Constructivist Research and InfoComputational Knowledge Generation

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http://www.idt.mdh.se/~gdc
The point of departure:
Research methods & philosophy of science theory vacua

Working within a project run jointly at Mälardalen University, Blekinge Institute of Technology and Lund University with the goal to provide a web-based support for knowledge exchange between academia, industry and research on Software Engineering Master Thesis, we noticed the lack of methodological support for a kind of research typical for the field, and in general representative of all of Computing and which we identify as Constructive Research Method. [http://se-ts.weebly.com/snippets.html](http://se-ts.weebly.com/snippets.html)
SE research methods
(http://se-ts.weebly.com/snippets.html)

Case Study

Controlled Experiment

Survey

Systematic Review

Document analysis

**Design Research***/Prototype Development

*Developmental Research Methods: Creating Knowledge from Instructional Design and Development Practice
http://www.springerlink.com/content/h56x575171h72714/fulltext.pdf*
General research perspectives/paradigms

<table>
<thead>
<tr>
<th>Paradigm</th>
<th>Focus</th>
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<tbody>
<tr>
<td><strong>Positivist</strong></td>
<td>Data and their interpretation, as for example in physics</td>
</tr>
<tr>
<td><strong>Interpretive</strong></td>
<td>Existing knowledge – and its interpretation as for example in history</td>
</tr>
<tr>
<td><strong>Constructive</strong></td>
<td>Construction of new artefacts as a source of new knowledge, as in AI</td>
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## Philosophical assumptions of research perspectives

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<tr>
<th></th>
<th><strong>Positivist</strong></th>
<th><strong>Interpretive</strong></th>
<th><strong>Constructive</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Ontology</strong></td>
<td>A single reality, knowable, probabilistic</td>
<td>Multiple realities, subjective, socially constructed</td>
<td>Multiple, context dependent world states, socio-technologically enabled</td>
</tr>
<tr>
<td><strong>Epistemology</strong></td>
<td>Objective, dispassionate, detached observer</td>
<td>Subjective. Values of knowledge emerge from the researcher-participant interaction</td>
<td>Knowing through making. Objectively constrained construction within a context.</td>
</tr>
<tr>
<td><strong>Methodology</strong></td>
<td>Observation, quantitative, statistical</td>
<td>Participation, qualitative, hermeneutical</td>
<td>Developmental investigation of artifactual impacts on the composite system</td>
</tr>
<tr>
<td><strong>Axiology</strong></td>
<td>Truth, universal, prediction</td>
<td>Understanding, situated and description</td>
<td>Control, creation, improvement, understanding</td>
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</table>
However, nothing is quite what it seems to be: Direct observation?!

There is very little in the universe that we can observe directly. So even the paradigmatic positivist world of physics is densely populated by non-observable knowledge and knowledge derived from previously accepted one. Physical experiments are examples of constructive research, even though the phenomena of interest are not experimental apparatuses but what we study in the physical world.

Traces of collisions of protons and anti-protons - evidence for top quark.
A real-life example of constructive (design) research

Rikard Lindell: Jag älskar att allt ligger överst”: En designstudie av ytinteraktion för kollaborativa multimedia-framträdanden A PhD thesis where the aim was to develop an artifact a user interface for performing musicians

(I love to have everything on the surface. A design study of surface interaction for collaborative multimedia performances)

Resembles the project described in:
Mariana Shellard and José Fornari
Abduction and meaning in evolutionary soundscapes
How to understand knowledge produced by this research?
Existing alternative no 1: grounded theory

Steve Borgatti defines grounded theory as a method of using empirical data without preconceived theories.

This contrasts with theory derived deductively from the existing theories, without the help of data, and which could therefore turn out to fit no data at all.

“Constant comparison is the heart of the process. At first you compare interview (or other data) to interview (or other data). Theory emerges quickly. When it has begun to emerge you compare data to theory.”

Does not sound as the main task of an engineer or scientist constructing an artifact!

(The researcher has designed an artifact which has for a goal to enable smooth communication and control of different information streams in a multimedia performance. What is of interest is how this construction evolved and how the artifact relates to the world.)
Existing alternative no2: action research

“a comparative research on the conditions and effects of various forms of **social action** and research leading to social action” that uses “a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action”.

Does not sound as the main task of an engineer or scientist constructing an artifact!
Missing alternative no3: constructive research

Both grounded theory and action research can be applied to the phase in engineering research/design research/economic research when artifact which is central for the first design or prototype phase is already done, when employing a new construct in a social context (group of users applying a programming or theoretical tool or other artifact previously developed).

However the main research and development work have been done before, during the construction phase of the research.

The main task of an engineer or scientist constructing an artifact is construction itself, and it needs to be studied with the same rigor and be given at least as much attention from the philosophy of science point of view as Grounded Theory and Action Research perspective of the same research project.
The role of constructivism

The idea of constructivism exists but it is unclear what role in theory of science is played by constructive research.

More general, it is unclear what sort of knowledge can be produced by constructive methods and how it relates to knowledge produced in other research traditions.
What is the contribution of a constructive knowledge and how can it be justified.
Forms of constructivism

Social constructionism & social constructivism

Although both social constructionism and social constructivism deal with ways in which social phenomena develop, they are distinct. Social constructionism refers to the development of phenomena relative to social contexts while social constructivism refers to an individual's making meaning of knowledge within a social context (Vygotsky 1978). For this reason, social constructionism is typically described as a sociological construct whereas social constructivism is typically described as a psychological construct.
Constructivist epistemology

In Constructivist epistemology scientific knowledge is \textit{constructed} by scientists and not \textit{discovered} from the world.

Constructivism holds that there is no single valid methodology for scientific knowledge production. The role of the researcher is active (creative)

Positivism, which claims that all scientific knowledge is based on actual sense experience articulated through scientific method is sometimes seen as opposing constructivist epistemology. The role of the researcher is seen as passive by positivists.

Nevertheless, research-methodological constructivism often leads to knowledge based on actual sense experience, although, as a rule, not knowledge about natural phenomena but about human-constructed artifacts (which often are \textit{complex systems} constructed out of naturally existing basic elements)
Design research involves the analysis of the use and performance of designed artifacts to understand, explain and very frequently to improve on the behavior of aspects of designed systems.

Such artifacts include - algorithms (e.g. for information retrieval), human/computer interfaces and system design methodologies or languages.

Design researchers can be found in many disciplines and fields, notably in engineering and computer science and information systems and they are using a variety of approaches, methods and techniques.

http://ais.affiniscape.com/displaycommon.cfm?an=1&subarticleid=279
# The outputs of design research

<table>
<thead>
<tr>
<th>Output</th>
<th>Description</th>
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<tbody>
<tr>
<td>Constructs</td>
<td>Basic elements. The conceptual vocabulary of a domain</td>
</tr>
<tr>
<td>Models</td>
<td>A set of propositions or statements expressing relationships between constructs</td>
</tr>
<tr>
<td>Methods</td>
<td>A set of steps used to perform a task – how-to knowledge</td>
</tr>
<tr>
<td>Instantiations</td>
<td>The operationalization of constructs, models and methods.</td>
</tr>
<tr>
<td>Improved theories</td>
<td>Artifact construction as analogous to experimenta in natural science</td>
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</tbody>
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Design research as constructive research – 
A bridge between natural and human spheres

Design research aims at producing artifacts (constructs) which both are 
natural and intentional.

(“No information without representation” W. H. Zurek,)

That implies understanding both of the workings of basic mechanisms 
(physics, chemistry, biology, logic, mathematics) and the role for the 
broader context including humans a given construct may play.
Figure 3. Reasoning in the Design Cycle
Constructive research characteristics

Constructive research method implies *building of an artifact* (practical, theoretical or both) that solves a domain problem (including a model for existing phenomena) in order to create knowledge about how the problem can be solved (or understood, explained or modeled), and if previous solutions/models exist, how the solution/model is better than previous ones. 

*Results* can have both practical *and* theoretical relevance. The research should solve some related knowledge problems, such as

*Feasibility*: How a previously unsolved problem can be solved.

*Novelty*: How a previously solved problem can be solved in a new way.

*Improvement*: How a previously solved problem can be solved in a better way than before. The emphasis should be on the theoretical relevance of the construct. What are the elements of the solution central to the benefits? How could they be presented in the most condensed form?
Modeling complex systems

In modern science, technology, economy and a number of other fields we depend on (computational) models.

Do models yield information on which strategic decisions could be based?

We argue that meaningful data does not necessarily have to be true to make useful information.

Partially true information or even false information can lead to scientific/technological discovery. (e.g. serendipity)

In empirical sciences we find adequacy more powerful and appropriate concept than truth.
An example of constructivist research project: Blue Brain neuroinformatics

The Blue Brain Project is the first comprehensive attempt to reverse-engineer the mammalian brain, in order to understand brain function and dysfunction through detailed simulations.

http://bluebrain.epfl.ch/
Blue Brain project

The BB project, started in 2005 by the Brain and Mind Institute of the École Polytechnique in Lausanne, Switzerland is led by Henry Makram. The project is using a Blue Gene supercomputer running Michael Hines's NEURON software, the simulation based on biologically realistic model of neurons. The aim is the study the brain's architectural and functional principles which will help elucidate the nature of consciousness.

Among sub-projects, there is the Cajal Blue Brain, coordinated by the Supercomputing and Visualization Center of Madrid (CeSViMa), and others run by universities and independent laboratories in the UK, US, and Israel. Headed by Javier DeFelipe, a renowned anatomist and electron microscopy expert from CSIC, and Jose Peña, an expert in informatics and visualization research from UPM, Cajal Blue Brain will focus on obtaining the detailed anatomical ultra-structure of the neocortex through modern electron microscopy as well as to develop the necessary bioinformatics tools to process the massive amounts of acquired data. Furthermore, through the involvement of the Center for Supercomputing and Visualization the Cajal Blue Brain will contribute to the visualization challenges of the Blue Brain Project. Nanotechnology, in a newly designed brain microscope, plays an important role.
Modeling Neurons

Neurons are not all alike - they come in a variety of complex shapes. The precise shape and structure of a neuron influences its electrical properties and connectivity with other neurons. A neuron's electrical properties are determined to a large extent by a variety of ion channels distributed in varying densities throughout the cell's membrane. Scientists have been collecting data on neuron morphology and electrical behavior of the rat in the laboratory for many years, and this data is used as the basis for a model that is run on the Blue Gene to recreate each of the 10,000 neurons in the Neo Cortical Column.

http://ditwww.epfl.ch/cgi-perl/EPFLTV/home.pl/?page=video&lang=2&connected=0&id=335&plugin=9&plugin=1&checkplugin=1 video illustrations
Modeling connections

To model the neocortical column, it is essential to understand the composition, density and distribution of the numerous cortical cell types. Each class of cells is present in specific layers of the column. The precise density of each cell type and the volume of the space it occupies provides essential information for cell positioning and constructing the foundation of the cortical circuit.

Each neuron is connected to thousands of its neighbors at points where their dendrites or axons touch, known as synapses.

In a column with 10,000 neurons, this translates into trillions of possible connections.

The Blue Gene is used in this extremely computationally intensive calculation to fix the synapse locations, "jiggling" individual neurons in 3D space to find the optimal connection scenario.
Modeling the column

The result of all these calculations is a re-creation, at the cellular level, of the neocortical column, the basic microcircuit of the brain. In this case, it's the cortical column of a rat. This is the only biologically accurate replica to date of the NCC - the neurons are biologically realistic and their connectivity is optimized. This would be impossible without the huge computational capacity of the Blue Gene. A model of the NCC was completed at the end of 2006.

In November, 2007, The Blue Brain Project officially announced the conclusion of Phase I of the project, with three specific achievements:

1. A new **modeling framework** for automatic, on-demand construction of neural circuits built from biological data
2. A new **simulation and calibration process** that automatically and systematically analyzes the biological accuracy and consistency of each revision of the model
3. The first **cellular-level neocortical column** model built entirely from biological data that can now serve as a key tool for simulation-based research
Simulating the microcircuit

Once the microcircuit is built, the exciting work of making the circuit function can begin. All the 8192 processors of the Blue Gene are put into service, in a massively parallel computation solving the complex mathematical equations that govern the electrical activity in each neuron when a stimulus is applied.

As the electrical impulse travels from neuron to neuron, the results are communicated via inter-processor communication (MPI). Currently, the time required to simulate the circuit is about two orders of magnitude larger than the actual biological time simulated. The Blue Brain team is working to streamline the computation so that the circuit can function in real time.
Interpreting the results

Running the Blue Brain simulation generates huge amounts of data. Analyses of individual neurons must be repeated thousands of times. And analyses dealing with the network activity must deal with data that easily reaches hundreds of gigabytes per second of simulation. Using massively parallel computers the data can be analyzed where it is created (server-side analysis for experimental data, online analysis during simulation).

Given the geometric complexity of the column, a visual exploration of the circuit is an important part of the analysis. Mapping the simulation data onto the morphology is invaluable for an immediate verification of single cell activity as well as network phenomena. Architects at EPFL have worked with the Blue Brain developers to design a visualization interface that translates the Blue Gene data into a 3D visual representation of the column. A different supercomputer is used for this computationally intensive task. The visualization of the neurons' shapes is a challenging task given the fact that a column of 10,000 neurons rendered in high quality mesh (see picture) accounts for essentially 1 billion triangles for which about 100GB of management data is required. Simulation data with a resolution of electrical compartments for each neuron accounts for another 150GB. As the electrical impulse travels through the column, neurons light up and change color as they become electrically active.
Modeling in Blue Brain Project
Reverse Engineering of Mammalian brain down to Molecular Level

SIMPLIFICATION OF A COMPLEX PROBLEM BY IDEALIZATION, AND ABSTRACTION IN A SIMPLIFIED CONTEXT, DIVIDE AND CONQUER

“THE REAL WORLD” “AS IS”: MEANINGFUL DATA (INFORMATION) + NOT YET MEANINGFUL DATA + EXISTING KNOWLEDGE

COMPARISON OF SIMULATED NCC WITH BIOLOGICAL ONE

http://www.visualbiotech.ch/downloads/visualbiotech_biostech08.pdf
Neurons are not all alike - they come in a variety of complex shapes. The precise shape and structure of a neuron influences its electrical properties and connectivity with other electrical properties and connectivity with other neurons. A neuron's electrical properties are determined to a large extent by a variety of ion channels distributed in varying densities throughout the cell's membrane. Scientists have been collecting data on neuron morphology and electrical behavior of the juvenile rat in the laboratory for many years, and this data is used as the basis for a model that is run on the Blue Gene to recreate each of the 10,000 neurons in the NCC.
Model Validation

real system  modeling  conceptual model

expected behavior validation simulated behavior

http://www.cs.clemson.edu/~found04/Foundations02/Session_Briefs/T1B_desel.pp
Teaching System Modeling, Simulation and Validation 29
requirements

specifying

specification / design

implementing

system implementation

verifying

the ideal solution

validation

testing
Astrocytes are characteristic star-shaped glial cells in the brain and spinal cord.

Astrocytes propagate *intercellular Ca2+ waves over long distances* in response to stimulation, and, similar to neurons, release transmitters (called gliotransmitters) in a Ca2+-dependent manner. Data suggests that astrocytes also signal to neurons through Ca2+-dependent release of glutamate.

(Perreira & Furlan, Analog modeling of human cognitive functions with tripartite synapses, MBR09)
Info-Computationalist approach
Computation as Information Processing

Information as a stuff of the universe (informational structural realism, Floridi)

Computation as a dynamics (process) –
Computing universe (natural computationalism)

With information as the primary stuff of the universe, and computation as its time-dependent behavior (dynamics), we have a Dual-aspect Universe: informational structure with computational dynamics.

Information and computation are closely related – no computation without information, and no information without dynamics (computation).
Info-computational nature

- Agent-centered (information and computation is in the agent)
- Agent is a cognizing biological organism or an intelligent machine or a combination
- Interaction with the physical world (and other agents as a part of it) is essential
- Kind of physicalism with information as a stuff of the universe
- Agents are parts of different cognitive communities
- What is considered to exist and can exist (ontology) depends on agency – in the next step agency depends on what is taken for granted to exist and can exist
Naturalizing Epistemology

Naturalized epistemology (Feldman, Kornblith, Stich) is, in general, an idea that knowledge may be studied as a natural phenomenon -- that the subject matter of epistemology is not our concept of knowledge, but the knowledge itself.

*The stimulation of his sensory receptors is all the evidence anybody has had to go on, ultimately, in arriving at his picture of the world. Why not just see how this construction really proceeds? Why not settle for psychology?* ("Epistemology Naturalized", Quine 1969; emphasis mine)

I will re-phrase the question to be: **Why not settle for computing?**

**Epistemology** is the branch of philosophy that studies the nature, methods, limitations, and validity of knowledge and belief.
Naturalist understanding of cognition

According to Maturana and Varela (1980) even the simplest organisms possess cognition and their meaning-production apparatus is contained in their metabolism. Of course, there are also non-metabolic interactions with the environment, such as locomotion, that also generates meaning for an organism by changing its environment and providing new input data.

Maturana’s and Varelas’ understanding of cognition is most suitable as the basis for a computationalist account of the naturalized evolutionary epistemology.
Info-computational account of knowledge generation

Dual-aspect unification of information and computation as physical phenomena

Natural computing as a new paradigm of computing goes beyond the Turing Machine model and applies to all physical processes including those going on in our brains.
Info-computational account of knowledge generation

The Turing Machine model is about mechanical, syntactic symbol manipulation as implemented on the hardware level. All complexity is to be found on the software level. Different levels of complexity have different meanings for different cognizing agents.

Semantics is essential for living organisms. Semantics defines the relationship between the mind and the world.

Information has both declarative and non-declarative forms (e.g. biology), each of them with their own role for living systems.
Info-computational account of knowledge generation

Info-computationalist approach as *agent-centered* allows for pluralism: logical, epistemological and ethical. It is supported by research results from physics, biology, neuroscience and philosophy of mind, among others.

At the physical level, living beings are open complex computational systems in a regime on the edge of chaos, characterized by maximal informational content. Complexity is found between orderly systems with high information compressibility and low information content and random systems with low compressibility and high information content.
Cognition as re-structuring an agent in interaction with the environment

All cognizing beings are in constant interaction with their environment. They are open complex systems in a regime on the edge of chaos, which is characterized by maximal informational capacity, Flake.

The essential feature of cognizing living organisms is their ability to manage complexity, and to handle complicated environmental conditions with a variety of responses which are results of adaptation, variation, selection, learning, and/or reasoning, Gell-Mann.
Cognition as re-structuring an agent in interaction with the environment

As a result of evolution, increasingly complex living organisms arise that are able to survive and adapt to their environment. It means they are able to register inputs (data) from the environment, to structure those into information, and in more developed organisms into knowledge. The evolutionary advantage of using structured, component-based approaches is improving response-time and efficiency of cognitive processes of an organism.

The Dual network model, suggested by Goertzel for modeling cognition in a living organism describes mind in terms of two superposed networks: a self-organizing associative memory network, and a perceptual-motor process hierarchy, with the multi-level logic of a flexible command structure.
Cognition as re-structuring an agent in interaction with the environment

In a nutshell, naturalized knowledge generation acknowledges the body as our basic cognitive instrument. All cognition is embodied cognition, in both microorganisms and humans (Gärdenfors, Stuart). In more complex cognitive agents, knowledge is built upon not only reasoning about input information, but also on intentional choices, dependent on value systems stored and organized in agents memory.

It is not surprising that present day interest in knowledge generation places information and computation (communication) in focus, as information and its processing are essential structural and dynamic elements which characterize structuring of input data (data → information → knowledge) by an interactive computational process going on in the agent during the adaptive interplay with the environment.
Summary on constructive research

Constructive research relies on models
   (physical, logical, info-computational artifacts)

Models are investigative instruments

Models are always instances (certain viewpoint, partial truth)

Multiple explanations are not only possible but often necessary
Summary on constructive research

Models are tools for making inferences

Models make inaccessible reality accessible and communicable

Coherence between models (partial truths) is sought

The two-way learning process – both about the modelled phenomena and about the nature of the model itself

The info-computational approach is our most powerful modelling tool
INFORMATION AND COMPUTATION

Forthcoming Book by World Scientific Publishing Co.
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Brier Søren - Cybersemiotics and the question of knowledge

Burgin Mark - Information Dynamics in a Categorical Setting

Chaitin Greg - Leibniz, Complexity & Incompleteness

Collier John - Information, Causation and Computation

Cooper Barry - From Descartes to Turing: The computational Content of Supervenience

Dodig Crnkovic Gordana and Mueller Vincent - A Dialogue Concerning Two Possible World Systems

Hofkirchner Wolfgang - Does Computing Embrace Self-Organization?

Kreinovich Vladik & Araiza Roberto - Analysis of Information and Computation in Physics Explains Cognitive Paradigms: from Full Cognition to Laplace Determinism to Statistical Determinism to Modern Approach
INFORMATION AND COMPUTATION

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MacLennan Bruce J. - Bodies — Both Informed and Transformed

Menant Christophe - Computation on Information, Meaning and Representations. An Evolutionary Approach

Mestdagh C.N.J. de Vey & Hoepman J.H. - Inconsistent information as a natural phenomenon

Minsky Marvin - Interior Grounding, Reflection, and Self-Consciousness

Riofrio Walter - Insights into the biological computing

Roglic Darko - Super-recursive features of natural evolvability processes and the models for computational evolution

Shagrir Oron - A Sketch of a Modeling View of Computing

Sloman Aaron - What's information, for an organism or intelligent machine? How can a machine or organism mean?

Zenil Hector & Delahaye Jean-Paul - On the algorithmic nature of the world

45