Esri Federal User Conference

GIS: The Geographic Approach for the Nation

ArcGIS Spatial Analyst Suitability Modeling

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esri

Outline

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

Manipulation of Raster Data

- 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 function it must know
  - What is its value
  - What function to apply
  - What other cell locations to include in the calculations
    - Within a grid
    - Between grids

Discrete and Continuous Phenomena

- **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)

Outline

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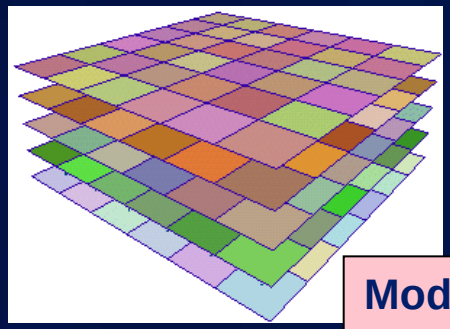
Types of Problems

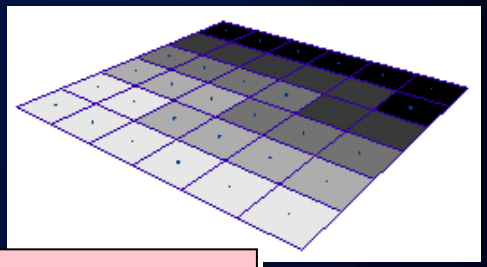
- Where to site a new housing development?
- Which sites are better for deer habitat?
- Where is economic growth most likely to occur?
- Where is the population at the greatest risk if a chemical spill were to happen?

Reality

GIS layers



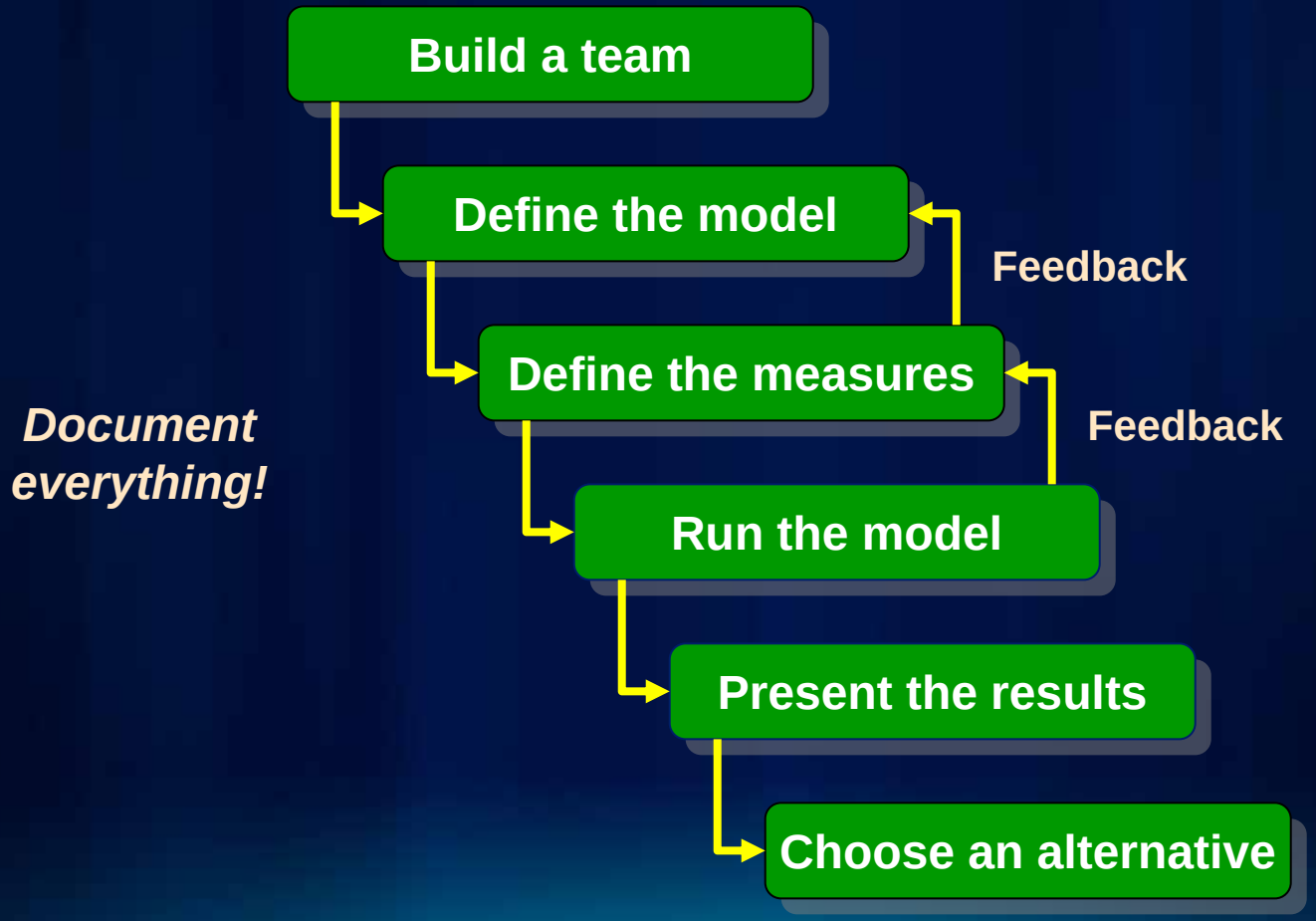
Suitability for store



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

The weighted suitability methodology

- There is a fairly standard methodology to follow:

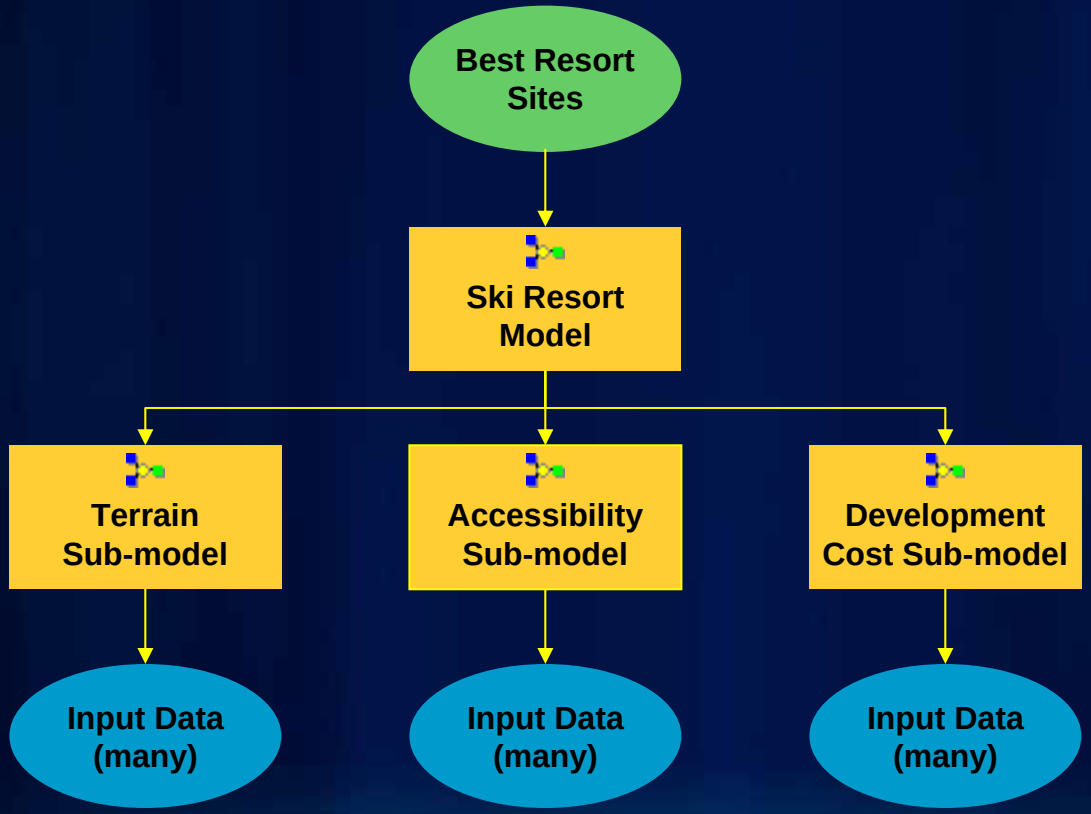


Define the model

- This is a team activity
  - Stakeholders, decision makers
- Define the problem
  - “Locate a ski resort”
- Identify issues
  - “Accessible to skiers”
- Determine how to measure
  - “Drive time to the city”
- Obtain GIS data
  - DEM, roads, land use, and houses

Break big models into sub-models

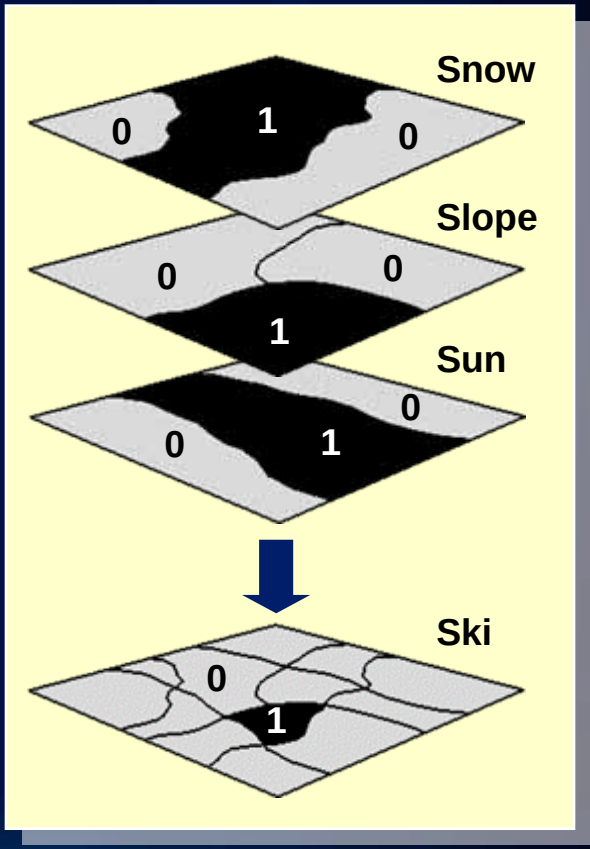
- Helps clarify relationships, simplifies problems



Binary suitability models

- 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

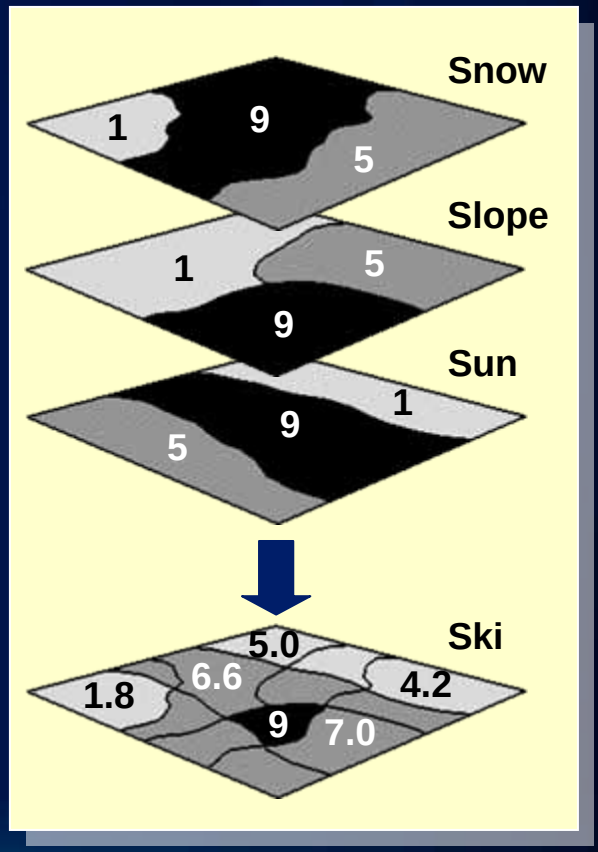


Weighted suitability models

- 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 harder

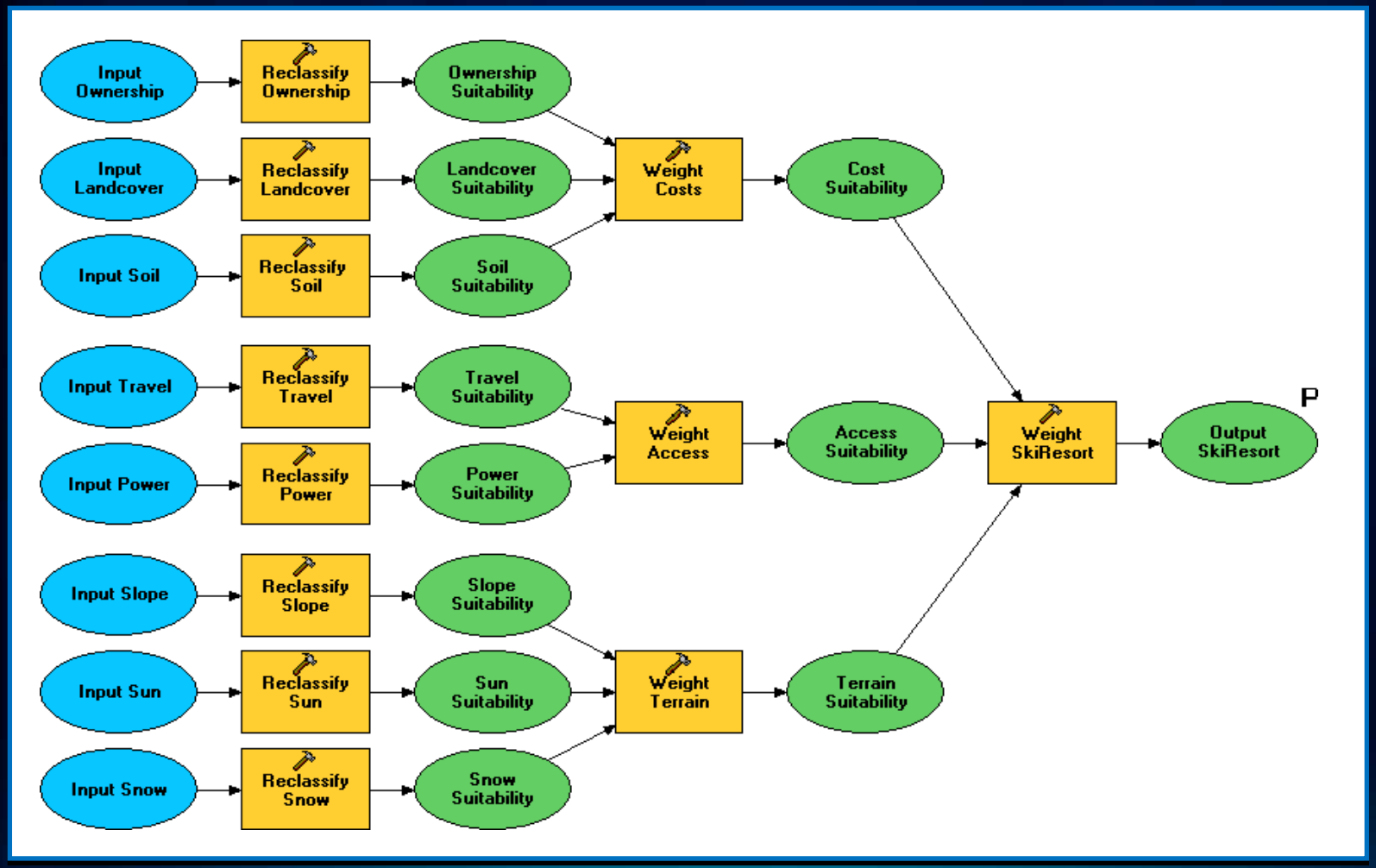


Suitability Modeling Steps

- **Determine significant** layers to 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

ESRI Modeling software

- ArcGIS incorporates model building capabilities



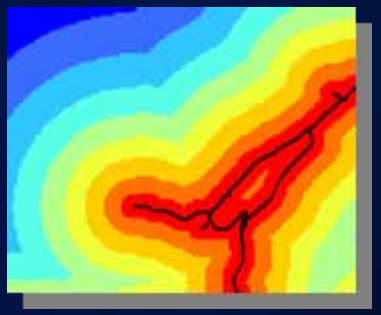
Determining significant layers

- 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

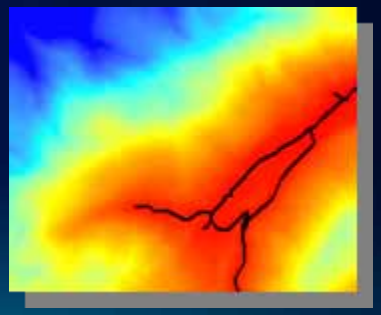
Reclassify - Decide how to measure the issues

- Base data may not useful for measuring issues
  - Need to measure access, not road location

- May be very easy:
  - ArcGIS Spatial Analyst tools
  - Like distance to roads

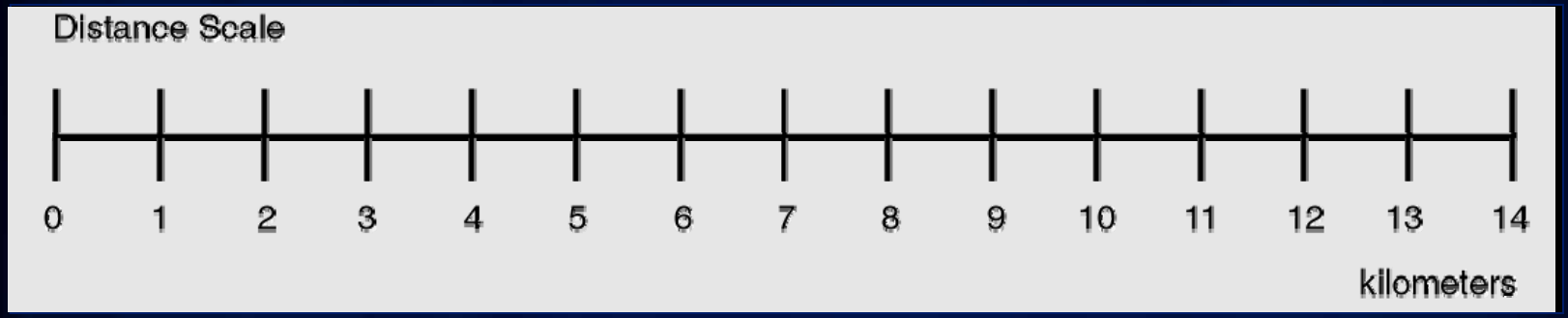


- May be harder:
  - Require another model
  - Like travel time to roads

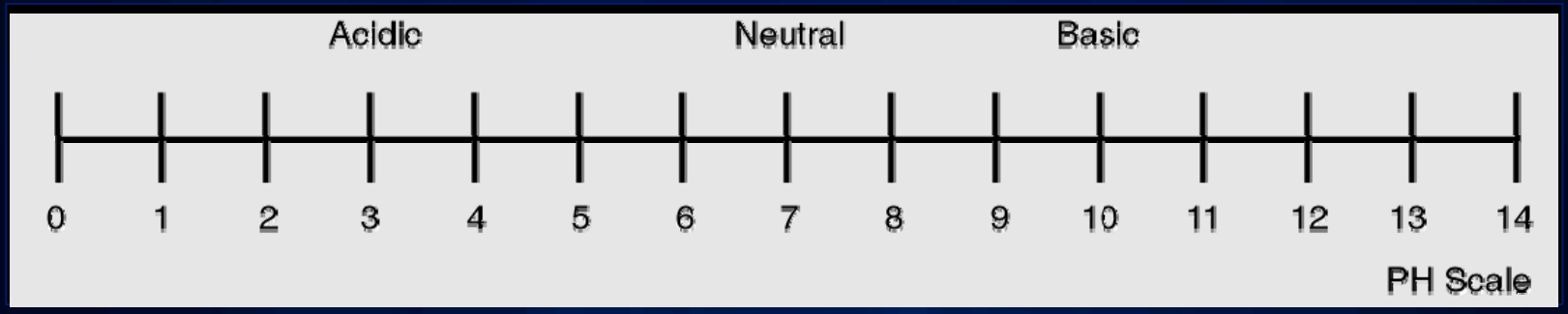


Reclassify -Types of Values

Ratio:



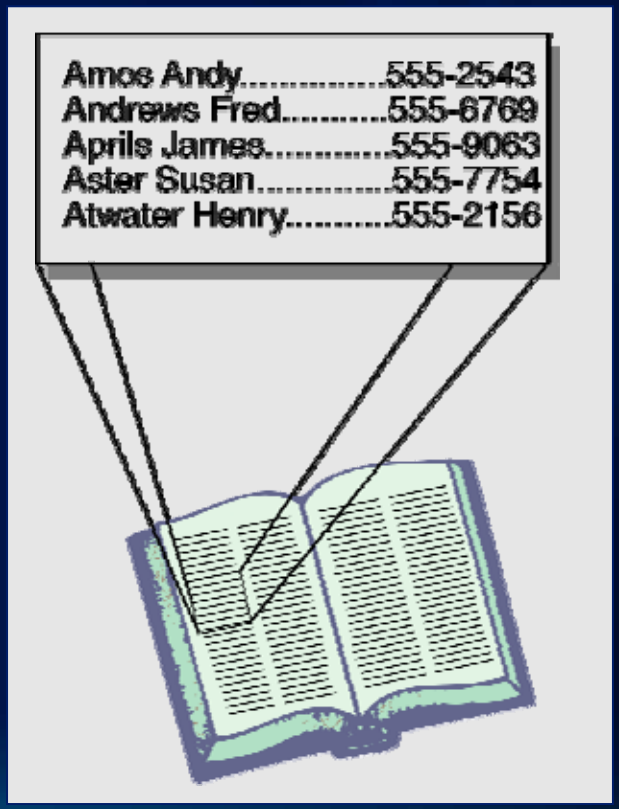
Interval:



Reclassify -Types of Values (cont.)

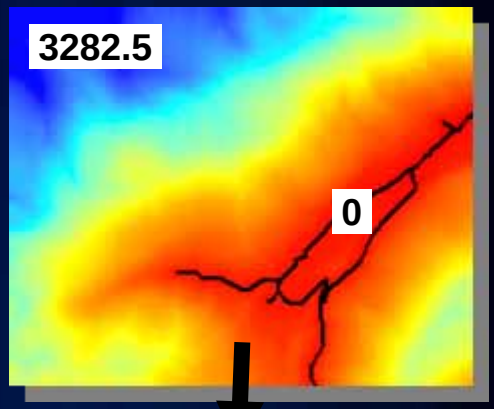
Ordinal:

Nominal:



Reclassify - Define a scale of suitability

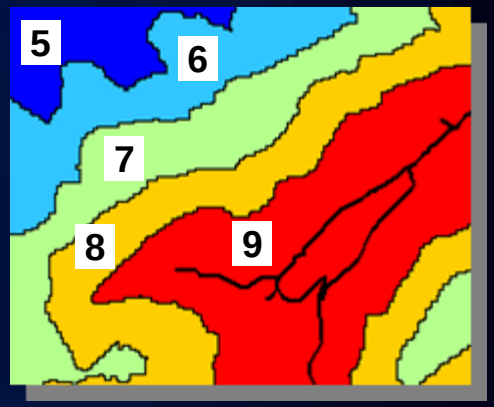
- **Define a scale for suitability**
  - Many possible; typically 1 to 9 (worst to best)
  - Reclassify layer values into relative suitability
  - Use the same scale for all layers in the model



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

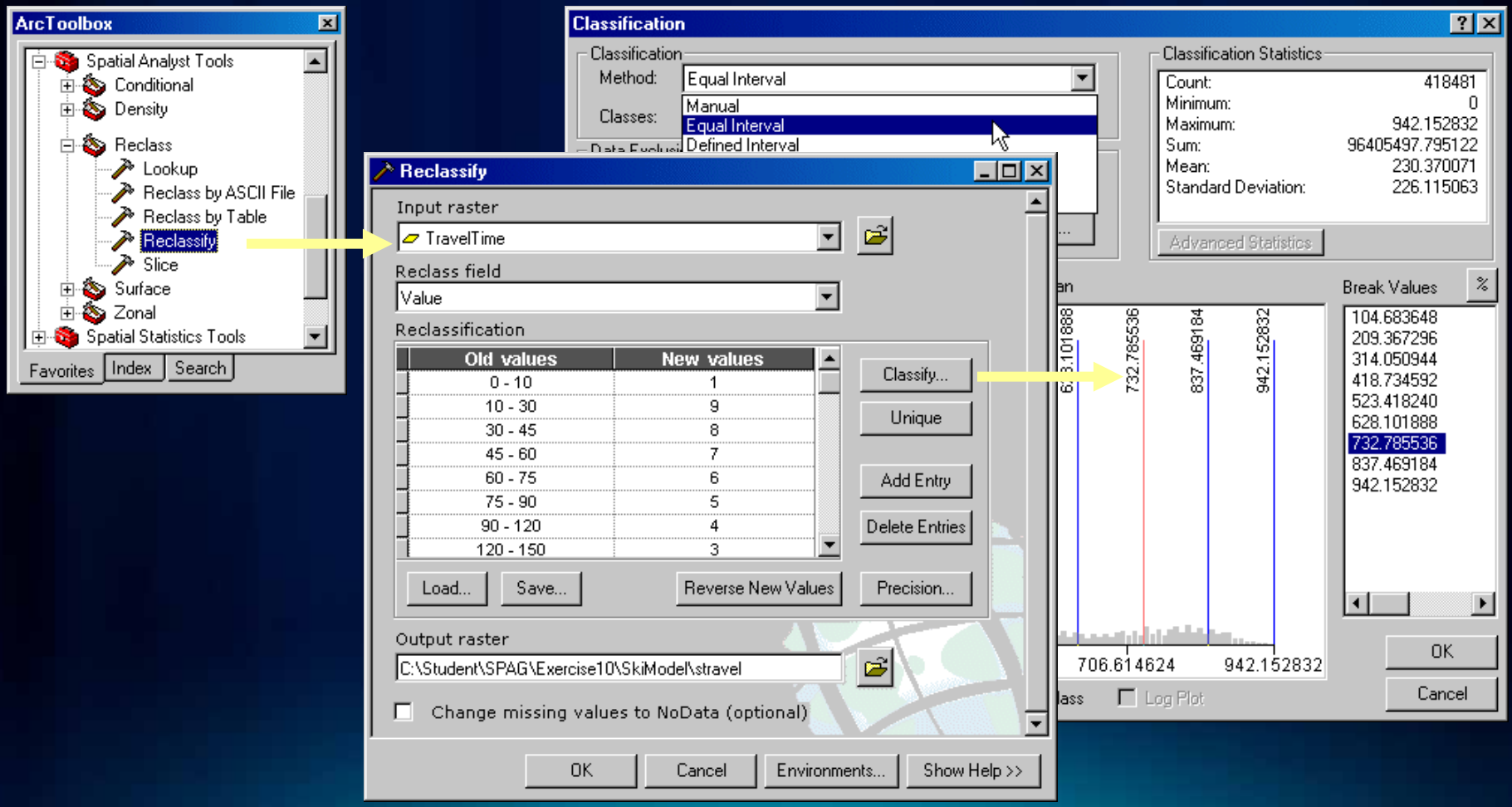


Suitability for Ski Resort

Within and between layers

The Reclassify tool

- May use to convert measures into suitability

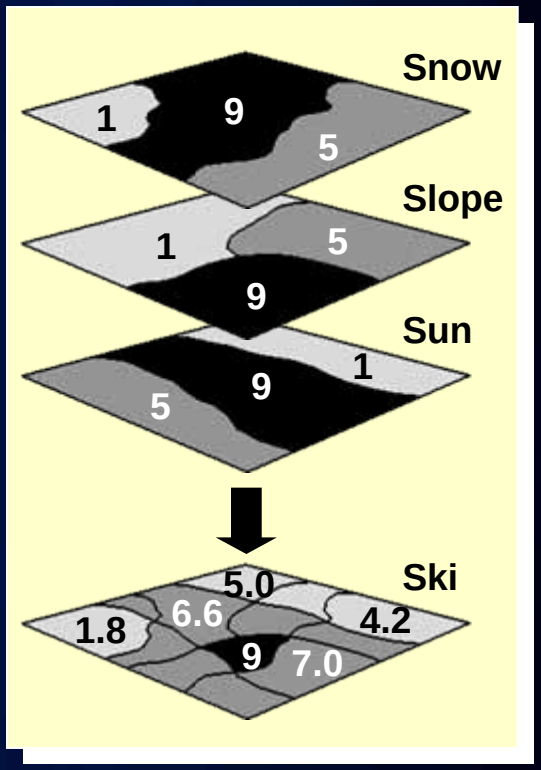


Suitability Modeling Steps

- **Determine significant** layers to 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

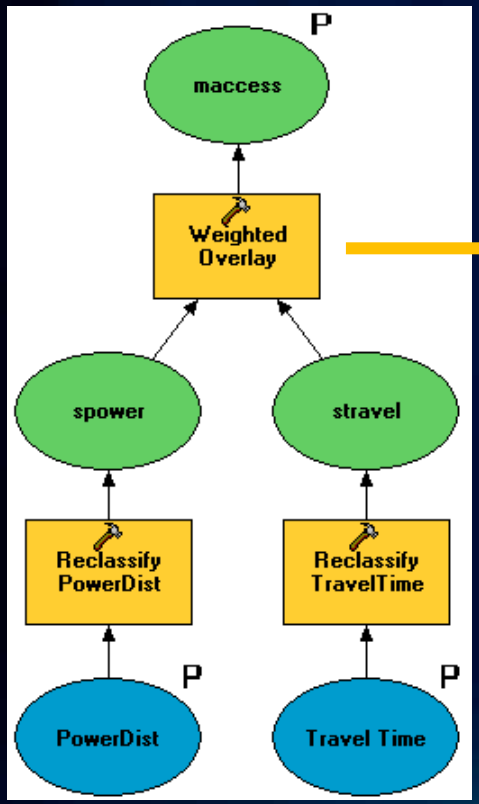
- Certain layers will be more significant than others and must be weighted appropriately before they are combined
  - For example, soil type and slope may be more significant to house siting than aspect
- Use the Weighted Overly tool
- Or , use a Map Algebra expression:

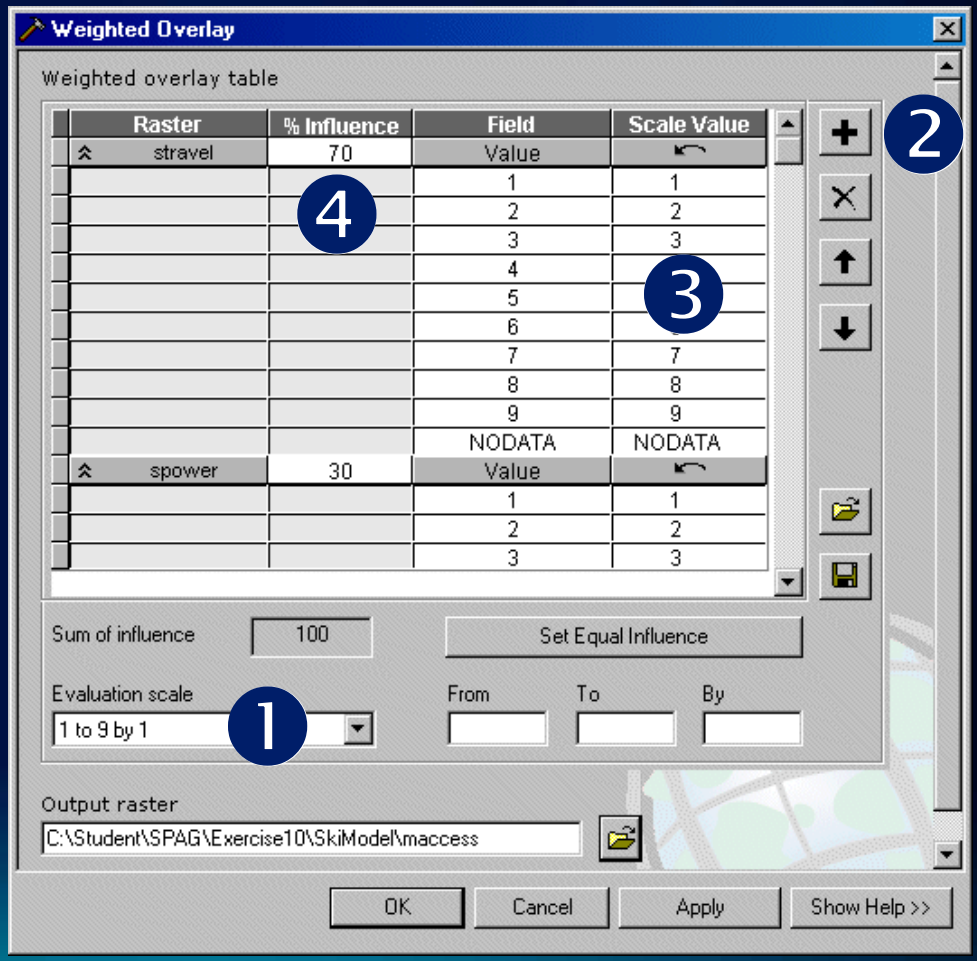



```
Ski = ([Snow] * 0.5) + ([Slope] * 0.3) + ([Sun] * 0.2)
```

The Weighted Overlay tool

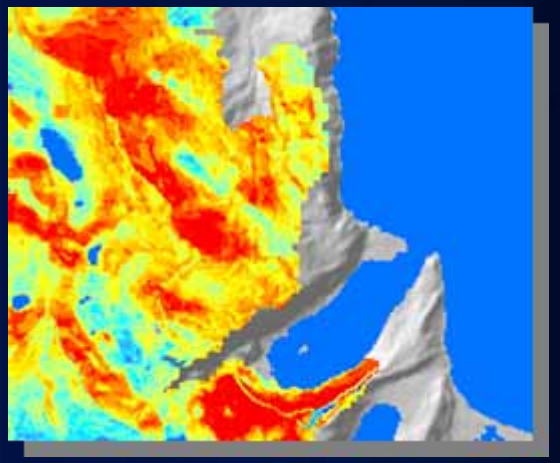
- Weights and combines multiple inputs



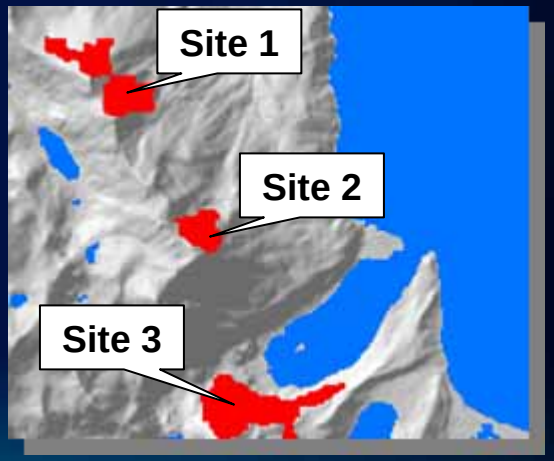


Analyze - find the best locations

- 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 indicate 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 reclassified and weighted values.**

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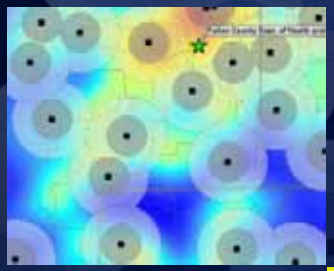
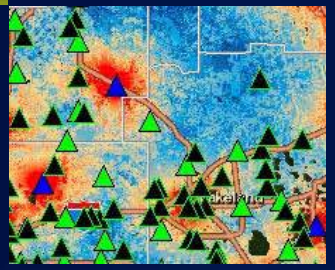
Demo Title: Suitability model





Reclass

Weight

Add

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
  - Available understanding of the phenomenon
- Provide you with alternative approaches
- To make you think about the values and weights

The 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

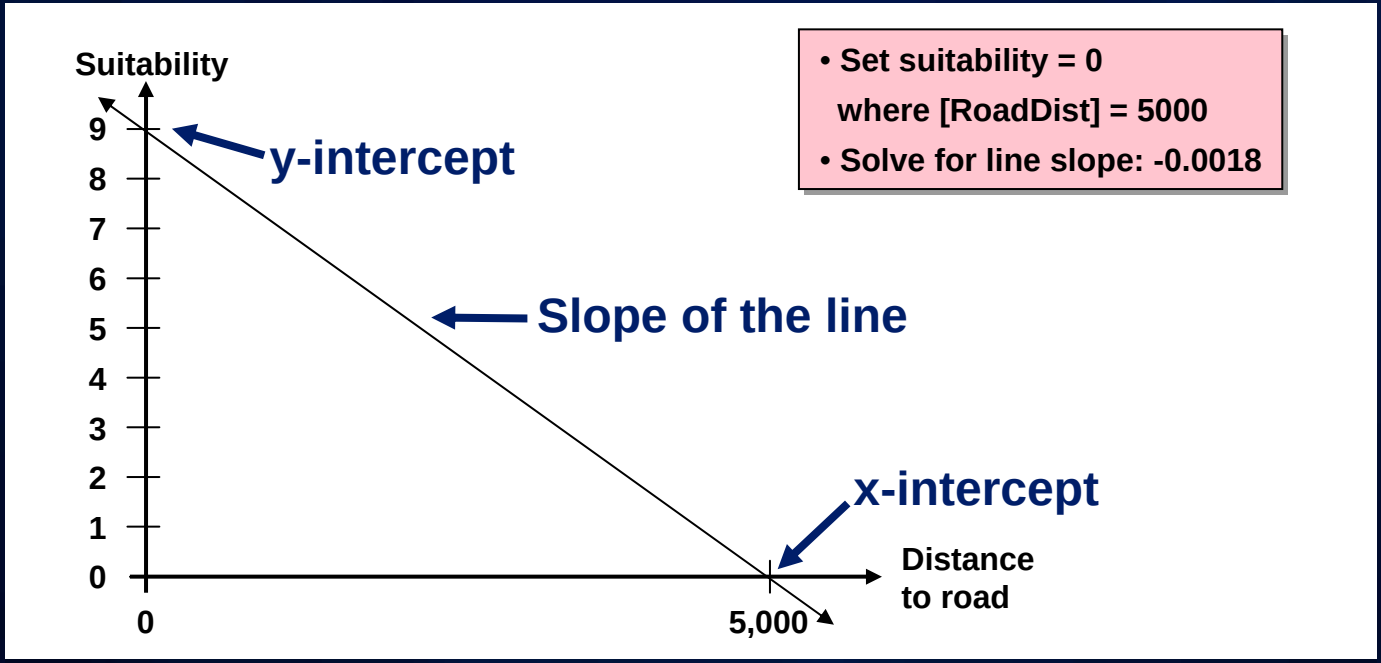
(Determine significant layers and Reclass)

- **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**



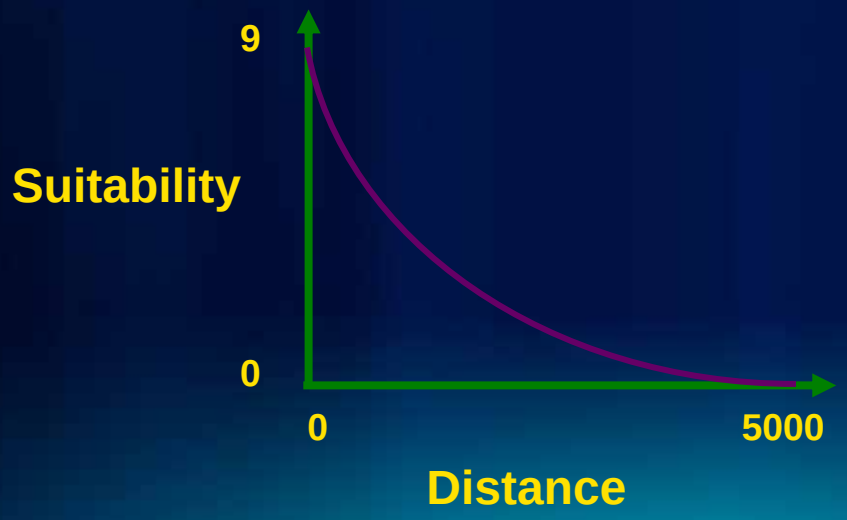
Implement with Map Algebra or a model:

```
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 infeasible 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

Distance to water

The framework

- The one presented is:
  - Determine significant layers
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Criterion Weighting - (Weight)

- 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 - (Weight)

- 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 – (Weight)

- 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

- The one presented is:
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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

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Sensitivity Analysis (and Error Analysis)

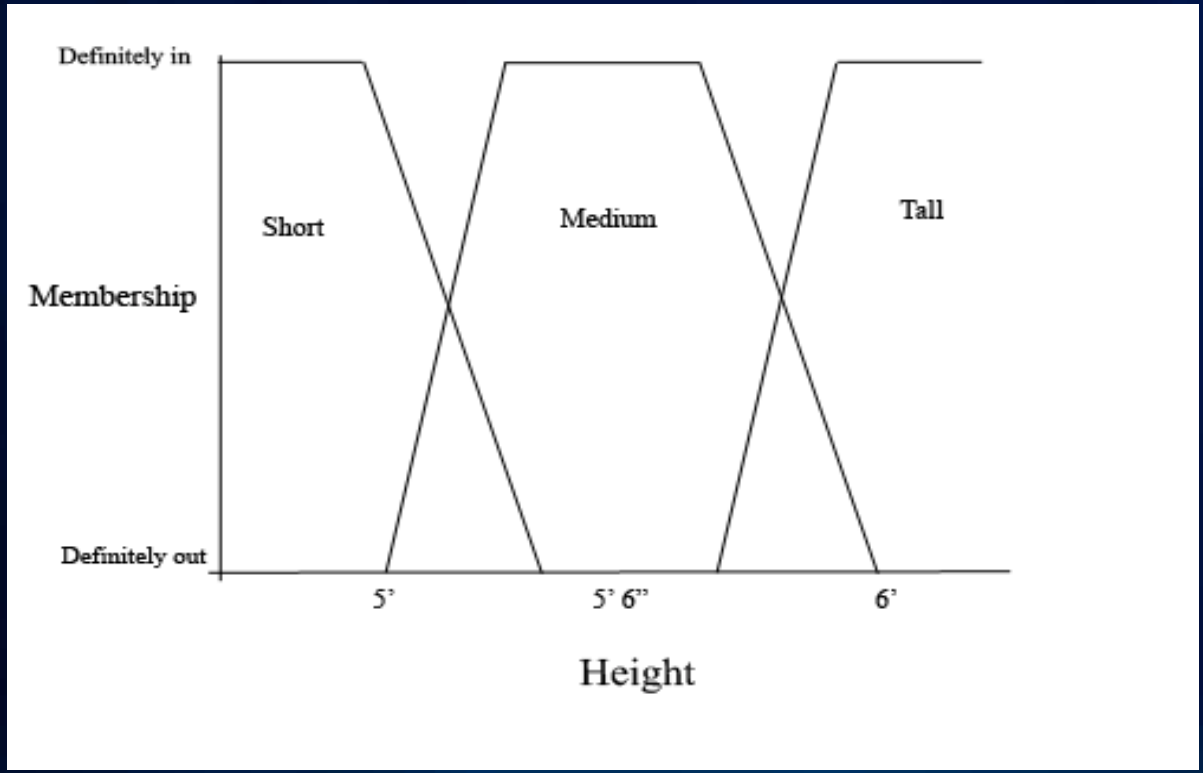
- Systematically change one parameter slightly
- See how it affects the output
- Error
  - Input data
  - Parameters
  - Address by calculations or through simulations

Suitability Modeling Steps – Fuzzy analysis

- **Determine significant** layers to 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 Analysis – The problem

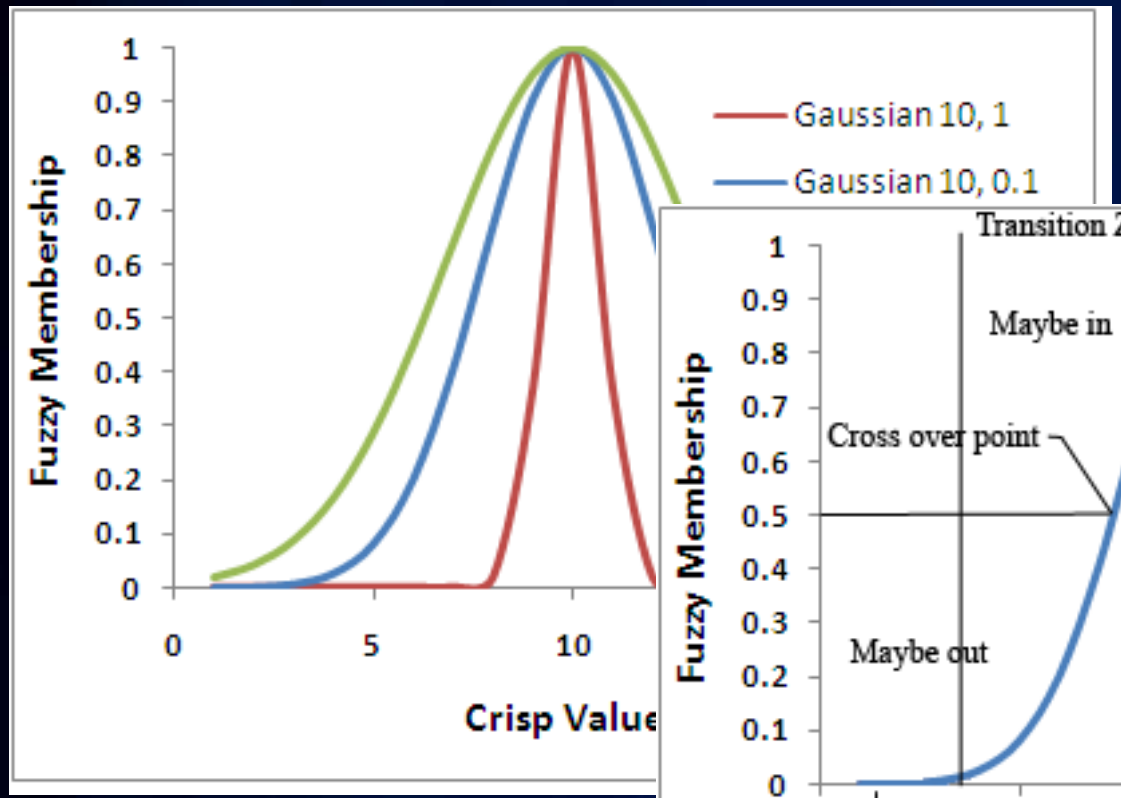
- Inaccuracies in geometry
- Inaccuracies in classification process

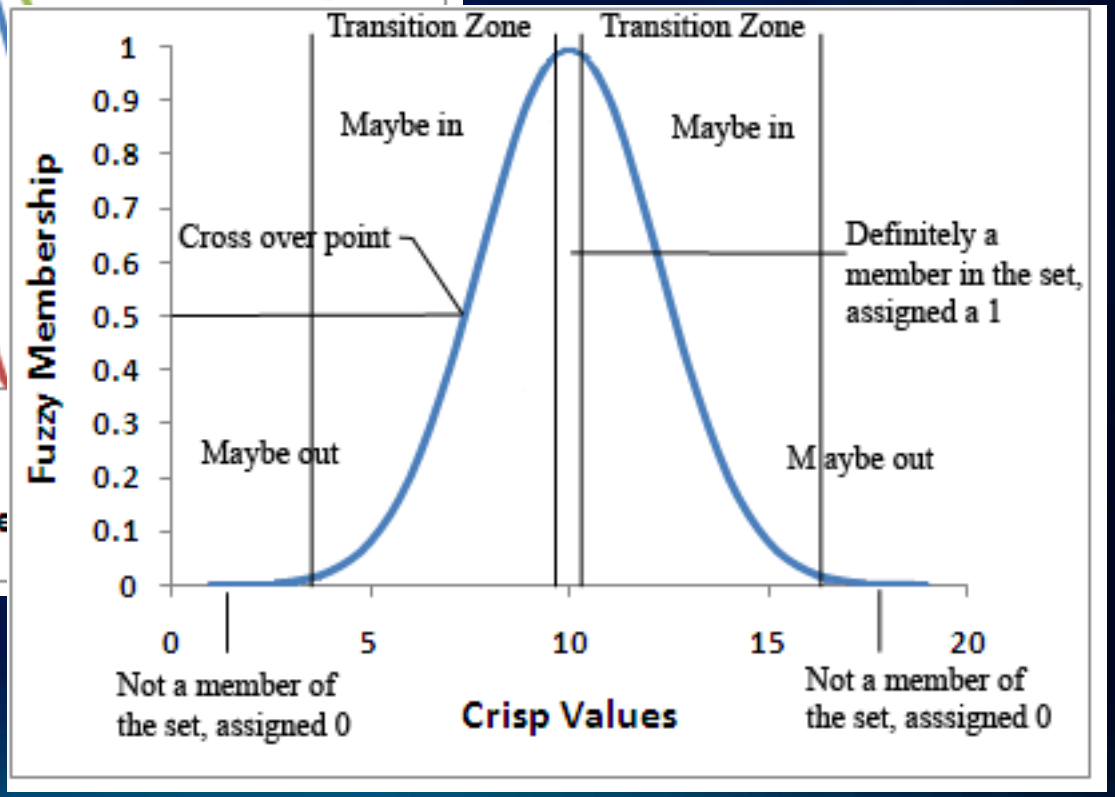


Fuzzy Analysis - Reclass

- 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 Analysis - Reclass





Fuzzy Analysis - (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

The Framework

- First part of the presentation:
  - Determine significant layers
  - Reclassify
  - Weight
  - Add
  - Analyze

- The decision support world:
  - Problem definition
  - Evaluation criteria
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  - Criterion weights
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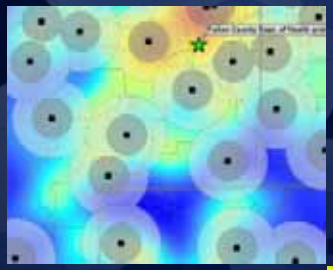
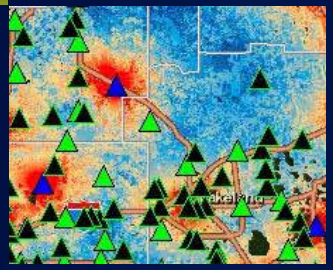
- Demonstration
- Looking into the values and weights a little deeper
- Demonstration
- Questions and answers





Demo Title: Non-linear suitability modeling

- Use functions for reclassification
- Fuzzy analysis

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

Open to Questions

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