Introduction to Empirical Software Engineering

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Outline

- Introduction to the need for Empirical Software Engineering
- Research Questions and Empiricism
- Theory Building

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Introduction

- 1968: “Software Engineering” was coined and a discipline formed
- 1968: “Software Crisis” term was coined by attendees at the first NATO Software Engineering Conference

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Software Crisis

- **"Software Crisis** is a term used in the early days of computing science for the difficulty of writing useful and efficient computer programs in the required time. The software crisis was due to the rapid increases in computer power and the complexity of the problems that could now be tackled. With the increase in the complexity of the software, many software problems arose because existing methods were inadequate." - Wikipedia

IEEE Definition

Software Engineering: application of a systematic, disciplined, quantifiable approach to development, operation, and maintenance of software

1. This implies a software process
2. This stresses the need for a **systematic** and **disciplined** approach
3. This highlights the importance of **quantification**

The Challenge

- To address the **Software Crisis** and bolster the new field of Software Engineering
  - People started to develop new methods, techniques, languages and tools
- Each of these new inventions came with purported claims of reducing the time it took to build the software
- The challenge: These new inventions should not simply be suggested, published, and marketed, rather they **must be evaluated in comparison with existing ones**

Software Process

- **Process Model**: used to describe the steps to take and the activities to perform when developing software

Example Process Models

- Waterfall
- Incremental development
- Evolutionary development
- Spiral model
- Agile approaches

Process Model Abstraction

Process Complexity

- Software process are very complex
- They consist of many activities and produce many artifacts
- They are often difficult to optimize
- It is often difficult to find a good process
- It is important for companies to continually strive to improve their process to stay competitive

Process Improvement

- Approaches to improve and assess SE process have been proposed
  - PIM, CMM, and others
- The questions is not how do we measure improvement, but rather how do we evaluate the improvement itself without involving people?
- Unfortunately, there is no method by which we can do this.
- Rather, we can only propose the improvement and evaluate the changes after they have been used.
- Thus, we must experiment.

Research Methods

- First step to **design** a research proposal: adopt a general (and guiding) **framework**
- Three frameworks (approaches to research): **Qualitative**, **Quantitative**, and **Mixed Methods**
- These approaches include:
  - **philosophical** assumptions (postpositivist, constructivist, emancipatory/critical, pragmatic)
  - strategies of **inquiry** (experimental, ethnographic, narrative, mixed methods design)
  - research **methods** (data collection and analysis)

Discussion Questions

- How do you select a framework or approach?
- Examples of Qualitative, Quantitative, and Mixed Methods research in SE?
- Which of these approaches apply best in your own research?

What will you accept as knowledge?

- Positivist (or "Post-positivist")
  - Knowledge is objective
  - "Causes determine effects/outcomes"
  - Reductionist: study complex things by breaking down to simpler ones
  - Prefer quantitative approaches
  - Verifying (or Falsifying) theories
- Critical Theorist
  - Research is a political act
  - Knowledge is created to empower groups/individuals
  - Choose what to research based on who it will help
- Constructivist/Interpretivist
  - Knowledge is socially constructed
  - Truth is relative to context
  - Theoretical terms are open to interpretation
  - Prefer qualitative approaches
  - Generating "local" theories
- Eclectic/Pragmatist
  - Research is problem-centered
  - "All forms of inquiry are biased"
  - Truth is what works at the time
  - Prefer multiple methods / multiple perspectives

Meta-theories

- Logical Positivism:
  - Separates discovery from validation
  - Logical deduction, to link theoretical concepts to observable phenomena
  - Scientific truth is absolute, cumulative, and unifiable
- Popper:
  - Theories can be refuted, not proved;
  - Only falsifiable theories are scientific
- Campbell:
  - Theories are underdetermined
  - All observation is theory-laden, biased
- Quine:
  - Terms used in scientific theories have contingent meanings
  - Cannot separate theoretical terms from empirical findings
- Kuhn:
  - Science characterized by dominant paradigms, punctuated by revolution

Meta-theories

- Lakatos:
  - Not one paradigm, but many competing research programmes
  - Each has a hard core of assumptions immune to refutation
- Feyerabend:
  - Cannot separate scientific discovery from its historical context
  - All scientific methods are limited
  - Any method offering new insight is ok
- Toulmin:
  - Evolving Weltanschauung determines what is counted as fact;
  - Scientific theories describe ideals, and explain deviations
- Laudan:
  - Negative evidence is not so significant in evaluating theories
  - All theories have empirical difficulties
  - New theories seldom explain everything the previous theory did

What Type of Question are you asking?

- Exploratory
- Baserate
- Correlation
- Causal Relationship
- Design

Exploratory Questions

- Existence:
  - Does X exist?
- Description and Classification
  - What is X like?
  - What are its properties?
  - How can it be categorized?
  - How can we measure it?
  - What are its components?
- Descriptive-Comparative
  - How does X differ from Y?

Baserate Questions

- Frequency and Distribution
  - How often does X occur?
  - What is an average amount of X?
- Descriptive-Process
  - How does X normally work?
  - By what process does X happen?
  - What are the steps as X evolves?

Correlation Questions

- Relationship
  - Are X and Y related?
  - Do occurrences of X correlate with occurrences of Y?

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Causal Relationship Questions

- Causality
  - Does X cause Y?
  - Does X prevent Y?
  - What causes X?
  - What effect does X have on Y?
- Causality-Comparative
  - Does X cause more Y than does Z?
  - Is X better at preventing Y than does Z?
  - Does X cause more Y than does Z under one condition but not others?

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Design Questions

- What is an effective way to achieve X?
- How can we improve X?

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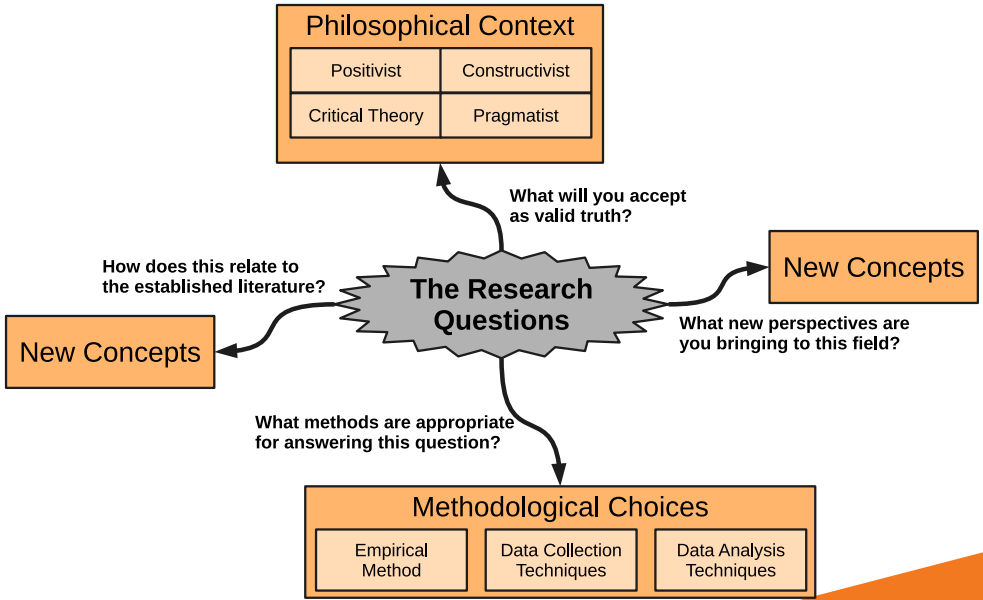
Putting the Question in Context



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Theory

- Our Theories impact how we see the world
  - Real-world phenomena too rich and complex
  - Need a way of filtering our observations
  - The theory guides us, whether it is explicitly stated or not
- In Quantitative Methods:
  - Theoretical lens tells you what variables to measure..
  - ...and which to ignore or control
- In Qualitative Methods:
  - Theoretical lens usually applied after data is collected
  - ...and used to help with labeling and categorizing the data

Theories are good for generalization…

Statistical Generalization

- Generalize from sample to population
- Can only be used for quantifiable variables
- Based on random sampling:
  - Test whether results on a sample apply to the whole population
- Not useful when:
  - You can't characterize the population
  - You can't do random sampling
  - You can't get enough data points

Analytical Generalization

- Generalize from findings to theory
- Applicable to quantitative and qualitative studies
- Compares findings with theory
  - Do the data support/refute the theory?
  - Do they support this theory better than rival theories?
- Supports empirical induction:
  - Evidence builds if subsequent studies also support the theory

Theory

"A theory provides explanations and understanding in terms of basic concepts and underlying mechanisms, which constitute an important counterpart to knowledge of passing trends and their manifestation."

- Law - a notion for a description of a repeatable phenomenon in a natural science context
- Theories - explain the laws
- Hypotheses - propose a tentative explanation for why the phenomenon behaves as observed
- Conjecture - a guess about the phenomenon

Types of Theories

General types of theories

1. **Analysis**: theories of this type describe the object of study, and include, for example, taxonomies, classifications and ontologies.
2. **Explanation**: This type of theories explains something, for example, why something happens.
3. **Prediction**: These theories aim at predicting what will happen, for example, in terms of mathematical or probabilistic models.
4. **Explanation and prediction**: these theories combine types 2 and 3, and is typically what is denoted an “empirically-based theory”.
5. **Design and action**: theories that describe how to do things, typically prescriptive in the form of design science. It is debated whether this category should be denoted theory at all.

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Software Engineering Theory

Sjoberg et al. classification of Software Engineering theory:

- **Constructs**: entities in which the theory are expressed, and to which the theory offers a description, explanation or prediction, depending on the type of theory.
- **Propositions**: made up from proposed relationships between the constructs.
- **Explanations**: originate from logical reasoning or empirical observations of the propositions, that is, the relationship between the constructs.
- **Scope**: defines the circumstances, under which the theory is assumed to be applicable.

Scoping Theory

Archetype class	Subclasses
Actor	Individual, team, project, organization or industry
Technology	Process model, method, technique, tool or language
Activity	Plan, create, modify, or analyze (a software system)
Software system	Software systems may be classified along many dimensions, such as size, complexity, application domain, business/scientific/student project or administrative/embedded/real time, etc.

Research in SE

- SE is a cross-disciplinary human-intensive endeavor
- Thus, with exception of a few technical niches, we cannot expect to find any formal rules or laws.
- What we need to know is what research methods are available to us:
  - **Scientific** - The world is observed and a model is built based on the observations, i.e, a simulation model.
  - **Engineering** - The current solutions are studied and changes are proposed, and then evaluated.
  - **Empirical** - A model is proposed and evaluated through empirical studies, i.e., case studies or experiments
  - **Analytical** - A formal theory is proposed and then compared with empirical observations.
- Note: these approaches are not orthogonal, but rather complementary and may be used together.

Methods

Analytical Method

- Traditional to Computer Science and the study of algorithms
- For Example comparing algorithms on performance for a given data set

Engineering Method

- Most often found in industry

Scientific

- Used in applied areas, i.e., simulating a telecommunication network to evaluate performance

Choose a Method…

- Exploratory Used to build new theories where we don't have any yet
  - E.g. What do CMM level 3 organizations have in common?
  - E.g. What are the experiences of developers who have adopted Ruby?
- Descriptive Describes sequence of events and underlying mechanisms
  - E.g. How does pair programming actually work?
  - E.g. How do software immigrants naturalize?
- Causal Determines whether there are causal relationship between phenomena
  - E.g. Does tool X lead to software with fewer defects?
  - E.g. Do requirements traceability tools help programmers find information more rapidly?
- Explanatory Adjudicates between competing explanations (theories)
  - E.g. Why does software inspection work?
  - E.g. Why do people fail to document their requirements?

Empirical Methods

- Come from the social sciences and psychology
- Empirical methods have been used in SE since the early 1960s and have been growing since
- Empirical methods used in SE include:
  - Formal Experiments
  - Industrial and academic cases studies
  - Surveys, Interviews

Are there any questions?