

# The IBD Concept: A Mathematical and Adaptive Framework for Decision-Making Under Uncertainty

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## Abstract

This paper presents the IBD (Integrated Bio-Digital) concept, a theoretical framework that integrates classical mathematical optimization with adaptive machine learning techniques to support decision-making in complex productive systems under uncertainty. The approach emphasizes interpretability, probabilistic optimal regions, and robustness to biological and environmental variability.

## 1 Introduction

Decision-making in productive systems often relies on heuristics or static recommendations, despite the nonlinear and multivariate nature of the underlying processes. This work proposes a conceptual framework that combines calculus-based optimization with adaptive learning to address this gap.

## 2 Mathematical Modeling

Let the system output be defined as:

$$y = f(x_1, x_2, \dots, x_n, t) + \varepsilon$$

where  $x_i$  are controllable variables,  $t$  represents time, and  $\varepsilon$  captures stochastic variability.

## 3 Optimization Framework

Optimal regions are identified by analyzing first- and second-order derivatives of the response function. Rather than computing a single optimal point, the framework defines probabilistic optimal intervals.

## 4 Adaptive Layer

Machine learning techniques are introduced to dynamically adjust model parameters based on observed data, preserving the interpretability of the mathematical structure.

## 5 Conclusion

By integrating mathematical rigor with adaptive learning, the IBD framework offers a structured approach to decision-making under uncertainty.