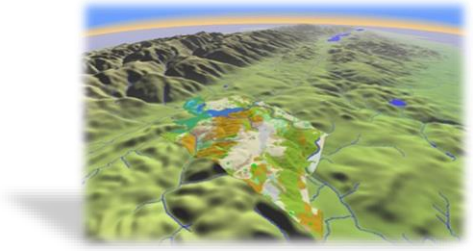
NICHOLAS SCHOOL OF THE ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY



ENVIRON 761:
Fuzzy Logic and GIS

Instructor: John Fay

What is fuzzy logic?

Who in this picture is **tall**?

Who is **short**?

Who is **average**?

What is fuzzy logic?

- Binary logic → Output is 1 (true) or 0 (false)

Tall > 6’

Name	Height	Tall (binary)
Natalie Portman	5'3"	0
Scarlett Johansson	5'3"	0
Haley Atwell	5'7"	0
Mark Ruffalo	5'8"	0
Cobie Smeulders	5'8"	0
Robert Downy Jr.	5'8.5"	0
Don Cheadle	5'8.5"	0
Jeremy Renner	5'10"	0
Chris Evans	6'	0
Tom Hiddleston	6'2"	1
Chris Pratt	6'2"	1
Samuel L. Jackson	6'2.5“	1
Chris Hemsworth	6'2.75"	1
Dave Bautista	6'4.5"	1

What is fuzzy logic?

- Fuzzy logic is an alternative to binary logic.
- Outputs are not limited to the sets of **1** and **0**.
  - e.g. Tall or not tall
- Instead, it assigns *fuzzy* values based on degree of membership to the sets of 1 and 0…
  - e.g. 80% tall & 20% not tall
- Fuzzy values are assigned based on fuzzy membership functions…

What is fuzzy logic?

Sorites paradox:

If I remove one sand grain from a pile, it's still a pile, but if I carry on, it's soon not a pile…

At what point is a pile no longer a pile?

What is fuzzy logic?

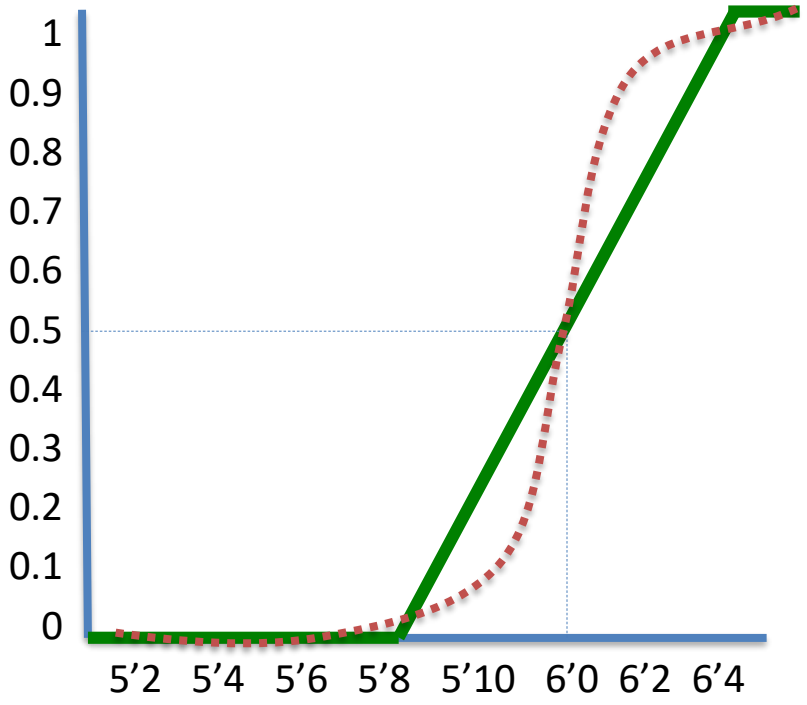
Tall > 6’

Name	Height	Tall (binary)	Tall (fuzzy)	
Natalie Portman	5'3"	0	0.00	Definitely not tall
Scarlett Johansson	5'3"	0	0.00	
Haley Atwell	5'7"	0	0.00	
Mark Ruffalo	5'8"	0	0.20	
Cobie Smeulders	5'8"	0	0.20	
Robert Downy Jr.	5'8.5"	0	0.25	
Don Cheadle	5'8.5"	0	0.25	
Jeremy Renner	5'10"	0	0.30	
Chris Evans	6'	0	0.50	
Tom Hiddleston	6'2"	1	0.60	Mostly tall
Chris Pratt	6'2"	1	0.60	
Samuel L. Jackson	6'2.5"	1	0.70	
Chris Hemsworth	6'2.75"	1	0.80	
Dave Bautista	6'4.5"	1	1.00	→ Definitely tall

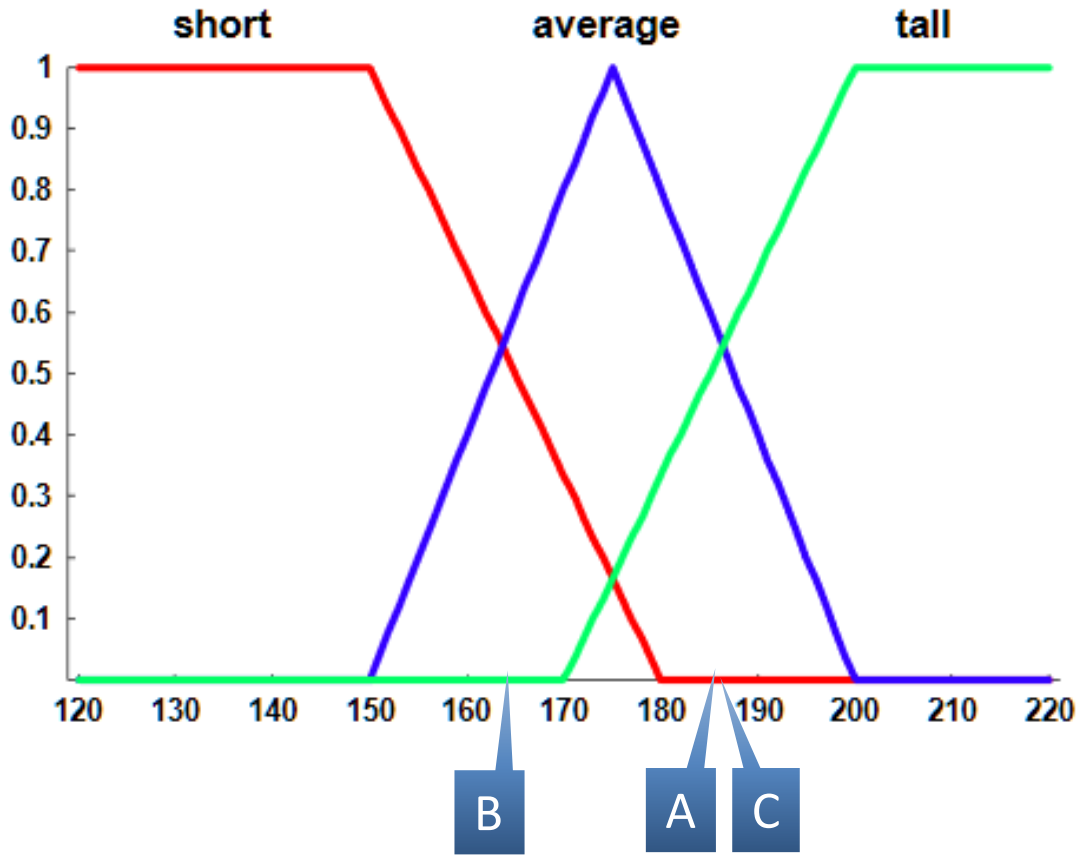
How are fuzzy values calculated?

- Answer: *Membership functions*

Name	Height	Tall (binary)	Tall (fuzzy)
Natalie Portman	5'3"	0	0.00
Scarlett Johansson	5'3"	0	0.00
Haley Atwell	5'7"	0	0.00
Mark Ruffalo	5'8"	0	0.20
Cobie Smeulders	5'8"	0	0.20
Robert Downy Jr.	5'8.5"	0	0.25
Don Cheadle	5'8.5"	0	0.25
Jeremy Renner	5'10"	0	0.30
Chris Evans	6'	0	0.50
Tom Hiddleston	6'2"	1	0.60
Chris Pratt	6'2"	1	0.60
Samuel L. Jackson	6'2.5"	1	0.70
Chris Hemsworth	6'2.75"	1	0.80
Dave Bautista	6'4.5"	1	1.00



Membership functions: multiple classes



Short: < 165cm

Average: > 165cm & < 185cm

Tall: > 185cm

A – 185cm

B – 165cm

C – 186cm

binary

	Short	Average	Tall
A	0	1	0
B	1	0	0
C	0	0	1

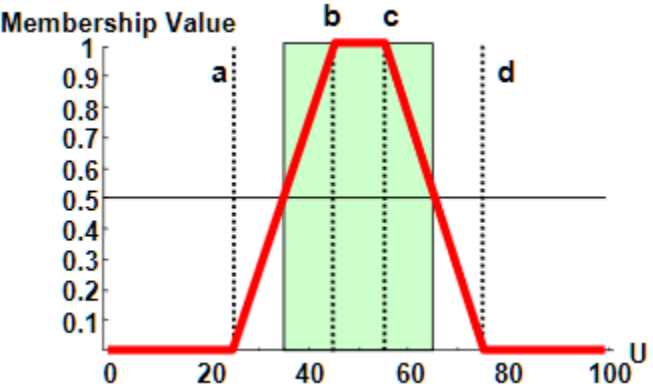
fuzzy

	Short	Average	Tall
A	0.00	0.60	0.50
B	0.50	0.60	0.00
C	0.00	0.56	0.53

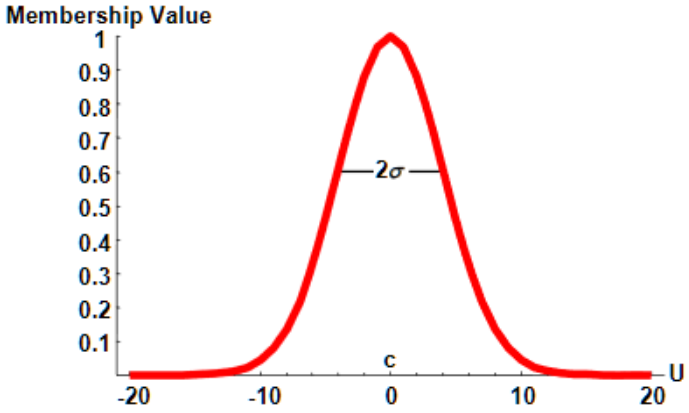
Fuzzy membership functions

Transform “crisp” values into values between 0 and 1, indicating strength of membership in a set…

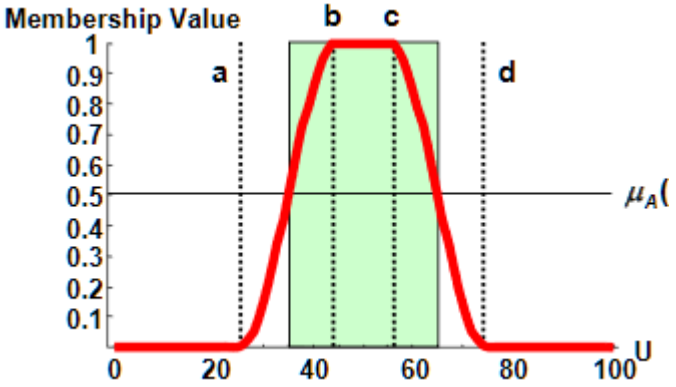
Linear



Gaussian



Sinusoidal



Fuzzy inference

- In binary logic:
  - Premise 1: *If x = A, then y = B*
  - Premise 2: x is A
  - Conclusion: y is B

  - If grass is wet, it has rained.
  - The grass is wet, therefore it has rained.

Fuzzy inference

- In fuzzy logic:
  - Premise 1: *If x = A, then y = B*
  - Premise 2: x is A' *(an acceptably likely member of A)*
  - Conclusion: y is B' *(an acceptably likely member of B)*

  - If grass is long, I should mow.
  - The grass is *fairly* long, therefore *maybe* I'll mow
  - The grass is *really* long, I'd better mow right now!

Fuzzy inference: more conditions

If grass is long and it isn't too hot, I should mow?

Rules:

- Grass is long, not too hot: I should mow now!
- Grass is not very long, not too hot: I'll mow later.
- Grass is long, too hot: I may mow now.
- Grass is not very long, too hot: I'll mow later.

Another example…

Risk analysis based on degrees of risk ranging from 1 (low risk) to 4 (very high risk).

- If slope is **flat** & aspect is **favorable**, then risk is **1**.
- If slope is **steep** & aspect is **favorable**, then risk is **2**.
- If slope is **flat** & aspect is **unfavorable**, then risk is **1**.
- If slope is **steep** & aspect is **unfavorable**, then risk is **4**.

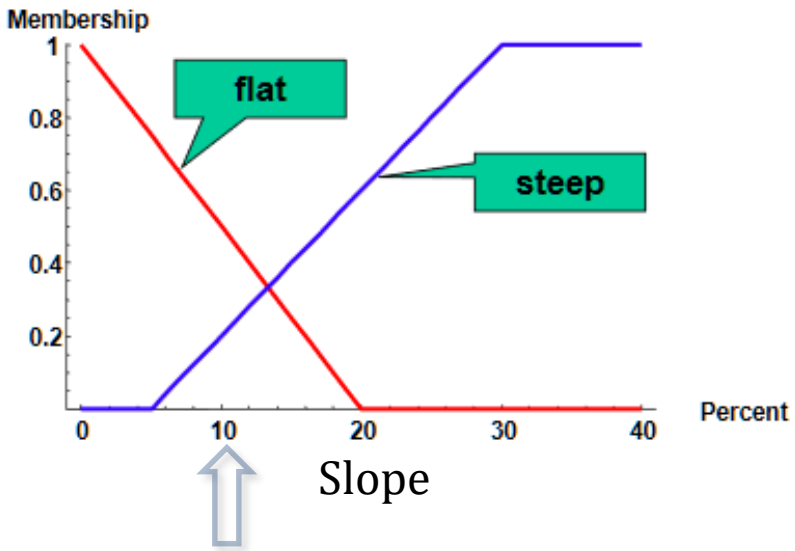
Fuzzy factors

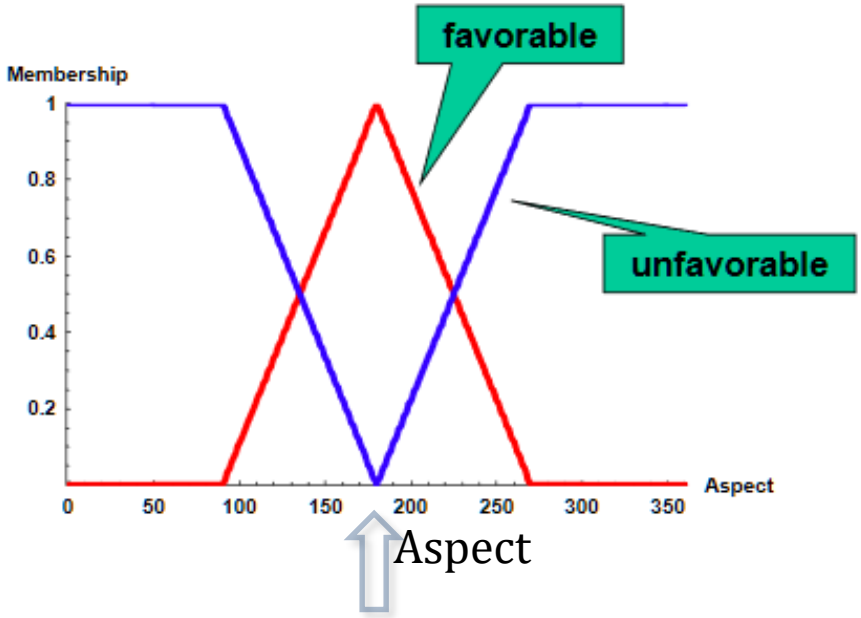
Consequence

http://homepage.univie.ac.at/wolfgang.kainz/Lehrveranstaltungen/ESRI_Fuzzy_Logic/File_2_Kainz_Text.pdf

Another example…

Fuzzy memberships:





Slope of 10% and aspect of 180°

	Slope (s)	Aspect (a)
Flat and Favorable	Rule1	0.5	1
Steep and Favorable	Rule2	0.2	1
Flat and Unfavorable	Rule3	0.5	0
Steep and Unfavorable	Rule4	0.2	0

Computing overall scores..

- Compute the *minimum score* (conservative)
- "Conclusion" is (*score* * *consequence*)

Consequences

Rule 1…risk is **1**.
Rule 2…risk is **2**.
Rule 3…risk is **1**.
Rule 4…risk is **4**.

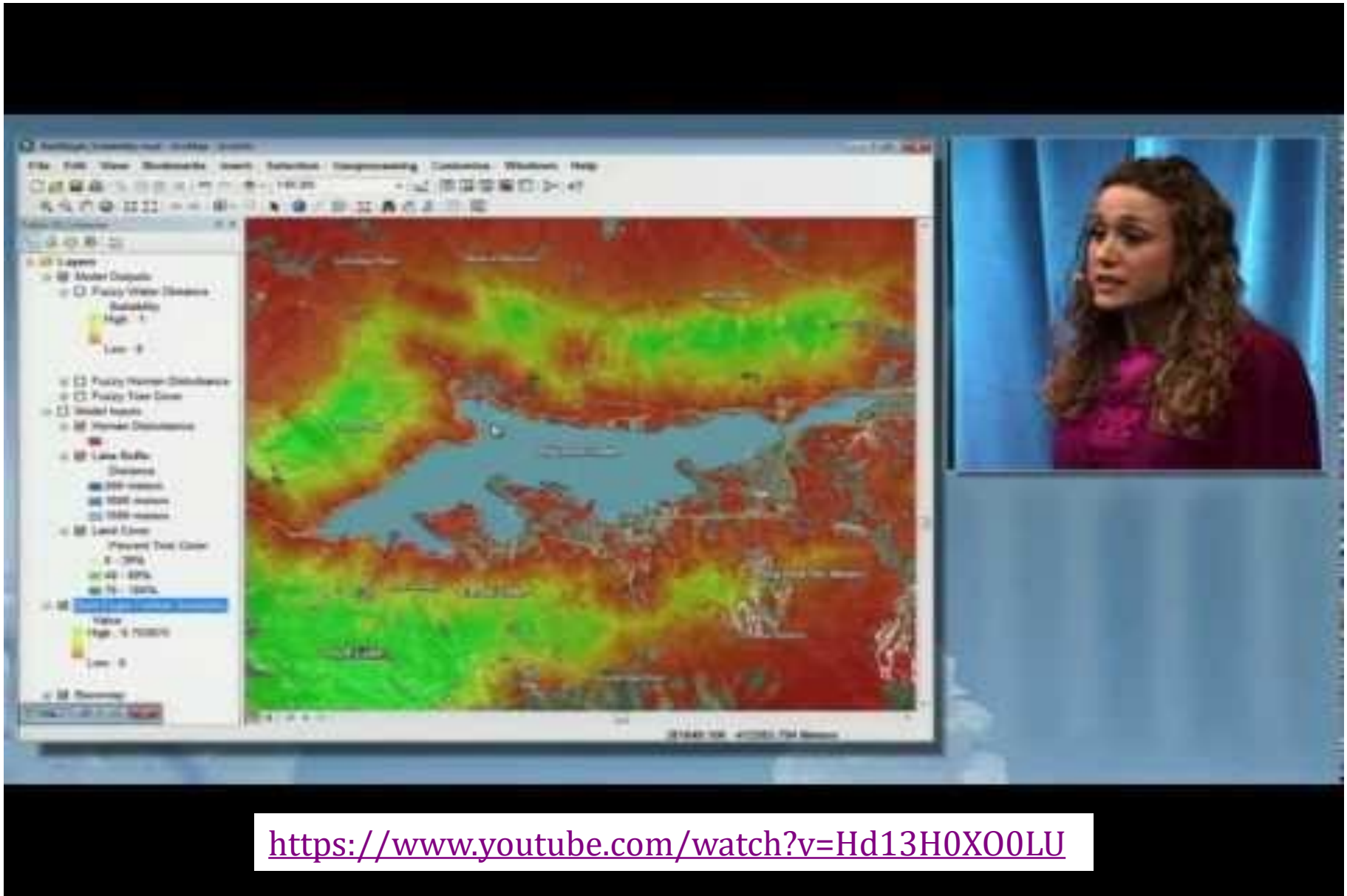
For a slope of 10 percent and an aspect of 180 degrees we have the following results:

	Slope (s)	Aspect (a)	Min(s,a)	Score	Conclusions
Rule1	0.5	1	0.5	1	0.5
Rule2	0.2	1	0.2	2	0.4
Rule3	0.5	0	0	1	0
Rule4	0.2	0	0	4	0

For the final result we get $c' = \frac{0.5+0.4+0+0}{0.5+0.2+0+0} = 1.29$, which means a low risk.

- *"Defuzzification"*: divide Σ(conclusion) by Σ(min score)
  - It's a weighted sum of the risk (1 thru 4 in this case)

Fuzzy Analysis in ArcGIS



https://www.youtube.com/watch?v=Hd13H0XO0LU

Bald eagle habitat criteria

- *Land cover*
  - "Not *too sparse* and not *too dense*…"
  - Areas within 40 and 70% forest cover…
- *Water*
  - "Like to be *close* to water"
  - 500, 1000, 1500 m buffer...
- *Human disturbance*
  - *"Far from* from urban areas, roads, etc…"

Bald eagle habitat criteria

Binary logic:

Resulting pixel values are either 1 or 0

Habitat = 1 if:

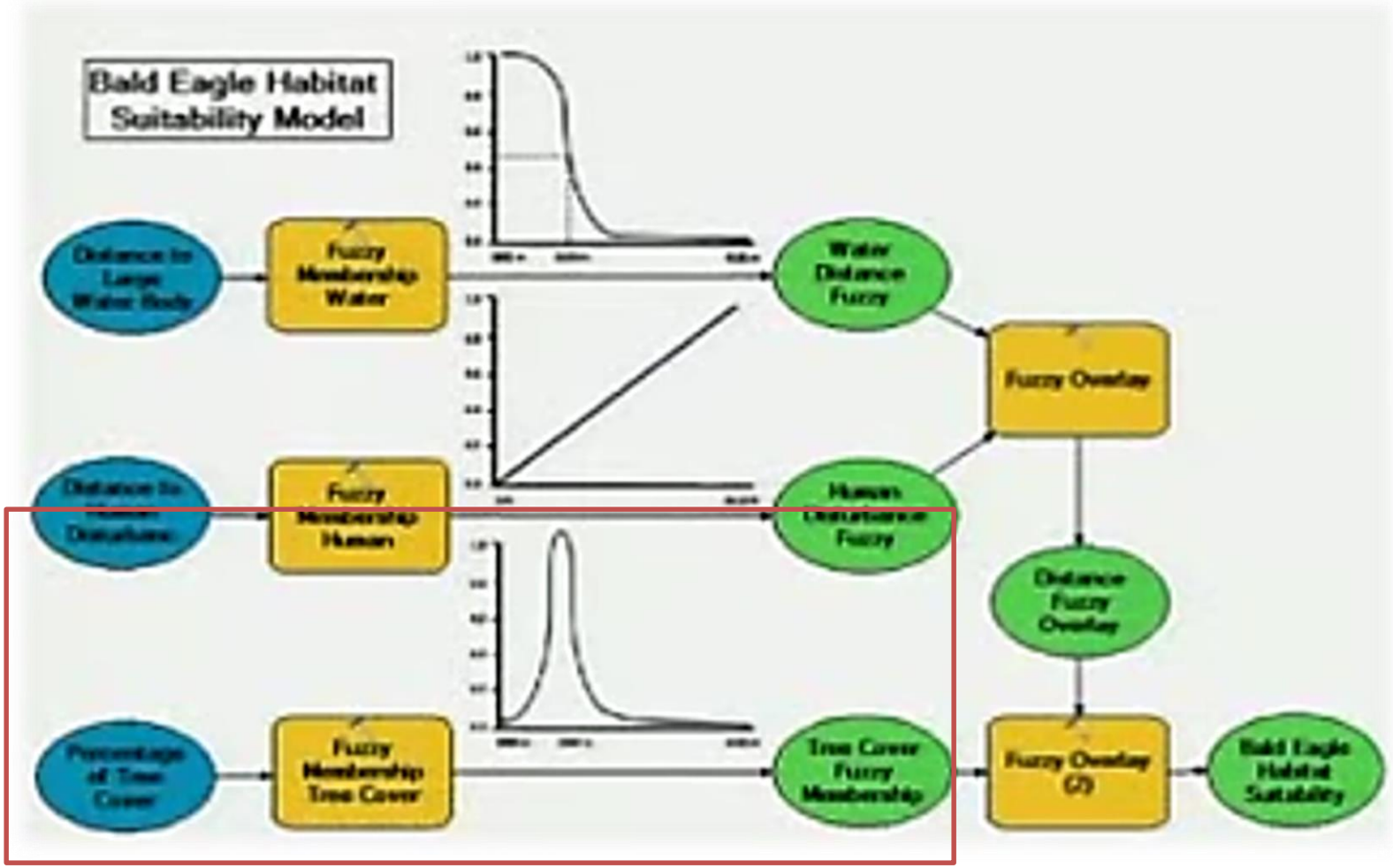
- > 40% forest
  &
- < 70% forest
  &
- < 1000 m of lake or river
  &
- > 1500 m from developed area

Otherwise, Habitat = 0

Bald eagle habitat criteria

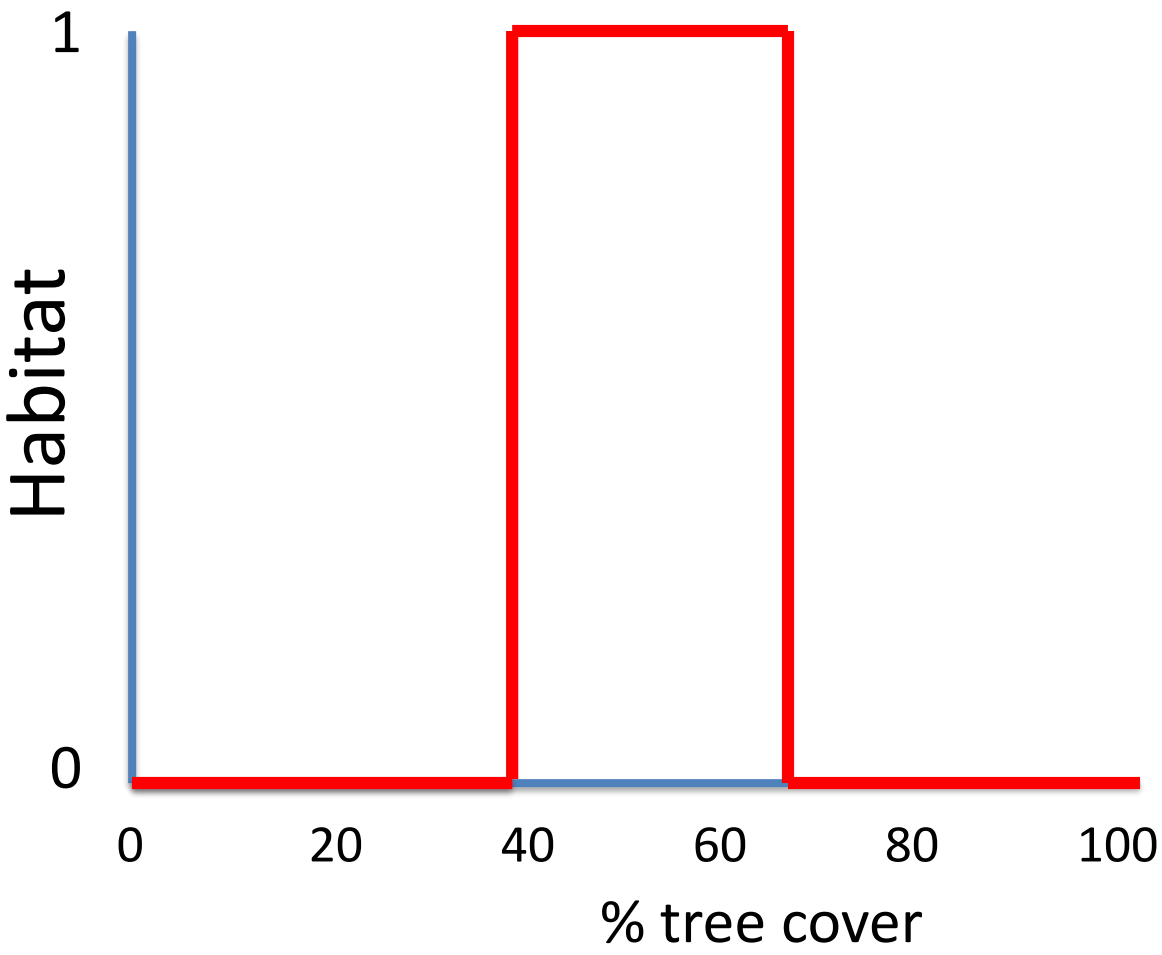
Fuzzy logic:

Results are a ***continuum*** between 1 and 0



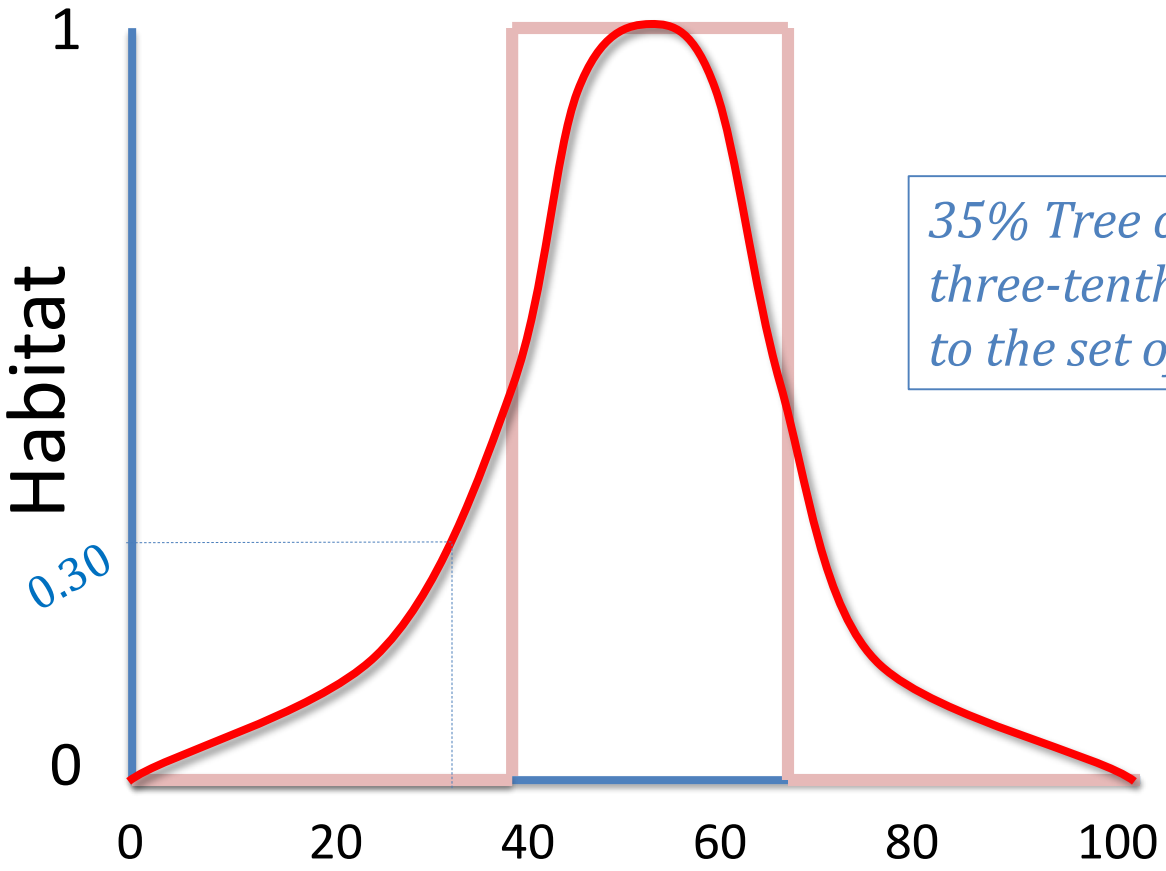
Bald eagle habitat criteria

Binary logic - Forest:



Bald eagle habitat criteria

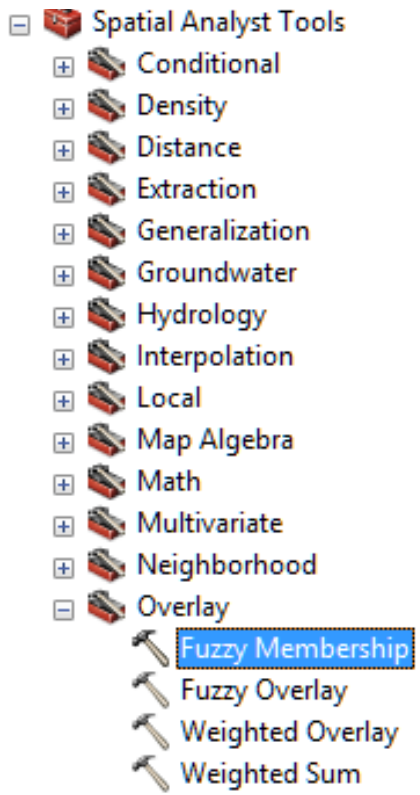
Fuzzy logic - Forest:

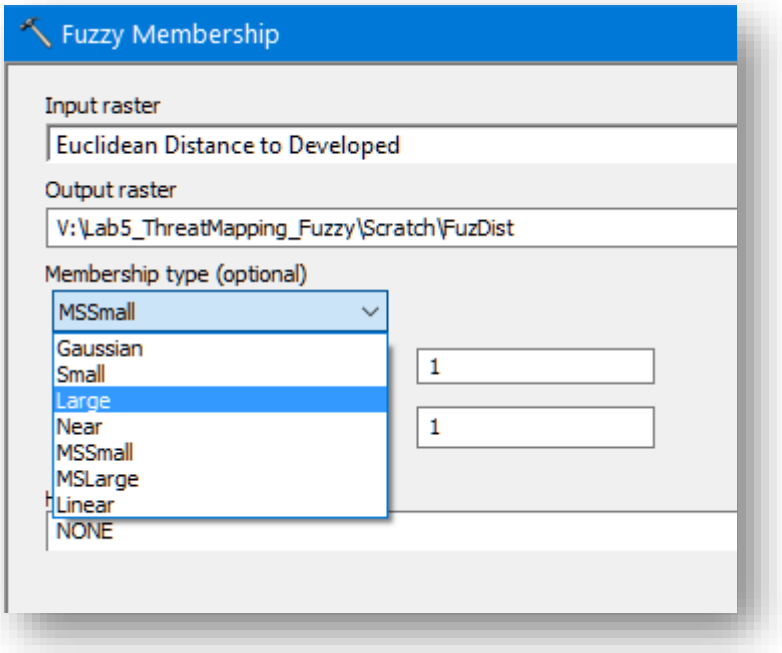


35% Tree cover implies a three-tenths membership to the set of "habitat".

35% Tree cover → Habitat = 0.30

Fuzzy membership functions - ArcMap

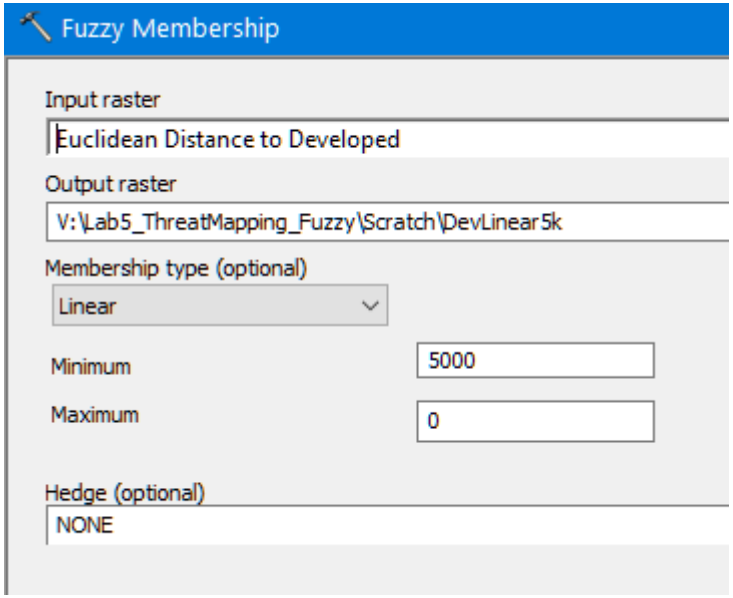




http://www.esri.com/news/arcuser/0410/fuzzy-logic-table2.pdf

Fuzzy membership functions - ArcMap

- Linear:
  - A linear increasing or decreasing membership between two inputs.



Fuzzy analysis – Pronghorn

- Criteria for unthreatened habitat:
  - Far from developed areas
  - Far from power lines
  - Few nearby roads
  - Mostly open land

Fuzzy analysis – Pronghorn

- Criteria
  - Far from developed areas
    - “Far”: > 5000 m, with linear response
  - Far from power lines
    - “Far”: > 6000 m, with sigmoidal response
  - Few nearby roads
    - “Few”: < 3km per, sq. km with linear response
  - Mostly open land cover
    - 60% to 90% herbaceous or scrub within 1km

Conclusions

- Fuzzy analysis allows us to soften the impact of somewhat arbitrary cutoffs (e.g. 1km from roads).
- We can do a bit of fuzzy analysis (and did do this) by reclassifying continuous values (e.g. distance from roads) into non-binary classes.
- Alternatively, we can apply fuzzy membership functions, but what function to use involves a different set of assumptions.
- We still need to interpret how to combine the outputs (fuzzy overlay).
- In short, fuzzy analysis doesn't really solve our problem of involving subjective analysis; the subjectivity is just used elsewhere.
- However, fuzzy analysis offers new ways to break down these problems and use decision analysis techniques in our methods.