GRADED LOGIC
AND
PROFESSIONAL DECISION MAKING

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HUMAN-CENTRIC APPROACH TO PROPOSITIONAL LOGIC

Two contrasting approaches to propositional logic

- **The theoretical approach** where logic is developed as a formal axiomatic deductive system. All degrees of truth are anonymous real numbers.
- **The human-centric approach** based on observing, measuring, and modeling human commonsense logical reasoning in a specific context of decision making. All degrees of truth have semantic identity.
- Our goal is to show main advantages of the human-centric approach and the applicability of this approach in the area of professional decision making.

The stakeholder/decision-maker

- Logical reasoning is a **human mental activity**, i.e., there is no logical reasoning without explicit presence of a specific human thinker.
- Human thinker: **the stakeholder/decision-maker (SDM)** can be an individual or an organization engaged in decision making (evaluation and selection of the best alternative/candidate).
- SDM exists in a specific environment, interacts with the environment, has goals and requirements, and uses logical reasoning to make decisions necessary to satisfy requirements and attain goals. That creates semantic identity of logic variables.
- SDM bears all consequences of accepted decisions.

Human graded percepts and graded truth

- Human percepts are defined as quantifiable mental sensations/impressions of perceiving and/or reasoning.
- Each graded percept p can vary in the range $p_{min} \leq p \leq p_{max}$ (regularly $p_{min} = 0$).
- All graded percepts can be directly related to graded truth. If we define $t = (p - p_{min})/(p_{max} - p_{min})$, then $t \in [0,1]$, and t denotes the degree of truth of the statement **"the percept p attained its maximum value."**
- An example of statement that has graded truth: "our car fully satisfies all our requirements." ($t = 0.7$: 70% of requirements)

Examples of graded percepts (all belong to [0,1])

- Truth
- Importance
- Satisfaction
- Suitability
- Preference
- Confidence
- Trust
- Quality
- Value
- Likelihood
- Significance
- Probability
- Possibility
- Pain
- Worth
- Weight
- Aptness
- Reliability
- Round
- Heavy
- Light
- Dark
- Inexpensive
- Dense
- Attractive
- Tall
- Old

Observable steps in human natural decision-making

- **Specify goals and requirements** (what are the goals we want to achieve?)
- **Identify the goal attainment alternatives** (one or more)
- **Evaluate and compare the alternatives** (each alternative has a degree of suitability)
- **Find the most suitable alternative**

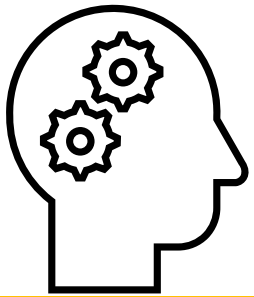
  $(Suitability \in [0,1],\ \ 0 = unacceptable,\ 1 = perfect)$

- **Is the best alternative acceptable?**

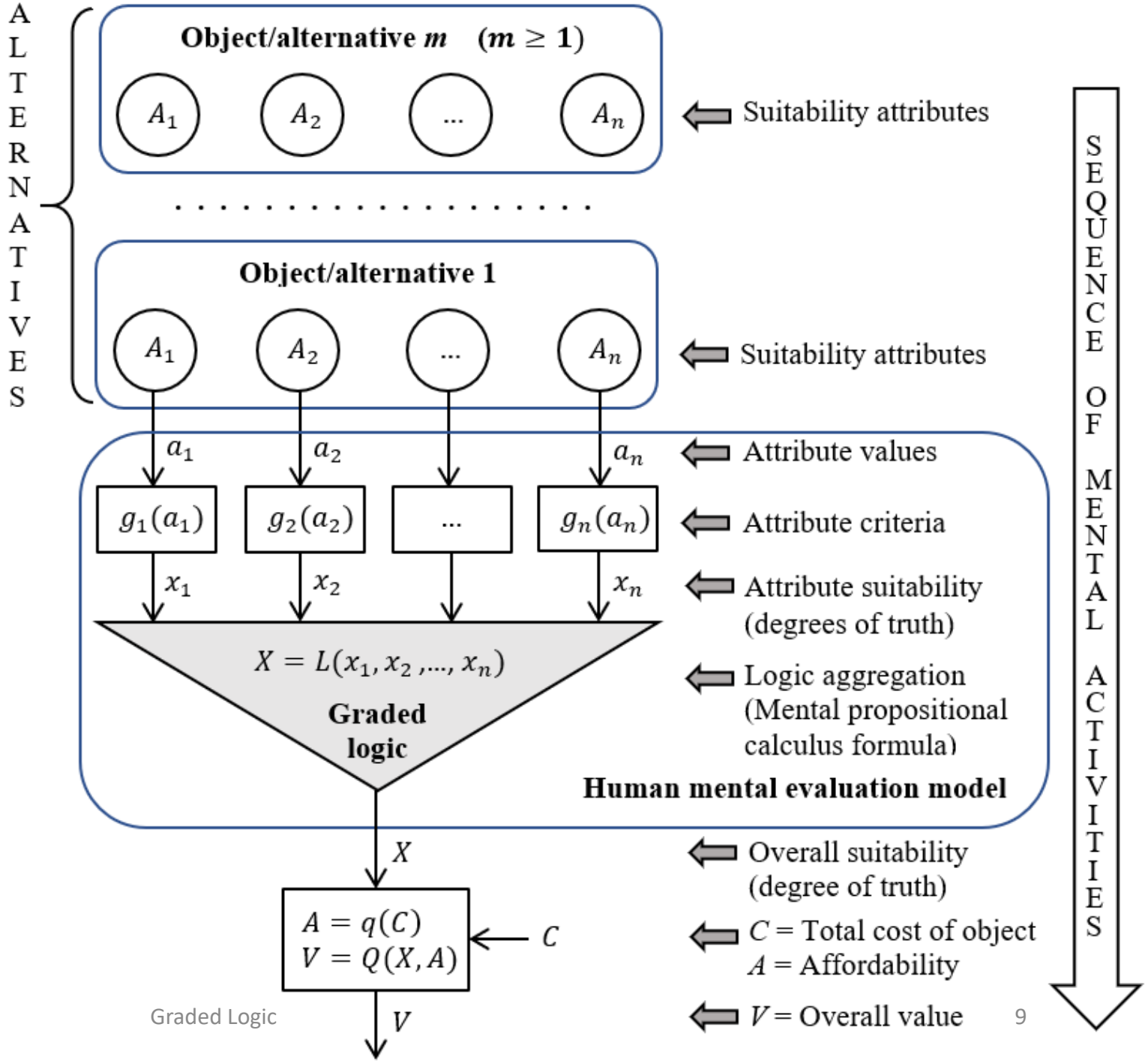
  $(Suitability \geq acceptability\ threshold: yes\ or\ no?)$

- **If it is acceptable, we decide to select and realize the selected alternative.**

Observable human commonsense decision making



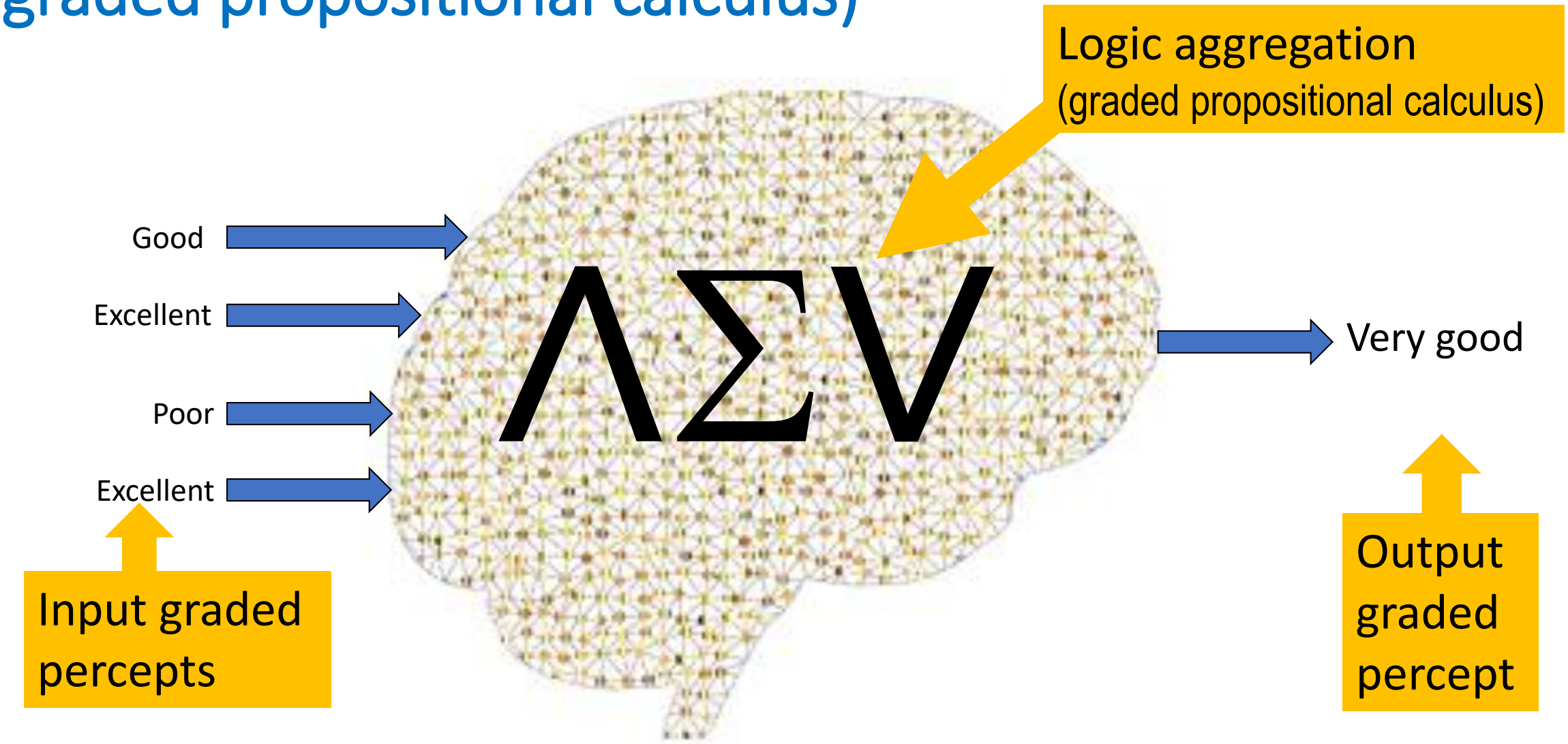
The Logic Scoring of Preference (LSP) decision method is strictly following this model of commonsense decision making



Decision making: the case of a single candidate

- The decision making can be defined as the process of comparison of alternatives (or candidates) and selection (and possible realization) of the best alternative.
- The fundamental problem is **the case of a single candidate**:
  - Selection of suitability attributes.
  - Development of suitability attribute criteria.
  - Generating the attribute suitability degrees.
  - Logic aggregation of attribute suitability degrees.
  - Final result of evaluation = overall suitability $\in [0,1]$
- **Comparison of m candidates can (and should ☺) be reduced to m evaluations of a single candidate.** **This school of thought eliminates the need for m(m-1)/2 pairwise comparisons, or outranking methods. E.g.: individual grading of m students used as the selection criterion.**

Mental logic aggregation of suitability percepts (natural graded propositional calculus)



Sample suitability attribute tree

Attribute tree for project Laptop

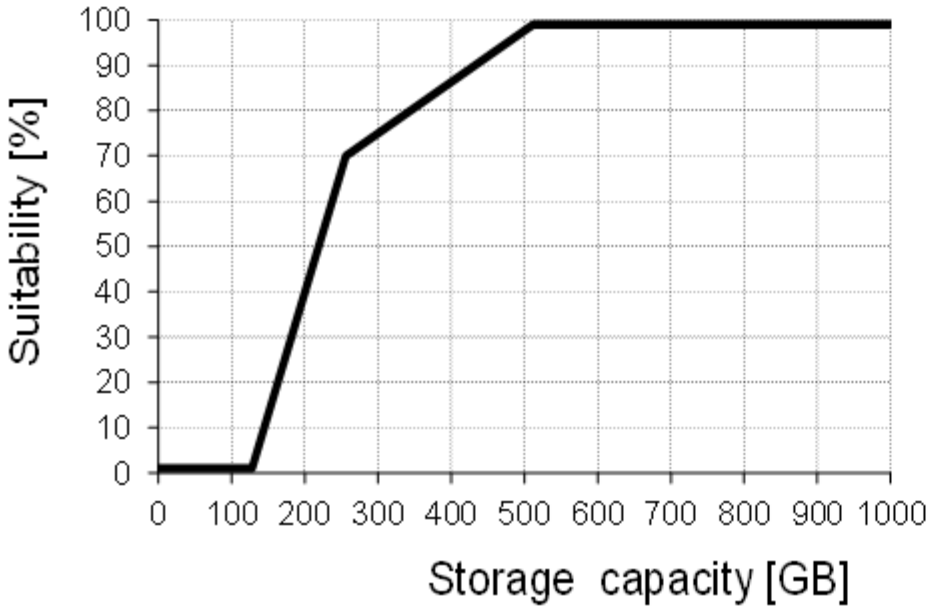
1 Laptop
- **11 Hardware**
  - 111 Processor (clock rate, cache size, number of cores)
  - 112 Memory capacity (RAM)
  - 113 Storage capacity (SSD or HDD)
  - 114 Input/output devices
    - 1141 Keyboard quality and organization
    - 1142 Graphics card and display (resolution and size)
    - 1143 Camera
    - 1144 Audio and speakers
  - 115 Communication devices
    - 1151 Ports (type and number)
    - 1152 Wireless (Wi-Fi and Bluetooth)
- **12 Software**
  - 121 Operating system (Win home/pro, Linux, macOS)
  - 122 Programming languages
  - 123 Utilities and application software
- **13 Performance**
  - 131 Published performance results
  - 132 User's personal benchmarks
- **14 Usability**
  - 141 Weight of laptop
  - 142 Battery life
  - 143 Battery recharge time
- **15 Manufacturer, maintenance, and support**
  - 151 Manufacturer's warranty
  - 152 HW/SW maintenance and support (manufacturer, employer, and others)
  - 153 Laptop availability (time on market)

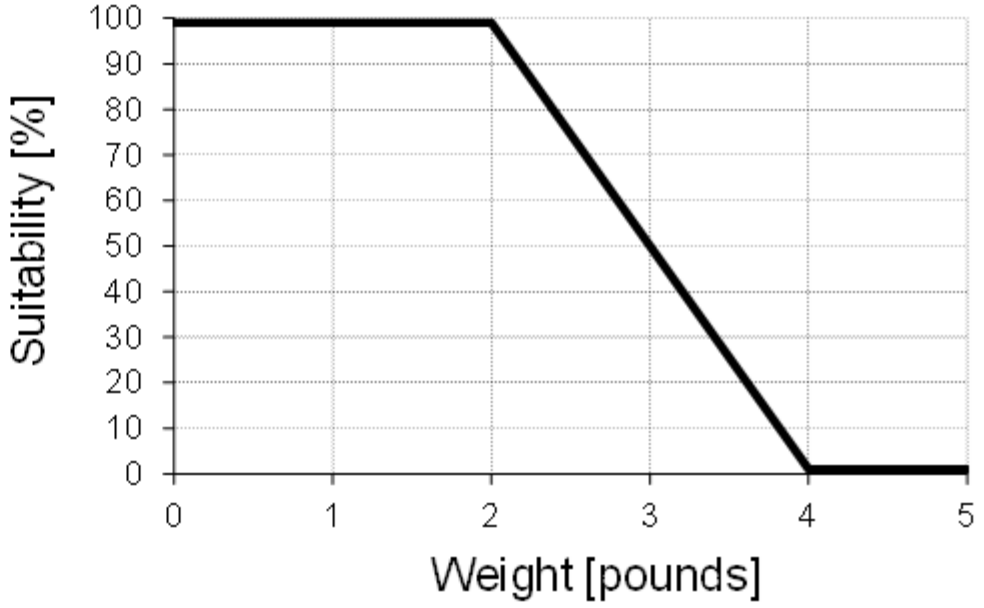
Suitability attributes for a laptop computer

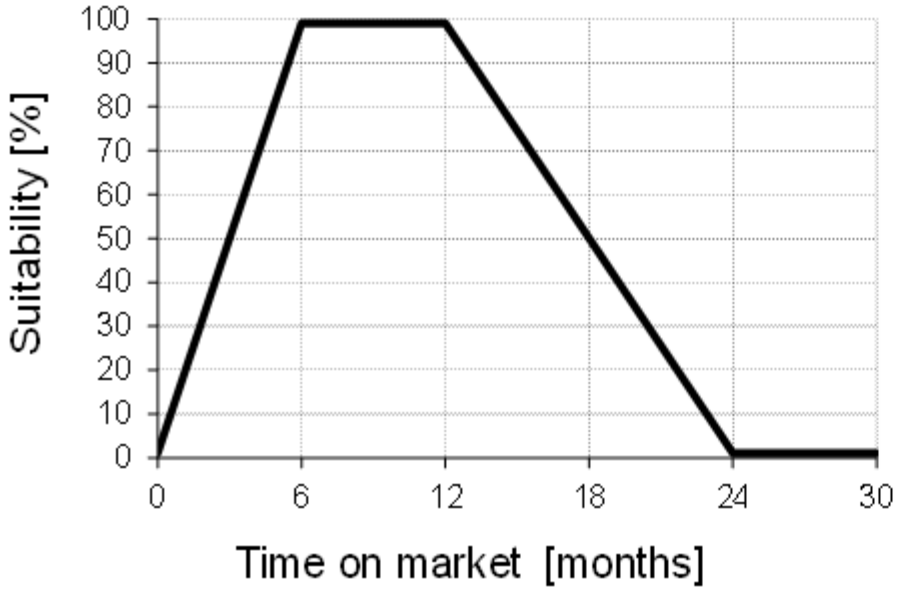
Suitability attributes for project Laptop

1. Processor (clock rate, cache size, number of cores)
2. Memory capacity (RAM)
3. Storage capacity (SSD or HDD)
4. Keyboard quality and organization
5. Graphics card and display (resolution and size)
6. Camera
7. Audio and speakers
8. Ports (type and number)
9. Wireless (Wi-Fi and Bluetooth)
10. Operating system (Win home/pro, Linux, macOS)
11. Programming languages
12. Utilities and application software
13. Published performance results
14. User's personal benchmarks
15. Weight of laptop
16. Battery life
17. Battery recharge time
18. Manufacturer's warranty
19. HW/SW maintenance and support (manufacturer, employer, and others)
20. Laptop availability (time on market)

Sample attribute criteria







PROPERTIES OF A FULLY CONTINUUM-VALUED GRADED PROPOSITIONAL LOGIC

Continuum-valued propositional logic

- Graded Logic is a continuum-valued propositional logic of human commonsense reasoning and decision making.
- Graded Logic must be fully continuum-valued, i.e., everything is a matter of degree (**Natura non facit saltum**):
  - Continuum-valued logic variables (graded truth)
  - Continuum-valued simultaneity (graded conjunction)
  - Continuum-valued substitutability (graded disjunction)
  - Continuum-valued importance of logic variables (death to commutativity ☺ !!!).

Ten Postulates of Graded Logic (1/2)

- The truth of statements must be continuum-valued (graded in the range $[0,1]$).
- The importance of statements must be continuum-valued (graded in the range $]0,1[$).
- The simultaneity of statements must be continuum-valued (graded conjunction) up to drastic conjunction, and support nondecreasing monotonicity in each variable.
- The substitutability of statements must be continuum-valued (graded disjunction) up to drastic disjunction, and support nondecreasing monotonicity in each variable.
- The simultaneity and substitutability must be simultaneously present, unified and complementary (an increase of simultaneity must cause a corresponding decrease of substitutability and vice versa).

Ten Postulates of Graded Logic (2/2)

- Logic neutrality must be available as a balance of simultaneity and substitutability.
- The idempotency of logic aggregators must be selectable (either included or excluded).
- The annihilator support for idempotent simultaneity must be selectable (either included or excluded).
- The annihilator support for idempotent substitutability must be selectable (either included or excluded).
- The simultaneity and substitutability models must be dual in their whole range.

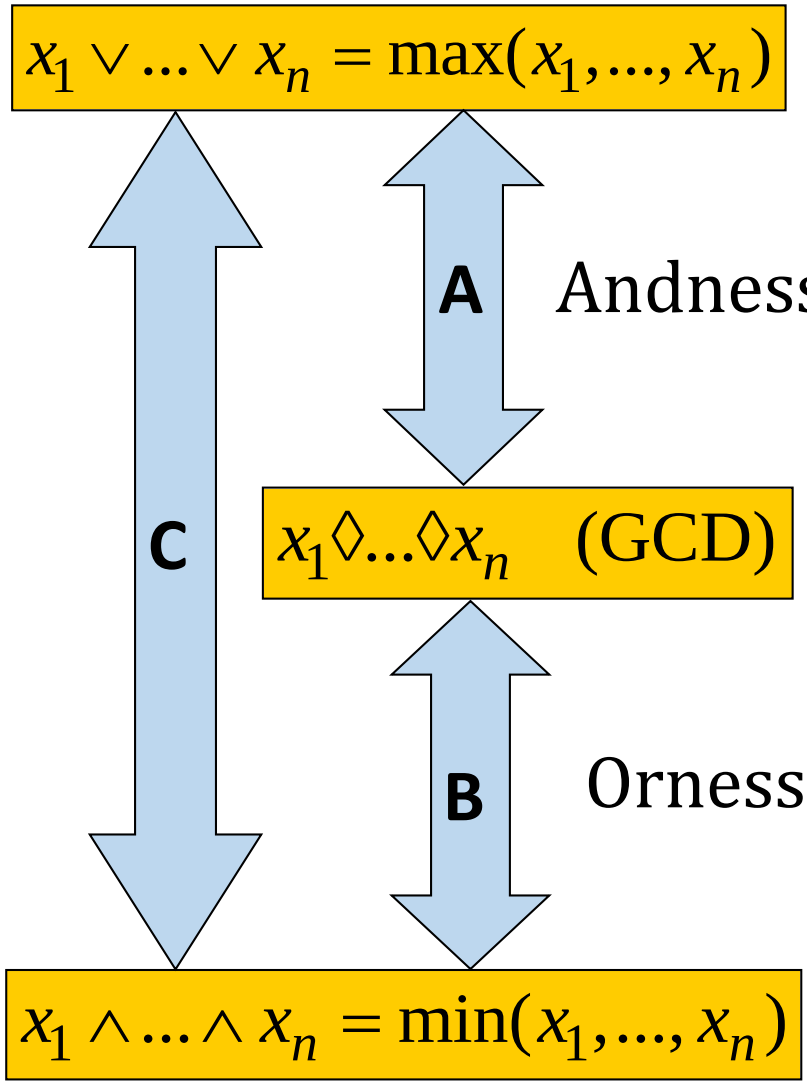
Basic graded logical function (GCD) properties

- **Graded Conjunction/Disjunction (GCD):**
  - Continuum-valued (range [0, 1])
  - Aggregator status (nondecreasing monotonicity, GCD(0,0)=0, GCD(1,1)=1)
  - Andness-directed (nonincreasing monotonicity in andness)
  - Importance-weighted (noncommutativity)
  - Idempotence-selectable (either idempotent or nonidempotent)
  - Annihilator-selectable (annihilator 0 or 1 supported or not supported)
- The strict use of continuum-valued concepts and variables is a unique distinctive property introduced in Graded Logic. Based on that property, GL is a seamless generalization of the classical bivalent Boolean logic, fuzzy logic propositional calculus, and non-classical continuum-valued logics.

Modeling andness and orness of the GCD aggregator

Andness = degree of similarity between the GCD and the full conjunction (AND)

Orness = degree of similarity between the GCD and the full disjunction (OR)

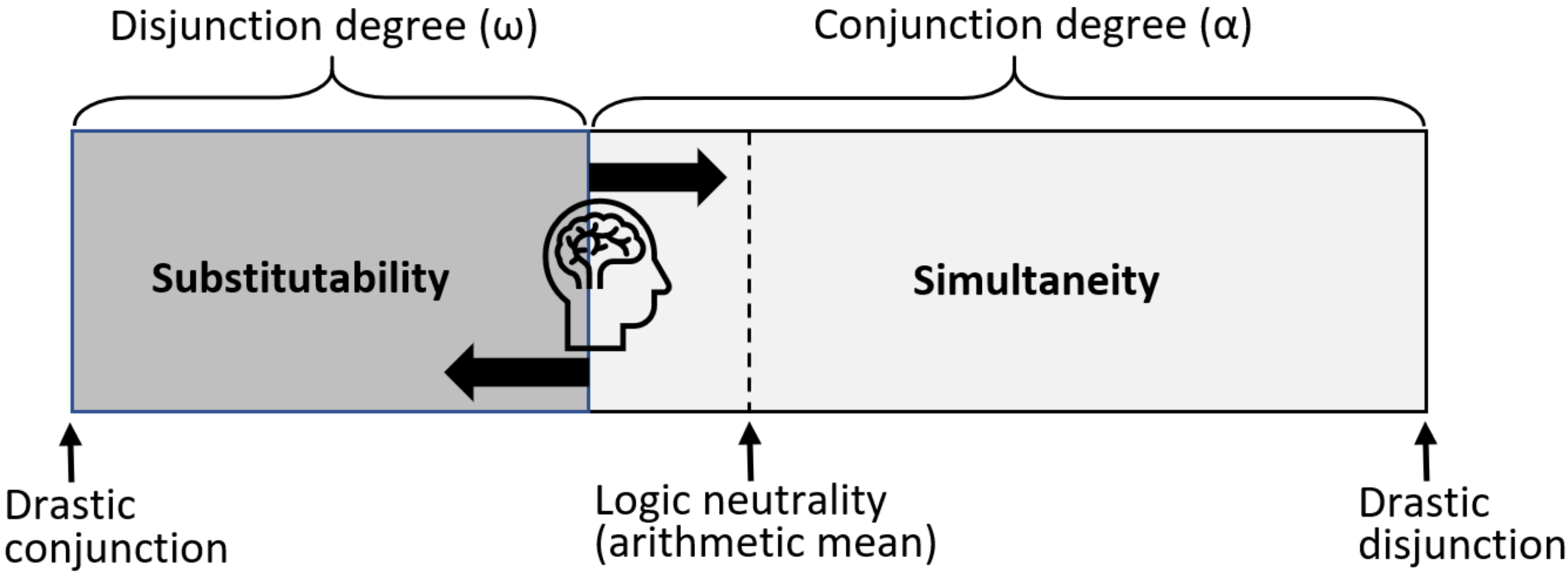


$$\text{Andness } \alpha = \frac{A}{C} = \frac{A}{A+B} \in [0,1]$$

Andness + Orness = 1

$$\text{Orness } \omega = \frac{B}{C} = \frac{B}{A+B} \in [0,1]$$

Combining simultaneity and substitutability



Geometric interpretation of andness and orness

$$\boldsymbol{\alpha} = \frac{\int_{I^n} \max(\boldsymbol{X}) dx_1 \dots dx_n - \int_{I^n} A(\boldsymbol{X}; \underline{\boldsymbol{W}}) dx_1 \dots dx_n}{\int_{I^n} \max(\boldsymbol{X}) dx_1 \dots dx_n - \int_{I^n} \min(\boldsymbol{X}) dx_1 \dots dx_n} = \frac{\boldsymbol{n - (n+1)V}}{\boldsymbol{n-1}}$$

$$\boldsymbol{\omega} = \frac{\int_{I^n} A(\boldsymbol{X}; \underline{\boldsymbol{W}}) dx_1 \dots dx_n - \int_{I^n} \min(\boldsymbol{X}) dx_1 \dots dx_n}{\int_{I^n} \max(\boldsymbol{X}) dx_1 \dots dx_n - \int_{I^n} \min(\boldsymbol{X}) dx_1 \dots dx_n} = \frac{\boldsymbol{(n+1)V - 1}}{\boldsymbol{n-1}}$$

$$V = \int_{I^n} A(\boldsymbol{X}; \underline{\boldsymbol{W}}) dx_1 \dots dx_n = volume\ under\ the\ surface\ of$$

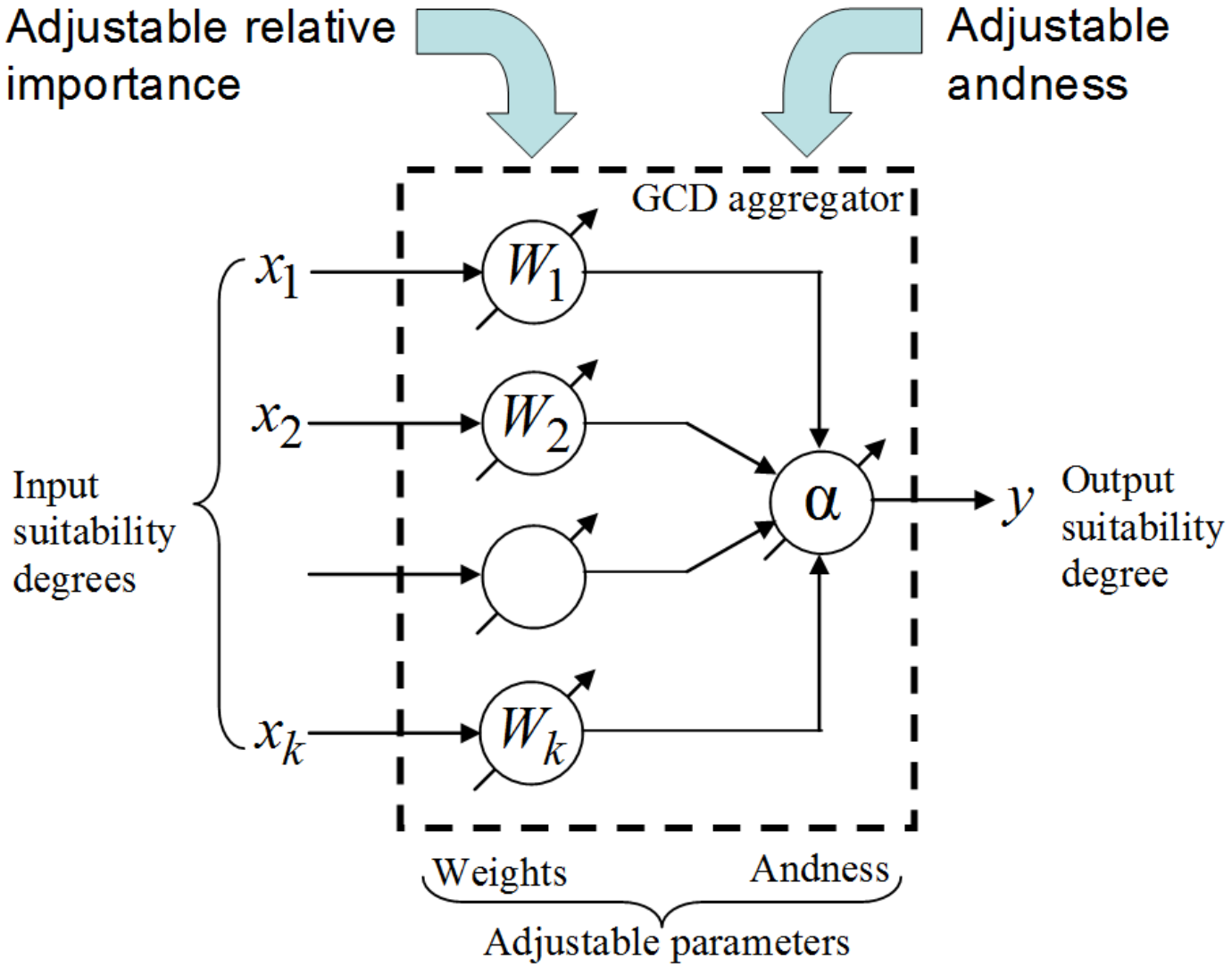
$$aggregator\ A\ inside\ the\ unit\ hypercube$$

Conjunction degree (andness, α) and disjunction degree (orness, ω)

- GCD aggregator: $y = x_1 \Diamond \ldots \Diamond x_n$
- Volume: $V = \int_{[0,1]^n} (x_1 \Diamond \ldots x_n) dx_1 \ldots \mathrm{d}x_n$
- Andness: $\alpha = \frac{n-(n+1)V}{n-1}$
- Orness: $\omega = 1 - \alpha$
- Conjunction: $V = \int_{[0,1]^n} (x_1 \wedge \cdots \wedge x_n) dx_1 \ldots \mathrm{d}x_n = \frac{1}{n+1}$, $\alpha = 1,\ \omega = 0$
- Disjunction : $V = \int_{[0,1]^n} (x_1 \vee \cdots \vee x_n) dx_1 \ldots \mathrm{d}x_n = \frac{n}{n+1}$, $\alpha = 0,\ \omega = 1$

Graded Conjunction/Disjunction

GCD



Independently adjustable semantic properties (W) and formal logic properties (α)

Andness and orness of drastic conjunction and drastic disjunction

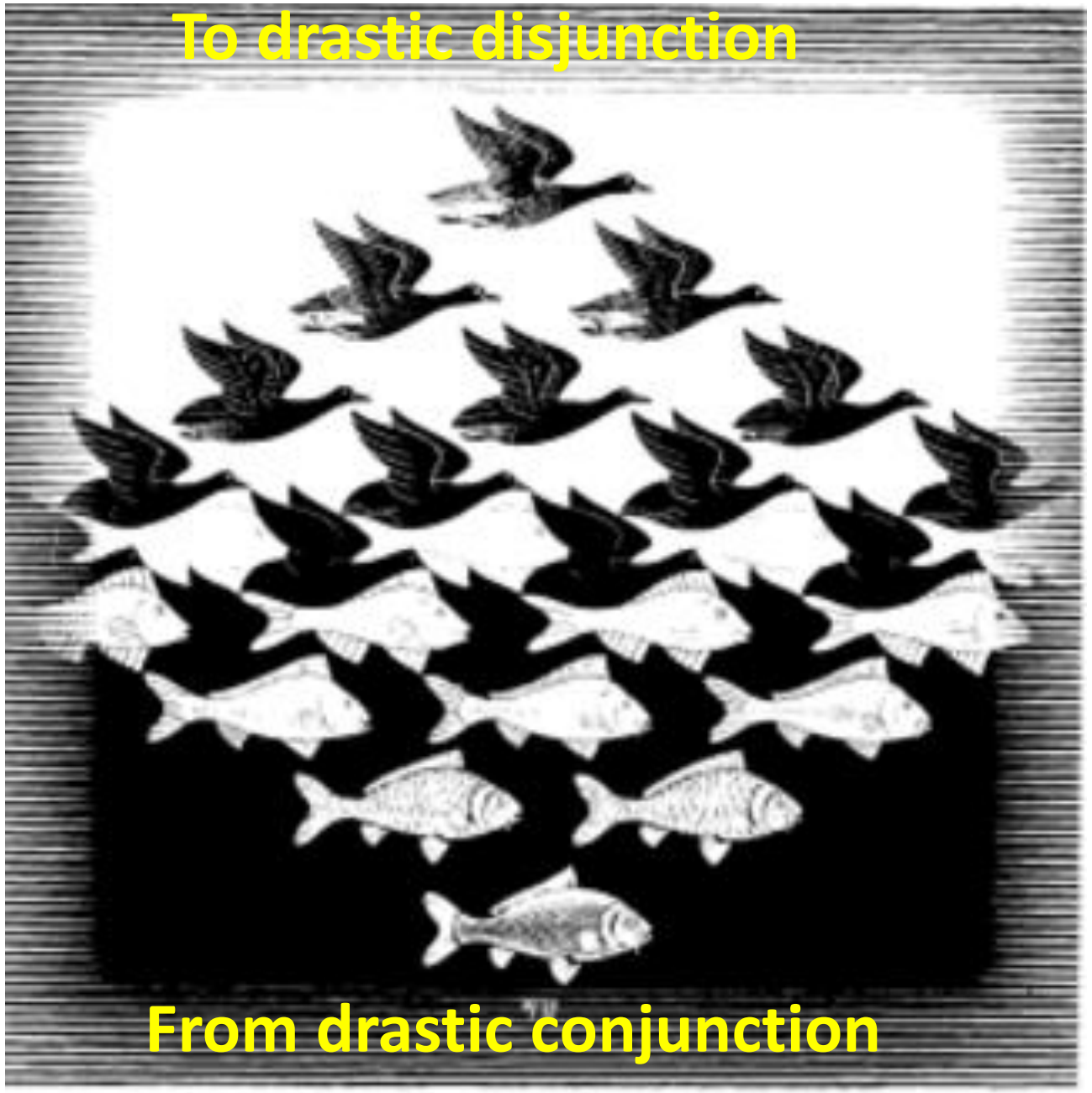
- **Drastic conjunction**: for all inputs equal 1 the output value is 1. In all other cases the output value = 0

$$y = \left\lfloor \prod_{i=1}^{k} x_i \right\rfloor, \qquad V = 0, \quad \boldsymbol{\alpha = k/(k-1)}$$

- **Drastic disjunction**: for all inputs equal 0 the output value is 0. In all other cases the output value = 1.

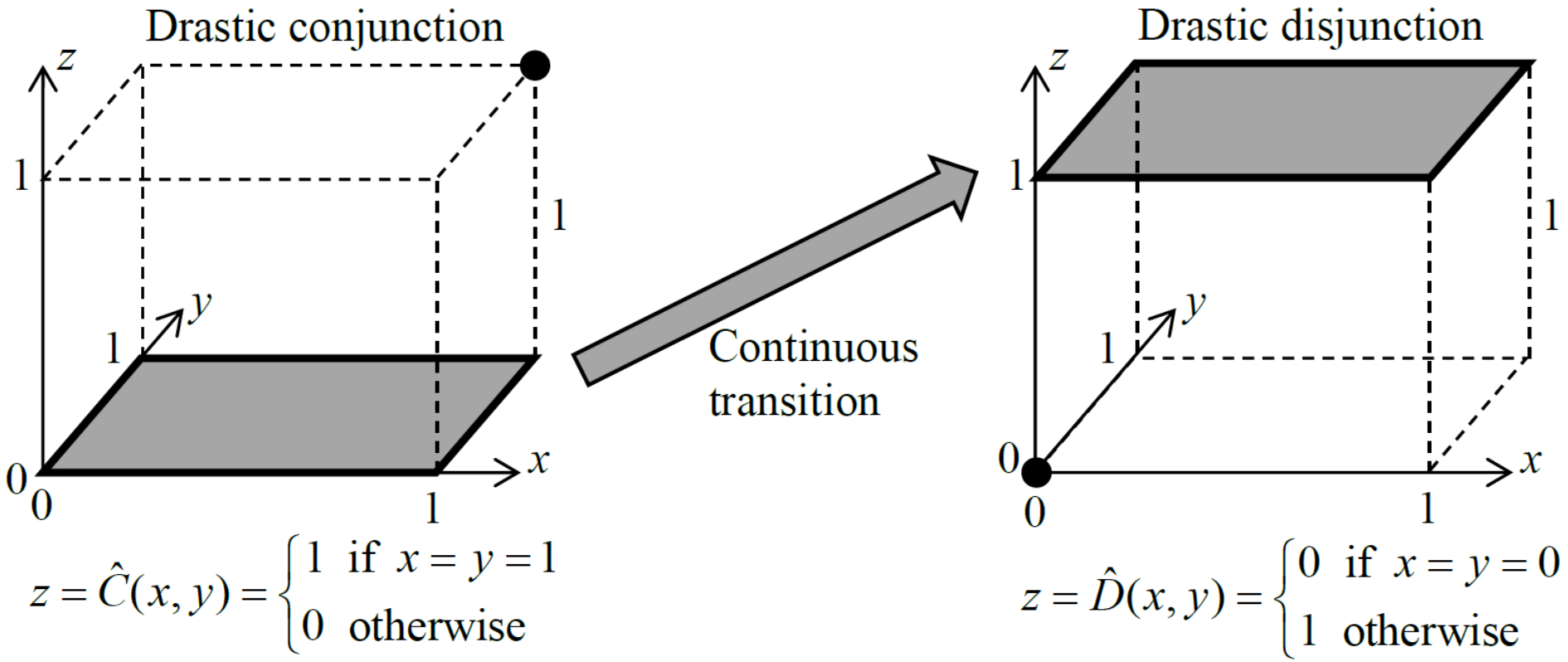
$$y = 1 - \left\lfloor \prod_{i=1}^{k} (1 - x_i) \right\rfloor, \quad V = 1, \quad \boldsymbol{\alpha = -1/(k-1)}$$

- **Range of andness**: $\boldsymbol{-1/(k-1) \leq \alpha \leq k/(k-1)}$



With gratitude to
Maurits C. Escher

Continuous transition from drastic conjunction to drastic disjunction: andness/orness beyond the [0,1] range



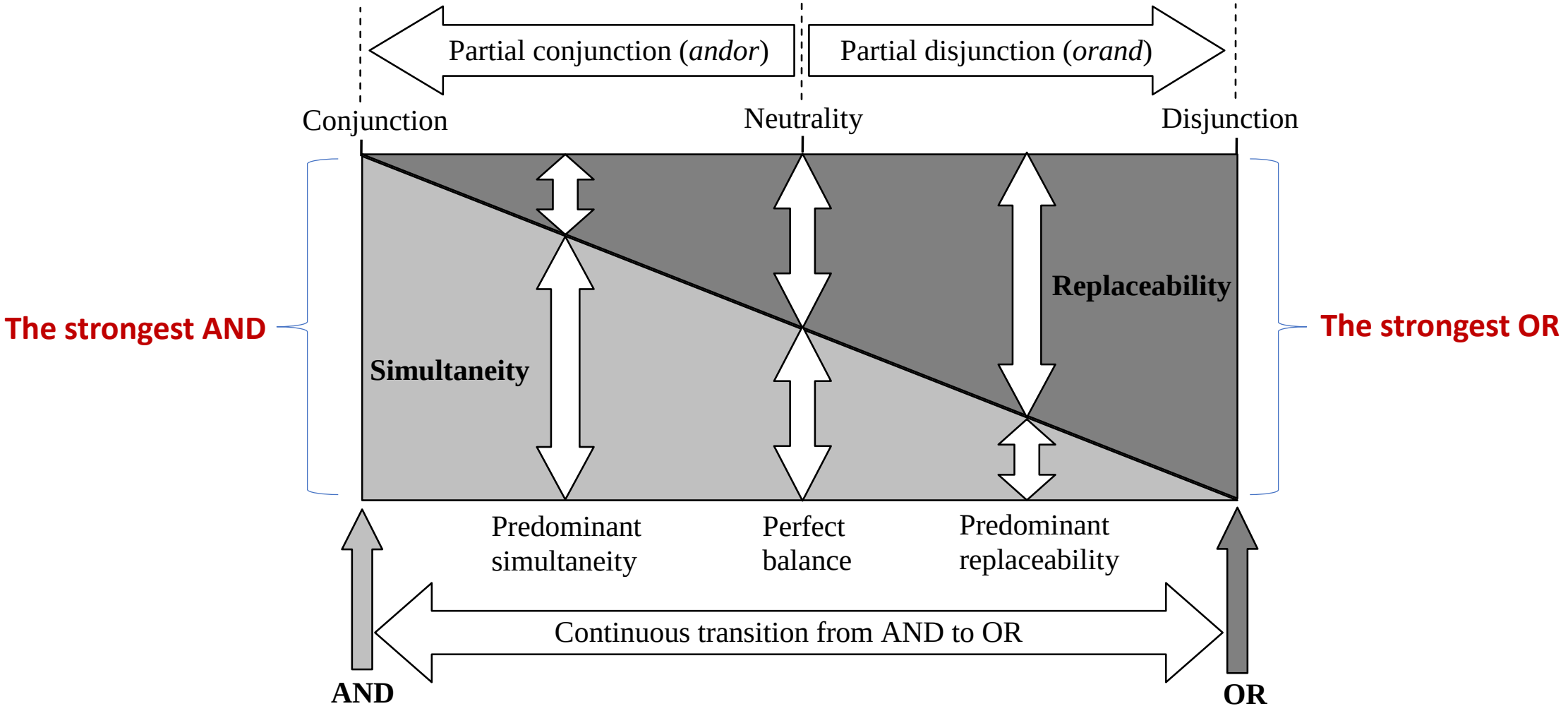
$$z = \hat{C}(x,y) = \begin{cases} 1 & \text{if } x = y = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$z = \hat{D}(x,y) = \begin{cases} 0 & \text{if } x = y = 0 \\ 1 & \text{otherwise} \end{cases}$$

Drastic conjunction and drastic disjunction are limit functions of logic aggregators. They are logic functions but formally they do not have the status of logic aggregator.

Continuous transition from AND to OR

Simultaneity and substitutability are complementary



The graded logic conjecture: there are ten necessary and sufficient graded logic functions:

1. Graded hyperconjunction	$(\alpha > 1)$	[C/A0/NI]
2. Pure conjunction – minimum	$(\alpha = 1)$	[C/A0/ID]
3. Hard graded conjunction	$(0.75 \leq \alpha < 1)$	[C/A0/ID]
4. Soft graded conjunction	$(0.5 < \alpha < 0.75)$	[C/NA/ID]
5. Logic neutrality	$(\alpha = 0.5)$	[N/NA/ID]
6. Soft graded disjunction	$(0.25 < \alpha < 0.5)$	[D/NA/ID]
7. Hard graded disjunction	$(0 < \alpha \leq 0.25)$	[D/A1/ID]
8. Pure disjunction - maximum	$(\alpha = 0)$	[D/A1/ID]
9. Graded hyperdisjunction	$(\alpha < 0)$	[D/A1/NI]

10. Negation (which is not an aggregator)

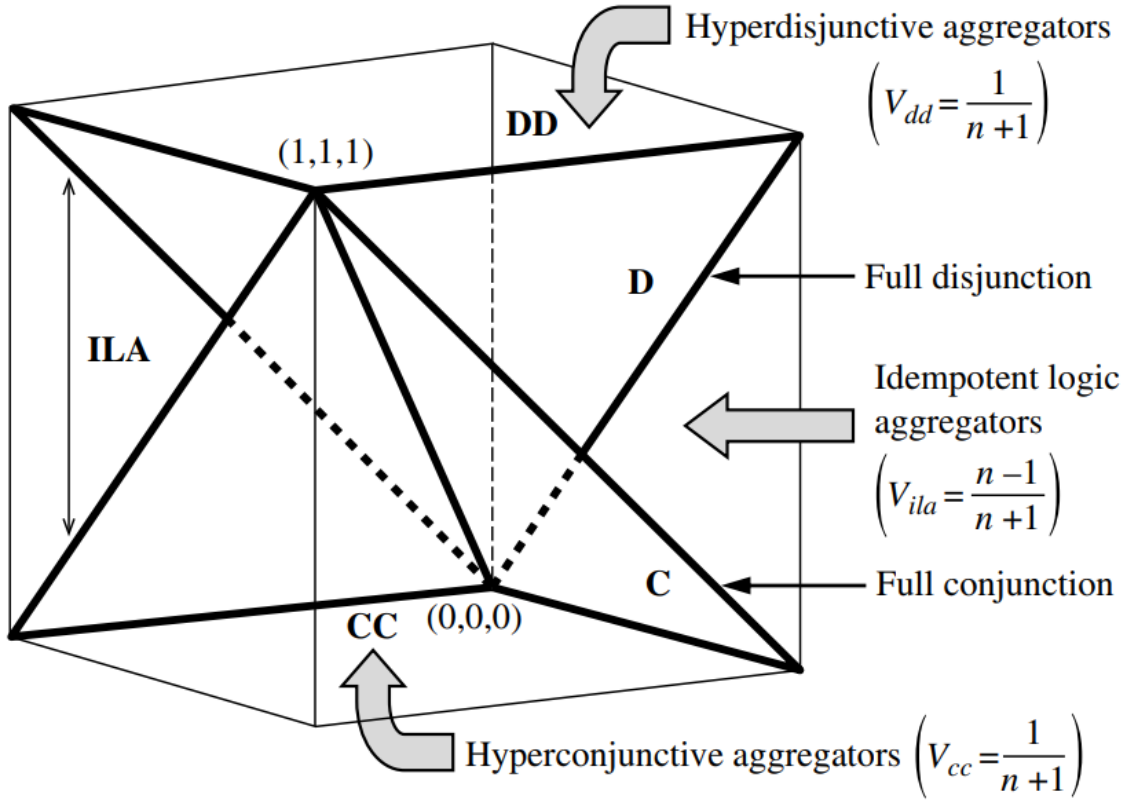
Some functions have adjustable parameters, and some have fixed parameters.

Reasons supporting necessity

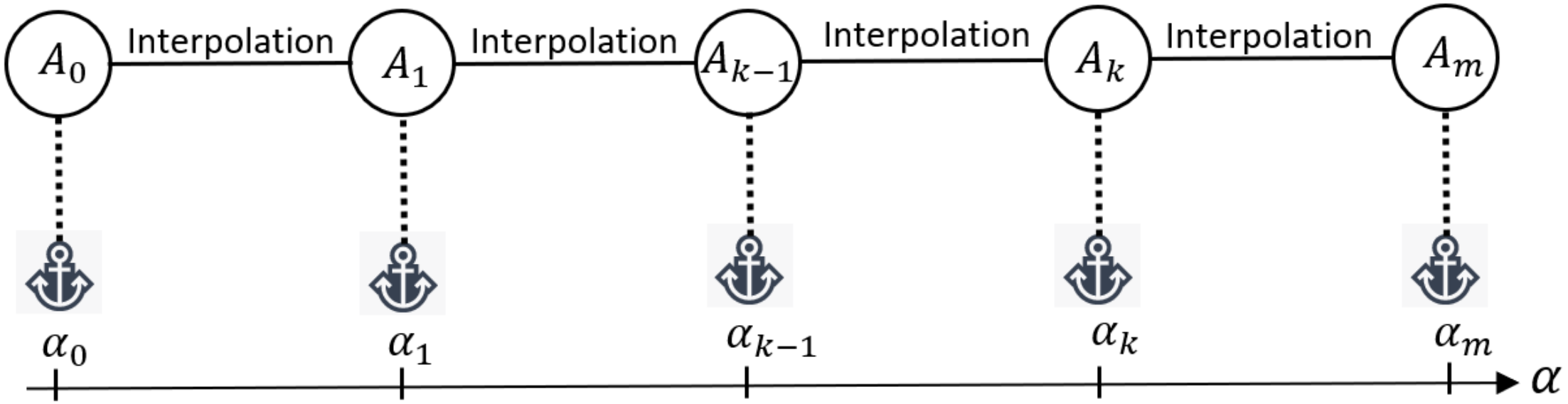
- In human-centric logic we are interested in modeling observable forms of natural human reasoning
- For each of 10 basic operations we have a proof of existence in the observable reasoning practice of natural (intuitive) human reasoning

Reasons supporting sufficiency

- Logic functions exist inside the unit hypercube.
- The set of 9 conjunctive, disjunctive, and neutral logic aggregators is sufficient to systematically cover all existing regions of the unit hypercube (nothing is missing)
- The set of 10 basic functions is sufficient to create all observable compound logic functions (partial absorption, partial implication, partial abjunction, equivalence, and others)



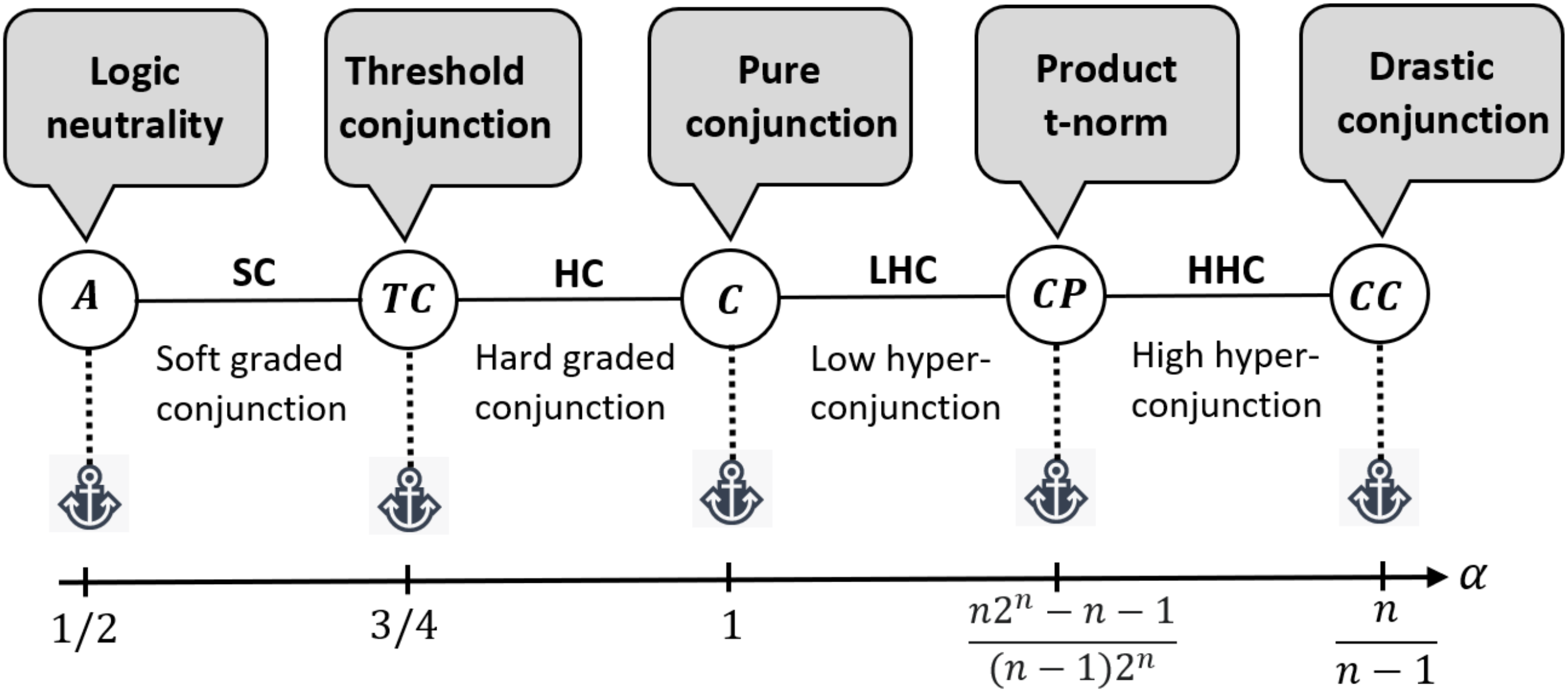
Segmented interpolative GCD logic aggregators



$$ADIGCD(\boldsymbol{x};\boldsymbol{W},\alpha) = \frac{\alpha_k - \alpha}{\alpha_k - \alpha_{k-1}} A_{k-1}(\boldsymbol{x};\boldsymbol{W},\alpha_{k-1}) + \frac{\alpha - \alpha_{k-1}}{\alpha_k - \alpha_{k-1}} A_k(\boldsymbol{x};\boldsymbol{W},\alpha_k), \quad \alpha_{k-1} \le \alpha \le \alpha_k,$$

$$k = 1, \ldots, m .$$

The conjunctive part of andness-directed interpolative UGCD aggregator



Recursive form of GCD (provides duality)

The aggregator $GCD(\mathbf{X}; \mathbf{W}, \alpha)$ in the full range $-1/(n-1) < \alpha < n/(n-1)$ can be recursively implemented using the same $GCD(\mathbf{X}; \mathbf{W}, \alpha)$ function, defined in the half range, either $1/2 \leq \alpha < n/(n-1)$ or $-1/(n-1) < \alpha \leq 1/2$. In other words, $GCD(\mathbf{X}; \mathbf{W}, \alpha)$ can be implemented in most programming languages using either $ARI(\mathbf{X}; \mathbf{W})$ and $AND(\mathbf{X}; \mathbf{W}, \alpha)$, or $ARI(\mathbf{X}; \mathbf{W})$ and $OR(\mathbf{X}; \mathbf{W}, \alpha)$ as shown in the following conditional expressions based on C-style ternary operator:

$$GCD(\mathbf{X}; \mathbf{W}, \alpha) = (\alpha == 0.5 \; ? \; ARI(\mathbf{X}; \mathbf{W}) : (\alpha > 0.5 \; ? \; AND(\mathbf{X}; \mathbf{W}, \alpha) : 1 - GCD(\mathbf{1} - \mathbf{X}; \mathbf{W}, 1 - \alpha)),$$

$$GCD(\mathbf{X}; \mathbf{W}, \alpha) = (\alpha == 0.5 \; ? \; ARI(\mathbf{X}; \mathbf{W}) : (\alpha < 0.5 \; ? \; OR(\mathbf{X}; \mathbf{W}, \alpha) : 1 - GCD(\mathbf{1} - \mathbf{X}; \mathbf{W}, 1 - \alpha))).$$

Andness-directed interpolative commutative version of Uniform Graded Conjunction/Disjunction (UGCD) for n=2

The simplest special case: two variables, equal importance

Recursive notation:

$$z = \begin{cases} F(x,y;\alpha) = \begin{cases} (xy)^{\sqrt{3/(2-\alpha)}-1}, & 1.25 < \alpha < 2, \text{ High Hypercon.} \\ xy, & \alpha = 1.25, \text{ HC Product norm} \\ 4[(1.25-\alpha)\min(x,y) + (\alpha-1)xy], & 1 < \alpha < 1.25, \text{ Low Hyperconj.} \\ \min(x,y), & \alpha = 1, \text{ Full conjunction} \\ (0.5x^{r(\alpha)} + 0.5y^{r(\alpha)})^{1/r(\alpha)}, & \tfrac{3}{4} \le \alpha < 1, \text{ Hard partial conj.} \\ (3-4\alpha)(0.5x+0.5y) + (4\alpha-2)(0.5x^R + 0.5y^R)^{1/R}, & \tfrac{1}{2} < \alpha < \tfrac{3}{4}, \text{ Soft partial conj.} \\ 0.5x + 0.5y, & \alpha = \omega = \tfrac{1}{2}, \text{ Neutrality} \end{cases} \\ 1 - F(1-x, 1-y; 1-\alpha), & -1 \le \alpha < 0.5 \end{cases}$$

$$R = -0.7201 = const$$

Uniform GCD: range of soft conjunction = range of hard conjunction = range of soft disjunction = range of hard disjunction = ¼

Threshold andness (border between the soft and hard GCD = ¾ (75%)

Andness-directed GCD (general formula)

Interpolative recursive version with adjustable threshold andness

$r_{wpm}(\alpha) =$ Numerical approximation

$R = r_{wpm}(\alpha_\theta)$

$$n > 1, \quad \mathbf{x} = (x_1, \ldots, x_n), \quad \mathbf{1} - \mathbf{x} = (1 - x_1, \ldots, 1 - x_n),$$

$$\mathbf{W} = (W_1, \ldots, W_n), \quad 0 < W_i < 1, \quad i = 1, \ldots, n, \quad \sum_{i=1}^{n} W_i = 1$$

$$r_{wpm}(\alpha) = \frac{0.25 + a_n(½ - \alpha) + b_n(½ - \alpha)^2 + c_n(½ - \alpha)^3 + d_n(½ - \alpha)^4}{\alpha(1 - \alpha)}$$

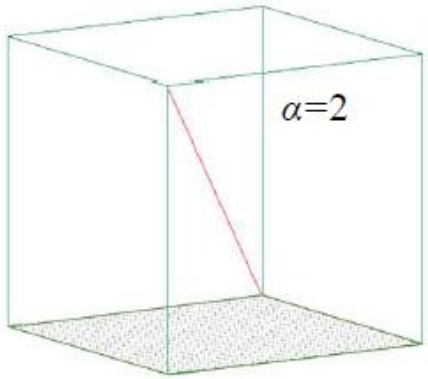
$$z = F(\mathbf{x}; \mathbf{W}, \alpha) = \begin{cases}
\textbf{Drastic conjunction:} & \\
\left\lfloor \prod_{i=1}^{n} x_i \right\rfloor, & \alpha = \alpha_{\max} = n/(n-1), \\
\textbf{High hyperconjunction:} & \\
\left(\prod_{i=1}^{n} x_i \right)^{\{(n+1)/[n-(n-1)\alpha]\}^{1/n}-1}, & \alpha_{cc}(n,1) < \alpha < \alpha_{\max}, \\
\textbf{Medium hyperconjunction (product t-norm):} & \\
\prod_{i=1}^{n} x_i, & \alpha = \alpha_{cc}(n,1) = \dfrac{n2^n - n - 1}{(n-1)2^n} \\
\textbf{Low hyperconjunction:} & \\
\dfrac{\alpha_{cc}(n,1) - \alpha}{\alpha_{cc}(n,1) - 1} \min(\mathbf{x}) + \dfrac{\alpha - 1}{\alpha_{cc}(n,1) - 1} \prod_{i=1}^{n} x_i, & 1 < \alpha < \alpha_{cc}(n,1) \\
\textbf{Full conjunction:} & \\
\min(x_1, \ldots, x_n), & \alpha = 1 \\
\textbf{Hard partial conjunction:} & \\
\left(\sum_{i=1}^{n} W_i x_i^{r(\alpha)} \right)^{1/r_{wpm}(\alpha)}, & \alpha_\theta \le \alpha < 1 \\
\textbf{Soft partial conjunction:} & \\
\dfrac{\alpha_\theta - \alpha}{\alpha_\theta - ½} \left(\sum_{i=1}^{n} W_i x_i \right) + \dfrac{\alpha - ½}{\alpha_\theta - ½} \left(\sum_{i=1}^{n} W_i x_i^R \right)^{1/R}, & ½ < \alpha < \alpha_\theta \\
\textbf{Neutrality:} & \\
\sum_{i=1}^{n} W_i x_i, & \alpha = \omega = ½ \\
\textbf{Dual disjunctive aggregators:} & \\
1 - F(\mathbf{1} - \mathbf{x}; \mathbf{W}, 1 - \alpha), & \alpha_{\min} = -1/(n-1) \le \alpha < 0.5
\end{cases}$$

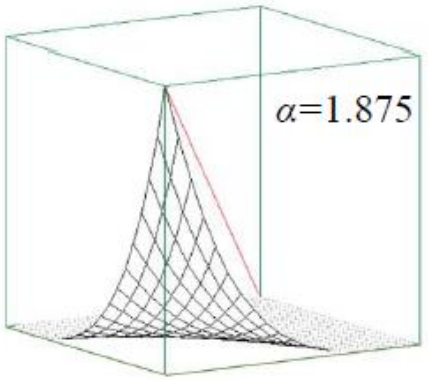
GCD

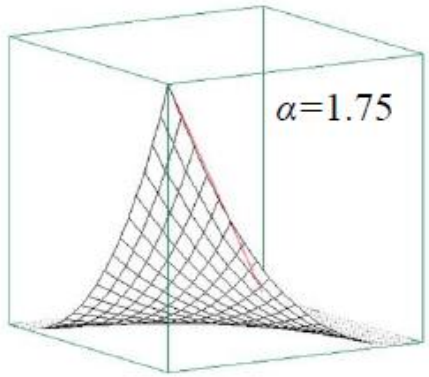
Substitutability	Complementing	Simultaneity	Operator	Model
Lowest	Simultaneity / Substitutability	Highest	Drastic conjunction	$z = \lfloor xy \rfloor$
Low		High	Pure conjunction	$z = \min(x, y)$
Medium		Medium	Arithmetic mean	$z = (x + y)/2$
High		Low	Pure disjunction	$z = \max(x, y)$
Highest		Lowest	Drastic disjunction	$z = 1 - \lfloor (1 - x)(1 - y) \rfloor$

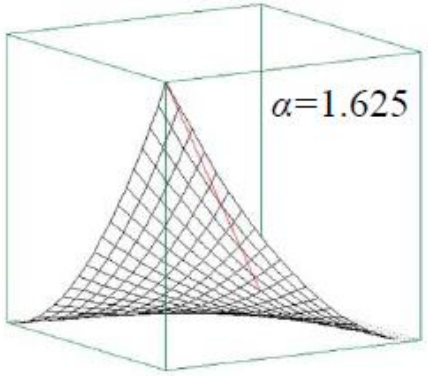
GCD: GRADED CONJUNCTION/DISJUNCTON (logic aggregators from drastic conjunction to drastic disjunction)																		
Models of simultaneity									Logic neut-rality	Models of substitutability								
Hypercon.		Conjunction								Disjunction							Hyperdis.	
CC	CP	C	HC+	HC	HC-	SC+	SC	SC-	A	SD-	SD	SD+	HD-	HD	HD+	D	DP	DD
Hard conjunctive aggregators: an.= 0						Soft aggregators (no annihilators)				Hard disjunctive aggregators: an.= 1								
Nonidempo	Idempotent logic aggregators (means): from pure conjunction (C) to pure disjunction (D)																Nonidempo	

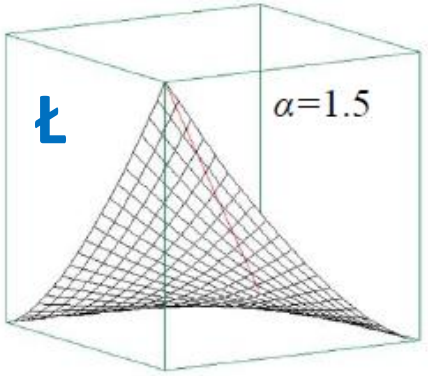
Nonidempotent hyperconjunction

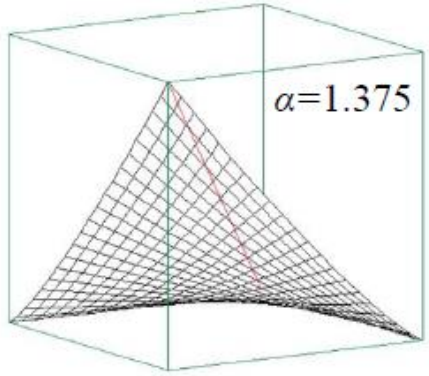


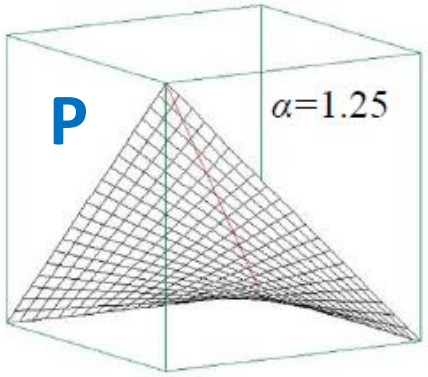


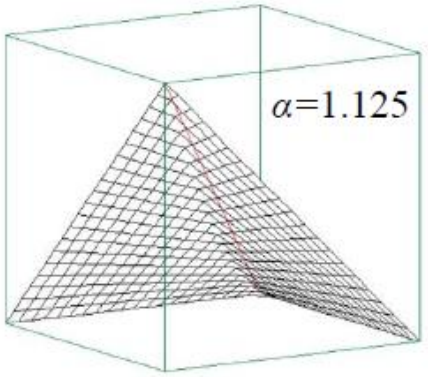


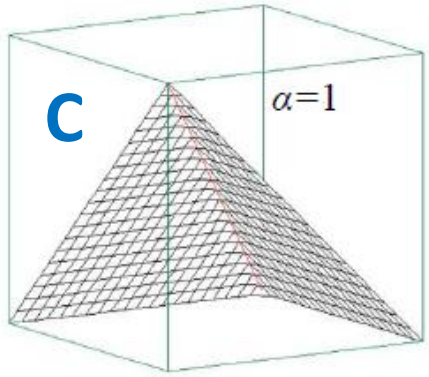




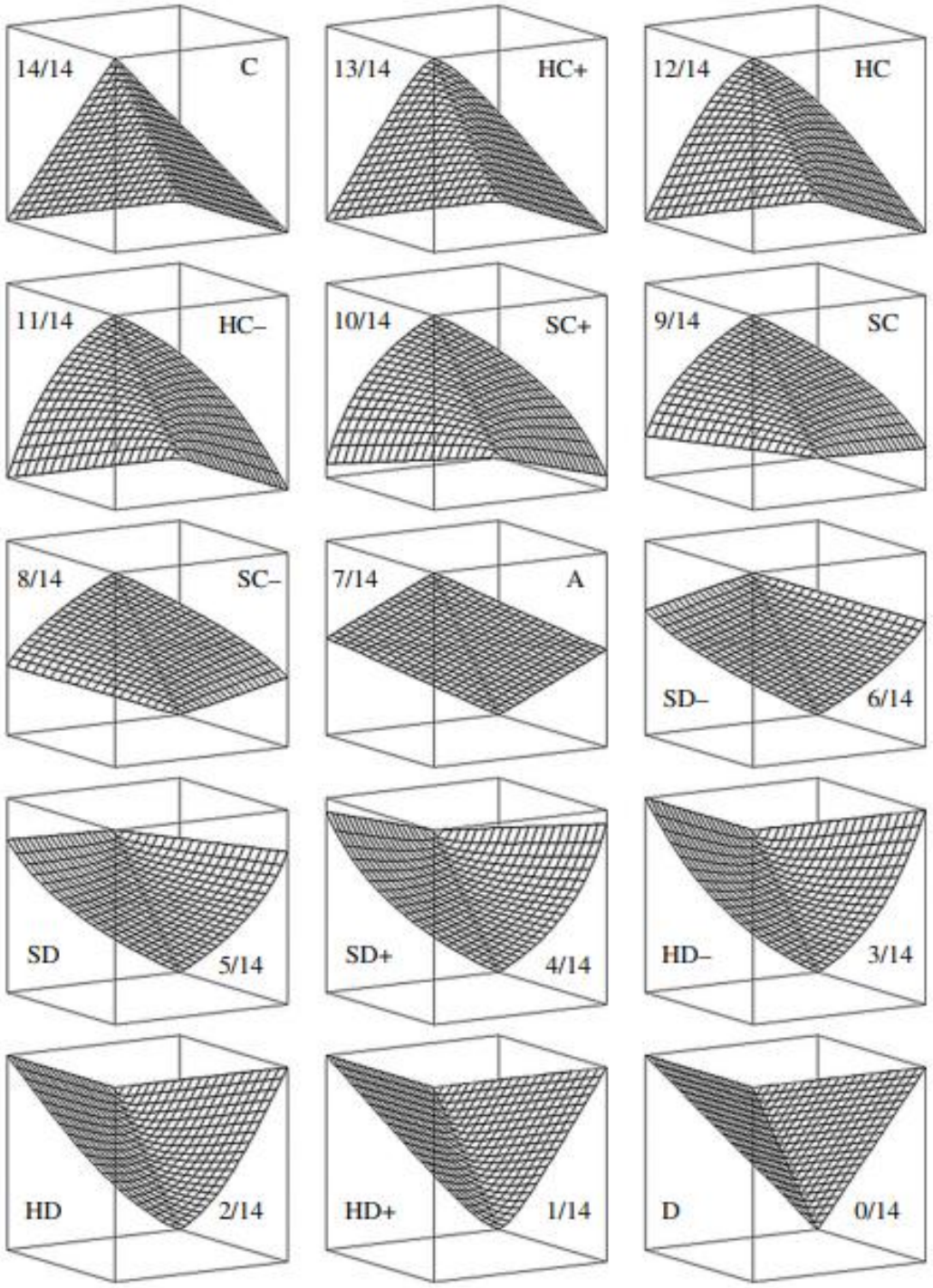




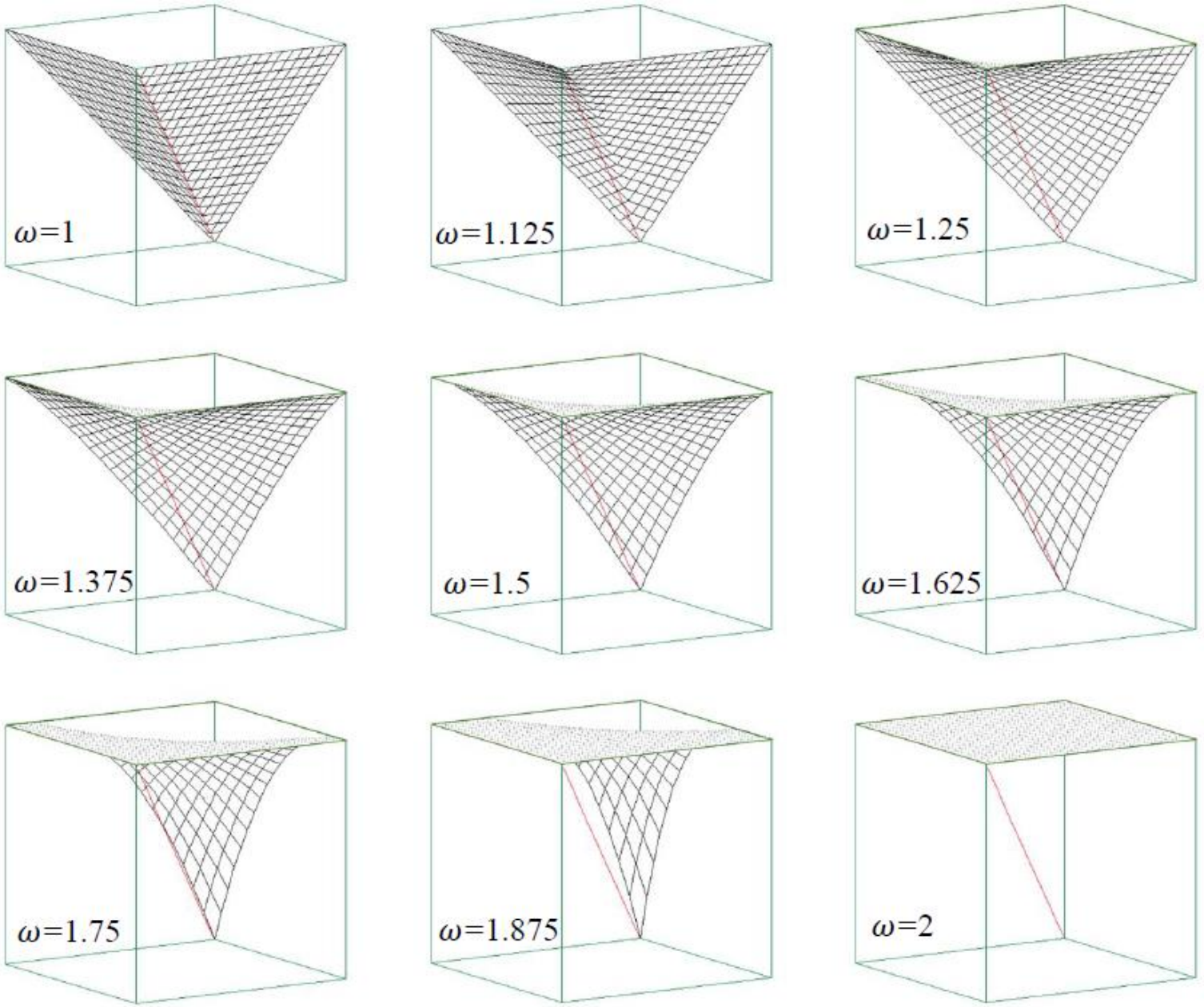




Idempotent UGCD with medium granularity 15

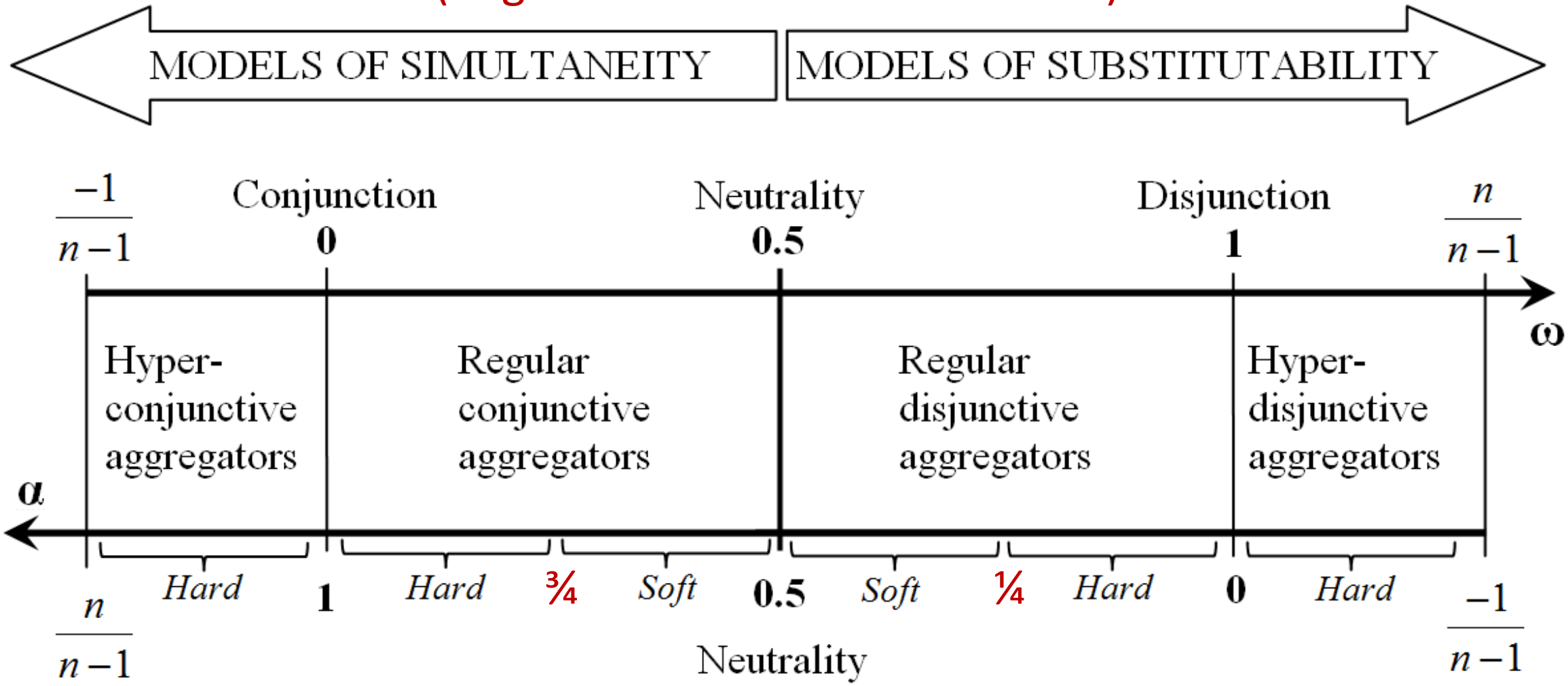


Nonidempotent hyperdisjunction



Range of andness/orness for UGCD

(A general case of n>1 variables)



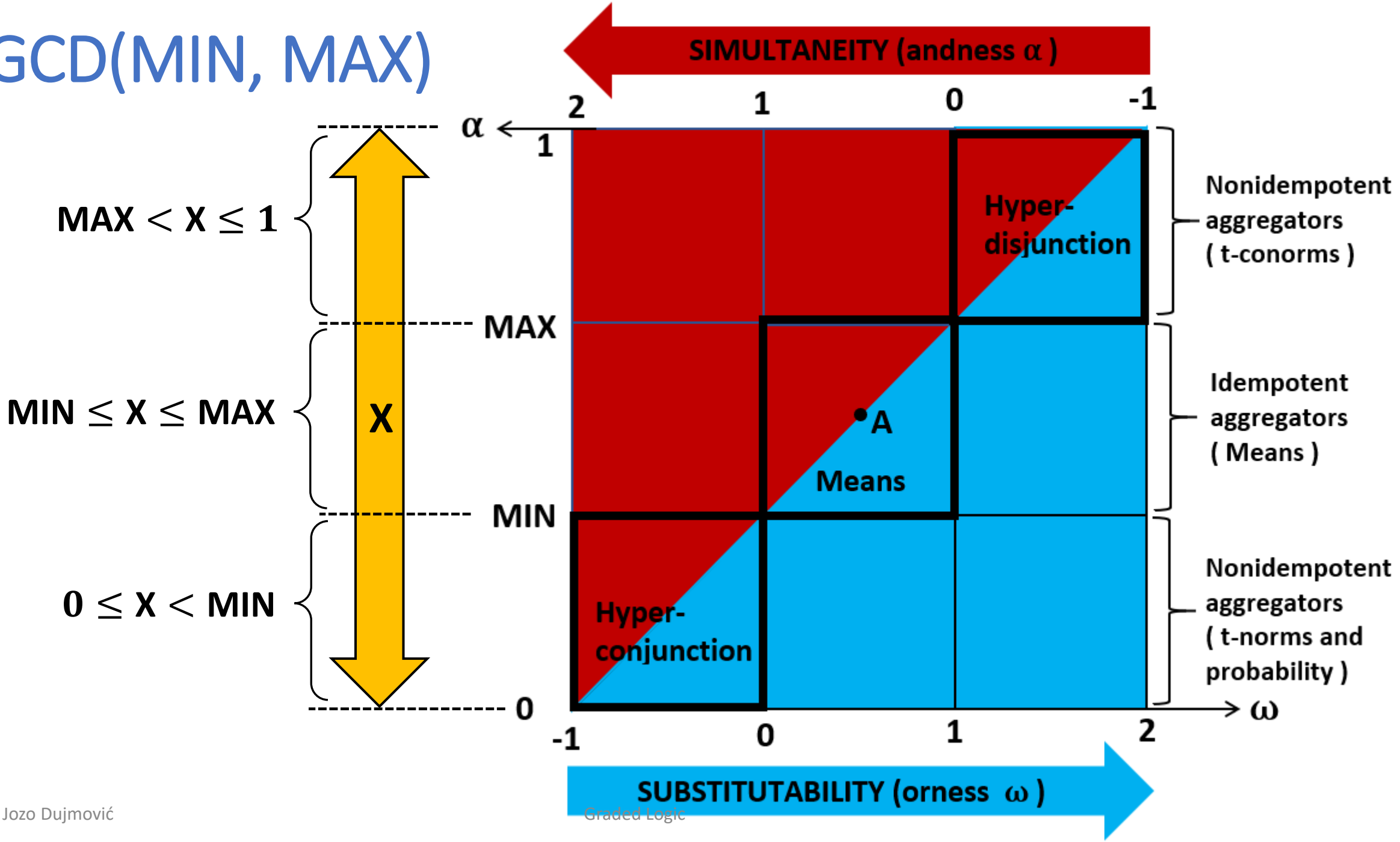
Verbalized interpretation of GCD aggregators

	Hyperconjunction
• Must have **all** inputs satisfied :	Hard graded conjunction
• Nice to have **most** inputs satisfied :	Soft graded conjunction
• Nice to have inputs satisfied :	Neutrality
• Nice to have **some** inputs satisfied :	Soft graded disjunction
• Enough to have **any** input satisfied :	Hard graded disjunction
	Hyperdisjunction

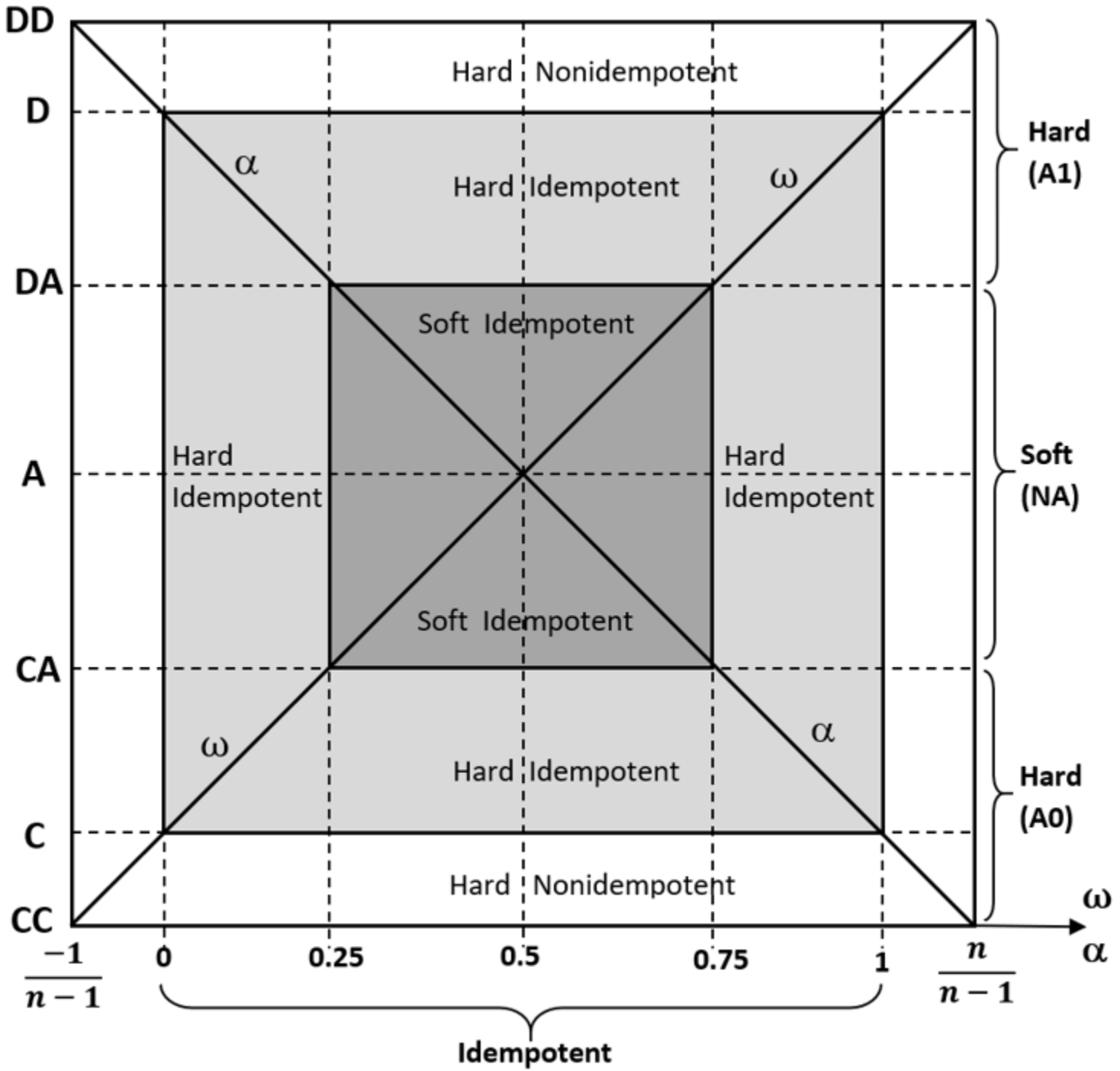
Four main types of human-centric logic properties supported by GCD

Verbal requirements for satisfied inputs	Type of requirement	Type of aggregator	Supported annihilator	Type of logic connective	Relationship of components
"Must have all"	Mandatory	Hard	0	Conjunctive	Simultaneity
"Nice to have most"	Optional	Soft	None	Conjunctive	Simultaneity
"Nice to have some"	Optional	Soft	None	Disjunctive	Substitutability
"Enough to have any"	Sufficient	Hard	1	Disjunctive	Substitutability

X=GCD(MIN, MAX)

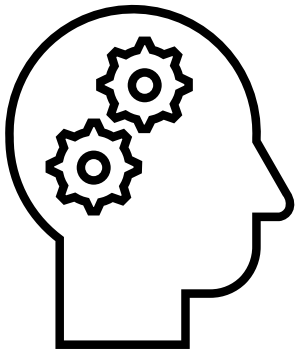


GCD logic aggregator in the full range of andness/orness



PROFESSIONAL DECISION MAKING

1. Stakeholder
2. Domain expert
3. Decision engineer



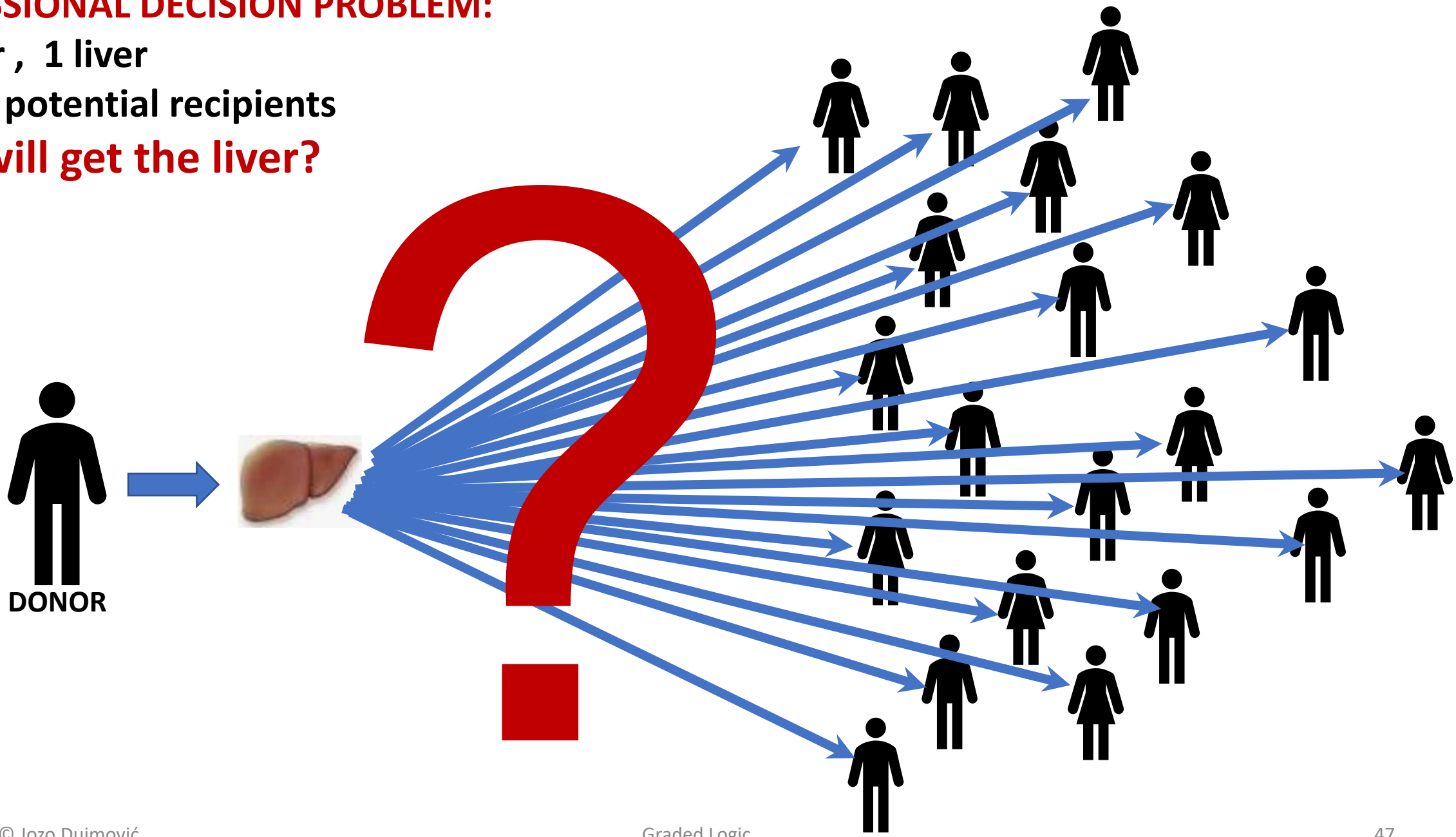
PROFESSIONAL DECISION PROBLEM:

1 donor , 1 liver

m >> 1 potential recipients

Who will get the liver?

Why?



Selection of decision method (Q & A)

Q: Why to use the LSP method?

A1: Comparison of m alternatives =
m evaluations of a single alternative

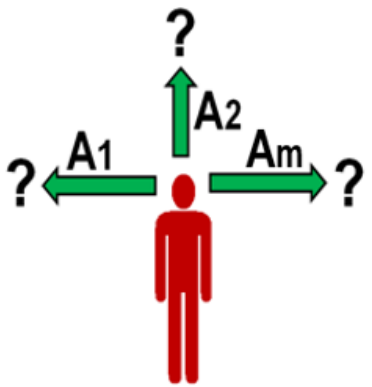
A2: Full consistency with observable
human commonsense reasoning

A3: LSP provides explainability of Transplantation
Priority Score (TPS) and other results

LSP method

Identify stake-holders and their goals

For a specific stakeholder identify one or more alternatives (m ≥ 1) for achieving stakeholder's goals. Use LSP to find the best alternative.



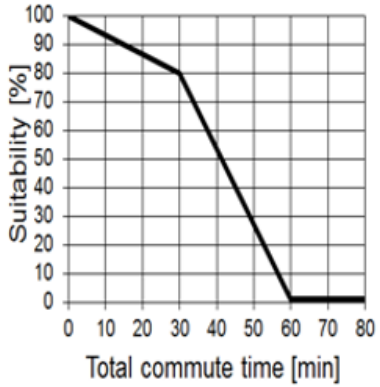
Develop a suitability attribute tree

Top-down suitability decomposition structure that generates all relevant suitability attributes as leaves of the attribute tree.

1 Project
- **11 .....**
  - **111 .....**
  - **112 .....**
- **12 .....**
  - **121 .....**
  - **122 .....**
  - **123 .....**

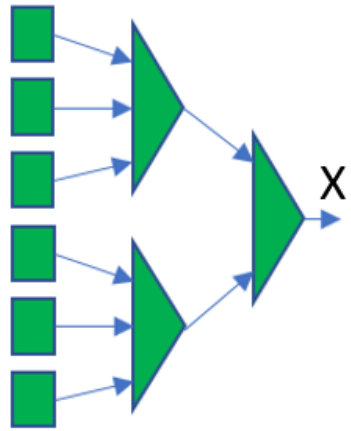
Define elementary attribute criteria

For each suitability attribute create a specific evaluation criterion as a function that assigns a desired suitability degree (score) to each value of attribute.



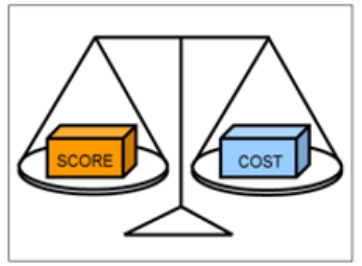
Create the graded logic aggregation structure

According to the attribute tree, aggregate attribute suitability degrees (scores) using logic aggregators and compute the overall suitability score (X).



Compute the overall suitability and value

Using the overall suitability X and the overall cost C , compute the overall value V(X, C) of each alternative and use it for final ranking of all alternatives.



1. Alpha
2. Beta
3. Delta

LIVER TRANSPLANTATION PRIORITY EVALUATION

1. Stakeholder = government
   (organ procurement, distribution, and allocation organization)
2. Domain expert = MD
3. Decision engineer

The main groups of organ transplantation priority factors

1 PRIORITY FACTORS FOR ORGAN TRANSPLANTATION

11 MEDICAL PRIORITY FACTORS

111 Medical urgency for organ transplantation

112 Medical prerequisites for organ transplantation

113 Expected recovery time after organ transplantation

114 Medical benefits of organ transplantation

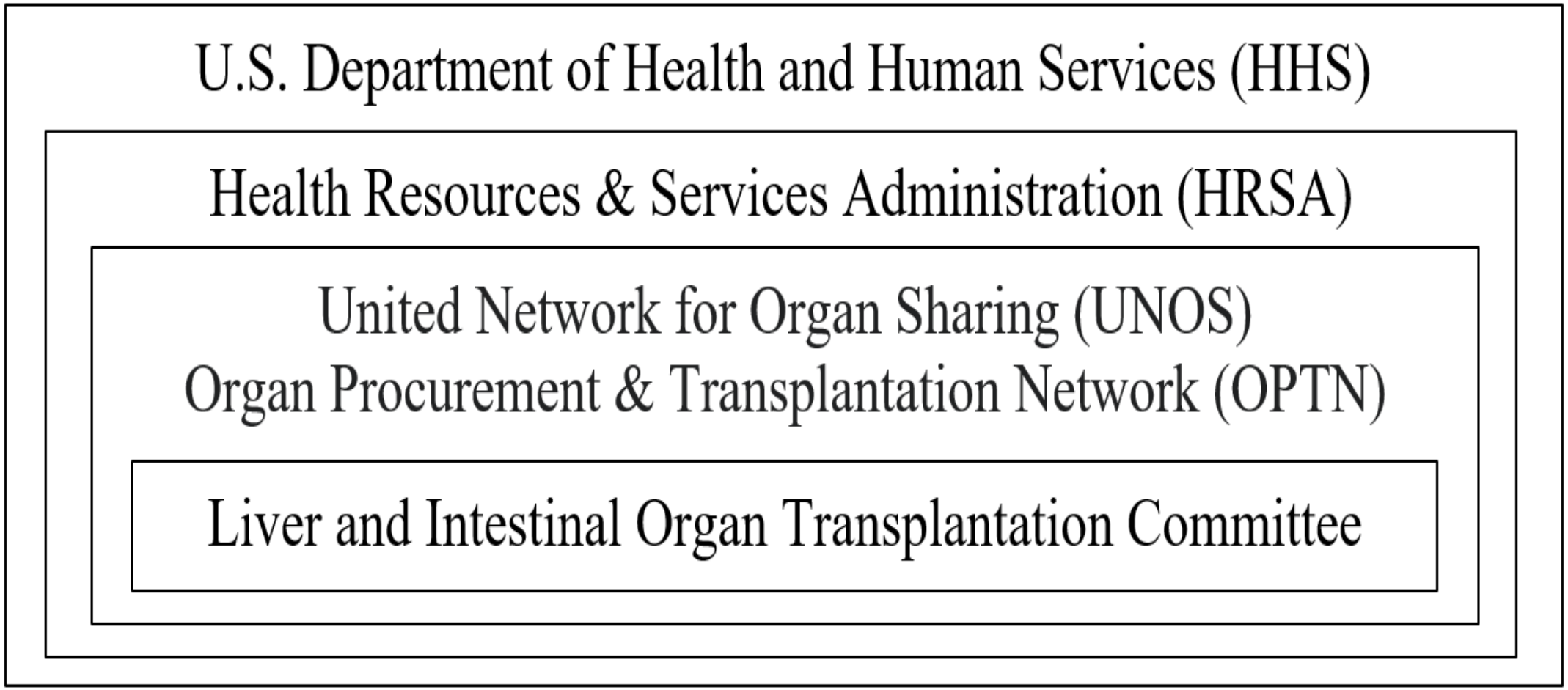
12 SOCIAL AND ETHICAL PRIORITY FACTORS

121 Priority factors based on recipient's contribution to society

122 Priority factors that reflect expected social benefits for recipient

123 Priority factors that support ethical aspects of organ transplantation

Liver and intestinal organ allocation organizations used by the U.S. federal government



LSP attribute tree

MEDICAL FACTORS

1 TRANSPLANTATION PRIORITY SCORE (TPS)
11 MEDICAL PRIORITY FACTORS FOR LIVER TRANSPLANTATION
111 Medical urgency for organ transplantation
1111 Disease severity
11111 MELD score for liver disease severity evaluation
11112 MELD exceptions: complications of liver disease
1112 Waiting time for organ transplantation
1113 Expected time of life without organ transplantation
112 Medical prerequisites for organ transplantation
1121 Donor-recipient compatibility
11211 Donor-recipient blood compatibility
112111 Donor-recipient ABO compatibility
112112 Donor-recipient HLA compatibility
11212 Donor-recipient age compatibility
11213 Donor-recipient organ size compatibility
112131 Donor-recipient height compatibility
112132 Donor-recipient weight compatibility
1122 Organ delivery time
1123 Organ recipient overall health status and comorbidities
113 Expected recovery time after organ transplantation
114 Medical benefits of organ transplantation
1141 Expected time of life after organ transplantation
1142 Utility: collective benefits of allocation optimization

LSP attribute tree

SOCIAL AND ETHICAL FACTORS

12 SOCIAL AND ETHICAL PRIORITY FACTORS
- 121 Priority factors based on recipient's contribution to society
  - 1211 Governmental role/responsibility
  - 1212 Important professional status or responsibility
- 122 Priority factors that reflect expected social benefits for recipient
  - 1221 Priority factors based on recipient's family and social support
    - 12211 Number of family members of the organ recipient
    - 12212 Number of dependents of the organ recipient
    - 12213 Social support network of the organ recipient
    - 12214 Parenthood status of the organ recipient
  - 1222 Priority factors based on organ recipient residential environment
    - 12221 Living in non-retirement homes
    - 12222 Living in retirement and nursing homes
    - 12223 Degree of urbanity in the patient residential area
    - 12224 Density of population in the patient residential area
- 123 Priority factors that support ethical aspects of organ transplantation
  - 1231 Priority factors based on organ allocation policies and regulations
    - 12311 Donor selection policy
    - 12312 Fairness of the organ allocation process
    - 12313 Transparency of the organ allocation process
    - 12314 Accountability of the organ allocation organizations and individuals
    - 12315 Data protection, privacy, and security
    - 12316 Public feedback during the development of organ allocation policies
  - 1232 Priority factors based on reducing health inequities
    - 12321 Protection of disadvantaged groups
    - 12322 Protecting patients with low economic status
    - 12323 Educational, cultural, and language priority factors
    - 12324 Promoting equity, inclusivity, and diversity
  - 1233 Recipient's responsible adherence to medical recommendations

Liver TPS attributes

MEDICAL FACTORS

1. MELD score for liver disease severity evaluation
2. MELD exceptions: complications of liver disease
3. Waiting time for organ transplantation
4. Expected time of life without organ transplantation
5. Donor-recipient ABO compatibility
6. Donor-recipient HLA compatibility
7. Donor-recipient age compatibility
8. Donor-recipient height compatibility
9. Donor-recipient weight compatibility
10. Organ delivery time
11. Organ recipient overall health status and comorbidities
12. Expected recovery time after organ transplantation
13. Expected time of life after organ transplantation
14. Utility - collective benefits of allocation optimization

Liver TPS attributes

SOCIAL AND ETHICAL FACTORS

15. Governmental role/responsibility
16. Important professional status or responsibility
17. Number of family members of the organ recipient
18. Number of dependents of the organ recipient
19. Social support network of the organ recipient
20. Parenthood status of the organ recipient
21. Living in non-retirement homes
22. Living in retirement and nursing homes
23. Degree of urbanity in the patient residential area
24. Density of population in the patient residential area
25. Donor selection policy
26. Fairness of the organ allocation process
27. Transparency of the organ allocation process
28. Accountability of the organ allocation organizations and individuals
29. Data protection, privacy, and security
30. Public feedback during the development of organ allocation policies
31. Protection of disadvantaged groups
32. Protecting patients with low economic status
33. Educational, cultural, and language priority factors
34. Promoting equity, inclusivity, and diversity
35. Recipient's responsible adherence to medical recommendations

Liver TPS attribute criteria

11111		MELD score for liver disease severity evaluation
Value	%	In the case of liver transplantation, the disease severity for adult patients is primarily assessed using the Model for End-Stage Liver Disease (MELD 3.0 score). MELD score is used as a predictor of the three-month mortality risk for patients without access to liver transplant. For children below 12 years of age, the Pediatric End-Stage Liver Disease (PELD) score is used instead of the MELD score, but the range [6, 40] remains the same.
0 6 40	0 10 100	

11112		MELD exceptions: complications of liver disease
Value	%	MELD 3.0 is the primary indicator of liver transplantation urgency. MELD exceptions are the liver disease severity scores based on complications of liver disease. OTPN identifies 14 diagnoses that can be presented to the Review Board with a request to be used instead of the MELD score. E.g., the hepatocellular carcinoma (HCC) currently accounts for 20-25% of liver transplants. The liver disease severity scores used as MELD exceptions can be evaluated using the following rating scale: 1=lowest, 2=very low, 3=low, 4=mid-low, 5=medium, 6=mid-high, 7=high, 8=very high, 9=highest.
0 9	0 100	

Attribute criteria #1-2

11111	MELD score for liver disease severity evaluation
Value	%
0 6 40	0 10 100

In the case of liver transplantation, the disease severity for adult patients is primarily assessed using the Model for End-Stage Liver Disease (MELD 3.0 score). MELD score is used as a predictor of the three-month mortality risk for patients without access to liver transplant.

For children below 12 years of age, the Pediatric End-Stage Liver Disease (PELD) score is used instead of the MELD score, but the range [6, 40] remains the same.

11112	MELD exceptions: complications of liver disease
Value	%
0 9	0 100

MELD 3.0 is the primary indicator of liver transplantation urgency. MELD exceptions are the liver disease severity scores based on complications of liver disease. OTPN identifies 14 diagnoses that can be presented to the Review Board with a request to be used instead of the MELD score. E.g., the hepatocellular carcinoma (HCC) currently accounts for 20-25% of liver transplants. The liver disease severity scores used as MELD exceptions can be evaluated using the following rating scale:

1=lowest, 2=very low, 3=low, 4=mid-low, 5=medium, 6=mid-high, 7=high, 8=very high, 9=highest.

1112	Waiting time for organ transplantation
Value	%
1 12	20 100

According to donors1.org the average wait time for liver transplant in the USA is 11 months. This criterion prioritizes patients who spent longer time waiting for transplant.
[The wait time is measured in months]

1113	Expected time of life without organ transplantation
Value	%
5 50	100 20

This criterion prioritizes patients with a short expected lifespan without liver transplantation. The expected time of life without liver transplantation is evaluated by a team of experts in the range from Tmin to Tmax. The evaluation is based on the following ratio: R = 100*Tmean/T [%] , where Tmean = (Tmin+Tmax)/2 denotes the mean expected remaining lifetime, and T denotes the current recipient age.

112111	Donor-recipient ABO compatibility
Value	%
0 1	0 100

Blood type compatibility is a critical factor in liver transplantation. Rh compatibility is not a primary concern and blood types A, B, AB, and O are evaluated as follows:
1 = compatible donor->recipient blood types for adults:
A->A, O->A
B->B, O->B
A->AB, B->AB, AB->AB, O->AB (AB = universal recipient)
O->O (O = universal donor)
0 = incompatible blood types (can be used in special cases)

112112	Donor-recipient HLA compatibility
Value	%
0 100	0 100

Human leukocyte antigen compatibility (HLA) plays a crucial role in some organ transplantation. It is used in simultaneous liver-kidney transplantation. In strictly liver transplantation it is not used.
Evaluation is based on the donor->recipient HLA Matching Score that is normalized to range [0,100]. Higher scores describe higher HLA compatibility. In some cases, a partial match can be sufficient for a successful transplantation.

11212	Donor-recipient age compatibility
Value	%
0 50	100 50

This criterion gives moderate credit to donors and recipients that are of similar age. Evaluation is based on the following age compatibility (AC) indicator:
AC = 100 |AD - AR| / (AD + AR) [%]
Inputs: AD = age of donor ; AR = age of recipient .

112131	Donor-recipient height compatibility
Value	%
0 40	100 0

Evaluation is based on the following height compatibility (HC) indicator:
HC = 100 |HD - HR| / (HD + HR) [%] .
Inputs: HD = height of donor ; HR = height of recipient.
Low values of HC denote good match.

112132	Donor-recipient weight compatibility
Value	%
0 30	100 0

Evaluation is based on the following weight compatibility (WC) indicator:
WC = 100 |WD - WR| / (WD + WR) [%] .
Inputs: WD = weight of donor ; WR = weight of recipient.
Low values of WC denote good match.

1122	Organ delivery time
Value	%
0 100	100 0

Geographic location of recipient affects the organ delivery time.
Evaluated as the following relative organ delivery time:
Trel = 100*Tdel/Tmax [%].
Here we use the following variables:
Tdel = organ delivery time (transport time from current organ location to recipient's surgery room).
Tmax = maximum organ viability time.
In the case of liver transplantation, this criterion can be based on Tmax=24 h (or 27 h), or defined as the cold ischemia time criterion, e.g. {(0,100), (12,85), (24,0)}

1123	Organ recipient overall health status and comorbidities
Value	%
0 4	0 100

A patient's overall health status includes kidney functions, cardiovascular health, and comorbidities that affect the likelihood of successful surgery and post-transplant recovery. The overall health rating scale is 0=very poor, 1=below average, 2=average, 3=good, 4=excellent

Attribute criteria #3-4

113	Expected recovery time after organ transplantation
Value	%
0 4	10 100

Patient ability to recover after the organ transplantation can be measured as the expected patient recovery time (time necessary to reach a steady health state). Evaluation can be based on the expert opinion provided for a specific organ and a specific patient, using a rating scale, as follows:

0=very long, 1=long, 2=medium, 3=short, 4=very short.

This criterion can be precisiated using 5 components: (1) hospital stay after the transplant surgery, (2) first few weeks after the surgery (immunosuppressive medications with side effects), (3) first few months, (4) first year, and (5) long-term.
In the case of liver transplants the criterion can be {(3 month, 100), (12 months, 50)} .

1141	Expected time of life after organ transplantation
Value	%
0 1 5 10	0 40 75 100

The main medical benefit is the patient's time of life after an organ transplantation. The life expectancy after an organ transplantation can vary in a wide range and is influenced by many factors, including age, healthy lifestyle, management of comorbidities, adherence to medication regimens, and other factors.
In the case of liver transplantation, UNOS data for USA show the one-year survival rate around 85% to 90%, and the five-year survival rate around 70% to 80%. The proposed rating scale reflects this situation. The time is measured in years.

1142	Utility: collective benefits of allocation optimization
Value	%
0 4	0 100

This criterion balances the limited supply of organs with the long-term survival and quality of life of patients. The contribution to optimizing the allocation of available donor organs is evaluated using the following contribution rating scale:
0=no contribution, 1=low contribution, 2=average, 3=high, and 4=very high contribution

1211	Governmental role/responsibility
Value	%
1 21	100 0

This criterion gives credit to patients of any age who have high responsibility and roles that are indispensable for functioning of society and directly or indirectly affect the lives of most people. Evaluated using 20 rank steps based on the scoring criterion SCORE = 100-5(RANK-1) as follows:

```
   1  = The top rank              (score = 100%)
   2  = Next to the top rank      (score = 95%)
   ...
   20 = Lowest rank               (score = 5%)
   21 = Not in this group         (score = 0)
```

1212	Important professional status or responsibility
Value	%
1 21	100 0

This criterion gives credit to patients who have significant professional status and/or important roles in various areas, such as industry, medicine, business, entertainment, research, sports, education, military, police, etc. Evaluated using 20 rank steps based on the scoring criterion SCORE = 100-5(RANK-1) as follows:

```
   1  = The top rank              (score = 100%)
   2  = Next to the top rank      (score = 95%)
   ...
   20 = Lowest rank               (score = 5%)
   21 = Not in this group         (score = 0)
```

12211	Number of family members of the organ recipient
Value	%
1 2 4 6	20 50 80 100

This criterion gives credit to organ transplantation patients who are members of large families. All family members benefit if one of them (the organ recipient) significantly improves her/his health status. The family is defined in a traditional way, or as any strongly connected social unit, primarily those that share residential units and maintain permanent contacts.

12212	Number of dependents of the organ recipient
Value	%
0 1 3	0 50 100

Adult patients with more dependents deserve more help because positive health effects caused by organ transplantation are shared by all dependents. Dependents can be children or adults.

Pediatric patients are assumed to be counted as dependents and can be evaluated using the same criterion.

12213	Social support network of the organ recipient
Value	%
0 10	0 100

This criterion evaluates the number of members of the organ recipient social support network who can regularly assist with the post-transplant recovery process. This includes adult family members, friends, and other people (or organized support groups) who can help with adherence to follow-up care and medications.

12214	Parenthood status of the organ recipient
Value	%
0 3	40 100

This criterion gives credit to organ recipients who are parents. Measured as the number of recipient's children.

For pediatric patients, this criterion can be based on the number of siblings and the rating
0 => 60
2 => 100

12221	Living in non-retirement homes
Value	%
0 100	0 100

This criterion gives credit to patients who live in groups with other people. Evaluated using the following (or similar) group living options:
Life in family, group homes/dorms, or homeless shelters with the total of n members: SCORE = min[100, 20(n-1)]

Attribute criteria #5-6

12222	Living in retirement and nursing homes
Value / %	This criterion gives credit to patients who live in retirement homes and assisted living institutions. Evaluation is based on the following rating scale: 0 = excellent conditions 1 = very good conditions 2 = average conditions 3 = poor conditions 4 = very poor conditions
0 / 0 4 / 100	

12223	Degree of urbanity in the patient residential area
Value / %	This criterion gives credit to patients who live in areas with a low degree of urbanity (e.g., in underdeveloped areas), regardless of the density of population. Such areas are assumed to have limited access to medical services. Evaluated using the following rating scale for the degree of urbanity: 0 = very low (isolated rural areas) 1 = low 2 = medium 3 = high 4 = very high
0 / 100 4 / 0	

12224	Density of population in the patient residential area
Value / %	This criterion gives credit to patients who live in areas with low density of population, which are presumably less developed and offer less health protection opportunities. Evaluated using the following rating scale for the density of population: 0 = very low density of population 1 = low 2 = medium 3 = high 4 = very high
0 / 100 4 / 0	

12311	Donor selection policy
Value / %	This criterion gives credit to social policies that contribute to the availability of donor organs. Evaluation based on the following scale: 1 = "opt-out" organ donation system: all individuals are presumed to consent to be organ donors unless they explicitly opt out. 2 = "opt-in" organ donation system: individuals who voluntarily agree to donate their organs register their consent. 3 = insufficient legal and organizational support for recruiting organ donors.
1 / 100 3 / 0	

12312	Fairness of the organ allocation process
Value / %	Ensuring that the organ procurement organizations are not biased and do not discriminate against individuals or groups based on religion, race, gender, socioeconomic status, or ethnicity. Existing policies and practice are evaluated for fairness using the following fairness rating scale: 0 = unknown, 1 = low, 2 = medium, 3 = high, 4 = very high
0 / 0 4 / 100	

12313	Transparency of the organ allocation process
Value / %	Providing clear and publicly available explanations of allocation rules, decisions, and practice. Transparency builds trust and allows patients and their families to understand and challenge outcomes. Transparency is evaluated using the following transparency rating scale: 0 = unknown, 1 = low, 2 = medium, 3 = high, 4 = very high.
0 / 0 4 / 100	

12314	Accountability of the organ allocation organizations and individuals
Value / %	Holding organ procurement and allocation organizations and leading individuals responsible for the development of organ allocation policies and the practice of organ procurement and allocation (serving the maximum number of patients in equitable and efficient way). Accountability is evaluated using the following accountability rating scale: 0 = unknown, 1 = low, 2 = medium, 3 = high, 4 = very high.
0 / 0 4 / 100	

12315	Data protection, privacy, and security
Value / %	This criterion evaluates organized activity for protecting the privacy of organ transplantation recipients: (1) Implementing strong data protection measures. (2) Obtaining patient's informed consent for the collection, sharing, and use of personal information. Security includes the following activities: (1) Preventing unauthorized access to transplantation database (2) Preventing manipulation or malicious use of sensitive data Privacy and security are jointly evaluated using the following rating scale: 0 = unknown, 1 = low, 2 = medium, 3 = high, 4 = very high.
0 / 0 4 / 100	

12316	Public feedback during the development of organ allocation policies
Value / %	In the process of development of the organ transplantation policy and prioritization criteria, there is a period reserved for collecting and considering public feedback (comments, suggestions, concerns) from professionals, patients, caregivers, and general public. 0 = not available 1 = available
0 / 0 1 / 100	

Attribute criteria #7

Suitability aggregation structure

12321	Protection of disadvantaged groups
Value	%
0 4	0 100

This criterion evaluates organized protection of ethnic/social/racial minority groups disadvantaged in relation to organ transplantation and health care (based on religion, place of residence, race, ethnicity, education, occupation, etc.). That can include selected people from homeless shelters, people with intellectual or development disabilities, substance use disorder, and sexual and gender minorities.
Disadvantaged groups protection is evaluated using the following rating scale: 0 = no protection, 1 = low, 2 = medium, 3 = high, 4 = very high.

12322	Protecting patients with low economic status
Value	%
0 4	0 100

This criterion evaluates protection of people living in poverty with poor access to health care. People in this group usually also experience the problem in necessary time and travel cost to go to places offering health protection.
Evaluation is based on the following rating scale:
0 = no protection, 1 = low, 2 = medium, 3 = high, 4 = very high.

12323	Educational, cultural, and language priority factors
Value	%
0 4	0 100

This criterion evaluates protection of people with insufficient education, low socioeconomic status, family problems (no parents, single parents, family conflicts), cultural and language isolation, and similar factors that reduce health care equity. Health risks for people in this group are evaluated using the following rating scale:
0 = no risk, 1 = low, 2 = medium, 3 = high, 4 = very high.

12324	Promoting equity, inclusivity, and diversity
Value	%
0 4	0 100

Evaluation of existing policies and regulations that explicitly promote equity, inclusivity, and diversity for organ transplantation recipients.
Equity, inclusivity, and diversity are evaluated using the following rating scale:
0 = unknown, 1 = low, 2 = medium, 3 = high, 4 = very high.

1233	Recipient's responsible adherence to medical recommendations
Value	%
0 4	0 100

This criterion evaluates the expected patient's contribution to success of organ transplantation.
Potential recipients of transplanted organs are expected to be responsible and cooperating in health protection:
(1) Actively engaged in maintaining their health
(2) Adhering to medical recommendations (e.g., no substance abuse, healthy lifestyle, sustenance, etc.)
Evaluation is based on the following expected responsibility rating scale:
0 = very low, 1 = low, 2 = medium, 3 = high, 4 = very high

- **1 [CPA: P=20%, R=15%]** TRANSPLANTATION PRIORITY SCORE (TPS)
  - **11 [MAN; HC]** MEDICAL PRIORITY FACTORS FOR LIVER TRANSPLANTATION
    - **111 [30%; HC]** Medical urgency for organ transplantation
      - **1111 [75%; D]** Disease severity
        - **11111 [50%]** MELD score for liver disease severity evaluation
        - **11112 [50%]** MELD exceptions: complications of liver disease
      - **1112 [15%]** Waiting time for organ transplantation
      - **1113 [10%]** Expected time of life without organ transplantation
    - **112 [30%; HC+]** Medical prerequisites for organ transplantation
      - **1121 [60%; HC]** Donor-recipient compatibility
        - **11211 [60%; HC]** Donor-recipient blood compatibility
          - **112111 [70%]** Donor-recipient ABO compatibility
          - **112112 [30%]** Donor-recipient HLA compatibility
        - **11212 [15%]** Donor-recipient age compatibility
        - **11213 [25%; SC+]** Donor-recipient organ size compatibility
          - **112131 [40%]** Donor-recipient height compatibility
          - **112132 [60%]** Donor-recipient weight compatibility
      - **1122 [20%]** Organ delivery time
      - **1123 [20%]** Organ recipient overall health status and comorbidities
    - **113 [20%]** Expected recovery time after organ transplantation
    - **114 [20%; SC]** Medical benefits of organ transplantation
      - **1141 [60%]** Expected time of life after organ transplantation
      - **1142 [40%]** Utility: collective benefits of allocation optimization
  - **12 [OPT; SC]** SOCIAL AND ETHICAL PRIORITY FACTORS
    - **121 [20%; D]** Priority factors based on recipient's contribution to society
      - **1211 [50%]** Governmental role/responsibility
      - **1212 [50%]** Important professional status or responsibility
    - **122 [40%; SC-]** Priority factors that reflect expected social benefits for recipient
      - **1221 [70%; SC-]** Priority factors based on recipient's family and social support
        - **12211 [30%]** Number of family members of the organ recipient
        - **12212 [30%]** Number of dependents of the organ recipient
        - **12213 [20%]** Social support network of the organ recipient
        - **12214 [20%]** Parenthood status of the organ recipient
      - **1222 [30%; SD]** Priority factors based on organ recipient residential environment
        - **12221 [30%]** Living in non-retirement homes
        - **12222 [20%]** Living in retirement and nursing homes
        - **12223 [30%]** Degree of urbanity in the patient residential area
        - **12224 [20%]** Density of population in the patient residential area
    - **123 [40%; SC]** Priority factors that support ethical aspects of organ transplantation
      - **1231 [40%; SC-]** Priority factors based on organ allocation policies and regulations
        - **12311 [18%]** Donor selection policy
        - **12312 [18%]** Fairness of the organ allocation process
        - **12313 [18%]** Transparency of the organ allocation process
        - **12314 [18%]** Accountability of the organ allocation organizations and individuals
        - **12315 [18%]** Data protection, privacy, and security
        - **12316 [10%]** Public feedback during the development of organ allocation policies
      - **1232 [35%; A]** Priority factors based on reducing health inequities
        - **12321 [30%]** Protection of disadvantaged groups
        - **12322 [30%]** Protecting patients with low economic status
        - **12323 [20%]** Educational, cultural, and language priority factors
        - **12324 [20%]** Promoting equity, inclusivity, and diversity
      - **1233 [25%]** Recipient's responsible adherence to medical recommendations

Suitability aggregation structure

MEDICAL FACTORS

1 [CPA: P=20%, R=15%] TRANSPLANTATION PRIORITY SCORE (TPS)
- **11 [MAN; HC]** MEDICAL PRIORITY FACTORS FOR LIVER TRANSPLANTATION
  - **111 [30%; HC]** Medical urgency for organ transplantation
    - **1111 [75%; D]** Disease severity
      - **11111 [50%]** MELD score for liver disease severity evaluation
      - **11112 [50%]** MELD exceptions: complications of liver disease
    - **1112 [15%]** Waiting time for organ transplantation
    - **1113 [10%]** Expected time of life without organ transplantation
  - **112 [30%; HC+]** Medical prerequisites for organ transplantation
    - **1121 [60%; HC]** Donor-recipient compatibility
      - **11211 [60%; HC]** Donor-recipient blood compatibility
        - **112111 [70%]** Donor-recipient ABO compatibility
        - **112112 [30%]** Donor-recipient HLA compatibility
      - **11212 [15%]** Donor-recipient age compatibility
      - **11213 [25%; SC+]** Donor-recipient organ size compatibility
        - **112131 [40%]** Donor-recipient height compatibility
        - **112132 [60%]** Donor-recipient weight compatibility
    - **1122 [20%]** Organ delivery time
    - **1123 [20%]** Organ recipient overall health status and comorbidities
  - **113 [20%]** Expected recovery time after organ transplantation
  - **114 [20%; SC]** Medical benefits of organ transplantation
    - **1141 [60%]** Expected time of life after organ transplantation
    - **1142 [40%]** Utility: collective benefits of allocation optimization
- **12 [OPT; SC]** SOCIAL AND ETHICAL PRIORITY FACTORS

Suitability aggregation structure

SOCIAL AND ETHICAL FACTORS

12 [OPT; SC] SOCIAL AND ETHICAL PRIORITY FACTORS
- **121 [20%; D]** Priority factors based on recipient's contribution to society
  - **1211 [50%]** Governmental role/responsibility
  - **1212 [50%]** Important professional status or responsibility
- **122 [40%; SC-]** Priority factors that reflect expected social benefits for recipient
  - **1221 [70%; SC-]** Priority factors based on recipient's family and social support
    - **12211 [30%]** Number of family members of the organ recipient
    - **12212 [30%]** Number of dependents of the organ recipient
    - **12213 [20%]** Social support network of the organ recipient
    - **12214 [20%]** Parenthood status of the organ recipient
  - **1222 [30%; SD]** Priority factors based on organ recipient residential environment
    - **12221 [30%]** Living in non-retirement homes
    - **12222 [20%]** Living in retirement and nursing homes
    - **12223 [30%]** Degree of urbanity in the patient residential area
    - **12224 [20%]** Density of population in the patient residential area
- **123 [40%; SC]** Priority factors that support ethical aspects of organ transplantation
  - **1231 [40%; SC-]** Priority factors based on organ allocation policies and regulations
    - **12311 [18%]** Donor selection policy
    - **12312 [18%]** Fairness of the organ allocation process
    - **12313 [18%]** Transparency of the organ allocation process
    - **12314 [18%]** Accountability of the organ allocation organizations and individuals
    - **12315 [18%]** Data protection, privacy, and security
    - **12316 [10%]** Public feedback during the development of organ allocation policies
  - **1232 [35%; A]** Priority factors based on reducing health inequities
    - **12321 [30%]** Protection of disadvantaged groups
    - **12322 [30%]** Protecting patients with low economic status
    - **12323 [20%]** Educational, cultural, and language priority factors
    - **12324 [20%]** Promoting equity, inclusivity, and diversity
  - **1233 [25%]** Recipient's responsible adherence to medical recommendations

Variations of the typical patient P1

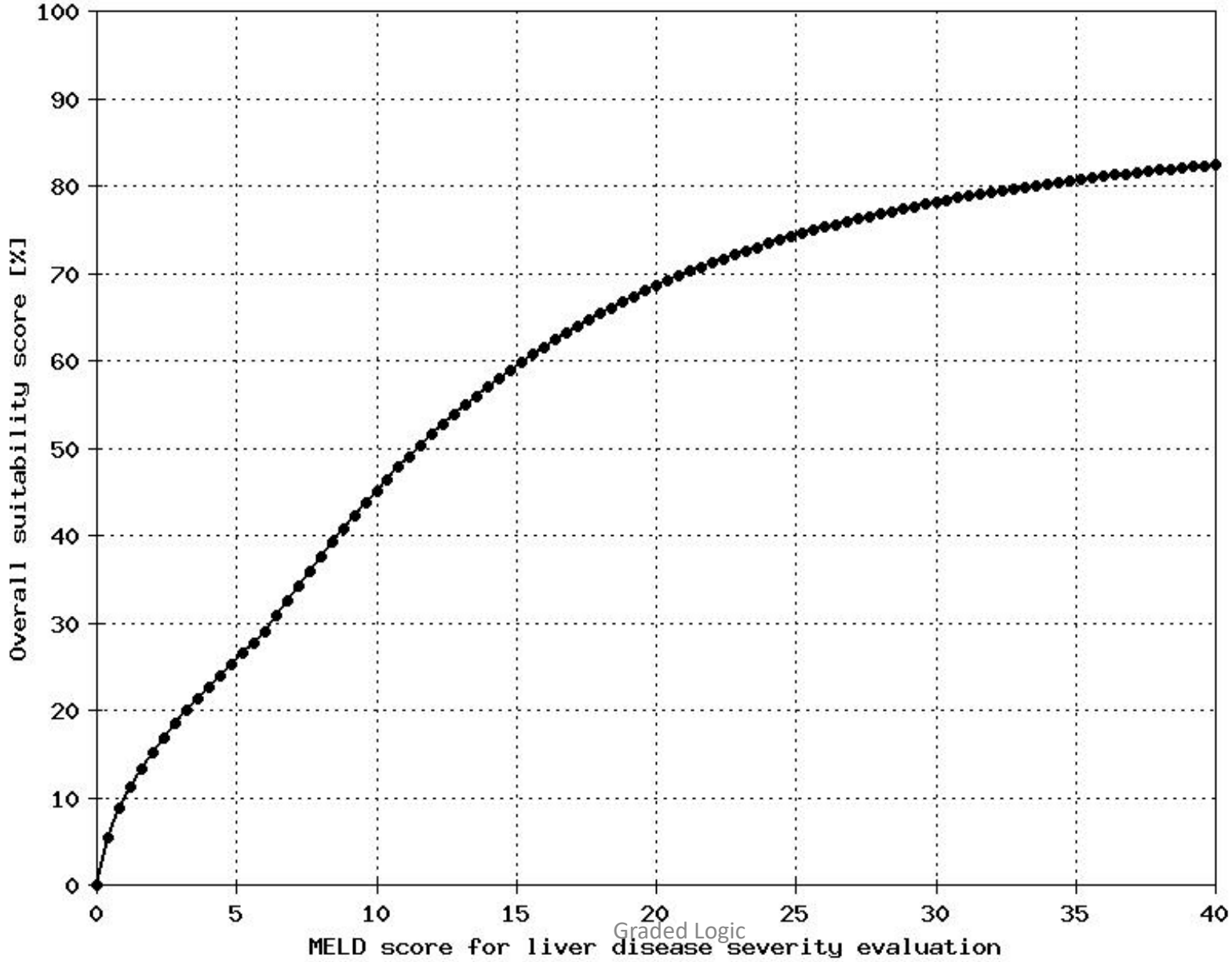
Id	Attribute	P1	P2	P3	P4	P5
	Cost	1.0000	1.0000	1.0000	1.0000	1.0000
11111	MELD score for liver disease severity evaluation	35	35	35	35	35
11112	MELD exceptions: complications of liver disease	0	0	0	0	0
1112	Waiting time for organ transplantation	10	10	10	10	10
1113	Expected time of life without organ transplantation	10	10	10	10	10
112111	Donor-recipient ABO compatibility	1	1	1	1	1
112112	Donor-recipient HLA compatibility	80	80	80	80	80
11212	Donor-recipient age compatibility	10	10	10	10	10
112131	Donor-recipient height compatibility	5	5	5	5	5
112132	Donor-recipient weight compatibility	8	8	8	8	8
1122	Organ delivery time	10	10	10	10	50
1123	Organ recipient overall health status and comorbidities	3	3	3	3	3
113	Expected recovery time after organ transplantation	3	3	3	3	3
1141	Expected time of life after organ transplantation	8	8	8	8	8
1142	Utility: collective benefits of allocation optimization	3	3	3	3	3
12	SOCIAL AND ETHICAL PRIORITY FACTORS	70	0	*****	100	70

Resulting TPS values

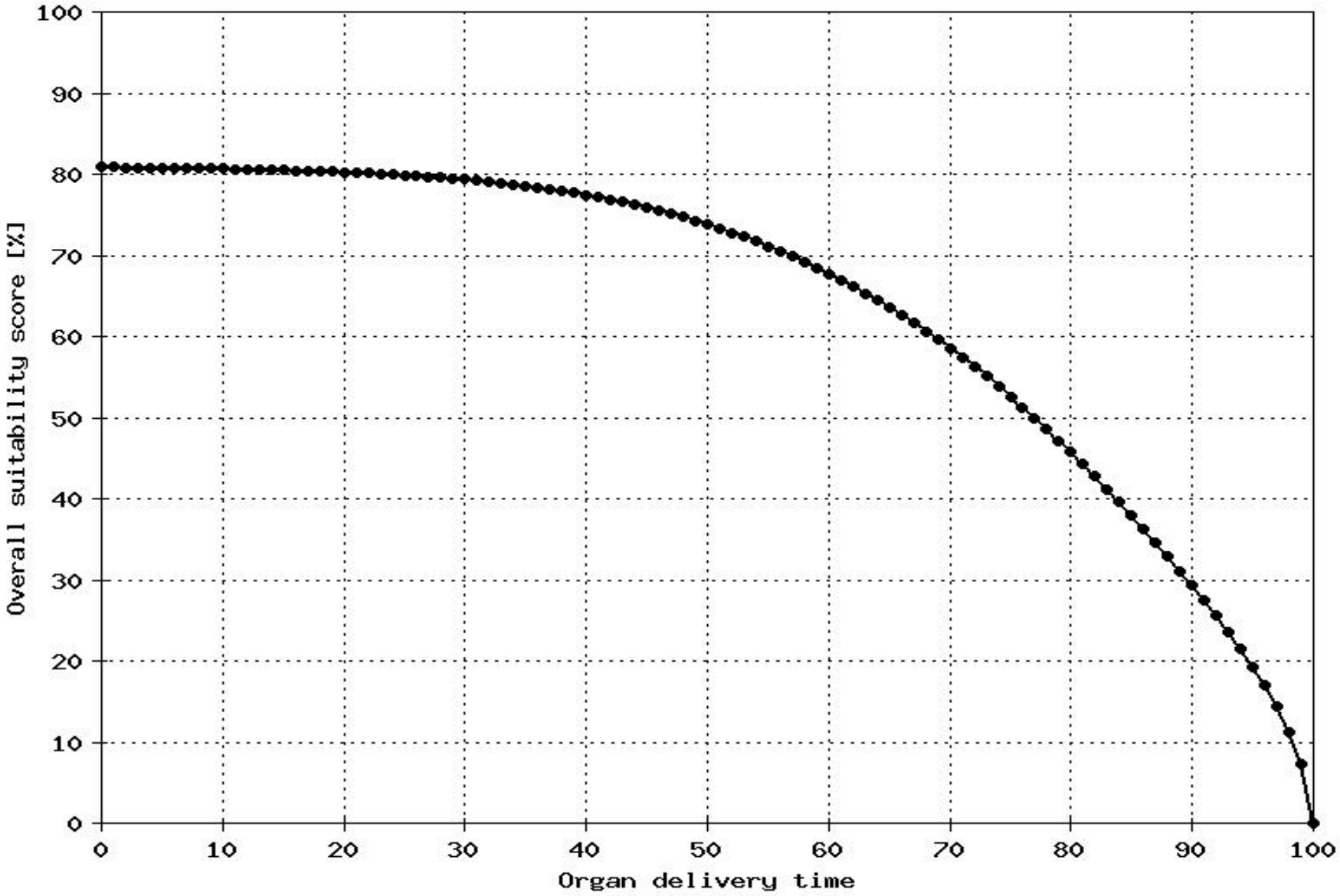
(Transplantation Priority Score)

Id	Attribute	P1	P2	P3	P4	P5
1	TRANSPLANTATION PRIORITY SCORE (TPS)	80.67	66.59	83.16	86.28	73.80
11	MEDICAL PRIORITY FACTORS FOR LIVER	83.16	83.16	83.16	83.16	74.68
111	Medical urgency for organ transplantation	86.98	86.98	86.98	86.98	86.98
112	Medical prerequisites for organ transplantation	83.53	83.53	83.53	83.53	62.59
114	Medical benefits of organ transplantation	83.67	83.67	83.67	83.67	83.67
1111	Disease severity	86.76	86.76	86.76	86.76	86.76
1121	Donor-recipient compatibility	86.63	86.63	86.63	86.63	86.63
11211	Donor-recipient blood compatibility	92.06	92.06	92.06	92.06	92.06
11213	Donor-recipient organ size compatibility	78.56	78.56	78.56	78.56	78.56
12	SOCIAL AND ETHICAL PRIORITY FACTORS	70.00	0.00	*****	100.00	70.00
1142	Utility: collective benefits of allocation optimization	75.00	75.00	75.00	75.00	75.00
1141	Expected time of life after organ transplantation	90.00	90.00	90.00	90.00	90.00
113	Expected recovery time after organ transplantation	77.50	77.50	77.50	77.50	77.50
1123	Organ recipient overall health status and comorbidities	75.00	75.00	75.00	75.00	75.00
1122	Organ delivery time	90.00	90.00	90.00	90.00	50.00
112132	Donor-recipient weight compatibility	73.33	73.33	73.33	73.33	73.33
112131	Donor-recipient height compatibility	87.50	87.50	87.50	87.50	87.50
11212	Donor-recipient age compatibility	83.33	83.33	83.33	83.33	83.33
112112	Donor-recipient HLA compatibility	80.00	80.00	80.00	80.00	80.00
112111	Donor-recipient ABO compatibility	100.00	100.00	100.00	100.00	100.00
1113	Expected time of life without organ transplantation	91.11	91.11	91.11	91.11	91.11
1112	Waiting time for organ transplantation	85.45	85.45	85.45	85.45	85.45
11112	MELD exceptions: complications of liver disease	0.00	0.00	0.00	0.00	0.00
11111	MELD score for liver disease severity evaluation	86.76	86.76	86.76	86.76	86.76

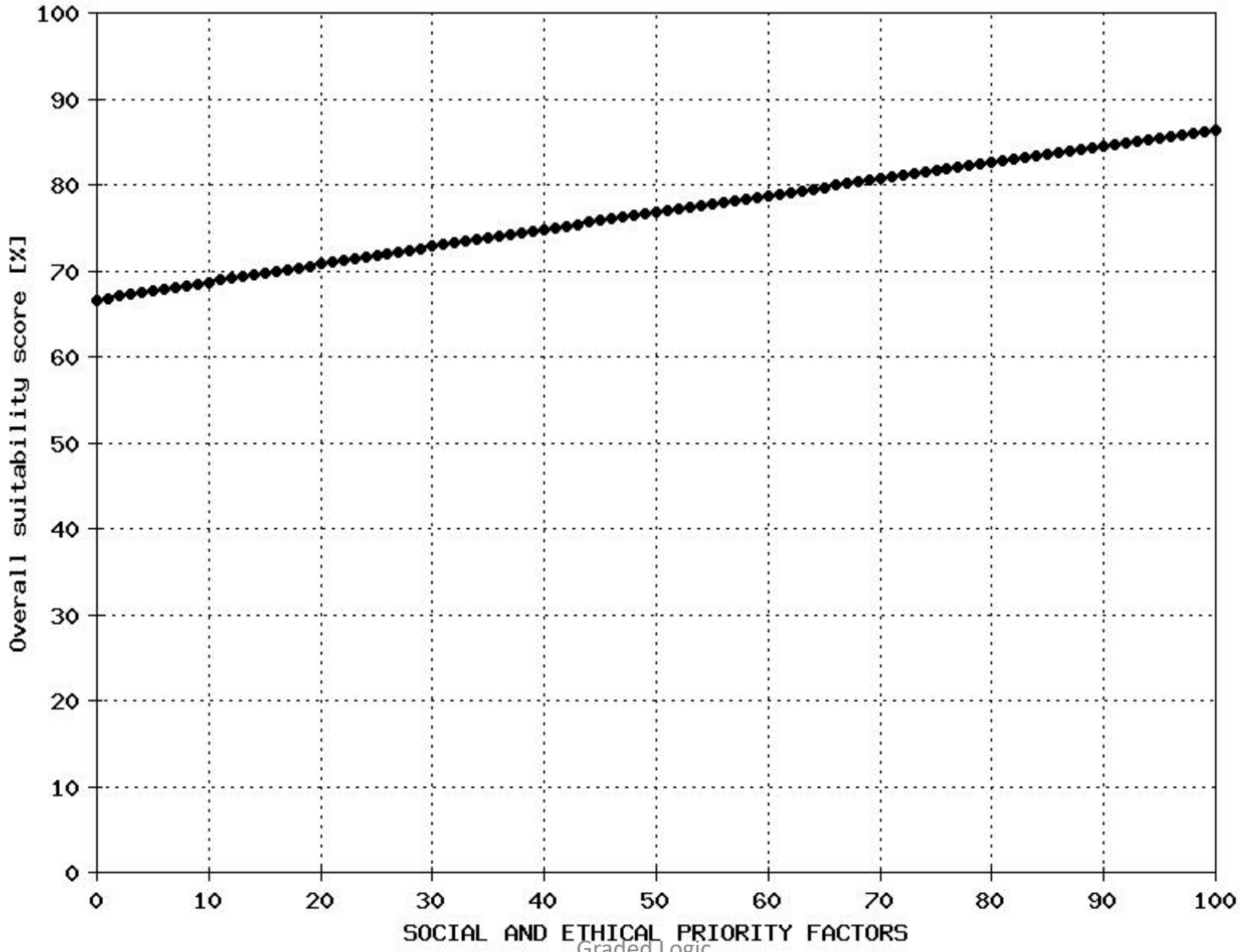
TPS as a function of the MELD score



TPS as a function of the organ delivery time



TPS as a function of social and ethical priority factors



Conclusions

- Human-centric approach yields Graded Logic as a fully continuum-valued propositional calculus.
- Graded Logic is a model human commonsense logical reasoning.
- The LSP decision method uses Graded Logic to create decision models consistent with human reasoning.
- LSP method is successfully used in professional decision models with large number of inputs in variety of application areas.
- LSP method can evaluate a single object/alternative.

THANKS!