Contextual Emergence of Mental States from Neurodynamics

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1 Interlevel Relations

2 Statistical Mechanics and Thermodynamics

3 Neurodynamics and Mental States

4 Stable Partitions and Symbolic Dynamics

5 First Tests and Perspectives
social systems – collective behavior
embodied systems – behavior
mental systems – consciousness
neural systems – action potential
non-equilibrium systems – order parameters
thermal systems – thermodynamic variables
many-particle systems – moments of distributions
quantum systems – canonical observables
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<table>
<thead>
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<th>$\mathcal{L}$ contains necessary conditions for $\mathcal{H}$</th>
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</thead>
<tbody>
<tr>
<td>strong reduction</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>supervenience</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>contextual emergence</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>radical emergence</td>
<td>no</td>
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</tr>
</tbody>
</table>

Bishop and Atmanspacher 2006
Supervenience: \( \mathcal{L} \) sufficient but not necessary for \( \mathcal{H} \)

A thermodynamic system (\( \mathcal{H} \)) can be multiply realized by a many-particle system (\( \mathcal{L} \)) as long as the statistical distribution of particular particle properties in \( \mathcal{L} \) satisfies particular conditions.

\( \mathcal{L} \): many configurations of particles with \( q_i, p_i \), associated with \( \langle E_{kin} \rangle \)

\( \mathcal{H} \): temperature \( T \) can be related to \( \mathcal{L} \) by \( T \propto \langle E_{kin} \rangle \)

\[ \uparrow \]

why correlation for individual realizations?
Contextual emergence: $\mathcal{L}$ necessary but not sufficient for $\mathcal{H}$

$\mathcal{L}$: canonical observables, equations of motion, statistical distributions

$\mathcal{H}$: temperature $T$

can be related to $\mathcal{L}$

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$T \propto <E_{\text{kin}}>$

- select contexts in $\mathcal{H}$: therm. limit, therm. equilibrium
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- implement them due to stability criteria in $\mathcal{L}$: KMS states

Statistical Mechanics and Thermodynamics

Neurodynamics and Mental States

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First Tests and Perspectives

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- select contexts in $\mathcal{H}$: th. limit, th. equilibrium
- implement them due to stability criteria in $\mathcal{L}$: KMS states
- identify proper coarse graining (topology change) in $\mathcal{L}$
- assign equivalence classes of $\mathcal{L}$-states to single $\mathcal{H}$-states with same temperature

Haag et al. 1974, Takesaki 1970
Supervenience: $\mathcal{L}$ sufficient but not necessary for $\mathcal{H}$

A neural correlate of consciousness can be multiply realized by minimally sufficient neural subsystems ($\mathcal{L}$) correlated with states of consciousness ($\mathcal{H}$).

$\mathcal{L}$: many configurations of neurons with particular properties $\implies$ $\mathcal{H}$: one mental state (state of consciousness)

↑

why correlation for individual realizations?

Chalmers 2000
Contextual emergence: $\mathcal{L}$ necessary but not sufficient for $\mathcal{H}$

$\mathcal{L}$: action potentials, firing rates, correlations in neuronal ensembles

$\mathcal{H}$: one mental state (state of consciousness)
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- select contexts in $H$: “phenomenal families”
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**neurodynamics–mental states**

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Atmanspacher & beim Graben 2006
Trajectories of a system in its phase space $X (\mathcal{L})$ are mapped onto strings of a finite set of symbols ($\mathcal{H}$) by partitioning $X$ into disjoint cells $A_i$. $X$ is thereby mapped onto a set of symbol sequences $s$. If these sequences can be generated by a finite transition graph, the symbolic dynamics in $\mathcal{H}$ is a Markov shift.

Stable partitions can be constructed for cyclic or irreducible shifts.
cyclic shift
multiple fixed points
basins of attraction

irreducible shift
chaotic attractor
generating partition
Generating Partitions (Markov Partitions)
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- Well-defined mental states require coarse grainings in $X$ that are stable under the dynamics in $X$. Such partitions are:
  (i) basins of attraction for multiple fixed points,
  (ii) generating partitions for chaotic attractors.
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Fell 2004
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  (i) basins of attraction for multiple fixed points,
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- Generating partitions provide a rigorous theoretical constraint for well-defined mental states, independent of their empirical plausibility. Fell 2004
- Only generating partitions entail mutually compatible mental descriptions that are topologically equivalent with the underlying neurodynamics. beim Graben & Atmanspacher 2006
Numerical Tests

Collaboration with Carsten Allefeld & Jiri Wackermann, EAP/IGPP
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- use first eigenvectors for identification of partition
Interlevel Relations
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Tests with Empirical Data
Perspectives

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- relevant eigenvectors: proper phase space partition
- partitioned data to be compared with original data
Contextual Emergence of Mental States from Neurodynamics

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Contextual Emergence of Mental States from Neurodynamics
Can mental or behavioral states be derived from a proper partition provided by a suitable empirically registered neurodynamics?
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Potential examples for future work:

• “microstates” as proposed from topographical EEG analyses (Lehmann, Wackermann)
• behavioral states of spontaneously behaving animals from multielectrode signals (Eschenko, Logothetis)
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*First Tests and Perspectives*

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**Contextual Emergence of Mental States from Neurodynamics**
Generating partitions $\mathcal{P}$, which are stable under the dynamics in $X$, imply descriptions that are *topologically equivalent* with descriptions based on $X$. (Then the intertwiner $\pi : X \rightarrow s$ is invertible, $\pi \circ \Phi = \sigma \circ \pi$.)

\[
\begin{array}{c}
X \xrightarrow{\Phi} \Phi(X) \\
\downarrow \pi \quad \quad \quad \downarrow \pi \\
\downarrow \downarrow \\
S \xrightarrow{\sigma} \sigma(S)
\end{array}
\]
Generating partitions $\mathcal{P}$, which are stable under the dynamics in $X$, imply descriptions that are \textit{topologically equivalent} with descriptions based on $X$. (Then the intertwiner $\pi : X \rightarrow s$ is invertible, $\pi \circ \Phi = \sigma \circ \pi$.)

If partitions $\mathcal{P}, \mathcal{P}'$ are not generating, observables based on $\mathcal{P}$ and $\mathcal{P}'$ are \textit{incompatible} (or even \textit{complementary}). Observables are incompatible (complementary) if they do not have all (have no) eigenstates in common.
Entropy of a partition $\mathcal{P} = (A_1, A_2, ..., A_m)$ over phase space $X$:

$$H(\mathcal{P}) = - \sum_{i=1}^{m} \mu(A_i) \log \mu(A_i)$$

Dynamical entropy of an automorphism $T : X \rightarrow X$ with respect to $\mathcal{P}$:

$$H(T, \mathcal{P}) = \lim_{n \to \infty} \frac{1}{n} H(\mathcal{P} \vee T\mathcal{P} \vee ... \vee T^{n-1}\mathcal{P})$$

The Kolmogorov-Sinai entropy of $T$ is $H(T, \mathcal{P}_g)$, iff $\mathcal{P}_g$ is generating. Otherwise, $H(T, \mathcal{P}) < H(T, \mathcal{P}_g)$, hence $H(T, \mathcal{P}_g) = \sup_\mathcal{P} H(T, \mathcal{P})$.

- $\mathcal{P}_g$ minimizes correlations among partition cells $A_i$, so that they are stable under $T$ and only correlations due to $T$ itself contribute to $H(T, \mathcal{P}_g)$. (Spurious correlations due to blurring cells are excluded).
- $\mathcal{P}_g$ allows the definition of symbolic states whose pre-images for $n \to -\infty$ are dispersion-free. (In simple cases: boundaries of $A_i$ are mapped onto one another.)
A **phenomenal family** is a set of mutually exclusive phenomenal states (with phenomenal properties) that jointly partition (some subset of) the space of mental states.

Chalmers 2000
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- **color consciousness**: red / yellow / green / blue / etc.