

The Hidden Time Problem: The Present State of an Experiment Depends on How It Was Reached

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HEB-011 · Independent Technical Article · Version v0.3 · 23 September 2026

Abstract

Experiments are often analysed as though each observation depends only on the variables recorded at the moment of measurement. Many systems retain memory. Instruments warm up, references drift, reactive materials age, solvents evaporate, oxygen is consumed and replenished, networks continue to evolve, surfaces condition and operators alter the sequence through handling. Two specimens can therefore share the same nominal current conditions while occupying different physical states because they arrived there by different paths. This methodological article develops the hidden time problem: the failure created when experimental history is treated as irrelevant. The central proposition is that time is not merely a coordinate on the data table; in a path-dependent system it is part of the state definition.

Keywords: drift; hysteresis; ageing; warm-up; sequence effect; history dependence; time; path dependence; stability

1. Purpose and evidence boundary

HEB-001 documents reference drift, instrument equilibration and environmental time dependence [1]. ER-174 owns optical-state drift detection in VPP equipment [3]. HEB-011 generalises the reasoning problem across experimental science.

2. Current settings do not uniquely define current state

A thermostat reading of 25 °C does not prove that the instrument, specimen and surrounding structure are in thermal equilibrium [2]. A resin stored for one day and one stored for six months can be measured at the same temperature yet differ chemically or physically. State variables can therefore require history descriptors in addition to instantaneous settings.

3. Warm-up is a transient, not a nuisance label

Instrument response can change after switch-on as electronics, lamps, detectors, optics and enclosures approach thermal steady state. If samples are measured in a fixed order during this transient, run order becomes correlated with instrument state. Repeating the same order can reproduce the bias consistently.

4. Drift differs from ageing

ER-174 separates baseline non-uniformity, drift and ageing: drift is a supported change from baseline, while ageing attributes that change to a time- or use-dependent mechanism [3]. This distinction is general. Observing change does not identify its cause. Repositioning, contamination, warm-up and environmental change can imitate long-term ageing.

5. Sequence effects can create apparent treatment effects

If low-level samples are always measured first and high-level samples last while the response drifts upward, the sequence can generate or magnify an apparent concentration effect. Randomised order breaks systematic alignment, while bracketing references can make local drift visible. Neither strategy proves stationarity; they reduce or diagnose a specific failure mode.

6. Materials have histories

Reactive formulations can change through inhibitor consumption, oxygen uptake, evaporation, phase evolution or slow reactions. Cured networks can continue post-cure, relax stress, absorb water or physically age. A nominal composition is therefore not always a complete state description. Storage time, temperature and prior exposure can be experimental variables even when they were not intended as factors.

7. Hysteresis means the route matters

In a hysteretic system, the response at a given input depends on whether that input was approached from above or below or on previous cycling. Heating and cooling, loading and unloading, wetting and drying, exposure and dark recovery can therefore produce different trajectories. A single equilibrium-style curve can conceal this memory.

8. Time can couple to reference validity

HEB-001's quantum-yield case shows that a chemically correct reference measured hours away from the unknown can become metrologically inappropriate if the instrument response changes [1]. Temporal proximity is therefore part of the reference's validity whenever stationarity has not been demonstrated. HEB-005 retains the separate series question of reference, blank, control and calibration validity; HEB-011 owns the temporal condition under which an otherwise appropriate reference can cease to represent the same measurement state.

9. Stability is an experimental claim

A stable plateau should be demonstrated over the time window relevant to the experiment, not assumed from a manufacturer's nominal warm-up period or from visual calm. Stability criteria should be linked to the smallest effect the study aims to resolve. A method can be stable enough for a coarse classification and inadequate for a small quantitative difference.

10. Practical history map

Record the events capable of changing state: preparation time, mixing, degassing, storage, equilibration, exposure, delays, sequence, cleaning, loading, cycling and prior measurements. Where path dependence is plausible, deliberately reverse order, repeat anchor conditions, compare fresh and aged states, and test whether the claimed result survives alternative histories.

11. Clock time and exposure history are different variables

Two specimens measured after 24 hours may not have experienced the same history. One may have spent the entire interval at constant temperature in the dark; another may have undergone intermittent light, mixing, cycling or environmental exposure. Reporting elapsed time without the intervening state changes can therefore be insufficient. Age should be described in the coordinates that drive the mechanism: cumulative dose, cycles, thermal history, humidity exposure, shear history, storage atmosphere or another relevant integral. Clock time is a convenient index, not always the causal variable.

12. Carryover creates history dependence between samples

The previous sample can change the next measurement through contamination, memory in tubing, residual solvent, surface conditioning, detector persistence or incomplete cleaning. Sequence then matters even if the instrument itself is stable. Blank and wash steps should therefore be tested for their ability to restore baseline, not assumed to erase history. Randomisation can spread carryover bias but does not remove it. Where carryover is important, the experiment may require directionally designed sequences, dedicated blanks or reset conditions.

13. Stability claims need a decision-relevant timescale

A response that drifts by 0.1% per hour may be irrelevant for a coarse five-minute screen and critical for a high-precision eight-hour sequence. 'Stable' therefore has no useful meaning without a time window and tolerance connected to the scientific decision. The same instrument or material can be stable for one experiment and unstable for another. Stability qualification should compare observed change with the smallest effect the study intends to resolve and with the duration over which the result is assumed transferable.

14. Conditioning defines the time origin

Many experiments begin with a nominal time zero that is operational rather than physical. A specimen may already have experienced minutes of exposure during preparation, transport or instrument loading; a resin may have been at process temperature for different periods before the timer starts; a mechanical specimen may have relaxed after demoulding. If the relevant mechanism begins before the recorded clock, samples can have different effective ages at nominal $t = 0$. A rigorous protocol therefore defines the conditioning sequence and the event that establishes the time origin. When that event cannot be made identical, the prehistory should be recorded as a covariate or controlled by design.

15. Synchronising instruments does not synchronise states

Multi-instrument experiments can create an additional time problem. Spectroscopy, temperature, force and imaging channels may have different acquisition delays, integration times and trigger definitions. Aligning their timestamps in software does not guarantee that they observed the same physical instant or spatial state. This matters when the system evolves rapidly. A defensible time-resolved study therefore documents trigger latency, acquisition windows and any sample movement between instruments. Temporal resolution is a property of the complete measurement chain, not simply the fastest clock displayed by one device.

16. Conclusions

The present state of an experiment may depend on how it was reached. Warm-up, drift, ageing, sequence and hysteresis are different phenomena that can all violate a memoryless analysis. Time must therefore enter the measurement model whenever history can change the instrument, specimen, reference, environment or analysis. A reproducible sequence can reproduce a reproducible bias.

References

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Knowledge boundary

HEB-011 owns the general methodological problem of history dependence. ER-174 retains delivered optical-state characterisation and drift detection for VPP equipment; other application-specific ageing reviews retain their own mechanisms and qualification requirements.

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.