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# Sugeno Utility Functionals for Monotonic Classification

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## Monotonic Classification & Decision Rules

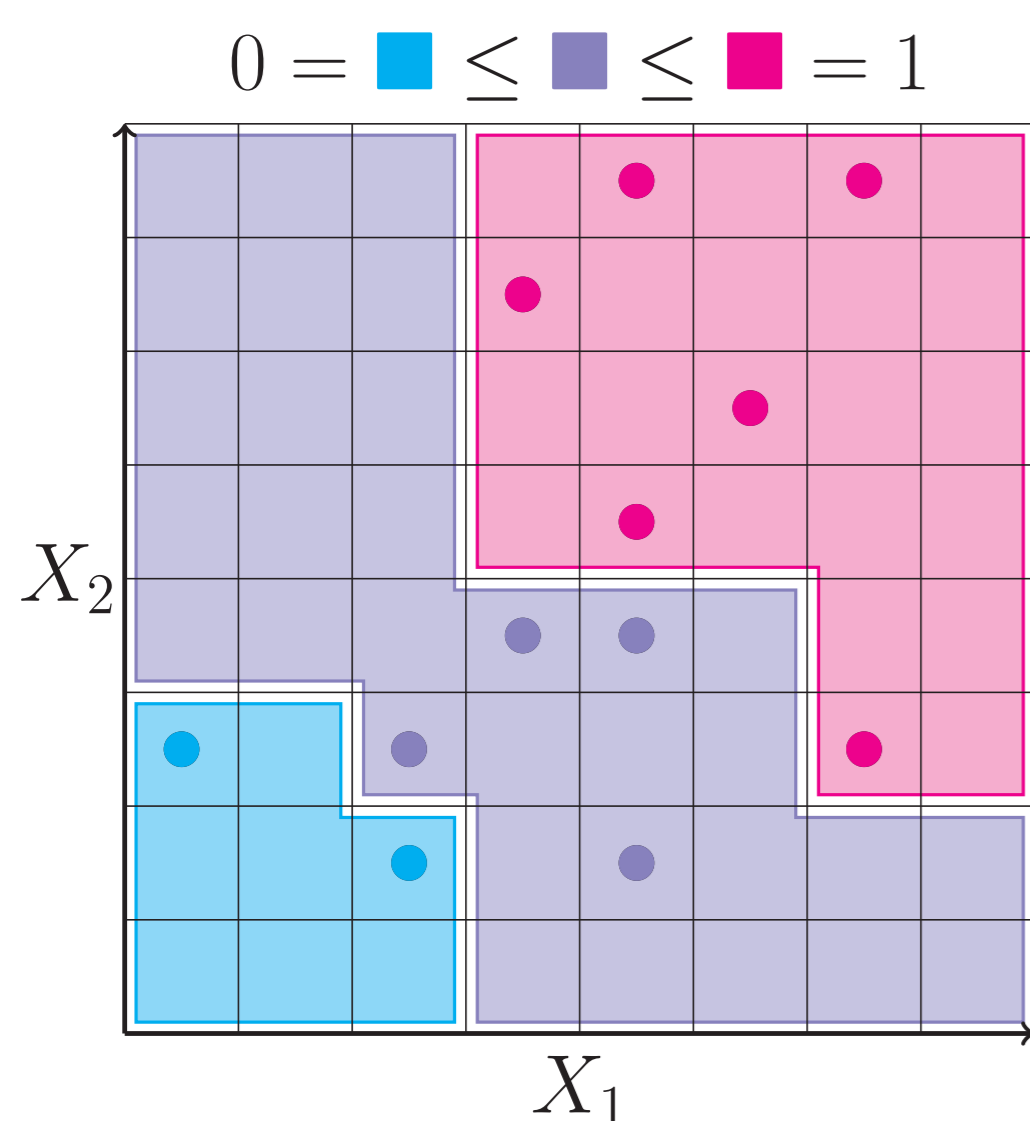
**Feature space:**  $\mathbf{X} = X_1 \times \dots \times X_n$ , where  $X_i$  is a totally ordered set. Each object is represented by a tuple  $\mathbf{x} = (x_1, \dots, x_n) \in \mathbf{X}$ .

**Labels:** Each object has a label  $l(\mathbf{x})$  from a totally ordered set  $L$ .

The relation between descriptions and labels is assumed to be **order-preserving**

$$a_1 \leq b_1, \dots, a_n \leq b_n \Rightarrow l(a_1, \dots, a_n) \leq l(b_1, \dots, b_n).$$

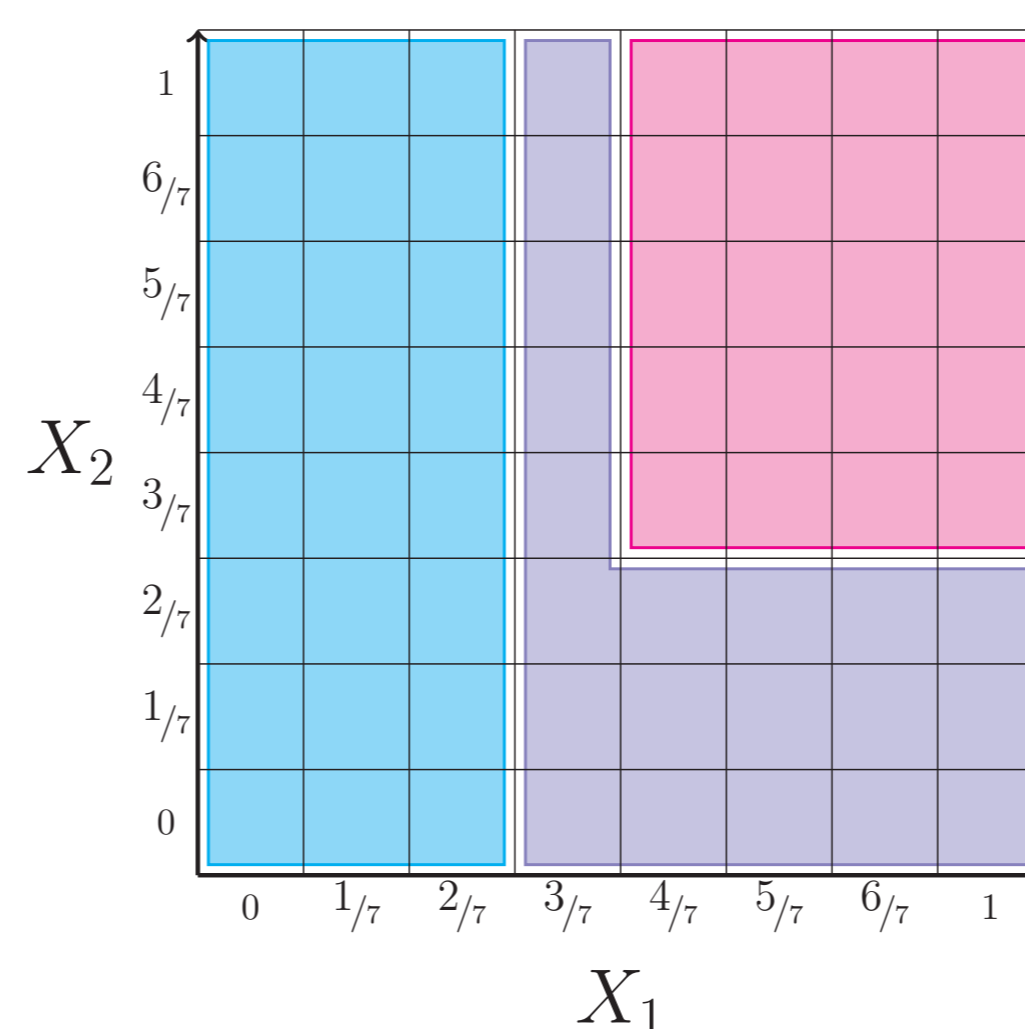
**Aim:** to predict the label of objects from their descriptions, with a non-decreasing function  $f : \mathbf{X} \rightarrow L$ .



The function can be specified by decision rules of the form:

$$\forall i \in A, x_i \geq \alpha_i \Rightarrow l(\mathbf{x}) \geq \delta,$$

where  $A \subseteq \{1, \dots, n\}$ . Sets of such rules can describe any non-decreasing function from  $\mathbf{X}$  to  $L$ .



**Example:** These rules express the function at the left.

$$x_1 \geq 3/7 \Rightarrow l(\mathbf{x}) \geq \text{purple}$$

$$x_1 \geq 4/7, x_2 \geq 3/7 \Rightarrow l(\mathbf{x}) \geq \text{pink}$$

## Sugeno Utility Functionals (SUF)

A **capacity**  $\mu : 2^{\{1, \dots, n\}} \rightarrow L$  is a set function verifying

- $\mu(\emptyset) = 0$  and  $\mu(\{1, \dots, n\}) = 1$
- $I \subseteq J \Rightarrow \mu(I) \leq \mu(J)$ .

The **Sugeno integral**  $S_\mu$  defined by  $\mu$  is the **aggregation function**

$$\max_{I \subseteq \{1, \dots, n\}} \min(\mu(I), \min_{i \in I} x_i).$$

Let  $\varphi = (\varphi_1, \dots, \varphi_n)$ , where each mapping  $\varphi_i : X_i \rightarrow L$  verifies

- $\varphi_i(0) = 0$  and  $\varphi_i(1) = 1$
- $a_i \leq b_i \Rightarrow \varphi_i(a_i) \leq \varphi_i(b_i)$ .

A SUF is a combination of a Sugeno integral and mappings  $\varphi_1, \dots, \varphi_n$  of the form

$$S_\mu(\varphi_1(x_1), \dots, \varphi_n(x_n)).$$

A single SUF is less expressive than decision rules. A maximum of several SUFs can represent any set of decision rules.

## Application

Maxima of SUFs enable a non-parametric method [1] for monotonic classification.

**Principle:** To fit the data with a max-SUF using the smallest possible number of SUFs.

The max-SUF can then be translated back into rules.

**Result:** The method is competitive (in terms of accuracy) with state of the art methods [2] for learning decision rules.

## References

Try the method on your data: <https://github.com/QGBrabant/SUF4OC>

- [1] Q. Brabant, M. Couceiro, D. Dubois, H. Prade, and A. Rico. Extracting Decision Rules from Qualitative Data via Sugeno Utility Functionals. In *IPMU, Communications in Computer and Information Science*, 253–265. Springer, 2018.
- [2] J. Blaszczynski, R. Slowinski, and M. Szelag. Sequential covering rule induction algorithm for variable consistency rough set approaches. *Information Sciences*, 181(5):987–1002, March 2011.