The Neuroethical Challenges of Large-Scale Brain Simulations

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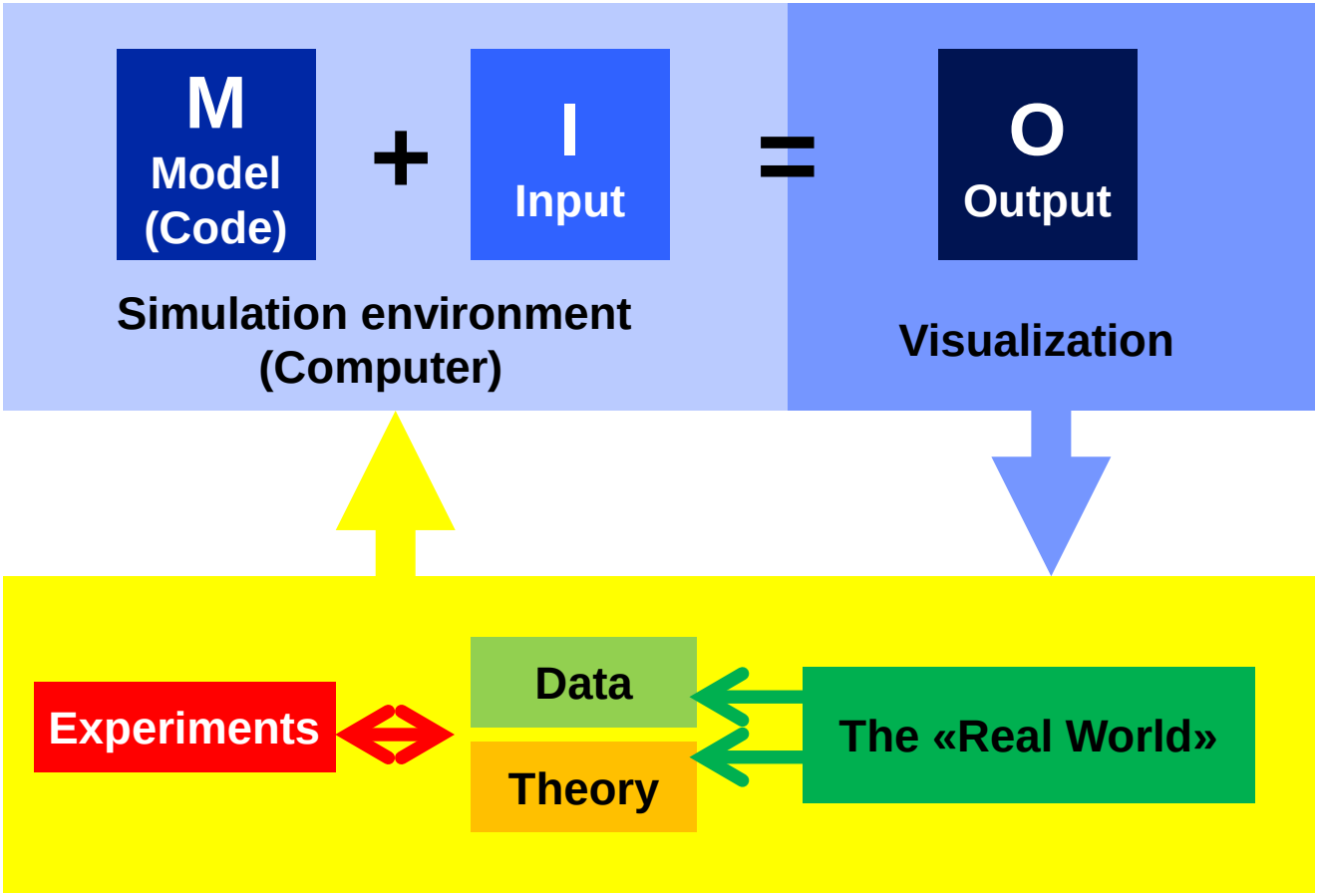
What are simulations?



What are simulations for?

$$M + I \rightarrow O \quad \text{(Prediction)}$$

$$M + O \rightarrow I \quad \text{(Retrodiction)}$$

$$I + O \rightarrow M \quad \text{(Explanation)}$$

$$\{M_i\} + \{I_i\} \rightarrow \{O_i\} \quad \text{(Exploration)}$$

Brain Simulations: Historical Notes

There are three lessons from history to keep in mind when talking about brain simulations:

1) There is a “special relation” between epistemic object (brain) and the simulation tool (computer).
   → “**mutual inspiration**”

2) There was a phase of disillusion with respect to the use of an “information approach” in neuroscience.
   → **“simulation skepticism”**

3) Public culture (science fiction) is full of narratives on “computers becoming brains”.
   → **“distractor of ethics discourse”**

Brain simulations: Basic classification

What is not considered to be a *brain* simulation (but may help in building them):

- "Classical" neural networks (e.g. for classification purposes)
- Single cell models and the like (e.g. neuron compartment models)
- Biologically inspired cognitive architectures (Goertsel et al. 2010)

Basic distinction of brain simulations:

- **Simulations using digital computers:** Simulations implemented in classical digital computer architectures (inclusive parallel computing)

- **Neuromorphic engineering:** Simulations implemented in hardware that is mimicking neuronal information processing principles (e.g. combining digital and analog computing)

Brain simulation models of decreasing neuro-biological fidelity (de Garis et al. 2010)

1) Models that can **actually be connected to parts of the human brain** or body, and can serve the same role as the brain systems they simulate.

2) A **precise functional simulation** of a brain subsystem, i.e. its internal dynamics and its mapping of inputs to outputs with adequate fidelity to explain exactly what the brain subsystem does to control the organism .

3) Models that **quantitatively simulate the generic behavior and internal dynamics** of a certain subsystem of the brain, but without precisely functionally simulating that subsystem.

4) Models that **qualitatively simulate brain subsystems or whole brains** at a high level, without simulating the particular details of dynamics or I/O, but with a goal of exploring some of the overall properties of the system.

5) Models that demonstrate the **capacity of hardware to simulate** large neural models based on particular classes of equations.

Example “The Human Brain Project”

The human brain project should (HBP Report 2012, 3):

- lay the technical foundations for a new model of **ICT-based brain research**,
- driving **integration between data and knowledge** from different disciplines,
- and catalysing a community effort to achieve a **new understanding of the brain**,
- **new treatments** for brain disease
- and new **brain-like computing technologies**

This outlines that the largest “brain simulation” project involves much more than merely “simulating” a brain.

Questions related to large-scale brain simulations

First group of questions: Epistemological consequences of *in silico* experiments in neuroscience (e.g. the meaning of core concepts like 'information' in neuroscience, the credibility of the results etc.).

Those questions are not addressed in this contribution.

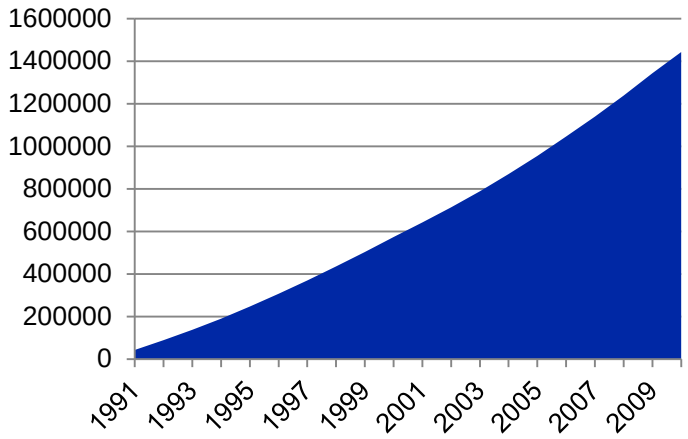
Second group of questions: Ethical issues of large-scale brain simulations:

1) **"Context ethics":** The "too big promises" and "doomed for success" problems related to large-scale science funding.

2) **"Output ethics":** Given that a brain simulation can (or may in the future) do X: How problematic is X?

3) **"Process ethics":** Which ethical issues arise when simulation approaches become an important tool within neuroscience?

Why brain simulations are inevitable



The amount of publications on all levels of neuroscience is immense. Simulations seem to be the only method available that may have a chance to allow for an integrative view on this immense amount of information.

"the major obstacle that hinders our understanding of the brain is the fragmentation of brain research and the data it produces"

"We propose that the HBP (...) generates a scaffold of <u>strategically selected data</u> on the structure and functional organization of the human brain"

"We are not building a model; we are building a data integration strategy to render biologically realistic models"

New role of brain simulations: guiding experiments

Given the complexity of the brain and the many ways of getting data out our brains, the “possible data space” is too big to be completely explorable. Furthermore, the costs associated with (time, money, legal) data acquisition in “real brains” are high.

Thus, brain simulations will become instruments that inform empirical researchers which experiments are worthwhile to perform, they will become instruments that guide research.

Problem of misguidance → **Need for a defined collaboration of the involved researchers with clear-cut interfaces and defined roles.**

New role of brain simulations: knowledge structuring

Building up brain simulations aiming for multi-level integration will need a structured access to data and publications referring to the phenomena one wants to model. This is connected to normative decisions with respect to what should be included in these knowledge libraries and what not.

Thus, brain simulations will lead to a representation of knowledge that is at least partly driven by the needs of the simulators. This knowledge will be mapped onto software code that may be hard, if impossible to change.

Problem of conflicting data → **Need for a novel type of peer review that may also involve simulation code and may need design principles that are robust for changes even of rather fundamental type.**

New role of brain simulations: communication tools

Visualization of processes within the brain are difficult and complex; and still rather unstandardized (e.g. neuroimaging; Christen et al. 2013). Simulations will allow for rather easy generation of visualizations of various kinds that are very difficult to obtain from the real object (e.g. neuronal microcircuits).

Thus, brain simulations will become instruments that accompany the interpretation and communication of results related to functions of the (simulated) brain both within neuroscience as well as towards the public.

Problem of "deception" → **Need for careful decisions with respect to creating visualization of simulation results including unique "labels" of simulation results compared to other type of visualizations.**

Are these concerns relevant? Climate modeling (1)

Weather and climate modeling (starting with general circulation models) have probably the longest history of (computer) simulations (due to economic and military importance) and have become politically very influential. Researchers from ethnography and science studies started to analyze the various social processes that accompany model generation (Lahsen 2005; Sundberg 2010)

Clear-cut interfaces and collaborations?

- Model developers typically are also model users.
- Blurring of origins of code fragments.
- Even scientists ('model users') who are not primarily model developers typically modify the models they have obtained from elsewhere.
- Increased specialization has reduced the amount of time model developers have to study the atmosphere by means of empirical data.

Are these concerns relevant? Climate modeling (2)

Novel peer review for simulations?

- The empiricists whose role is checking models against empirical knowledge have been alienated from the GCMs.
- Empiricists complain that model developers often freeze others out and tend to be resistant to critical input, living in a ‘fortress mentality’
- The psychological and social investment in models and the social worlds of which the modelers are a part can reduce their critical distance from their own creations.
- Model codes are seldom subjected to peer review and large-scale model studies are never replicated in their entirety by other scientists.
- The nearest climate models come to close scrutiny of their subcomponents is in the comparison of international peer reviewed studies and a variability of models that converge in their findings.

Are these concerns relevant? Climate modeling (3)

Unique labels for simulations?

- It has often been observed that (e.g. at conferences) it was unclear whether overhead charts and figures were based on observations or simulations.
- Similar conflation of simulations with ‘observations’, ‘samples’, and ‘data’ has been identified in studies of scientists in other fields of research

Lessons to keep in mind:

- Collaboration between modelers and empirical scientists are tricky
- Visualizations tend to blur important differences
- Various psychological mechanisms may undermine the critical function of the knowledge base that underlies the modeling process.

These shortcomings have real-world impact with respect to the credibility of policy changes that are based on climate modeling.

What does this mean for brain simulations?

Brain simulations may soon become politically important: Given the enormous burden brain-related diseases have and the high research costs, it is probable that brain simulations may guide resource allocation for research in neurodegenerative diseases.

It may even be possible that – in combination with approaches in personalized medicine – that brain simulations guide therapy decisions in individual patients, making the ethical impact immediate.

Neuroethicists, whose job is to critically accompany these developments, may lack the competences in doing so, as most promoters have a background in medicine and are not shaped by a culture of information technology and physics.

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Thank you!