Requirements Engineering Research Methodology: Principles and practice

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Outline

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

Kinds of artifacts & usage domains

Software products
- Information systems,
- WFM systems,
- Embedded control systems,
- Ambient systems,
- Mobile systems,
- ...

Used in some domain
- Manufacturing
- Cars
- Telecom,
- Government,
- Finance,
- Health care,
- ...

Process technology
- Techniques
- Notations
- Tools
- Process models
- Job roles
- Task structures
- ...

Used in some domain
- Software production
- Software maintenance
- Software management
- Systems engineering
- Business redesign
- ...

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.*
   - *Current process? Current IT? Problems? Goals?*
   - *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

Problem investigation is research

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*

RE research, RE technology

	Research: Investigating things	Technology: Improving things	
	1. Doing RE • Investigating the alignment of technology and stakeholder goals	3. Doing RE • Improving the alignment of artifacts and stakeholder goals	Any domain
	2. RE research • Investigating the RE process	4. RE technology • Improving the RE process	Domain is 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*
- *Maintaining software*
- *Developing a questionnaire*
- *Developing a maintenance method*

- *Writing a paper*
- *Interviewing software users*
- *Evaluating a maintenance method*

3. Knowledge problems and practical problems

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 uses 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

Doing
Changing the world
Future-oriented

Thinking
Changing our mind
Past-oriented

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

Specification problem

(a.k.a. design problem)

- How-to-do X
  - Specify a solution
    - *How to provide logistics support to Holland Casino* → *Specification of business process & IT*
    - *How to control paper sorter* → *Specification of controller & operations*
    - *How to select a new WFMS* → *Specification of selection process*
    - *How to improve our claim handling process* → *Specification of business process*

Action problem

- Do X
  - Implement a specification
    - ....

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
    - Decompositrions 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?

Journalistic questions
• yield facts

Evaluation questions:
Comparison with a norm

Investigative questions
• yields understanding

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

Prediction yields
•Descriptions of future facts
•No new explanations
•Truth (approximate)

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
•...

What kind of problem?

- Conceptual model must be useful
  - *Allows us to recognize entities*
  - *Allows us to communicate about entities*
  - *Allows us to store & retrieve information*
  - *Allows us to generalize*
  - *Allows us to prescribe*
- Conceptual modeling is changing our mind, not changing the world
- Conceptual models are not arbitrary
  - They show structures in reality
  - They allow us to make true/false statements

Practical problems

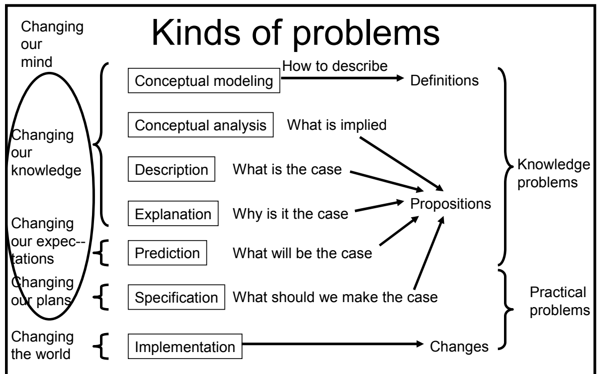
CM is a knowledge problem

Conceptual analysis questions

- What are the consequences of a conceptual model?
  - Mathematical analysis
    - *Prove that for all regular polyhedra Vertices – Edges + Faces = 2*
  - Mathematical construction
    - *Inscribe a square in a given triangle*
  - Logical analysis
    - Is state A reachable from state B?
  - 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

Knowledge questions

Kinds of problems



- Prediction can be regarded as practical problem too
- Future-oriented

Distinction between practical problems and knowledge questions is fuzzy

	Mind versus world	Past versus future	Truth versus utility	Direction of fit
Conceptual modeling	Mind		Truth & utility	Proposition must fit the world
Conceptual analysis			Correctness	
Description		Past	Truth	
Explanation			Truth	
Prediction		Future	Truth & utility	
Specification			Utility	World must fit proposition
Implementation	World		Utility	

} Empirical research questions (Description, Explanation, Prediction)

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 → Mixing this up causes severe problems:
    - •Truth as a matter of choice
    - •Utility as determined by designer
    - •Correctness is arbitrary
- Sources of criteria are different
  - Logic, experience, stakeholders
- So what we should to answer them is different
  - Analysis, research, problem solving

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

3.3. Nested problems

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
    - ....

→ Solving this may require (Specify a solution)
- K Describing the problems with logistics
- K Surveying available solutions
- P Selecting an available solution
- P Assembling a new solution from parts of available solutions
- P Inventing a totally new solution
- K Prediction the properties of a planned solution
- P Building a solution prototype
- P Experimenting with a solution prototype
- ...

→ Doing this may require solving subproblem (Implement a specification)
- P Specifying parts
- K Finding out which parts are available
- ...

K = knowledge question
P = practical problem

Subproblems of knowledge questions

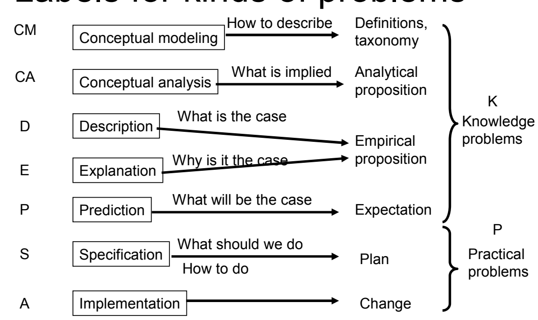
- Description
  - What is the case
    - *Who is involved?*
    - *What do they want?*
    - *What happened?*
    - *When did this happen?*
    - *How often?*
    - *Where did it happen?*
    - *How good/bad is this?*
- Explanation
  - Why is it the case

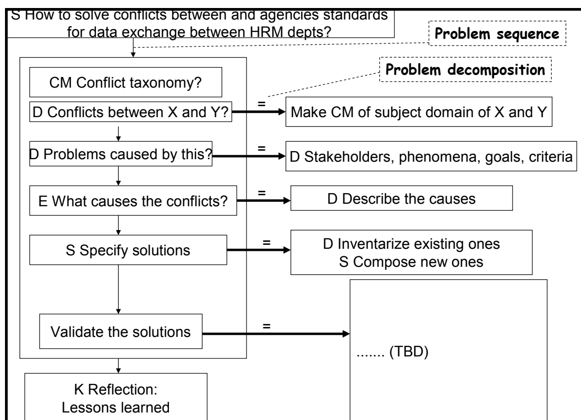
Answering these may require
- P Obtaining access to subjects
- P Designing a questionnaire
- P Designing an experiment
- P Placing probes
- K Surveying state of the art
- K Studying similar problems
- P Participating in a project
- K Designing a conceptual model
- ...

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





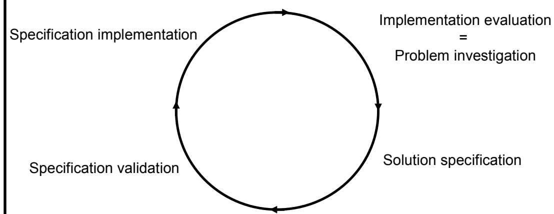
4. Engineering cycle

Engineering cycle

- **Problem investigation:** What is the problem?
- **Solution specification:** Describe one or more solutions
- **Specification validation:** Which alternative best solves the problem? **Feed forward** **Design cycle / Specification cycle / RE**
- **Selection**
- **Specification implementation**
- **Implementation evaluation:** How well did it solve the problem? **Feedback** **Engineering cycle**

•Engineering is a rational way to solve a practical problem
•RE = alignment between problems and solutions

Engineering cycle



Subproblems

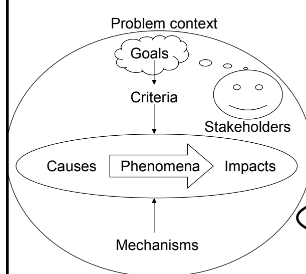
- Problem investigation
  - K Stakeholders?
  - K Their goals?
  - K Problematic phenomena?
  - K Their causes?
  - K Impacts?
  - K Solution criteria?
- Solution specification
  - K Available solutions?
  - S Design new ones
- Solution validation
  - K Solution properties?
  - K Satisfaction of criteria?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

K = Knowledge problem
A = Action problem
S = specification problem

4.1 Practical problem investigation / Evaluation research

Practical problem investigation

Practical problem structure



Typical research questions

- *Who are the stakeholders?*
- *What are their goals?*
- *How do these translate into solution criteria?*
- *What are the relevant phenomena?*
- *What are their causes and impacts?*
- *How does this compare with the criteria?*
- *By what mechanism are impacts produced?*

No treatment if no diagnosis

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*

Damian, Marczak, Kwan – Collaboration patterns and the impact of distance on awareness in requirements-centered social networks. RE'07

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

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

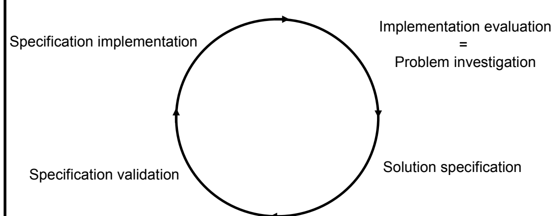
Mechanisms give us a clue about possible solutions

Assignment 3

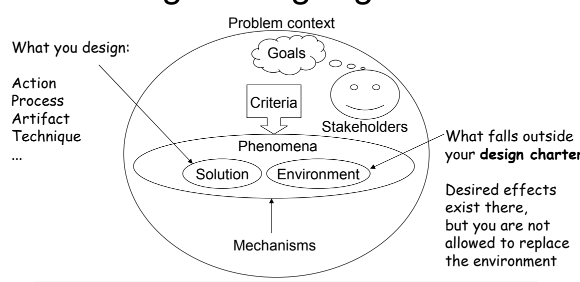
- Select a practical problem and write down the research questions for investigating this problem

4.2 Validation research

Engineering cycle



Engineering argument



- Solution & Environment satisfy Criteria

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?

How will the solution and environment interact?

What are the environment properties relevant for the solution?

Will the interaction satisfy the criteria?

•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

Trade-off analysis:
What happens if we vary solution properties?
(Useful to determine preferences)

Sensitivity analysis:
Does the solution still work in a different context?
(External validity)

Validation methods

- Validation is **predicting** the properties of something that does not exist yet
- Solution & Environment satisfy Criteria

Need a law of similitude

Conditions of practice

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

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

Answering a research question about a new process technique not yet used

	Technique used by its designer	Technique used by others
In the lab: Controlled context	Illustration	Lab experiment
	Lab demo	
	Benchmark	
In the field: Realistic context	Field trial	Field experiment
	Action research	Pilot project

Solving a practical problem using a new process technique

	Technique used by its designer	Technique used by others
In the lab: Controlled context		
In the field: Realistic context	Action research	Project
	Consultancy	

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

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

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

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?
  - Does the solution still work in a different context?
    - Different sets of requirements
    - Different feature sets
    - Different coders
  - What happens if we vary solution properties?
    - Different clustering algorithms
    - Different requirements engineers

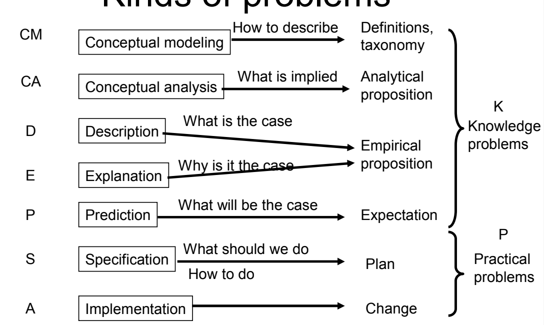
Laurent, Cleland-Huang, Duan – Towards automated requirements triage. RE'07

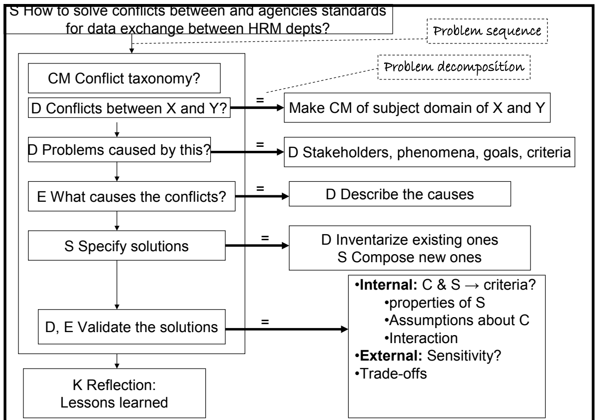
Assignment 4

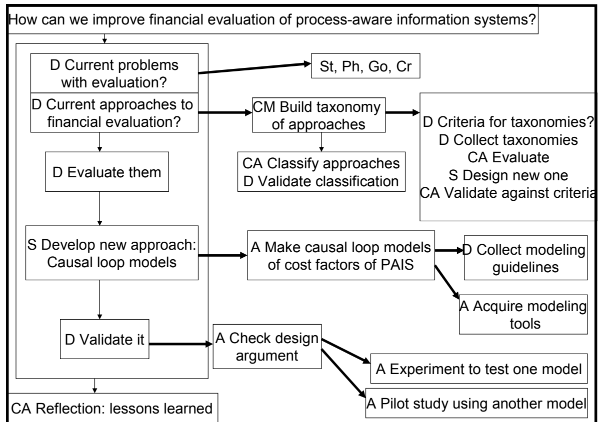
- Select a solution technique and write down the validation questions for this technique

4.3 More problem nesting

Kinds of problems





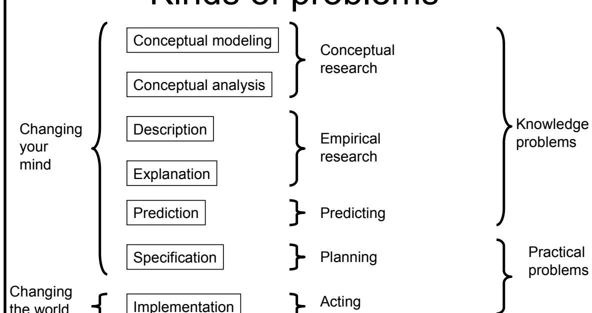


Assignment 6

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

5. The research cycle

Kinds of 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?

Investigative journalism

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

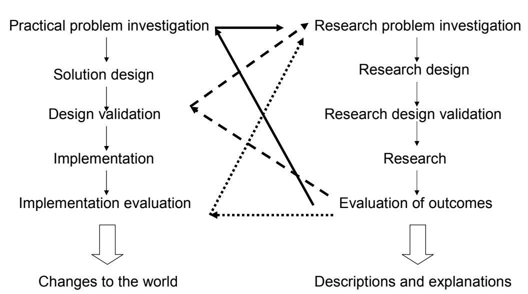
Critical attitude

- 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?

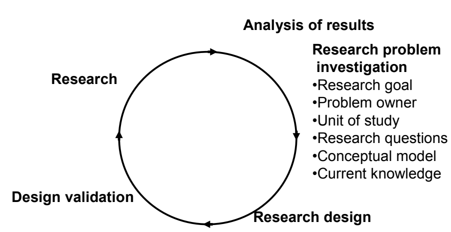
How to do research is itself a practical problem

- **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?

Doing research is one particular subproblem in a hierarchy of practical problems



Research cycle



5.1 Research problem investigation

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?
  - *Engineering cycle: Improvement of architecture decision making in company X*
  - *Problem investigation: what is the s.o.t.p. in X?*
- Problem owner:
  - Who wants to know?
  - *Software engineering managers of X*
- Unit of study / Population
  - What does the problem owner want to know something about?
  - *Architecture decisions?*
  - *Projects?*
  - *Classes of software?*

} **Different possibilities**

For any unit of study:
•How can it be observed?
•When does it exist? When does it occur?
•How can it be counted?

The population,
by definition,
is the set of
all possible units of study

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)*

•We cannot formulate the research questions if we have not decided on a unit of study
•And vice versa

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)

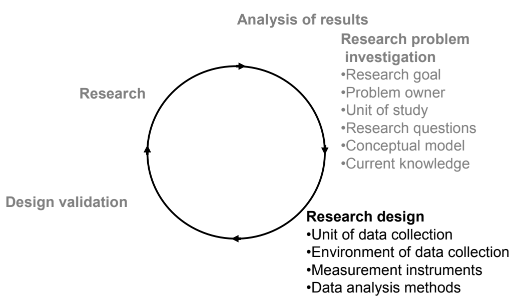
- What is known about this problem already?
  - *Literature study of patterns*
  - *Surveying research about architectural decision making*
  - *Collecting available software to recognize patterns in software*

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 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

In validation research this does not yet exist

Stand-in for sample

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

All future airplanes with jet engines

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

Model jet engines

Your units of data collection.

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

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

Answering a research question about a new process technique not yet used

	Technique used by its designer	Technique used by others
In the lab: Controlled context	Illustration	Lab experiment
	Lab demo	
	Benchmark	
In the field: Realistic context	Field trial	Field experiment
	Action research	Pilot project

Sampling if technique used by professionals, otherwise modeling

Modeling

Solving a practical problem using a new process technique

	Technique used by its designer	Technique used by others
In the lab: Controlled context		
In the field: Realistic context	Action research	Project
	Consultancy	

Sampling

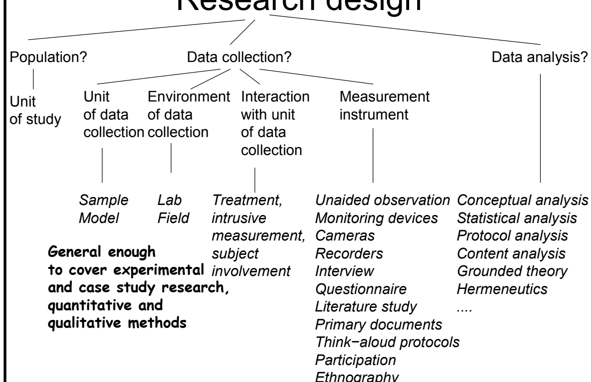
Research design continued

- 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*
  - ....

Research design

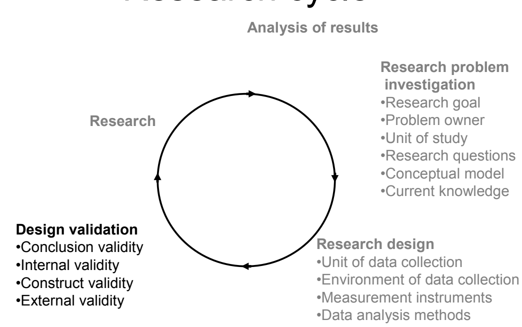


Assignment 7

- 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



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
- ....

See Shadish, Cook & Campbell 2002.

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

See Shadish, Cook & Campbell 2002.

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
  - *S. Grimstad, M. Jørgensen. A Preliminary Study of Sequence Effects in Judgment-based Software Development Work- Effort Estimation. EASE 2008*
    - *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?"
    - Managers like information about conditions of practice
    - 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 bujt looks at "face similarity".

Threats to external validity

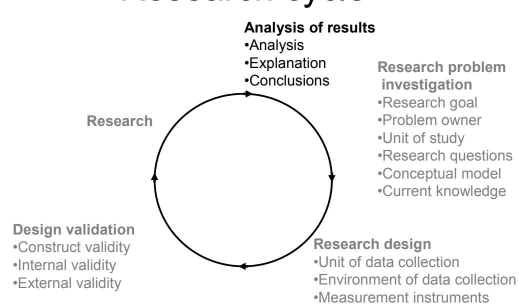
- Effects present in this data collection unit may not be present
  - when other observations would have been made
    - *usability defined as time-to-understand interface or as times-to-misunderstand interface, even when these constructs are operationalized correctly*
  - or in other units
    - *Other 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:** 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

•http://www.fsc.yorku.ca/york/istheory/wiki/index.php/Main_Page for theories used in IS research

5.5 Some well-known research methods

Some well-known research methods

	Unit of data collection	Environment	Manipulation of phenomena	Intrusion when collecting data	Subject involvement
Experiment	Sample or model	Lab or field	Yes	Lo to hi	Lo
Survey	Sample	Field	No	Lo	Lo
Field studies (e.g. case study)	Small sample	Field	No	Lo	Lo to Hi
Action research	Unit of study	Field	Yes	Lo to Hi	Hi
Aggregation research	Scientific literature	Research desk	None	None	None

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)
- Nuissance 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
  - Phenomenon 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
    - H3: Skill set of requirements engineer is subset of skill-set of entrepeneur
- 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

•R.J. Wieringa, J.M.G. Heerkens. "The Methodological Soundness of Requirements Engineering Papers: A Conceptual Framework and Two Case Studies." *Requirements Engineering Journal,* 11(4), 2006, pages 295-307.

- **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

Case study example 2 (continued)

- Evaluation
  - Analysis
    - Twice as many design as research papers
    - Design papers present solutions to isolated problems
    - Little problem investigation
    - Little validation
    - No implementation
    - Research papers fail to specify research questions
    - Half describe no research design or validation
  - Explanation
    - We are designers, don't like research
    - Validation of process techniques is hard
- Validity
  - Conclusion
    - No threats identified
  - Internal
    - No threats identified
  - Construct
    - Two readers, differences resolved
    - Clear operationalizations
  - External
    - No generalization
    - Other cases may exhibit other patterns
    - Mechanisms may be at work elsewhere too, but this does not follow from these case studies

Technical action research

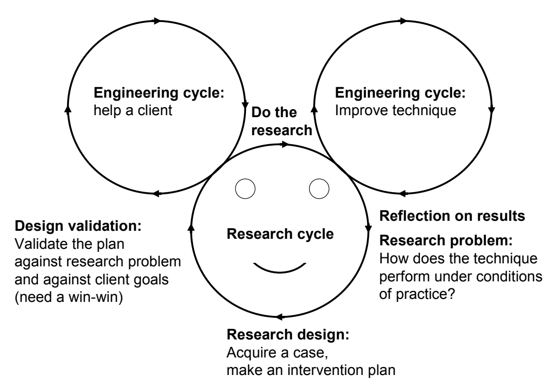
- Researcher applies technique to a case to help a client
- Now there are two engineering cycles
  - One of the researcher developing her techniques
  - One of the client solving a client problem
- There must be a win-win that is clear to both parties.

Technical action research

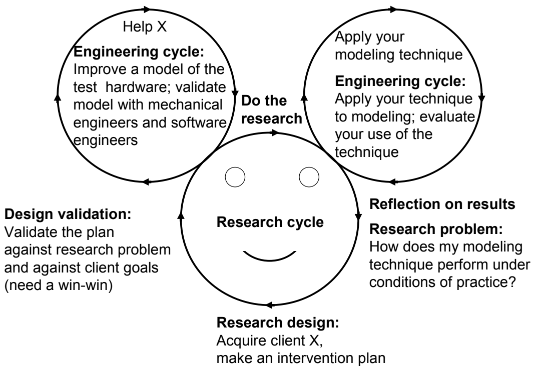
- Problem investigation
- Solution design
- Validate your solution proposal
  - Research problem: Does my technique work?
  - Research design: Acquire an action case
  - Design validation: Context of this case & Your technique → effects; trade-offs, sensitivity. You and client both interested?
  - Do 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

E R E I I E

Iterative structure of TAR



Iterative structure of TAR



Example of TAR (continued)

- Conclusion invalidity
  - Conclude there is **no** relationship between your technique and some effect where there is one
  - Conclude that there **is** a relationship when there is none
  - *Documenting assumptions about the plant improves model quality*
- Internal invalidity
  - Conclude that there is a **causal** relationship and some effect vwhen there is none, or when there are possible other explanations
  - *Model quality may have been improved because the modeler is competent (confounding variable)*
- Construct invalidity
  - Modeling concepts such as “domain” may have been operationalized incorrectly
- External invalidity
  - Sensitivity of technique to changes in context?
  - *Conclusions may hold for Jelena doing the modeling at X only.*
  - Managers need context-rich stories when deciding to adopt new techniques in their situation. Zelkowitz et al. 1998.
  - Analogic reasoning, where observation of similarity is based on gut feeling rather than known mechanisms

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

Low risk → High risk

Practical goals

Normal engineering:
- Repair
- Improve performance
- Flowdown in composite system → *Aircraft architecture imply some engine requirements*
- Flowdown in network of systems → *Natural gas car engines require logistics system, tax incentives, insurance policies*

Radical engineering:
- Surpass predicted performance limits → *Jet engine; Solid state switching; Quantum computer*
- Meet speculated demand → *Relational databases; Laptops*

Normal engineering

- Normal engineering
  - Stakeholders, goals, problematic phenomena exist and are known
  - May or may not require problem investigation
    - *Building a house: No problemative 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*
- ....

·No problem investigation
·All solution specifications
·Some solution validation

6.2 Validation methods in software engineering

Validation methods in SE

Zelkowitz & Wallace 1998	**Description**	**This tutorial**
Project monitoring	Collection and storage of project data	Measuring instrument (primary sources)
Case study	Collection of project data with a research goal in mind	Research method
Assertion	The researcher has used the technique in an example, with the goal of showing that the technique is superior	Not a research method
Field study	Collection of data about several projects with a research goal in mind	Research method
Literature search		Measurement instrument
Legacy data	Collection of project data after the project is finished	Measuring instrument (primary sources)

Difference between assertion and action research is
·Real project
·Discussion of validity

Validation methods in SE

Zelkowitz & Wallace 1998	Description	This tutorial
Lessons learned	Study of documents produced by a project	Data analysis method (Conceptual analysis)
Static analysis	Studying a program and its documentation	Measuring instrument (Primary sources)
Replicated experiment	Several projects are staffed to perform a task in multiple ways	Research method (field experiment)
Synthetic environment experiment	Several projects are performed in an artificial environment	Research method (lab experiment)
Dynamic analysis	Instrumenting a software product to collect data	Measuring instrument (monitoring devices)
Simulation	Executing a product in an artificial environment	Research method (lab experiment)

6.3 Design science and technical research

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

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

} Design

- How to evaluate X — Evaluation
- How to choose between X and Y — Selection

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

•M. Shaw. “What makes good research in software engineering?” *International Journal of Software Tools for Techology Transfer*, 4(1), October 2002, pages 1-7.

reformulated and reclassified by me

Research questions at ICSE' 02

- s.o.t.p. of X?
- s.o.t.a. of X?

} Descriptive research

- Does X exist?
- Model of X?
- Kinds of Xs?
- Properties of X?
- Property P of X?

} What is X

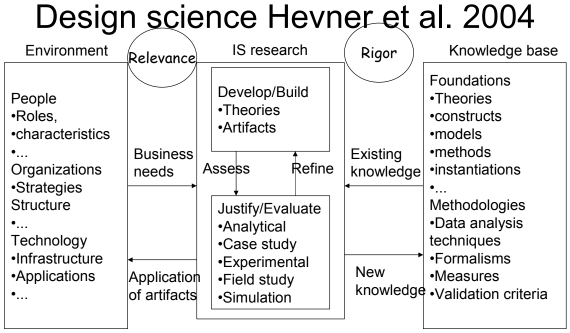
- Relationships among Xs?
- What is X given Y?
- How does X compare to Y?

} Relation of X and Y

Shaw 2002

- Discussions of design science mix up design and research

Design science Hevner et al. 2004



- Mixup of research and technology

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

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

Have been merged in the RE and CAiSE conferences

7. Further reading

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Web resources

- General
  - http://www.socialresearchmethods.net/kb/constval.php
- Statistics
  - http://en.wikipedia.org/wiki/Sampling_(statistics)
  - http://faculty.vassar.edu/lowry/webtext.html
- Theories used in IS
  - http://www.fsc.yorku.ca/york/istheory/wiki/index.php/Main_Page
- Action research
  - http://carbon.cudenver.edu/~mryder/itc_data/act_res.html
  - http://www.scu.edu.au/schools/gcm/ar/arr/arow/rmasters.html
  - http://www.scu.edu.au/schools/gcm/ar/arhome.html
- 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/drisISworld.htm