Part 3

- ***Scientific method***
- ***Intellectual discovery***
- ***Classifications of research***

Research Methods in Computer Science

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Scientific method

- Scientists use observations and reasoning to develop technologies and propose explanations for natural phenomena in the form of hypotheses
- Predictions from these hypotheses are tested by experiment and further technologies developed
- Any hypothesis which is cogent enough to make predictions can then be tested reproducibly in this way
- Once it has been established that a hypothesis is sound, it becomes a theory.
- Sometimes scientific development takes place differently with a theory first being developed gaining support on the basis of its logic and principles

Scientific method

The essential elements of a scientific method are iterations, recursions, interleavings and orderings of the following:

- Characterisations
  (Quantifications, observations and measurements)
- Hypotheses
  (theoretical, hypothetical explanations of observations and measurements)
- Predictions
  (reasoning including logical deduction from hypotheses and theories)
- Experiments
  (tests of all of the above)

Both characterisations and experiments involve data collection

Intellectual discovery

- Knowing what the elements of a scientific method are does not tell us how to come up with the right instances of these elements
  - What predictions does a theory make?
  - What is the right hypothesis in a particular situation?
  - What is the right experiment to conduct?

- These are commonly derived by a process involving
  - Deductive reasoning
  - Abductive reasoning
  - Inductive reasoning

Classification by Charles Sanders Peirce (1839-1914)
See `http://plato.stanford.edu/entries/peirce/` for additional details

Deduction *(tümdengelim)*

- Deductive reasoning proceeds from our knowledge of the world (theories) and predicts ‘likely’ observations

  Example:

  – Assume we know that A implies B.
  – A has been observed.
  – Then we should also obverse B.

- Useful for experiment generation for theories

  Example:

  Newton’s theory of gravity versus Einstein’s theory of relativity

  - Largely make the same predictions
  - Both predict that the sun’s gravity should bend rays of light
  - However, Einstein’s theory predicts a greater deflection
  - Correctness of Einstein’s prediction confirmed by observation in 1919

Deduction *(tümdengelim)*

- Deductive reasoning is often said not to lead to new knowledge (Note: This implies pure mathematicians largely waste their time)
  - ⇝ Seriously underestimates the computational effort involved in deductive reasoning
  - ⇝ Most theories are undecidable
    (There is no algorithm that even given infinite time could determine whether a statements follows from a theory or not)
  - ⇝ Thus, establishing that a statement follows from a theory extends our knowledge

Deduction *(tümdengelim)*

899 in Claremont, Cape Town)
Four Colour Problem in 1852.
ıder John Lindley at University
52 with first class honours.
least four colours were
same colour. He postulated
ne known as the Four Color
in graph theory for more than
puter-aided proof by Appel

ntertained by Dr Dale (later Sir
versity of the Cape of Good
at the Graaff-Reinet College.
y in 1862 and thus started a
to take up the study of botany

Francis Guthrie

Four color theorem

57 languages

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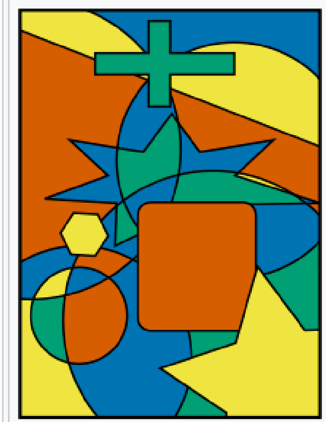
(Redirected from Four color conjecture)

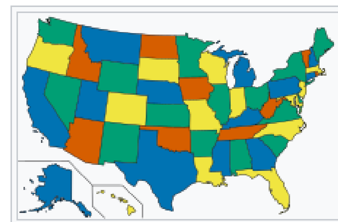
In mathematics, the **four color theorem**, or the **four color map theorem**, states that no more than four colors are required to color the regions of any map so that no two adjacent regions have the same color. *Adjacent* means that two regions share a common boundary of non-zero length (i.e., not merely a corner where three or more regions meet).[1] It was the first major theorem to be proved using a computer. Initially, this proof was not accepted by all mathematicians because the computer-assisted proof was infeasible for a human to check by hand.[2] The proof has gained wide acceptance since then, although some doubts remain.[3]



Example of a four-colored map

The theorem is a stronger version of the five color theorem, which can be shown using a significantly simpler argument. Although the weaker five color theorem was proven already in the 1800s, the four color theorem resisted until 1976 when it was proven by Kenneth Appel and Wolfgang Haken. This came after many false proofs and mistaken counterexamples in the preceding decades.

The Appel–Haken proof proceeds by analyzing a very large number of reducible configurations. This was improved upon in 1997 by Robertson, Sanders, Seymour, and Thomas who have managed to decrease the number of such configurations to 633 – still an extremely long case analysis. In 2005, the theorem was verified by Georges Gonthier using a general-purpose theorem-proving software.



A four-colored map of the states of the United States (ignoring lakes and oceans)

Formulation [edit]

In graph-theoretic terms, the theorem states that for loopless planar graph G, its chromatic number is $\chi(G) \leq 4$.

Abduction

- Abductive reasoning proceeds from observations to causes

  Example:

  – The phenomenon X is observed.
  – Among hypotheses A, B, C, and D,
  only A and B are capable of explaining X.
  – Hence, there is a reason to assume that A or B holds.

  $\rightsquigarrow$ Requires a theory linking A, B, C, D to X
- Useful for hypothesis generation
- Hypotheses must then be confirmed / eliminated through further observation
- It is not easy from the outside to decide whether someone uses deduction or abduction

  $\rightsquigarrow$ The two are often confused

Induction *(tümevarim)*

- Inductive reasoning proceeds from a set of observations to a general conclusion

  Example:

  – Tycho Brahe, a 16th century astronomer, collected data on the movement of the Mars.

  – Johannes Kepler analysed that data which was consistent with Mars moving in an elliptic orbit around the sun.

  – Inductive conclusion:
  Mars, and all other planets, move in elliptic orbits around the Sun, with the Sun at one of the focal points of the ellipse.

- Primary tool for theory formation

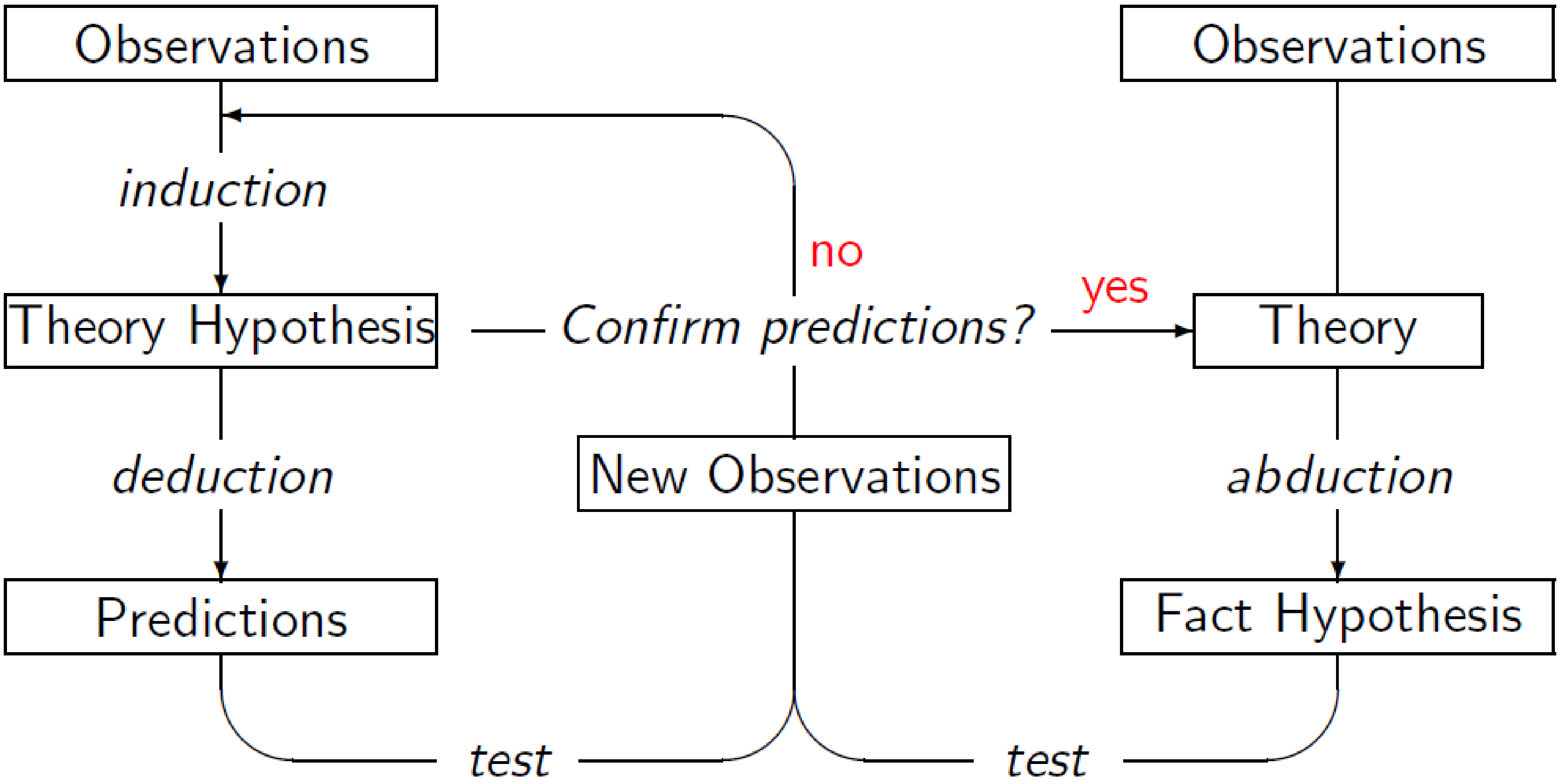
- An incomplete set of observations can easily lead to incorrect inductive conclusions

  Example:

  – All swans I've ever seen are white

  – Inductive conclusion: All swans are white

Scientific method as a model



Additional techniques for problem solving

- Analogy: Look for similarity between one problem and another one already solved
- Partition: Break the problem into smaller sub problems which are easier to solve
- Random/Motivated Guesses: Guess a solution to the problem then prove it correct
- Generalise: Take the essential features of the specific problem and pose a more general problem
- Particularise: Look for a special case with a narrower set of restriction than the more general case
- Subtract: Drop some of the complicating features of the original problem
- Add: A difficult problem may be resolved by adding an auxiliary problem

Classifying research

Research can be classified from three different perspectives:

1. Field

   Position of the research within a hierarchy of topics

   Example:

   Artificial Intelligence $\longrightarrow$ Automated Reasoning $\longrightarrow$
   First-Order Reasoning $\longrightarrow$ Decidability

2. Approach

   Research methods that are employed as part of the research process

   Examples:

   Case study, Experiment, Survey, Proof

3. Nature
   - Pure theoretical development
   - Review of pure theory and evaluation of its applicability
   - Applied research

Nature of research

- Pure theory:
  Developing theories and working on their consequences, with regard to experimentation or application

- Descriptive studies:
  Reviewing and evaluating existing theories, including describing the state of the art, comparing predictions with experimental data
- Exploratory studies:
  Investigating an 'entirely' new area of research, exploring a situation or a problem
  See `http://www2.uiah.fi/projects/metodi/177.htm`
- Explanatory studies:
  Explaining or clarifying some phenomena or identifying the relationship between things

Nature of research

- Causal studies:
  Assessing the causal relationship between things
- Normative studies:
  Producing a theory of design (or of other development) like recommendations, rules, standards, algorithms, advices or other tools for improving the object of study
- Problem-solving studies:
  Resolving a problem with a novel solution and/or improving something in one way or another
- Development and Application studies:
  Developing or constructing something novel

Research methods

- Quantitative research methods
  - Methods associated with measurements (on numeric scales)
  - Stemming from natural sciences
  - Used to test hypotheses or create a set of observations for inductive reasoning
  - Accuracy and repeatability of vital importance
- Qualitative research methods
  - Methods involving case studies and surveys
  - Stemming from social sciences
  - Concerned with increasing understanding of an are, rather than an explanation
  - Repeatability usually a problem

Research methods

- Action research:
  - Pursues action (or change) and understanding at the same time
  - Continuously alternates between action and critical reflection, while refining methods, data and interpretation in the light of the understanding developed in the earlier cycles

  Example: Reflective teaching

- Case study:
  - In-depth exploration of a single situation
  - Usually generates a large amount of (subjective) data
  - Should not merely report the data obtained or behaviour observed but attempt to generalise from the specific details of the situation observed

  Example: Case study of open source software development

Research methods

- Survey:
  - Usually undertaken using questionnaires or interviews
  - Questionnaire and interview design important!
    (See Dawson 2005 for details)
  - Determination of sample size and sample elements important!
    (See specialist literature for details)

  Example: Survey on the popularity or use of programming languages

- Experiment:
  - Investigation of causal relationships using test controlled by the researcher
  - Usually performed in development, evaluation and problem solving projects

  Example: Evaluation of processor performance

Key elements of an experiment

- A precise hypothesis that the experiment will confirm or refute
- A completely specified experimental system, which will be modified in some systematic way to elicit the effects predicted by the hypothesis
- Quantitative measurement of the results of modifying the experimental system
- Use of controls to ensure that the experiment really tests the hypothesis
- Analysis of the measured data to determine whether they are consistent with the hypothesis
- Report of procedures and results so that others can replicate the experiment

Key issues for questionnaires

- Determining the target audience
- Determining the most appropriate medium
- Achieving an acceptable response rate
- Ensuring anonymity if necessary
- Obtaining additional information about the respondents
- Questionnaire design
  - Layout and size (not too long, uncluttered)
  - Question types
    1. Quantity or information
       How many hours . . .
    2. Classification
       Gender
    3. List or multiple choice
       How do you keep informed?
    4. Scale
       How easy is . . .
    5. Ranking
       Rank in order of importance
    6. Complex grid or table
       Multiple classifications
    7. Open-ended
       What do you think about . . .

End of part 3

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