

# TempoBench-Grounded Human/AI Benchmark Game Family (GF-01): Standalone Formal Specification with Decision and Hypothesis Glossary

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Project Specification

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## Abstract

This document gives a standalone formal specification for the current TempoBench-grounded benchmark family **GF-01** (see Definition 8). Ground truth is defined over a canonical substrate: (*HOA/reactive-system object, finite trace, explicit intervention semantics*). Primary scoring is machine-checkable through structured certificates rather than free-form explanation. To keep the document readable without access to repository-internal notes, all referenced decision labels (**DEC**-\*), hypothesis labels (**HYP**-\*), and renderer labels (**GF-01-R**\*) are explicitly defined here.

**Public implementation repository.** A publishable mirror of the benchmark implementation artifacts is available at <https://github.com/official-Auralin/Benchmark-game>.

## 1 Reading Guide and Label Glossary

### 1.1 What the labels mean

- **DEC**-\*: locked project decisions that are normative in this specification.
- **HYP**-\*: explicit hypotheses (not yet treated as facts), each with a validation plan.
- **Q**-\*: open or deferred questions.
- **EVAL**-\*: evaluation-condition tracks (closed-book, tool-augmented, oracle-ceiling).
- **MET**-\*: metric/scoring regimes.
- **Code/field identifiers**: shown in monospace (e.g., `family_id`, `eval_track`).

### 1.2 Renderer labels used in this document (see Definition 8)

- **GF-01-R1**: side-scroller renderer where each segment/column corresponds to one timestep; interventions for timestep  $t$  are chosen before advancing to  $t + 1$ .
- **GF-01-R2**: puzzle-style renderer that presents the same canonical observation information in puzzle-board form.

- **GF-01-R3:** turn-locked grid/tower renderer under consideration; treated as a renderer variant only if semantic parity checks pass.

### 1.3 Normative decisions referenced in this spec

DEC-001

report EVAL-CB, EVAL-TA, and EVAL-OC separately; do not mix tracks.

DEC-001a

keep naming separation: EVAL-\* for conditions, MET-\* for metric regimes.

DEC-002

interventions occur online during play.

DEC-003

intervention semantics are ternary per  $(t, AP)$ : set 0, set 1, unchanged.

DEC-004

primary efficiency cost is number of distinct intervened timesteps; atom-count is secondary.

DEC-005

action availability must not leak hidden state.

DEC-012

normative minimality is singleton-removal.

DEC-012a

subset-minimality is optional and non-scoring.

DEC-012b

subset-minimality diagnostics must be exact-only when run.

DEC-014

hard mode uses exact-time objective; normal mode uses windowed objective.

DEC-014a

normal-mode window scales with complexity.

DEC-014b

current normal-window coefficients are fixed defaults, pending post-pilot calibration.

DEC-016

renderer variants are allowed only under semantic parity.

DEC-018

per-timestep intervention cardinality is unrestricted, constrained by global budgets.

DEC-019

exact normative checks are always mandatory.

DEC-020

optional-diagnostic infeasibility uses hybrid caps  $(P_{\text{ref}}, A_{\text{ref}})$ .

DEC-021

initial cap freeze timing is tied to the scheduled pilot checkpoint.

DEC-022

cap derivation uses a dual-threshold rule.

DEC-023

current provisional dual-threshold defaults are  $p = 0.90$ ,  $k = 3$ .

DEC-024

generator determinism is mandatory for fixed input tuple.

DEC-025

AP/TS PRF under non-unique minima uses deterministic best-match mapping.

DEC-031

run artifact schemas are versioned and metadata-rich.

DEC-038

implementation priority is GF-01-R1 first.

DEC-038a

GF-01-R3 promotion requires pre-registered parity/leakage/reporting gates.

## 2 Objective and Evidence Anchors

### 2.1 Objective

The benchmark is designed to evaluate temporal causality reasoning, aligned with TempoBench TCE-style tasks where the model must recover causally relevant interventions over time [3].

### 2.2 Evidence policy

Nontrivial factual claims in this document are backed by cited sources. Project-policy locks are identified by DEC labels. Statements not yet established empirically are marked as HYP labels.

## 3 Canonical Substrate and Formal Notation

### 3.1 Finite-trace benchmark scope

TempoBench defines task objects over automata and finite traces for temporal reasoning and temporal causality [3]. Coenen et al. formalize temporal causality in reactive systems in an  $\omega$ -trace setting with explicit counterfactual structure [2]. This benchmark intentionally uses a finite-trace operational scope while keeping formal causality checks machine-verifiable.

**Definition 1** (System and proposition partition). *Each instance uses a system object  $A$  with atomic propositions*

$$AP = AP_{\text{in}} \uplus AP_{\text{out}},$$

*where  $AP_{\text{in}}$  are intervenable input propositions and  $AP_{\text{out}}$  are observable output propositions.*

**Definition 2** (Base trace). *Let*

$$\tau = (\tau_0, \dots, \tau_{T-1}), \quad T \geq 1,$$

where each  $\tau_t : AP_{\text{in}} \rightarrow \{0, 1\}$  is an input valuation.

**Intuition.**  $\tau$  is the default input schedule. The player/agent edits this schedule via interventions (see Definition 3, Definition 4, and Definition 5).

### 3.2 Intervention semantics

**Definition 3** (Intervention atom). *An intervention atom is  $(t, a, v)$  with  $t \in \{0, \dots, T-1\}$ ,  $a \in AP_{\text{in}}$ ,  $v \in \{0, 1\}$ .*

**Definition 4** (Certificate). *A certificate is a finite set*

$$C \subseteq \{0, \dots, T-1\} \times AP_{\text{in}} \times \{0, 1\}.$$

**Definition 5** (Apply operator). *Define the intervened trace  $\tau[C] = \text{Apply}(\tau, C)$  (**Apply**) by*

$$\tau[C]_t(a) = \begin{cases} v, & \text{if } (t, a, v) \in C, \\ \tau_t(a), & \text{otherwise.} \end{cases}$$

*Malformed certificates with conflicting assignments to the same  $(t, a)$  are rejected by structural validation.*

**Intuition.** “Unchanged” is represented by omission: if no atom targets  $(t, a)$ , base trace value  $\tau_t(a)$  remains.

### 3.3 Run and canonical observation object

**Definition 6** (Run).

$$\rho = \text{Run}(A, \tau[C])$$

*denotes the benchmark rollout under the intervened trace (**Run**). For a fixed instance bundle and evaluator version, rollout semantics are replay-deterministic ([DEC-024](#), [DEC-031](#)).*

**Definition 7** (Canonical observation object). *At timestep  $t$ , the canonical agent-facing object is*

$$O(s_t) = \{t, y_t, \text{effect\_status}_t, b_T^{\text{rem}}, b_A^{\text{rem}}, C_{\leq t}, \text{mode}, t^*\},$$

*with hidden internal state omitted. All renderers must be semantics-preserving maps from this canonical object.*

## 4 Instance Definition and Game Interpretation

### 4.1 What GF-01 means (family-level definition)

**Definition 8** (GF-01 benchmark family). *GF-01 is a forward-time, intervention-driven benchmark family in which:*

1. *the environment evolves over discrete timesteps  $t = 0, \dots, T-1$ ,*

2. at each timestep, an agent (human or AI) can apply do-style edits to input propositions in  $AP_{\text{in}}$ ,
3. the episode objective is to achieve a formal effect predicate  $e$  with a certificate that passes machine-checkable causal-validity tests (sufficiency + minimality),
4. scoring is computed from structured artifacts (intervention logs and final certificate), not from natural-language explanation.

**Plain-language interpretation.** GF-01 is the core game family name for this benchmark. All renderer variants (e.g., side-scroller, puzzle, turn-locked grid/tower) are just different user interfaces over the same formal game: same state semantics, same intervention rules, same ground truth, and same evaluator.

**Definition 9** (GF-01 instance). A *GF-01 instance* is

$$I = (A, AP_{\text{in}}, AP_{\text{out}}, \tau, T, e, t^*, \text{mode}, w(I), B_T, B_A, \text{meta}).$$

**Field meanings.**

- $e$ : machine-checkable effect predicate,
- $t^*$ : target timestep for effect objective,
- $\text{mode} \in \{\text{normal}, \text{hard}\}$ ,
- $w(I)$ : trailing window size used in normal mode,
- $B_T$ : primary timestep intervention budget,
- $B_A$ : optional atom-budget field (diagnostic/constraint use).

This object is the formal instance contract used throughout the evaluator (see Definition 9).

## 4.2 Mode-specific effect objective

$$\begin{aligned}
E_{\text{hard}}(\rho, e, t^*) &:= [\rho_{t^*} \models e], \\
E_{\text{norm}}(\rho, e, t^*, w) &:= \exists t \in [\max(0, t^* - w), t^*] [\rho_t \models e]. \\
E_I(\rho) &= \begin{cases} E_{\text{norm}}(\rho, e, t^*, w(I)), & \text{mode} = \text{normal}, \\ E_{\text{hard}}(\rho, e, t^*), & \text{mode} = \text{hard}. \end{cases}
\end{aligned}$$

This normal/hard split is locked by [DEC-014](#).

## 4.3 Normal-mode window scaling policy

Current locked default:

$$w(I) = \text{clamp}(w_{\min}, w_{\max}, \text{round}(\alpha_0 + \alpha_T T + \alpha_C z(I))),$$

with provisional defaults ([DEC-014b](#)):  $\alpha_0 = 1$ ,  $\alpha_T = 0$ ,  $\alpha_C = 2$ ,  $w_{\min} = 1$ ,  $w_{\max} = 6$ , and equal-weight normalized complexity composite  $z(I)$  based on TempoBench-linked structural factors [\[3\]](#).

## 5 Ground-Truth Causality Contract

**Definition 10** (Sufficiency).

$$\text{Suff}_I(C) := \mathbf{1}[E_I(\text{Run}(A, \tau[C])) = 1].$$

**Definition 11** (Normative minimality (singleton-removal)).

$$\text{Min1}_I(C) := \mathbf{1}\left[\forall c \in C : E_I(\text{Run}(A, \tau[C \setminus \{c\}])) = 0\right].$$

**Definition 12** (Normative validity).

$$\text{Valid}_I(C) := \text{Suff}_I(C) \wedge \text{Min1}_I(C).$$

**Definition 13** (Ground-truth certificate set).

$$\mathcal{M}(I) := \{C \mid \text{Valid}_I(C) = 1\}.$$

*Multiple distinct valid minimal certificates are allowed.*

**Normative policy.** [DEC-012](#) locks singleton-removal minimality as normative scorer behavior.

### 5.1 Optional stronger diagnostic

Optional (non-scoring) exact subset-minimality diagnostic:

**Definition 14** (Optional exact subset-minimality diagnostic).

$$\text{SubsetMin}_I(C) := \mathbf{1}[\nexists C' \subset C \text{ with } \text{Suff}_I(C') = 1].$$

By policy ([DEC-012a](#), [DEC-012b](#)), this diagnostic is optional and exact-only when run.

## 6 Coenen Alignment and Scope Divergence

Coenen et al. define causality with explicit PC1/PC2/PC3 structure, contingencies, and strict-subset/property-level minimality [2]. This benchmark intentionally diverges in normative scoring by using finite intervention certificates with singleton-removal minimality. The divergence is explicit and policy-locked (centered on [DEC-012](#)), not implicit.

## 7 Evaluation Tracks and Metric Regimes

### 7.1 Evaluation-condition tracks

- **EVAL-CB**: closed-book (no external tools beyond model-internal reasoning/scratchpad).
- **EVAL-TA**: tool-augmented with predeclared allowlist and full tool logging.
- **EVAL-OC**: solver-oracle ceiling track, reported separately.

Track separation is mandatory ([DEC-001](#), [DEC-001a](#)).

## 7.2 Metric regimes

The symbols in this section reuse formal objects from Definition 10, Definition 11, Definition 12, and Definition 13.

**MET-C (Certified Causality).**

$$\text{Score}_C(I) = \mathbf{1}[\text{Valid}_I(C_a) = 1].$$

where the implementation artifact name is `Score_C`.

**MET-M (Multi-objective).** For agent certificate  $C_a$ :

$$\begin{aligned} M(I) &= \mathbf{1}[\text{Valid}_I(C_a) = 1], & G(I) &= \mathbf{1}[\text{Suff}_I(C_a) = 1], \\ \text{Eff}_t(I) &= |\text{TS}(C_a)|, & \text{TS}(C) &= \{t \mid \exists a, v : (t, a, v) \in C\}, \\ \text{Eff}_a(I) &= |C_a|. \end{aligned}$$

Per-instance lexicographic key:

$$\kappa(I) = (M(I), G(I), -\text{Eff}_t(I), -\text{Eff}_a(I)).$$

with implementation key name `kappa`.

**Intuition.** The scoring priority is: valid minimal causality first, then effect success, then fewer intervention timesteps.

## 7.3 AP/TS precision-recall-F1 under non-unique minima

TempoBench reports AP/TS causality metrics [3]. With non-unique  $\mathcal{M}(I)$  (Definition 13), deterministic best-match target is (DEC-025):

$$C^*(I, C_a) = \arg \max_{C \in \mathcal{M}(I)} F1_{AP}(C_a, C),$$

then tie-break by  $F1_{TS}$ , then lower  $\text{Eff}_t$ , then canonical atom hash order.

## 7.4 Required reporting dimensions

Official reports must stratify by

$$(\text{family\_id}, \text{eval\_track}, \text{renderer\_track}, \text{difficulty\_slice}, \text{split\_id}).$$

No cross-track pooling is allowed. This follows evidence that aggregate single scores can hide major failures [4] and that contamination/governance choices can distort benchmark conclusions [1, 7, 8].

# 8 Generator Contract and Difficulty Scaling

## 8.1 Generator input object

$$G_{\text{in}} = (A, \tau, AP_{\text{in}}, AP_{\text{out}}, F, \text{seed}, \text{cfg}).$$

where implementation-facing field names include `seed` and `cfg`. Generation is defined for any finite trace length  $T \geq 1$ . Candidates are accepted only if exact normative checking confirms  $\mathcal{M}(I) \neq \emptyset$  (see Definition 13).

## 8.2 Determinism lock

For fixed  $(A, \tau, AP_{\text{in}}, AP_{\text{out}}, F, \text{seed}, \text{cfg}, \text{generator\_version})$ , output must be bit-identical (DEC-024). No wall-clock or system-entropy randomness is permitted.

## 8.3 Connection to TempoBench generation evidence

TempoBench describes a formal generation/evaluation pipeline using specification-to-automaton synthesis and causal extraction over generated traces [3]. Repo-side benchmark-runner artifacts provide AP/TS-scored execution/logging behavior [6]. Solver-validated generation as a general methodology is also supported by SATBench-style design [9].

# 9 Optional-Diagnostic Infeasibility Policy

Normative exact checks are always required. Only optional diagnostics may be marked infeasible (DEC-019).

Hybrid policy (DEC-020):

- platform/runtime caps  $P_{\text{ref}}$ ,
- algorithmic-budget caps  $A_{\text{ref}}$ .

Initial cap freeze timing is aligned with DEC-021 checkpoint; derivation uses dual-threshold rule from DEC-022 with provisional defaults  $p = 0.90$ ,  $k = 3$  (DEC-023).

# 10 Partial Observability and No-Query Rule

Hidden state is allowed but not directly exposed. Agents gather information only from passive observations and intervention consequences. Explicit query actions are excluded. The agent-facing channel is the canonical observation object in Definition 7. This aligns with interactive-agent evaluation practices that require explicit environment protocols rather than static one-shot prompts [5, 10].

# 11 Renderer Policy and Current Priority

## 11.1 Renderer parity requirement

Renderer variants are allowed only if they preserve canonical  $O(s)$  semantics, intervention semantics, and scoring outcomes (see Definition 7 and Definition 12).

## 11.2 Current lock

By DEC-038, implementation priority is:

- first: GF-01-R1 (side-scroller),
- deferred candidate: GF-01-R3 (turn-locked grid/tower), promoted only after DEC-038a gates pass: semantic parity, leakage-audit parity, and track-separated reporting.



## 12 Active Hypotheses and Validation Plans

- **HYP-005:** exact subset-minimal diagnostics may be costly at scale. Validation: runtime/cost curves versus instance complexity.
- **HYP-006:** forward-time defensive gameplay can preserve TCE fidelity while improving engagement. Validation: matched human/agent pilot.
- **HYP-007/HYP-008:** complexity-scaled normal windows and current trigger constants are useful but provisional. Validation: post-pilot recalibration audit.
- **HYP-011/HYP-012:** current family ranking and decision matrix are inference-first and require empirical backfill.
- **HYP-013/HYP-014:** hybrid infeasibility caps improve cross-lab comparability when frozen from pilot evidence.
- **HYP-015/HYP-016:** Python-first implementation is sufficient for near-term scale but requires larger stratified sweep confirmation.
- **HYP-017:** turn-locked grid/tower renderer may scale better than vertical side-scroller on high-complexity slices. Validation: matched-seed parity/usability pilot versus R1.

## 13 Deferred Items and Current Risk Note

- **Q-033 (deferred):** confirm profiling gates on larger stratified sweeps with stronger hardware.
- Optional-diagnostic coverage comparability depends on successful cap freeze execution and transparent run metadata.

## 14 Summary

This specification locks the current normative benchmark contract while keeping hypotheses and deferred items explicitly labeled. The document is self-contained: all key labels and renderer identifiers used in formal sections are defined in Section 1.

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