Professional Skills in Computer Science
Lecture 5: Computer Science Research

Ullrich Hustadt

Department of Computer Science
School of Electrical Engineering, Electronics, and Computer Science
University of Liverpool
Contents

1 What is research?
   The difficulty of characterising ‘Computer Science Research’?
   Definitions of ‘Research’
   Knowledge and Theories
   Gain
   Originality
   Investigation

2 Research processes in Computer Science
   Theoretical research
   Experimental research
   Research through design
   Interdisciplinary research methods

Relevant learning outcome:

1 Ability to describe and discuss
   economic, historic, organisational, research, and social
   aspects of computing as a discipline and computing in practice
What is ‘Computer Science Research’?

- Computer Science is an academic discipline and a scientific discipline.
- Any academic discipline has two parts:
  - domain of study
  - methods for studying the domain
- The definition of ‘Computer Science’ also includes the phrase ‘systematic study’.

What do methods for studying and systematic study refer to?

Both refer to the processes and methods by which we advance our knowledge, that is, research.
Computer Science Research

Compared to other Sciences

- it is not as easy to see what distinguishes 'Computer Science Research' from other activities in Computer Science
- arguably, there is a wider range of processes and methods in use than in many other academic disciplines

E.g. Chemistry:

Worker

Researcher
Computer Science Research

Compared to other Sciences

- it is not as easy to see what distinguishes 'Computer Science Research' from other ICT related activities
- arguably, there is a wider range of processes and methods in use than in many other academic disciplines

Computer Science:

Officer Worker  Software Developer  Computer Science Researcher
Computer Science Research

- We cannot rely on a nice photograph to illustrate what Computer Science Research looks like

- We also cannot say

  ‘Research is what you do in a lab that is later done on a larger scale in industry’

(although that might apply to particular areas of Computer Science Research)

- Instead we have to define what Computer Science Research is and how it is conducted
What is ‘Research’?


An active, diligent, and systematic process of inquiry in order to discover, interpret or revise facts, events, behaviours, or theories, or to make practical applications with the help of such facts, laws, or theories.

Higher Education Funding Council for England: Research

Original investigation undertaken in order to gain knowledge and understanding.

Sharp, Peters and Howard (2002): Research

Seeking through methodical process to add to one’s own body of knowledge and to that of others, by the discovery of non-trivial facts and insights.
## What is ‘Research’? (Comparison)

<table>
<thead>
<tr>
<th>Wikipedia</th>
<th>HEFCE</th>
<th>Sharp et al.</th>
</tr>
</thead>
<tbody>
<tr>
<td>active, diligent, and systematic process of inquiry</td>
<td>(original) investigation</td>
<td>methodical process</td>
</tr>
<tr>
<td>discover, interpret, or revise</td>
<td>gain</td>
<td>discovery</td>
</tr>
<tr>
<td>facts, events, behaviours, or theories</td>
<td>knowledge and understanding</td>
<td>knowledge / non-trivial facts and insights</td>
</tr>
</tbody>
</table>
Research (http://en.wikipedia.org/wiki/Research)

An active, diligent, and systematic process of inquiry in order to discover, interpret or revise facts, events, behaviours, or theories, or to make practical applications with the help of such facts, laws, or theories

Research (Higher Education Funding Council for England)

Original investigation undertaken in order to gain knowledge and understanding

Research (Sharp, Peters and Howard, 2002)

Seeking through methodical process to add to one’s own body of knowledge and to that of others, by the discovery of non-trivial facts and insights
Knowledge and Theories

Knowledge (Dawson, 2005)

- higher level understanding of things
- represents our understanding of the ‘why’ instead of the mere ‘what’
- interpretation of information in the form of rules, patterns, decisions, models, ideas, etc.

Scientific knowledge is often organised into theories.

Theory

- a logically self-consistent model or framework describing the behaviour of a certain natural or social phenomenon, thus either originating from observable facts or supported by them
- formulated, developed, and evaluated in a methodical process
Knowledge and Theories: Criteria

A body of (descriptions of) knowledge is usually only called a theory once it has a firm empirical basis, that is, it

1. is consistent with any pre-existing theory to the extent that the pre-existing theory was experimentally verified, though it will often show pre-existing theory to be wrong in an exact sense,

2. is supported by many strands of evidence rather than a single foundation, ensuring that it probably is a good approximation if not totally correct,

3. makes (testable) predictions that might someday be used to disprove the theory, and

4. has survived many critical real world tests that could have proven it false,

5. is a/the best known explanation, in the sense of Occam’s Razor, of the infinite variety of alternative explanations for the same data.
### Gain

**Research (HEFCE):** Original investigation undertaken in order to **gain** knowledge and understanding

**Contribution**

Research is supposed to **add to the world’s body of knowledge** and understanding (in contrast to adding to the researcher’s knowledge and understanding)
Research (HEFCE): Original investigation undertaken in order to gain knowledge and understanding

Originality

Doing something that has not been done before

Dawson (2005):
There is no point in repeating the work of others and discovering or producing what is already known

But you need to repeat the work of others to DISPROVE what they claim to have discovered!

- Theories make predictions, which need to be tested
- The people performing those tests are neither infallible nor trustworthy
- Tests need to be repeated and results replicated
(In)Fallibility: Faster than light travel


- Paper describes a neutrino experiment conducted at CERN
- Muon neutrinos were sent across a distance of 730km from CERN to Gran Sasso in Italy (CNGS $=$ CERN Neutrino beam to Gran Sasso)
- At the speed of light, travelling that distance takes about 2.4 milliseconds
- The neutrinos were observed to arrive 60 nanoseconds (60 billionth of a second) earlier
- **Contradicts** Einstein’s theory of special relativity

$\leadsto$ Repeat the experiments with a different setup / instruments
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
(Un)Trustworthiness

Jan Hendrik Schön
(http://en.wikipedia.org/wiki/Jan_Hendrik_Sch%C3%B6n)

- Researcher at Bell Labs working in the field of condensed matter physics and nanotechnology
- Extremely productive, with a lot of publications in prominent scientific journals, including Science and Nature
- In 2001, claimed to have produced an organic transistor on the molecular scale
- Published (and peer reviewed) papers were suspected to contain duplicated and anomalous data
- He was dismissed after an investigation found 24 cases of misconduct
- Science withdrew 8 papers and Nature 7 papers co-authored by Schön

〜 Experimental results can be fraudulent
- Only independent repetition provides a safeguard
Investigation

An active, diligent, and systematic process of inquiry

- If it is supposed to be systematic, then there should probably be a description of it
  ~ Research process models
- There are four categories of research process models
  - Sequential
  - Generalised
  - Circulatory
  - Evolutionary
- We first look at research processes in Computer Science presented as sequential research processes
What is Computer Science: Research processes

- Mathematical deduction over formal systems
  We create a mathematical model and study its properties
  ⇝ as in Pure Mathematics

1. Characterise objects of study (definition)
2. Conjecture possible relationships among them (conjecture)
3. Determine whether the relationships are true (proof; conjecture becomes theorem)
4. Interpret results

Research along these lines is also called theoretical research
What is Computer Science: Research processes

- Experiments and computational simulations
  We can perform experiments with computer programs
  We run simulations on a computer
  similar to Physics, Chemistry

1. Construct a **proto-theory** (hypothesis, model)
2. Make a **prediction** based on the proto-theory
3. Design and carry out experiments to test the prediction
4. Analyse and compare outcome of the experiments with prediction
   (if the predictions by the proto-theory are confirmed often enough,
   then it becomes a **theory**)

Research along these lines is also called **experimental research** or
research based on the **scientific method**
What is Computer Science: Research processes

- Creation of artifacts and prototype
  We build something and study its features
  - as in Engineering
    1. Gather requirements
    2. State specification
    3. Design and implement the system
    4. Test, analyse, and evaluate the system

Research along these lines is also called research through design
What is Computer Science: Interdisciplinary research methods

- Undertaking experiments with human users
  We run simulations with real people
  ↦ as in Psychology and Behavioural Economics

- Reasoning about the behaviour of groups
  We ask how groups of people may communicate and act
  ↦ as in Sociology, Social Psychology and Ecology

- Action Research / Reflective narrative
  We undertake some activity and reflect on our experience
  ↦ as in Anthropology and Business Strategy
What is Computer Science: Interdisciplinary research methods

- Personal Introspection
  We ask ourselves how we think and reason and do (Reasoning about your own reasoning)
  ~ as in Philosophy

- Reasoning about others’ individual reasoning
  We ask how other people may think and reason and do
  ~ as in Economics and Game Theory
Further reading

- For more on research in Computer Science see

  C. W. Dawson:
  Projects in computing and information systems: a student’s guide.
  Addison-Wesley, 2009.
  http://library.liv.ac.uk/record=b2321167~S8
  Chapter 2