1. Introduction

Goals and expectations

- Audience
  - PhD candidate
  - Industry or Academia
- Expectations
- Goals
  - Distinguish design problems from research questions
  - Understand how they interact
  - Be able to design research
  - Understand the special case of RE research

2. Research, Technology and Requirements Engineering

What is technology?

- Technology is the development and maintenance of artifacts
- Artifacts are means to achieve goals
  - Physical tools
  - Software
  - Techniques
  - Notations
  - Processes
- Artifacts reduce uncertainty in the cause-effect relationships involved in achieving a desired outcome (Rogers 2003, page 139).
What is research?

- Research is critical knowledge acquisition
  - Organized skepticism
  - Acceptance of uncertainty
  - Not claiming more than you know
- Research is objective knowledge acquisition
  - Avoid opinions
  - Avoid desires and aversions to influence observations or inferences

What is RE?

- RE = alignment between solutions and problems
  - Technology
  - Society
  - Goals, resources (time, money, data, hardware, software, people, ...)
  - Markets, money, businesses, stakeholders, goals, processes, information, ...
  - Development and maintenance of artifacts
  - RE = alignment between solutions and problems

Kinds of artifacts & usage domains

<table>
<thead>
<tr>
<th>Software products</th>
<th>Process technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information systems,</td>
<td>Techniques</td>
</tr>
<tr>
<td>WFM systems,</td>
<td>Notations</td>
</tr>
<tr>
<td>Embedded control systems,</td>
<td>Tools</td>
</tr>
<tr>
<td>Ambient systems,</td>
<td>Process models</td>
</tr>
<tr>
<td>Mobile systems,</td>
<td>Job roles</td>
</tr>
<tr>
<td>...</td>
<td>Task structures</td>
</tr>
<tr>
<td>Used in some domain</td>
<td>Used in some domain</td>
</tr>
<tr>
<td>Manufacturing,</td>
<td>Software production</td>
</tr>
<tr>
<td>Cars,</td>
<td>Software maintenance</td>
</tr>
<tr>
<td>Telecom,</td>
<td>Systems engineering</td>
</tr>
<tr>
<td>Government,</td>
<td>Business redesign</td>
</tr>
<tr>
<td>Finance,</td>
<td>...</td>
</tr>
<tr>
<td>Health care,</td>
<td>...</td>
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</tbody>
</table>

In all cases we must align the technique with its usage domain

Doing RE involves research

1. Design IT-enabled procurement- and distribution process for Holland Casino
   - Current processes? Goals?
   - Desired process. IT components.
2. Design an architecture for an IT system that supports logistics across a set of businesses.
   - Desired process. IT architecture.
3. Develop/acquire a WFMS for a company
   - Current systems? Goals? Currently available WFMs?
   - Requirements.
4. Develop a method for buying a WFMS
   - Current procurement process? Goals?
   - Desired method.

If there is no diagnosis, there is no treatment

The RE process itself may be investigated too

- RE’06 research question examples:
  - How do customers reach agreement of requirements priorities?
  - Aggregate empirical research results about the effectiveness of requirements elicitation techniques.
  - Draw lessons learned from applying agile RE in standardized processes in the public sector

Technology may be developed for the RE process

- Examples from RE’06:
  - Design an IR technique to retrieve quality attributes from early RE documents.
  - Design a technique to disambiguate NL specifications
  - Design a way to maintain traceability in a cost-effective way
Research, RE technology

Research: Investigating things

1. Doing RE
   - Investigating the alignment of technology and stakeholder goals

2. RE research
   - Investigating the RE process

Technology: Improving things

3. Doing RE
   - Improving the alignment of artifacts and stakeholder goals

4. RE technology
   - Improving the RE process

Research versus technology

- Research delivers propositions:
  - Observing, analyzing, explaining, publishing
  - Truth
- Technology delivers artifacts:
  - Designing, building, delivering, maintaining
  - Utility

Research or technology?

- Rebuilding your house
- Writing software
- Developing a maintenance method
- Writing a paper
- Interviewing software users
- Evaluating a maintenance method

Two kinds of problems

- A problem is a difference between experience and desire
  - Practical problem: Difference between phenomena and the way stakeholders desire them to be.
    - Market share is too small
    - Information is not available when needed
  - Knowledge question: Difference between knowledge and the way stakeholders like it to be
    - Which WFM packages are available?
    - What is the security risk of this package?

Knowledge question or practical problem?

- What are the goals of these users?
  - K. Empirical question
- What would be a good procurement process for Office supplies?
  - P. Design an improved procurement process
- What is the complexity of this algorithm?
  - K. Analytical question
- Why is this algorithm so complex?
  - K. Analytical question
- Find an algorithm to solve this problem
  - P. Design an algorithm to solve this problem
- How do users interact with this system?
  - K. Empirical question
- Why do users interact with the system this way?
  - K. Empirical question
- What would be a good architecture for hospital-insurance company communication?
  - P. Design an architecture

Non-heuristics

- "What" and "How" don’t give a clue
- Someone else’s practical problem may be my knowledge question
  - E.g. goals
- Practical problems may contain knowledge questions
  - E.g. What is the current procurement process and why is it done this way
- Answering knowledge questions may contain practical problems
  - E.g. How to collect data
Heuristics

• Practical problems
  – Are solved by changing the state of the world
  – Solution criterion is utility
    • Problem-dependent: stakeholders and goals
    • Several solutions, but trade-offs

• Knowledge questions
  – Are solved by changing the knowledge of stakeholders.
  – Solution criterion is truth
    • Problem-independent: no stakeholders
    • One solution; but approximations

Assignment 1

• Identify one practical problem and one knowledge question you are (or have been) working on
  – How would you evaluate candidate solutions/answers?

3.1 Kinds of practical problems

Kinds of practical problems

• **How-to-do X**
  – Specify a solution
    • How to provide logistics support to Holland Casino
    • How to control paper sorter
    • How to select a new WFMS
    • How to improve our claim handling process

• **Do X**
  – Implement a specification
    • ... Solution of business process & IT
    • Specification of control & operations
    • Specification of selection process
    • Specification of business process

Solutions may be

• software
• business processes
• hardware
• methods

An aside

• To design is to create and specify a plan of action
  – De-sign is specification
    • To design is to plan, to conceive in the mind (Webster’s)
    • De-sign
    • Designing is saying what you want to do
  – Specification is design
    • Product specification is parts list

• Requirements are satisfied by a composition of elements
  – Decomposition
    • Software design = software decomposition
    • Interactions between elements cause overall system properties
    • Decompositions can be specified
  – Requirements
    • Desired properties of a solution
    • We can specify requirements

3.2 Kinds of knowledge problems
Kinds of knowledge questions

- Description
  - What is the case
  - Who is involved?
  - What do they want?
  - What happened?
  - When did this happen?
  - How often?
  - Where did it happen?
  - How good/bad is this?

- Explanation
  - Why is it the case
  - Why is it so good/bad?

Evaluation questions: Comparison with a norm

Investigative questions: Evaluation

Knowledge questions

Prediction problems

- What will be the case?
  - How will this software system perform in this environment?
  - Will this business process be more efficient?
  - What will happen if we do nothing?

- Evaluated by truth
- No change of the world
- Change of our expectations
- Will become knowledge only when events occur as expected

Knowledge problem!

Not true/false now
No new knowledge

Conceptual modeling questions

- What concepts are we going to use?
  - What concepts are used to describe logistic processes?
  - What kinds of entities must be controlled in the paper sorter?
  - What kind of customers do we have?
  - What is usability?
  - How to measure it?

The result may be called:
- Conceptual model
- Dictionary
- Ontology
- Conceptual framework
- Operationalization
- ...

Conceptual analysis questions

- What are the consequences of a conceptual model?
  - Mathematical analysis
    - Prove that for all regular polyhedra Vertices + Faces = 2
  - Mathematical construction
    - Inscribe a square in a given triangle
  - Logical analysis
  - Conceptual analysis
    - What is the relation between credit accounts as defined by bank A and bank B?

- The result must be "true" in the sense of being conceptually correct

Conceptual analysis

- What is implied
- Changing our expectations
- Changing our plans
- Changing our mind

Kinds of problems

- Knowledge problems
  - Definitions
  - Propositions

- Practical problems
  - Conceptual modeling
  - Conceptual analysis
  - Description
  - Explanation
  - Prediction
  - Specification
  - Implementation

- Changes

Conceptual modeling has changed our knowledge, not our world

Conceptual modeling is a knowledge problem

Knowledge problems

Changing our mind

Changing our knowledge

Changing our expectations

Changing our plans

Changing the world

Knowledge questions

Prediction can be regarded as practical problem too

Future-oriented
### Distinction between practical problems and knowledge questions is fuzzy

<table>
<thead>
<tr>
<th>Mind versus world</th>
<th>Past versus future</th>
<th>Truth versus utility</th>
<th>Direction of fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual modeling</td>
<td>Mind</td>
<td>Truth &amp; utility</td>
<td>Proposition must fit the world</td>
</tr>
<tr>
<td>Conceptual analysis</td>
<td>Past</td>
<td>Correctness</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Future</td>
<td>Past</td>
<td></td>
</tr>
<tr>
<td>Explanation</td>
<td></td>
<td>Truth</td>
<td></td>
</tr>
<tr>
<td>Prediction</td>
<td></td>
<td>Truth &amp; utility</td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>World</td>
<td>Utility</td>
<td>World must fit proposition</td>
</tr>
<tr>
<td>Implementation</td>
<td></td>
<td>Utility</td>
<td></td>
</tr>
</tbody>
</table>

### Distinction between practical problems and knowledge questions is important

- The answers are different
  - Definitions, propositions, changes to the world
- Criteria to evaluate answers are different
  - Correctness, truth or utility
- Sources of criteria are different
  - Logic, experience, stakeholders
- So what we should to answer them is different
  - Analysis, research, problem solving

Mixing this up causes severe problems:
- Truth as a matter of choice
- Utility as determined by designer
- Correctness is arbitrary
- Stakeholders do not determine what is true
- Engineer does not determine what stakeholder finds useful

### Relations between problems

- You can work on many kinds of problems simultaneously
- In order to solve any problem, you need a conceptual model
  - Language to talk about phenomena
  - Language to talk about solutions
- Prediction without explanation
  - Weather forecast: patterns without understanding
- Explanation without prediction
  - Business problem caused by business merger: Explanation when problem occurs, but problem not predictable
- Specification without explanation
  - Wooden cart construction: It always works this way
- Specification without prediction
  - Tinkering
  - Evolutionary development

### Assignment 2

- Identify one example of each class of problem (slide Kinds of problems) from your own practice

### Subproblems of practical problems

- How-to-do problems
  - Specify a solution
  - How to provide logistics
  - Support to Holland Casino
  - How to exchange patient data between hospitals & insurance companies
  - How to select a new WFMS
  - How to improve our claim handling process
  - Implement a specification
  - ...

K = knowledge question
P = practical problem

Solving this may require
- K Describing the problems with logistics
- K Surveying available solutions
- K Selecting an available solution
- P Specifying parts
- K Finding out which parts are available
- ...

Doing this may require solving subproblem
- P Building a solution prototype
- P Experimenting with a solution prototype
- P Assembling a new solution from parts of available solutions
- P Inventing a totally new solution
- K Predicting the properties of a planned solution
- K Describing the problems with logistics
- K Surveying available solutions
- K Selecting an available solution
Subproblems of knowledge questions

- **Description**
  - What is the case
  - Who is involved?
  - What do they want?
  - What happened?
  - When did this happen?
  - How often?
  - Where did it happen?
  - How good/bad is this?

- **Explanation**
  - Why is it the case

Answering these may require:
- P Obtaining access to subjects
- P Designing a questionnaire
- P Designing an experiment
- P Placing probes
- K Surveying state of the art
- K Studying similar problems
- P Participating in a project
- K Designing a conceptual model

Mutual problem nesting

- Practical problem may occur during answering a knowledge question
- Knowledge question may occur when solving a practical problem

Labels for kinds of problems

- **CM**
  - Conceptual modeling
  - How to describe
  - Definitions, taxonomy

- **CA**
  - Conceptual analysis
  - What is implied
  - Analytical proposition

- **D**
  - Description
  - What is the case
  - Empirical proposition

- **E**
  - Explanation
  - Why is it the case
  - Expectation

- **P**
  - Prediction
  - What will be the case

- **S**
  - Specification
  - What should we do
  - Plan

- **A**
  - Implementation
  - How to do
  - Change

How to solve conflicts between and agencies standards for data exchange between HRM depts?

<table>
<thead>
<tr>
<th>Problem decomposition</th>
<th>Problem sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM Conflict taxonomy?</td>
<td>Make CM of subject domain of X and Y</td>
</tr>
<tr>
<td>D Conflicts between X and Y?</td>
<td>P Problems caused by this</td>
</tr>
<tr>
<td>K What causes the conflict?</td>
<td>D Stakeholders, phenomena, goals, criteria</td>
</tr>
<tr>
<td>S Specify solutions</td>
<td>D Describe the causes</td>
</tr>
<tr>
<td>A Implementation</td>
<td>D Inventarize existing ones</td>
</tr>
<tr>
<td>Change</td>
<td>S Compose new ones</td>
</tr>
<tr>
<td>...... (TBD)</td>
<td>Validate the solutions</td>
</tr>
<tr>
<td>Reflection: Lessons learned</td>
<td></td>
</tr>
</tbody>
</table>

Engineering cycle

- **Problem investigation**: What is the problem?
- **Solution specification**: Describe one or more solutions
- **Specification validation**: Which alternative best solves the problem?

**Selection**
- Specification implementation
- Implementation evaluation: How well did it solve the problem?
Engineering cycle

Subproblems

- Problem investigation
  - K Stakeholders?
  - K Their goals?
  - K Their causes?
  - K Impacts?
  - K Solution criteria?
- Solution specification
  - K Available solutions?
  - S Design new ones
- Solution validation
  - K Solution properties?
  - K Satisfaction of criteria?
  - K Whose goals achieved/inhibited?
  - K Trade-offs?
  - K Sensitivity?
- A Solution selection
- A Implementation
- K Implementation evaluation

Subproblems

- Problem investigation
  - K Stakeholders?
  - K Their goals?
  - K Their causes?
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  - K Sensitivity?
- A Solution selection
- A Implementation
- K Implementation evaluation

4.1 Practical problem investigation / Evaluation research

Practical problem investigation

Example from RE’07

- What is the impact of distance on awareness in global RE? (phenomena)
- Why do these exist? (mechanisms)
- Research design: Case study
- Collected data: Interaction graph
- Explanation: Distance correlates negatively with awareness

Turning this into a problem investigation

- Who are the stakeholders?
  - Requirements engineers
  - Customers
  - Software engineers
- What are their goals?
  - Producing valid requirements
    - Requirements engineers want to communicate with all relevant stakeholders
- How do these translate into solution criteria?
  - # of requirements-caused errors
    - # of requirements revisions
- What relevant phenomena?
  - Interaction graph, data about communications
- What is their impact?
  - (not investigated)
- How does this compare with the criteria?
  - (not investigated)
- By what mechanism are results produced?
  - Awareness

Mechanisms give us a clue about possible solutions

The RE’07 paper was interested in impact of distance on awareness. Its goal was not to identify or diagnose problems

No treatment if no diagnosis
Assignment 3

- Select a practical problem and write down the research questions for investigating this problem

4.2 Validation research

Engineering cycle

Solution and environment

1. Design IT-enabled procurement- and distribution process for Holland Casino
   - Solution: Procurement & distribution processes & IT support
   - Environment: Other processes, other IT support of HC and of partners
2. Design an architecture for an IT system that supports logistics across a set of businesses
   - Solution: IT architecture
   - Environment: IT infrastructure, IT management processes, business network
3. Develop/acquire a WFMS for a company
   - Solution: A WFMS
   - Environment: IT infrastructure, DBs, work processes, policies, ...
4. Develop a method for buying a WFMS
   - Solution: A method for buying a WFMS
   - Environment: Other procurement processes, other software, procurement department
   - Solutions make assumptions about environments
   - Will not work in all environments

Examples from RE ‘07

Technical papers
- Combine i* with satisfaction arguments
- Combine i* with tracing
- Improve requirements revision based on field reports
- Improved techniques requirements prioritization
- Propose a technique for RE based on analysis of competitive environment
- Identify missing objects and actions in NL RE document
- Apply statistical clustering to prioritize RE

- In all cases the solution is an RE technique
- In all cases the environment consists of requirements engineers
- The processes they follow
- The solutions and usage contexts they aim to align
- Validation requires criteria motivated in terms of stakeholder goals
### Solution validation questions

- **Solution & Environment satisfy Criteria**
  - What will be the solution properties?
  - What are the environment properties relevant for the solution?
  - Will the interaction satisfy the criteria?
  - How will the solution and environment interact?

  - This is **internal validity** of the solution specification.
  - There are usually many solutions that satisfy the criteria in different ways.

### More validation questions

- **Solution & Environment satisfy Criteria**
  - Sensitivity analysis: Does the solution still work in a different context? (External validity)
  - Trade-off analysis: What happens if we vary solution properties? (Useful to determine preferences)

### Validation methods

- **Validation is predicting** the properties of something that does not exist yet

- **Solution & Environment satisfy Criteria**
  - Prediction by computation from specification:
    - Requires sufficient knowledge of the behavior of S in context C
    - Requires approximation if exact computation is not possible
  - Full complexity of conditions of practice can only be achieved by modeling and simulation
  - Scaling up from simplified conditions to full conditions

- Need a law of similitude

### Validating products or processes

- **Validation of hardware or software specification** can be done by modeling
  - throw-away prototypes
- **Validation of a process technique** requires people to act as models of the real user

### Validating (RE)process techniques (1)

- **Illustration**
  - Small example to explain the technique
  - Allows reader to understand the technique
- **Lab demo**
  - Technique used by author on realistic example in artificial environment
  - Shows that the technique could work in practice
- **Benchmark**
  - Technique used by author on standard example in artificial environment
  - Allows comparison of technique with others
- **Field trial**
  - Author uses technique in the field to acquire knowledge
  - Shows that the technique can be used in practice
- **Action research**
  - Author uses technique in the field to achieve project goals
  - Shows that the technique can be used in practice to help others

---

<table>
<thead>
<tr>
<th>Answering a research question about a new process technique not yet used</th>
<th>Validating (RE)process techniques (1)</th>
</tr>
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<tbody>
<tr>
<td>Technique used by its designer</td>
<td>Technique used by others</td>
</tr>
<tr>
<td>In the lab: Controlled context</td>
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</tr>
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<td>Lab demo</td>
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<tr>
<td>In the field: Realistic context</td>
<td>Field trial</td>
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<tr>
<td>Solving a practical problem using a new process technique</td>
<td>Action research</td>
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Validating (RE) process techniques (2)

- Pilot project
  - Others use technique under conditions of practice to provide data to researcher
  - Can be used to answer research questions; analogic generalization but may be based on similarity of mechanisms in other projects
- Project
  - Others use the technique under conditions of practice to achieve project goals
  - Can be used to answer research questions; analogic generalization but may be based on similarity of mechanisms in other projects
- Lab or field experiment
  - Others use technique to achieve goals set by researcher in lab or field
  - Can be used to answer research questions; generalization by statistical reasoning or by mechanism, depending on understanding of mechanisms

Examples from RE '07

<table>
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<td>Identify missing objects and actions in NL RE document</td>
<td>Spec, lab demo</td>
</tr>
<tr>
<td>Apply statistical clustering to prioritize RE</td>
<td>Spec, benchmark</td>
</tr>
<tr>
<td>Extend persona-based RE to deal with requirements conflicts</td>
<td>Spec, field trial</td>
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</table>

Rational reconstruction of one example

- Practical problem: prioritization of large sets of requirements
- Specification of automated clustering followed by manual prioritization
- Validation
  - What will be the solution properties?
  - Properties of clustering algorithms
  - What are the environment properties relevant for the solution?
  - Large sets of stable requirements
  - Features of requirements have to be identified manually first
  - How will the solution and environment interact?
  - Will the interaction satisfy the criteria?
  - Different clustering algorithms
  - Different feature sets
  - Different coders
  - What happens if we vary solution properties?
  - Different clustering algorithms
  - Different requirements engineers

Assignment 4

- Select a solution technique and write down the validation questions for this technique

4.3 More problem nesting

Kinds of problems

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<td>A</td>
<td>Implementation</td>
<td>How to do</td>
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</table>
Assignment 6

- Write down the nested problem structure of a technical research project you are involved in.

5. The research cycle

Kinds of problems

Changing your mind
- Conceptual modeling
- Conceptual analysis
- Description
- Explanation
- Prediction
- Specification

Changing the world
- Implementation

Types of research
- Conceptual research
- Empirical research

Knowledge problems
- Predicting
- Planning
- Acting

Practical problems

Ways of answering knowledge problems
- By opinion
- By hearsay
- By authority
- By journalistic inquiry
- By literature study
- By scientific investigation
**Journalistic questions**

- **What** happened?
- **Who** is involved? Who did it? Who was it done to? Who wanted it?
- **Where** did it happen?
- **When** did it happen? How often? How long?
- **How** did it happen? In which steps? By what means?
- **Why** did it happen? Causes? Reasons? Goals?

**Scientific attitude**

- Researchers should
  - evaluate their own and other’s research solely by standards of scientific merit
  - adopt an attitude of doubt towards the truth of their own and other’s claims
  - be ready to admit error in public
  - be tolerant for new ideas
  - accept that there is no final truth

**Critical attitude**

- For scientists
  - In which ways could this be wrong?
  - Can we find better approximations of the truth?
- For engineers
  - In which ways could this fail to achieve these criteria?
  - In which ways could this artifact be improved?

**How to do research is itself a practical problem**

- **Research problem investigation**
  - What research problem do we have?
- **Research design**
  - How are we going to answer the research problem?
- **Research design validation**
  - Would that answer the research questions we have?
- **Research**
- **Evaluation of results**
  - What is the answer to our research questions?
  - Do we know enough now to solve our original practical problem?

**Research cycle**

- Research problem investigation
- Solution design
- Design validation
- Implementation
- Implementation evaluation
- Changes to the world
- Descriptions and explanations

- Analysis of results
- Research problem investigation
- Research design
- Research
- Design validation
- Evaluation of outcomes
5.1 Research problem investigation

- **Research goal:**
  - Where are we in which higher-level engineering cycle?
- **Problem owner:**
  - Who wants to know?
- **Unit of study / Population:**
  - What do we want to know something about?
- **Research questions:**
  - What do we want to know?
- **Conceptual framework:**
  - Constructs (= concepts defined by researcher)
  - Operationalization: Indicators for the constructs?
  - Construct validity: Do the indicators really indicate the constructs?
- **What is known about this problem already?**

**Example (1):**
- **Research goal:**
  - Where are we in which higher-level engineering cycle?
- **Problem owner:**
  - Software engineering managers of X
- **Unit of study / Population:**
  - Architecture decisions?
  - Projects?
  - Classes of software?

**Example (2):**
- **Research questions:**
  - What do we want to know?
  - What architectural decisions have been made in the production of embedded software in company X in the past 5 years? (Decisions made by anyone, even if overruled later.)
  - What architectural decisions have been made in embedded software delivered by projects in company X in the past 5 years? (decisions identifiable in software as finally delivered)

**Example (3):**
- **Conceptual framework:**
  - Constructs
    - Architectural patterns
  - Components and connectors
  - Operationalization: Indicators for the constructs?
    - How to observe a pattern? Can it be present partly?
    - Software to recognize architectural patterns?
  - Construct validity: Are the indicators valid?
    - Are the observation instructions unambiguous?
    - Do different recognizers observe the same patterns?

**Example (4):**
- **What is known about this problem already?**
  - Literature study of patterns
  - Surveying research about architectural decision making
  - Collecting available software to recognize patterns in software
Assignment 6

• Describe a research problem related to a project you are involved in
  – Research goal
  – Problem owner
  – Unit of study
  – Research questions
  – Conceptual model
  – Current knowledge

5.2 Research design

Research cycle

Research
Analysis of results
Research problem
Investigation
• Research goal
• Problem owner
• Unit of study
• Research questions
• Conceptual model
• Current knowledge

Research design
• Unit of data collection
• Environment of data collection
• Measurement instruments
• Data analysis methods

Research design

• Unit of data collection: where do you get your data from?
  – Sample (subset of population, called subjects)
  – Model (represent arbitrary unit of study)
  – Other (documents, professionals, ...)
• Environment of data collection
  – Lab or field
• Measurement instruments
  – Unaided, recorders, probes, interviews, questionnaires, participation, ...
• Interaction with unit of data collection
  – Manipulation of phenomena
  – Intrusion while collecting data
  – Involvement of subjects

Example (5)

• Unit of data collection
  – Sample:
    • Random sample of projects finished in the past 5 years
    • Accessible sample of projects finished the last 5 years
  – Model
    • Not necessary in this example

Unit of data collection: Sample

Target population:
Units of study that you like to generalize to
All embedded software projects in company X

Study population
What you can get access to
All projects in company X finished in the last 5 years

Sampling frame:
How you access the study population
A list of projects in company X finished in the last 5 years provided to you by its CIO

Sample:
The subset you selected
A set of projects from the list

Your units of data collection
Also called subjects
Sampling

- Probability sampling
  - Simple random sampling
  - Allows you to generalize to the target population
  - Stratified random sampling
    - Partition into groups, random sample per group
    - Allows you to generalize about groups
    - Cluster random sampling
      - Random sample of groups, all subjects in a group
      - Used for geographic samples
    - ....
- Nonprobability sampling
  - Convenience
  - Extreme cases
  - Heterogeneous cases
  - Experts (panel)
  - Snowball
  - ....

How can you generalize from the sample to the target population?

How could those generalizations be false?

Example (6)

- Nonprobability sampling of projects
  - Convenience
  - Simply accept the project list handed over to you
  - Extreme cases
  - Two successful and two failed projects
  - Two large and two small projects
  - Heterogeneous cases
  - Unlike systems
  - Different architects
  - Experts (panel)
    - Only projects with the best architects
  - Snowball
    - Project participants point you to another project to investigate

Practical goal: Improvement of architecture decision making in company X

What do we want to know:

- What is it that needs to be improved → sample heterogeneous cases
- What are the best practices → sample projects with experts

Unit of data collection: Model

- Target population:
  - Units of study that you like to generalize to
  - Does not exist yet, or is inaccessible

- Modeling techniques:
  - How you acquire knowledge about the study population
  - How can you transfer conclusions about the model to conclusions about the targets?

Models:

- The models of the units of study that you will construct
- Your units of data collection

Validation of product solutions

- User interfaces, algorithms, software systems
- Investigation of solution specification:
  - Throw-away prototyping
  - Model checking
- Investigation of solution in context
  - Field tests
  - Model checking including environment

Modeling in validation research

- You acquire or build a model that should contain the same mechanisms as those that produce the intended effects in the unit of study
  - Positive analogy: Similarities between model and target
    - Need a law of similitude that justifies conclusions about the target from observations of the model
    - Similitude should be based on identity of mechanisms
    - Turbulence in wind tunnel and in the air
    - Psychology of SE master students and SE professionals
  - Negative analogy: Differences between model and target
    - Age, material, size, etc.
    - These are not the properties you try to conclude something about
- By scaling up you evolve a model into the target
  - Iterate over engineering cycle, starting with model, ending with real prototype
Research design continued

- Environment of data collection
  - Lab or field
  - Consider conditions of practice: Many relevant variables
- Measurement instruments
  - Unaided, recorders, probes, interviews, questionnaires, participation, primary documents, ...
- Interaction with unit of data collection
  - Manipulation of phenomena
    - In experimental research you administer a treatment
  - Intrusion while collecting data
    - E.g. reading documents versus interviewing people
  - Involvement of subjects
    - Using their memory to provide you with data
    - Interpreting events to provide you with data

Research design finally: Data analysis methods

- Methods must be valid considering the other elements of the research design
  - Conceptual analysis
  - Statistical analysis
  - Protocol analysis
  - Content analysis
  - Grounded theory
  - Hermeneutics
  - ....

Assignment 7

- Make a research design for the problem you identified in assignment 7
  - Unit of data collection
    - Sample or model
  - Environment of data collection
    - Lab or field
  - Measurement instruments
    - Treatment,
    - Intrusive measurement,
    - Subject involvement
  - Data analysis methods

5.3 Research design validation

Research cycle

- Analysis of results
  - Research problem investigation
    - Research goal
    - Problem owner
    - Unit of study
    - Research questions
    - Conceptual model
    - Current knowledge
  - Research design
    - Unit of data collection
    - Environment of data collection
    - Measurement instruments
    - Data analysis methods
Research design validation

• Conclusion validity
  – Did you follow proper logic when reasoning about the data?
• Internal validity
  – Do the conclusions that you reached that way indicate a relationship between the indicators that really exists in the unit of data collection?
• Construct validity
  – Is this relationship really a relationship among the constructs?
• External validity
  – Can we generalize this beyond the unit of data collection?

A note of caution

• Validity is about the quality of your arguments
• It is not about the truth of propositions
  – but about their justification
• Discussing validity is not claiming more than you can justify
  – Critical attitude

Conclusion validity

• Did you follow proper logic when reasoning about the data?
  – Are statistics computed correctly?
  Assumptions satisfied?
  – Are the (statistical or qualitative) conclusions from the data found by proper reasoning?
  • E.g. there is so much variety in your observations of architecture decisions that you cannot conclude anything from them.

Internal validity

• Do the conclusions that you reached that way indicate a relationship between the indicators that really exists in the unit of data collection?
  – Are our claims about the data true?
  – Is there really a relationship between the variables?
  – A causal relationship between X and Y?
  • If X would not have changed, Y would not have changed
  – Change in X must precede change in Y
  – X covaries with Y
  – No other plausible explanation of change in Y

Threats to internal validity

• Temporal precedence may be unclear
  – Competence leads to schooling leads to competence leads to more schooling leads to ...
• Sample may not be a-select
  – E.g. Hidden variables
• History: Previous events may influence experiment
• Maturation: Events during experiment influence outcome
  – subjects learn techniques as by doing the experiment
• Attrition: Subjects drop out
• Instrumentation: Measurement instrument may influence outcome
  • ...

Construct validity

• Is the observed relationship really a relationship among the constructs?
  – Do the indicators really indicate the constructs?
  – Are concepts operationalized correctly?
  – Can we generalize from data to concepts?
• Validity tests:
  – Convergence: Different indicators correlate well
  – Two independently developed sets of indicators for usability should score interfaces in the same way
  – Discrimination: Indicators discriminate groups that should differ according to the construct
  – Indicators for usability and performance should not score all programs the same way.
The problem of constructs

- How to define
  - what a requirement is?
  - an assumption?
  - requirements error?
  - requirements evolution?
  - stakeholder?
  - requirements pattern?
- If we cannot define them, then how can we observe them?

Threats to construct validity

- Measuring easy things rather than things of interest
  - Redefining an architecture patterns so that it can be recognized by software
- Wrong scale
  - Incorrect classification of patterns
- Mono-operation bias
  - Giving only one characteristic of each pattern
- Participants' perception of experiment are part of the construct being measured
  - What is a pattern anyway?
  - Experimenter expectancy
  - Novelty of technique
  - Disruption of work of participants


External validity

- Can our results be generalized beyond the unit of data collection?
  - E.g. to the target population?
  - To other target populations?
  - To some individual case?
  - etc.

Statistical generalization versus mechanism-based generalization

- Statistical generalization
  - Relationships between variables observed in sample
  - Assumptions about distribution of properties over population
  - Conclusion about target population
- Mechanism-based generalization
  - Relationships observed in model
  - Same mechanisms (Law of similitude)
  - Conclusion about target population

Example

- Statistical generalization
  - 56 software professionals from one company estimating medium size task after estimating small or large size task
  - Noticeable effect.
  - "whatever the mechanism, this will occur in any company?"

Example

- Mechanism-based generalization
  - Propellers
    - Vincenti 1990
    - Behavior in wind tunnel differs from behavior on a wing in the air
    - Understanding of turbulence phenomena allows inference to behavior on a wing in the air
    - Versus: 56 propellers behaved this way, therefore the real propeller will also behave this way
Generalization by analogy

- Generalization by analogy transfers conclusions about one case to another, "similar" case.
  - No statistical reasoning
  - No reasoning in terms of underlying mechanisms
  - May be totally unfounded
- Master students
  - Turn out to behave similarly to software professionals in study with small tasks (Runeson 2003)
  - Some threats to validity
  - Can we imagine a mechanism that makes master students good models of software professionals?
  - Managers must decide whether to adopt technology this way
  - "Is that case similar to my case?"
  - "What is the risk that I am wrong?"
- Zelkowitz 1998

- Generalization from sample to target population is usually statistical
  - Generalization from model to target population is usually based on similarity of underlying mechanisms
  - Generalization by analogy does not consider underlying mechanisms but looks at "face similarity".

Threats to external validity

- Effects present in this data collection unit may not be present
  - when other observations would have been made
    - usability defined as time-to-understand interface or as time-to-misunderstand interface, even when these constructs are operationalized correctly
  - or in other units
    - Other users
  - or with other treatments
    - performing other tasks
  - or in other environments
    - in other work processes
- This may be uncertainty we have to live with as long as we do not understand underlying mechanisms
- Risk taking

Assignment 8

- Validate the design that you made in assignment 7
  - Conclusion validity
    - How could your conclusions not follow from your observations?
  - Internal validity
    - How could you be mistaken about the existence of relationships in your unit of data collection?
  - Construct validity
    - Did you correctly operationalize your constructs?
  - External validity
    - What could prevent your conclusions to be valid for other subjects?

5.4 Analysis of results

Research cycle

- Analysis of results
  - Analysis
  - Explanation
  - Conclusions
- Design validation
  - Construct validity
  - Internal validity
  - External validity
- Research design
  - Unit of data collection
  - Environment of data collection
  - Measurement instruments
- Research problem investigation
  - Research goal
  - Problem owner
  - Unit of study
  - Research questions
  - Conceptual model
  - Current knowledge
Analysis of results

- **Analysis**: What did we observe?
  - Conceptual analysis
  - Statistical analysis
  - Protocol analysis
  - Content analysis
  - Grounded theory
  - Hermeneutics
  - ...

- **Explanation**: Why did these phenomena occur?
  - Can they be explained by a theory?
    - Model of program comprehension
    - Theory of group decision making
    - Social presence theory
    - ...
  - Is any other explanation possible?

- See Hannay et al 2007 for theories used in SE research

5.5 Some well-known research methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Unit of data collection</th>
<th>Environment</th>
<th>Manipulation of phenomena</th>
<th>Intrusion when collecting data</th>
<th>Subject involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>Sample model</td>
<td>Lab or field</td>
<td>Yes</td>
<td>Lo to Hi</td>
<td>Lo</td>
</tr>
<tr>
<td>Survey</td>
<td>Sample</td>
<td>Field</td>
<td>No</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Field studies (e.g. case study)</td>
<td>Small sample</td>
<td>Field</td>
<td>No</td>
<td>Lo to Hi</td>
<td>Hi</td>
</tr>
<tr>
<td>Action research</td>
<td>Unit of study</td>
<td>Field</td>
<td>Yes</td>
<td>Lo to Hi</td>
<td>Hi</td>
</tr>
<tr>
<td>Aggregation research</td>
<td>Scientific literature</td>
<td>Research desk</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Experimental research

- Manipulation of independent variables X (treatment) to measure effect on dependent variables Y
  - In quasi-experiments, assignment of treatment to subjects is not random
- Used for hypothesis testing
  - X and Y are correlated
  - X causes Y
  - In the lab, variables other than X and Y are held constant (controlled)
  - Nuisance variables (those that impact X and Y and cannot be eliminated) are controlled by research design and by statistical analysis
    - Not always possible in field experiments
- Generalization to target population is statistical or mechanism-based
- May lead to in-depth understanding of relationships between a few variables

Case study research

- Unobtrusive observation of a unit of data collection in its natural environment
  - Many variables that cannot be controlled
  - Phenomena cannot be produced in the lab
  - Subjects may help researcher in interpreting events
- Used for
  - Hypothesis-testing
  - Exploration
- May lead to context-rich understanding of mechanisms
- Generalizations be based on mechanism or on analogy

Case study example 1

- Research problem
  - Research goal: Exploration
  - Problem owner: researcher
  - Unit of study: Small companies < 50 employees
  - Research questions
    - How do they manage requirements?
    - Impact of context?
    - Why these practices?
    - Conceptual model
    - Current knowledge
- Research design
  - Unit of data collection
    - Snowball sample of 12 small companies near Toronto
  - Environment
    - Field
  - Instruments
    - Interviews
      - Intrusive
      - Participation of subject
  - Other (undocumented) with 7 companies
Case study example 1 (continued)

• Evaluation
  -- Analysis
  • Many practices
  • Relational coordination
  • Strong cultural cohesion
  • CEO is requirements engineer
  -- Explanation
  • For small companies:
    • H1: Diversity of techniques is result of evolutionary adaptation
    • H2: Team dynamics more important than choice of RE technique
  • Skill set of requirements engineer is subset of skill-set of entrepreneur

• Validity
  -- Conclusion
  • Not discussed
  -- Internal
    • Participants recounted their interpretation of history
    • Construct
      • "small company" and "requirements management" may not have been operationalized correctly
    -- External
      • All companies headquartered in Toronto

Case study example 2

• Research problem
  -- Research goal: Improve structure of RE papers
  -- Problem owner: RE research community
  -- Unit of study: RE conferences
  -- Research questions
    • What is the methodological structure of these papers?
    • Is difference between accepted and rejected papers?

• Conceptual model
  -- This tutorial
  -- Current knowledge

• Research design
  -- Unit of data collection
    • Two samples from RE'03 submissions
  -- Environment
    • Desk
    -- Instruments
      • Two readers
        -- Non intrusive

• Research problem: Does my technique work?
  -- Design validation: Context of this case & Your technique $\rightarrow$ effects; trade-offs, sensitivity; You and client both interested?
  -- Do the research: 2 parallel engineering cycles
    • You: Help a client using your technique
    • Client: Ask you to help them improve something
  -- Analyze results
  -- Implement your solution: Let others use the technique
  -- Evaluate it: Investigate how they use it

Technical action research

• Problem investigation
• Solution design
• Validate your solution proposal
  -- Research problem: Does my technique work?
  -- Research design: Acquire an action case
  -- Design validation: Context of this case & Your technique $\rightarrow$ effects; trade-offs, sensitivity; You and client both interested?
  -- Do the research: 2 parallel engineering cycles
    • You: Help a client using your technique
    • Client: Ask you to help them improve something
  -- Analyze results
• Implement your solution: Let others use the technique
• Evaluate it: Investigate how they use it

Iterative structure of TAR

Engineering cycle: help a client
Do the research
Engineering cycle: improve technique
Reflection on results
Research problem: How does the technique perform under conditions of practice?

Research cycle
Design validation:
Validate the plan against research problem and against client goals (need a win-win)

Acquire a case, make an intervention plan

6. Discussion

6.1 Normal and radical engineering

No problems

• Researchers may choose to ignore goals and problems and focus on charting and understanding phenomena instead.
• Technologists may develop technology that does not solve any current problem.

Goals of practical problems

<table>
<thead>
<tr>
<th>Practical goals</th>
<th>Low risk</th>
<th>High risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>Aircraft architecture imply some engine requirements</td>
<td></td>
</tr>
<tr>
<td>Improve performance</td>
<td>Natural gas car engines require logistics system, tax incentives, insurance policies</td>
<td></td>
</tr>
<tr>
<td>Flowdown in composite system</td>
<td>Quantum computer</td>
<td></td>
</tr>
<tr>
<td>Flowdown in network of systems</td>
<td>Jet engine; Solid state switching;</td>
<td></td>
</tr>
<tr>
<td>Surpass predicted performance limits</td>
<td>Relational databases; Laptops</td>
<td></td>
</tr>
<tr>
<td>Meet speculated demand</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Normal engineering

• Normal engineering
  – Stakeholders, goals, problematic phenomena exist and are known
  – May or may not require problem investigation
    • Building a house: No problematic phenomena
    • Investigation of current logistics problems not needed: problems known, causes understood
    • Investigation of current data exchange patterns hospitals-insurance companies needed: insufficient knowledge
  – Solution technology is known
    • Improvement may or may not require solution investigation

Radical engineering

• Radical engineering
  – Stakeholders etc. may not exist or be unknown
  • Investigation of problems with propellors and piston engines does not help developing jet engines
  • No laptop user behavior to investigate before laptops were introduced
  – Solution technology unknown
    • A lot of solution investigation
  • There is also curiosity-driven engineering
    – Radical engineering in a low-risk environment
    – Speculative technology, no clear idea of market

RE research, RE technology

Many technical RE papers propose radical solutions or improve existing radical solutions

Research
1. Doing RE
   • Investigating the alignment of technology and stakeholder goals
2. RE research
   • Investigating the RE process

Technology
3. Doing RE
   • Improving the alignment of artifacts and stakeholder goals
4. RE technology
   • Improving the RE process

Examples from RE ’07

Research papers
• What techniques exist for legal RE?
• What is the role of creativity in RE?
• What are NFRS?
• What requirements are collected by different SBRE techniques?
• How is RE done in small companies?
• What collaboration patterns in GRE?
• What is the relationship between requirements quality and project success?
• ....

• One CM question
• Mostly descriptive questions
• One explanatory question

Technical papers
• Combine i* with satisfaction arguments
• Combine i* with tracing
• Improve requirements revision based on field reports
• Improved techniques requirements prioritization
• Propose a technique for RE based on analysis of competitive environment
• Identify missing objects and actions in NL RE document
• Apply statistical clustering to prioritize RE
• Extend persona-based RE to deal with requirements conflicts
• ....

• One CM question
• Mostly descriptive questions
• One explanatory question

Validation methods in SE

<table>
<thead>
<tr>
<th>Description</th>
<th>This tutorial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project monitoring</td>
<td>Measuring instrument (primary sources)</td>
</tr>
<tr>
<td>Case study</td>
<td>Research method</td>
</tr>
<tr>
<td>Assertion</td>
<td>Not a research method</td>
</tr>
<tr>
<td>Field study</td>
<td>Research method</td>
</tr>
<tr>
<td>Literature search</td>
<td>Measurement instrument (primary sources)</td>
</tr>
<tr>
<td>Legacy data</td>
<td>Collection of project data after the project is finished</td>
</tr>
</tbody>
</table>

Difference between assertion and action research is
• Real project
• Discussion of validity
### Validation methods in SE

<table>
<thead>
<tr>
<th>Description</th>
<th>This tutorial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lessons learned</td>
<td>Study of documents produced by a project</td>
</tr>
<tr>
<td>Static analysis</td>
<td>Studying a program and its documentation</td>
</tr>
<tr>
<td>Replicated experiment</td>
<td>Several projects are performed in multiple ways</td>
</tr>
<tr>
<td>Synthetic environment experiment</td>
<td>Several projects are performed in an artificial environment</td>
</tr>
<tr>
<td>Dynamic analysis</td>
<td>Instrumenting a software product to collect data</td>
</tr>
<tr>
<td>Simulation</td>
<td>Executing a product in an artificial environment</td>
</tr>
</tbody>
</table>

---

### 6.3 Design science and technical research

- What is called “research” in software engineering is usually design

- Discussions of design science mix up design and research

---

### Design questions at ICSE ’02

- How to create X
- How to automate X
- What is a design of X
- What is a better design of X
- How to evaluate X
- How to choose between X and Y

- Design goal not always clear
- Source of design goal usually not indicated


- Discussions of design science mix up design and research
Design science Hevner et al. 2004

- Mixup of research and technology

Technical research

- Wieringa et al. 2006
- Engineering cycle allows us to classify papers
  - Problem investigation/Implementation evaluation: Evaluation research paper
  - Solution specification: Technical solution paper
  - Solution validation: Validation paper
- Also:
  - New conceptual framework: Philosophical papers
  - Opinion papers
  - Lessons learned in practice: Personal experience papers
- Each paper class comes with its own evaluation criteria

7. Further reading


Nunamaker et al. 1990-1991

- “A research process of systems development.
  - Construct a conceptual framework
  - Develop a system architecture
  - Analyze and design the system
  - Build the prototype system
  - Observe and evaluate the system”
- This is the engineering cycle with embedded research cycles

Web resources

• General
  – http://www.socialresearchmethods.net/kb/consval.php
• Statistics
  – http://faculty.vassar.edu/lowry/webtext.html
• Theories used in IS
• Action research
• Action research in IS
  – http://www.cis.gsu.edu/~rbaskerv/CAIS_2_19/CAIS_2_19.html
• Qualitative research in IS
  – http://www.qual.auckland.ac.nz/
• Design research in information systems
  – http://www.isworld.org/Researchdesign/DratW0rd.htm