

The Hidden Classification Problem: When Categories Conceal Continuous Behaviour

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Abstract

Scientific work depends on categories: cured or uncured, soluble or insoluble, rigid or flexible, hydrophilic or hydrophobic, compatible or incompatible, pass or fail. Categories compress complex observations into usable decisions. The hidden classification problem appears when that compression is mistaken for a sharp boundary in nature. Many material and experimental behaviours are continuous, multidimensional or state-dependent, so two objects assigned to the same category can differ materially while two objects on opposite sides of a threshold can be nearly identical. This methodological article examines how operational categories should be defined, measured and bounded. The central proposition is that a category is a decision rule imposed on evidence unless a physical discontinuity has independently been demonstrated.

Keywords: classification; threshold; continuum; categories; boundary; measurement scale; binary decision; state variable; taxonomy

1. Purpose and evidence boundary

HEB-002 is the series article on understanding, visualisation and scientific boundaries; HEB-014 does not restate its content and instead owns the classification problem within the HEB series [2]. HEB-001 supplies the broader measurement-system context [1]. The purpose here is not to argue against categories, but to declare what they operationalise.

2. Categories are useful compressions

A laboratory needs decisions: accept/reject, soluble/insoluble, transparent/opaque. A category can reduce a high-dimensional state to an action. That is legitimate when the rule is explicit and the lost information is not needed for the claim. Some boundaries correspond to genuine physical transitions rather than arbitrary bins; gelation is a useful example, and photorheology shows that its operational assignment depends on the measurement criterion and conditions [3].

3. Thresholds discretise continuous variables

Contact angle, modulus, conversion, transmission, swelling and concentration vary continuously. Choosing a threshold converts a continuum into classes. The threshold can be justified by application need, detection capability or convention, but its existence does not prove a discontinuity at that numerical value.

4. Multidimensional behaviour resists one-label descriptions

A material can be stiff in short-time loading and compliant over long times, hydrophilic at the surface and less so in the bulk, soluble under one solvent history and only swell under another. A single adjective can therefore hide the state variables and timescales that determine the behaviour.

5. Borderline cases contain information

Objects close to a decision threshold are often treated as inconvenient ambiguity. They are scientifically valuable because they expose sensitivity to uncertainty, environment and protocol. If a tiny change in measurement method flips classification, the category may be operationally fragile even when the underlying continuum is smooth.

6. Binary labels can hide asymmetric consequences

A pass/fail rule can be appropriate when consequences are non-linear, but false-pass and false-fail costs are rarely identical. The classification method should therefore be linked to uncertainty and decision risk. A measured value just above a limit is not epistemically different from one just below it by more than the uncertainty allows [6].

7. Mechanism-based categories can still overlap

Type I and Type II photoinitiator labels, network classes or failure modes can be useful mechanistic taxonomies, yet real systems can contain hybrid pathways or multiple simultaneous mechanisms. Taxonomy should therefore support reasoning without forcing every case into one pure box when evidence supports overlap [5].

8. Categories can move with conditions

Compatibility, solubility, flexibility and cure state depend on temperature, composition, time, geometry and measurement protocol. A classification made under one condition may not transfer. The condition belongs to the label if changing it can change the state.

9. Report the variable behind the label

Whenever feasible, pair a category with the measured quantity and decision rule that created it. 'Hydrophobic' becomes more informative when the contact-angle method and value are reported; 'cured' becomes more informative when the chemical or mechanical endpoint is declared; 'compatible' becomes more informative when phase, time and function are specified [4].

10. Practical classification discipline

Ask four questions: What continuous or multidimensional evidence is being compressed? What threshold or rule creates the category? What uncertainty can change membership? Under what conditions does the label transfer? If those answers are unavailable, the category should be treated as a provisional shorthand rather than a physical fact.

11. Uncertainty can make category membership probabilistic

Suppose a pass/fail threshold is 10 units and the measured result is 10.1 with an uncertainty comparable with the 0.1 margin. A deterministic label may still be required operationally, but the evidence does not support pretending that the physical state is clearly separated from a result of 9.9. Guard bands, repeated measurements or decision rules can manage such cases, but they should be recognised as decision architecture. The closer a result is to the threshold relative to uncertainty, the more the category reflects policy and measurement capability rather than a sharp physical distinction.

12. Different taxonomies can classify the same system differently

One taxonomy may group materials by chemistry, another by mechanical behaviour, another by use, and another by failure mode. None is automatically privileged for every question. A urethane acrylate can be classified chemically, a cured specimen can be described mechanically as elastomeric or rigid depending on state and test, and the same object can belong to a biomedical or engineering application class. Classification becomes misleading when categories built for one purpose are imported into another without checking whether the relevant distinctions are preserved.

13. Decision categories should be reversible to their evidence

A high-quality classification system lets a reader reconstruct why the label was assigned. That means retaining the measured variables, threshold, test method, uncertainty and conditions. If only the final label survives, later changes in thresholds or improved measurements cannot be applied without repeating the experiment. Reversible classification is therefore a data-governance principle as well as a scientific one: preserve the evidence behind the category so the decision can be audited or reinterpreted.

14. Conclusions

Categories are indispensable scientific tools, but they are models of evidence. A threshold can create a decision boundary without creating a natural boundary. Multidimensional and state-dependent systems make labels especially fragile. The hidden classification problem is controlled when the measured variables, operational rules, uncertainty and transfer conditions remain visible behind the category.

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Knowledge boundary

HEB-014 owns the methodological distinction between operational categories and underlying continuous or multidimensional states. Specific material taxonomies and application thresholds remain with their corresponding technical reviews.

Limitations

This methodological article is a bounded synthesis of the controlled HEB and Engineering Review corpus. It does not report a new experimental dataset, does not establish universal numerical thresholds, and does not convert examples from one domain into application-wide specifications. Claims that require application-specific qualification remain with the corresponding technical review or primary study.