Macro vs. Micro

Consciousness as a maximum of integrated information across spatio-temporal scales

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September 18, 2016
At what spatiotemporal grain should we study the brain if our goal is to understand conscious experience?
The neural substrate of consciousness?

Spinal cord: <1 billion neurons

Brainstem: <1 billion neurons

Cerebellum: 70 billion neurons

Basal Ganglia: 0.4 billion neurons

NCC candidate: Posterior cortical hot zone

Cerebral Cortex: 16 billion neurons
100 trillion synapses

No!
According to Integrated Information Theory (IIT)

The physical substrate of consciousness is a global maximum of integrated information ($\Phi^{\text{max}}$) over sets of elements/space/time.

The spatial and temporal scales of consciousness?
The Micro Assumption

The micro does all the causal work.

Blue Brain Project & Human Brain Project

Coarse-grains:
• practical impossibility
• insufficient sampling
• convenience

Is the assumption warranted? ➔ Properly define cause-effect power and check!
Integrated information $\Phi$ (3.0) as a measure of cause-effect power

Proof-of-concept that $\Phi$ can peak at a macro level in small networks of logic-gates


From Micro to Macro

A macro element that is constituted of more than one micro element, and/or more than one micro time step

• Coarse-grain: Average of micro elements or micro time steps

\[
\begin{align*}
A & \quad B \\
C & \quad D
\end{align*}
\]

\[
\begin{align*}
\alpha & \quad \beta
\end{align*}
\]

• Black box: Input-output relation of a set of micro element

\[
\begin{align*}
A & \quad E & \quad F \\
B & \quad C & \quad D
\end{align*}
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\begin{align*}
\alpha & \quad \beta
\end{align*}
\]
Macro Elements

A macro element consists of a several of micro elements (spatial) over several micro time steps (temporal).

It has the following properties:

• At least one input and output (element)

• In a specific state (information)

• Internal elements are hidden (black-box)
  • Internal elements are unidentifiable (coarse-grain)

• Internal elements contribute to output (integration)

• No overlap between black box elements (exclusion)
Macro elements: Black boxes of micro elements

Output

Inputs

NOR

I₁

I₃

NOR

NOR
Macro elements: Black boxes of micro elements

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Black Box

Inputs

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Macro elements: Black boxes of micro elements

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Perturbational Causal Analysis
Macro elements: Black boxes of micro elements

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Perturbational Causal Analysis

Inputs

Output

Black Box

AND Logic
Macro elements: Black boxes of micro elements

Proof-of-concept that $\Phi$ can peak at a macro level in small networks of logic-gates

Macro elements: Black boxes of micro elements

Proof-of-concept that $\Phi$ can peak at a macro level in small networks of logic-gates

$\Phi = 0.453$

- 55 micro elements
- 55 first order concepts
- 0 high order concepts

$\Phi = 0.080$

- 20 macro elements
- 20 first order concepts
- 0 high order concepts

$\Phi = 2.33$

- 5 macro elements
- 5 first order concepts
- 25 high order concepts

Increasing spatiotemporal grain size
How can the Macro beat the Micro?

• Composition + Integration
  • More common inputs
  • More common outputs
  → More high-order concepts
  → More integrated system
How can the Macro beat the Micro?

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  - Increase determinism
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How can the Macro beat the Micro?

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→ More integrated information $\Phi$
Micro ($\Phi = 0.453$)

Meso ($\Phi = 0.080$)

Macro ($\Phi = 2.333$)

Average Spatial Grain Size

1 1.57 2.75 3.66 11
Extrinsic Entities

Organizational levels with emerging causal structures

- 55 micro elements
- 55 first order concepts
- 0 high order concepts

Micro (Φ = 0.453)

Meso (Φ = 0)

Macro (Φ = 2.333)

- 5 macro elements
- 5 first order concepts
- 25 high order concepts

Average Spatial Grain Size

1 1.57 2.75 3.66 11
Intrinsic Entities

Micro ($\Phi = 0.453$)  Meso ($\Phi = 0.080$)  Macro ($\Phi = 2.333$)

Average Spatial Grain Size
Testable Prediction

• The physical substrate of consciousness is a set of elements that is a maximum of cause-effect power, over space, time and state of elements.
Testable Prediction

Identify the spatio-temporal scale at which the elements of the system make the greatest difference for itself.

Optogenetic perturbation and unit recording

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http://integratedinformationtheory.org

Python software available at Github → WMayner
→ pyphi
https://github.com/wmayner/pyphi

Or email to:
Albantakis@wisc.edu