Large-scale brain simulations will become an indispensible tool in neuroscience as they are the most promising instruments to integrate knowledge gained on all levels of neuronal organization. In future, I predict that they will lead to a reorganization of knowledge, guide research, and dominate result communication. The ethical consequences of these likely changes require a shift of the ethical analysis away from „sexy" but unlikely topics like „conscious machines". Experiences from climate modeling show that the practice of simulation is associated with difficult normative problems. Neuroethics will have to built up competences in this more technical field.

Ethical challenges of large-scale brain simulations

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Objective

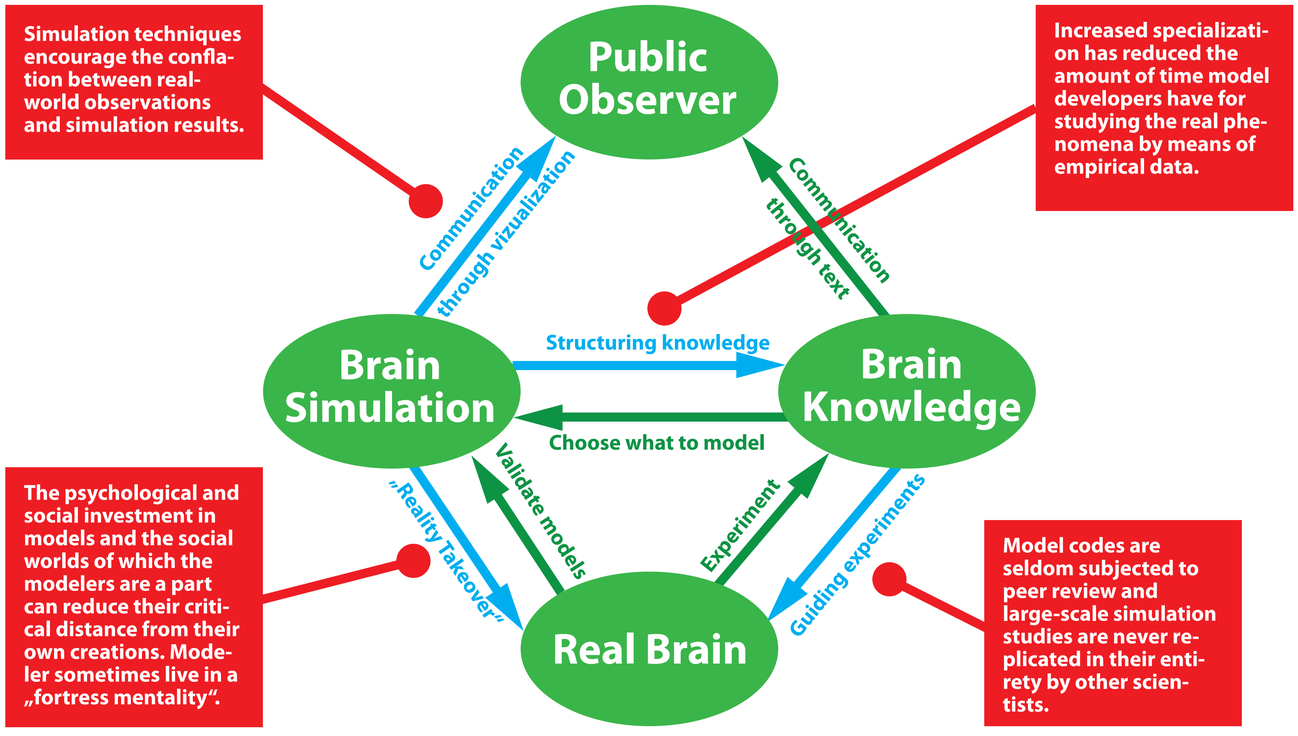
Large-scale brain simulations are an increasingly important tool in neuroscience. This is exemplified by the selection of the Human Brain Project as one of the two scientific „Flagships" of the European Union in January 2013. I discuss the ethical consequences when the brain is object of large-scale simulation approaches that intend to guide the research process in neuroscience. Referring to experiences made in climate modeling, I claim that the focus of an ethical assessment should not merely be output-oriented, but should assess the (often hidden) normative decisions that model generation involves, may include the notion of value-sensitive design, and should be sensible to side-effects of the research project, e.g. with respect to differences in „working philosophies" of the involved disciplines.

Methods

Comparative qualitative assessment of recent examples of large-scale brain simulations with respect to the history of the brain-computer relation and to sociological and ethnographic research on climate modeling. Former is important, because in neuroscience, the relation between the tool for simulation and the object of simulation is bidirectional. Latter is illustrative due to the long history and political importance of climate modeling, such that there is some ethnographic and sociological work available on the various social processes that accompany model generation.

Results

The scheme below exemplifies in a simplified manner the expected changes in emphasize large-scale brain simulations will have on the interrelation of „players" in neuroscience. Normative „hot spots" based on a comparative analysis with climate modeling are outlined in red.



The ethical assessment of large-scale research projects is traditionally **output-oriented**, i.e. one analyses benefits and risks of potential results (example: ELSI in HUGO). Most prominently discussesd is that brain simulation may in the future reach a degree of complexity such that the simulation mimics brain functions that are considered to express human competences like consciousness, imagination or moral concern. By referring to this possibility, brain simulations gain attractiveness as they allow a reference to various deep philosophical problems. It is tempting for neuroethicists to use the field of brain modeling as a "playing field" for (re-)discussion these topics. The problem, however, I see here is less the fact that such advanced brain simulations are still highly speculative, but that these discussions may cover more important normative issues that refer to the methodology of simulations.

Definitions: Models/Simulations

Models are abstractions of real-world structures and/or processes mostly in the form of mathematical equations or algorithms (although some models are physical, e.g. in hydrology).

Simulations refer to the behavior of the model in time, whereas the equations or algorithms are usually implemented on a computer, requiring in most cases numerical approximations. Simulations may specify inputs, information handling mechanisms, or outputs in order to allow for prediction, retrodiction, explanation or exploration. Due to the numerical nature of most simulation calculations, simulations can be understood as approximations of models.

Challenges for Neuroethics

Many promoters of neuroethics have a background in medicine and focus on issues that relate to medical problems like enhancement, incidental findings, or side effects of neurological interventions. But addressing the ethical challenges of brain simulation will require experts that grew up in a quite different culture shaped by information technology and physics. This expertise should be established in the near future.

Potential Solutions

- Define **interfaces** and **modes of collaboration** between modelers and empirical scientists to allow for knowledge & experience transfer and avoid „fortress mentalities".
- Use **programming strategies** to avoid that empirical knowledge embedded in code cannot be revised due to prohibitive investments when revising the code.
- **Communicate openly** when models involve choices among conflicting data/theories.
- Define procedures such that working with or adapting of simulation code is **reproducible**.
- Determine protocols that allow for **quality control** of simulation code in a similar way as peer review of scientific contributions.
- Support **varieties of models/simulations** that deal with similar problems.
- Analyze the effect of model creation on **structuring and selecting the data** that provides the foundation of the models.

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