Critical Analysis of Computer Science Methodology

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Computer Science Research

Two main types of methods:

1. experimental methods (based on measurements and/or observations)
2. formal methods (based on logic and/or mathematics)

Computer Science Research

Two main types of methods:

1. experimental methods – Jan Gustafsson

2. formal methods – Björn Lisper

The experimental research process using the hypothetical-deductive method

Existing theory $\rightarrow$ Problem formulation $\rightarrow$ Hypothesis $\rightarrow$ Experiment $\rightarrow$ Conclusion

Two main possible conclusions:

- The result verifies/corroborates the hypothesis
- The result falsifies the hypothesis

Notes

- Experiments can only verify/corroborate general hypotheses, never prove them (Popper).
- A scientific theory must be falsifiable (Popper).
- Experiments must be repeatable.

Pitfalls

There are many pitfalls that should be avoided.

I will discuss four typical examples.

Computer scientists should be aware of these pitfalls and improve their experimental skills!

Typical example 1

Existing theory: We have method x.

Problem formulation: Method x has shortcomings.

Hypothesis: We propose our method y, which has the following advantages (precision, efficiency, handles more cases...) compared to method x.

Experiment: We use method x and y on some benchmark, and observe that y exhibits the advantages we predicted.

Conclusion (correct?): We conclude that our method has the advantages we predicted.

Problems with the conclusion

- We have support for our hypothesis only in a small number of cases
- Is the benchmark we have chosen really suitable (representative), i.e. are we really allowed to make generalizations?
- We have not tried to falsify the hypothesis
- There can be other disadvantages with method y, which are not observed

Typical example 2

Existing theory: We have method x.

Problem formulation: Method x has shortcomings.

Hypothesis: We propose our method y, which has the following advantages (precision, efficiency, handles more cases...) compared to method x.

Experiment: We use our method y on one or more cases which we constructed ourselves, and observe that y exhibits the advantages we predicted.

Conclusion (correct?): We conclude that our method has the advantages we predicted.

Problems with the conclusion

- There is a risk that we (in our eagerness to publish) choose ”nice” cases
- We have support for our hypothesis only in a small number of cases
- We have not tried to falsify the hypothesis (maybe we even subconsciously – or actively – avoided this...)
- We did not try to repeat method x on our cases, which endangers the conclusion
- There can be other disadvantages with method y, which are not observed

Typical example 3

Existing theory: We have a system x.

Problem formulation: We need to describe a behaviour b of x to be able to predict the system.

Hypothesis: We claim that the behaviour b of x can be described by a function y.

Experiment: We measure the behaviour b for a number of cases and show that our measurements lie on the curve of y.

Conclusion (correct?): The behaviour b of x can be descibed by the function y.

Problems with the conclusion

- We have only measured a subset of possible cases
- We don't know what happens for other inputs
- We have not tried to falsify the hypothesis (which can take "forever")

Note 1: The correct use of statistics may help for some types of measurements.

Note 2: Statistics may not help if we have a discrete system.

Typical example 4

Existing theory: We have a system x.

Problem formulation: We want to improve the behaviour b.

Hypothesis: We claim that the behaviour b changes to a better behaviour b' if we make the change y to the system.

Experiment: Since the system is very complex, we build a model m of it and apply the change y to it. We observe or measure that the behaviour of m changes to b'.

Conclusion (correct?): The change y will improve the behaviour of the system to b'.

Problems with the conclusion

- How can we claim the the model exhibits the same behaviour as the system?
- Even if the model exhibits the same behaviour as the system, how can we claim that the change y has the same effect on the model as on the system?
- In addition to this, all the problems with measurements as in example 3 above

Note: The art of building models and doing simulations is central here.

Final remarks

- There are many pitfalls that should be avoided.
- Computer scientists should be aware of these pitfalls and improve their experimental skills!
- Basic knowledge of science theory and research methodology is necessary.
- Careful selection of measurement methods and test data cases is important.
- Knowledge of model building and simulations is essential.