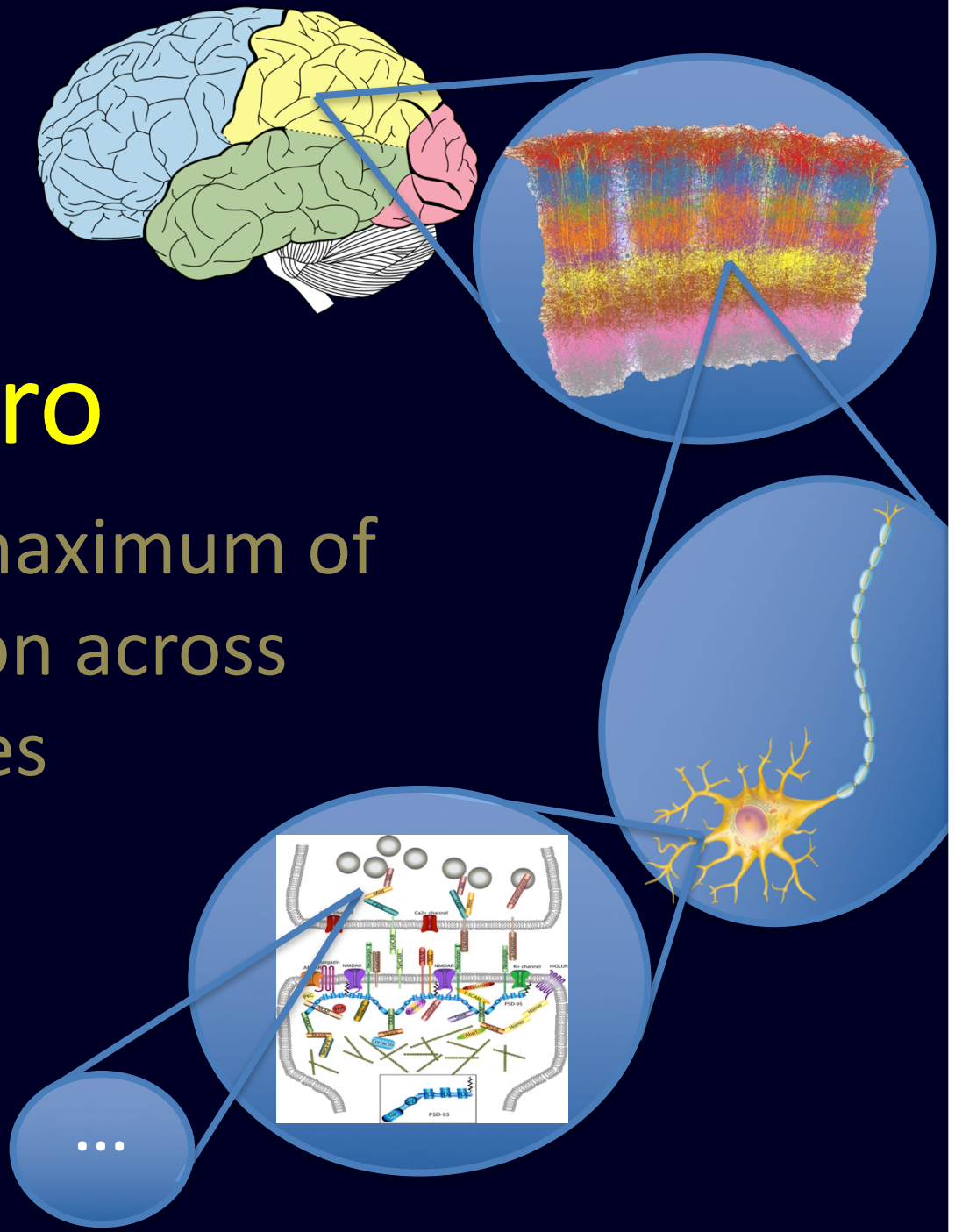


Macro vs. Micro

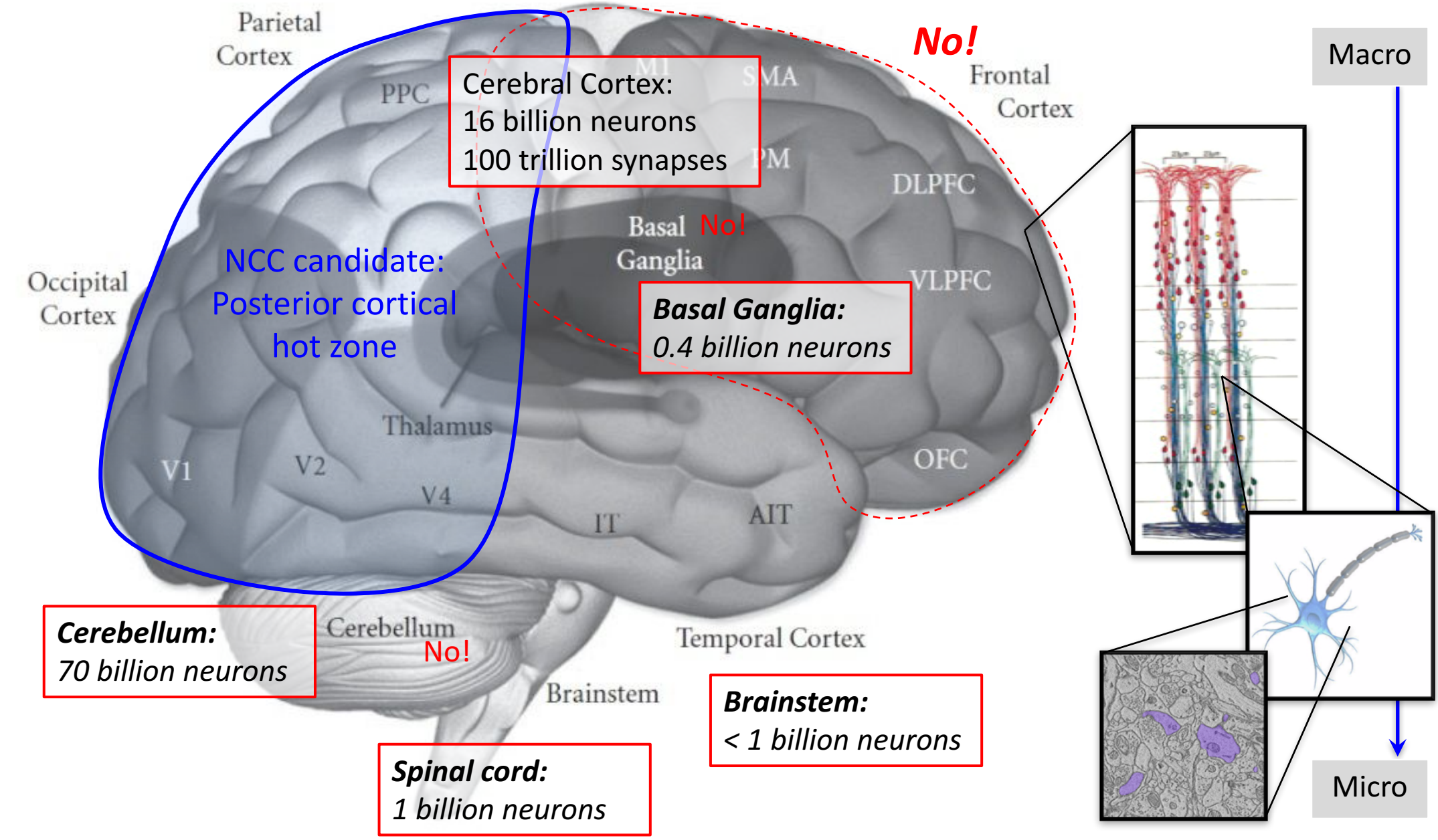
Consciousness as a maximum of integrated information across spatio-temporal scales

Larissa Albantakis
September 18, 2016

Question

At what spatiotemporal grain should we study the brain if our goal is to understand conscious experience?

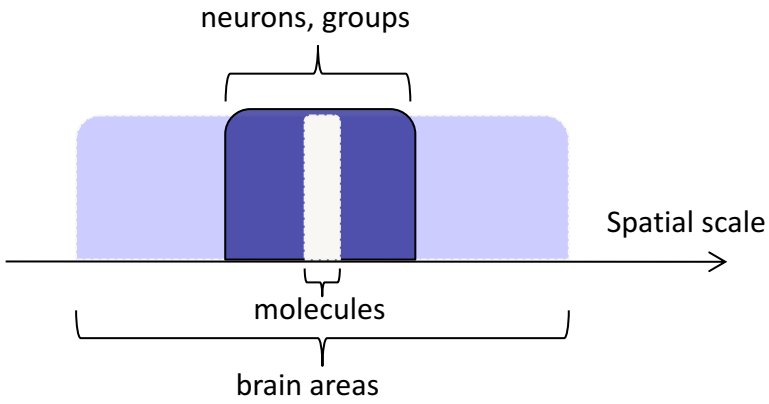
The neural substrate of consciousness?

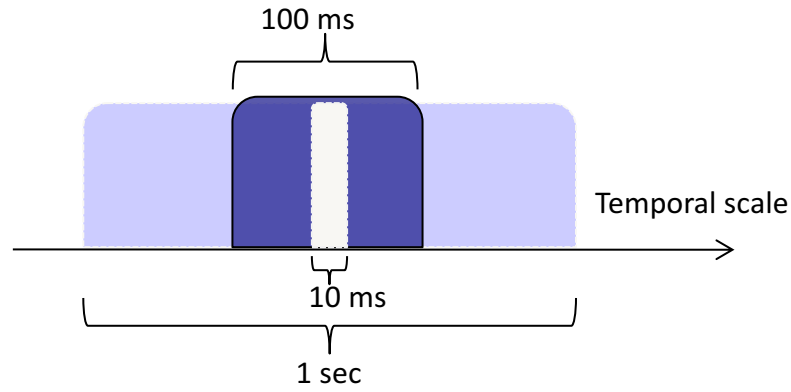


According to Integrated Information Theory (IIT)

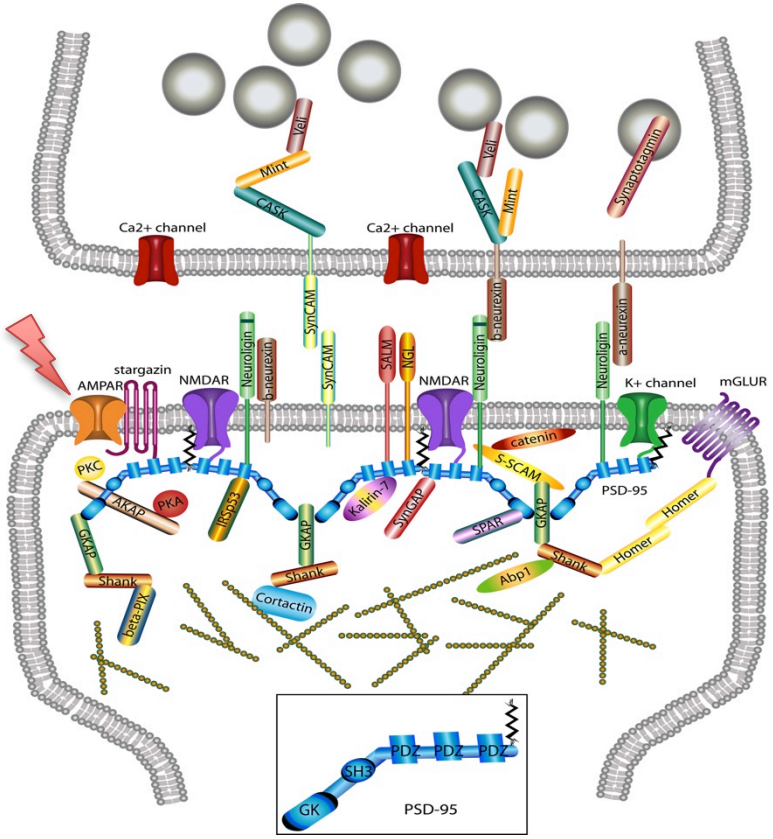
The physical substrate of consciousness is a global maximum of integrated information (Φ^{max}) over sets of elements/space/time

The spatial and temporal scales of consciousness?





The Micro Assumption

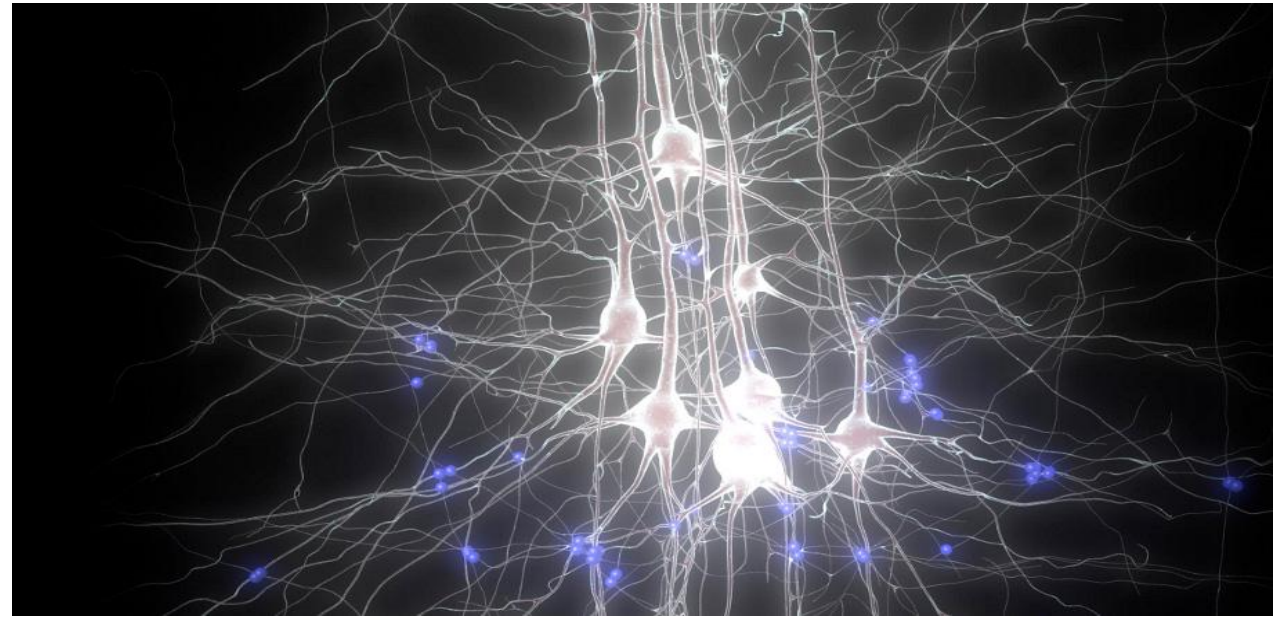


Coarse-grains:

- *practical impossibility*
- *insufficient sampling*
- *convenience*

The micro does all the causal work.

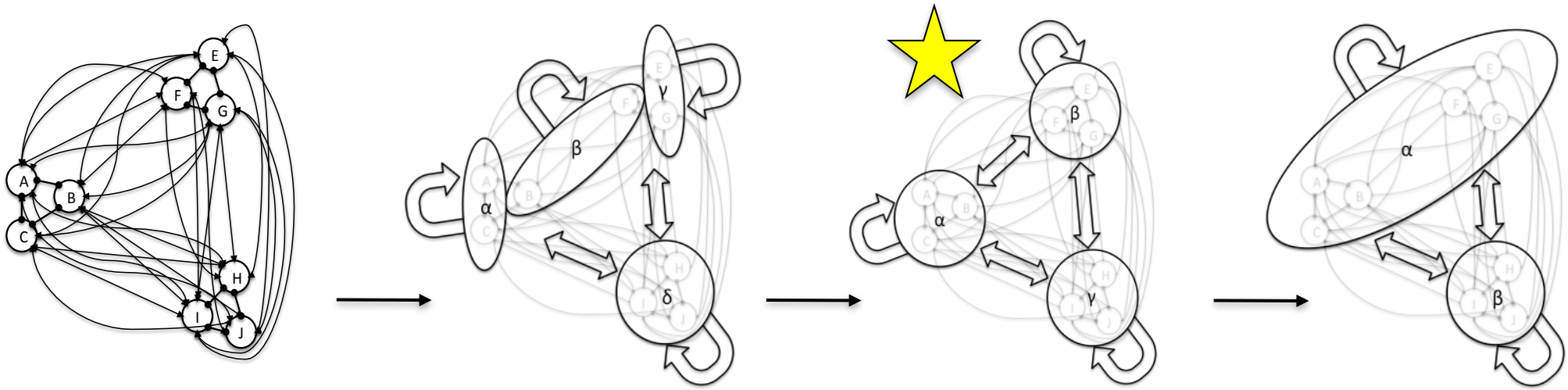
Blue Brain Project & Human Brain Project



Is the assumption warranted? → Properly define cause-effect power and check!

Integrated information Φ (3.0) as a measure of cause-effect power

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



Hoel EP, Albantakis L, Tononi G (2013) Quantifying causal emergence shows that macro can beat micro. PNAS 110: 19790–19795.

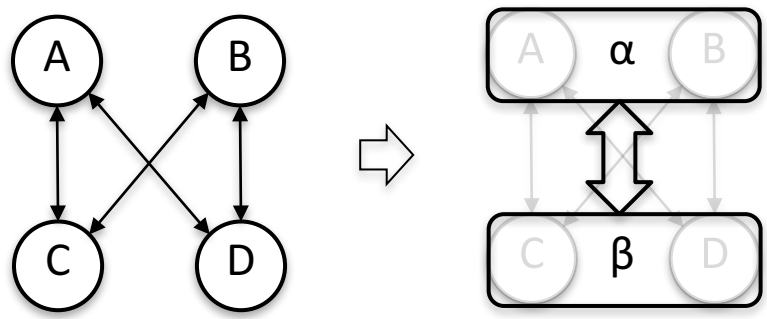
Marshall W, Albantakis L, Tononi G (2016) Black boxing and cause-effect power. ArXiv:1608.03461.

Hoel EP, Albantakis L, Marshall W, Tononi G (2016) Can the macro beat the micro? Integrated information across spatiotemporal scales. Neurosci Conscious 2016.

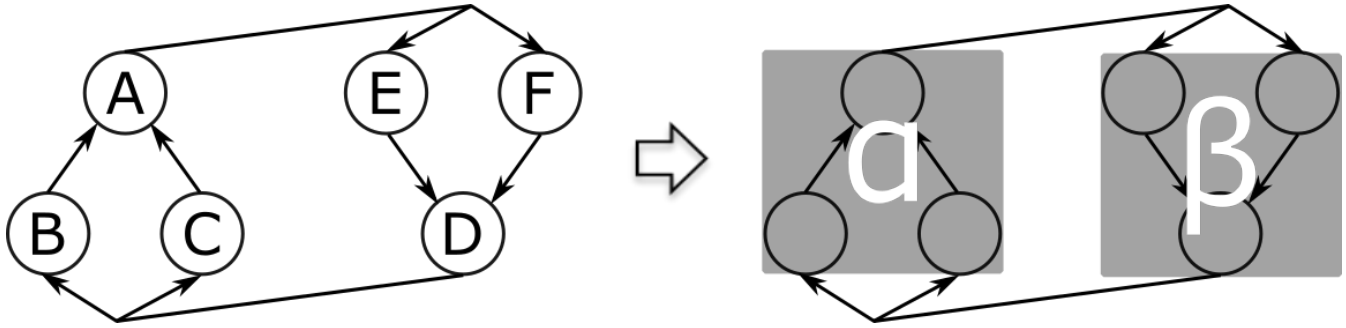
From Micro to Macro

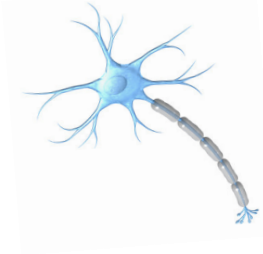
A macro element that is constituted of more than one micro element, and/or more than one micro time step

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



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





Macro Elements

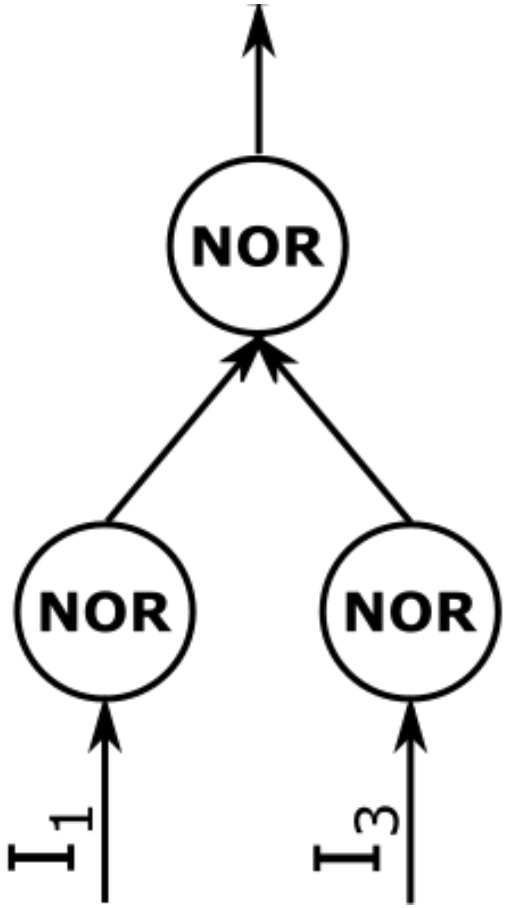
A macro element consists of a several of micro elements (spatial) over several micro time steps (temporal).

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)

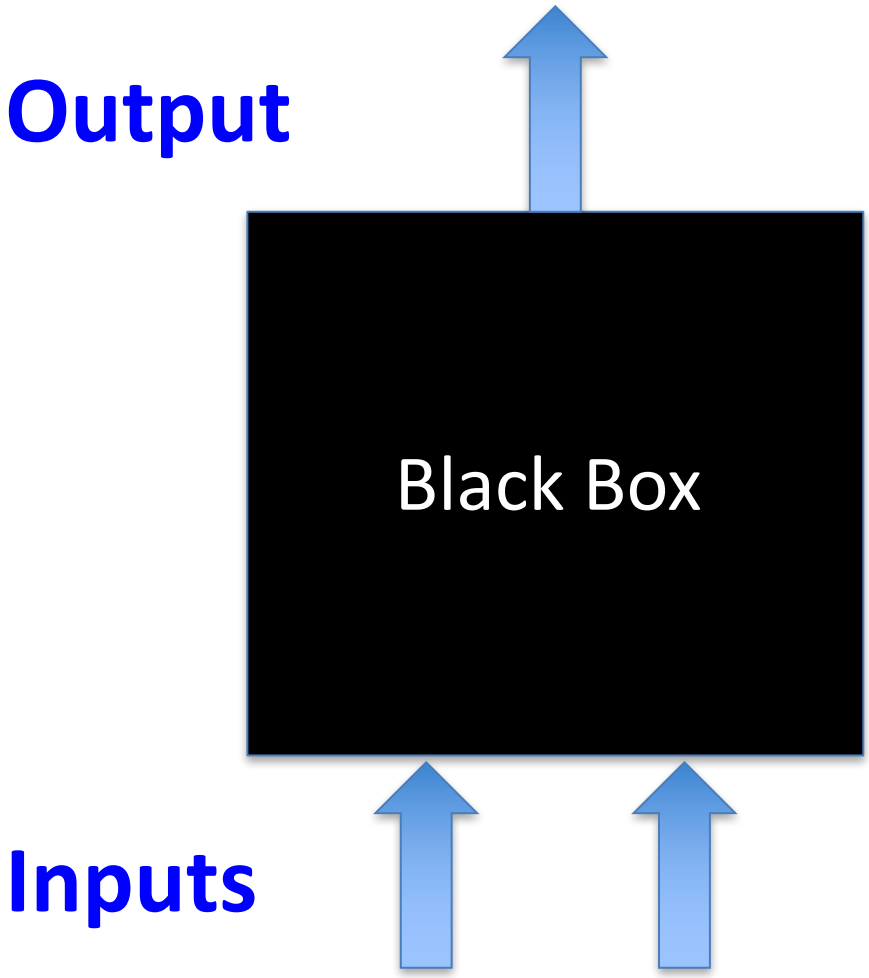
Macro elements: Black boxes of micro elements

Output



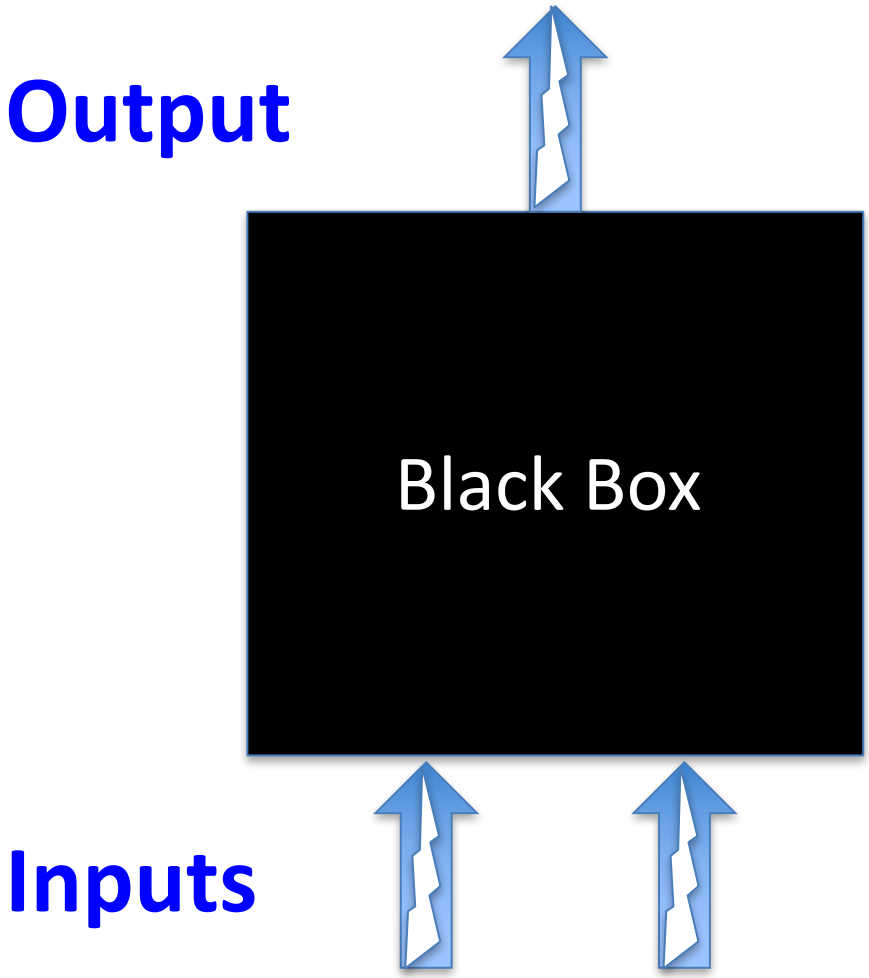
Inputs

Macro elements: Black boxes of micro elements



Truth Table	
Input State	Output State
(0, 0)	?
(1, 0)	?
(0, 1)	?
(1, 1)	?

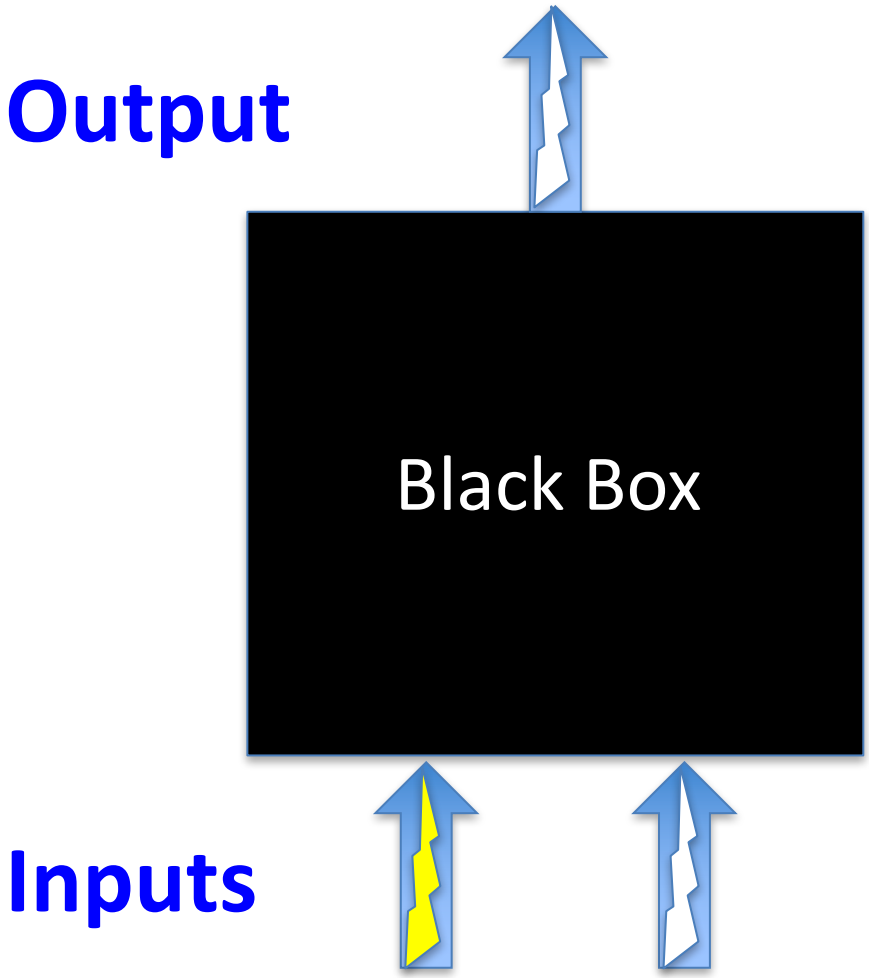
Macro elements: Black boxes of micro elements



Truth Table	
Input State	Output State
(0, 0)	0
(1, 0)	?
(0, 1)	?
(1, 1)	?

Perturbational Causal Analysis

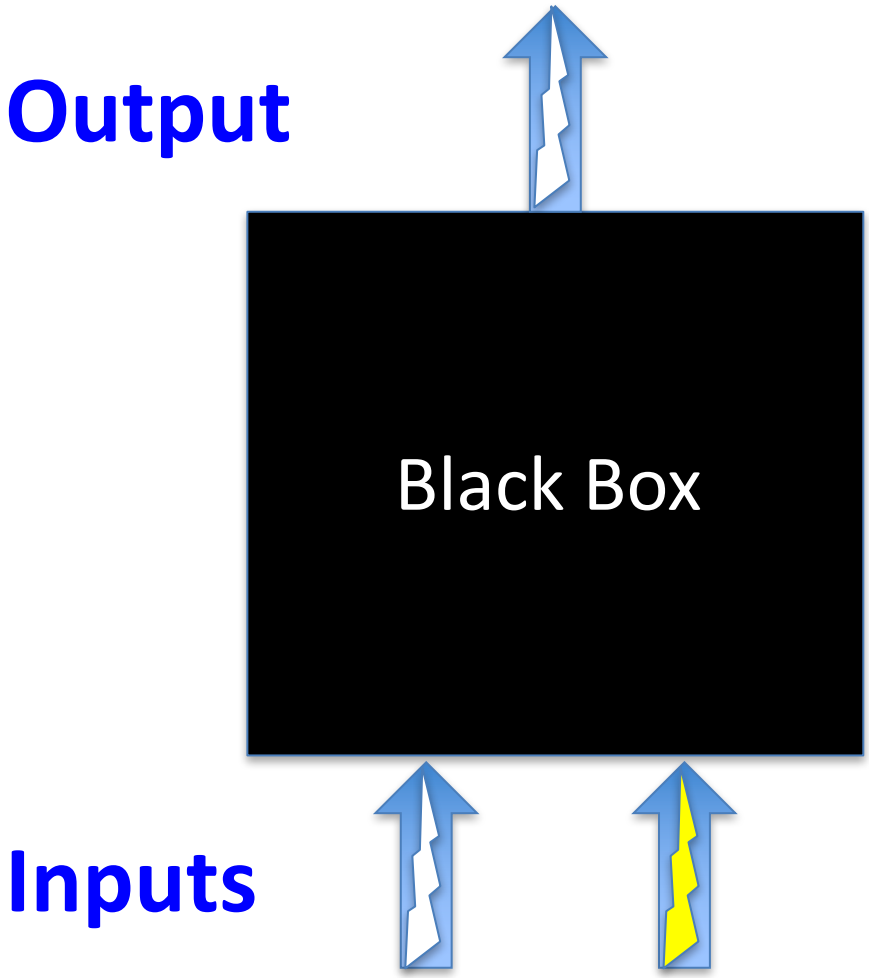
Macro elements: Black boxes of micro elements



Truth Table	
Input State	Output State
(0, 0)	0
(1, 0)	0
(0, 1)	?
(1, 1)	?

Perturbational Causal Analysis

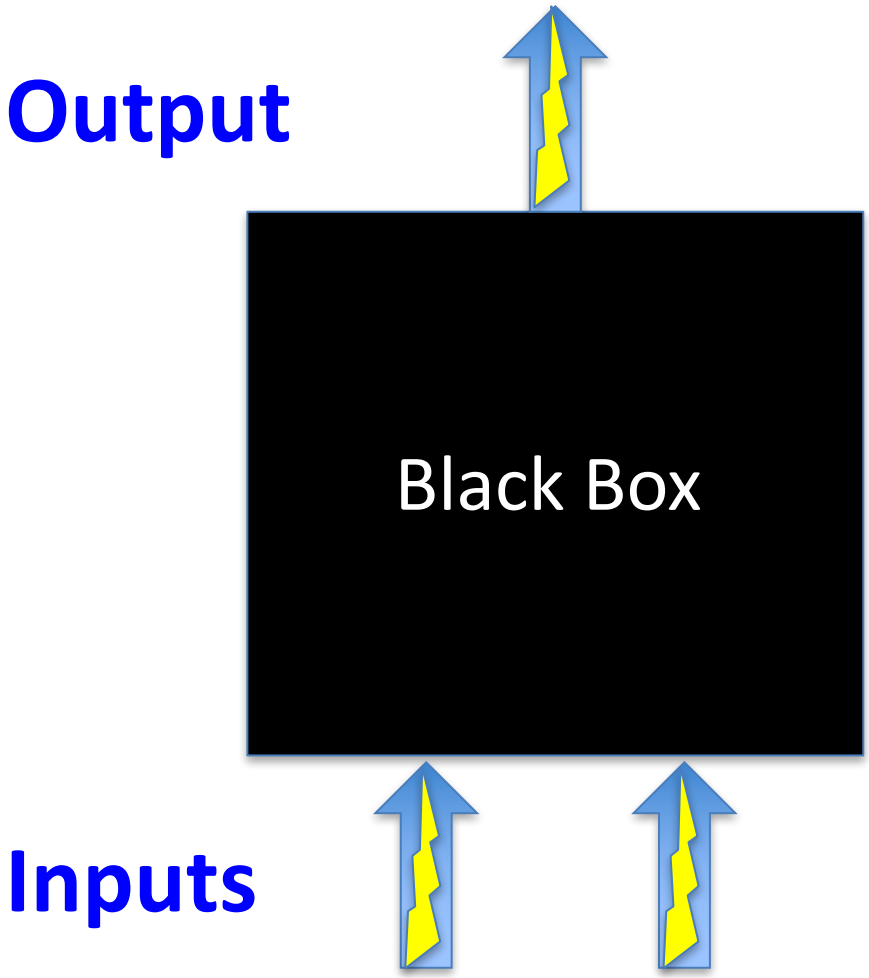
Macro elements: Black boxes of micro elements



Truth Table	
Input State	Output State
(0, 0)	0
(1, 0)	0
(0, 1)	0
(1, 1)	?

Perturbational Causal Analysis

Macro elements: Black boxes of micro elements



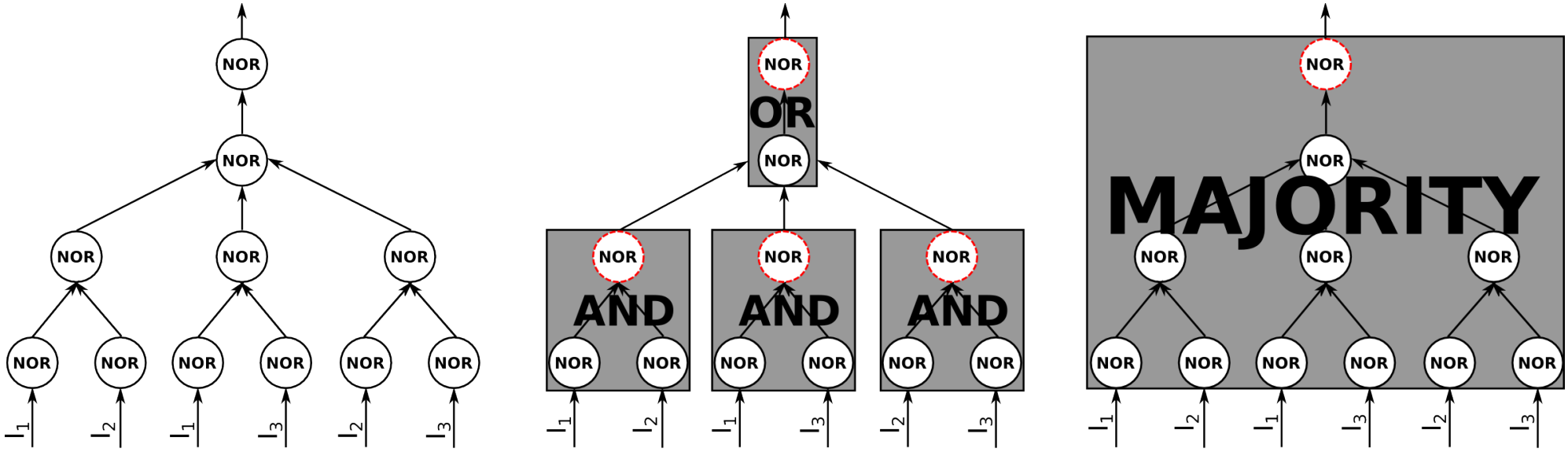
Truth Table	
Input State	Output State
(0, 0)	0
(1, 0)	0
(0, 1)	0
(1, 1)	1

AND Logic

Perturbational Causal Analysis

Macro elements: Black boxes of micro elements

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



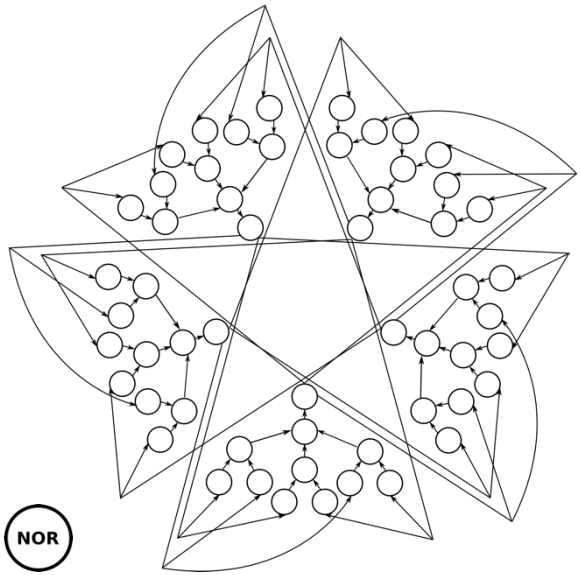
Micro → increasing spatiotemporal grain size → Macro

Marshall W, Albantakis L, Tononi G (2016) Black boxing and cause-effect power. ArXiv:1608.03461.

Macro elements: Black boxes of micro elements

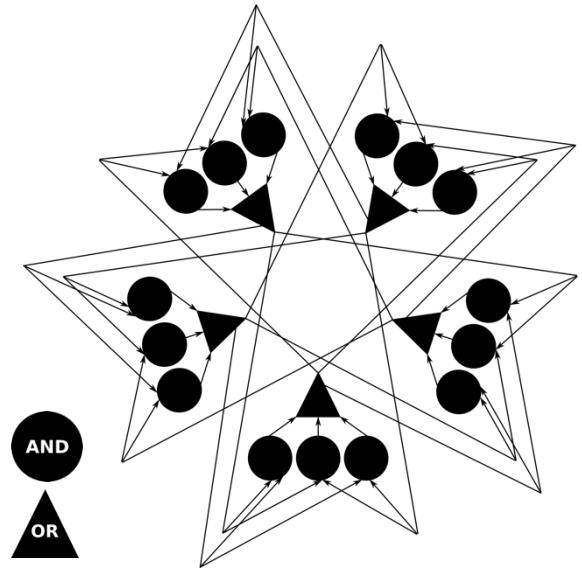
Proof-of-concept that Φ can peak at a macro level in small networks of logic-gates

Φ = 0.453



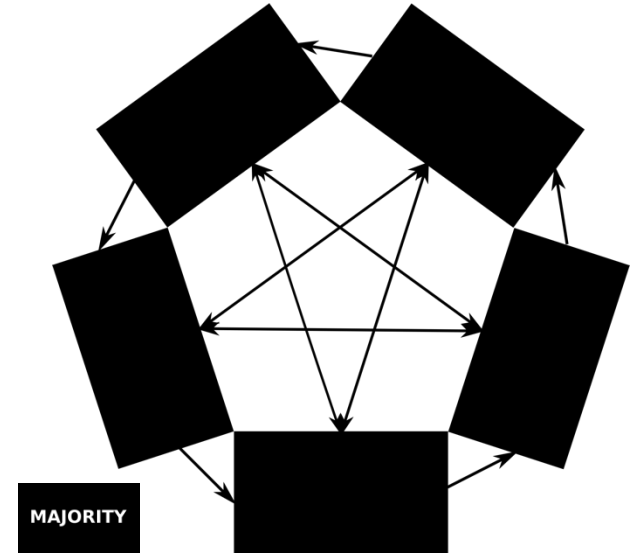
- 55 micro elements
- 55 first order concepts
- 0 high order concepts

Φ = 0.080



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

Φ = 2.33

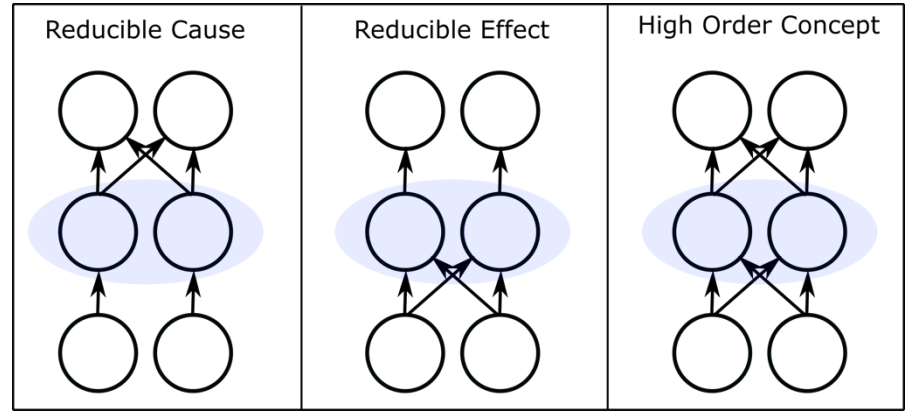


- 5 macro elements
- 5 first order concepts
- 25 high order concepts

Micro → increasing spatiotemporal grain size → Macro

How can the Macro beat the Micro?

- **Composition + Integration**
  - More common inputs
  - More common outputs
  - → More high-order concepts
  - → More integrated system



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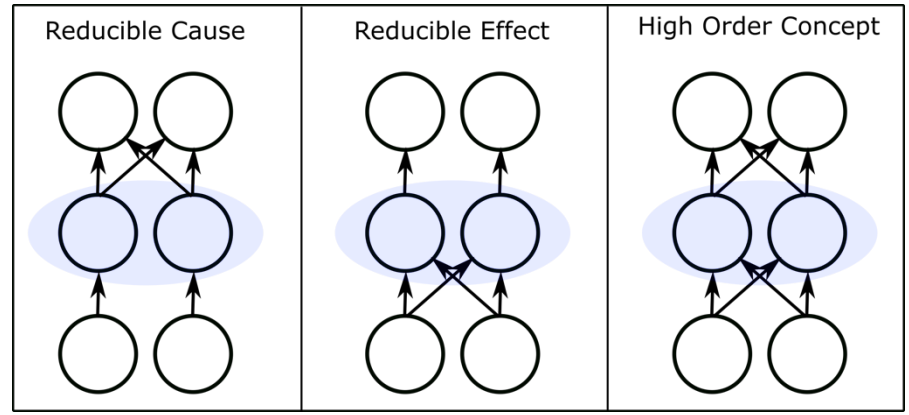
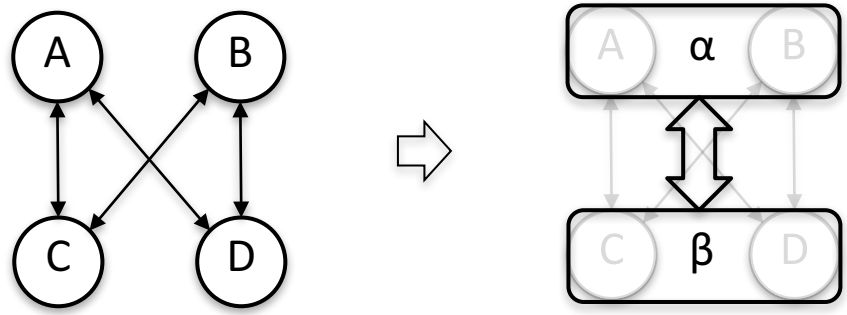
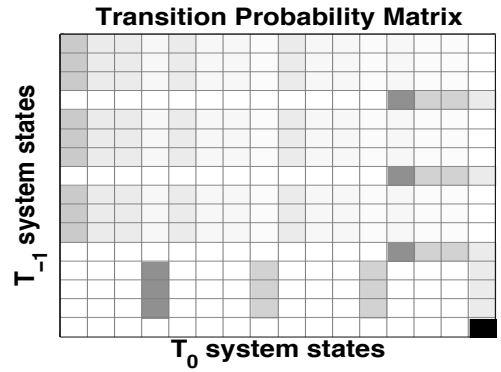
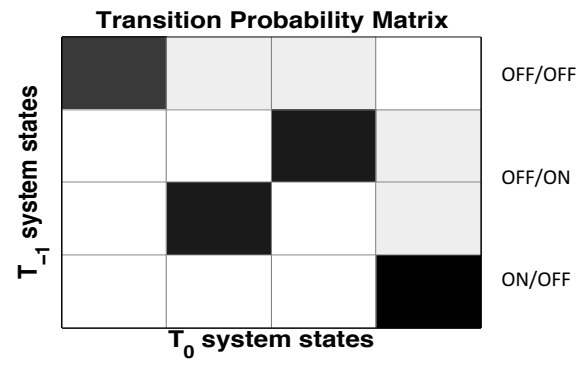


- **Information**
  - Increase determinism
  - Decrease degeneracy







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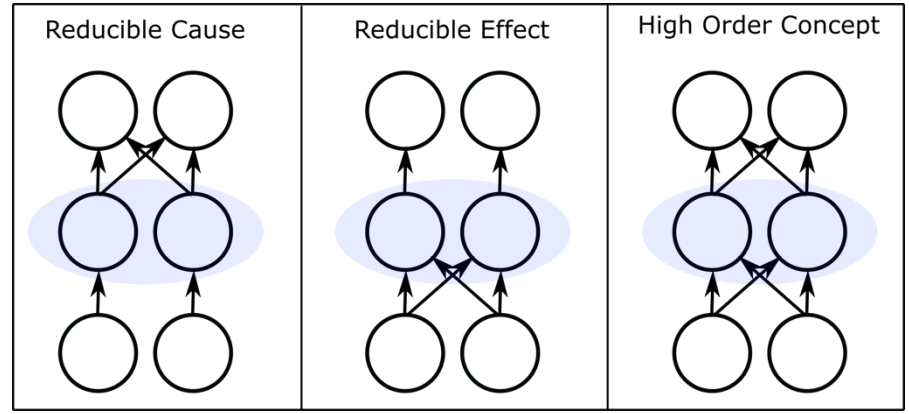

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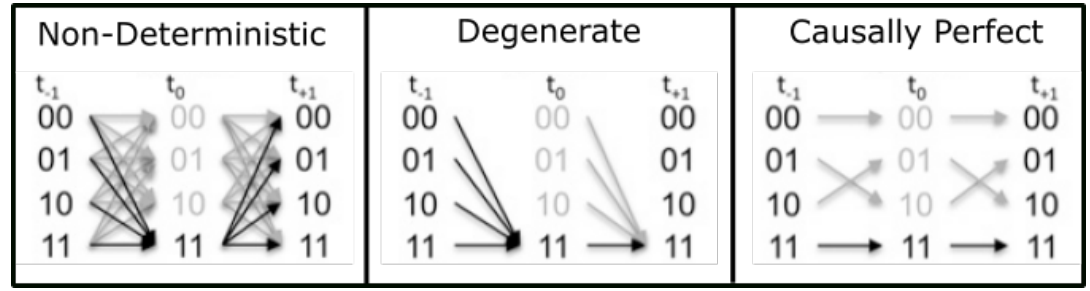
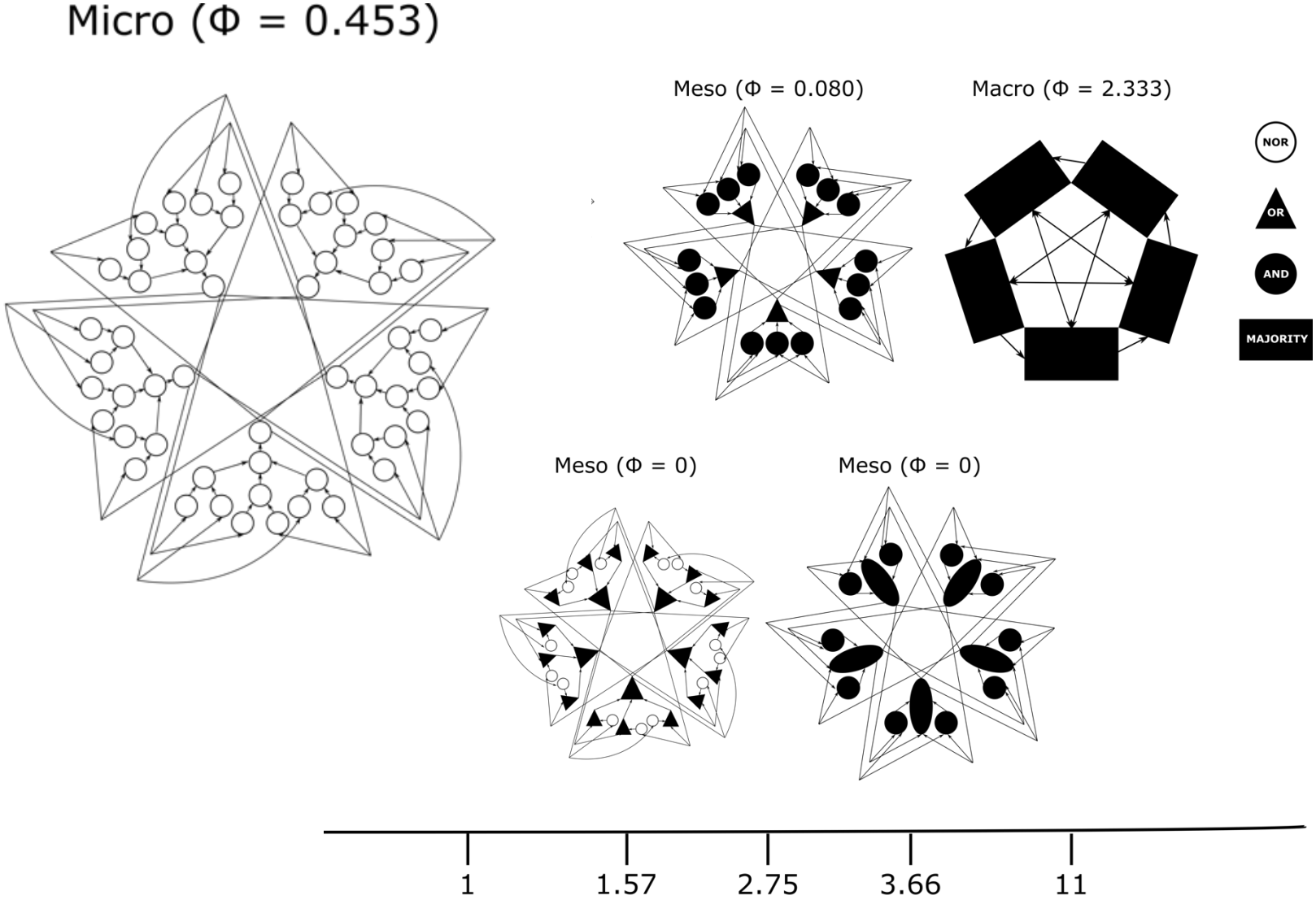
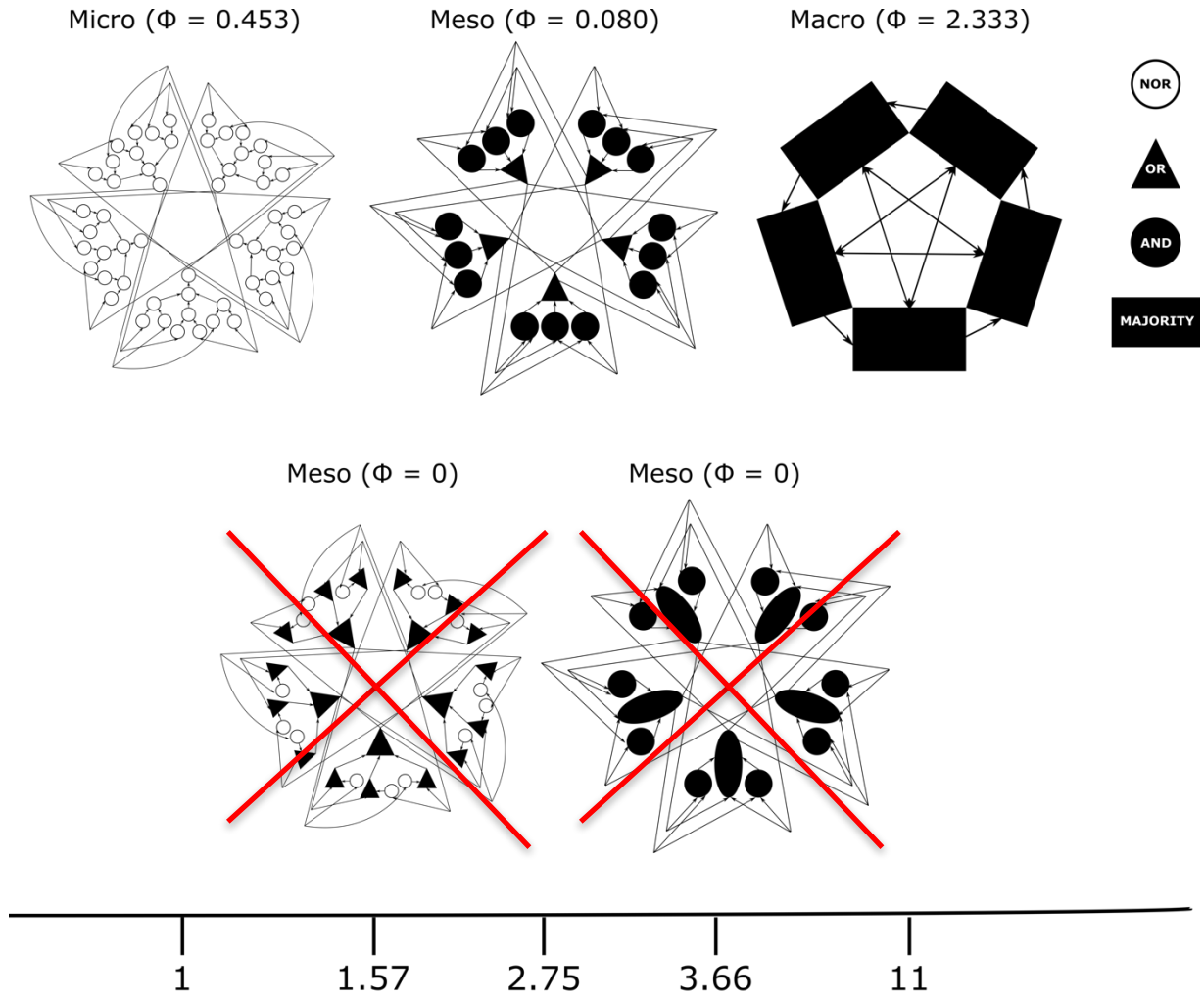


→ More integrated information Φ


Micro (Φ = 0.453)
Meso (Φ = 0.080)
Macro (Φ = 2.333)
NOR
OR
AND
MAJORITY
Meso (Φ = 0)
Meso (Φ = 0)
1
1.57
2.75
3.66
11
Average Spatial Grain Size


Micro (Φ = 0.453)
Meso (Φ = 0.080)
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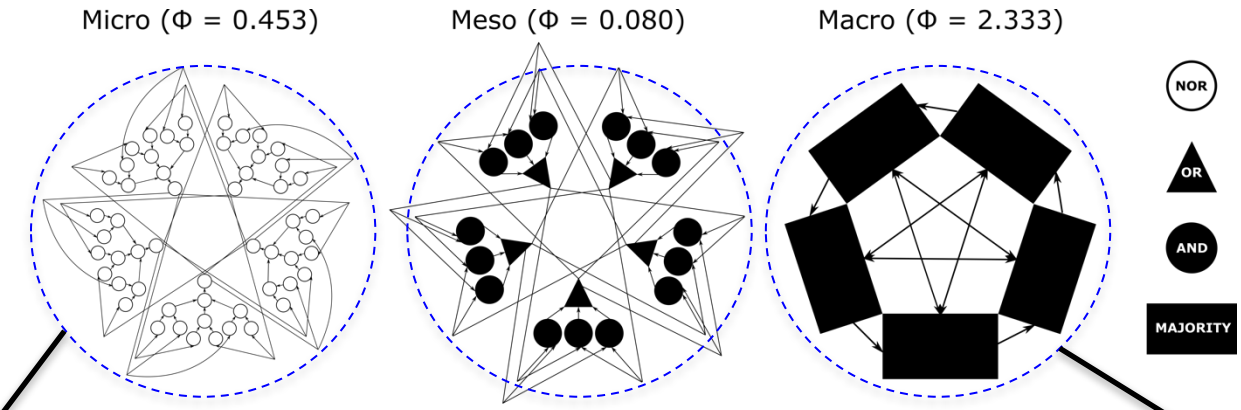
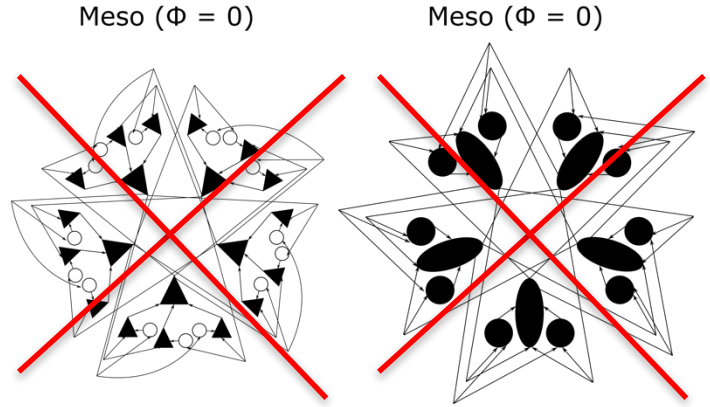
Meso (Φ = 0)
1
1.57
2.75
3.66
11
Average Spatial Grain Size

Extrinsic Entities

Organizational levels with emerging causal structures



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



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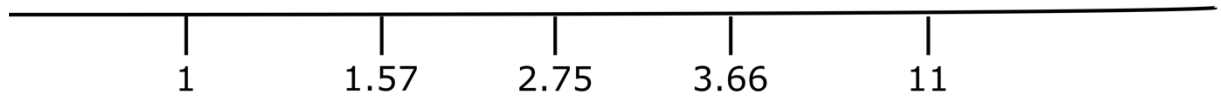
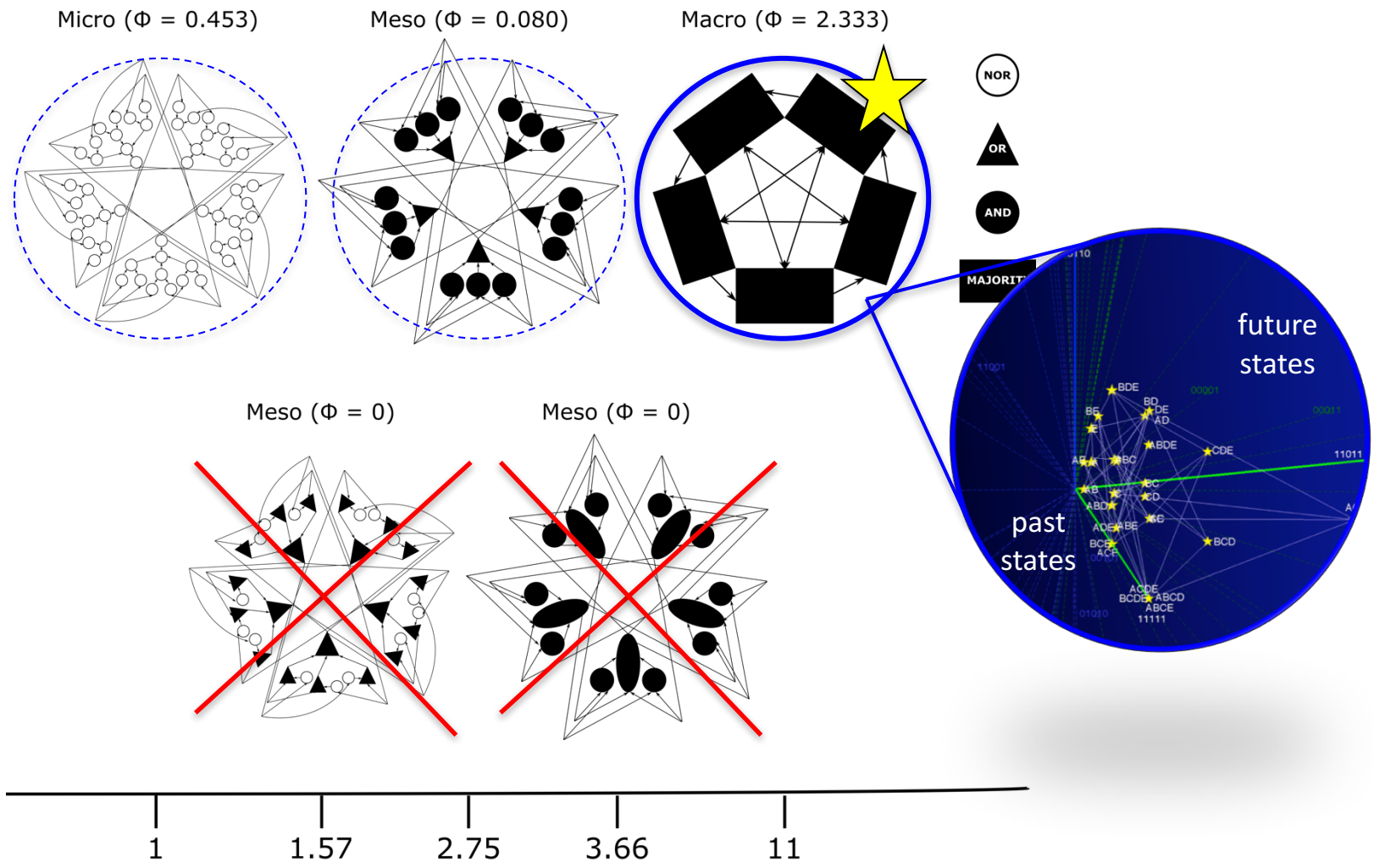


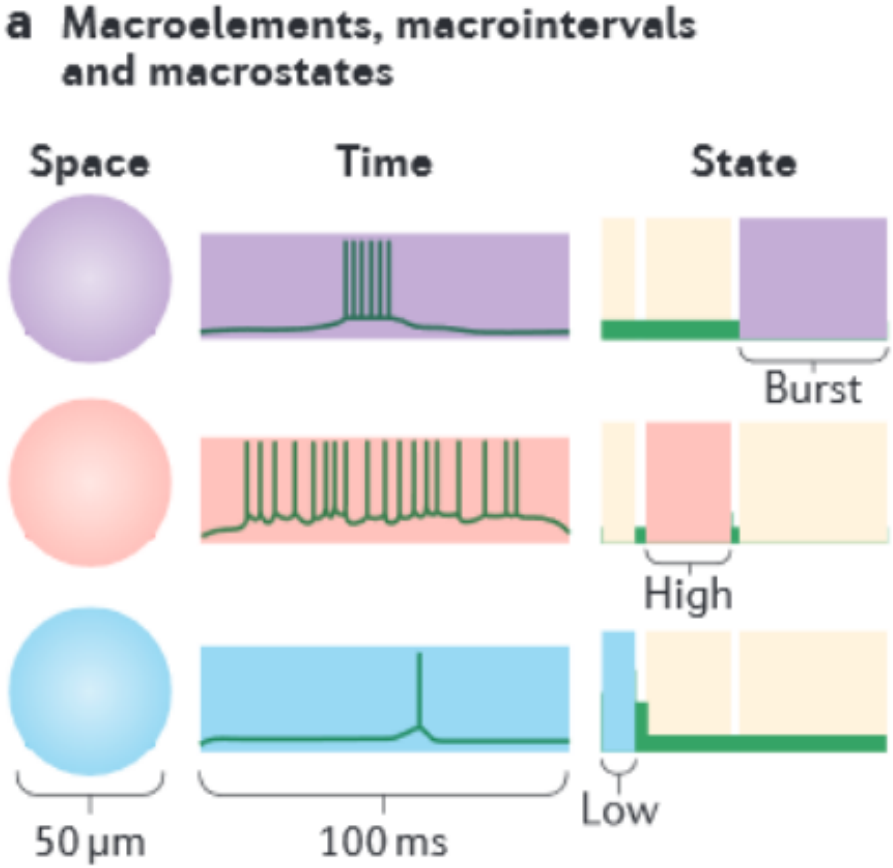
Average Spatial Grain Size

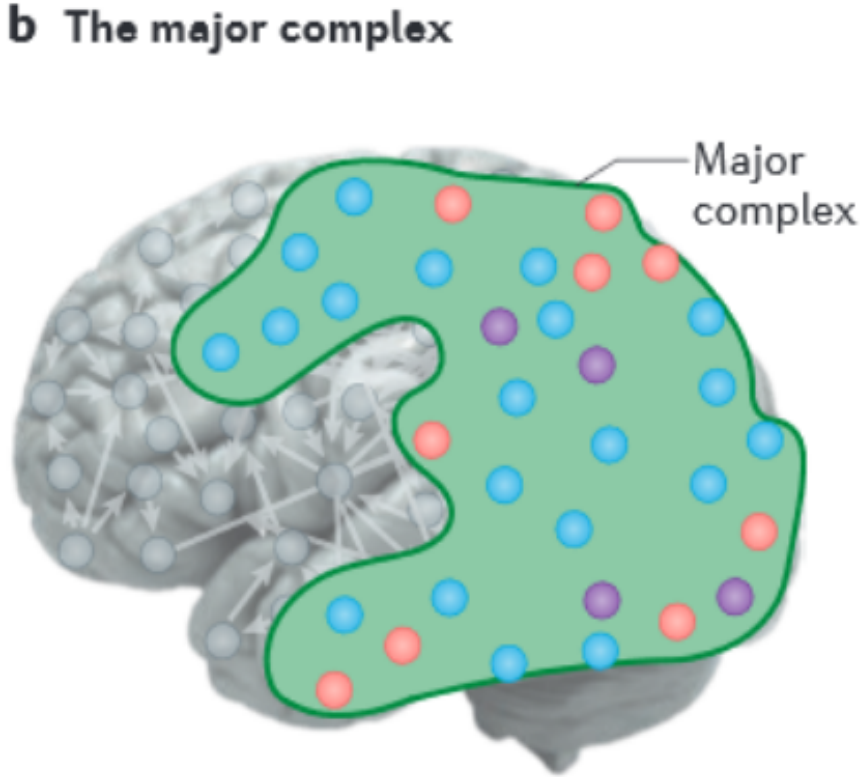
Intrinsic Entities



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.

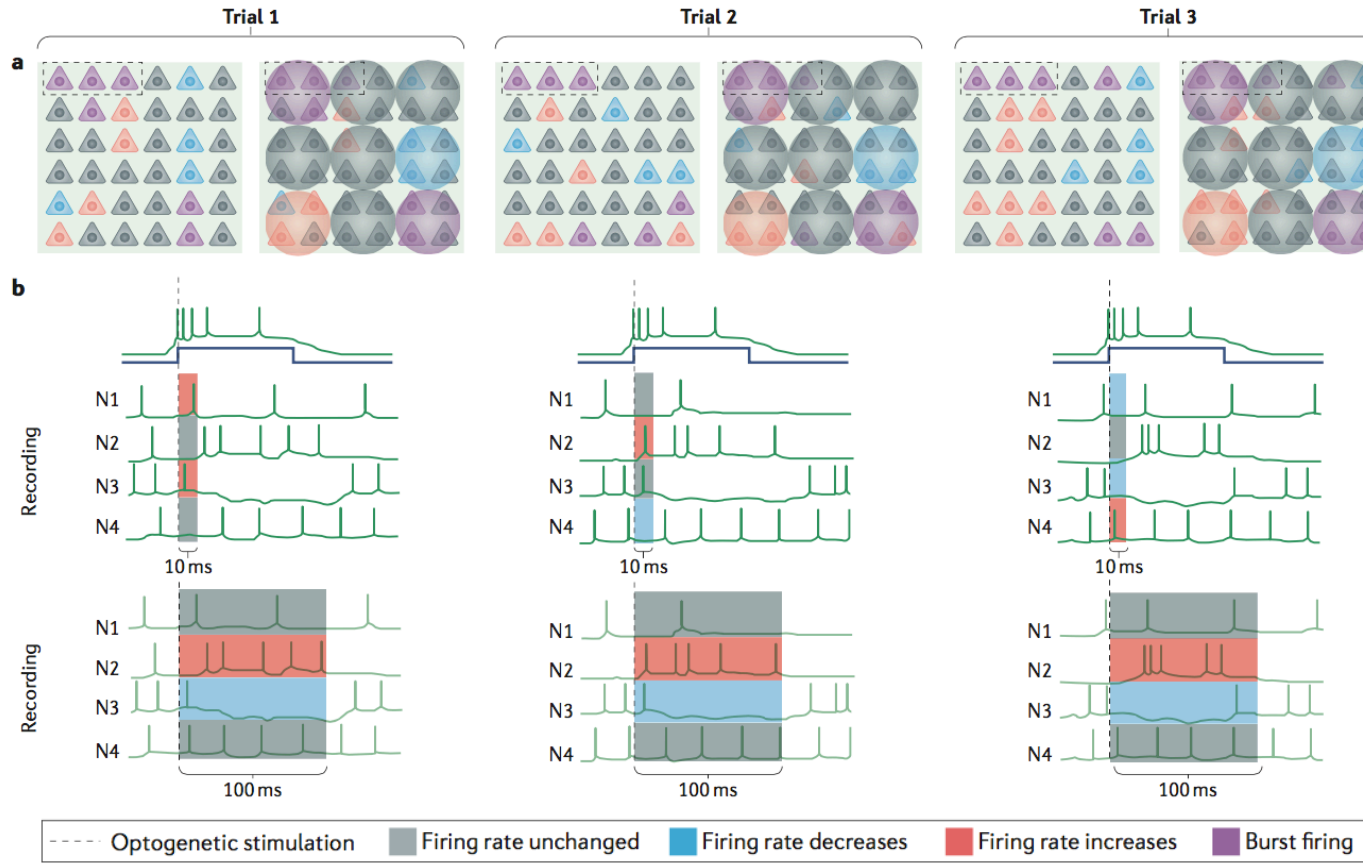




Testable Prediction

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

Optogenetic perturbation and unit recording



Tononi G, Boly M, Massimini M, Koch C (2016) Integrated information theory: from consciousness to its physical substrate. Nat Rev Neurosci 17:450-461.

Thank you!

http://integratedinformationtheory.org

Python software available at Github → WMayner
→ pyphi

https://github.com/wmayner/pyphi

Or email to:
Albantakis@wisc.edu