On Computational Hypotheses and Computational Experiments

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Standard Meanings of Computational Hypothesis

1. a formulation of standard scientific hypotheses where the system under experimentation is virtual, or simulated, or expressed through computable equations

2. any claim formulated and then tested in computer science research, concerning for example the invention of a new technique or algorithm
    - tested behaviourally, i.e. by analysing how the system or systems under scrutiny behave when operational on some input of interest and in a controlled environment
    - tested in relation to the extent to which they apply, i.e. in reference to the class of systems satisfying them
    - tested for efficiency

Stronger epistemic interpretation

To reconsider standard scientific principles of

- hypothesis formulation,
- experiment design and
- experiment execution

for the context of computing as an experimental science, i.e. to provide an interpretation of them as computational statements.

Types of Hypotheses

1. Declarative hypothesis: a positive statement expressing a relationship between the variables of interest.
2. Null hypothesis: a negative statement expressing that no significant difference exists between the variables of interest.
3. Alternative hypothesis: a hypothesis contrary to the null hypothesis.
4. Interrogative hypothesis: a question about certain relationship between the variables of interest;
5. Predictive hypothesis: a positive statement expressing expected principles emerging from testing.

Computational Declarative Hypothesis

Definition (Computational Declarative Hypothesis – Black Box Version)

A statement about the existence of an algorithmic behaviour expressing a given I/O relation.

Computational Declarative Hypothesis

Definition (Computational Declarative Hypothesis – White Box Version)

A statement about the structure of an algorithmic behaviour expressing a given I/O relation.

Computational Null Hypothesis

Definition (Computational Null Hypothesis)

A provable statement that a certain I/O relation does not hold.

Computational Alternative Hypotheses

Definition (Computational Alternative Hypothesis)

A provable statement that a certain I/O relation holds.

Computational Interrogative Hypothesis

Definition (Computational Interrogative Hypothesis)

Does a certain algorithmic relationship hold between the input and output variables of the problem of interest?

Computational Predictive Hypothesis

Definition (Computational Predictive Hypothesis)

A prediction about how a system will behave algorithmically (including output expectation) when provided with a given input.

Computational Hypothesis Falsification

Definition (Black Box Falsifier)

An instance of an I/O relation which given an input appropriate to a computational hypothesis returns an output different from the one expected.

Computational Hypothesis Falsification

Definition (Black Box Falsifier)

An instance of an I/O relation which given an input appropriate to a computational hypothesis returns an output different from the one expected.

Definition (White Box Falsifier)

An istance of an algorithm different from the one defined according to the computational hypothesis, which realises the intended I/O relation.

Nelson Goodman's Equivalence Thesis

Thesis (Equivalence from observation)

A set of observed I/O relations will equally support multiple hypotheses on the underlying algorithmic behaviour.

Carl Hempel's Logical Equivalence Thesis

Thesis (Logical equivalence from observation)

An observed algorithmic behaviour confirming a hypothesis about an underlying I/O relation, also confirms all the logically equivalent behaviours.

Karl Popper's Informational Content Thesis

Thesis (Informational Content)

The informational content of a White Box (resp. Black Box) computational hypothesis is inversely (resp. directly) proportional to the amount of its Black Box (resp. White Box) falsifiers.

On Computational Hypotheses

On Computational Experiments

An early analysis of the experimental process for Computing [Basili, 1986]

1. the process starts with a study definition phase: problem, objective, goals,
2. followed by a study planning phase: instruments selection, threats consideration
3. a study operation phase: measurements collection
4. with a final phase of interpretation: measurements analysis.

Four Parameters [Basili, 1996]

1. object of study: what is the system of which a model is sought;
2. purpose: for which aim is the model designed (definition, evaluation, prediction, control, improvement);
3. focus: the aspect of interest of the system (reliability, defect prevention, accuracy);
4. point of view: the user benefitting from the analysis.

Types of Experiments [Basili, 1996]

1. descriptive: searching for patterns in data
2. correlational: searching for relations between independent and dependent variables
3. cause-effective: searching for cause-effect relations between independent and dependent data.

Types of Experiments in current literature

- Demonstration: showing a system feasible, reliable, cost-efficient, through construction and demonstration;
- Trial: showing that a system meets some specification through a test;
- Testing: showing a functional system in a live environment;
- Comparison: showing that a system outperforms another system on a given task, with a given dataset and parameters;
- Control: standard application of the scientific method, to show that a given computational hypothesis holds;
- Exploration: a process of testing technologies in their socio-technical contexts, with control applied a posteriori.

Evaluation I

- (independent and dependent) variables selection, with corresponding measurement scale, range and tests.
- Representative examples selection of algorithms and their I/O relations: training and test set of inputs;
- varied, unbiased, generally acknowledged and well designed set of input examples must be chosen;
- selection done by random, systematic, stratified, convenience and quota sampling.
- evaluation through White or Black Box systems;

Evaluation II

- size of the sample with large variability in the population.
- controlled experiments compared with sufficiently similar algorithmic systems;
- Similarity defined in terms of knowledge of the algorithmic structure, languages used and physical support deployed.

First experimental method: Testing

1. Computational Declarative Hypothesis types have each a corresponding testing method
   - Black Box: testing functionalities
   - White Box: testing mechanisms

2. commonalities of testing with science:
   - reliance on falsifiability to prove that software works,
   - the skeptical approach of testers,
   - the underlying notion of knowledge of a system as systematically weak
   - the combination of skills, inferential and conjectural methods following the design of a model of the system.

3. testing consists of guiding principles and it is not a strict method.

4. testing requires essentially a software and hardware artefact construction, and as such it crucially involves property generalization.

Second experimental method: Simulation

1. increases the inferential nature of the process, mainly based on the formulation of a model for the target system
2. requires the implementation in a computational model, i.e. the translation in a language and its execution on hardware (limitation on generalization)
3. main problem in establishing a simulation model sufficiently apt for extrapolation of valid results is to provide a balanced design between generality and precision

Experimental Validity

- Conclusion Validity: concerned with the relationship between the experimental method chosen (testing or simulation) and its output.
- Internal validity: considering the causal relationship between method chosen and output.
- Construct validity: concerned with the relation between model and observed behaviour in the chosen method;
- External validity: concerned with the generalization of results from the observed behaviour to the model.

Main Aims

- Construction of correct model
- Correct implementation
- Validation (establishing that the experimental results actually apply to the system of interest)
- Evaluation

Computing, today more than ever before, is a multi-faceted discipline which collates several methodologies, areas of interest, and approaches: mathematics, engineering, programming, applications. Given its enormous impact on everyday life, it is essential that its debated origins are understood, and that its different foundations are explained. *On the Foundations of Computing* offers a comprehensive and critical overview of the birth and evolution of computing, and it presents some of the most important technical results and philosophical problems of the discipline, combining both historical and systematic analyses.

The debates this text surveys are among the latest and most urgent ones: the crisis of foundations in mathematics and the birth of the decision problem, the nature of algorithms, the debates on computational artefacts and malfunctioning, and the analysis of computational experiments. By covering these topics, *On the Foundations of Computing* provides a much-needed resource to contextualize these foundational issues.

For practitioners, researchers, and students alike, a historical and philosophical approach such as what this volume offers becomes essential to understand the past of the discipline and to figure out the challenges of its future.

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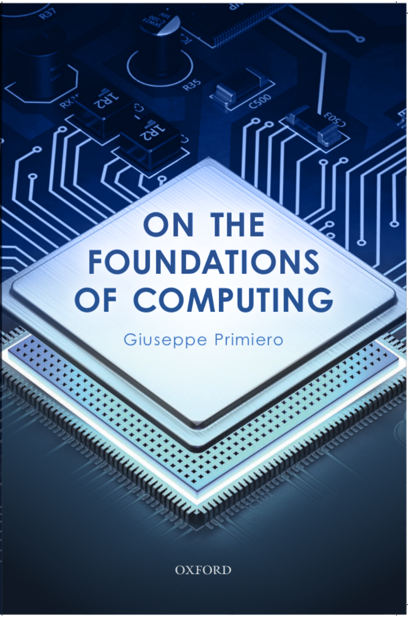

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