Information Integration, Data Integration and Machine Consciousness

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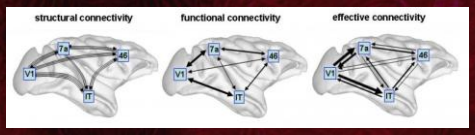
Talk Overview

- Introduction to information integration.
- Information or data integration?
- Testing the link between information integration and consciousness.
- Applications

INFORMATION Integration

Introduction

- Information measures, such as mutual information or transfer entropy, have often used in neuroscience research to identify anatomical, functional and effective connections between parts of the brain or a neural simulation.



Introduction

- Integration has often been claimed to be a key features of conscious states (Baars, 1988; Metzinger, 2003).
- So measures of functional and effective connectivity could be used to identify parts of the brain linked to conscious states.

Information Integration

- "Information integration" is typically used to refer to a *combination* of differentiation and integration in a system of elements.
- Information integration algorithms attempt to measure:
  - The extent to which a system of elements is capable of entering a large number of different states.
  - The extent to which these states result from causal interactions among the elements.

Christmas Lights Switch

- Switch used to control a million Christmas lights.
- Each light mirrors the state of the switch: when the switch is on the light is on; when the switch is off the light is off.
- High level of integration between the lights and the switch.
- Low differentiation of the system – it can only enter one of two states (on or off).

Digital Camera Sensor

- Digital camera sensor with a million photodiodes.
- The camera has $2^{1,000,000}$ possible states – a lot of differentiation.
- No integration: each photodiode acts entirely independently of the rest.
- The next state of the camera sensor does not result from causal interactions among the photodiodes.

Brain

- Highly functionally specialized: many areas that only respond to specific information.
- Globally integrated at many different levels: recursive signalling between areas across massively parallel paths.
- Differentiated states of the brain result from causal interactions among its elements.
- Parts of the brain are associated with consciousness.

Information Integration and Consciousness

- High levels of information integration could be correlated with consciousness.
- Phenomenological evidence for this claim.
- Very limited amount of experimental evidence.
- Tononi (2008, p. 217), claims that "at the fundamental level, consciousness is integrated information, and ... its quality is given by the informational relationships generated by a complex of elements."

Information Integration Algorithms

- A number of information integration algorithms have been put forward:
  - Neural complexity (Tononi, Sporns and Edelman, 1994)
  - Stateless Φ (Tononi and Sporns, 2003)
  - State-based Φ (Balduzzi and Tononi, 2008)
  - Causal density (Seth et al., 2006)
  - Liveliness (Aleksander and Gamez, 2010)

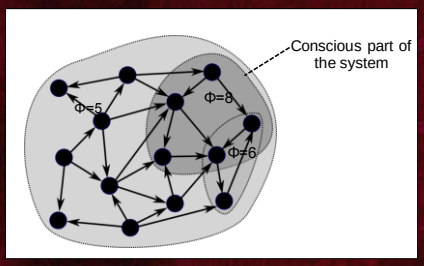
Advantages of Information Integration

- Information integration is *system neutral.*
- It can be applied to natural *and* artificial systems.
- If it could be shown that information integration is necessary and sufficient for consciousness in humans, then we could make convincing predictions about the consciousness of artificial systems.

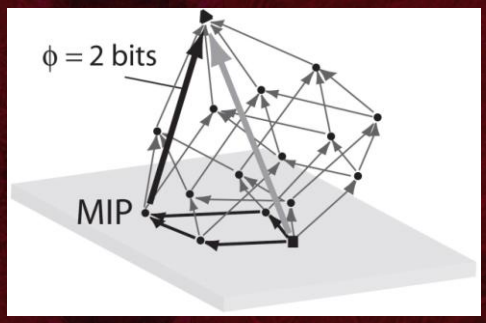
Advantages of Information Integration

- Precise enough to be experimentally tested.
- For example, Tononi's (2008) theory can predict for each state of a system:
  - The areas of the system that are associated with consciousness.
  - The amount of consciousness present.
  - The qualitative character of the consciousness.
- Points the way towards a scientific approach to consciousness in which mathematically formulated theories of consciousness are systematically compared.

Conscious Part of the System



Contents of Consciousness



EEG Experiments

- Lee et al. (2009) made multi-channel EEG recordings from eight sites in conscious and unconscious subjects.
- Constructed a covariance matrix of the recordings on each frequency band, which was used to identify the complexes within the 8 node network using Tononi and Sporns' (2003) algorithm.
- Information integration capacity of the network in the gamma band was significantly higher when subjects were conscious.

TMS / EEG Experiments

- For example, Massimini et al. (2009)
- Pulse of TMS applied to different cortical regions and resulting activity recorded using EEG.
- Activity in cortical areas was more modular and less differentiated during sleep stages 3 and 4.
- Activity in cortical areas was less modular and more differentiated during REM sleep and wakefulness.

INFORMATION or Data?

Information and Brain Connectivity

- In work on brain connectivity, the exact nature of information is not important.
- Shannon's information equations are used as mathematical tools to identify functional and effective connections between groups of neurons.
- The *relationships* between neurons are important, not the absolute nature of information.

Information and Consciousness

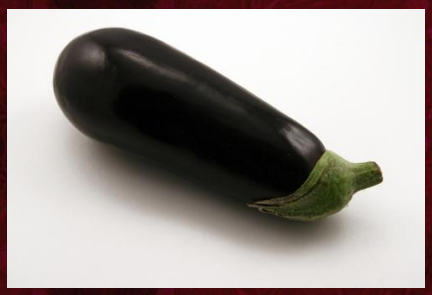
- In work on the link between information integration and consciousness, consciousness is said to be *correlated with* or to ***be*** information integration in the brain.
- In this case, information integration cannot just be an abstraction or a subjective interpretation.
- It must be a *metaphysically real property of the physical world*.

Information

- But... information appears to be a subjective interpretation of the world: the information states a system holds appear to be *relative* to an observer.
- Consciousness is real, so how can it be correlated with or *be* a subjective interpretation of the physical system?

Information in an Aubergine

- There is an aubergine.



Information in an Aubergine

- Pattern of seeds

Information in an Aubergine

- Other levels of information:
  - Location of each cell relative to a reference point.
  - Location of each atom relative to a reference point.
  - Sequence of nucleotides
  - ...
- Aubergine contains a virtually infinite quantity of information.
- This information is *relative to an observer and level of abstraction*.

General Definition of Information

- Theory of information that can handle this apparent relativity is Floridi's (2009) interpretation of the General Definition of Information.
- Distinguishes between:
  - Data
  - Information, defined as *meaningful* data.

General Definition of Information

- Floridi (2009): something is an instance of information, understood as semantic content, if and only if:
  - GDI.1) it consists of n data, for *n* >= 1;
  - GDI.2) the data are well-formed;
  - GDI.3) the well formed data are meaningful.

Data

- Lack of uniformity in the world
- Depends on pre-theoretical differences in the physical world called *dedomena*, which cannot be experienced without an interpretation that is applied to the world.
- *Dedomena* are a bit like Kant"s noumena: they make the differences that we measure and manipulate possible.
- For example, *dedomena* make the measureable difference between higher and lower charge in a battery possible.

Data

- Only *dedomena* can be considered to be an objective property of the physical world.
- The set of differences that we actually identify and measure are always the result of a particular interpretation.
- However, differences in a physical attribute of the system, such as its electric field, are thought to be more than just a subjective interpretation.

Well Formed Data

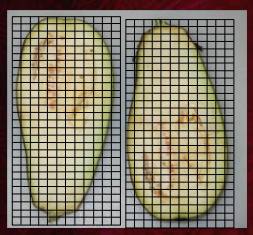
- Syntax enables data to be extracted in a systematic way.
- For example, to interpret an aubergine's seed pattern as Arabic writing:
  - The shape of the seeds has to match the shape of Arabic letters.
  - The order of the letters has to conform to orthography of Arabic.
  - The order of words has to conform to grammar of Arabic.

Interpretation of Seed Pattern as Writing

- Seeds interpreted as the phrase: "Ya-Allah"

Meaningful Data

- Well formed data is easy to extract, but it might not be meaningful in any way.
- For example, extraction of binary data from seed pattern.



Floridi's Approach

- Floridi (2009) describes meaningful data as a combination of data and queries.
- The proposition "The earth only has one moon" can be interpreted as a piece of meaningful data in which the semantic content is the question "Does the Earth only have one moon?" and the answer "yes" is a single bit of data.

Information Theory

- Shannon's mathematical theory of communication is a theory about *data* transmission, not *information* transmission because it does not take the meaning of messages into account:

  "since MTC is a theory of information without meaning (not in the sense of meaningless, but in the sense of not yet meaningful), and since we have seen that [information – meaning = data], 'mathematical theory of data communication' is a far more appropriate description of this branch of probability theory than 'information theory'."

  Floridi (2010), p. 33

Information Theory

- Information integration algorithms are actually measures of data integration, unless it can be shown that the integrated data carries semantic content.
- Separate question about whether there is a link between *information* integration and consciousness.
- This is particularly relevant when considering embodied theories of consciousness.

TESTING
Information Integration

Testing Information Integration

1. Select a system that is known to be conscious or commonly agreed to be conscious.
2. Measure the consciousness of the system.
3. Measure the information integration of the system.
4. Identify correlations between information integration and consciousness.
5. Test predictions made by information integration about the consciousness of the system.

Platinum Standard System

- To establish link between information integration and consciousness, have to start with a system that is commonly agreed to be conscious.
- The only system that is confidently associated with consciousness is the awake normal adult human brain.
- Artificial systems cannot be used to test the link between information integration and consciousness.

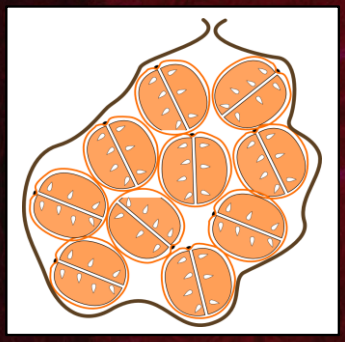
Measuring Consciousness in the Platinum Standard System

- Consciousness is typically measured through first person reports, although other behaviours can be used to infer the presence of consciousness and its contents.
- Also possible to use cognitive abilities systematically linked to consciousness to infer the presence of consciousness in a platinum standard system (Shanahan, 2010).
- Numerous problems with the measurement of consciousness, such as the dependence on potentially fallible memory and the limited bandwidth and accuracy of human language.

Measuring Information Integration in Platinum Standard System

- Have to define level at which analysis will take place – brain areas, neurons, ion channels, atoms etc.
- The choice of level might affect the results, or different levels might coincide.

Colour in a Sack of Oranges



Performance

- The majority of the current algorithms are inapplicable to systems with more than 100 neurons.
- Predicted to take 10^{9000} years to analyze a network of 18,000 neurons using the stateless Φ algorithm (Gamez, 2008).
- Predicted to take 10^{10} years to analyze 30 neurons using the state-based Φ algorithm (Aleksander and Gamez, 2010).

Knowledge about Causal Structure

- Most of the algorithms for information integration depend on knowledge about the underlying causal structure of the system.
- We do not have this knowledge with the platinum standard system.
- Could be addressed to some extent by inferring causal relationships using Granger causality or mutual information.

Limited Access to the Brain

- fMRI. Approximately 1 mm^3 or 50,000 neurons resolution over a time scale of 1 second.
- EEG. Max ~300 electrodes recording over large brain areas through skull. Frequencies up to ~100 Hz
- Electrodes. ~300 electrodes recording from individual neurons in real time. Only applicable to subjects who are being operated on for other reasons.

Accuracy

- Information integration algorithms might be outputting rubbish that has nothing to do with what we believe the information integration of the system to be.
- How can we measure the accuracy of information integration algorithms?

From Correlations to Predictions

- If the experimental issues could be overcome, it might be possible to identify correlations between information integration and consciousness.
- Could then test information integration theories by making *predictions* about consciousness in the platinum standard system.
- If these predictions were shown to be correct, we would start to believe information integration theories about consciousness.

Predictions about the Consciousness of Other Systems

- If information integration was a good predictor of consciousness in the platinum standard system, we could use it to make predictions about the consciousness of *other* systems, such as animals and artificial systems.
- We would believe these predictions to the extent that information integration has been shown to be necessary and sufficient for consciousness in the platinum standard system.

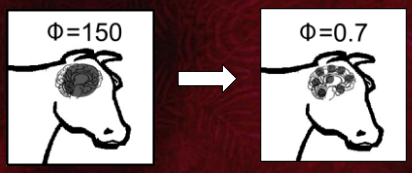
APPLICATIONS

Medical Applications

- Measuring the degree of consciousness in coma patients.
- Identifying whether a person is conscious during an operation.
- Brain interfaces for paraplegic and locked-in patients.
- Would raise privacy concerns about being able to read a person's mind.

Animals

- Could make accurate predictions about animal consciousness.
- Could even breed/genetically engineer food animals to have no consciousness.



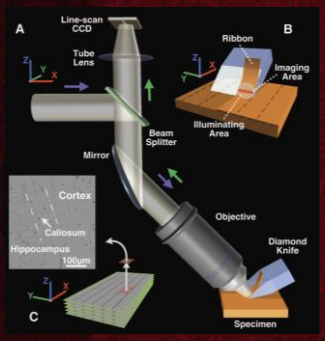
Machine Consciousness

- Information integration could be used to measure the degree to which an artificial conscious system has been constructed.
- Could also determine whether artificial systems are suffering – Shanahan's concerns about simulated mice brains.

Uploading a Brain into a Computer

- After a person dies, a succession of thin slices of their brain could be scanned and integrated together to map their neurons and connections.
- This could be used to build a simulated neural network with the same neurons and connections.
- The simulated brain could be connected to the spinal column of the person's actual body (but many problems with this).

Scanning Neurons and Connections



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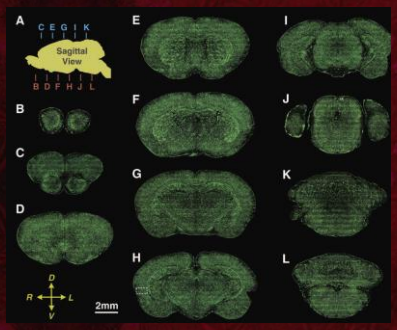
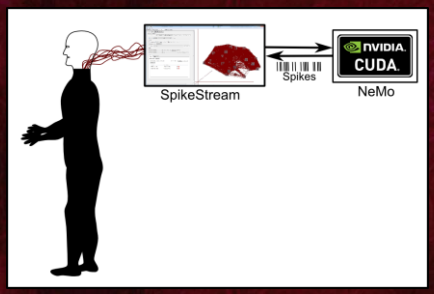


Simulating Brain on Computer



Uploading a Brain into a Computer

- Body may have the same external behaviour as the person had before their death.
- But would it have the same consciousness?
- Information integration algorithms could be used to predict the extent to which a simulation of a person's brain is as conscious as the person was before their death.
- Predictions about the consciousness of digital brains could make people think carefully about the way in which they are uploaded after their death.

CONCLUSIONS

Conclusions

- It has been proposed that a combination of integration and differentiation is linked to consciousness in the brain.
- The nature of information is critical if it is claimed that consciousness is correlated with or *is* information integration.
- Have argued that information integration theories are really about data integration.
- Data can plausibly be argued to be a feature of the physical world.
- Information is meaningful data.

Conclusions

- The link between information integration and consciousness has to be demonstrated on a platinum standard system (the waking normal adult human brain).
- The demonstration of this link faces many experimental issues, including the performance and accuracy of current algorithms.
- Eventually we may be able to make falsifiable predictions about consciousness using information integration.
- Also possible that information integration is *poorly* correlated with consciousness!

Conclusions

- Accurate predictions about consciousness have many applications:
  - Medical
  - Animals
  - Machine consciousness
  - Uploaded brains

Acknowledgements

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  - The Association for Information Technology Trust.
  - Engineering and Physical Science Research Council (EP/F033516/1).

More Information

- Slides: http://www.davidgamez.eu/talks/Gamez_AISB11.pdf.
- Papers related to this material: http://www.davidgamez.eu/pages/publications/
- SpikeStream: http://spikestream.sf.net.
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- Feel free to contact me if you have any questions: david@davidgamez.eu.