Novelty-Generating Materials as a Substrate for Open-Ended Computation

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Abstract

1. Bio-intelligence is Fundamentally Different from Current AI:

- Bio-Intelligence: Continuous learning, evolving complexity, open-ended novelty, emergent hierarchical structures.
- Current AI: Fixed datasets (i.i.d assumptions), static learning paradigms, limited adaptability, predefined tasks.

2. Bio-intelligence within an Evolving Framework:

- Relies inherently on novelty generation and emergent higher-order patterns.
- Continuously creates new organizational levels, enhancing adaptive complexity.

3. Open-Ended Computations:

Do not fit current ML frameworks which rely heavily on i.i.d. assumptions.
Require new theoretical foundations:
- New mathematics embracing novelty and complexity.
- Nonlinear dynamics and recursive, open-ended procedural formulations.

Example problems include:
- Emergent Pattern Autopoiesis (EPA): Autonomous emergence of novel, increasingly complex oscillatory patterns.
- Adaptive Signal Classification Cascade (ASCC): Continual, hierarchical adaptive signal classification.
- Hierarchical Memory Scaffold (HMS): Spontaneous formation and extension of hierarchical memory structures.

4. Multiple Paths to Multiple Life (Hierarchy of Complexity Levels):

- Fundamental physical/chemical level.
- Cellular and biological evolution.
- Cognitive and ecological systems.
- Social and technological collective intelligence.

Each level displays distinct "edge-of-chaos" dynamics, enabling continual novelty and adaptive emergence.

5. Experimental Observables for Novelty-Generating Materials:

To evaluate materials for their capacity to support open-ended computations, the following observables should be assessed:

- Nonlinear threshold responses and excitability analogous to neuron spiking.
- Transient and metastable states indicating potential for dynamic memory and pattern formation.
- Power-law distributed event sizes (e.g., avalanches in switching behavior).
- Phase transitions and hysteresis loops marking multistability and complex state-space structure.
- Spontaneous emergence of coherent spatiotemporal patterns under simple driving forces.
- Mutual information and transfer entropy between components over time as indicators of nontrivial structure.
- Complexity growth metrics such as statistical complexity or compressibility trends.

6. Candidate Novel Materials for Open-Ended Computation:

- Resistive switching and memristive devices: Rich nonlinear dynamics, capable of long-term and volatile memory, ideal for synaptic and neuronal functions [1, 2].
- Spintronic (skyrmion-based) systems: Topologically stable yet dynamically evolving, allowing intrinsic complexity generation [3, 4]
- Metal-Insulator Transition (MIT) devices (e.g., VO_2) and volatile memristors: Intrinsic threshold, excitability, and neuron-like dynamic behavior essential for hierarchical emergent behaviors [5, 6].

7. Challenges Towards Realizing Open-Ended Computations:

- Mathematical Foundations: Development of new recursive procedural sets, constructive intuitionistic mathematics, and formalisms supporting intrinsic novelty.
- Material Design: Engineering novel materials with required dynamical complexity and scalability.
- Algorithmic Innovation: Creating new algorithms capable of evolving indefinitely and embracing non-i.i.d, adaptive scenarios.
- Computing Architectures: Designing hardware architectures specifically optimized for continual novelty generation, self-organization, and adaptive, hierarchical complexity growth.

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