_Bartz.jpg

An example

• V
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- Die kantonalen Amtsstellen beurteilen das Projekt als grundsätzlich genehmigungsfähig.
- Mit Ersatzmassnahmen aus dem Kraftwerkprojekt kann die sinnvolle Renaturierung des Chamuerabaches im Bereich des Siedlungsgebietes mitfinanziert werden.
- Das Engadin importiert Strom, weshalb nicht die sauberste Energie vor Ort produzieren und ca. 2'800 Haushaltungen mit Strom versorgen.
- Wasserzinsen sind ein willkommener Beitrag in die Gemeindekasse. Nicht überlebensnotwendig aber willkommen.
- Das Thema Bartgeier wird ernst genommen, im Moment aber sehr emotional und vermenschlicht behandelt und überbewertet.

Auf Antrag von Herr Roger Thouvenin wird die Abstimmung per Skrutinium vorgenommen. Dies mit dem folgenden Resultat:

• Eingegangene Stimmzettel	=	138
• leere Stimmzettel	=	0
• Ja-Stimmen	=	64
• Nein-Stimmen	=	74

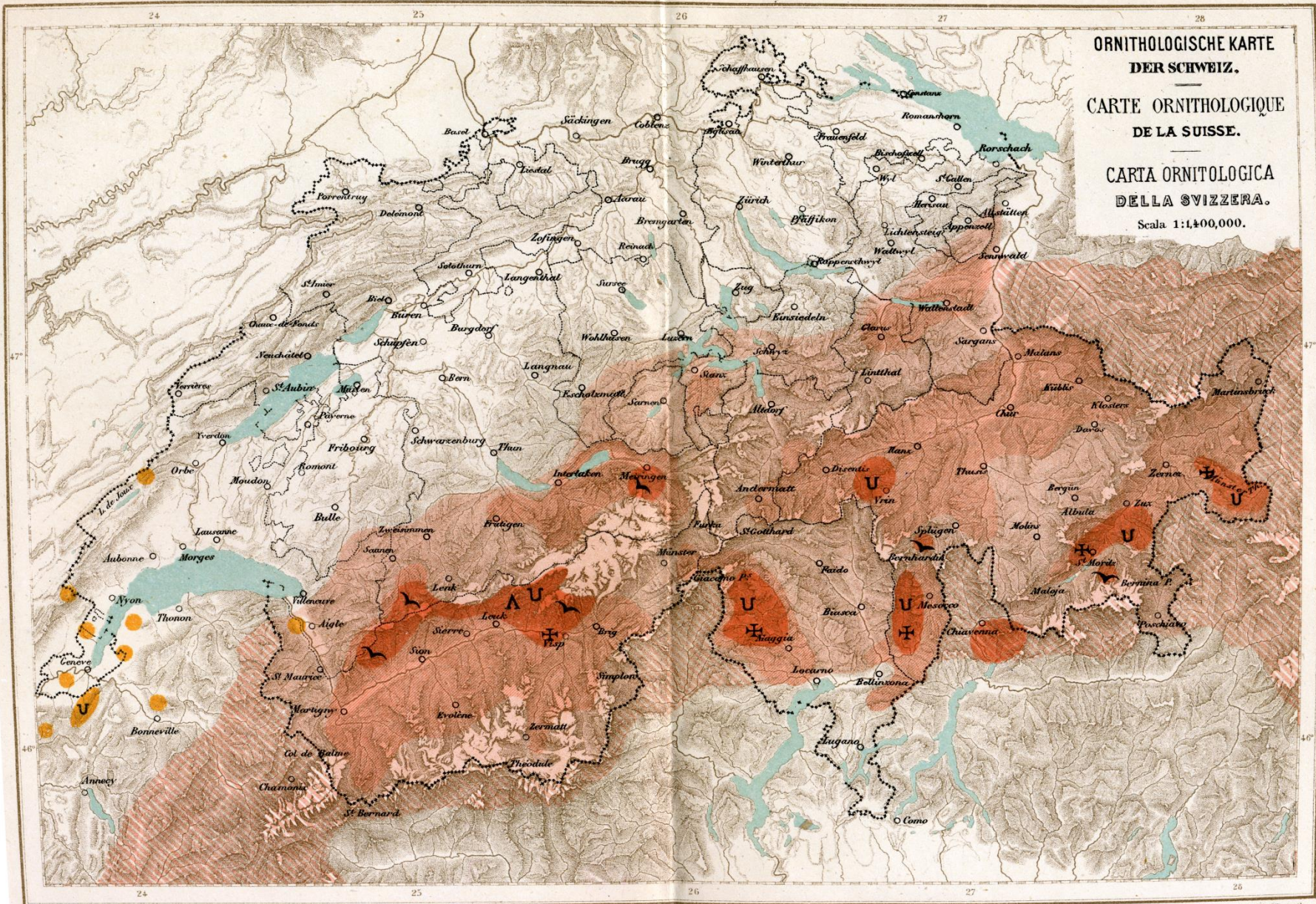
<http://www.lapunt.ch/fileadmin/PDF/Gemeindevers.18.08.14.pdf>
question?

[News report 1](#)

[News report 2](#)

From:http://de.academic.ru/pictures/dewiki/66/Bartgeier_Gypaetus_barbatus_front_Richard_Bartz.jpg





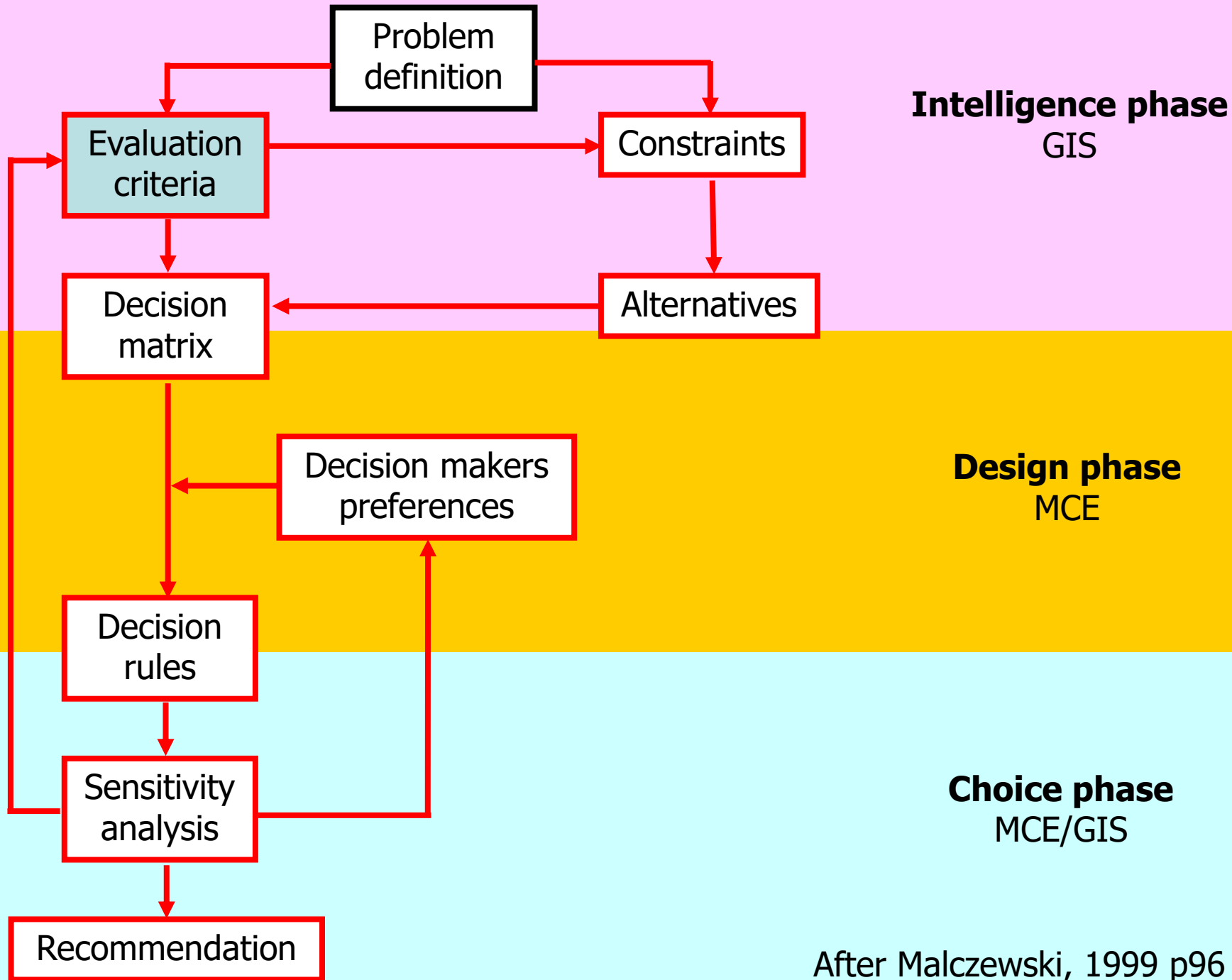
ORNITHOLOGISCHE KARTE
DER SCHWEIZ.
—
CARTE ORNITHOLOGIQUE
DE LA SUISSE.
—
CARTA ORNITOLOGICA
DELLA SVIZZERA.
Scala 1:1,400,000.

Neophron perenopterus ●

Gypaetus barbatus XVI, XVII, XVIII Sec.

- 1801 - 1859

- 1860 - 1888.



Evaluation criteria

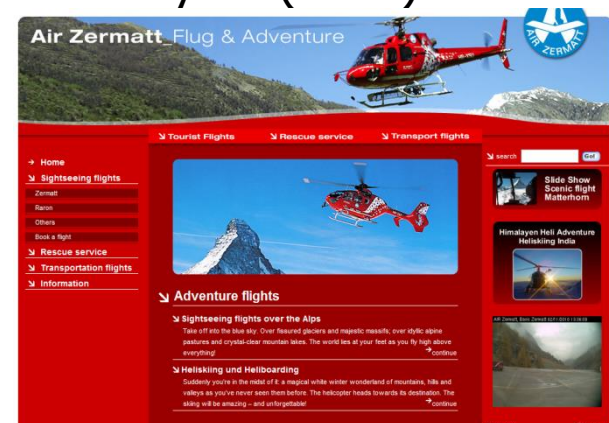
- These might include (for habitat and nesting):

- potential for food;
- cliffs for nesting;
- accessibility to thermals;
- potential for disturbance;
- types of local agriculture;
- proximity of airports;
- proximity of cables;
- distance to border;
- current bird population;
- proximity to conservation area;
- political situation.

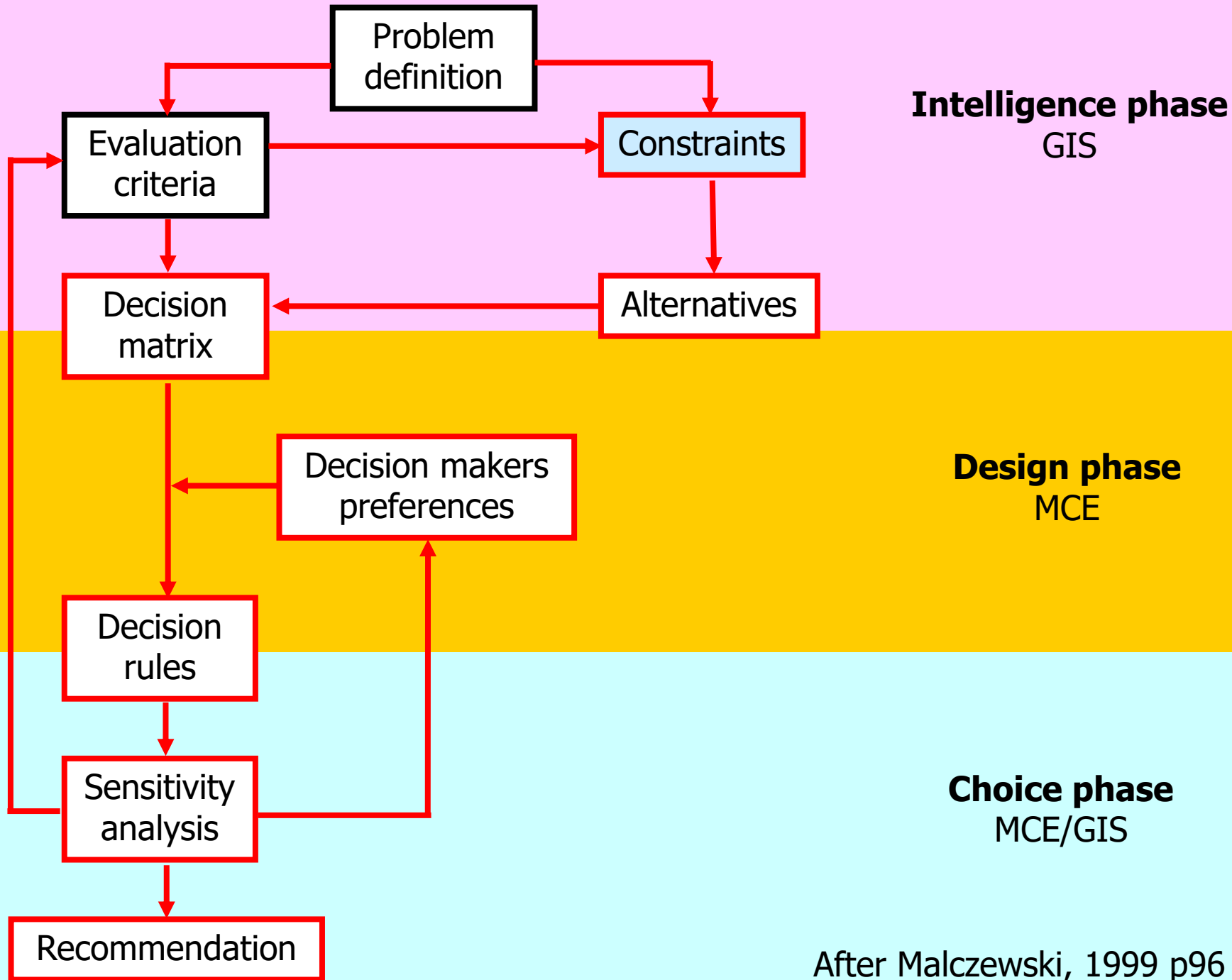


From: Ryffel (2008)

- Are these independent?
- Who might choose these criteria?

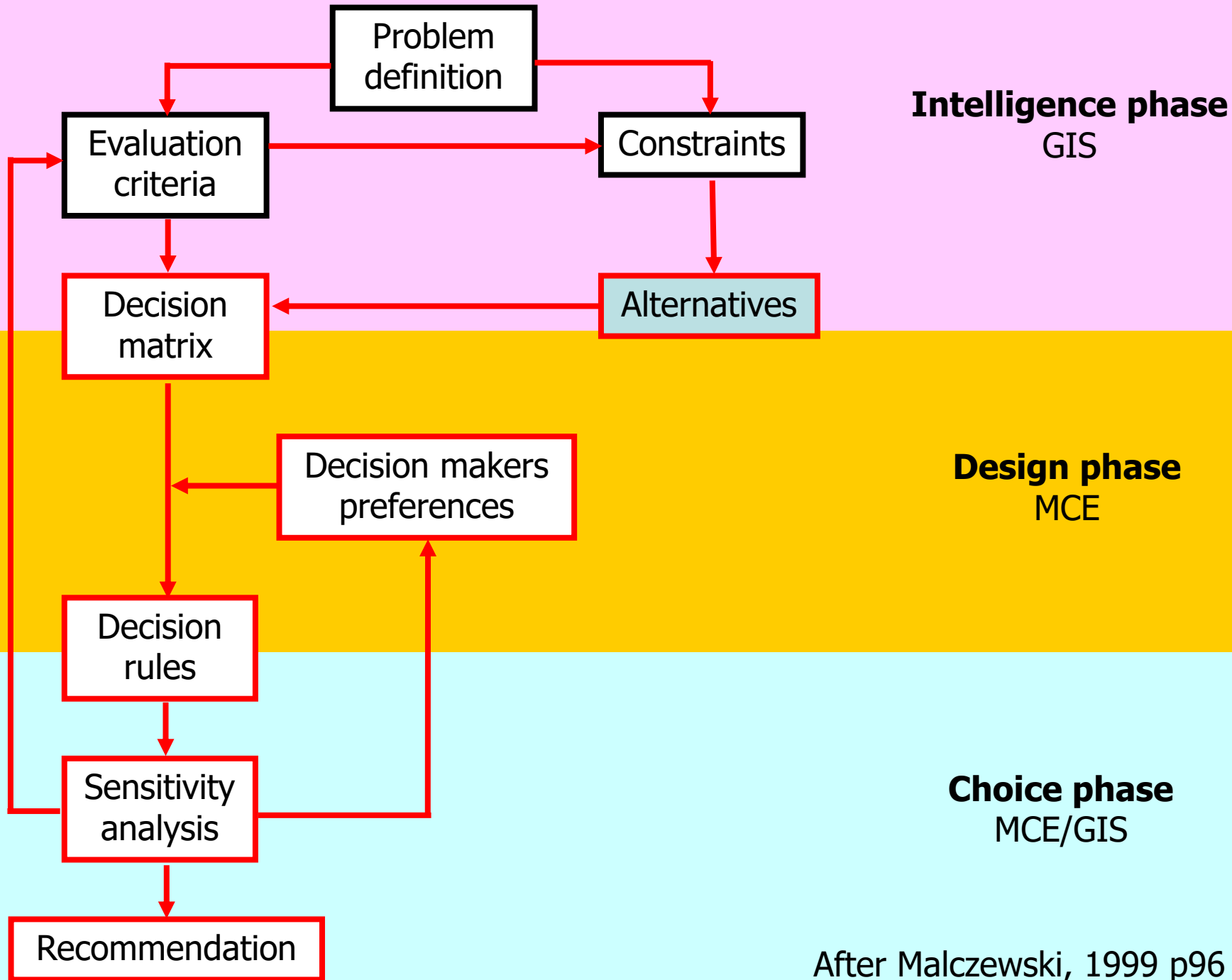


From: www.air-zermatt.ch



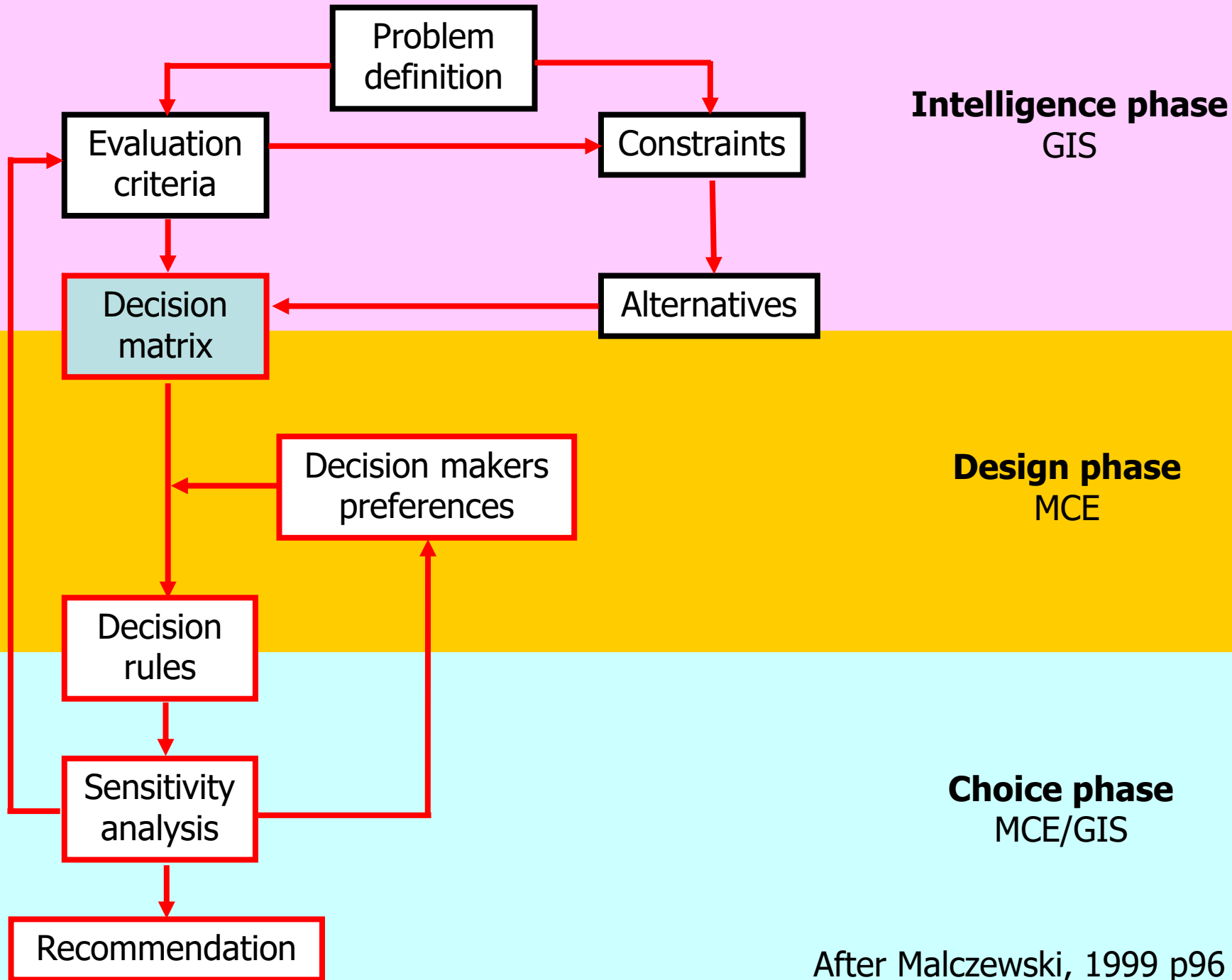
Constraints

- Constraints are the **limitations** on the values that our evaluation criteria may take
- We apply them by some boolean operation and are left with a number of feasible sites
- Some constraints here are:
 - **Slopes greater than 50°**
 - **Bedrock (no vegetation)**
- What do you think these constraints define?
- What problems can you see (think of data and algorithms we have seen so far)?



Alternatives

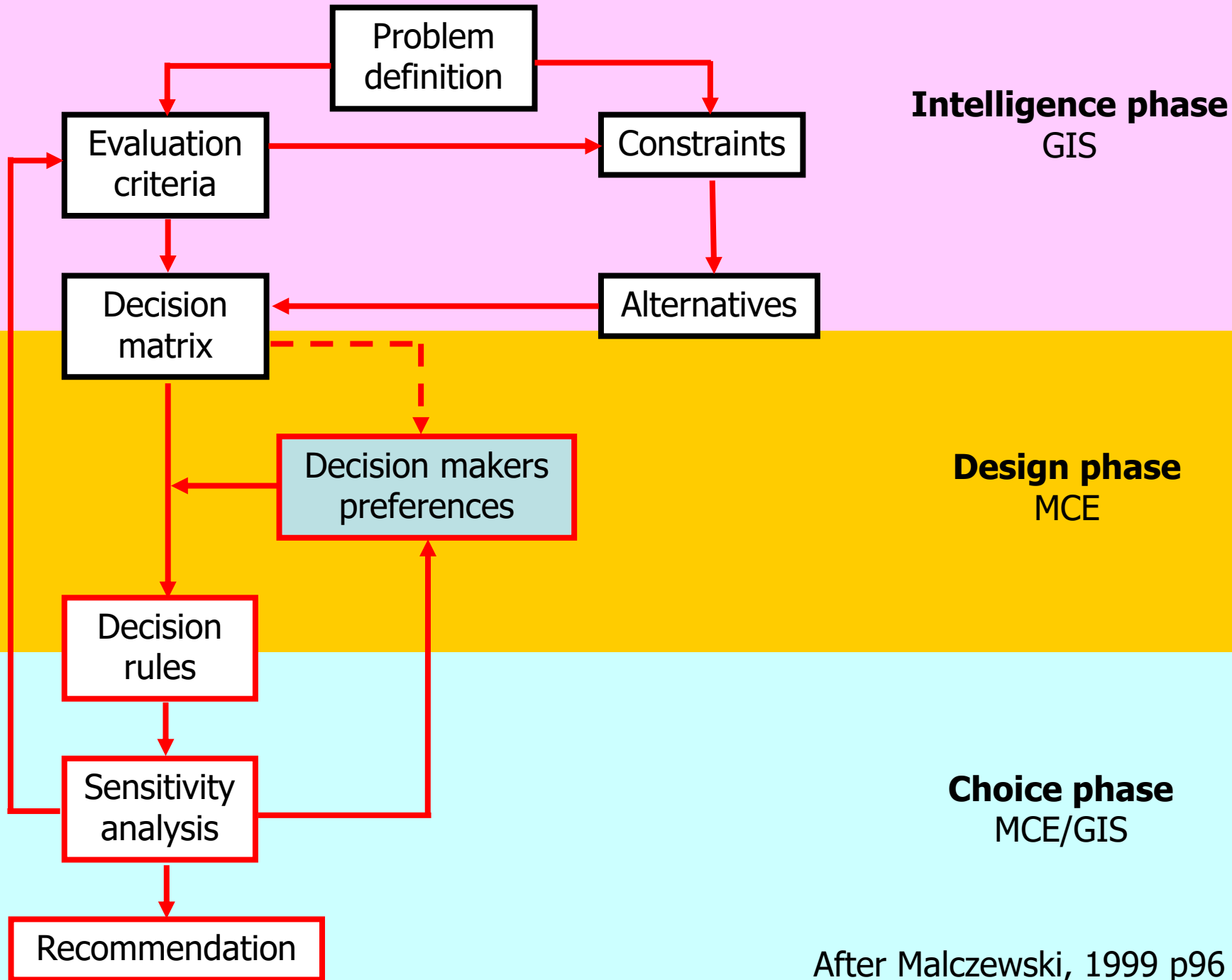
- The alternatives are the **possible sites** that could be suitable as nest places or habitats, based on the constraints
- In our case, the **potential nest sites** are **very limited** (relatively few locations are rocky and steeper than 50°) whilst there are few hard constraints on **habitat**
- What do you think might be **hard constraints** on **habitat** in the Swiss Alps?
- In general identifying the alternatives leaves sites which you want to **make a choice** between...

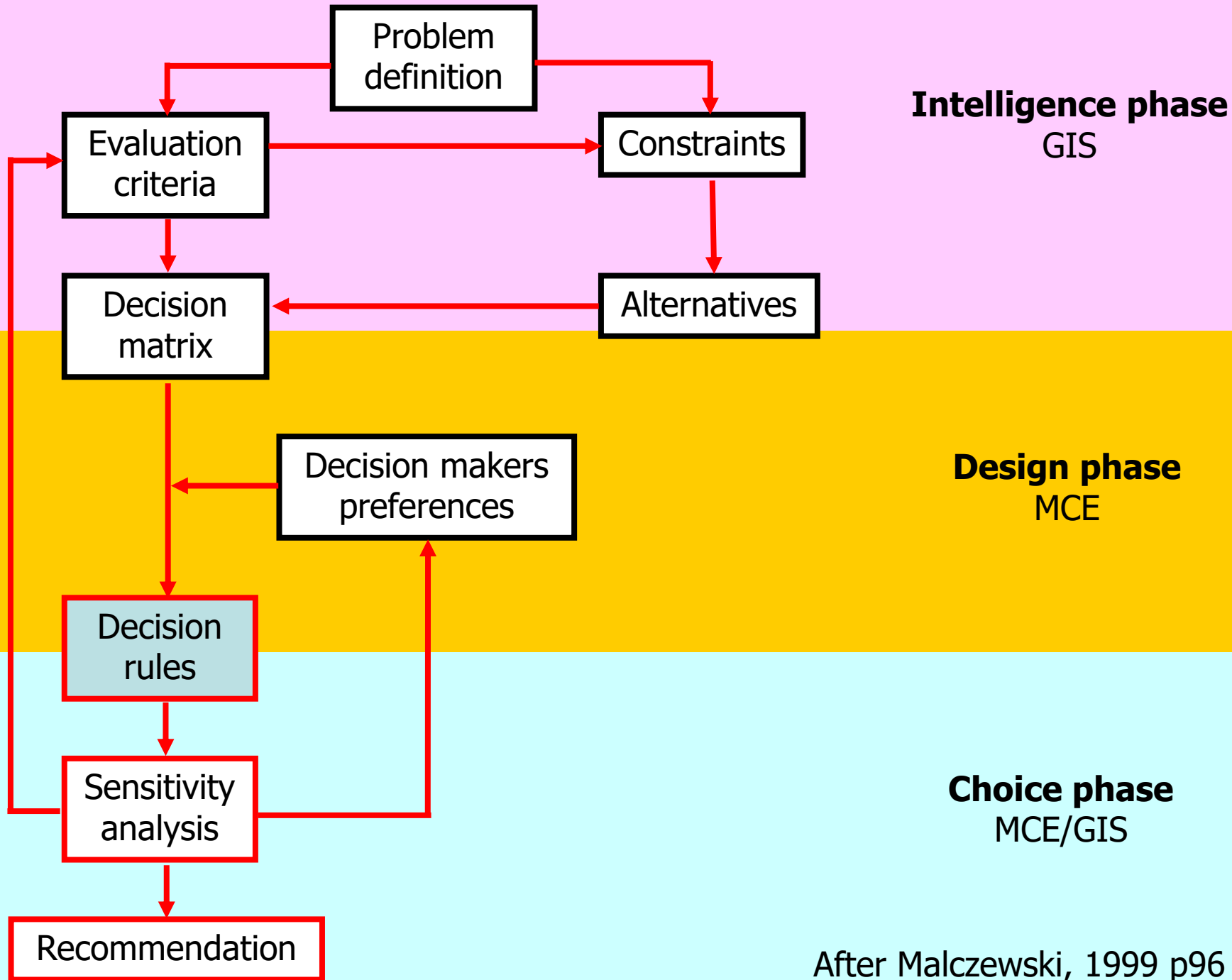


Decision matrix

- To rank potential nest sites a **decision matrix** could be used
- It can be used to apply our ranking techniques (from the first half of the lecture)
- The matrix normally contains standardised attributes, with each having some range (say 1-100) where 1 is least suitable and 100 is most suitable...

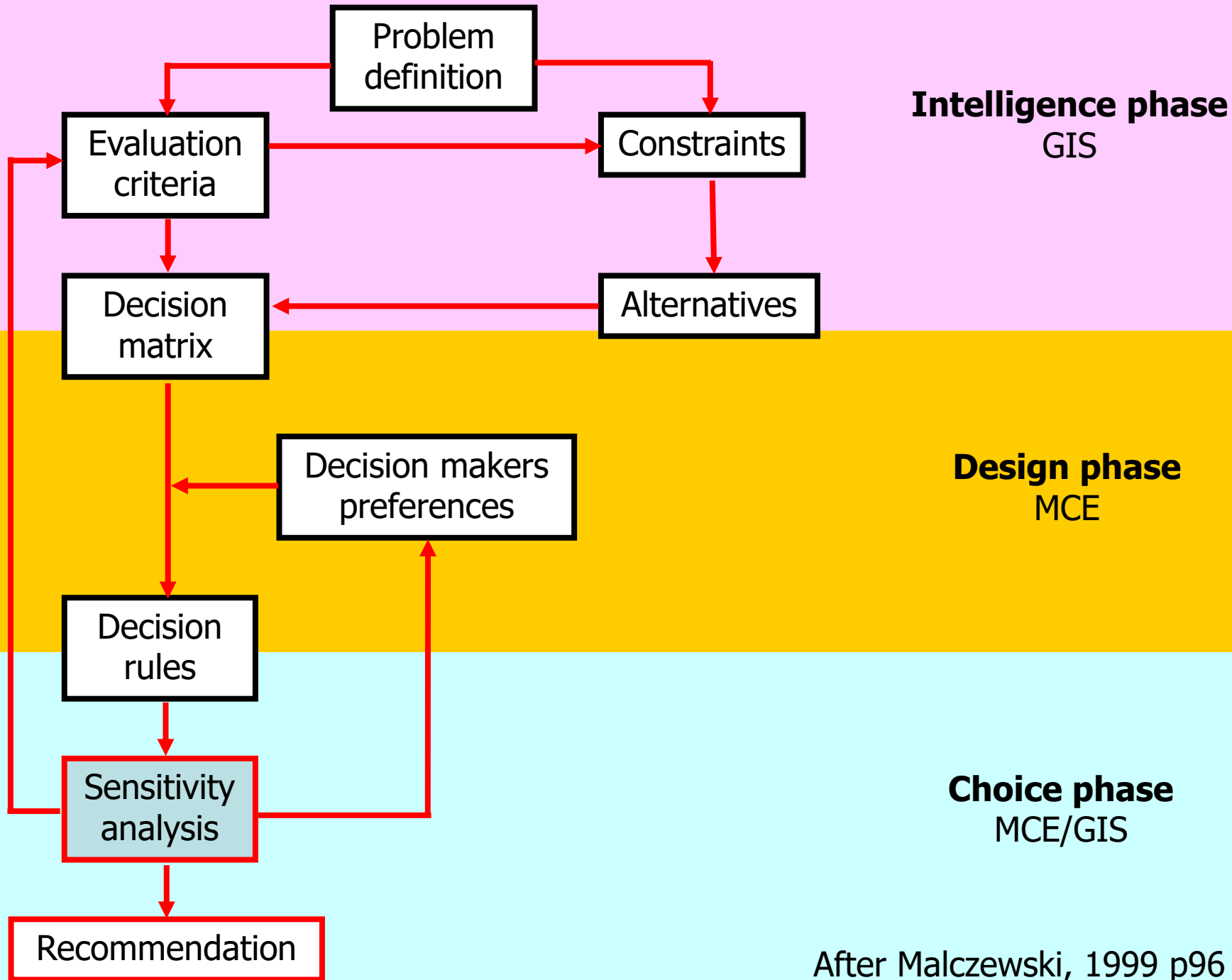
	A^1	A^2	A^3	...	A^N
Site A	V_{A1}	V_{A2}	V_{A3}	...	V_{AN}
Site B	V_{B1}	V_{B2}	V_{B3}	...	V_{BN}
...					
Site N	V_{N1}	V_{N2}	V_{N3}	...	V_{NN}





Decision rules

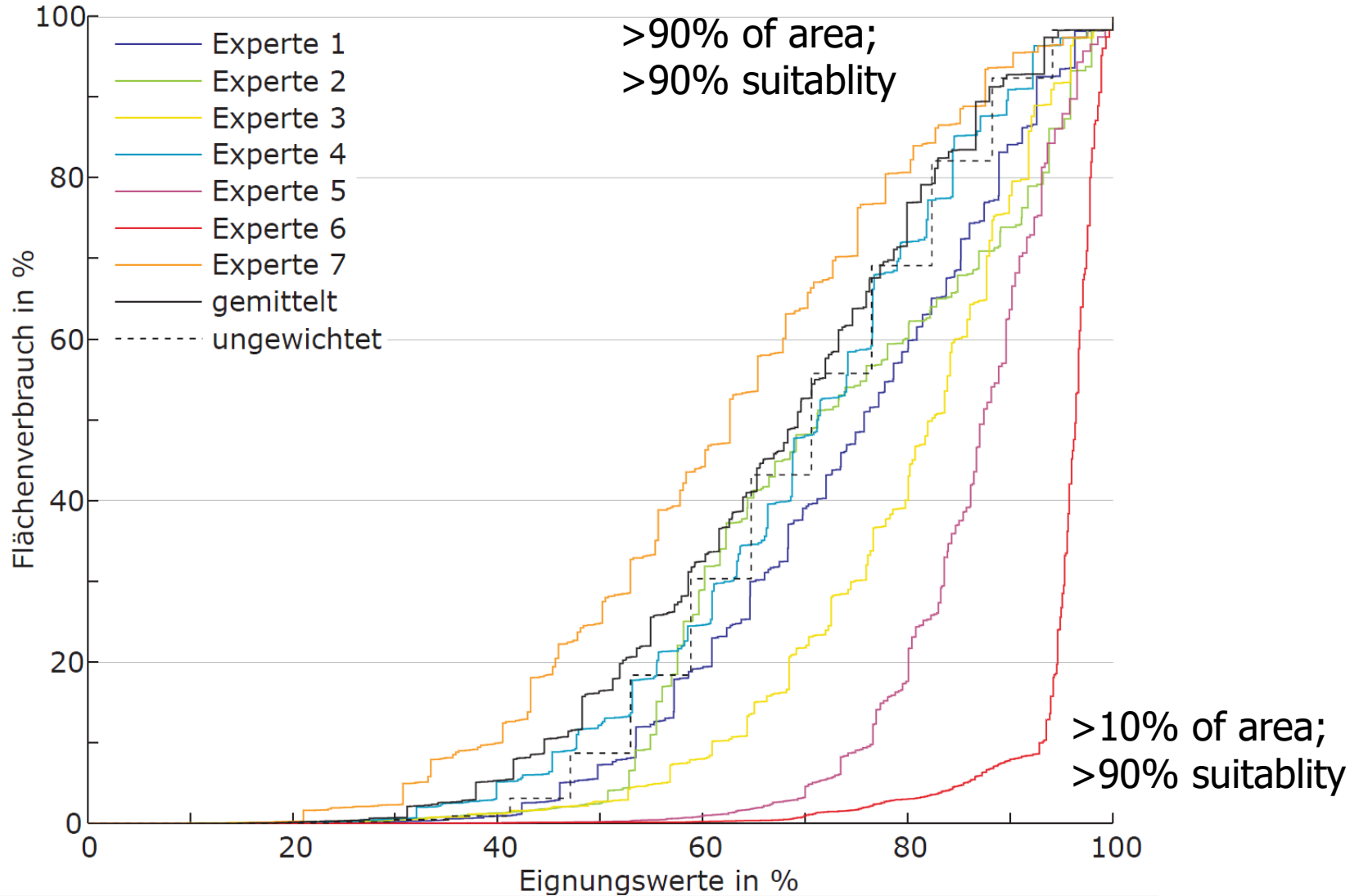
- The **decision rules** are used to **rank** the possible alternatives
- We saw a number of potential decision rules in the first half of the lecture, including:
 - Weighted linear combination
 - Analytical hierarchy process
 - Ideal point method
 - Concordance techniques
- Remember we could also have **multiple objectives** so need to use some MOEA techniques...
- These are only a small subset of possible decision rules – we can also use much more complex or simpler rules...



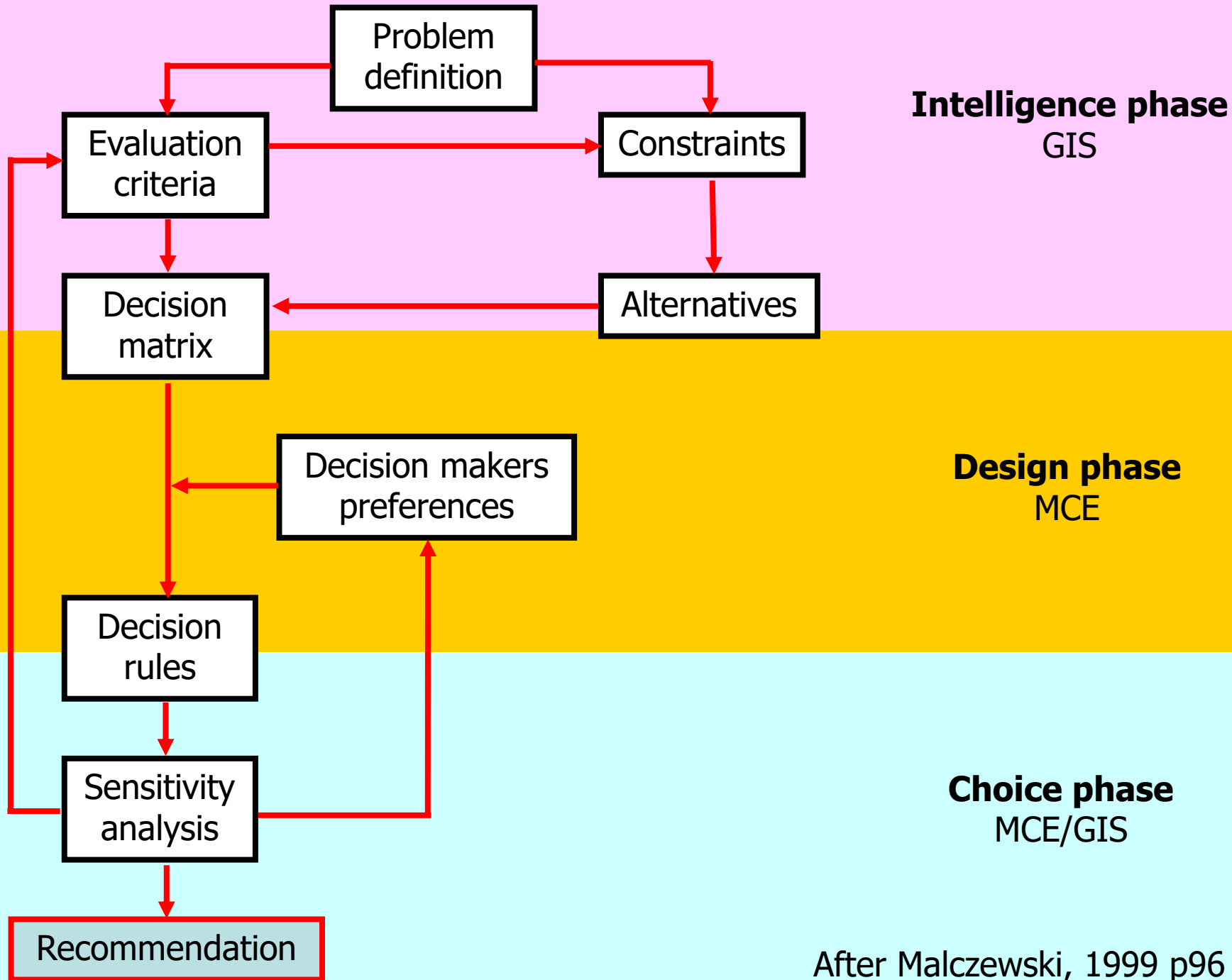
Sensitivity analysis

- Sensitivity analysis shows how much a **recommendation changes** if we change the inputs
- For instance, what happens if
 - we change an evaluation criteria a small amount?
 - the weightings are changed a small amount?
 - we use a different decision rule?
 - data have spatial or attribute errors?
- A solution is **robust** if the ranking is relatively **insensitive** to such changes
- Sensitivity analysis helps us understand how our evaluation criteria are related to the problem

Example sensitivity analysis



The "suitable" area as a function of total area for different experts (and thus weights)



Recommendation

- Is based on a **ranking of alternatives** and **sensitivity analysis**
- May include **the best** or a **group of possible solutions**
- We can use **GIS to present visualisations** of possible solutions
- We should also provide **decision makers** with **information on how the recommendation** was reached...

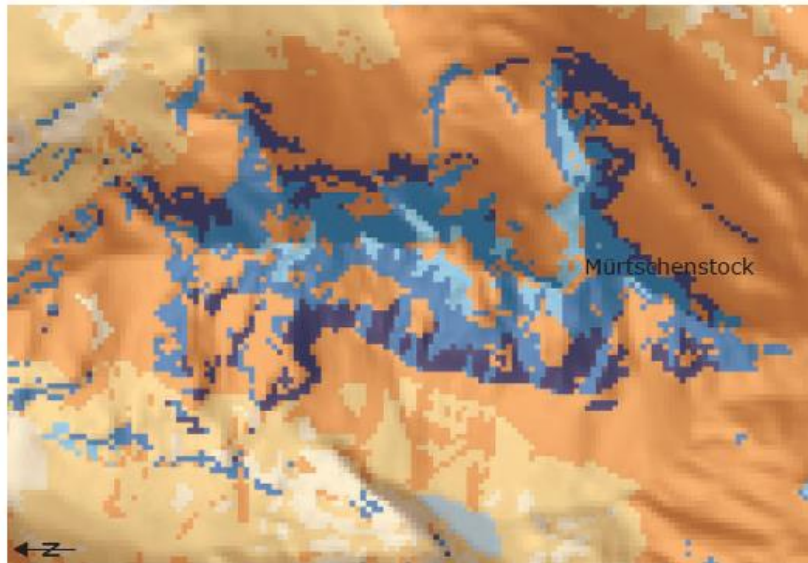


Abbildung 8.1: Modelliertes Nistplatz- und Habitatpotenzial am Mürtschenstock. Reproduziert mit Bewilligung von swisstopo (BA081097).

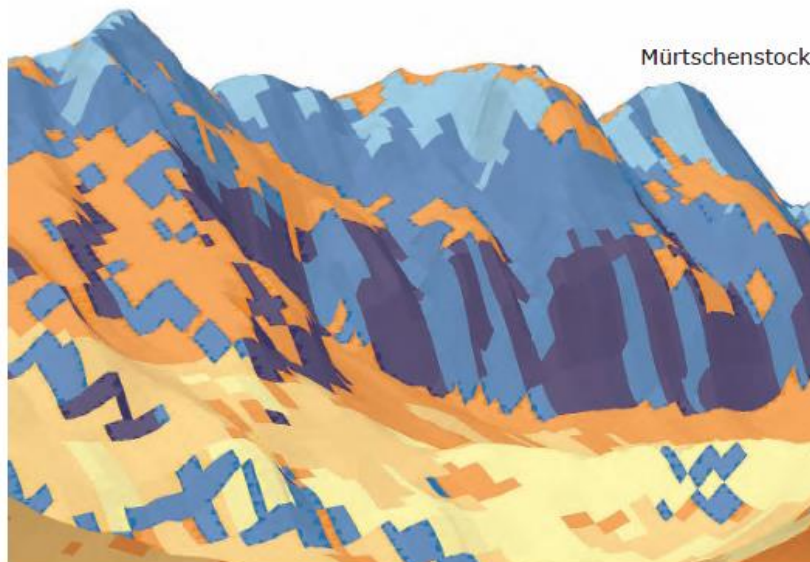


Abbildung 8.2: 3D Darstellung des modellierten Nistplatz- und Habitatpotenzials am Mürtschenstock. Reproduziert mit Bewilligung von swisstopo (BA081097).

- Visualisations combine nest potential (blues) with habitat (yellow)
- How useful do you think these visualisations are to decision makers?
- What other information/ methods might be useful?



Nistplatzpotenzial

- gering
- mittel
- hoch

Habitatpotenzial

- mittel
- hoch

- Gewässer
- Siedlungsgebiet
- Grenze

0 10 km

Masstab: 1:300'000

Some final points

- You should think about **who** you would need to make these decisions
- Clearly, just knowing about GIS is not enough
- We need a knowledge of **bartgeier (or tranquility or wind power)** too...
- If we have multiple (or competing) objectives it is likely that we need a **range of experts and interest groups** involved in the decision making process
- Through using the framework described here and a suitable environment, decision makers can **explore** and **discuss** possible solutions in a way not possible without GIS and MCE...

Summary

- Examined an example of Spatial Decision Support – looking at Bartgeier habitat
- We have looked at a framework for decision making – identifying **three phases** in the process
 - **intelligence**
 - **design**
 - **choice**
- The process was **non-linear** – you should think back to the alternative uses of spatial analysis presented in the first lecture
- The process involves people and not just tools – this is very important

Next week

- We'll introduce some ideas about spatial databases
- You are using these behind the scenes in ArcGIS – however I've now given you all the theory you need to implement your projects
- Some more lecture content might be relevant to the background – don't forget to read as well as doing practical work!

References

- Malczewski, J. 1999. *GIS and Multicriteria decision making*. Wiley.
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- Jones, C. 1997. *GIS and Computer Cartography*. Longman.
- Andrea Ryffel: *Räumlich-zeitliche Charakterisierung und Modellierung von Bartgeierbrutgebieten in den Alpen* 2008, [PDF](#)