Lecture 4:

Research Classifications, Methods, & Techniques

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- Science is a well formed knowledge structure (a system for accumulating reliable knowledge).
- Information is a well formed data structure.
- All of them are the results of our interaction with the real world.

Science

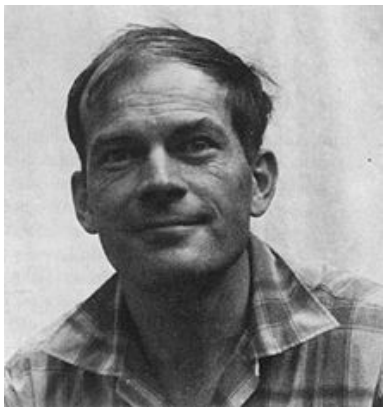
Science from latin word *scientia*:

- Knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific Method
- Such knowledge or system of knowledge concerned with the physical world and its phenomena $\Rightarrow$ natural science
- A system or method reconciling practical ends with scientific laws

Science

Robert H. MacArthur

To do science is to search for repeated patterns, not simply to accumulate facts.



"Science" Approach

"Science" approach:

- Theory
- Derive a hypothesis (from theory)
- Formulate experiment to test hypothesis
- Perform experiment (test hypothesis)
- Evaluate results $\Rightarrow$ positive/negative evidence
- If contradiction: modify theory

Scientific Method

- The process of science begins with *Observation*, which are developed into hypothesis, tested by proof, or experimentation.
- Each new *hypothesis* builds on a bed of existing theory.

- Read critically: Reading a research paper must be critical process. Be suspicious.
- Critical reading involves asking appropriate questions
  - What kind of paper is it?
  - What is the problem the authors are trying to solve?
  - Are the **assumptions** the authors make reasonable?
- Critical thinking is rationally deciding what to believe or do.
- To rationally decide something is to evaluate claims to see whether they make sense, whether they are coherent, and whether they are well-founded on evidence, through inquiry and the use of criteria developed for this purpose.

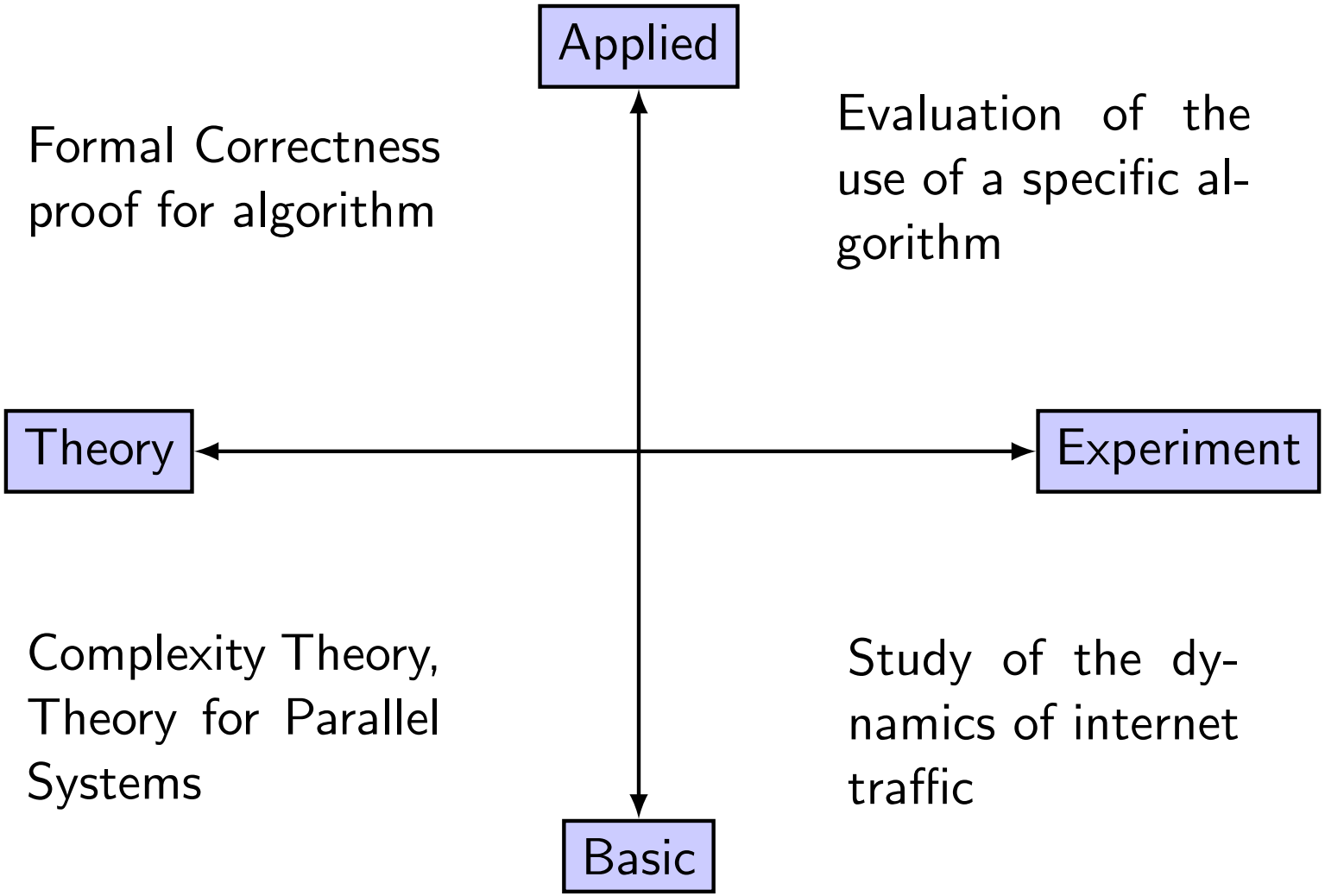
Research Paradigms in Computer Science

- Empirical: Computer science is concerned with the study of a class of phenomena
- Mathematical: Computer Science is concerned with the study of algorithms and properties of information structures (abstraction from real objects)
- Engineering: managing the cost-effective design and construction of complex software-hardware systems (commercially and socially valuable)

Terminology!

- Research Classification: commonly refers to Basic, Applied, Experimental, and Theoretical.
- Research Method: refers to the manner in which a particular research project is undertaken.
- Research Technique: refers to a specific means, approach, or tool-and-its-use, whereby data is gathered and analysed, and inferences are drawn.
- Research Methodology: refers to the study of research methods.

Research Classification in Computer Science



Basic vs. Applied

- Basic research (aka fundamental or pure)
  - Main motivation is to investigate the fundamental issue of a system.
  - There is no obvious commercial value to the discoveries that result from basic research.
  - e.g., What hyper-parameter tuning methods optimize the predictive accuracy?
- Applied research
  - Designed to solve practical problems of the modern world.
  - One might say that the goal of the applied scientist is to improve the human condition.
  - e.g., How to combine different predictive models to optimize the bank loan application process?

Experimental vs. Theoretical

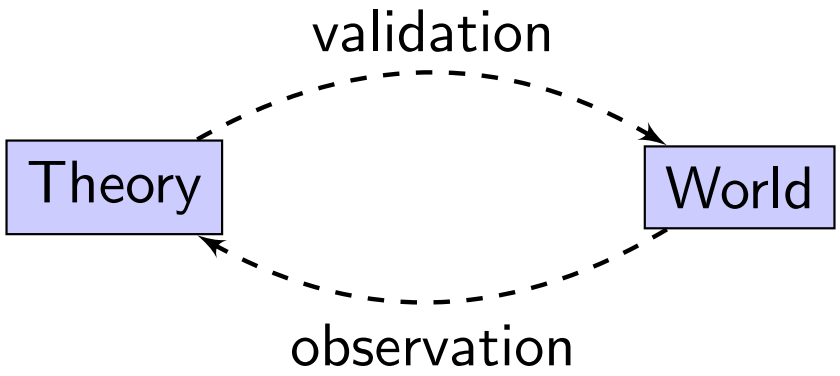
- Experimental computer science (ECS) refers to the building of, or the experimentation with or on, nontrivial hardware or software systems
- ECS does not depend on a formalized theoretical foundation in the same way that experimental physics can draw on theoretical physics According to theory XYZ we must observe this – then experimentally we look for it (if it is not observed the theory is falsified, see K. Popper)
- Good experimentalists do create models (theories) and test (reject or accept) hypotheses

Experimental vs. Theoretical

- "Theory" in CS is very close to mathematics – theoreticians prove theorems
- Experiments are most often conducted to validate some informal thesis derived from a computational model (but not rigorously specified by theory) that may have been developed for the experiment
- The complexity of the systems built in ECS and of the underlying models and theories means that experimental implementation is necessary to evaluate the ideas and the models or theories behind them.

Research Methods

- The purpose of the research determines the method to use
- There is no single research method
- Many methods are available and have to be combined
- But somehow, scientists/researchers are supposed to do this:



Research Methods

The different methods that exist:

- Exploratory: structures and identifies new problems.
- Constructive: develops solutions to a specific persisting problem.
- Empirical: tests the feasibility of a solution using empirical evidence.

Exploratory Research Method

- This is done to improve the basic knowledge on the concept and walk in to the unknown realms of the subject.
- It is a type of research conducted for a problem that has not been clearly defined.
- It should draw definitive conclusions only with extreme caution.
- Given its fundamental nature, exploratory research often concludes that a perceived problem does not actually exist.

Constructive Research Method

- This is done by technical professionals to find a new solution to a specific persisting problem.
- It is very commonly used in computer science research.
- The term “construct” is often used in this context to refer to the new contribution being developed, such as a new theory, algorithm, model, software, or a framework.
- This approach demands a form of validation that doesn’t need to be quite as empirically based as in other types of research.
- Nevertheless the conclusions have to be objectively argued and defined.
- This may involve evaluating the “construct” analytically against some predefined criteria or performing some benchmark tests with the prototype.

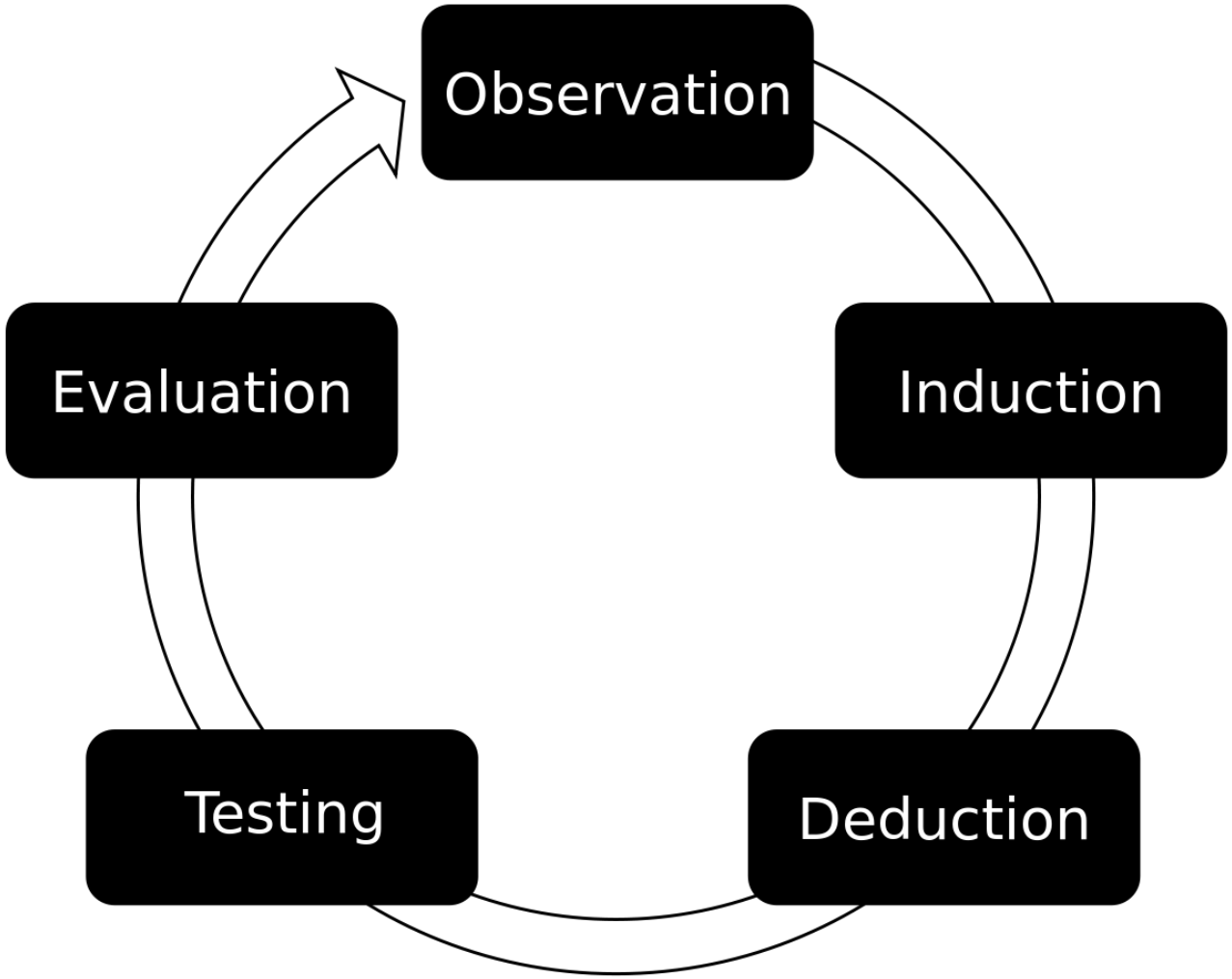
Empirical Research Method

- *Empirical* comes from the Greek word for experience
- Empirical research is a way of gaining knowledge by means of direct and indirect observation or experience.
- Empirical evidence/observations can be analyzed quantitatively or qualitatively.
- Through quantifying the evidence or making sense of it in qualitative form, a researcher can answer empirical questions, which should be clearly defined and answerable with the evidence collected (usually called data).
- Research design varies by field and by the question being investigated.
- A combination of qualitative and quantitative analysis is often used to better answer questions.

Empirical Research Method - Example

- Observation is the key: A way of gaining knowledge by direct observation or experience.
- Used to answer empirical questions, e.g., "Does AI help in speeding up the approval process in loan application?"
- Based on existing theories about the topic, some hypotheses will be proposed, e.g., "AI has positive effect on loan application process."
- This prediction can then be tested with a suitable experiment.
- Depending on the outcomes of the experiment, the theory on which the hypotheses and predictions were based will be supported to a certain degree of confidence or not, e.g., "Banks that deploy AI will have an ROI of 50% and above than those banks practicing conventional methods."

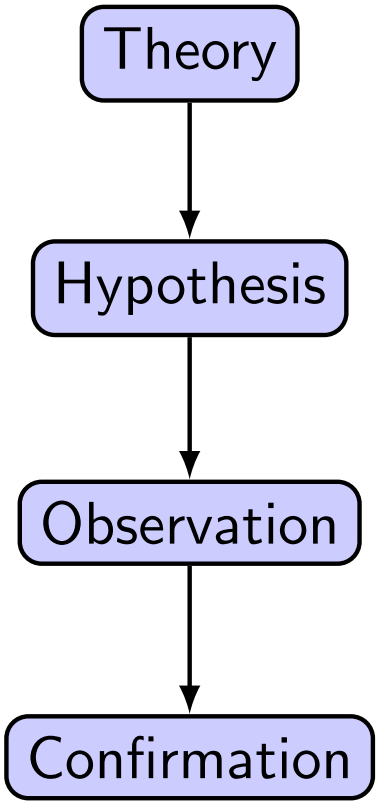
A.D de Groot's Empirical Cycle



A.D de Groot's Empirical Cycle

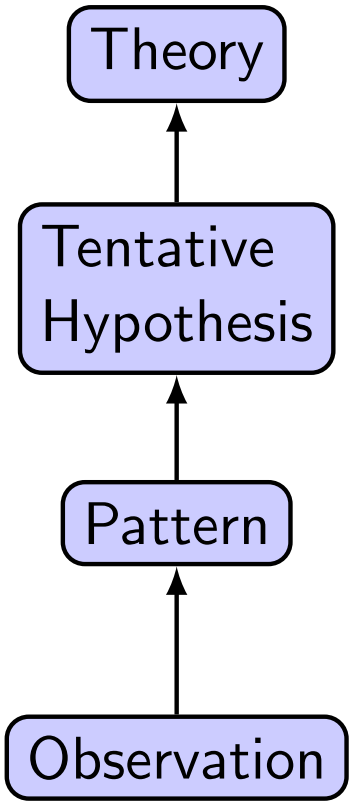
- Observation: The collecting and organization of empirical facts.
- Induction: Formulating hypothesis.
- Deduction: Deducting consequences of hypothesis as testable predictions.
- Testing: Testing the hypothesis with new empirical material.
- Evaluation: Evaluating the outcome of testing

Deduction



1. Deductive reasoning works from the more general $\rightarrow$ the more specific.
2. Sometimes this is informally called a "top-down" approach.
3. Conclusion follows logically from premises (available facts)

Induction



1. Inductive reasoning works the other way, moving from specific observations to broader generalizations and theories.
2. Informally, we sometimes call this a "bottom up" approach
3. Conclusion is likely based on premises.
4. Involves a degree of uncertainty

Advantages of Empirical Research Method

- Go beyond simply reporting observations or proving theorems
- Prove relevancy of theory by working in a real world environment (context)
- Help integrating research and practice
- Understand and respond more appropriately to dynamics of situations
- Provide respect to contextual differences
- Provide opportunity to meet standards of professional research

Research Techniques

- Interpretivist or qualitative research techniques
- Research techniques at the scientific/interpretivist boundary
- Quantitaive and scientific research techniques
- Non-empirical techniques
- Engineering research techniques

- Have their roots in the social sciences
- Primarily concerned with increasing and in-depth understanding of an area
- Investigate why and how of decision making, not just what, where, when.
- Often associated with fieldwork, face-to-face interviews, focus groups, site visits
- Focus on the analysis of a limited number of samples/settings
- Produce information only on the particular cases studied; not beyond the cases studied!
- repeatability of experiments may not be possible.

- Interpretivists work out people's interpretations of the world by putting themselves in their shoes, hence are subjective and biased.
- Assumption that people make own choices that are not connected to laws of science or nature.
- Research tends to be done in greater detail and looks at culture and how people live their lives.
- Results will be personal and in depth, therefore cannot be necessarily generalised.
- Tends to undermine realiability and representativeness
- Interpretivists tend to involve emotions and bias in their views but, this may not always be beneficial as they may get in the way of what is really happening.

- Descriptive/interpretive research: empirical observation is subjected to limited formal rigor. Controls over the researcher's intuition include self-examination of the researcher's own pre-suppositions and biases, cycles of additional data collection and analysis, and peer review;
- Focus group research: gathering of a group of people, commonly members of the public affected by a technology or application, to discuss a topic. Its purpose is to surface aspects, impacts and implications that are of concern.
- Action research: the researcher plays an active role in the object of study, e.g. by acting as a change-agent in relation to the process being researched.
- Ethnographic research: applies insights from social and cultural anthropology to the direct observation of behaviour.

- Systematic empirical investigation of quantitative properties and phenomena and their relationships.
- The goal is develop models, theories, and hypotheses pertaining to natural phenomena (how it works)
- The research is generally driven by hypotheses, which are formulated and tested rigorously.
- Measurement is fundamental since it gives the connection between observation and the formalization of the model, theory and hypothesis
- Repeatability of the experiments and testing of hypotheses are vital to the reliability of the results, since they offer multiple opportunities for scrutinising the findings.

- Forecasting: involves the application of regression and time-series techniques, in order to extrapolate trends from past data.
- Field experimentation and quasi- experimental designs: opportunities are sought in the real-world which enable many factors, which would otherwise confound the results, to be isolated, or controlled for.
- Laboratory experimentation: this involves the creation of an artificial environment, in order to isolate and control for potentially confounding variables.

- Field study: the object of study is subjected to direct observation by the researcher.
- Questionnaire-based survey: involves the collection of written data from interviewees, or the collection of verbal responses to relatively structured questions.
- Case study: this involves the collection of considerable detail, from multiple sources, about a particular, contemporary phenomenon within its real-world setting.
- Secondary research: this technique analyses the contents of existing documents. Commonly, this is data gathered by one or more prior researchers, and it is reexamined in the light of a different theoretical framework from that previously used.

- Conceptual research: opinion and speculation, comprising philosophical or 'armchair' analysis and argumentative/dialectic analysis.
- Theorem proof: applies formal methods to mathematical abstractions in order to demonstrate that, within a tightly defined model, a specific relationship exists among elements of that model.
- Futures research, scenario-building, and game- or role-playing: individuals interact in order to generate new ideas, gather new insights into relationships among variables, and postulating possible, probable, and preferable futures.
- Review of existing literature, or "meta-analysis": the opinions and speculations of theorists, the research methods adopted by empirical researchers, the reports of the outcomes of empirical research, and materials prepared for purposes other than research.

- Construction: involves the conception, design and creation (or "prototyping") of an artifact and/or technique.
  - The new technology is designed to intervene in some setting, or to enable some function to be performed.
  - The design is usually based upon a body of theory
  - Artifact/technology is usually subjected to some form of testing, in order to establish the extent to which it achieves its aims.
- Destruction: new information is generated concerning the characteristics of an existing class of technologies.
  - Typically achieved through testing the technology, or applying it in new ways.
  - The design is usually based upon a body of theory.

Declaration & Acknowledgment

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