Substrate-Agnostic Black-Box Equivalence and Conformance

[0135] In certain embodiments, the computational identity of a DecaQuasar implementation is defined primarily by its computational pathway rather than by any single underlying hardware substrate.

[0136] More particularly, a DecaQuasar implementation may be characterized by a defined sequence comprising:

(a) input encoding;

(b) state construction within a DecaQuasar cell or multi-cell structure;

(c) one or more state-transition operations;

(d) one or more coupling or dependency operations; and

(e) one or more readout or decoding operations.

[0137] In such embodiments, two or more distinct hardware realizations may constitute equivalent embodiments of the same DecaQuasar computational architecture when they preserve the same or substantially the same computational pathway, even if the underlying physical carriers, materials, devices, timing characteristics, energy profiles, noise signatures, or implementation details differ.

[0138] Thus, a digital binary-site realization, an FPGA realization, an ASIC realization, a photonic realization, a quantum-dot realization, a plasmonic realization, a spintronic realization, or a hybrid realization may each constitute a valid embodiment of the same DecaQuasar architecture, provided that each realization conforms to a common operational specification.

[0139] In some embodiments, conformance is determined by a black-box test in which an implementation is evaluated according to one or more of:

(a) admissible input classes;

(b) state-transition semantics;

(c) coupling semantics;

(d) output mapping;

(e) bounded error tolerances;

(f) probabilistic output agreement;

(g) trajectory agreement;

(h) observable agreement; and

(i) reproducibility under repeated execution.

[0140] In certain embodiments, the hardware substrate is therefore not essential to the architectural identity of the invention, provided that the substrate realizes the defined DecaQuasar state model, transition rules, coupling behavior, and readout mapping.

[0141] In some embodiments, equivalence between heterogeneous substrates is exact.

[0142] In some embodiments, equivalence between heterogeneous substrates is approximate and is defined within one or more tolerances, confidence bounds, probabilistic thresholds, or acceptance regions.

[0143] In some embodiments, equivalence is evaluated on the basis of final outputs only.

[0144] In some embodiments, equivalence is evaluated on the basis of intermediate trajectories, internal state projections, transition histories, local observables, coupling observables, or combinations thereof.

[0145] Accordingly, the invention includes not only a specific physical device, but also a substrate-agnostic computational architecture whose identity is preserved across heterogeneous implementations satisfying a common black-box conformance specification.

Exemplary Formalism for Black-Box Equivalence

[0146] In one exemplary formulation, let a hardware embodiment H of a DecaQuasar system define a computational pathway:

$$\Pi_H(x) = R_H \circ C_H \circ \Phi_H^{(T)} \circ E_H(x)$$

where:

- E_H denotes an input encoding operation for hardware embodiment H;
- $\Phi_H^{(T)}$ denotes a sequence of one or more state-transition operations over T steps;
- C_H denotes one or more coupling, dependency, or correlation operations; and
- R_H denotes a readout and decoding operation.

[0147] In this formulation, the computational identity of the embodiment is given by the pathway Π_H, rather than by the specific material substrate used to instantiate that pathway.

[0148] In one embodiment, two hardware realizations H_A and H_B are considered computationally equivalent when, for all inputs x in an admissible input domain X, they satisfy:

$$d(\Pi_{H_A}(x), \Pi_{H_B}(x)) \leq \varepsilon,$$

where $d(\cdot, \cdot)$ is a comparison metric and ε is an allowed tolerance.

[0149] In some embodiments, the comparison metric d is an output-distance metric.

[0150] In some embodiments, the comparison metric d is a distributional distance, a trajectory distance, an observable mismatch function, a state-projection distance, or a weighted aggregate thereof.

[0151] In a more detailed exemplary embodiment, equivalence may be assessed over encoded states, transition trajectories, coupling observables, and readout outputs according to:

$$\begin{aligned} D(H_A, H_B; x) = \lambda_1 \left\| E_{H_A}(x) - E_{H_B}(x) \right\| \\ + \lambda_2 \sum_{t=1}^{T} \left\| Q_{H_A}^{(t)}(x) - Q_{H_B}^{(t)}(x) \right\| \\ + \lambda_3 \sum_{t=1}^{T} \left\| \Gamma_{H_A}^{(t)}(x) - \Gamma_{H_B}^{(t)}(x) \right\| \\ + \lambda_4 \left\| R_{H_A}(x) - R_{H_B}(x) \right\|. \end{aligned}$$

where:

- $Q_H^{(t)}(x)$ denotes the DecaQuasar state at transition step t;
- $\Gamma_H^{(t)}(x)$ denotes a coupling, dependency, correlation, or entanglement-related observable at step t;
- $R_H(x)$ denotes the readout result; and
- $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ are weighting coefficients.

[0152] In such embodiments, H_A and H_B may be deemed conformant realizations of the same DecaQuasar architecture when:

$$\sup_{x \in X} D(H_A, H_B; x) \leq \tau,$$

for a predetermined conformance threshold τ.

[0153] In some embodiments, the above formulation is used for exact conformance.

[0154] In some embodiments, the above formulation is used for approximate conformance.

[0155] In some embodiments, the above formulation is used to certify that a digital realization and a physical realization are behaviorally equivalent embodiments of the same DecaQuasar architecture.

[0156] In some embodiments, the above formulation is used to certify that a first physical substrate and a second physical substrate implement the same defined computational pathway despite differing materials or carrier mechanisms.

Optional Closing Paragraph

[0157] Accordingly, in certain embodiments, the invention encompasses a substrate-independent DecaQuasar computational architecture in which the operative identity of the system is defined by a common input-state-transition-coupling-readout pathway, and in which multiple heterogeneous substrates may be recognized as equivalent implementations when they satisfy a common black-box conformance criterion.

Optional Additional Claim Set

31. The system of claim 1, wherein the computational identity of the system is defined by a prescribed input encoding, state-transition pathway, coupling behavior, and readout mapping, independent of a particular hardware substrate.

32. The system of claim 31, wherein two or more distinct hardware substrates are deemed equivalent embodiments when they satisfy a common black-box conformance specification for the prescribed input encoding, state-transition pathway, coupling behavior, and readout mapping.

33. The system of claim 32, wherein the black-box conformance specification includes at least one of output equivalence, trajectory equivalence, observable equivalence, bounded probabilistic agreement, or bounded tolerance agreement.

34. The hybrid computational system of claim 30, wherein the translation layer is configured to verify behavioral equivalence between a digital realization and a physical realization of a DecaQuasar computational process.