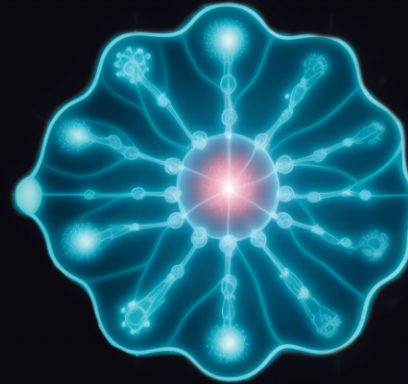


Giersch - School & International Conference

CONDENSED COMPLEXITY

The Essence of Information
Processing and Cognition?

November 6th to 10th, 2023



funded by

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FIAS Frankfurt Institute
for Advanced Studies



Information processing (+) across many realms & scales

- Quantum computing
- Intracellular signaling / Gene regulation
- Tissue patterning / Dev Bio
- Sensory systems
- Brain dynamics
- Evolution of cognition
- Human communication
- Machine learning
- Astronomy / „Galactic inference“
- High energy physics

Some take-home thoughts

- A single framework = **information theory** can be applied to a wide range of systems:
 - Gene regulatory networks
 - Neural networks (natural + artificial)
 - Human communication
 - Signals of the stars
- „Simple“ small interacting systems can implement efficient information processing with the right set of **specific interactions** (e.g., fine-tuning gene regulation)
- „Simple“ and **unspecific** interaction rules can do as well (if not better) in sufficiently **large** systems (e.g., neural networks)
- Both can be surprisingly hard to understand **mechanistically**
- Information is **more than flipping bits**
- Natural **non-digital** representations / encodings
 - Quantum computers
 - Oscillating neurons

Some take-home thoughts

- Information is meaningless (or „just“ entropy) if its **purpose / utility** is unknown
 - „To be alive means to generate one's own meaning.“
 - This requires realizing relevance
 - Can this be formalized?
 - Attention = focused information → relevance
- Information processing for certain purpose can „**evolve**“ / get passed on
 - Information bottleneck / evolved compression
 - Simplicity bias
- Intended utility might be a harsher constraint than **energy cost**
- Particular system designs arise when intended utility meets **physical constraints**
- **Sensitivity** (mK) vs. **responsiveness**

Some take-home thoughts

- **Adaptation = successful** information processing
 - Sensory adaptation
 - Ghost states
 - Antithetic integral feedback
- Adaptation vs. **memory / storage**:
 - long-lived transients
 - system-wide correlations
- **Criticality** for creating long time and spatial scales
- **Stochasticity** does not need to be a detriment
 - Stochastic trajectories can carry lots of information
 - Some control schemes require stochasticity
- „**What I cannot create, I do not understand**“
 - Experimental predictions from information-theoretic analyses
 - Synthetic biology „vs“ Digital twins
- Information can be outstandingly persistent ($t \sim$ age of universe)

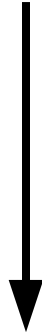
Trade-off

Energy

OPTIMIZATION



PHYSICAL CONSTRAINTS

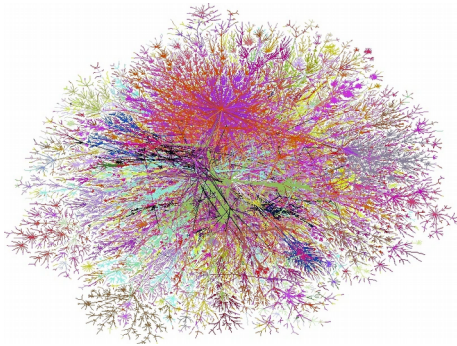


ADAPTING
SYSTEMS



Complexity

Purpose focus



Information vs „mere entropy“

„Information can emerge and be processed by adapting dynamical complex systems to relevant purposes within physical constraints.“

What does AI say?

- Put the sequence of **talk** abstracts → ChatGPT?
- Based on this text, summarize „the essence of information processing and cognition“.

...

„The essence of information processing and cognition, as discussed in the conference, lies in the intricate and dynamic nature of systems across various disciplines. From cellular memory generation to the efficiency of neural circuits and the integration of quantum computing, the talks underscored the need for new theories and computational principles.

Relevance realization was highlighted as a fundamental aspect in cognition, emphasizing that the ability to derive meaning and solve problems goes beyond logical rules and requires a process of realizing relevance.

Overall, the discussions unveiled the complex interplay of information processing mechanisms, adaptive inference processes, and the quest for efficient learning systems in the face of resource constraints.“

What does AI say?

- Based on this text, define the term "condensed complexity".

...

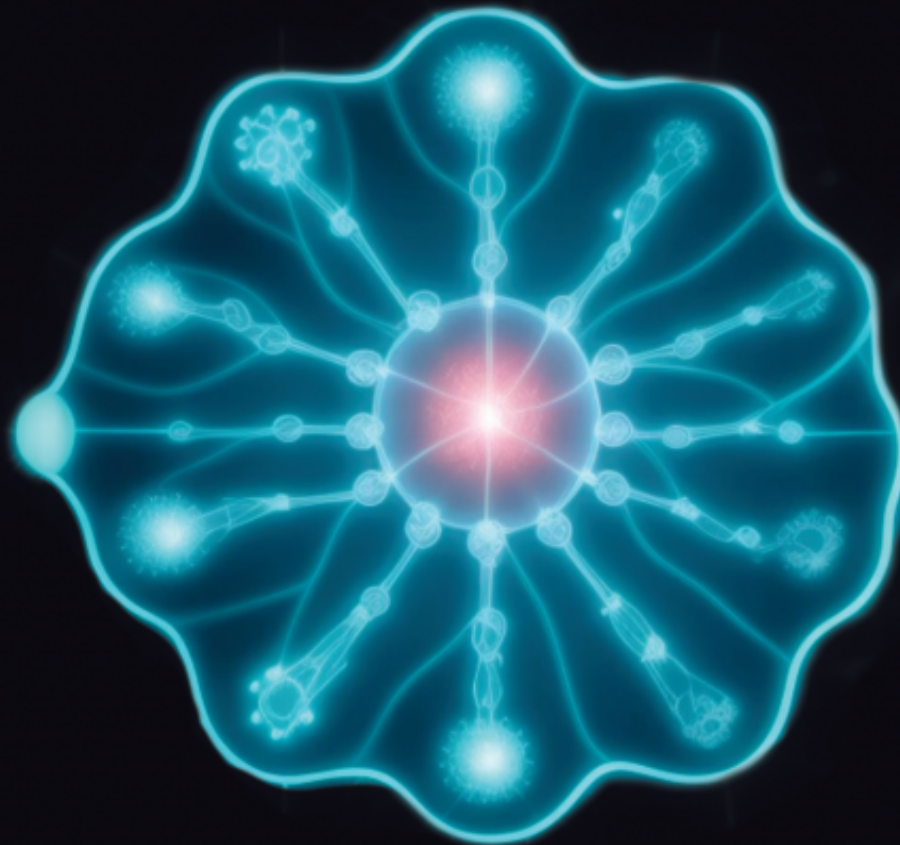
„The term "condensed complexity" isn't explicitly mentioned in the text, but it could potentially be inferred from discussions about information processing in living systems.

In the context of the talks, it might refer to the idea that despite the complexity inherent in biological processes, there are fundamental principles and mechanisms that condense this complexity into organized and efficient systems. This could include the emergence of patterns in embryonic development, the efficient adaptation of neural circuits under resource constraints, and the realization of relevance in cognition.

In essence, it could signify the ability of living systems to manage and streamline complexity to achieve purposeful and adaptive behaviors.“

Future perspectives: Much to do!

- Information theory and AI are both „**technocratic**“: no notion of purpose or relevance
- Nature contains notions of purpose and relevance, and AI needs to be applied to nature purposefully
- Need for better measures and models for describing natural information processing in particular
- Better understanding of temporal dynamics of information emergence and processing



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