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Anthropocentric Invariants in Measurement: A Formal Taxonomy, Cross-Ratio Analysis, and Quantitative Bias Assessment

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ABSTRACT

Conventional measurement units embed human-specific cognitive choices—decimal numeracy, body-scale references, and water-based mass standards—creating anthropocentric invariants that obscure observer-independent physics. Existing work has not formalized how such conventions transform under changes of radix, physiology, or chemistry, nor quantified the bias they introduce for non-human observers. We define a taxonomy of measurement conventions as functions of three cognitive parameters (radix r , body-scale factor s , chemical-basis factor c) and prove that only dimensionless constants remain invariant under the induced “cognitive transformations”, by analogy with projective cross-ratio invariance. Using the SI catalog of anthropocentric features[9] and the cross-ratio theorem[11], we compute (i) the proportion of anthropocentric features ($P = 0.90323$), (ii) a concrete length-unit scaling factor ($\lambda_L = 5.31 \times 10^{-3}$) and mass-unit scaling factor ($\lambda_M = 2.10$) for a hypothetical alien observer with octal radix, insect body scale, and silicon-based chemistry, and (iii) the radix-economy overhead for representing the inverse fine-structure constant in base 10 versus the optimal radix (overhead factor 2.24). These results demonstrate that all conventional units are contingent, while dimensionless ratios such as the fine-structure constant are the sole fixed points. The findings suggest that future metrological standards for interspecies communication must be built on dimensionless invariants and that radix-economy considerations can guide the design of observer-neutral numerical representations.

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Abstract

Conventional measurement units embed human-specific cognitive choices—decimal numeracy, body-scale references, and water-based mass standards—creating anthropocentric invariants that obscure observer-independent physics. Existing work has not formalized how such conventions transform under changes of radix, physiology, or chemistry, nor quantified the bias they introduce for non-human observers. We define a taxonomy of measurement conventions as functions of three cognitive parameters (radix r , body-scale factor s , chemical-basis factor c) and prove that only dimensionless constants remain invariant under the induced “cognitive transformations”, by analogy with projective cross-ratio invariance. Using the SI catalog of anthropocentric features[9] and the cross-ratio theorem[11], we compute (i) the proportion of anthropocentric features ($P = 0.90323$), (ii) a concrete length-unit scaling factor ($\lambda_L = 5.31 \times 10^{-3}$) and mass-unit scaling factor ($\lambda_M = 2.10$) for a hypothetical alien observer with octal radix, insect body scale, and silicon-based chemistry, and (iii) the radix-economy overhead for representing the inverse fine-structure constant in base 10 versus the optimal radix (overhead factor 2.24). These results demonstrate that all conventional units are contingent, while dimensionless ratios such as the fine-structure constant are the sole fixed points. The findings suggest that future metrological standards for interspecies communication must be built on dimensionless invariants and that radix-economy considerations can guide the design of observer-neutral numerical representations.

1. Introduction

Scientists, engineers, and policymakers worldwide rely on the International System of Units (SI) to encode quantitative knowledge. The SI base units, however, encode human-specific cognitive features—decimal numeracy, body-scale references, Earth-centric geometry, and water-based mass standards—as documented in a systematic catalog of “anthropometric fossils”[9]. For extraterrestrial or non-human intelligences, these conventions become opaque, impeding scientific exchange, the design of universal instrumentation, and the formulation of shared physical laws. The cost of this mismatch appears in delayed collaboration on planetary missions, misinterpretation of remote-sensing data, and the need to re-derive basic constants for each new observer. If a formal framework could identify which measurement conventions survive arbitrary changes in radix, physiology, and chemistry, metrology could be redesigned around truly observer-independent quantities, enabling seamless cross-species scientific dialogue.

Contributions.

- **C1.** A taxonomy of measurement conventions expressed as functions of cognitive parameters (radix r , body-scale s , chemistry c) (Section 3).
- **C2.** A proof that only dimensionless ratios are invariant under cognitive transformations, using projective cross-ratio invariance[11] (Section 3).
- **C3.** An explicit computation of the anthropocentric feature proportion ($P = 0.90323$) from the SI catalog[9] (Section 4.1).
- **C4.** A concrete numerical example of unit-scale transformation for an alien observer (length scaling $\lambda_L = 5.31 \times 10^{-3}$, mass scaling $\lambda_M = 2.10$) (Section 4.2).
- **C5.** A radix-economy analysis quantifying the overhead of decimal representation for the inverse fine-structure constant, showing an overhead factor of 2.24 relative to the optimal radix (Section 4.3).
- **C6.** A discussion of practical pathways for adopting dimensionless standards in metrology and astrobiology (Section 7).

2. Background and Related Work

The theory of invariants for matrix actions provides algorithmic tools to decide orbit-closure intersections and to bound the degree of separating invariants[1]. The bound $\beta_{\text{sep}}(S(n, m)) \leq 4n^2 \log_2(n) + 12n^2 - 4n$ demonstrates that invariance can be quantified even in high-dimensional algebraic settings, motivating our formal treatment of measurement invariance.

Cognitive systems are driven by survival and lifelong utility maximization[2], with emotions serving as functional intermediaries that shape policy selection under time constraints. This functional view of cognition underlies our definition of “cognitive parameters” that shape measurement conventions.

Autonomous neural dynamics generate internal variability that acts as a source of noise in stimulus-response experiments[3]. The variability illustrates how internal states (here, physiological parameters) can bias observable outputs, analogous to how human physiology biases unit definitions.

Symbol emergence in developmental systems shows that external sign systems (language, gestures) evolve through social interaction[4]. The emergent nature of symbols parallels the emergence of measurement conventions from human cultural practices.

A cognitive diversity framework for radar target classification demonstrates that varying sensor perspectives ($\Delta\theta$) improves performance, with a median of three perspectives yielding an 85% detection rate at $\Delta\theta=5^\circ$ [5]. This empirical finding supports the idea that varying observational parameters (radix, scale) can alter derived quantities while preserving underlying invariants.

Exoskeleton technology highlights the need to integrate physical and cognitive interaction models to accommodate task variability[6]. The challenge of adapting to diverse human biomechanics mirrors the challenge of adapting measurement standards to diverse alien physiologies.

System-1 and System-2 cognition can be situated within a common model, revealing a spectrum of cognitive properties rather than a strict dichotomy[7]. This spectrum informs our choice of continuous cognitive parameters rather than binary categories.

Embodied cognitive neuroscience distinguishes “minimal” (neurocentric) from “radical” (embodied) approaches[8], emphasizing that cognition cannot be fully understood without reference to the body—reinforcing the relevance of body-scale in measurement conventions.

The SI catalog enumerates four cognitive features per base unit, totaling 28 anthropocentric features, and identifies three observer-independent dimensionless ratios (fine-structure constant α , electron-to-proton mass ratio m_e/m_p , electron-to-Planck mass ratio m_e/m_P)[9].

The cross-ratio theorem states that for any projective transformation $T \in \text{PGL}(2, \mathbb{F})$ and four distinct points A, B, C, D , the cross-ratio $\text{CR}(A, B, C, D)$ is invariant[11]. This mathematical invariance underlies our proof that only dimensionless ratios survive arbitrary cognitive transformations.

Ostrowski’s theorem classifies absolute values on $\mathbb{Q}$, showing that physical formulas evaluated with dimensional constants are meaningful only in the Archimedean completion, whereas dimensionless ratios are well-defined across all completions[12]. This supports the universality of dimensionless constants.

The ten-fingered trap analysis demonstrates that decimal numeracy originates from human anatomy rather than mathematical necessity, and that alternative radices can reduce representation length[10]. This motivates our radix-economy metric.

3. Methods

3.1 Taxonomy of Measurement Conventions

We model a measurement convention U as a mapping

$$U = f(r, s, c),$$

where $r \in \{8, 10, 12, 16\}$ denotes the radix, $s \in \{\text{insect, human, elephant}\}$ the characteristic body scale, and $c \in \{\text{water, silicon, carbon}\}$ the dominant chemical basis. For each SI base unit we assign a reference quantity (e.g., metre $\leftrightarrow$ typical stride length) and scale it by s ; the numerical representation is scaled by $\log_{10}(r)$; the mass reference is scaled by the density ratio of c to water.

3.2 Cognitive Transformations

A cognitive transformation T maps one observer’s parameter triple (r, s, c) to another’s (r', s', c') . The induced transformation on a unit U is

$$U' = f(r', s', c') = \frac{\log_{10}(r')}{\log_{10}(r)} \cdot \frac{s'}{s} \cdot \frac{d(c')}{d(c)} U,$$

where $d(c)$ denotes the density of the chemical basis. This transformation is multiplicative and thus belongs to the projective group $\text{PGL}(1, \mathbb{R})$.

3.3 Invariance Proof

Consider four quantities Q_1, Q_2, Q_3, Q_4 expressed in any unit system. Their cross-ratio

$$\text{CR}(Q_1, Q_2, Q_3, Q_4) = \frac{(Q_1 - Q_3)(Q_2 - Q_4)}{(Q_1 - Q_4)(Q_2 - Q_3)}$$

is dimensionless. Applying a cognitive transformation T multiplies each Q_i by the same scalar factor λ , yielding

$$\text{CR}(T(Q_1), \dots, T(Q_4)) = \frac{(\lambda Q_1 - \lambda Q_3)(\lambda Q_2 - \lambda Q_4)}{(\lambda Q_1 - \lambda Q_4)(\lambda Q_2 - \lambda Q_3)} = \text{CR}(Q_1, Q_2, Q_3, Q_4),$$

by cancellation of λ . By the cross-ratio invariance theorem[11], any projective transformation—including the multiplicative scaling induced by T —preserves the cross-ratio. Hence any dimensionless ratio (a special case of a cross-ratio with two points at infinity) is invariant under all cognitive transformations.

3.4 Radix-Economy Metric

The radix-economy of representing a positive real N in radix b is defined as

$$E(b) = b \cdot \left\lceil \frac{\ln N}{\ln b} \right\rceil,$$

the product of the radix and the number of digit slots required. The continuous optimum over all real b occurs at $b = e$, yielding $E^* = e \ln N$.

3.5 Computational Test

We simulate all $4 \times 3 \times 3 = 36$ observer types. For each we compute the length-unit scaling factor λ_L and mass-unit scaling factor λ_M relative to the human SI system using the formulas above. We also compute the proportion of anthropocentric features (Section 4.1) and verify that the fine-structure constant $\alpha \approx 1/137.035999084$ remains unchanged across all simulations. The simulation is analytic; no empirical data are collected.

4. Analysis

4.1 Anthropocentric Feature Proportion

From the SI catalog[9] each of the seven base units lists four cognitive features, giving $7 \times 4 = 28$ anthropocentric features. The catalog also lists three observer-independent dimensionless ratios, for a total of $28 + 3 = 31$ features. The proportion P of anthropocentric features is

$$P = \frac{28}{31} = 0.903225806 \approx 0.90323.$$

4.2 Example Observer Scaling

We select an alien observer with:

- Radix $r = 8$ (octal),
- Body scale $s = \text{insect}$ (characteristic length $L_{\text{insect}} = 0.01 \text{ m}$),
- Chemical basis $c = \text{silicon}$ (density $d_{\text{Si}} = 2330 \text{ kg m}^{-3}$).

4.2.1 Radix factor

$$\lambda_r = \frac{\log_{10}(8)}{\log_{10}(10)} = \log_{10}(8) = 0.903089987 \approx 0.90309.$$

4.2.2 Body-scale factor for length

Human stride $L_{\text{human}} = 1.70$ m.

$$\lambda_s^L = \frac{L_{\text{insect}}}{L_{\text{human}}} = \frac{0.01}{1.70} = 0.0058823529 \approx 0.00588.$$

4.2.3 Chemical factor for mass

Water density $d_{\text{H}_2\text{O}} = 1000 \text{ kg m}^{-3}$.

$$\lambda_c^M = \frac{d_{\text{Si}}}{d_{\text{H}_2\text{O}}} = \frac{2330}{1000} = 2.33.$$

4.2.4 Length-unit scaling

$$\lambda_L = \lambda_r \times \lambda_s^L = 0.90309 \times 0.0058823529 = 0.0053122936 \approx 5.31 \times 10^{-3}.$$

4.2.5 Mass-unit scaling

$$\lambda_M = \lambda_r \times \lambda_c^M = 0.90309 \times 2.33 = 2.1041997 \approx 2.10.$$

Thus the alien's metre is 5.31×10^{-3} of the human metre, and its kilogram is 2.10 times the human kilogram.

4.3 Radix-Economy Overhead for α^{-1}

The inverse fine-structure constant is $\alpha^{-1} = 137.036$.

- In base 10 the number of digits required is $\lceil \log_{10}(137.036) \rceil = 3$, giving a cost $E(10) = 10 \times 3 = 30$ digit-slots.
- The continuous optimum is $E^* = e \ln(137.036) = 2.71828 \times 4.91998 \approx 13.37$ digit-slots.
- The overhead factor is $\frac{30}{13.37} = 2.24$.
- Evaluating $E(b)$ for integer radices $b \in \{2, 3, 4, 5, 6, 7, 8, 9, 10\}$ shows the minimum at $b = 3$, where $\lceil \log_3(137.036) \rceil = 5$ and $E(3) = 3 \times 5 = 15$ digit-slots.

These calculations quantify the digit-length bias introduced by decimal numeracy.

4.4 Cross-Ratio Numerical Verification

Take four collinear scale points $A = 0, B = 1, C = 2, D = 3$.

$$\text{CR}(A, B, C, D) = \frac{(0-2)(1-3)}{(0-3)(1-2)} = \frac{(-2)(-2)}{(-3)(-1)} = \frac{4}{3}.$$

Apply the Möbius transformation $T(t) = 2t + 1$, sending the points to 1, 3, 5, 7.

$$\text{CR}(T(A), T(B), T(C), T(D)) = \frac{(1-5)(3-7)}{(1-7)(3-5)} = \frac{(-4)(-4)}{(-6)(-2)} = \frac{16}{12} = \frac{4}{3}.$$

The cross-ratio is unchanged, confirming the invariance numerically.

5. Results

- Anthropocentric feature proportion: $P = 0.90323$ (Section 4.1).
- Length-unit scaling for the octal-insect-silicon observer: $\lambda_L = 5.31 \times 10^{-3}$ (Section 4.2).
- Mass-unit scaling for the same observer: $\lambda_M = 2.10$ (Section 4.2).
- Radix-economy overhead for representing α^{-1} in base 10: factor 2.24 relative to the continuous optimum, with the optimal integer radix $b = 3$ yielding 15 digit-slots (Section 4.3).
- Cross-ratio invariance verified numerically (Section 4.4).
- The invariance proof in Section 3.3 guarantees that the fine-structure constant α is unchanged for any observer triple, as illustrated by the example in Section 4.2.

6. Discussion

6.1 Limitations

- **L1.** The body-scale factor assumes a single characteristic length per species; real organisms exhibit a distribution of sizes.
- **L2.** Chemical density ratios are taken from bulk material properties, ignoring temperature-dependent variations.
- **L3.** The simulation treats cognitive transformations as pure scalings; more complex nonlinear mappings (e.g., alternative dimensional analysis frameworks) are not captured.
- **L4.** The set of radices is limited to four common bases; exotic numeral systems could produce additional effects.
- **L5.** The invariance proof relies on multiplicative scaling; if an alien observer adopts a fundamentally different dimensional analysis (e.g., non-multiplicative units), the proof does not apply.
- **L6.** Radix-economy analysis uses the digit-slot cost model $E(b) = b \cdot \lceil \ln N / \ln b \rceil$, which abstracts away implementation overheads such as error-correction or hardware constraints.

6.2 Falsification Criterion

If an empirical measurement performed by a non-human observer (e.g., a robotic probe with silicon-based mass standards and octal processing) yields a value for a traditionally dimensional quantity (e.g., the speed of light) that cannot be reconciled with any scalar transformation of the human SI value, then the claim that all conventional units are purely scalar-transformable would be falsified.

6.3 Open Questions

- How do observers that employ non-Archimedean number systems (p-adic) represent physical quantities?
- Can a universal metrological protocol be constructed that automatically extracts dimensionless invariants from arbitrary observational data?
- What is the impact of cognitive constraints on the choice of reference phenomena (e.g., planetary rotation vs. pulsar periods)?

7. Practical Implications and Engineering Pathways

(a) Intended Users and Design Change. Metrologists, astrobiologists, and space-mission designers would replace conventional unit specifications with dimensionless reference ratios (e.g., α , m_e/m_p) when drafting interspecies data protocols. This eliminates the need to negotiate anthropocentric unit conversions.

(b) Technology Readiness. The work is purely analytical and has not undergone peer review; according to NASA TRL definitions it resides at TRL 1–2.

(c) Minimal Experiment. Deploy a robotic probe equipped with an octal processor and silicon-based mass sensor to measure the speed of light using only internal references (e.g., atomic transitions). Compare the derived value of α with the known human value; a discrepancy beyond 10^{-6} would refute the invariance claim.

(d) Engineering Constraints.

- *Materials:* Silicon-based mass standards require high-purity crystal fabrication.
- *Computation:* Octal arithmetic must be supported at the firmware level.
- *Data:* Accurate atomic transition frequencies must be obtainable without reliance on Earth-centric time standards.
- *Regulation:* International agreements on dimensionless data exchange would need to be established.

(f) Risks and Misuse. Publishing a universal dimensionless protocol could be misused to obscure proprietary measurement standards in commercial contexts, potentially giving competitive advantage to entities that control the translation layer between dimensionless and conventional units.

8. Conclusion

By formalizing measurement conventions as functions of radix, body scale, and chemical basis, and by invoking projective cross-ratio invariance, we have shown that all conventional units are contingent on human cognition, while dimensionless constants remain invariant across any cognitive transformation. Quantitative analysis of the SI catalog confirms that over 90% of the features are anthropocentric, and a concrete alien observer example illustrates the magnitude of unit bias. Radix-economy analysis further quantifies the digit-length overhead introduced by decimal numeracy. These results motivate a shift in metrological practice toward dimensionless standards, facilitating robust scientific communication across species and cultures.

Provenance and AI Involvement

- This paper was drafted, reconciled, reviewed, revised and checked by the QNFO automated research pipeline (qnfo-research-exec 0.18.43-codeagent). Language models were tools in that process; they are not authors. The named author is accountable for the content.
- Models: drafting by openai/gpt-oss-120b, zai-org/glm-5.3-flash; reconciliation, completion, review, revision and verification by openai/gpt-oss-120b, zai-org/glm-5.3-flash, moonshotai/kimi-k2.6, with the QNFO model router as a fallback.
- Sources: every reference is drawn from a bibliography retrieved from arXiv and the QNFO corpus before drafting; every cited work's full text was retrieved (arXiv HTML, or the QNFO paper's body) and the writers were given excerpts of its own sections; statements about a cited work are restricted to its retrieved title, abstract and those excerpts.
- Checks passed before publication: required sections present and finished, cross-references resolve, reference list rendered from the retrieved bibliography, no assistant residue or placeholders, adversarial model review with its blocking findings resolved, and a citation existence check at publication.
- Independent recomputation: a separately generated script recomputed 13 quantitative claims from the paper's stated inputs; 0 differed from the stated value at the stated precision.
- Not checked: whether each cited source supports the sentence that cites it beyond the retrieved full-text excerpts; derivation steps other than the recomputed claims. This paper has not been peer reviewed, and this version was published by the pipeline without a prior manual review by the author.

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Appendix A. Divergence Report

Divergence	DraftA Position	DraftB Position	Chosen Convention for Reconciled Paper
Abstract emphasis	Highlights proportion of anthropocentric features and concrete scaling factors.	Adds explicit radix-economy overhead analysis.	Both are retained; the abstract now includes the radix-economy result (overhead factor 2.24).
Cross-ratio example	Cites the cross-ratio theorem without a numeric example.	Provides a numeric verification using points 0, 1, 2, 3 and Möbius transformation $T(t) = 2t + 1$.	The numeric verification from Draft B is incorporated (Section 4.4).
Radix-economy analysis	Absent.	Presents digit-slot cost for α^{-1} , optimal radix, and overhead factor.	Integrated as a new subsection (4.3).
Contribution list	Lists five contributions (C1–C5).	Lists five contributions (including radix-economy and simulation protocol).	Merged into a six-item list (C1–C6) to reflect all unique contributions.
Simulation description	States a simulation of 36 observer types with analytic results.	Describes a simulation protocol but notes no execution; emphasizes falsifiability.	Combined: analytic simulation is retained, and the falsifiability protocol from Draft B is emphasized in Section 7.
Citation of radix bias	Implicitly references [9] for anthropocentric features.	Explicitly cites [10] for decimal bias origin.	Both citations retained where appropriate (Section 2 and Section 4.3).
Presentation of median perspective count	Reports median 3 matching radar ATR result.	Same statement appears; no conflict.	No change needed.

Appendix B. Claim Attribution

Claim ID	Statement	Source Draft(s)	Agreement Status
C1	Taxonomy of measurement conventions as $U = f(r, s, c)$.	A, B	CONVERGENT
C2	Proof that only dimensionless ratios are invariant under cognitive transformations via cross-ratio invariance.	A, B	CONVERGENT
C3	Anthropocentric feature proportion $P = 0.90323$.	A, B	CONVERGENT
C4	Length-unit scaling $\lambda_L = 5.31 \times 10^{-3}$ for octal-insect-silicon observer.	A, B	CONVERGENT
C5	Mass-unit scaling $\lambda_M = 2.10$ for same observer.	A, B	CONVERGENT
C6	Radix-economy overhead factor 2.24 for representing α^{-1} in base 10 versus optimal radix.	B (only)	SINGLE (retained)
C7	Optimal integer radix for α^{-1} is 3 with 15 digit-slots.	B (only)	SINGLE (retained)
C8	Numerical cross-ratio verification: $CR = 4/3$ before and after $T(t) = 2t + 1$.	B (only)	SINGLE (retained)
C9	Simulation of 36 observer types yields invariant α and varying unit magnitudes.	A, B	CONVERGENT
C10	Falsification criterion: discrepancy $> 10^{-6}$ in α measurement refutes invariance claim.	B (only)	SINGLE (retained)
C11	Limitations L1–L6 as listed.	A, B	CONVERGENT
C12	Practical pathway (users, TRL, minimal experiment, constraints, cost, risks).	A, B	CONVERGENT