Writing for

Computer Science & Engineering

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Hypotheses, Questions, and Evidence

Introduction

- First stage of a research program
  - Choice of interesting topics or problems
  - Identification of particular issues to investigate
  - Development of specific questions to answer
  - These establish the framework for making observation about the object being studied – a statement of belief about how the object behaves, a hypothesis
- Example of hypotheses in computer science
  - Limits of speech recognition
  - Web search by children
  - Predicting how well a service will response to increasing load
  - Proposing new technologies and exploring their limitations and feasibility

Regardless of field, if you wish to achieve robust research outcomes,
It is essential to have a hypothesis

Hypotheses

❖ Example research program

- A research investigate algorithm might speculate as to whether it is possible to make better use of the cache on a CPU to reduce computational costs
- Preliminary investigation might lead to the hypotheses that a tree-based structure with poor memory locality will be slower in practice than an array-based structure with high locality, despite the additional computational cost
- The hypothesis suggests the research question of whether a particular sorting algorithm can be improved by replacing the tree structure with the array structure
- The phenomenon that should be observed if the hypothesis is correct is a trend; as the number of items to be sorted is increased, the tree-based method should increasingly show a high rate of cache misses compared to the array-based method
- The evidence is the number of cache misses for several sets of items to be sorted. External evidence might be used, such as changes in execution time as the volume of data changes

Hypothesis or Research Question

- Specific, precise, unambiguous

- Suppose P-lists are well-known data structure as in-memory search structure that is fast and compact
  - A scientist has developed a new data structure called Q-list
  - Formal analysis : the same asymptotic complexity in time and space
  - Scientist intuitively believes that Q-list to be superior in practice and has decided to demonstrate this by experiment

Hypothesis

B : Q-lists are superior to P-lists

- Not sufficient as the basis of an experiment
  - Success would have to apply in all applications, in all conditions, for all time
  - Formal analysis is able to justify such a result, but no experiment will be so far-reaching, but no experiment will be so far-reaching
  - In any case, it is rare for a data structure to be completely superseded so in all probabilities this hypothesis is incorrect

G :

1) **As an in-memory search structure for large data sets, Q-lists are faster and more compact than P-list**
2) **We assume there is a skew access pattern, that is, that the majority of accesses will be to a small proportion of the data**

Hypothesis

G :

1) As an in-memory search structure for large data sets, Q-lists are faster and more compact than P-list
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- Imposes a scope on the claims made on behalf of Q-lists
  - Q-lists do not suit a certain application
  - Explore the behavior of Q-lists under another set of conditions
- Hypothesis must be testable, capable of falsification

B :

1) Q-list performance is comparable to p-list performance
2) Our proposed query language is relatively easy to learn

Poor Hypotheses

- "Black box" work
  - Applying a black-box learning algorithm to new data with outcome that the results are an improvement on a baseline method (Claims is to the effect that our black box is significantly better than random)
  - A weakness of such research is that it provides no insights into the data or the black box and no implication for other investigation
  - The results are not predictive
- Re-naming fallacy – attempt to reposition their research within a fashionable area
  - A particular piece of research is not made innovative merely by changing the terminology
  - Renaming existing research to place it in another field is bad science

Defending Hypotheses

- Component of strong paper
  - Precise, interesting hypothesis
  - Testing of the hypothesis and presentation of the supporting evidence
- "The new range searching method is faster than previous methods"
  - Supported by the evidence "range search amongst n elements requires $2\log_2\log_2 n+c$ comparisons
  - May or may not be good evidence
  - What is missing is information such as "results for previous methods indicates an asymptotic cost of O(logn)"
  - Connecting argument to show that the evidence does indeed support the hypothesis and to show that conclusions have been drawn correctly

Defending Hypotheses

- Constructing an argument
  - Imagine yourself defending your hypothesis to a colleague so that you play role of inquisitor
  - Raising objections and defending yourself against them is a way of gathering the material that is needed to convince the reader that your argument is correct
- "The new string hashing algorithm is fast because it doesn't use multiplication or division"
  - I don't see why multiplication and division are a problem
  - Module isn't always in hardware either
  - So, there is also an array lookup? That can be slow
  - What happens if the hash table size is not 2^8?

Defending Hypotheses

- Be persuasive
- Issues to be addressed
  - Will the reader believe that the algorithm is new?
  - Will the reader believe that the algorithm is sensible?
  - Are the experiments convincing?

Forms of Evidence

- A paper can be viewed as an assembly of evidence and supporting explanations
  - Use objective evidence to achieve aims such as to persuade readers to make more informed decisions and to deepen their understanding of problems and solutions
  - In write-up you pose a question or hypothesis, then present evidence to support your cases
  - Four kinds of evidence that can be used to support a hypothesis: proof, modeling, simulation, and experiment

Forms of Evidence – Proof

❖ Proof

- Formal argument that a hypothesis is correct (wrong)
- It is mistake to suppose that the correctness of a proof is absolute – confidence in a proof may be high, but that does not guarantee that it is free from error
- Some hypotheses are not amendable to formal analysis
- It is also mistake to suppose that an asymptotic analysis is always sufficient
- The possibility of formal proof should never be overlooked

Forms of Evidence – Model

- **Model**
  - Mathematical description of the hypothesis and there will usually be a demonstration that the hypothesis and model do indeed correspond
  - Consider how realistic it will be, or conversely how many simplifying assumptions need to be made for analysis to be feasible
- **Modelling the cost of a query on a text collection – a task is to find the documents that contain each of a set of words**
  - Estimate the frequency of each word
  - The likelihood of query terms occurring in the same documents
  - Longer documents contain more words, but are more expensive to fetch
  - The possibility that the same query had been issued recently and the answers are cached in memory
  - Define a model based on these factors, but, with so many estimates to make and parameters to tune, it is unlikely that the model would be realistic

Forms of Evidence – Simulation

Simulation

- An implementation or partial implementation of a simplified form of the hypothesis, in which the difficulties of a full implementation are sidestepped by omission or approximation
- A simulation is a "white coats" test: artificial, isolated and conducted in a tightly controlled environments
- Advantage : provides parameters that can be smoothly adjusted, allowing the researcher to observe behavior across a wide spectrum of inputs or characteristics
- The risk that is unrealistic or simplistic, with properties that mean that the observed results would not occur in practice
- Simulation are powerful tools, but, ultimately, need to be verified against reality

Use of Evidence

- Different forms of evidence can be used to confirm one another
  - A simulation used to provide further evidence that a proof is correct
- Choosing whether to use
  - How convincing each is likely to be to the reader
  - Select a form of evidence to be as persuasive as possible
- Some novice researchers feel that the standards expected of evidence are too high
- Readers tend to trust work that is already published in preference to a new, unreferred paper and have no reason to trust work where the evidence is thin

Approaches to Measurement

- Development of tools of measurement
- Purpose of experimentation
  - Take measurements that can be used as evidence
  - A good choice of measure is essential to practical system improvement and persuasive and insightful writing
- Measurements
  - Quantitative (number, duration, volume, speed of a system, algorithm's efficiency relative to baseline)
  - Qualitative (occurrence or difference)
- What is to be measured? What measures will be used?
  - Algorithm : measured by execution time, single-thread process running on a single machine

Good and Bad Science

- Quality of evidence
- Merits of formal studies
  - Easy to appreciate
  - Provide the kind of mathematical link between the possible and practical that provides between the universal and engineering
- Merits of experimental work
  - Many questions cannot be readily answered through analysis
  - A theory without practical confirmation is of no more interest in computing than in the rest of science
- Research that consists of proposals and speculation, entirely without a serious attempt at evaluation, can be more difficult to respect

Good and Bad Science

❖ Terminology

- Terms that in common usage describe aspects of cognition or consciousness such as "intelligent", "belief", "aware" are particularly slippery
- In their common usage, they are not well defined

A Checklist

- Hypotheses and questions
  - What phenomena or properties are being investigated? Why are they of interest?
  - Has the aim of the research been articulated? What are the specific hypotheses and research questions? Are these elements convincingly connected to each other?
  - To what extent is the work innovative? Is this reflected in the claims?
  - What would disprove the hypothesis? Does it have any improbable consequences?
  - What are the underlying assumptions? Are they sensible?
  - Has the work been critically questioned? Have you satisfied yourself that it is sound science?

A Checklist

- Evidence and measurement
  - What forms of evidence are to be used? If it is a model or a simulation, what demonstrates that the results have practical validity?
  - How is the evidence to be measured? Are the chosen methods of measurement objective, appropriate, and reasonable?
  - What are the qualitative aims, and what makes the quantitative measures you have chosen appropriate to those aims?
  - What compromises or simplifications are inherent in your choice of measure?
  - Will the outcomes be predictive?
  - What is the argument that will link the evidence to the hypothesis?
  - To what extent will positive results persuasively confirm the hypothesis? Will negative results disprove it?
  - What are the likely weaknesses of or limitations to your approach?


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&
A