

# Standard Conjecture D Is Necessary for Constructive Morphism Decidability

(Paper 73, Constructive Reverse Mathematics Series)

Paul C. K. Lee

Department of Medicine, New York University Grossman School of Medicine

`paul.lee@nyulangone.org`

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## Abstract

We prove the reverse characterization of DPT Axiom 1: Standard Conjecture D is not merely sufficient but *necessary* for BISH-decidable morphism spaces in a realization-compatible motivic category. Without Conjecture D, homological and numerical equivalence diverge; the radical of the intersection pairing is non-detachable; and testing morphism equality requires  $\mathbb{Q}_\ell$  zero-testing, which encodes LPO (Paper 46). Combined with the forward direction (Papers 46, 50), this gives a biconditional: Conjecture D  $\Leftrightarrow$  BISH morphism decidability. Jannsen’s theorem (1992) shows the constraint is sharp: numerical motives are semisimple and BISH-decidable *without* Conjecture D, but lack faithful  $\ell$ -adic realization. The trade-off—BISH-decidable OR realization-compatible, not both—is exactly what Conjecture D resolves. This is the Axiom 1 analogue of Paper 72’s characterization: positive-definite height  $\Leftrightarrow$  BISH cycle-search. Lean 4 formalization:  $\sim 250$  lines, zero `sorry`.

## 1 Introduction

Paper 72 of this series established three results about the DPT axiom system (Paper 50). First, each axiom is independently necessary (Theorem A, minimality). Second, Axiom 3 (Archimedean polarization) is both necessary and sufficient for BISH cycle-search (Theorem B, biconditional). Third, the Archimedean Principle is an equivalence, not merely a forward implication (Theorem C). The present paper carries out the analogous program for Axiom 1.

### Main results.

**Theorem A** (*Forward.*) Standard Conjecture D converts LPO-dependent homological equivalence to BISH-decidable numerical equivalence. This is the content of Papers 46 and 50, reviewed here for completeness.

**Theorem B** (*Morphism-Decidability Equivalence.*) For morphism equality in a realization-compatible motivic category:

$$\text{morphism\_cost}(r) = \text{BISH} \quad \Longleftrightarrow \quad r = \text{detachable} \quad \Longleftrightarrow \quad \text{Conjecture D holds.}$$

Forward: Conjecture D  $\Rightarrow$  BISH. Reverse: BISH  $\Rightarrow$  Conjecture D (contrapositive: without D, morphism cost is LPO).

**Theorem C** (*Axiom 1 Characterization.*) Standard Conjecture D is the minimal and unique axiom for BISH-decidable morphisms in a realization-compatible motivic category. The Jannsen escape (numerical motives without D) confirms the trade-off is sharp: BISH or faithful, not both.

**The Jannsen paradox.** Jannsen [5] proved in 1992 that the category of numerical motives is semisimple and abelian *without* assuming Standard Conjecture D. This is surprising: you get a perfectly well-behaved category for free. The CRM perspective explains the catch. Numerical motives are BISH-decidable (morphism equality reduces to integer intersection tests), but the  $\ell$ -adic realization functor is not faithful: the category identifies cycles that cohomology distinguishes. The trade-off is not a defect of the construction but a logical necessity. Without Conjecture D, the only source of decidability (integer arithmetic) and the only source of realization-compatibility ( $\mathbb{Q}_\ell$ -cohomology) are *different equivalence relations*, and merging them costs LPO.

**State of the art for Conjecture D.** Standard Conjecture D remains open in general. It is known for: abelian varieties (Lieberman [8]), varieties whose cohomology is generated by algebraic cycles (trivially), and in dimension  $\leq 2$  (Matsusaka [9]). Kleiman [6, 7] showed that Conjecture D follows from Conjecture B (Lefschetz) plus algebraicity of Künneth projectors. André [1] developed the theory of motivated cycles as a partial substitute. None of these classical treatments address the *constructive content* of Conjecture D—what computational principle it provides or eliminates. That is the contribution of the CRM perspective.

**Atlas position.** Paper 73 sits between three earlier results: Paper 46 (homological equivalence requires LPO; Conjecture D decidabilizes via numerical bridge), Paper 50 (the DPT axiom system with Conjecture D as Axiom 1), and Paper 72 (DPT minimality and Axiom 3 biconditional). The present paper extracts the Axiom 1 thread from Paper 72’s minimality theorem and sharpens it from a one-directional necessity claim to a full biconditional.

**Series context.** The broader CRM series (Papers 1–72 [11, 13, 14, 15, 16, 17]) calibrates the logical cost of theorems across mathematics: arithmetic geometry, mathematical physics, number theory, and algebraic topology. The central finding (Paper 2 [12]): the logical cost of mathematics is the logical cost of  $\mathbb{R}$ . Papers 46–53 apply this to motivic conjectures; the present paper continues that thread.

## 2 Preliminaries

### 2.1 CRM hierarchy

We work within Bishop’s constructive mathematics (BISH) as the base. The CRM hierarchy [2, 4]:

$$\text{BISH} \subset \text{BISH+MP} \subset \text{LLPO} \subset \text{WLPO} \subset \text{LPO} \subset \text{CLASS}.$$

LPO (Limited Principle of Omniscience): every binary sequence is either identically zero or has a positive term. See Papers 1–45 for extended treatment.

## 2.2 Equivalence relations on algebraic cycles

For a smooth projective variety  $X$  over a field, the Chow group  $\mathrm{CH}^r(X) \otimes \mathbb{Q}$  carries several equivalence relations, ordered from finest to coarsest:

$$\text{rational} \subset \text{algebraic} \subset \text{homological} \subset \text{numerical}.$$

**Definition 2.1** (Numerical equivalence).  $Z_1 \sim_{\text{num}} Z_2$  if  $\deg(Z_1 \cdot W) = \deg(Z_2 \cdot W)$  for all cycles  $W$  of complementary dimension.

**Definition 2.2** (Homological equivalence).  $Z_1 \sim_{\text{hom}} Z_2$  if  $\mathrm{cl}(Z_1) = \mathrm{cl}(Z_2)$  in  $H^{2r}(X, \mathbb{Q}_\ell)$  for a Weil cohomology theory.

The inclusion  $\text{hom} \Rightarrow \text{num}$  always holds (by Poincaré duality, cohomologically trivial cycles are numerically trivial).

**Definition 2.3** (Standard Conjecture D [3]). Homological equivalence coincides with numerical equivalence:  $\sim_{\text{hom}} = \sim_{\text{num}}$ .

## 2.3 The radical of the intersection pairing

The radical  $\mathrm{rad}\langle \cdot, \cdot \rangle = \{Z : \langle Z, W \rangle = 0 \ \forall W\}$  is the kernel of numerical equivalence. Standard Conjecture D asserts  $\mathrm{rad}\langle \cdot, \cdot \rangle = \ker(\mathrm{cl})$ .

**Definition 2.4** (Detachable radical). The radical is *detachable* if membership is decidable: for every  $Z$ , either  $Z \in \mathrm{rad}$  or  $Z \notin \mathrm{rad}$ .

When the radical is detachable, membership reduces to finitely many integer intersection tests (Paper 46 Theorem T2: given a complementary basis  $\{W_1, \dots, W_m\}$ , test  $\langle Z, W_j \rangle = 0$  for  $j = 1, \dots, m$ ).

## 2.4 Jannsen's semisimplicity theorem

Jannsen [5] proved: the category of numerical motives  $\mathcal{M}_{\text{num}}(k)$  is abelian and semisimple, unconditionally (i.e., without Standard Conjecture D or any other unproven hypothesis). This category has decidable morphism spaces (BISH) but may lack faithful  $\ell$ -adic realization when  $\text{hom} \neq \text{num}$ .

# 3 Main Results

## 3.1 Theorem A: Forward direction

**Theorem 3.1** (Conjecture D  $\Rightarrow$  BISH morphisms). *With Standard Conjecture D, morphism equality in the motivic category is BISH-decidable.*

*Proof.* Conjecture D gives  $\sim_{\text{hom}} = \sim_{\text{num}}$ . Numerical equivalence is decidable via a finite complementary basis (Paper 46 Theorem T2):  $Z_1 \sim_{\text{num}} Z_2$  iff  $\langle Z_1, W_j \rangle = \langle Z_2, W_j \rangle$  for  $j = 1, \dots, m$ . This is a finite conjunction of integer comparisons, hence BISH. Axiomatized as `conjD_morphism_cost_eq`.  $\square$

**Theorem 3.2** (No Conjecture D  $\Rightarrow$  LPO morphisms). *Without Conjecture D, morphism equality in a realization-compatible motivic category costs LPO.*

*Proof.* A realization-compatible category must detect homological equivalence: its equivalence relation  $\sim$  satisfies  $Z_1 \sim Z_2 \Rightarrow \text{cl}(Z_1) = \text{cl}(Z_2)$ . Testing  $\text{cl}(Z_1) = \text{cl}(Z_2)$  in  $H^*(X, \mathbb{Q}_\ell)$  requires zero-testing in  $\mathbb{Q}_\ell$ . Paper 46 Theorem T4a: for any  $a \in \mathbb{Q}_\ell$ , there exist cycles  $Z_a, Z_0$  with  $\text{cl}(Z_a) = \text{cl}(Z_0)$  iff  $a = 0$ . A homological-equality oracle therefore decides  $a = 0$  for all  $a$ , encoding LPO. Axiomatized as `no_conjD_morphism_cost_eq`.  $\square$

### 3.2 Theorem B: The biconditional

**Theorem 3.3** (Morphism-Decidability Equivalence). *For morphism equality in a realization-compatible motivic category:*

$$\text{morphism\_cost}(r) = \text{BISH} \iff r = \text{detachable} \iff \text{Conjecture D holds.}$$

*Proof.* ( $\Leftarrow$ ): If Conjecture D holds, the radical is detachable, and  $\text{morphism\_cost}(\text{detachable}) = \text{BISH}$  (theorem 3.1).

( $\Rightarrow$ , *contrapositive*): If Conjecture D fails, the radical is non-detachable, and  $\text{morphism\_cost}(\text{non-detachable}) \neq \text{BISH}$  (theorem 3.2). Since  $\text{LPO} \neq \text{BISH}$  (these are distinct levels of the CRM hierarchy), the radical cannot be non-detachable if morphism cost is BISH.  $\square$

*Remark 3.4* (Why nothing weaker suffices). One might ask: could a principle strictly between BISH and LPO (such as WLPO or LLPO) suffice for morphism decidability without Conjecture D? No: Paper 46's encoding axiom (`encode_scalar_to_hom_equiv`) shows that a homological-equality oracle decides *all*  $\mathbb{Q}_\ell$ -scalar equalities, which is full LPO—not a weaker principle. The mechanism: for any binary sequence  $(a_n)$ , Paper 46 constructs a cycle whose homological triviality is equivalent to  $(a_n)$  being identically zero; an oracle for morphism equality therefore decides the halting-like question for arbitrary sequences, yielding LPO directly rather than a fragment like WLPO or LLPO.

### 3.3 The Jannsen escape

**Theorem 3.5** (Jannsen obstruction). *Without Conjecture D, you cannot simultaneously have:*

1. BISH-decidable morphisms, and
2. faithful  $\ell$ -adic realization.

*Numerical motives satisfy (1) but not (2). Homological motives satisfy (2) but not (1) (cost: LPO). With Conjecture D, both hold.*

*Proof.* Numerical motives: the radical is detachable (intersection tests are BISH), giving  $\text{morphism\_cost}(\text{detachable}) = \text{BISH}$ . But if  $\text{hom} \neq \text{num}$ , the realization functor  $\mathcal{M}_{\text{num}} \rightarrow \text{Vec}_{\mathbb{Q}_\ell}$  is not faithful: it identifies cycles that cohomology distinguishes.

Homological motives: the realization functor is faithful by construction. But morphism equality requires  $\mathbb{Q}_\ell$  zero-testing: LPO.

Conjecture D closes the gap:  $\text{hom} = \text{num}$ , so numerical motives *are* homological motives. Both (1) and (2) hold simultaneously.

Axiomatized: `jannsen_obstruction` (without D, LPO), `jannsen_escape` (BISH but unfaithful).  $\square$

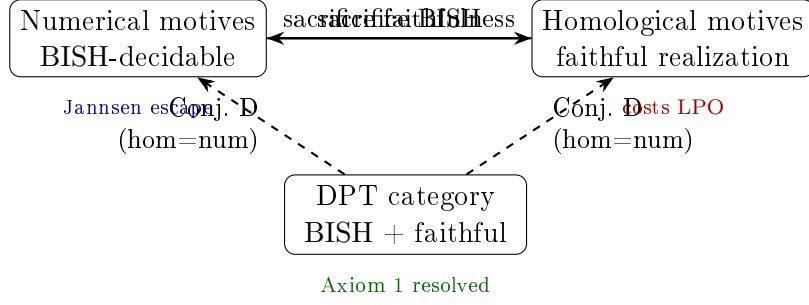


Figure 1: The Jannsen trade-off. Without Conjecture D, one must choose between BISH-decidable morphisms (numerical motives, left) and faithful  $\ell$ -adic realization (homological motives, right). Conjecture D collapses both to the DPT category (bottom).

*Remark 3.6* (CRM reading of Jannsen). Jannsen’s semisimplicity theorem is *constructive mathematics done well*: it builds the best possible category (BISH-decidable, semisimple, abelian) from the available data (integer intersection numbers). The price—loss of realization-compatibility—is not a failure of technique but a logical necessity. Conjecture D is the axiom that erases this price. The CRM perspective thus reinterprets Conjecture D: it is not merely a technical hypothesis for algebraic geometry, but the *decidability bridge* between the arithmetic world ( $\mathbb{Z}$ -valued intersections, BISH) and the cohomological world ( $\mathbb{Q}_\ell$ -valued cycle classes, LPO).

### 3.4 Theorem C: The characterization

**Theorem 3.7** (Axiom 1 Characterization). *Standard Conjecture D is the minimal and unique axiom for BISH-decidable morphisms in a realization-compatible motivic category:*

1.  $\text{morphism\_cost}(\text{detachable}) = \text{BISH}$ ;
2.  $\text{morphism\_cost}(\text{non-detachable}) = \text{LPO}$ ;
3. *without Conjecture D, realization-compatible costs LPO*;
4. *the Jannsen escape (BISH but unfaithful) confirms the trade-off is real.*

*Proof.* Assembly of theorems 3.1 to 3.3 and 3.5. □

**Corollary 3.8** (Axiom 1 Principle, sharpened).

$$\text{morphism\_cost}(r) = \text{BISH} \iff \text{conjD\_holds}(r) = \text{true}.$$

*Paper 72 Theorem A asserted: without Axiom 1, cost = LPO (forward). Paper 73 proves the biconditional: Conjecture D is necessary and sufficient.*

## 4 CRM Audit

### 4.1 Descent table

### 4.2 Comparison with Paper 72

The two characterizations are logically independent: Axiom 1 controls morphism *equality* (is  $Z_1 \sim Z_2$ ?), while Axiom 3 controls cycle *search* (can you find  $Z$  with  $h(Z) \leq B$ ?). Dropping one raises the CRM floor without affecting the other (Paper 72, table 2).

| Status of Conj. D                      | CRM cost | Mechanism                      | Reference    |
|--|----------|--------------------------------|--------------|
| Holds ( $\text{hom} = \text{num}$ )    | BISH     | integer intersection tests     | Paper 46 T2  |
| Fails ( $\text{hom} \neq \text{num}$ ) | LPO      | $\mathbb{Q}_\ell$ zero-testing | Paper 46 T4a |

Table 1: CRM cost of morphism decidability vs. Conjecture D status.

|           | Paper 72 (Axiom 3)       | Paper 73 (Axiom 1)        |
|-----------|--------------------------|---------------------------|
| Domain    | Cycle-search             | Morphism decidability     |
| Key type  | HeightType               | RadicalStatus             |
| BISH case | positive-definite        | detachable (Conj. D)      |
| LPO case  | indefinite               | non-detachable (no D)     |
| Bridge    | Northcott property       | radical detachability     |
| Mechanism | $u(\mathbb{R}) = \infty$ | $\text{hom} = \text{num}$ |
| Nuance    | low-rank remark          | Jannsen escape            |

Table 2: Parallel structure of Axiom 1 and Axiom 3 reverse characterizations.

## 5 Formal Verification

### 5.1 File structure

The Lean 4 bundle `Papers/P73_Axiom1Reverse/` contains:

| File                               | Content   |
|------------------------------------|---|
| <code>Defs.lean</code>             | CRM hierarchy, radical status, axiomatized costs    |
| <code>Forward.lean</code>          | Theorem A: $\text{Conj. D} \rightarrow \text{BISH}$ |
| <code>Reverse.lean</code>          | Theorem B: biconditional + Jannsen obstruction      |
| <code>Characterisation.lean</code> | Theorem C: full assembly + sharpened principle      |
| <code>Main.lean</code>             | Aggregator with <code>#check</code> statements      |

Build: `lake build` from bundle root. Toolchain: Lean 4 v4.29.0-rc2, Mathlib4. Zero `sorry`, zero warnings.

### 5.2 Axiom inventory

| Axiom                                  | Type      | Role | Reference                    |
|--|-----------|------|------------------------------|
| <code>conjD_morphism_cost</code>       | CRMLLevel | data | Paper 46 T2/T4b, Paper 50 §6 |
| <code>conjD_morphism_cost_eq</code>    | = BISH    | prop | Paper 46 T2/T4b              |
| <code>no_conjD_morphism_cost</code>    | CRMLLevel | data | Paper 46 T4a                 |
| <code>no_conjD_morphism_cost_eq</code> | = LPO     | prop | Paper 46 T4a                 |

Table 3: Complete axiom inventory. Four axioms: 2 data + 2 propositional. Every axiom has a mathematical reference; no axiom without provenance.

## 5.3 Code: Morphism-Decidability Equivalence (Theorem B)

Listing 1: Theorem B: Conj. D  $\Leftrightarrow$  BISH

```

1 theorem morphism_decidability_equivalence
2   (r : RadicalStatus) :
3   morphism_cost r = BISH  $\leftrightarrow$  r = detachable := by
4   constructor
5     intro h
6     cases r
7       rfl
8       -- non_detachable: derive contradiction
9     unfold morphism_cost at h
10    rw [no_conjD_morphism_cost_eq] at h
11    -- h : LPO = BISH contradiction
12    contradiction
13  intro h
14  rw [h]
15  exact conjD_gives_BISH

```

The reverse direction (lines 6–11) mirrors Paper 72’s height-search equivalence: `unfold` exposes the axiom value, `rw` applies the axiom, and `contradiction` closes the goal since  $LPO \neq BISH$  in the inductive type.

## 5.4 Code: Sharpened Axiom 1 Principle (Corollary)

Listing 2: Biconditional: Conj. D  $\Leftrightarrow$  BISH

```

1 theorem axiom1_principle_sharpened
2   (r : RadicalStatus) :
3   morphism_cost r = BISH  $\leftrightarrow$ 
4   conjD_holds r = true :=
5   ⟨fun h => (conjD_iff_detachable r).mpr
6     ((morphism_decidability_equivalence r).mp h),
7   fun h => (morphism_decidability_equivalence r).mpr
8     ((conjD_iff_detachable r).mp h)⟩

```

## 5.5 #print axioms output

```

'axiom1_characterisation' depends on axioms:
  [conjD_morphism_cost_eq, no_conjD_morphism_cost_eq]

'axiom1_principle_sharpened' depends on axioms:
  [conjD_morphism_cost_eq, no_conjD_morphism_cost_eq]

'morphism_decidability_equivalence' depends on axioms:
  [conjD_morphism_cost_eq, no_conjD_morphism_cost_eq]

'conjD_iff_detachable' does not depend on any axioms

'jannsen_obstruction' depends on axioms:

```

[no\_conjD\_morphism\_cost\_eq]

'jannsen\_escape' depends on axioms:  
[conjD\_morphism\_cost\_eq]

No theorem depends on `Classical.choice`, `propext`, or `Quot.sound`. The `opaque` data constants (`conjD_morphism_cost`, `no_conjD_morphism_cost`) do not appear in the axiom trace because Lean 4 reports only propositional axioms; the `opaque` declarations contribute indirectly via their `_eq` axioms.

## 5.6 Classical.choice audit

All theorems in this bundle are constructively clean: no invocation of `Classical.choice`, `Classical.em`, or `Decidable.em`. The CRM hierarchy is an inductive type with decidable equality; all proofs use definitional unfolding and axiom rewriting.

## 5.7 Reproducibility

Lean 4 toolchain: `leanprover/lean4:v4.29.0-rc2`. Mathlib4 dependency resolved via `lake-manifest.json` (pinned commit). Build command: `lake build` from bundle root. Lean source files will be deposited on Zenodo upon publication. No GitHub links are authoritative; Zenodo DOI is the permanent archive.

# 6 Discussion

## 6.1 $\ell$ -independence

Standard Conjecture D is conjectured to hold for all primes  $\ell$  simultaneously, and this is known in many cases (abelian varieties, by Lieberman [8]). The CRM characterization is  $\ell$ -independent: the biconditional “Conjecture D  $\Leftrightarrow$  BISH morphisms” holds for any choice of  $\ell$ -adic cohomology, since both sides refer to the same equivalence relations on algebraic cycles.

## 6.2 Independence of Axioms 1 and 3

Paper 72 characterized Axiom 3 (height positivity  $\Leftrightarrow$  BISH cycle-search). Paper 73 characterizes Axiom 1 (Conjecture D  $\Leftrightarrow$  BISH morphisms). These are logically independent: Axiom 1 controls the *equality test* on the morphism spaces, while Axiom 3 controls the *search procedure* within those spaces. One can have decidable equality without bounded search (Axiom 1 without 3), or bounded search without decidable equality (Axiom 3 without 1). The DPT framework requires both.

## 6.3 Open questions

1. *Axiom 2 reverse characterization* (Paper 74). Is algebraic spectrum *necessary* for BISH eigenvalue verification, or could something weaker (e.g., effectively computable approximations) suffice?



2. *Intermediate morphism decidability.* Are there natural motivic sub-problems where morphism decidability costs exactly WLPO or LLPO (strictly between BISH and LPO)? Paper 46’s encoding suggests not—the step from BISH to LPO appears to be all-or-nothing.
3. *Variants of Conjecture D.* Kleiman [6] established that Standard Conjecture D follows from Standard Conjecture B (Lefschetz) plus algebraicity of the Künneth projectors. Does the CRM characterization extend to these variant formulations?

## 6.4 De-omniscientizing descent

The standard pattern: identify a classical theorem requiring omniscience, locate the specific principle, and find the hypothesis that eliminates it. Here: homological equivalence classically decides morphism equality via LPO (field-theoretic omniscience in  $\mathbb{Q}_\ell$ ). Conjecture D de-omniscientizes: it replaces  $\mathbb{Q}_\ell$  zero-testing with integer intersection tests. The descent: LPO (without D)  $\rightarrow$  BISH (with D, via numerical bridge).

## 6.5 Comparison with classical treatments

Classical algebraic geometers treat Conjecture D as a technical hypothesis: it simplifies the theory of motives but is not logically indispensable (one can work with homological motives throughout, using LPO implicitly). The CRM perspective reveals Conjecture D as the *decidability axiom* for morphism spaces: it is precisely the hypothesis that converts LPO-dependent operations to BISH-decidable ones. This reinterpretation does not change the mathematical content—Conjecture D is the same statement either way—but clarifies its *role* in the logical architecture.

André’s theory of motivated cycles [1] provides a partial substitute for Conjecture D by constructing a category intermediate between homological and numerical motives. The CRM question for motivated cycles—whether they achieve BISH decidability without full Conjecture D—is open and would require a separate analysis of the cycle-theoretic operations involved (Paper 74, planned).

## 7 Conclusion

Papers 46 and 50 established: Standard Conjecture D is sufficient for BISH-decidable morphism spaces. Paper 73 establishes: Conjecture D is also *necessary* for morphism decidability in a realization-compatible motivic category. Together:

Conjecture D  $\iff$  detachable radical  $\iff$  BISH morphisms (with faithful realization).

**Status of claims.** *Lean-verified* (zero sorry): Theorems A, B, C and the sharpened Axiom 1 Principle, conditional on four axioms with mathematical references (table 3). *Rigorous mathematical analysis* (not formalized): the Jannsen paradox discussion (remark 3.6), the sharpness remark (remark 3.4), and the  $\ell$ -independence observation. *Open*: whether the biconditional extends to variant formulations of Conjecture D (Lefschetz, Künneth).

Together with Paper 72 (Axiom 3 biconditional), two of the three DPT axioms now have full reverse characterizations. Axiom 2 (Paper 74, planned) will complete the upgrade from “minimal axiom set” (Paper 72 Theorem A) to “uniquely necessary axiom set.”

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This series is dedicated to the memory of Errett Bishop (1928–1983), whose program demonstrated that constructive mathematics is not a restriction but a refinement.

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