Esri International User Conference | San Diego, CA

Technical Workshops | **********

ArcGIS Spatial Analyst – Suitability Modeling

Kevin M. Johnston

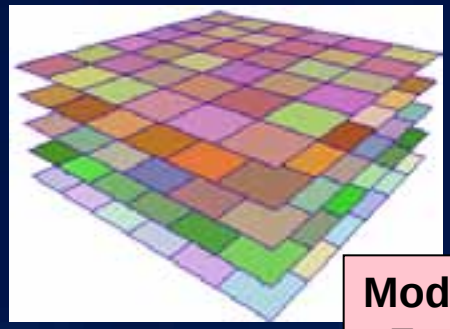
Elizabeth Graham

The problem to solve – Suitability modeling

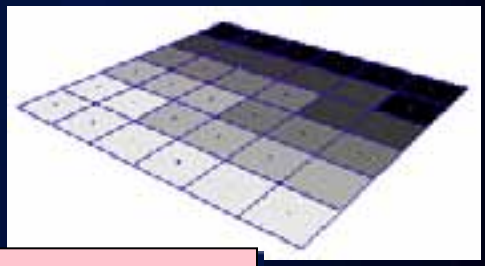
- Where to site a new housing development?
- Which sites are better for deer habitat?
- Where is economic growth most likely to occur?
- Where is the population at the greatest risk if a chemical spill were to happen?

Reality

GIS layers



Suitability for store



Model criteria:
- Zoned commercial
- Near target population
- Away from competition

What we know

- The best locations can be determined from the features at each location
- You can identify the features that define the best locations
- You can quantify the relative preference of the features relative to one another
- You know what is not important to the phenomenon
- The attributes and numbers associated with the data vary in type and meaning

The presentation outline

- Some background information
- How to create a suitability model and the associated issues
- Demonstration
- Looking into the values and weights a little deeper
- Demonstration
- Fuzzy logic

Manipulation of raster data - Background

- Locational perspective of the world
- Define a portion of the landscape then describe its attributes
- Worm's eye view
- To return a value for each cell when entered into a tool you must know
  - What is your value
  - What function to apply
  - What other cell locations to include in the calculations
    - Within a grid
    - Between grids

Discrete and continuous phenomena - Background

- **Discrete phenomena**
  - Landuse
  - Ownership
  - Political boundaries
- **Continuous phenomena**
  - Elevation
  - Distance
  - Density
  - Suitability

Discrete

0	1	1	2
No Data	1	1	1
No Data	1	2	2
1	1	2	2

Vegetation
0 = Rock
1 = Forest
2 = Water

Continuous

1.12	1.75	1.81	2.03
0.26	1.63	1.87	1.98
0.00	0.91	0.73	1.42
0.00	0.18	No Data	No Data

Rainfall (inches)

The presentation outline

- Background
- How to create a suitability model and the associated issues
- Demonstration
- Looking into the values and weights a little deeper
- Demonstration
- Fuzzy logic

General suitability modeling methodology

- There is a fairly standard methodology to follow:

Define the goal

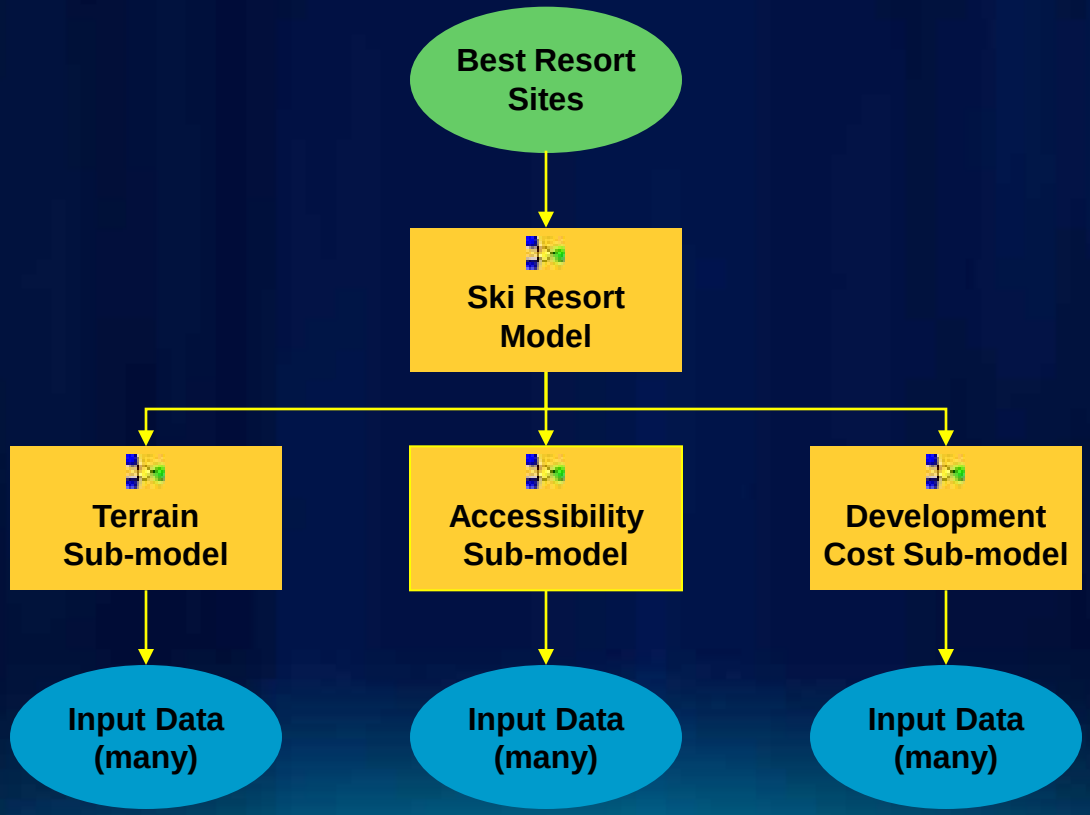
- Define the problem
  - “Locate a ski resort”
- Establish the over arching goal of the problem
  - Make money
  - Be the most fit ….
- This is a team activity
  - Stakeholders, decision makers
- Identify issues
  - Legal constraints
- Obtain GIS data
  - DEM, roads, land use, and houses

Define the measures of success for a model

- How will you know if the model is successful?
- Criteria should relate back to the overall goals of the model
- May need to generalize the functions of the phenomenon
  - On average near the water
- Determine how to quantify
  - “Drive time to the city”

Recommendation: Break model into sub-models

- Helps clarify relationships, simplifies problems

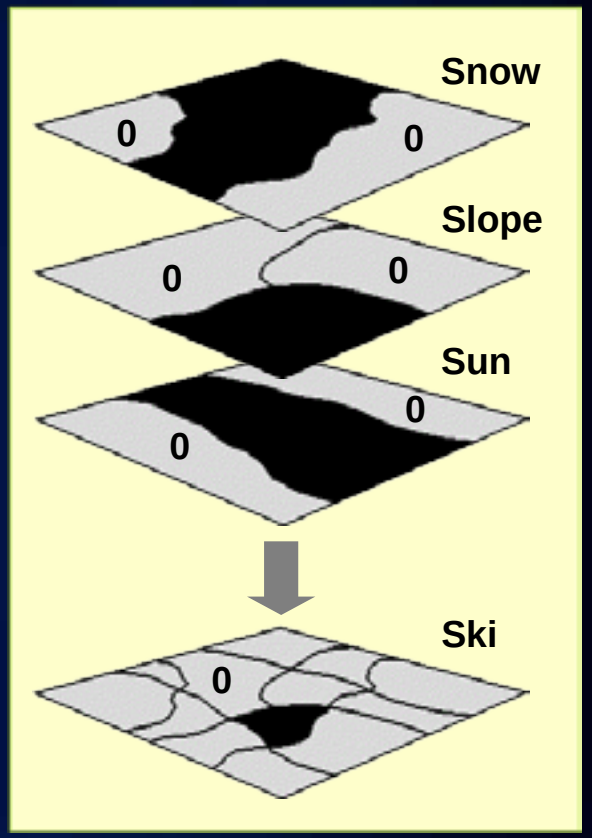


ModelBuilder

- ArcGIS incorporates model building capabilities

Types of suitability models - Binary

- Use for simple problems
  - Like a query
- Classify layers as good (1) or bad (0)
  - Combine:
    `[Ski] = [Snow] & [Slope] & [Sun]`
- Advantages:
  - Easy
- Disadvantages:
  - No “next-best” sites
  - All layers have same importance
  - All good values have same importance

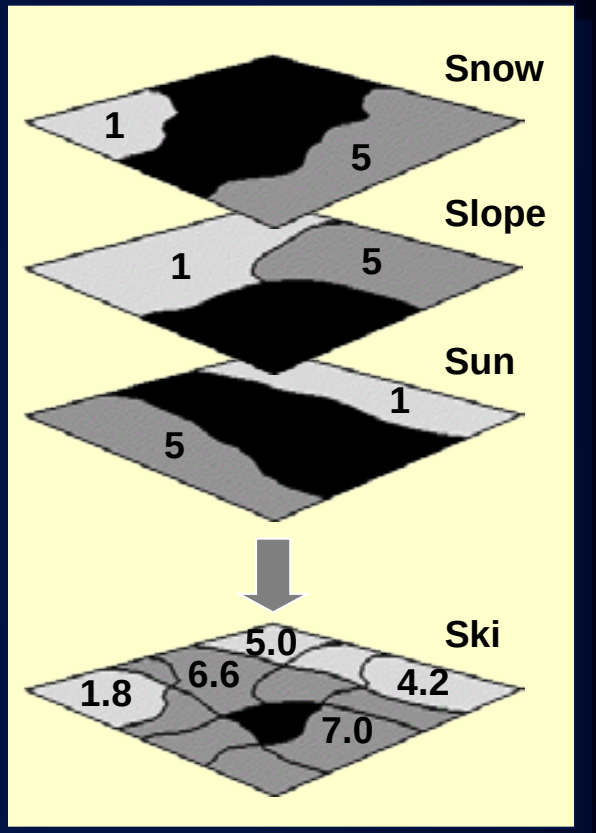


Types of suitability models - Weighted

- Use for complex problems
- Classify layers into suitability 1–9
  - Weight and add together:

```
Ski = ([Snow]  * 0.5)
    + ([Slope] * 0.3)
    + ([Sun]   * 0.2)
```

- Advantages:
  - All values have relative importance
  - All layers have relative importance
  - Returns suitability on a scale 1–9
- Disadvantages:
  - Preference assessment is more difficult



General suitability modeling methodology

- There is a fairly standard methodology to follow:

The suitability modeling model steps

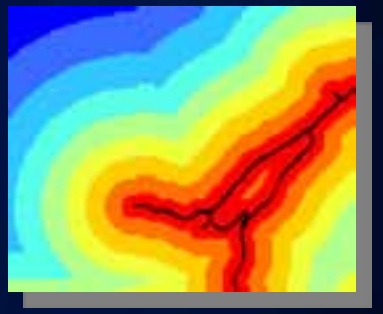
- **Determine significant** layers for the phenomenon being modeled
- **Reclassify** the values of each layer into a relative scale
- **Weight** the importance of each layer
- **Add** the layers together
- **Analyze** the results and make a decision

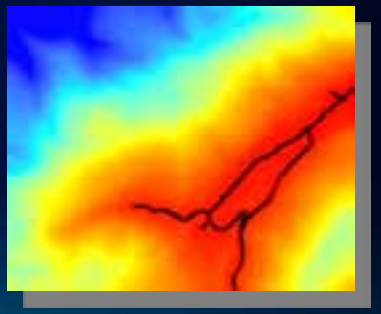
Determining significant layers

- The phenomena you are modeling must be understood
- What influences the phenomena must be identified
- How the significant layers influence the phenomena must be determined
- Irrelevant information must be eliminated
- Simplify the model
  - Complex enough to capture the essence
  - Needs to identify enough to address the question

Reclassify - Decide how to measure the criteria

- Base data may not be useful for measuring issues
  - Need to measure access, not road location
- May be easy:
  - ArcGIS Spatial Analyst tools
  - For example, distance to roads
- May be harder:
  - Require another model
  - For example, travel time to roads

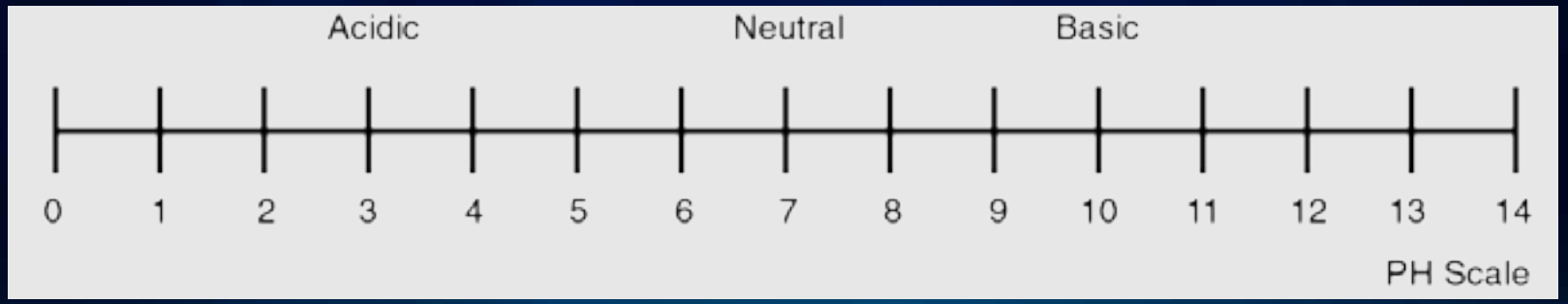




Why reclassify - Values vary

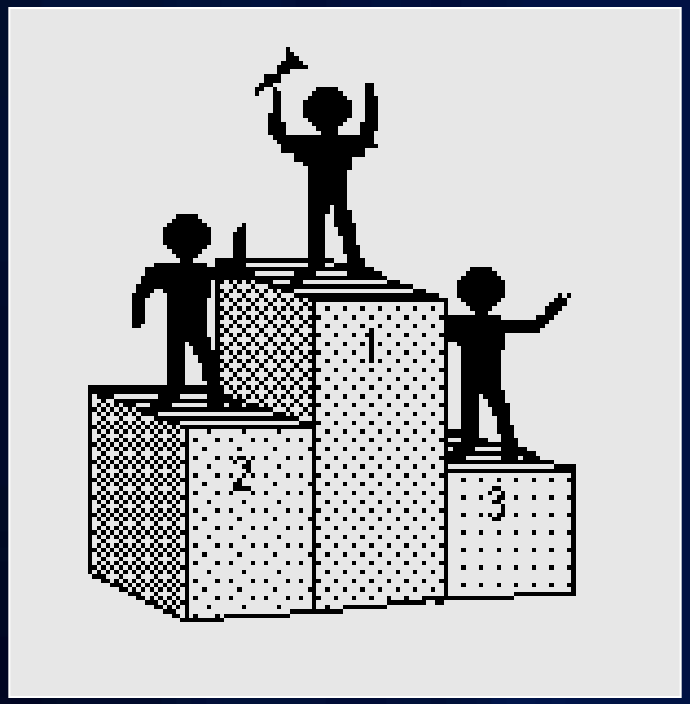
Ratio:

Interval:

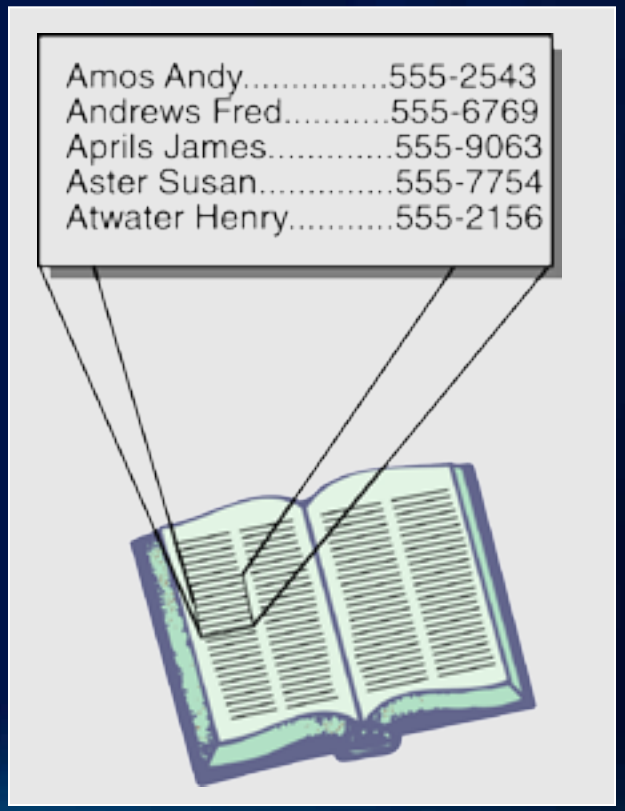


Why reclassify - Values vary

Ordinal:

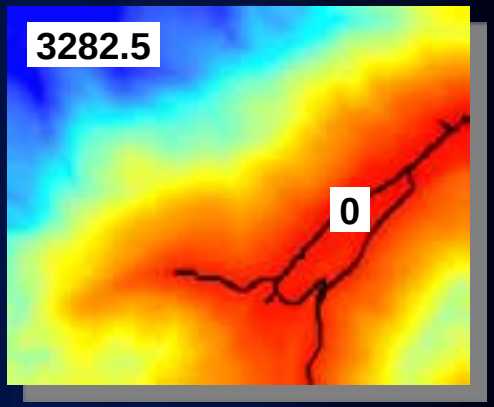


Nominal:



Reclassify - Define a scale of suitability

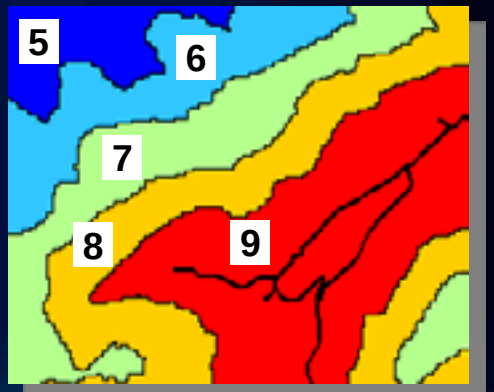
- **Define a scale for suitability**
  - Many possible; typically 1 to 9 (worst to best)
  - Reclassify layer values into relative suitability
  - Use the same scale for all layers in the model



Distance to roads

	Travel time suitability
Best	9 – 0 minutes to off ramp
	8
	7
	6
	5 – 15 minutes to off ramp
	4
	3
	2
Worst	1 – 45 minutes to off ramp

	Soil grading suitability
Best	9 – Recent alluvium; easy
	8
	7
	6
	5 – Landslide; moderate
	4
	3
	2
Worst	1 – Exposed bedrock; hard

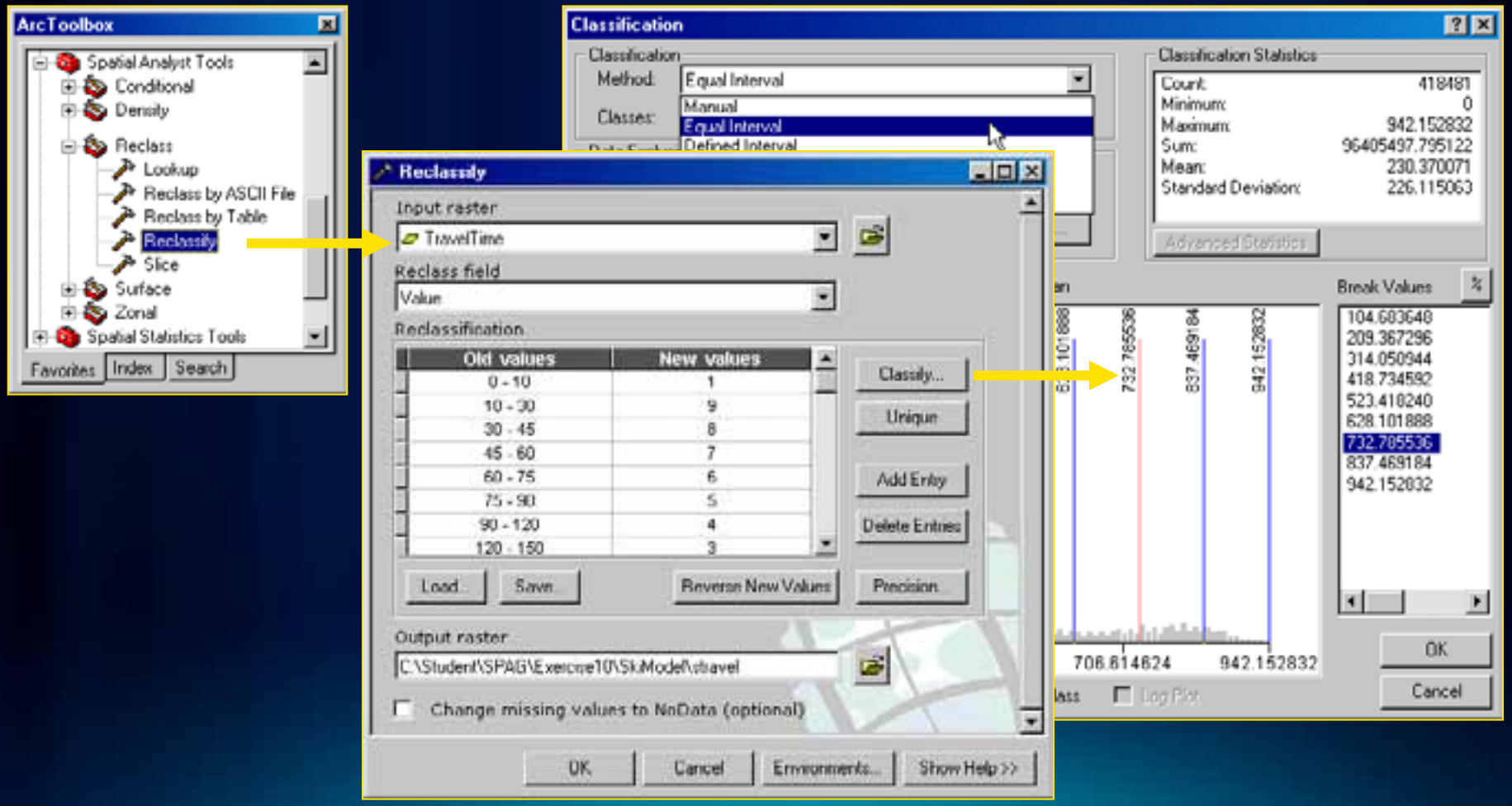


Suitability for Ski Resort

Within and between layers

The Reclassify tool

- May use to convert measures into suitability

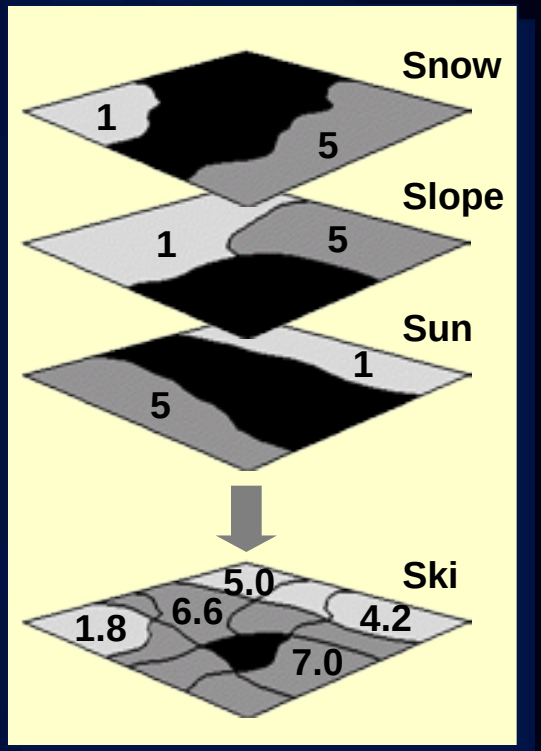


Suitability modeling steps

- **Determine significant** layers for the phenomenon being modeled
- **Reclassify** the values of each layer into a relative scale
- **Weight** the importance of each layer
- **Add** the layers together
- **Analyze** the results and make a decision

Weight and add the layers

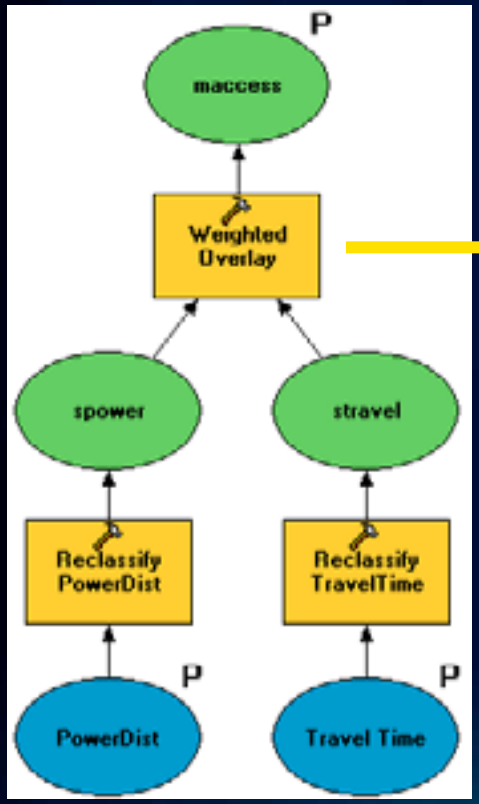
- Certain layers will be more significant than others and must be weighted appropriately before they are combined
  - For example, soil type and slope may be more significant to house siting than aspect
- Use the Weighted Overly tool
- Or , use a Map Algebra expression:

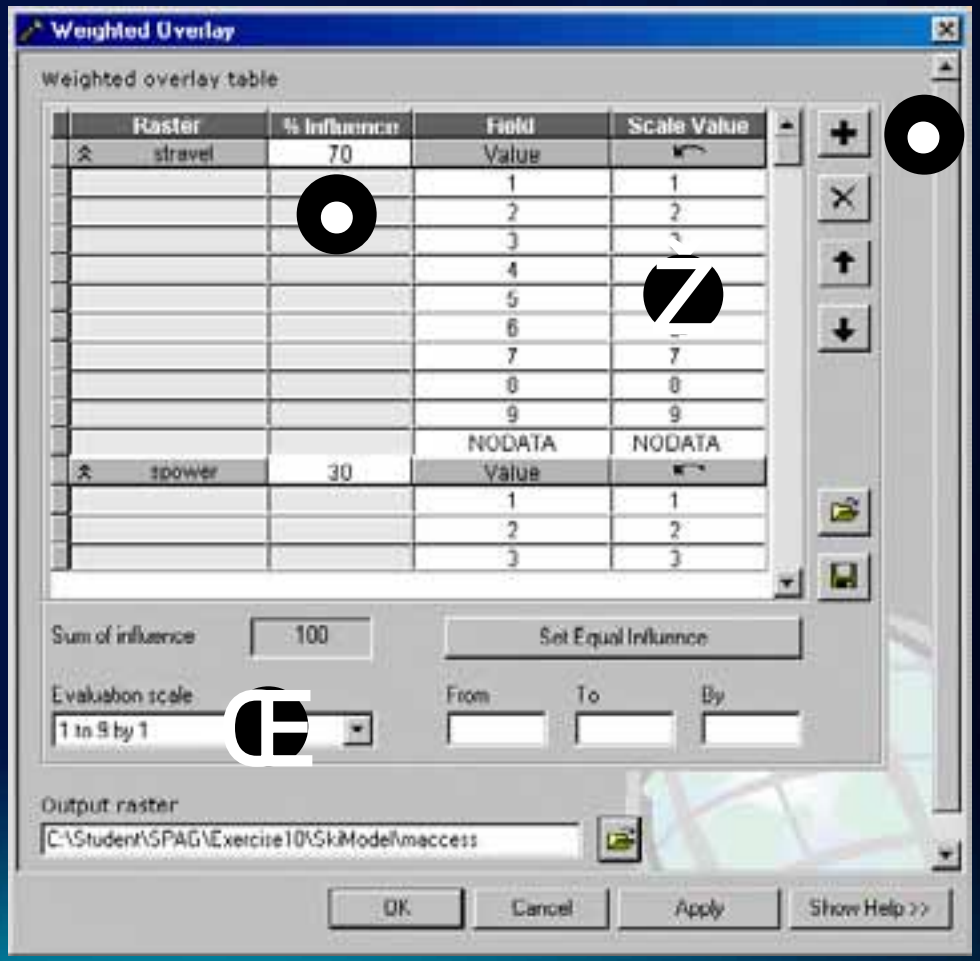



```
Ski = ([Snow] * 0.5) + ([Slope] * 0.3) + ([Sun] * 0.2)
```

The Weighted Overlay tool

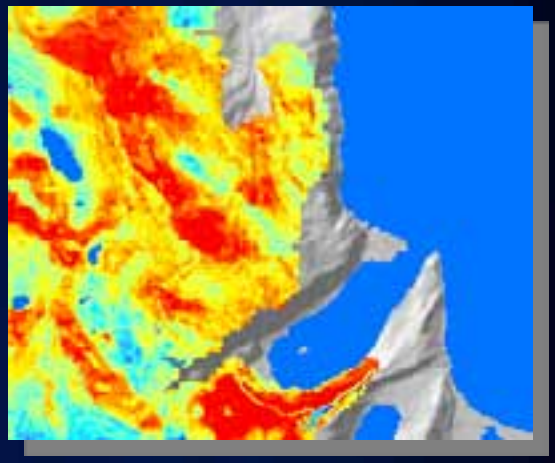
- Weights and combines multiple inputs





Present results/Choose an alternative

- Model returns a suitability “surface” – map ranking the relative importance of each site to one another with regards to a specified phenomenon



- Create candidate sites
  - Select cells with highest scores
  - Define regions with unique IDS
  - Eliminate regions that are too small

- Choose between the candidates
  - Another modeling problem?

Validation

- Ground truth
- User experience
- Alter values and weights
- Perform sensitivity analysis

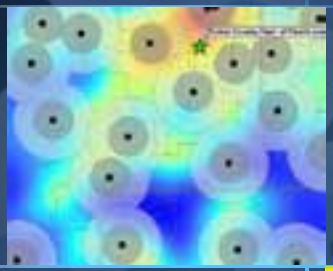
Limitations of a suitability model

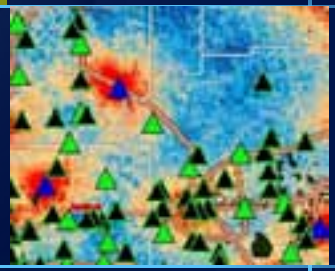
- Results in a surface indicating which sites are more preferred by the phenomenon than others
- Does not give absolute values (can the animal live there or not; ordinal not interval values)
- Heavily dependent on the reclass and weight values

The presentation outline

- Background
- How to create a suitability model and the associated issues
- Demonstration
- Looking into the values and weights a little deeper
- Demonstration
- Fuzzy logic

Demo 1: Suitability Model





Reclass

Weight

Add

The story is not over

- So far how the reclass values have been assigned has not been critically examined
- Does the reclassification values accurately capture the phenomenon?
- The reclassification has been assigned by expert opinion - you – are there other approaches?
- Continuous criterion were reclassified by equal interval
- We have assumed more of the good features the better
- What happens when there are many criteria?

Multicriteria decision making

- GIS and Multicriteria Decision Analysis (J. Malczewski)
- Operation Research (linear programming)
- Decision support
- This presentation not about identifying the best method
  - Problem you are addressing
  - Available data
  - Understanding of the phenomenon
- Provide you with alternative approaches
- To make you think about the values and weights

The model creation framework

- The one presented is:
  - Determine significant layers
  - Reclassify
  - Weight
  - Add
  - Analyze

- The decision support world:
  - Problem definition
  - Evaluation criteria (Determine significant layers and reclass)
  - Alternatives
  - Criterion weights (Weights)
  - Decision Rules (Add)
  - Sensitivity analysis
  - Recommendation

Problem definition

- Most important and most time consuming
- It is glossed over
- Measurable
- The gap between desired and existing states
- Break down into sub models
  - Helps clarify relationships, simplifies problem

Evaluation criteria

(Determine significant layers and Reclass)

- **Objectives and criteria**
  - **Build on slopes less than 2 percent**
- **Many times take on the form:**
  - **Minimize cost; Maximize the visual quality experience**
- **The more the better; the less the better**
- **Proxy criteria**
  - **Reduce the lung disease – amount of carbon dioxide**
- **How to determine influence of the attributes**
  - **Literature, studies, Survey opinions**
  - **Conflicts?**

Evaluation criteria methods

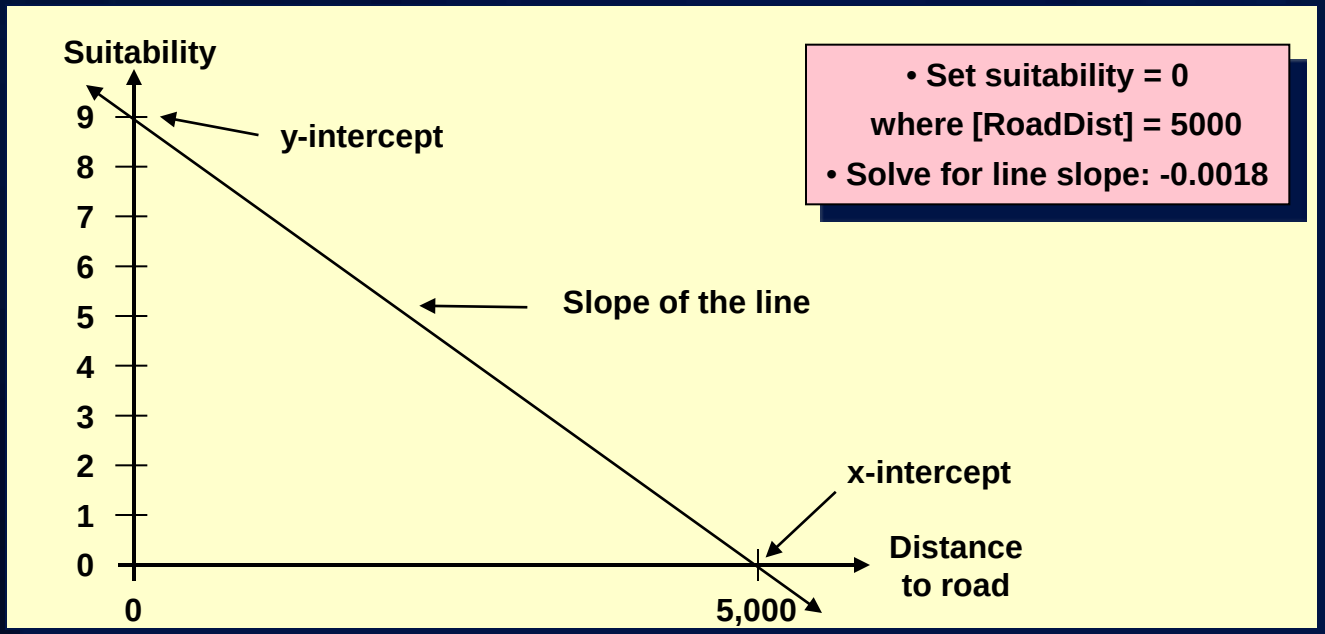
(Determine significant layers and Reclass)

- **Direct scaling (as you have seen)**
- **Linear transformation**
  - **Divide each value by the maximum value**
  - **Scale 0 – 1 (relative order of magnitude maintained)**
  - **Apply to each layer (to all types of data?)**
- **Value/utility functions**
- **Others:**
  - **Fuzzy sets**

Evaluation criteria: Value/Utility functions

(Determine significant layers and Reclass)

- **Reclassify with equations – ratio data**
  - **Mathematical relationship between data and suitability**



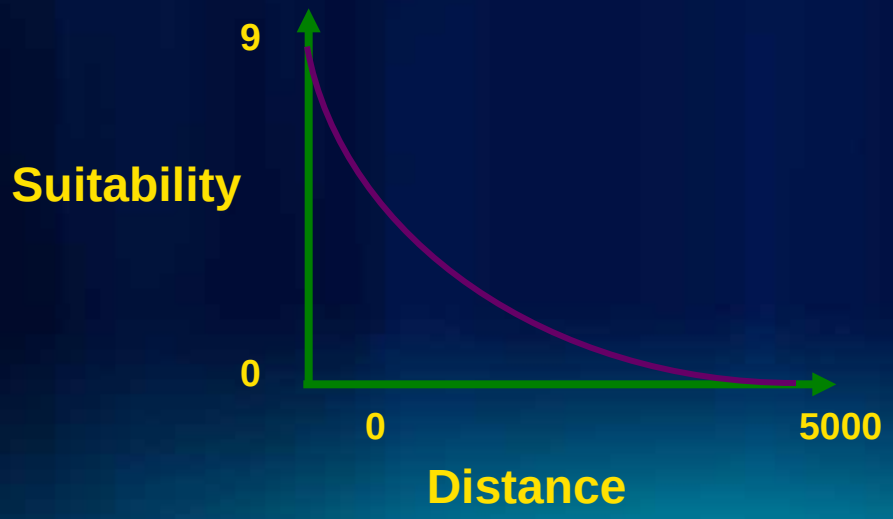
Implement with Map Algebra or a model:

```
RoadSuit = 9 + ( -0.0018 * RoadDist )
```

Evaluation criteria: Value/Utility functions

(Determine significant layers and Reclass)

- Not a linear decay in preference
- The intervals for the attribute are not equal
- Or the preference scaling is not equal



The framework

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Decision alternatives and constraints

- Constraints
  - Reduces the number of alternatives to be considered
  - Feasible and nonfeasible alternatives
- Types of Constraints
  - Noncompensatory
    - No trade offs - in or out (legal, cost, biological, etc.)
  - Compensatory
    - Examines the trade offs between attributes
      - Pumping water – (height versus distance relative a cost)
- Decision Space
  - Dominated and nondominated alternatives

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Criterion weighting - (Weights)

- Ranking Method
  - Rank order of decision maker (1 most, 2, second…)
- Rating Method
  - Decision maker estimates weights on a predetermined scale
  - Point allocation approach (similar to first demonstration)
  - Ratio estimation procedure (Easton)
    - Arbitrarily assign the most important, other assigned proportionately lower weights
- Pairwise
- Trade-off analysis

Criterion weighting: Pairwise - (Weights)

- Analytical hierarchy process (AHP) (Saaty)
- Three steps
  - Generate comparison matrix
  - Compute criterion weights
    - Sum columns – divide by column sum – average rows
  - Estimate consistency ratio (math formulas)
- Pairwise comparison
  - Rate on scale 1 to 9 two attributes of preference
  - 1: Equal importance – 9: Extreme importance

Attributes	Distance	Aspect	Cost
Distance	1	3	6
Aspect	1/3	1	8
Cost	1/6	1/8	1

Criterion weighting: Trade-off – (Weights)

- Direct assessment of trade offs the decision maker is willing to make (Hobbs and others)
- Decision maker compares two alternatives with respect to two criteria defining preference or if indifferent

Site 1		Site 2		
Cost	Distance	Cost	Distance	Preference
0	0	10	1	1
2	0	10	1	1
4	0	10	1	Indifferent
6	0	10	1	2
8	0	10	1	2
10	0	10	1	2

The framework

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Decision rules - (Add)

- These methods determine how to combine the feasible alternatives and rank them

- Have not yet discussed:
  - We have approached the criteria values and weights from a single view point, but what happens when there are conflicting perspectives?
    - Team
    - Coalition
    - Competitive

  - Decision making with certainty and uncertainty

Decision rules - (Add)

- Simple Additive Weighting (SAW) method
- Value/utility functions (Keeney and Raiffa)
-
- Group value/utility functions
- Ideal point method
- Others:
  - Concordance method
  - Probabilistic additive weighting
  - Goal programming
  - Interactive programming
  - Compromise programming
  - Data Envelopment Analysis

Decision rules: SAW - (Add)

- What we did earlier
- Assumptions:
  - Linearity
  - Additive
    - No interaction (complementary) between attributes
- Ad hoc
- Lose individual attribute relationships
- All methods make some trade offs

Decision rules: Group Value - (Add)

- A method for combining the preferences of different interest groups into a single recommendation

- General steps:
  - Have each group/individual create a suitability map
  - Have each individual provide weights of influence that the other individuals should have on the output
  - Using linear algebra solve the series of equations to obtain the weights for each individual's output
  - Combine the outputs

- Better for value/utility functions, can lead to paradoxical results for ordering techniques

Decision rules: Ideal Point - (Add)

- Alternatives are based on their separation from the ideal point
- General steps
  - Create a weighted suitability surface for each attribute
  - Determine the maximum value
  - Determine the minimum value
  - Calculate the relative closeness to the ideal point

$$C_{i+} = \frac{s_{j-}}{s_{i+} + s_{i-}}$$

  - Rank alternatives
- Good when the attributes have dependencies

The framework

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Sensitivity analysis (and error analysis)

- Systematically change one parameter slightly
- See how it affects the output
- Error
  - Input data
  - Parameters
  - Address by calculations or through simulations

The framework

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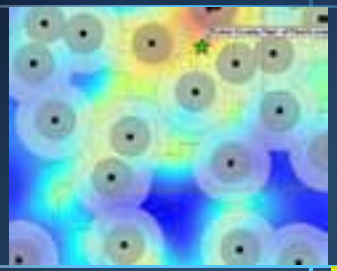
- How to create a suitability model and the associated issues
- Demonstration
- Looking into the values and weights a little deeper
- Demonstration
- Fuzzy logic

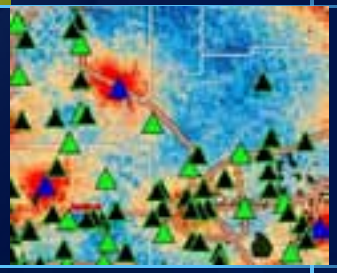


Demo 2: Non-linear Suitability Model

Use functions for reclassification

Reclassify

Raster Calculator

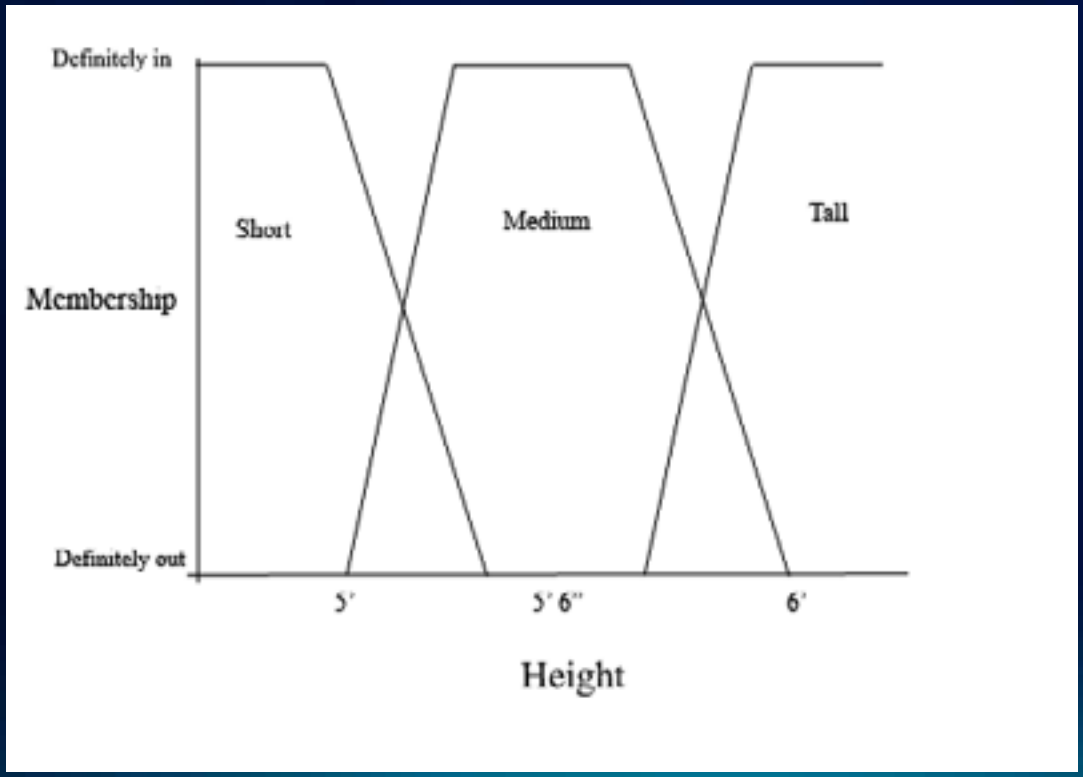


Suitability model steps – Fuzzy analysis

- **Determine significant** layers for the phenomenon being modeled
- **Reclassify** the values of each layer into a relative scale
- **Weight** the importance of each layer
- **Add** the layers together
- **Analyze** the results and make a decision

Fuzzy overlay – The problem

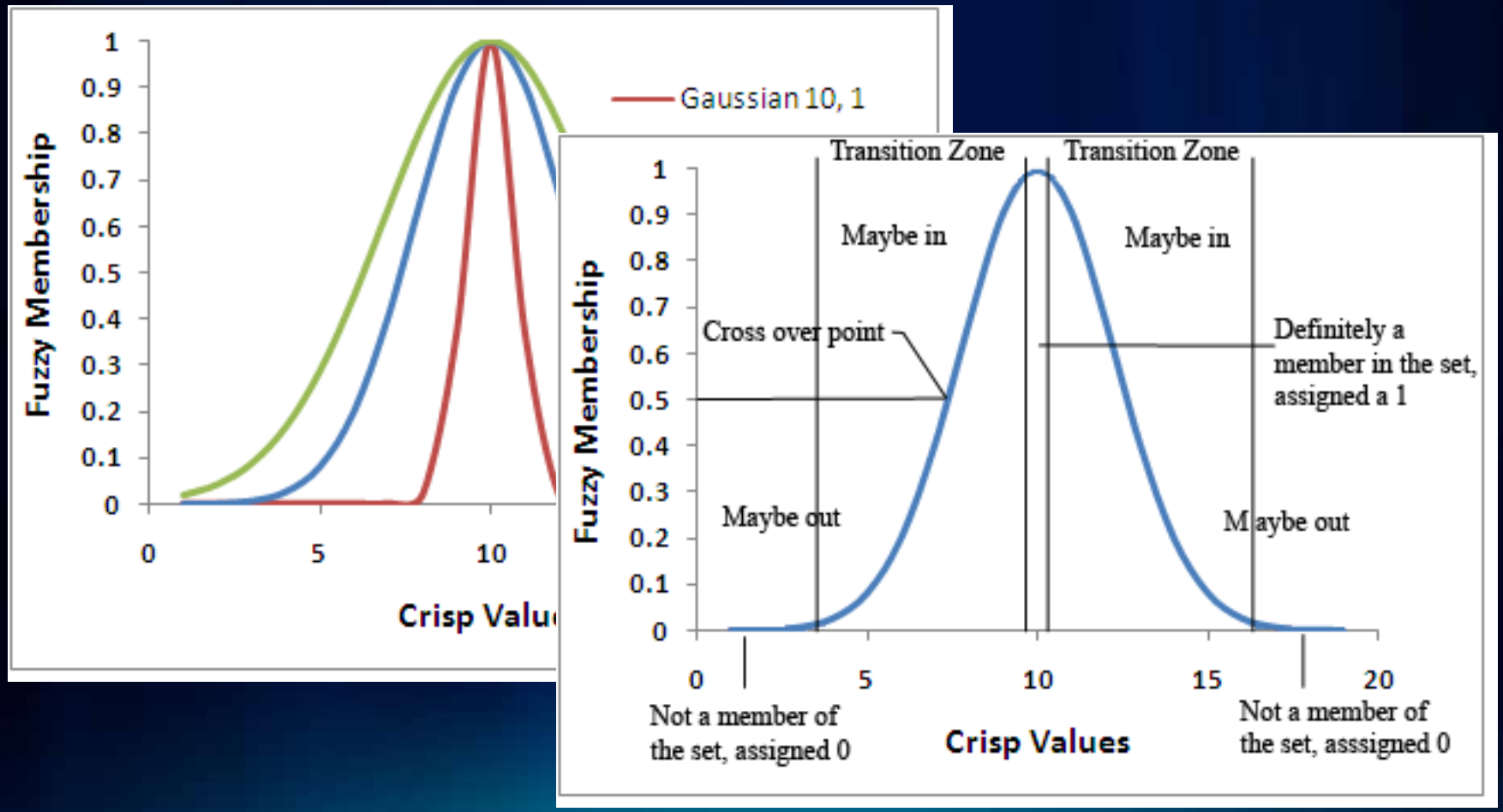
- Inaccuracies in geometry
- Inaccuracies in classification process



Fuzzy overlay - Reclass

- Predetermined functions are applied to continuous data
- 0 to 1 scale of possibility belonging to the specified set
- Membership functions
  - FuzzyGaussian – normally distributed midpoint
  - FuzzyLarge – membership likely for large numbers
  - FuzzyLinear – increase/decrease linearly
  - FuzzyMSLarge – very large values likely
  - FuzzyMSSmall - very small values likely
  - FuzzyNear- narrow around a midpoint
  - FuzzySmall – membership likely for small numbers

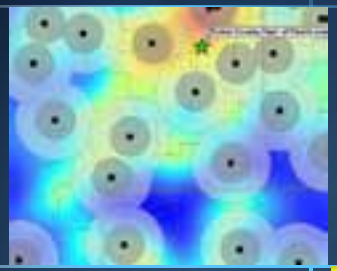
Fuzzy overlay - Reclass

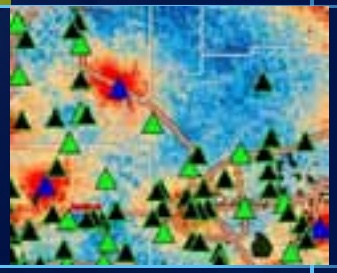


Fuzzy overlay - (Add)

- Meaning of the reclass values - possibilities therefore no weighting
- Analysis based on set theory
- Fuzzy analysis
  - And - minimum value
  - Or – maximum value
  - Product – values can be small
  - Sum – not the algebraic sum
  - Gamma – sum and product

Demo 3: Fuzzy Analysis





Fuzzification

Fuzzy Overlay

Summary

- Problems with:
  - Minimum size requirements (raster)
  - If locating one alternative influences the locating of another
- Can be done in the vector world
- Multiple ways to derive values and weights
- Multiple ways to combine the attributes
- Your values and weights depend on the goal of the problem, the data, and understanding of the phenomenon
- The values and weights used can dramatically change the results

Carefully think about the values and weights you use

ArcGIS Spatial Analyst Technical Sessions

- **An Introduction - Rm 1 A/B**

Tuesday, July 12, 8:30AM – 9:45AM
Thursday, July 14, 10:15AM – 11:30AM

- **Suitability Modeling - Rm 1 A/B**

Tuesday, July 12, 1:30PM – 2:45PM
Thursday, July 14, 8:30AM – 9:45AM

- **Dynamic Simulation Modeling – Rm 5 A/B**

Wednesday, July 13, 8:30AM – 9:45AM

- **Raster Analysis with Python – Rm 6C**

Tuesday, July 12, 3:15PM – 4:30PM
Wednesday, July 13, 3:15PM – 4:30PM

- **Creating Surfaces – Rm 5 A/B**

Wednesday, July 13, 1:30PM – 2:45PM

ArcGIS Spatial Analyst Short Technical Sessions

- **Creating Watersheds and Stream Networks – Rm 6A**

Tuesday, July 12, 10:40AM – 11:00AM

- **Performing Image Classification – Rm 6B**

Tuesday, July 12, 8:30AM – 8:50AM

- **Performing Regression Analysis Using Raster Data – 6B**

Tuesday, July 12, 8:55AM – 9:15AM

Demo Theater Presentations – Exhibit Hall C

- **Modeling Rooftop Solar Energy Potential**

Tuesday, July 12, 3:30PM – 4:00PM

- **Surface Interpolation in ArcGIS**

Wednesday, July 13, 9:00AM – 10:00AM

- **Getting Started with Map Algebra**

Wednesday, July 13, 10:00AM – 11:00AM

- **Agent-Based Modeling**

Wednesday, July 13, 5:30PM – 6:00PM

Open to Questions

…Thank You!

Please fill the evaluation form.

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