Research & Innovation
– Scientific Methodology–
Research Problem & Objective Definition – Building the Literature Review

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Some parts of this course are based on material from:

- Oliveira Eugenio, Research Planning ProDEI- Doctoral Program in Informatics Engineering (FEUP)
  https://web.fe.up.pt/~eol/PRODEI/pi1617.htm
- Kothari, Chakravanti Rajagopalachari. Research methodology: Methods and techniques. New Age International, 2004.
- GETA and Graduate School of Electrical and Communications Engineering course: Introduction to Research Methodology, Aarne Mammela, VTT-Helsinki University of Technology
- Informatics Research Review, Stratis Viglas, University of Edinburgh

Outline

Outline

Science

Definitions

"Systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions" (source wikipedia)

- *Natural* sciences targeted to the study of objects in the nature
- *Social* sciences targeted to the study of individuals and societies
- *Engineering* sciences targeted to the study of objects (products, services, methods) not found in the nature, using results of mathematics and natural sciences

Research

Definitions

"Creative and systematic work undertaken to increase the stock of knowledge, including knowledge of humans, culture and society, and the use of this stock of knowledge to devise new applications." (source OECD 2017)

Objectives of research:

1. to discover new facts
2. to verify and test important facts
3. to analyse an event or process or phenomenon to identify the cause and effect relationship
4. to develop new scientific tools, concepts and theories to solve and understand scientific and nonscientific problems
5. to find solutions to scientific, nonscientific and social problems and
6. to overcome or solve the problems occurring in our every day life.

Research – Technology

Definitions

- *Basic/Pure/Fundamental* Research "aims to improve scientific theories for improved understanding or prediction of natural or other phenomena research" (source NSF) – no specific application in mind –
- *Applied* Research "uses scientific theories to develop technology or techniques to intervene and alter natural or other phenomena" (source wikipedia) – ideas targeted to operational form –
- Technology: application of scientific knowledge for practical ends in engineering, medicine, agriculture, etc.

$\rightsquigarrow$ Research & Development: systematic use of the existing knowledge to produce technology

Informatics: Science or Technology?

Definitions

Informatics as Science:

- theory and experiment
- deepen understanding of tasks and techniques
- suggests new techniques
- cognitive modelling improves understanding of natural systems

Informatics as Technology:

- new techniques
- suggest new applications
- better understanding leads to greater dependability
- results feed back into science

Scientist – Engineer

Definitions

"All sciences are vain and full of errors if they are not born of Experience – mother of all certainty – and if they are not tested through experience ..."
Leonardo da Vinci

- *Scientist* sees a phenomenon and asks "why?" and then proceeds to research the answer to that question.
- *Engineer* sees a practical problem and wants to know "how" to solve it and "how" to implement that solution, or "how" to do it better if a solution exists

"A scientist builds in order to learn, but an engineer learns in order to build"
Dr. Leung Yee Hong, Australian Telecommunications Cooperative Research Centre

- A scientist builds a theory/knowledge in order to learn

but an engineer learns in order to build a system/technology

Source: Oliveira Eugenio, Research Planning ProDEI- Doctoral Program in Informatics Engineering (FEUP)

Outline

How does a scientist work?

Scientific Research

- Should follow *research methods* and not just project-oriented ones.
- Should develop and put in practice a *systematic scientific criticism* over all the subjects
- Practical clues:
  - make always notes in a “notebook”, “Logbook”
  - make summaries about what has been learned
  - make plans for the future all the time (outlines, roadmaps)
  - discuss, ask questions and argue (criticism)

Scientific Research involves:

- Research Methodologies
  - procedures by which researchers go about their work of describing, explaining and predicting phenomena
  - use set of *research methods* and *research techniques*
- Research Methods
  - various procedures, schemes and algorithms used that are applicable to a class of problems
- Research Techniques
  - means and specific *tools* to implement methods
  - i.e. enabling relevant information acquisition, the respective data analysis, as well as the inferences that can be made to get the results

Outline

Research Methods(1)

Fundamental/Pure research

- contributes to a deep theoretical understanding and to a more abstract formulation of the phenomena $\rightsquigarrow$ Theoretical Model

Applied or Problem-Oriented research

- contributes to make human intervention in real world environments, more effective, using some scientific theory

Research Methods(2)

- Quantitative Methods
  - based on the measurement of quantity or amount
  - *Theories* are build up to try to explain what has been observed. Theories are expressed in deductive form or using Axioms and Postulates which are then operated through Logics.
- Qualitative Methods
  - Trying to understand lived experience and how participants themselves make sense of their experiences
  - Concerned with the meanings which those experiences hold for the participants.
  - Phenomenological (wishes to explore an individual's personal perception or account of an event or state) as opposed to attempting to produce an objective record of the event or state.
- Engineering-oriented
  - Technology is very important (devices, artefacts, tools, practical techniques to be used)
  - At least up to a certain extent is the most suitable for research in Informatics, Information Systems, Electronics, Telecomm.

Source: Oliveira Eugenio, Research Planning ProDEI- Doctoral Program in Informatics Engineering (FEUP)

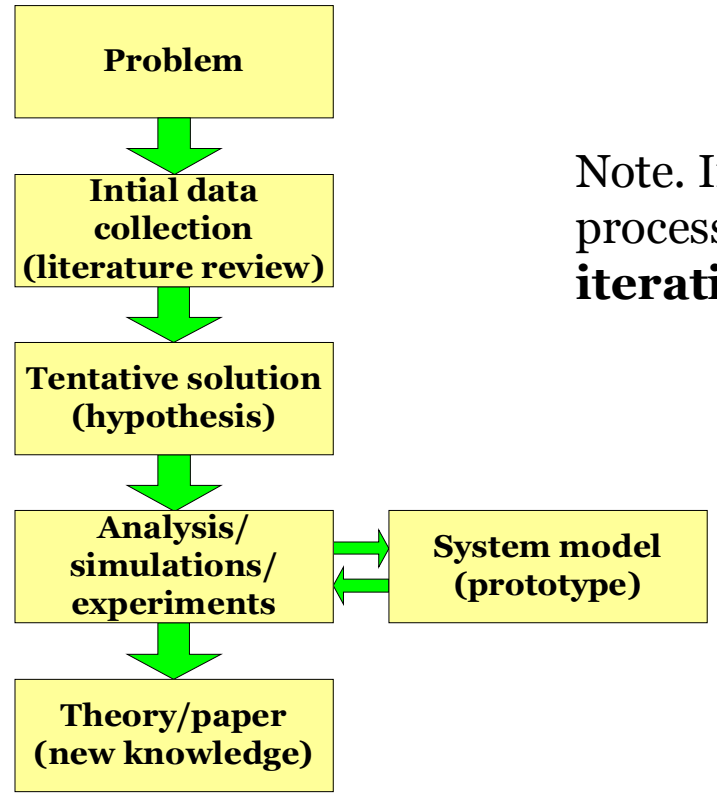
Research Methods(3)

Research methods depend on the Theory underlying the Research:

- Descriptive of all significative aspects of the domain (e.g. defining structure, architecture)
- Explicative of the behaviour of all the phenomena (e.g. analytical model)
- Predictive of the future phenomena behaviour (e.g. classification algorithm)
- Prescriptive: beyond the prediction it should also prescribe and apply norms and processes in identified specific circumstances (adaptive systems)

Outline

Research Process



Note. In practice the process is highly **iterative**.

Source: GETA and Graduate School of Electrical and Communications Engineering course: Introduction to Research Methodology, Aarne Mammela, VTT-Helsinki University of Technology

NOTE: in all of these steps, you have to read, to write, to talk, to check-up

Defining the Research Problem

Research Process

- The Research problem has to be absolutely identified
- Two main steps to iterate:
  - Understanding and formulating the problem thoroughly (initially the problem may be stated in a broad general way, ambiguities will be resolved through iteration)
  - Rephrasing the problem into **meaningful** and **operational** terms
- Actions:
  - Examine the **feasibility** of a particular solution to the problem
  - Examine **available literature** in relation with the problem:
    - Conceptual literature concerning the concepts and theories,
    - Empirical literature consisting of studies made earlier which are similar to the one proposed
  - Take some distance! some questions to ask:
    - Is it an **interesting** problem? is it research at all?
    - Is it an **important** problem? would anyone care if you solved it? (what is the potential impact?)
    - Didn't this problem already get a satisfactory solution/answer?
    - Who has already addressed this problem (or a similar and close one)?
    - When no answer, why? is there some reason? maybe a sign leaning to not address this problem

Literature review

Research Process

- Literature review is a springboard for describing your problem/hypothesis
- Demonstrate that you totally know the field
- Go to:
  - abstracting and indexing journals
  - published or unpublished bibliographies
  - Depending on the nature of problems, study academic journals, conference proceedings, government reports, books, etc
- One source will lead to another

Hypothesis generation

Research Process

Hypotheses:

- are scientifically reasonable predictions.
- should provide what we expect to find in the chosen research problem
- are the expected or proposed solutions based on available data and tentative explanations.
- are often stated in terms of *if-then* sentences in certain logical forms, in declarative sentence form. They relate, either generally or specifically, variables to variables

A research question is an hypothesis asked in the form of a question but it cannot be tested.

Research Question	Hypothesis
Is A related to B?	If A, then B.
How are A and B related to C?	If A & B then C.
How is A related to B under conditions C and D?	If A, then B under conditions C and D.

Hypothesis generation (2)

Working hypothesis are tentative assumptions whose logical or empirical consequences have to be drawn out and tested

- What hypothesis/claims are you investigating?
- What evidence is needed to establish this hypothesis?
- write and formulate hypotheses
- limit them to the piece of research
- It is easy to identify an impressive problem BUT that is not enough!
- You must convince that you stand some chance of solving it
- You absolutely must say what is the idea that you are bringing to the solve the problem.

Hypothesis generation (3)

Nature of Hypothesis

- It can be tested - verifiable or falsifiable
- Hypotheses are not moral or ethical questions
- It is neither too specific nor to general
- It is a prediction of consequences
- It is considered valuable even if proven false

Hypothesis generation (4)

Research Process

Imagine the following situation: You are a nutritionist working in a zoo, and one of your responsibilities is to develop a menu plan for the group of monkeys. In order to get all the vitamins they need, the monkeys have to be given fresh leaves as part of their diet. Choices you consider include leaves of the following species: (a) A (b) B (c) C (d) D and (e) E. You know that in the wild the monkeys eat mainly B leaves, but you suspect that this could be because they are safe whilst feeding in B trees, whereas eating any of the other species would make them vulnerable to predation. You design an experiment to find out which type of leaf the monkeys actually like best: You offer the monkeys all five types of leaves in equal quantities, and observe what they eat.
There are many different experimental hypotheses you could formulate for the monkey study. For example:
"When offered all five types of leaves, the monkeys will preferentially feed on B leaves."
This statement satisfies both criteria for experimental hypotheses. It is a

- Prediction: It predicts the anticipated outcome of the experiment
- Testable: Once you have collected and evaluated your data (i.e. observations of what the monkeys eat when all five types of leaves are offered), you know whether or not they ate more B leaves than the other types.

Hypothesis generation (5)

Research Process

Incorrect hypotheses would include (Example continued):
“When offered all five types of leaves, the monkeys will preferentially eat the type they like best.”

- This statement certainly sounds predictive, but it does not satisfy the second criterion: there is no way you can test whether it is true once you have the results of your study. Your data will show you whether the monkeys preferred one type of leaf, but not why they preferred it (i .e., they like it best). In fact, the above statement is as an assumption that is inherent in the design of this experiment, rather than as a hypothesis.

“When offered all five types of leaves, the monkeys will preferentially eat B leaves because they can eat these safely in their natural habitat.”

- This statement is problematic because its second part (“because they can eat these safely in their natural habitat”) also fails to satisfy the criterion of testability. You can tell whether the monkeys preferentially eat B leaves, but the results of this experiment cannot tell you why.

“In their natural habitat, howler monkeys that feed in B trees are less vulnerable to predation than monkeys that feed on A, C, D,or E.”

- This is a perfectly good experimental hypothesis, but not for the experiment described in the question. You could use this hypothesis if you did a study in the wild looking at how many monkeys get killed by predators whilst feeding on the leaves of A, B etc. However, for the experimental feeding study in the zoo it is neither a prediction nor testable.

“When offered all five types of leaves, which type will the monkeys eat preferentially?”

- This is a question, and questions fail to satisfy criterion 1: They are not predictive statements. Hence, a question is not a hypothesis.

Typical hypothesis in Informatics

Research Process

X is better than **Y** on task **Z** along some dimension **W**

- What kind of things are **X** and **Y**?
  - system, technique, parameter?
- What is task **Z**?
- What is the dimension **W**?
  - behaviour, coverage, efficiency, usability, dependability, maintainability?

Source: Informatics Research Review, Stratis Viglas, University of Edinburgh

How can hypothesis be established?

Research Process

- Theoretical evidence: proof of some property or relationship:
  - correctness, completeness, complexity, etc
- Experimental evidence:
  - Run computer program and analyse:
    - run times, success rates (e.g., comparison of computer output with "gold-standard" output), user's reactions, etc;
    - compare two or more programs.
  - Test and compare human performance:
    - with program, on different program variants, with other humans, etc.

Think early about evaluation

- Key part of project,
  - evidence to support hypothesis.
- Too risky to leave until late in project,
  - evaluation required may not be feasible.
- Interacts with hypothesis formation,
  - and so, determines nature of project.
- Write note outlining evaluation plan,
  - and discuss with your supervisor.

Analysis / Simulations / Experiments

Research Process

- write and refine hypothesis
- define principles for building a solution based on hypothesis
- test, evaluate, experiment
- experiment before, after, during
- use tools, programs, scripts, ...
- All experiments will not necessary be published

System model / Prototype

Research Process

- Model,
- Formalize,
- Write, prove
- Implement

Publish / Theory / Paper

Research Process

Produce new knowledge

- Writing the results
- Submit, receive evaluations, publish, present

$\rightsquigarrow$ discussions, feedbacks $\rightsquigarrow$ new problems, new ideas

Go to step 1

Outline

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