

Hidden Error Budget Series Synthesis: From Measurement to Inference and Transfer

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HEB-016 · Independent Technical Article · Version v0.4 · 23 September 2026

Abstract

The Hidden Error Budget series examines a recurring scientific pattern: an experiment can be technically sophisticated yet fail because an unexamined assumption sits between the physical system and the conclusion. Across the series, those assumptions appear at different locations in the evidence chain: the wrong measurand can be measured precisely; a reference can be correct but mismatched to the sample, time or system state; an observer can become part of the apparatus; a non-detect can be treated as zero; repeated readings can be mistaken for independent experiments; correction can create apparent confidence; interactions can remain invisible to one-factor designs; time and scale can change the physical regime; a fitted model can be promoted into mechanism; a category can conceal continuity; and a written procedure can fail to transfer the state that mattered. This synthesis integrates those failure modes into a single architecture for experimental reasoning. Its central proposition is that scientific reliability depends on the integrity of the complete chain from physical state to measurement, transformation, inference and transfer.

Keywords: measurement system; inference; uncertainty; proxy; reference; observer; detection limit; replication; correction; interaction; time; scale; model; classification; transfer

1. Purpose and series position

HEB-016 is the synthesis article of the Hidden Error Budget series. It does not introduce a new hidden failure category and does not replace the individual HEB articles. Its purpose is to show how the series components connect and where apparently independent weaknesses can reinforce one another. The synthesis therefore treats HEB-001 to HEB-015 as linked methodological layers rather than as isolated checklists.

2. The evidence chain

A useful generic chain runs from the physical system, through measurand definition, reference and observer, detection capability, replication, data treatment and model, to conclusion and transfer [2]. Failure at an early link can survive every later layer of sophistication. Statistical analysis can be correct on data that answer the wrong question; an elegant model can fit a biased response; a perfectly reproduced protocol can reproduce the same hidden error.

3. Measurement and representation failures: HEB-001 to HEB-005

HEB-001 defines the complete measurement system and hidden error budget [1]. HEB-002 examines hidden boundaries introduced by representation and visual reasoning, while HEB-003 follows the related problem from molecular structure to scientific prediction [5,6]. HEB-004 isolates proxy substitution: measuring a related quantity and silently promoting it to the intended target [7]. HEB-005 treats blanks, standards, controls and calibrations as active components of the measurement rather than external guarantees [8]. Together HEB-001 to HEB-005 establish that validity begins before data analysis.

4. Human and observability boundaries: HEB-006 and HEB-007

HEB-006 places the observer inside the measurement system when judgement, expectation or subjective endpoints influence the result [9]. HEB-007 places a boundary around what the method could see at all [10]. These articles define two different limits: who or what performed the discrimination, and what region of the physical state was observable.

5. Information structure: HEB-008, HEB-009 and HEB-010

HEB-008 asks what observations are genuinely independent [11]. HEB-009 asks what information survives correction and preprocessing [12]. HEB-010 asks whether the design made interactions estimable [13]. These are structural questions about information content. None can be repaired after the fact if the experiment did not generate the missing contrasts or independent units.

6. State dependence: HEB-011 and HEB-012

HEB-011 shows that the present state can depend on history [14]; HEB-012 shows that mechanism weighting can depend on scale [15]. Both reject the assumption that nominal settings define a transferable state. Time and geometry can be hidden coordinates of the experiment even when they are absent from the data table.

7. Inference compression: HEB-013 and HEB-014

HEB-013 separates fit, prediction, mechanism and optimum [16]. HEB-014 separates operational categories from underlying continua and multidimensional states [17]. Both concern compression: a model compresses observations into parameters; a category compresses variables into labels. Compression is useful only when its lost information does not matter to the claim.

8. Transfer: HEB-015

HEB-015 closes the chain by asking whether the state that supported the original conclusion can be recreated elsewhere [18]. A protocol is documentary information; transfer is a physical achievement. The distinction returns the series to HEB-001's core insight that the measurement system is larger than the instrument.

9. Failure modes interact

The HEB topics are not independent boxes. A proxy can be near a detection limit; its reference can drift; repeated technical readings can be miscounted as replication; smoothing can hide the drift; a fitted model can then locate an optimum; the optimum can fail at larger scale; a copied protocol can transfer none of the state variables that made the original result work. The combined failure can appear stronger than any single weak step because each layer supplies apparent confirmation to the next.

10. A compact experimental audit

Before trusting a conclusion, ask: What is the measurand? What proxy relation is assumed? What reference or observer defines the comparison? What could the method not detect? What was independently replicated? What transformations were applied? What interactions, time histories and scales were sampled? What role does the model play? What threshold created the category? What state must transfer for the claim to survive? These questions convert hidden assumptions into testable parts of the design [4].

11. The HEB principle

The synthesis supports one overarching principle: a scientific conclusion is only as transferable as the weakest untested link connecting the physical system to the claim. Reliability therefore grows less from adding analytical sophistication than from making each link explicit, perturbable and auditable.

12. Error propagation is not always a simple sum of variances

Classical uncertainty budgets combine recognised components under stated models, and the GUM explicitly accommodates correlated inputs through covariance terms [3]. The hidden-error problem is different: an omitted variable, broken inference or unrecognised dependence cannot be propagated numerically because it never entered the model. A drifting reference, a censored region, a missing interaction or a scale-dependent regime therefore first requires discovery and model correction before uncertainty propagation is meaningful.

13. Repair should occur as early as possible in the chain

When a problem is found, the strongest correction is usually the one closest to its physical origin. Control the physical state that created an artefact rather than correcting its numerical signature; measure the intended measurand rather than calibrating a weak proxy more precisely; add independent replication rather than adjusting p-values; redesign the experiment to estimate interactions rather than fitting a more elaborate model to OFAT data. Later-stage analysis can be essential, but it should not become a substitute for information that could have been generated directly. This hierarchy of repair is the practical counterpart of the complementary-failure principle.

14. Conclusions

The HEB series does not argue that experimental science is unreliable. It explains why reliable science requires deliberate control of the complete evidence chain. The most consequential error can be a variable, assumption or transformation that never entered the formal uncertainty budget because nobody recognised it as part of the measurement. The practical response is systematic: define, perturb, replicate, challenge, preserve boundaries and transfer only what has been demonstrated.

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Knowledge boundary

HEB-016 is a synthesis of the HEB methodological architecture. It does not add application-specific qualification requirements. Its claims are limited to relationships already established by HEB-001 to HEB-015 and the cited metrological and statistical sources.

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.