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FROM PARAMETRIC RULES TO ARTIFICIAL INTELLIGENCE: A NEW ERA IN MICROBIAL IMAGE ANALYSIS

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INTRODUCTION

In the pharmaceutical industry, image analysis plays a crucial role in the field of microbial identification. Traditional parametric algorithms, while effective for tracking microbial growth over time, struggle with differentiating bacterial from mold species due to their rigid predefined rules. Machine learning, particularly deep learning, offers a powerful alternative by learning complex patterns from large datasets, enabling more accurate and adaptable classification. The goal here is to explore the limitations of classical algorithms and the advantages of AI-driven approaches. A case study on automated mold identification on petri dishes will illustrate these concepts in a real-world application.

FROM PARAMETRIC RULES TO LEARNING ALGORITHMS

What is a parametric algorithm ?

Parametric algorithms are based on **explicit, human-defined rules** for analyzing images. These rules are fixed: once parameters are set (e.g., contrast threshold, minimum area, circularity), they **do not change,** regardless of image variability. This makes parametric algorithms **deterministic:** given the same input image, the output will always be identical, even when the image is reprocessed multiple times.

This deterministic nature offers two main advantages:
- **Transparency:** All steps are understandable, auditable, and easy to trace.
- **Efficiency:** They run quickly on standard hardware without GPUs or high computing power.

In microbiology, parametric approaches remain valuable for tasks like:
- Counting colonies when they are **well-separated**
- Classifying colonies **by diameter or roundness**
- Monitoring microbial growth in **controlled lighting environments**

Picture 1: Examples of parametric algorithm applications.

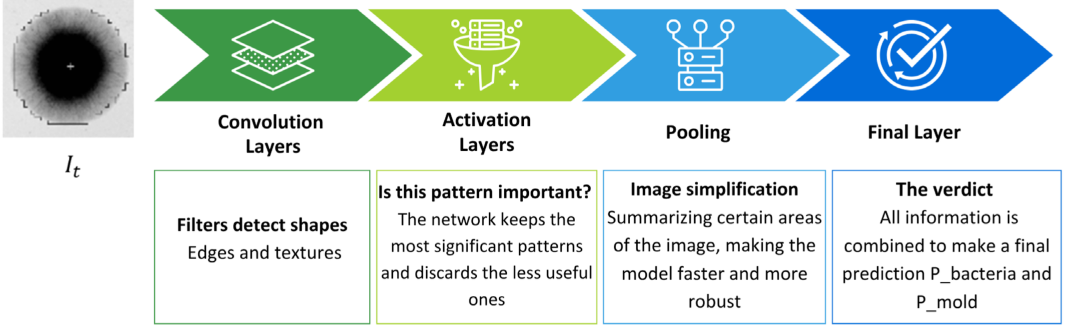
However, as image complexity increases (e.g., blurry contours, irregular shapes like molds), these methods become harder to adapt. The number of rules needed can quickly become unmanageable, and small changes in imaging conditions may result in errors or missed detections.

HOW AI OVERCOMES THESE LIMITATIONS

From Fixed Rules to Learned Representations

While parametric algorithms rely on predefined features, **Artificial Intelligence (AI),** and more specifically **Machine Learning (ML)** and **Deep Learning (DL),** extract relevant features **automatically** from labeled data. In microbial image analysis, this allows AI to recognize colony shapes, textures, and colors without requiring manual programming of rules.

At the core of many AI-based approaches is the **Convolutional Neural Network (CNN).** Inspired by the human visual cortex, CNNs scan images using successive filters, detecting simple edges at first, then gradually building up to more complex features like colony textures or morphology.

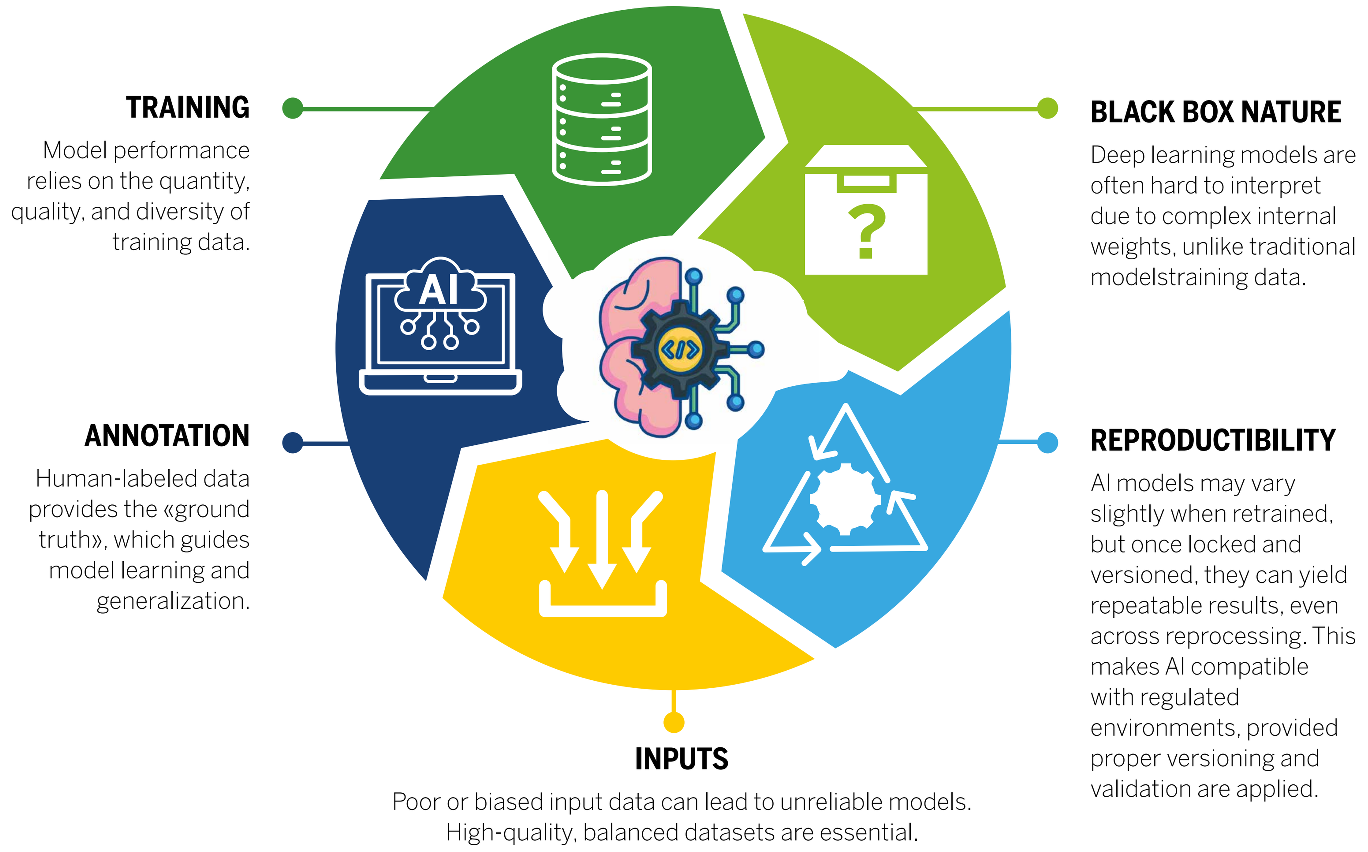


Calculation of P_B and P_M using the probabilities generated by I_{t-1}

Robustness, Adaptability, and the Role of Data

Unlike rigid parametric methods, well-trained AI models are:
- **Robust** to variations in lighting, image rotation, and contamination
- **Adaptable** to new or unseen data, as they generalize from training examples
- **Capable** of handling complex shapes and noisy backgrounds

But AI also introduces new challenges:



Comparative Overview – Parametric Algorithms vs AI Approaches

	Parametric Algorithms	AI / Machine Learning
Advantages	• Fully explainable, transparent rules • Fast, lightweight – no GPU required • Easy to validate and audit • Consistent results	• Learns directly from data • Robust to noise, rotation, image variability • Adapts to unseen or complex patterns • Automates feature extraction and complex classification
Limitations	• Fragile to image changes, blur, or contamination • Manual tuning of parameters • Low adaptability to new shapes or data • Inflexible for complex tasks	• Requires large, well-labeled datasets • Less transparent ("black box") • Can propagate training biases if not carefully curated

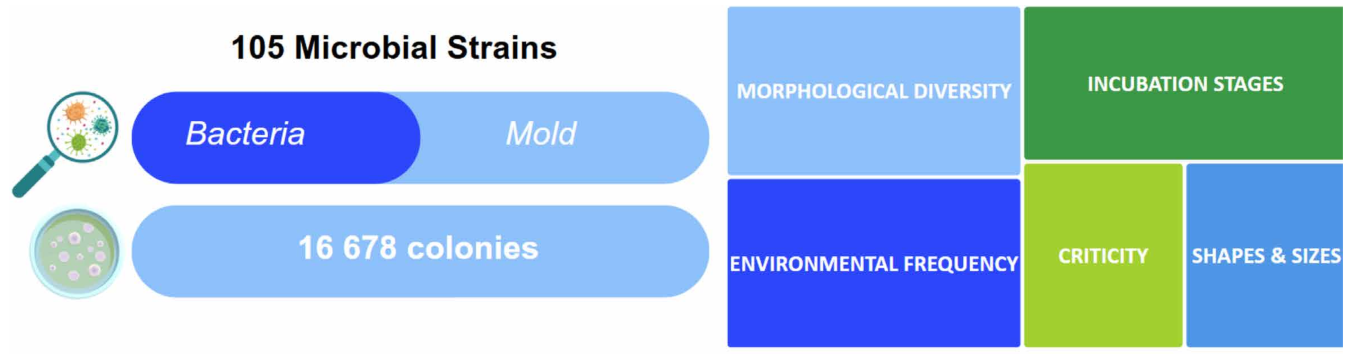
A CASE STUDY

Machine Learning for Mold vs Bacteria Classification on 3P®STATION

The system is an automated Petri dish incubator and colony counter capable of maintaining incubation temperatures between 20°C and 35°C with a precision of ±1°C. It continuously monitors the surface of the plates, detecting and tracking microbial colony growth. A real-time growth curve is generated for each colony, providing valuable insights into the microbial kinetics throughout the incubation process.

Picture 2: bioMérieux 3P® STATION.

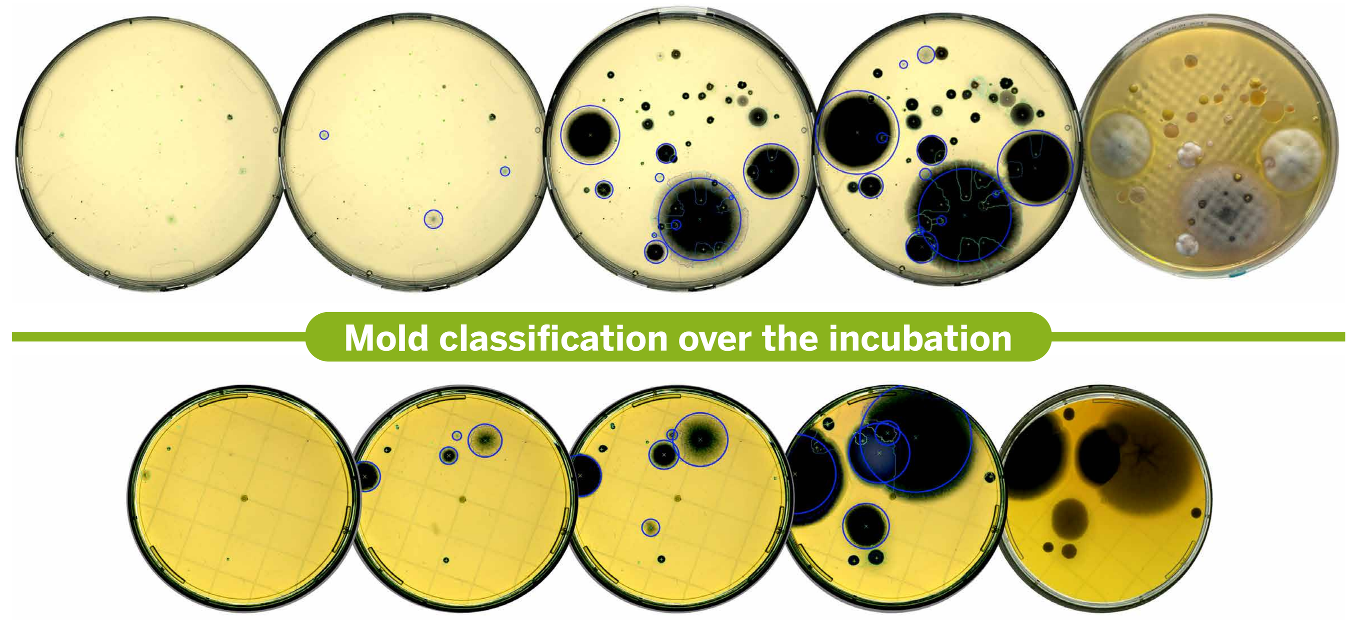
As part of a new version, the system is being enhanced to incorporate automated mold classification through the integration of a AI-based module. To train this new layer, a dedicated dataset composed of:



The algorithm must be able to **adapt to image variability,** including changes in lighting conditions, the **position of colonies** (e.g., molds growing near the edge of the plate), and morphological changes such as **colony fusion during incubation.**

To ensure optimal performance, several parameters must be carefully defined, such as the **confirmation timing** of a microorganism, the **number of images compared over time,** and the **classification confidence threshold** required to confirm a colony type.

The objective is to find the **right balance** between the **sensitivity** (correctly identifying molds) and the **specificity** (correctly identifying bacteria as non-mold). During the optimization phase, extensive **fine-tuning** was conducted, along with the **enrichment of the training dataset,** to improve model robustness and accuracy across various real-world scenarios.



Picture 3: Mold classification trends over time observed on 90mm and CT plates.

CONCLUSION

Parametric algorithms and AI represent two complementary paradigms in image analysis. Parametric methods **offer transparency, simplicity, and ease of validation, making them ideal in controlled, regulated environments.** In contrast, AI, particularly deep learning, **brings adaptability and robustness, excelling in complex and variable imaging conditions.** While parametric algorithms rely on fixed, expert-defined rules, AI models learn directly from data, enabling them to detect subtle and abstract features. However, this power comes at the cost of explainability and requires high-quality annotated datasets. Ultimately, combining both approaches allows us to build image analysis solutions that are both reliable and scalable, leveraging the strengths of each where they matter most.

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