COMP 516
Research Methods in Computer Science

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with material from Ullrich Hustadt, Rahul Savani, and Dominik Wojtczak

Research

What Is 'Research'?

Research (`http://en.wikipedia.org/wiki/Research` from 4th October 2005)

- 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.
- a collection o f information about a particular subject.
- derives from the Middle French and the literal meaning is "investigate thoroughly".

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Research into `http://en.wikipedia.org/wiki/Research`

- more than 250 edits in 2012
- the article has completely changed since 2011, not to mention 2005
- one would expect the etymology of the word to remain the same
  - 2005: Middle French and the literal meaning is "investigate thoroughly"
  - 2012: Middle French "recherche", which means "to go about seeking"
  - 2012: the term itself being derived from the Old French term "recerchier" a compound word from "re-" + "cerchier", or "sercher", meaning 'search'.
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- unlike for most websites one can see the whole revision history of any given article
- good for quickly learning about something, but not for referencing
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What Is 'Research'?

Research and experimental development (R&D) (Frascati Manual 2002)

"Creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications."

What Is 'Research'?

Basic research (Frascati Manual 2002)

"Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view."

Applied research (Frascati Manual 2002)

"It is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective."

Experimental development (Frascati Manual 2002)

Systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

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What Is 'Research'?

Research (a maxim)

"Copying from one source is plagiarism, copying from several sources is research".

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)

Knowledge

Epistemology

- What is knowledge?
- How is knowledge acquired?
- To what extent is it possible for a given subject or entity to be known?

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Knowledge: A Hierarchy

Knowledge is a particular level in a hierarchy:

1. Data
2. Information
3. Knowledge
4. Wisdom

Knowledge: Data and Information

Datum/Data

- statements accepted at face value (a 'given') and presented as numbers, characters, images, or sounds.
- a large class of practically important statements are measurements or observations of variables, objects, or events.
- in a computing context, in a form which can be assessed, stored, processed, and transmitted by a computer.

Knowledge: Data and Information

Information

- Data on its own has no meaning, only when interpreted by some kind of data processing system does it take on meaning and becomes information

Example:
The human genome project has determined the sequence of the 3 billion chemical base pairs that make up human DNA
$\rightsquigarrow$ identifying base pairs produces data
$\rightsquigarrow$ information would tell us what they encode!
$\rightsquigarrow$ knowledge would tell us what they do!
$\rightsquigarrow$ wisdom would tell us what part of this knowledge is important to what we do!
In analogy to OSI model of networking: Physical layer, Data link layer, Presentation layer, Application layer

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Knowledge: Alternative Definitions (1)

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.

In natural sciences, understanding 'why' is too ambitious most of time; understanding 'how' is usually what we aim for

In other areas, understanding 'why' is trivial, understanding 'how' is challenging

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Knowledge and Theories: Definition

Scientific knowledge is often organised into theories.

Theory (`http://en.wikipedia.org/wiki/Theories`)

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- formulated, developed, and evaluated according to the scientific method

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Knowledge and Theories: Criteria

Theory (http://en.wikipedia.org/wiki/Theories)

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 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's probably a good approximation if not totally correct

Knowledge and Theories: Criteria

Theory (http://en.wikipedia.org/wiki/Theories)

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

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.

Knowledge and Theories: Facts versus Theories

'This (e.g. evolution) is only a theory not a fact'

Fact

1. a truth (statement conforming to reality)

   or

2. data supported by a scientific experiment

- Status of a 'truth' is by and large unachievable
- A theory is formulated, developed, and evaluated according to the scientific method

  Given enough experimental support a theory can be (a scientific) fact

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Investigation

- Scientists use observations and reasoning to 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 established that a hypothesis is sound, it becomes a theory
- Sometimes scientific development takes place differently with a theory first being developed on the basis of its logic and principles

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Originality

Research and Originality (1)

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

Only true for what is truly known (i.e. very little)

- Theories make predictions, which need to be tested
- Those performing the tests are neither infallible nor trustworthy
- Tests need to be repeated and results replicated

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(In)Fallibility

Cold fusion (http://en.wikipedia.org/wiki/Cold_fusion)

- Cold fusion: Nuclear fusion reaction that occurs well below the temperature required for thermonuclear reactions, that is, near ambient temperature instead of millions of degrees Celsius
- First reported to have been achieved by Pons (University of Utah) and Fleischmann (University of Southampton) in 1989
- Scientists tried to replicate results shortly after initial announcement
- Teams at Texas A&M University and the Georgia Institute of Technology first confirmed the results, but then withdraw those claims due to lack of evidence
- Vast majority of experiments failed

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(Un)Trustworthiness

Jan Hendrik Schön

(http://en.wikipedia.org/wiki/Jan_Hendrik_Schon)

- Researcher at Bell Labs working in the field of condensed matter physics and nanotechnology
- In 2001, he was listed as an author on an average of one research paper every eight days
- Claimed to have produced a transistor on the molecular scale
- Published (and peer reviewed) papers were suspected to contain duplicated and anomalous data
- Dismissed after an investigation found 24 cases of misconduct
- Science withdrew 8 and Nature 7 papers co-authored by Schön

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Research and Originality (2)

Areas of originality (Cryer 1996)

- Exploring the unknown
  Investigate a field that no one has investigated before
- Exploring the unanticipated
  Obtaining unexpected results and investigating new directions in an already existing field
- The use of data
  Interpret data in new ways
- Tools, techniques, procedures, and methods
  Apply new tools/techniques to alternative problems
  Try procedures/methods in new contexts

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Summary

What Is 'Research'?

In summary, what are the three key aspects of research?

What is 'Research'?

http://en.wikipedia.org/wiki/Research

Systematic investigation to establish facts

Higher Education Funding Council for England

Original investigation to gain knowledge and understanding

Sharp et al. (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.

Who is Who in Computer Science Research

Prizes and Awards

- Scientific achievement is often recognised by prizes and awards
- Conferences often give a best paper award, sometimes also a best student paper award

  Example:
  ICALP Best Paper Prize (Track A, B, C)
  For the best paper, as judged by the program committee

- Professional organisations also give awards based on varying criteria

  Example:
  British Computer Society Roger Needham Award
  Made annually for a distinguished research contribution in computer science by a UK based researcher within ten years of their PhD

- Arguably, the most prestigious award in Computer Science is the A. M. Turing Award

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- Arguably, the most prestigious award in Computer Science is the A. M. Turing Award

Alan M. Turing (1912-1954)

- "The father of modern computer science"
- In 1936 introduced Turing machines, as a thought experiment about limits of mechanical computation (Church-Turing thesis)
  Gives rise to the concept of Turing completeness and Turing reducibility
- In 1939/40, Turing designed an electromechanical machine which helped to break the german Enigma code
  His main contribution was an cryptanalytic machine which used logic-based techniques
- In the 1950 paper 'Computing machinery and intelligence' Turing introduced an experiment, now called the Turing test
- 2012 was the Alan Turing year!

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Turing Award

Turing Award

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an individual selected for contributions of a technical nature made to the computing community. The contributions should be of lasting and major technical importance to the computer field.

The Association for Computing Machinery (ACM) is a society for computing founded in 1947. It is the largest and most prestigious scientific and educational computing society, with more than 100,000 members world-wide.

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Turing Award Winners

What contribution have the following people made?
Who among them has received the Turing Award?

Frances E. Allen
Leonard M. Adleman
Leonard Kleinrock
Timothy J. Berners-Lee (!)
Vinton G. Cerf
Edmund Clarke
Edgar F. Codd
Stephen A. Cook
Edsger W. Dijkstra
Lawrence J. Ellison
Douglas Engelbart
Paul Erdös
William H. Gates III
James A. Gosling
Stephen Hawking
Alan Kay
Donald E. Knuth
Robin Milner
John Nash
Lawrence Page
Alan J. Perlis
Amir Pnueli
Dennis M. Ritchie
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Leonard M. Adleman	✓	Donald E. Knuth	✓
Leonard Kleinrock	✗	Robin Milner	✓
Timothy J. Berners-Lee	✓(!)	John Nash	✗
Vinton G. Cerf	✓	Lawrence Page	✗
Edmund Clarke	✓	Alan J. Perlis	✓
Edgar F. Codd	✓	Amir Pnueli	✓
Stephen A. Cook	✓	Dennis M. Ritchie	✓
Edsger W. Dijkstra	✓	Ronald R. Rivest	✓
Lawrence J. Ellison	✗	Adi Shamir	✓
Douglas Engelbart	✓	Richard M. Stallman	✗
Paul Erdös	✗	Ken Thompson	✓
William H. Gates III	✗	Leslie Valiant	✓
James A. Gosling	✗	Moshe Vardi	✗
Stephen Hawking	✗	姚期智	✓

Sir Timothy John Berners-Lee

- Received the Turing award in 2016

  "for inventing the World Wide Web, the first web browser, and the fundamental protocols and algorithms allowing the Web to scale"

Frances E. Allen

- Received the Turing award in 2006

  "For pioneering contributions to the theory and practice of optimizing compiler techniques that laid the foundation for modern optimizing compilers and automatic parallel execution."

- First woman to receive the award
- Her 1966 paper on 'Program Optimization' and a 1971 paper with John Cocke provide the conceptual basis for the systematic analysis and transformation of computer programs
- Basis for modern machine- and language-independent program optimizers

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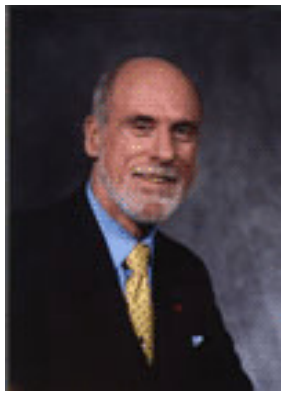


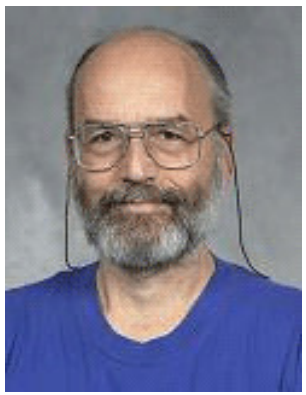
- Received the Turing award in 2004

  "For pioneering work on internetworking, including the design and implementation of the Internet's basic communications protocols, TCP/IP, and for inspired leadership in networking."

- Led the design and implementation of the Transmission Control Protocol and Internet Protocol (TCP/IP)
- Basis for current internetworking

Leonard M. Adleman, Ronald R. Rivest, Adi Shamir





- Received the Turing award in 2002

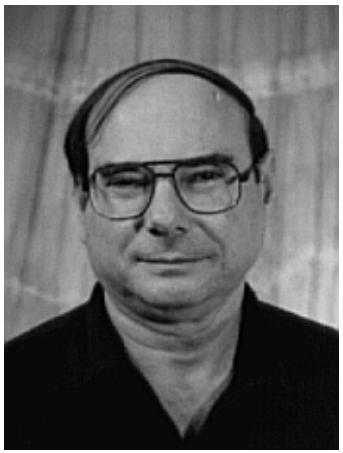
  "For their ingenious contribution for making public-key cryptography useful in practice."

- Created most widely used public-key cryptography system, RSA, in 1977
- Clifford Cocks described an equivalent system in an internal GCHQ document in 1973, but it was never deployed and kept secret until 1997

Amir Pnueli

- Received the Turing award in 1996

  "For seminal work introducing temporal logic into computing science and for outstanding contributions to program and system verification."



- Major breakthrough in the verification and certification of concurrent and reactive systems
- Landmark 1977 paper 'The Temporal Logic of Programs' in Proc. 18th IEEE Symp. Found. of Comp. Sci., 1977, pp. 46–57.
  - Focus: ongoing behaviour of programs (cf. input/output behaviour)
  - Easily specify qualitative progress properties of concurrent programs
  - Careful logic design enables automated verification of concurrent programs

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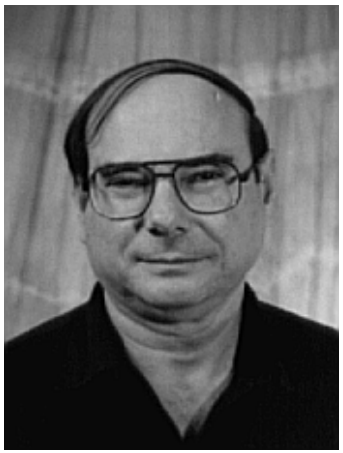

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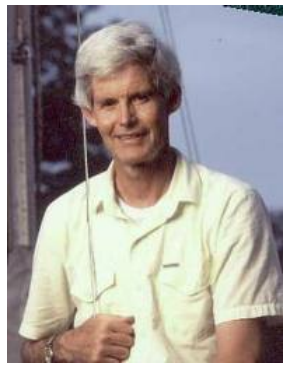

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  For his advancement of our understanding of the complexity of computation in a significant and profound way.

- Seminal paper 'The Complexity of Theorem Proving Procedures' at 1971 ACM SIGACT Symposium on the Theory of Computing
- Laid the foundations for the theory of NP-completeness
- P $\neq$ NP is still one of the most fundamental open problems
- Starting point for complexity theory

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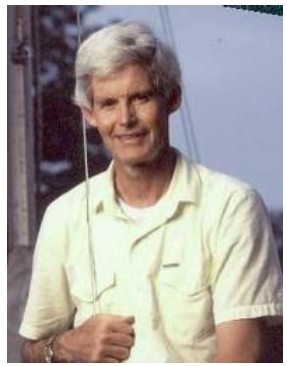

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How to Become a Turing Award Winner

To increase your chances to become a Turing award winner it might be advantageous to work in one of the following fields:

- programming language design and implementation
  (Backus, Floyd, Hoare, Milner, Naur, Iverson (APL), Dijkstra, Naur, Perlis (Algol), Fortran (Backus), Pascal, Modula (Wirth), Dahl, Nygaard (Simula), Kay (Smalltalk))
- program compilation (Cocke, Perlis), program optimisation (Allen)
- program verification (Dijkstra, Floyd, Pnueli, Clarke, Emerson, Sifakis)
- analysis and theory of algorithms including complexity theory
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Choosing or proposing a project

Questions

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- Your own goals and learning objectives
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- The project needs to have sufficient scope
- The project needs to interest you
- The project needs to have a serious purpose
- The project needs to have a clear outcome
- The project needs to be related to your degree programme
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- 2006 Chemistry: "Ultrasonic Velocity in Cheddar Cheese as Affected by Temperature".
- 2006 Mathematics: for calculating the number of photographs that must be taken to (almost) ensure that nobody in a group photo will have their eyes closed.
- 2007 Linguistics: for determining that rats sometimes can't distinguish between recordings of Japanese and Dutch played backward
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Suitability Tests for Projects

- 'So what?' test
  Is the topic meaningful?
  Will it be of value for anyone?
  What contribution will it make?
- Justification
  Can you explain your project and justify it in simple terms?
- Estimating your understanding
  Can you put a figure on what you know about your chosen subject?
- Contacts
  Are the contacts you require for your project (including your supervisor) available, accessible, and willing to help?
- Project proposal
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Project proposals

Preparing a Project Proposal: Implicit Content

- Introduction to the subject area
  - Sets the context for the project
  - Should motivate the relevance of the subject area
- Overview of current research in the area
  - Demonstrates current activities in the subject area
  - Shows your understanding of current research
- Identify a gap
  - Identify a need for further investigation or re-interpretation
- Identify how your work fills the gap
  - Explain how your project fills the gap
- Identify risks and solutions
  - Highlight the benefits that can be derived from your project
  - Account for the risks to your project

Preparing a Project Proposal: Implicit Content

- Introduction to the subject area
  - Sets the context for the project
  - Should motivate the relevance of the subject area
- Overview of current research in the area
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  - Identify a need for further investigation or re-interpretation
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- Title
  Clear, Concise, Preferably no acronyms
- Aims and Objectives
  Aims: Broad statement(s) of intent
  Identify the project's purpose

  Objectives: Identify specific, measurable achievements
  Quantitative and qualitative measures by which completion of the project can be judged
- Expected outcomes/deliverables
  Identify what will be produced/submitted in the project
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  - Motivation for the project
  - Motivation for you conducting the project
- Related Research
  Identifies other work and publications related to the topic
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  Identifies the research methods and project methods that will be used (e.g. theoretical investigation, case study)

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Preparing a Project Proposal: Explicit Structure (3)

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  Identifies the resources that will be needed for the project (e.g. hardware, software, data, personnel)
- Project Plan
  - More or less detailed 'timetable' for the project
  - Deadlines for deliverables

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- There are a number of techniques that can assist you
- In a project proposal or project specification
  - stick to the required structure and
  - address all the guiding questions as precisely as possible

Further reading:
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