Design Science Methodology MIKS

Winter 2016 – 2017

Prof. Dr. Roel Wieringa

0. Introduction

0.1 Goal of the course

Goal of the course

- Help you do your research projects (e.g. Master thesis)
  - Improve your capability to **justify** your solution
  - Help you **structure** your Master's thesis
- Improves your problem-solving capability
  - But not a creativity course

Reality check

What kind of problems?

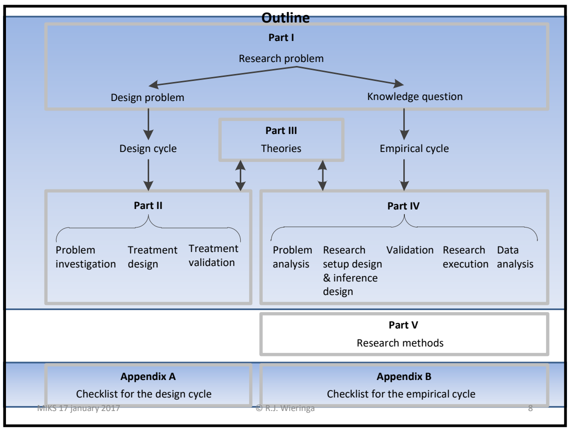
- Business Information Technology master thesis at the University of Twente:
  - http://essay.utwente.nl/view/programme/60025.html
- Computer Science master thesis at the University of Twente:
  - http://essay.utwente.nl/view/programme/60300.html
- Business Administration master thesis at the University of Twente:
  - http://essay.utwente.nl/view/programme/60644.html
- Master theses in human-media interaction
  - http://essay.utwente.nl/view/programme/60030.html

Two kinds of research problems

- (1) Design problems
  - *Improve something, design something , how-to-do something*
  - Problem, design of a treatment, validation of the treatment
  - **Design cycle**
  - Improvement is the goal, utility is the criterion
  - Knowledge is a side-effect
  - ``Technical research problems''
- (2) Knowledge questions
  - *Describe, explain, predict*
  - Questions, research design, research execution, data, analysis
  - **Empirical research cycle**
  - Knowledge is the goal, truth is the criterion
  - Utility is a side-effect

Focus on justification

- This is not a creativity course
  - Not about how to be original
- The course is about how to **justify** and **report** your research results
  - Why would anyone use your design? There are many other designs.
  - Why would anyone believe your answers? Opinions are cheap.
- This also helps you to organize the project itself.



0.2 Organization of the course

Material

- Book http://link.springer.com/book/10.1007/978-3-662-43839-8
- Slides

Schedule

- Today
  - Course on design cycle
  - Questions and exercises during the day
- After today: Make outline the table of contents of your thesis
- 21st February
  - Present your table of contents on a poster
  - Course on empirical research design
  - Finalize poster

Questions?

1 What is design science?

2.1 The subject of design science

- Design science is the **design** and **investigation** of artifacts in context

Reality check: **What is the artifact and what is the context?**

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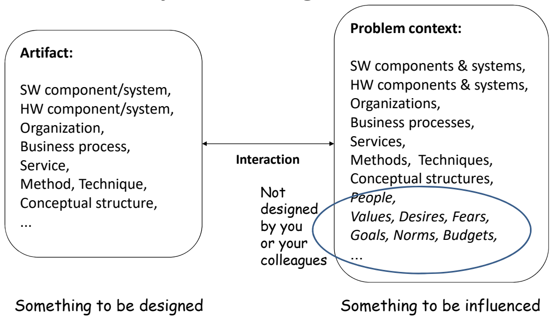
Subject of design science



- Without a context, an artifact does nothing

What is designed and what is given

- The problem context is given to you
  - It is not designed by you
  - May be designed by others
- The (renewed) artifact is (re)designed by you
  - It is not given to you
  - An older version of the artifact may be given to you

Interaction should provide a service for the context

- The artifact interacts with the problem context … in order to improve the context
- The interaction provides a **service** to the problem context

2.2 Research problems in design science

Research problems in design science

To design an artifact to improve a problem context → Problems & Artifacts to investigate → **To answer knowledge questions about the artifact in context**

To answer knowledge questions about the artifact in context → Knowledge, Design problems → **To design an artifact to improve a problem context**

Design software to estimate Direction of Arrival of plane waves, to be used in satelite TV receivers in cars	• *Is the DoA estimation accurate enough in this context?* • *Is it fast enough?*
Design a Multi-Agent Route Planning system to be used for aircraft taxi route planning	• *Is this routing algorithm deadlock-free on airports?* • *How much delay does it produce?*
Design a data location regulation auditing method	• *Is the method usable and useful for consultants?*
Artifact of a design problem = the artifact **to be** designed	Artifact of a knowledge question = the artifact **about which** we ask the knowledge question

Heuristics

- Design problems
  - √ Call for a change of the world
  - √ Solution is design
  - √ Many solutions
  - √ Evaluated by utility
  - √ Many degrees of utility
  - √ What is useful depends on stakeholder goals
- Knowledge questions
  - √ Ask for knowledge about the world
  - √ Answer is a proposition
  - √ One answer
  - √ Evaluated by truth
  - √ Many degrees of certainty about the answer
  - √ What is considered "true" does not depend on stakeholder goals

http://www.factcheck.o

Doing

Thinking

Reality check:
What is the artifact and what is the context?

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Conclusions

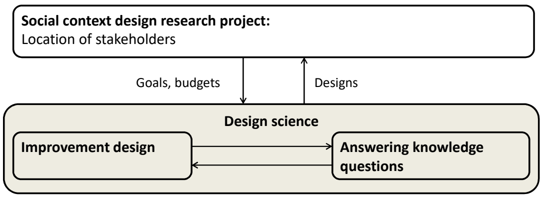
- The title of your thesis is the shortest summary of your research project.
  - The best titles mention the artifact and the context.
- The top-level research problem of a thesis is either a design problem or a knowledge question
  - The motivation of the research may be both curiosity/fun, as well as utility

Exercise: Ingredients for your thesis title

- What research problem(s) are you investigating?
  - Artifact and context

2.3 The social context of a design science project

The social context of design research



"Design a DoA estimation system to be used in cars":

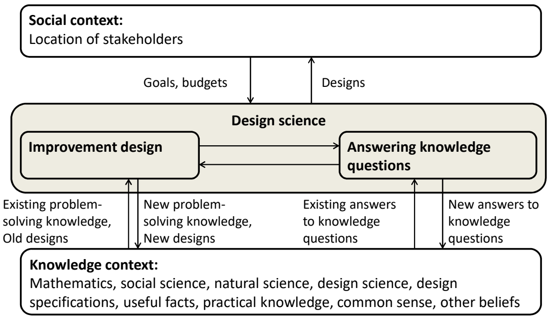
Stakeholders: Researchers, NXP (sponsor), component suppliers, car manufacturers, garages, car passengers

"Design an assurance method for cloud service provider data compliance".

Stakeholders: KPMG (sponsor), KPMG consultants (end-users), researchers, CSPs, CPS clients.

2.4 The knowledge context of a design science project

The context of design research



Knowledge sources

- Scientific literature
  - Scientific, peer reviewed journals and conferences (math, natural science, social science, design sciences)
- Technical literature
  - Design specifications, manuals
- Professional literature
  - Non-peer reviewed professional magazines, trade press, marketing literature, white papers (useful facts and opinions, practical knowledge, common sense)
- Oral communication
  - Colleagues, supervisors, practitioners (useful facts and opinions, practical knowledge, common sense, other beliefs)

What about the Web?

- The Web is a communication channel, not a source of information
- Sources are more diverse
  - Scientific literature
  - Technical literature
  - Professional literature
  - On-line databases
  - Social networks
- Did the information survive
  - Empirical tests? → Fact check
  - Critical judgment of peers? → Logic check

- How is the channel managed?
- How does the source ensure quality of information?

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Your research aims at theories

- Knowing the relevant properties of a particular artifact in a particular context is not enough
  - Theories should be general, so you can use them for prediction
  - Theories should explain, so that you understand why phenomena occur
- If the artifact prototype that you built disappears, what is the knowledge remains?
  - Tested, critiqued knowledge

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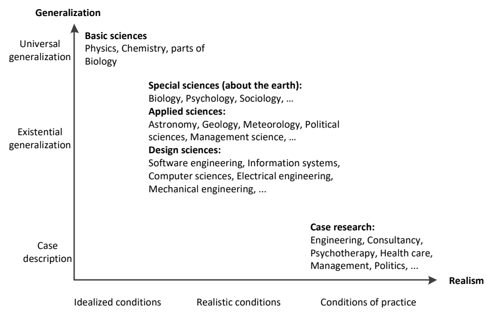
Sciences of the middle range



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- Useful idealizations in software engineering and information systems
  - All clocks are synchronized and correct
  - Synchronicity of response and stimulus
  - Unlimited memory (Turing machines)
  - Message arrival guarantees
  - Rational users
  - Organizations with a clearly defined structure
  - …
- Conditions of practice
  - Incorrect input
  - Messages get lost
  - Timeouts are discovered too late
  - Clocks drift
  - Users do not behave according to expectations
  - …

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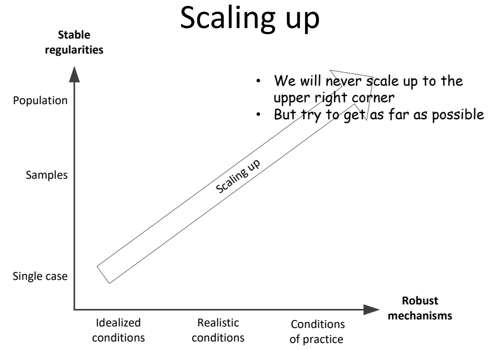
Scaling up



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Main points chapter 1 What is design science

- Design science is the **design** and **investigation** of **artifacts** in **context**
  - Research problems are **design problems** or **knowledge questions**
  - Artifacts **interact** with their context to deliver a **service**
- The **social context** of a design science project consists a.o. of stakeholders and their goals and budgets, laws, processes, norms, expectations, etc.
- The **knowledge context** consists of scientific knowledge, design specifications, useful facts, practical knowledge, common sense, etc. You aim to contribute scientific theories.
  - Sources and channels of information
- The design sciences are **middle-range sciences** aiming for partial generalizations about realistic conditions.
  - Need to scale up from idealized to practical conditions
  - Universal generalizations make unrealistic assumptions

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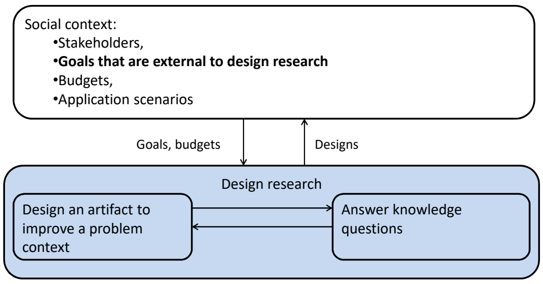
Exercise: Material for your elevator pitch

1. What design(s) will be delivered by your project?
   – What is new?
2. Who are the stakeholders of your project?
   – What are their goals?
3. What knowledge will be produced by your project?
   – What is new?

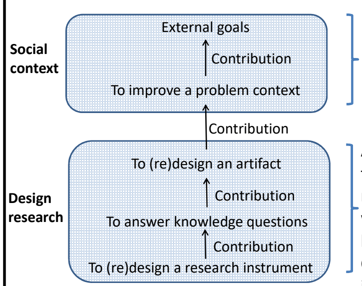
2. Research Goals and Research Questions

2.1 Research goals

External goals



Goal structure



Motivation of the research goal: friends, family, the government, sponsors, investors, etc. are interested in these.

A design **research goal** is the desired outcome of a research project, to which the research budget is allocated. Colleagues are interested in these.

Examples

Ucare

- *External goals:*
  - *Reduce health care cost (government)*
  - *Reduce work pressure, increase quality of care (health personnel)*
  - *Increase quality of care, increasse independence (elderly)*
- *Design goals*
  - *Design a mobile home care system for use by elderly that provides*
    - *Medicine dispensing*
    - *Blood pressure monitoring*
    - *Agenda*
    - *Remote medical advice*

Two kinds of design research problems

- To achieve the design goal, we need to answer research questions.
  - Design problems
    - A.k.a. technical research questions
  - Knowledge questions
    - Analytical research questions: can be answered by analysis
    - Empirical research questions: must be answered by collecting data

2.2 Design problems

Template for design problems

- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>

- *Improve my body / mind health*
- *by taking a medicine*
- *such that my headache disappears*
- *in order for me to get back to work*

Template for design problems

- Improve <problem context>
- by <treating it with a (re)designed artifact>
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- ***Improve my body / mind health***
- *by taking a medicine*
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External: Problem context and stakeholder goals

Template for design problems

- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>

- *Improve my body / mind health*
- ***by taking a medicine***
- ***such that my headache disappears***
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Design research problem: Artifact and its desired interactions

Template for design problems

- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>

- *Improve my body / mind health*
- *by taking a medicine*
- *such that my headache disappears*
- *in order for me to get back to work*

Particular problem

- *Improve home care*
- *By a mobile support device*
- *That provides some services …*
- *So that cost are reduced etc.*

General problem

2.3 Knowledge questions

Kinds of empirical knowledge questions

- Empirical knowledge questions may be
  - descriptive or explanatory,
  - open or closed,
  - effect-related or requirement-related

Knowledge questions

- **Descriptive questions:**
  - What happened?
  - When?
  - Where?
  - What components were involved?
  - Who was involved?
  - etc.

  (Journalistic questions, Provide facts)
- **Explanatory questions:**
  - Why?
    1. What has **caused** the phenomena?
    2. Which **mechanisms** produced the phenomena?
    3. For what **reasons** did people do this?

Example

- *Descriptive question: What is the performance of the Ucare system?*
  - *Accuracy of output*
  - *Reliability of communication infrastructure*
  - *Usability of interfaces*
  - *Etc. etc.*
- *Explanatory question: Why does Ucare have this performance?*
  1. ***Cause:** data entrance at 03:00 causes the datya to be lost*
  2. ***Mechanism:** because the hospital database server is down for maintainance at night and there is no fallback retention mechanism*
  3. ***Reasons:** Users feel free to enter data any time they are awake, and they are awake at 03:00.*

Prediction problems

- There are no predictive knowledge **questions**
  - We cannot know the future
  - Descriptive and explanatory **questions** are about the present and the past
- But there are prediction **problems**
  - *How will the program behave when given this input?*
  - *How would users behave when the program is changed?*
- To solve a prediction problem, we need a general theory that tells us what happens

Second classification of knowledge questions

- **Open questions (exploration):**
  - No hypothesis about the answers.
    - *What is the execution time?*
- **Closed questions (testing):**
  - Specific, testable hypotheses as possible answers.
    - *Is execution time less than 1 second?*
      - *Hypothesis: the execution time is less than 1 second.*

Third classification: Design research questions

- **Effect question:** Context X Artifact → Which Effects?
  - **Trade-off question:** Context X ***Alternative artifact*** → Effects?
  - **Sensitivity question:** ***Other context*** X artifact → Effects?
- **Requirements satisfaction question:** Do these Effects satisfy requirements sufficiently?

Example

- *Open descriptive effect questions: What is the performance of the Ucare system?*
  - *Accuracy of output*
  - *Reliability of communication infrastructure*
  - *Usability of interfaces*
  - *Etc. etc.*
- *Open descriptive trade-off questions*
  - *What happens to the performance if we change the design?*
- *Open descriptive sensitivity questions:*
  - *What happens if it is used by other elderly, in other homes?*
- *Open explanatory questions:*
  - *Why does Ucare have this performance?*
- *Open descriptive requirements satisfaction questions:*
  - *Does this satisfy our requirements?*

Main points chapter 2 Research goals & questions

- A design science projects has goals that range from designing an instrument (lowest level) to contribution to external stakeholder goals (highest level).
- Design problems have the form
  - Improve <problem context> by <treating it with a (re)designed artifact> such that <artifact requirements> in order to <stakeholder goals>
- Knowledge questions may be analytical or empirical.
  - Empirical knowledge questions may be
    - descriptive or explanatory,
    - open or closed,
    - effect-related or requirement-related
- To answer prediction problems, we need general theories

Questions about chapter 2?

Exercise: your top-level design problem

- What is/are your top-level design problem(s), using our template?
  - **Improve <problem context>**
  - **by <treating it with a (re)designed artifact>**
  - **such that <artifact requirements>**
  - **in order to <stakeholder goals>**
- For a knowledge-oriented thesis, think of a top-level design problem that motivates your knowledge question

Research questions

- Research questions form a hierarchy
  - Some questions are knowledge questions, others are design problems
  - All are subproblems of the top-level research problem
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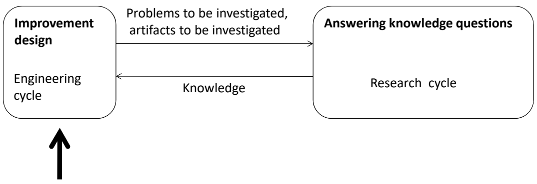
Exercise: your research questions

- Formulate the subproblems of your top-level research problem

3 The design cycle

Activities in design science

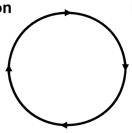


3.1 The design and engineering cycles

Engineering cycle

! = *Action*
? = **Knowledge question**

Treatment implementation



Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?

Treatment validation

- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design

- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

Treatment

- We avoid the word "solution".
  - Every solution is imperfect
  - … and introduces new problems

Specification and design

- Treatments are designed, and the design is specified
- **Designing** is deciding what to do
- **Specifying** is documenting that decision
- Contrast with the terminology in software engineering
  – Word games with ``what'' and ``how''.

What is implementation?

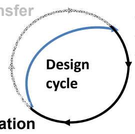
- Depends on who you talk to
  – *For a software engineer, this is writing and debugging a program until it works.*
  – *For a mechanical engineer, this is assembling the physical machine until it works*
  – *For the manager, this is introducing the machine in the organization until it works*
  – *For a marketeer, this is selling the system*

Implementation

- **Implementation** = introducing an artifact in the intended problem context
  – What this means depends on what your problem was
  – *For a software engineer: To construct software*
  – *For a mechanical engineer: To construct physical machine*
  – *For the manager: To change an organization*
  – *For a marketeer: To sell a product*
- In this course, our problems are real-world problems
  – Implementation = transfer to the problem context
  – = technology transfer to the real world

Design cycle

Real-world treatment Implementation: Technology transfer



Real-world implementation evaluation = Real-world problem investigation
- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?

Treatment validation
- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design
- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

Nesting of cycles

BIT M.Sc. project

Real-world problem investigation	
Treatment design	
Treatment validation	Problem investigation: what to test?
	Treatment design (design a prototype)
	Implementation (prototype construction)
	Evaluation (in the laboratory or field)
Implementation (tech transfer)	
Implementation evaluation (in the field)	

This is a very special engineering cycle. Later we will call this the empirical cycle. It is performed to answer empirical knowledge questions

Validation versus evaluation

- To **validate** a design for stakeholders is to justify that it would contribute to their goals **before** transfer to practice
  – Predicted effects?
  – Satisfaction of requirements?
  – (Requirements contribute to goals?)
- To **evaluate** an implementation is to investigate whether an implementation has contributed to to stakeholder goals **after** transfer to practice
  – Stakeholders, goals?
  – Effects?
  – Contribution?

What is the difference?

- **Implementation valuation** research studies real-world implementations with respect to actual stakeholder goals
  - Real-world research
- **Treatment validation** research uses a validation model to predict effects
  - Simulation

What kind of project do you have?

- Some projects do **implementation evaluation**
  - *E.g. investigate how UML is used in practice*
  - *Investigate traffic flow on internet*
  - *Investigate why our project effort estimations are always so wrong*
- Many projects **design and validate treatments**
  - *E.g. improve malware detection methods to get higher accuracy*
  - *Explore the use of social networks to communicate with our customers*

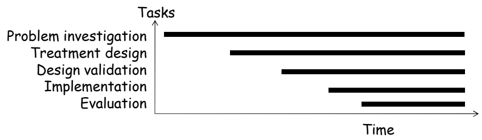
This determines the kind of research questions that you can ask

3.2 Design and engineering processes

- The design and engineering cycles are **rational reconstructions** of design and engineering
  - Rational reconstruction of mathematical proofs
  - Of empirical research
  - Of administrative processes
- The design and engineering **processes** execute tasks in different orders
  - Resources (time, money, people) must be managed
  - Deliverables nmust be scheduled, deadlines must be met

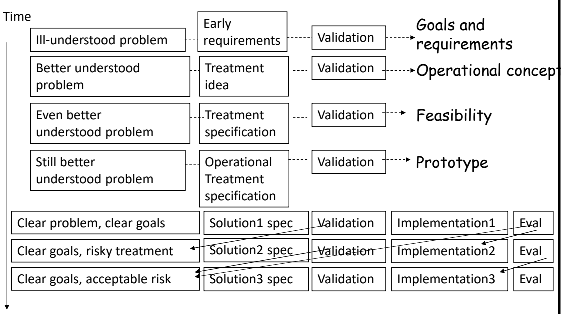
Concurrent engineering

- Development may be organized concurrently with successive versions of the artifact



Systems engineering

- Cycles of systems engineering
  - High level goals, high level requirements
  - Iterative refinement until
  - Low-level approved interfaces, low-level implemented specs.
- Shown on next slide



- Iteratively reduce uncertainty about the problem
- Once the goals are clear enough, reduce risk of choosing the wrong treatment

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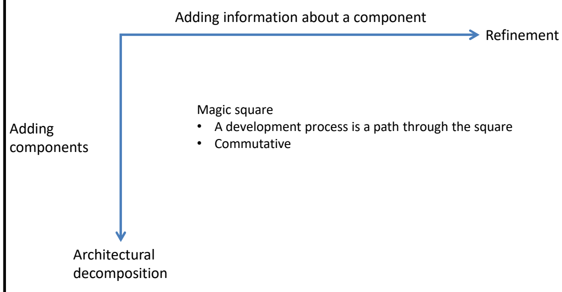
Two kinds of design decisions



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Engineering management

- Management is the art of achieving results by the work of others.
  - Acquiring resources
  - Organizing them
  - Planning work
  - Managing risks
  - Motivating people
  - Evaluating outcomes

Systems engineering is a particular way to plan work & manage risks

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Main points chapter 3 The design cycle

- The engineering cycle is a rational decision cycle:
  - Problem/evaluation: Look where you are and what you want to do;
  - Design possible treatments;
  - Validate treatments without executing them;
  - Choose one and implement it;
  - Evaluation/problem: Look where you are now and what you now want to do.
- The design cycle is the preparation for action:
  - Problem-design-validation.
- The cycles can be organized in many different ways.
  - All of them must allow you to justify your choices afterwards.
  - The engineering cycle allows you to justify your actions (validation) and to learn from their effects (evaluation)

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Questions about chapter 3?

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Exercise (design-driven thesis) your table of contents

- Make a poster with the outline of the table of contents of your thesis, following this pattern:
  1. Introduction: Societal improvement problem, stakeholders and their goals, current designs, gap with improvement needs.
  2. Research problem: top-level design problem; decomposition into subproblems and knowledge questions
  3. Research methodology
  4. State of the art: existing designs
  5. Requirements for a new design; motivation in terms of stakeholder goals; evaluation of current designs against the requirements
  6. New design
  7. Validation of new design: prototypes, simulations, field experiments, etc.
  8. (More designs and validations)
  9. Conclusions, recommendations, and further work

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Exercise (knowledge-driven thesis): your table of contents

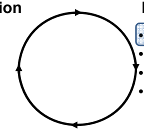
- Make a poster with the outline of the table of contents of your thesis, following this pattern:
  1. Introduction: Societal improvement problem, stakeholders and their goals, current knowledge, gap with desired knowledge.
  2. Research problem: Top-level knowledge question; decomposition into sub-questions
  3. State of the knowledge: existing knowledge
  4. Research methodology
  5. Study: observational study, experimental, case-based, sample-based, etc.
  6. (More studies)
  7. Conclusions, recommendations, and further work

4. Stakeholder and Goal Analysis

Engineering cycle

! = Action
? = Knowledge question

Treatment implementation



Implementation evaluation = Problem investigation

•Stakeholders? Goals?
•Conceptual problem framework?
•Phenomena? Causes, mechanisms, reasons?
•Effects? Positive/negative goal contribution?

Treatment validation

•Context & Artifact → Effects?
•Effects satisfy Requirements?
•Trade-offs for different artifacts?
•Sensitivity for different Contexts?

Treatment design

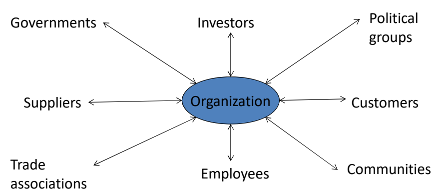
•Specify requirements!
•Requirements contribute to goals?
•Available treatments?
•Design new ones!

4.1 Stakeholders

Stakeholders

- A **stakeholder** of a problem is a biological or legal person affected by treating a problem.
  – *People, organizations, job roles, contractual roles, etc.*
- Typical stakeholders of a **design research project**
  – *Researchers, sponsors, developers, users, etc.*
  – They have an interest in the outcome.
- Typical stakeholders of a **development project**
  – *Designers, programmers, testers, users etc.*
- Typical stakeholders of a **software product**
  – See next slides

P. Clements, L. Bass. "Using business goals to inform software architecture." *18th IEEE International Requirements Engineering Conference.* Pages 69-78. IEEE Computer Science Press. 2010.



- The organization may be a company, government organization, department, project, etc.

Checklist by role (Ian Alexander http://www.scenarioplus.org.uk/papers/papers.htm > A taxonomy of stakeholders)

System under Development
- Normal operator (end user)
- Operational support
- Maintenance operator

Immediate context
- Functional beneficiary (client)
- Roles responsible for interfacing systems

Wider context
- Political beneficiary (who gains status)
- Financial beneficiary
- Negative stakeholder (who is/perceives to be hurt by the product)
- Threat agent (who wants to hurt the product)
- Regulator

Involved in development
- Champion/Sponsor
- Developer
- Consultant
- Purchaser (customer)
- Suppliers of components

None of these lists is complete

Examples of stakeholders

- *PISA: Design a system to help individuals to maintain their privacy on the internet at a desired level*
  - *Free lancer*
  - *Teleworker*
  - *Home banker*
  - *Concerned parent*
- *Ucare: Design a system that provides health care support for elderly people at home*
  - *Medicine taking*
  - *Blood pressure monitoring*
  - *Agenda*
  - *Remote advice*
- We omit researcher goals henceforth

4.2 Desires

Stakeholder awareness and commitment

Not aware:
Some possibility that stakeholders are not aware of

•Possibility to receive satellite TV in car
•Possibility to reduce taxiing time

An event pushes the possibility into awareness

Aware, not committed:
Not important enough to commit resources (money, time)

Indifferences, Desires, Fears

- *We could upgrade car DVD player to TV*
- *We could optimize taxi routes dynamically*

Stakeholder makes resources (time, money) available

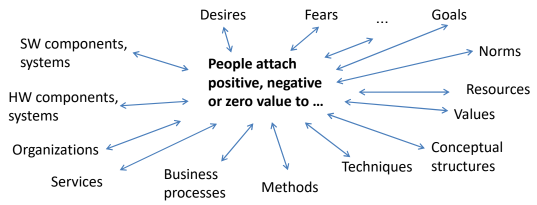
Aware & Committed:
Resources committed to act for a

Goals

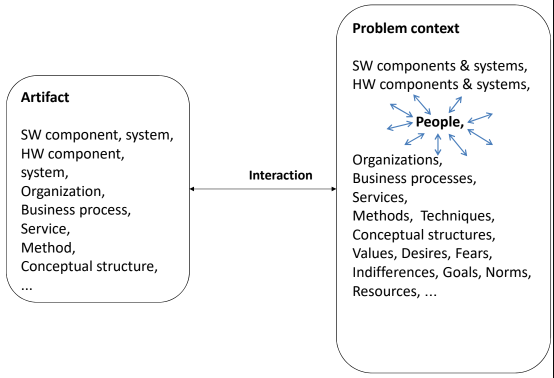
•Invest in car satellite TV
•Develop a prototype multi-agent route planning system

- A **goal** of a stakeholder is a desire to the realization of which the stakeholder has comitted resources (time, money)
  - People want a lot but they have only a few goals
  - Some goals are imposed

Anything can be the object of desire, fear or indifference



- Desires, fears and indifference are mental states:
  - They can be **directed upon** anything, whether real or imaginary
  - Every mental state is **about** something
  - They can even be about desire, fear or indifference



Examples of problem contexts

- *Ucare: Design a system that provides health care support for elderly people at home.*
  - *Context: Patient's home*
    - *Patient and their physical and technical context, budget, desires, norms and values*
    - *Friends and their budget, desires, norms and values*
    - *Family and their budget, desires, norms and values*
    - *Home care nurses and their budget, desires, norms and values*
    - *Remote medical personnel and their budget, desires, norms and values*
    - *The law*
    - *Ethical constraints*

4.3 Desires and conflicts

The multitude of desires

- Any one stakeholder may have infinitely many potential desires, fears and indifferences
- Many desires of one or more stakeholders may conflict

Conflicting desires

- **Logical conflict*:***
  - Analysis of the descriptions of the desires shows that both descriptions have opposite meaning; they are logically inconsistent.
  - *Spend your money and keep it*
- **Physical conflict:**
  - Realization of one desire makes realization of the other physically impossible.
  - *Eat more and stay the same weight*
  - *Add TV to a car and reduce weight without changing anything else*
  - Stakeholder lives in a phantasy world

- **Technical conflict:**
  - There is currently no technology to realize both desires in the same artifact.
  - *Secure and user-friendly system*
  - New technology may remove the conflict
- **Economic conflict:**
  - Desires exceed the budget
- **Legal conflict:**
  - Desires contradict the law
- **Moral conflict:**
  - Desires contradict moral norms

Examples of conflicting desires

- *Ucare: Design a system that provides health care support for elderly people at home*
  - *Technical conflict: Artifact should be simple to use, but is fragile & advanced technology.*
  - *Economic conflict: Artifact should be cheap, but is expensive*
  - *Value conflict: patient likes Skyping more than the advice functions*
- Conflicts give us relevant design goals.

Discussing questions 4 of ch 2 and 1 of ch 3

- ..\Q&A\Questions and Assignments.pdf

Main points chapter 4 Stakeholder and goal analysis

- A **stakeholder** of a problem is a biological or legal person affected by treating a problem
  - Positively or negatively affected
  - There are checklists of possible stakeholders
- A **goal** of a stakeholder is a *desire* to the realization of which the stakeholder has *committed* resources (time, money)
  - Desires are many, goals are few
- Desires may **conflict** with each other
  - Therefore, goals of one or more stakeholders may conflict too.
  - Logical, physical, technical, economic, legal, moral conflict

Exercise

- Make a list of stakeholders of your thesis project.
- What are the goals of each stakeholder?

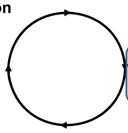
5 Implementation Evaluation and Problem Investigation

Engineering cycle

! = Action
? = Knowledge question

Treatment implementation

Implementation evaluation = Problem investigation
- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?



Treatment validation
- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design
- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

5.1 Research goals

Two alternative top-level goals of real-world research

- **Implementation evaluation** is the investigation of the effects of a treatment implementation *after* the improvement has been implemented
- **Problem investigation** is the investigation of the problem context *before* an improvement is undertaken
- There is always a current implementation of *something*!
  - So the research questions are the same, only the goals are different.

Examples

- Implementation evaluation
  - *Investigate the use of the UML in companies in Brazil. Our goal is to find out the extent of usage.*
  - *Investigate the sources of phishing messages received by our organization. Our goal is to find out how bad it is.*
- Problem investigation
  - *Investigate the causes why our effort estimations are usually wrong. Our goal is to find improvement opportunities.*
  - *Investigate coordination problems in global software engineering projects. Our goal is to reduce these problems.*

Research questions for implementation evaluation & problem investigation

- Effect questions
  - Descriptive: What effects does the implemented artifact have? Explanatory: Why do these effects arise? (causes, mechanisms, reasons)
- Goal contribution questions
  - Evaluative: Do they contribute to/detract from stakeholder goals? To which extent?
  - Explanatory: why does this happen? (causes, mechanisms, reasons)

5.2 Theories

Scientific theories

- A scientific theory is a belief about patterns in phenomena that has
  - been validated against experience
  - survived criticism by critical peers
- Examples
  - *Theory of classical mechanics*
  - *Theory of evolution*
  - *Theory of cognitive dissionance*
- Non-examples
  - *Theory that the gods were astronauts*
  - *Conspiracy theories about who killed president Kennedy*
  - *The belief that my thoughts are monitored by aliens*

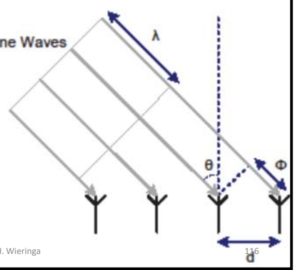
Problem theories

- Scientific theory of a problem
  - beliefs about problem patterns that have been validated against experience and survived critical analysis by peers
- *Ucare project: Design a system that provides health care support for elderly people at home.*
- *Problem theory:*
  - *People stay home till a higher age than previously*
  - *Travelling to health care centers is unpleasant*
  - *Health care personnel is expensive and is overburdened*
  - *Health care budgets grow at unsustainable rate*
  - *…*

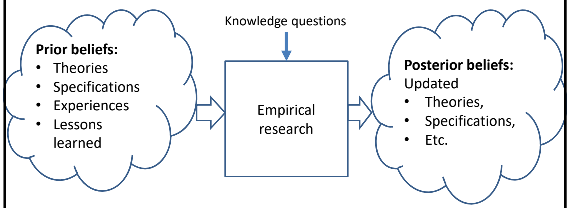
Satellite TV reception system for a car, contains an antenna array. Problem to be solved by a software system: recognize direction of arrival of plane waves.

Problem theory:

- *Definitions of concepts: Plane waves, wave length, bandwidth, etc.*
- *Generalization about the problem:* $\varphi = 2\pi\ (d/\lambda) \sin\theta$



5.3 Research Methods



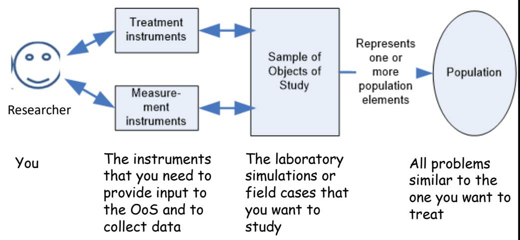
- The goal of empirical research is to develop, test, refine change, or otherwise **update** scientific theories

Kinds of empirical research methods

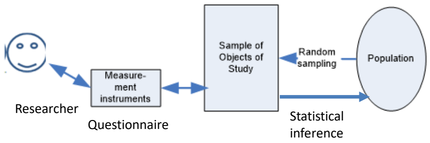
	Experimental study (treatment)	Observational study (no treatment)
Sample-based: investigate samples drawn from a population, look at averages and variation, infer population parameters	• **Statistical difference-making experiment**	**Survey**
Case-based: investigate cases one by one, observe case architecture and at interaction mechanisms among components	• Expert opinion • **Mechanism experiments** • Technical action research	**Observational case study**

- The methods in **bold** are useful for Problem research

The empirical research setup

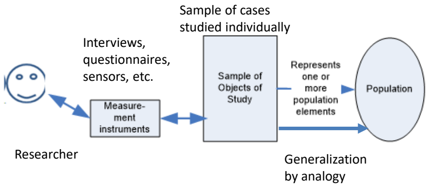


Survey research



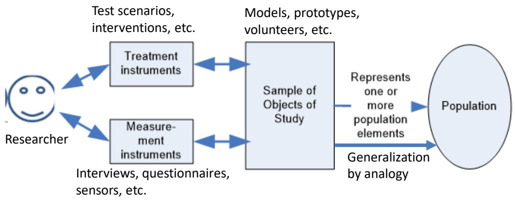
- **Surveys** of instances of the problem (large sample)
  - *Survey of the use of role-based access control in large companies*
  - *Survey of the use of agile development methods in small and medium-sized companies*
- Useful to describe statistical regularities (descriptive statistics, mean, variance, correlations) in classes of problems.

Observational case studies



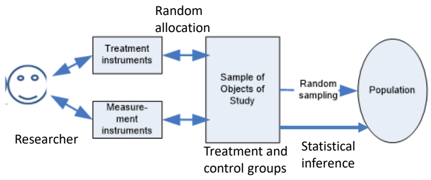
- **Observational case study** of instances of an implementation or problem:
  - *Case study of problems with effort estimation of project managers in one company*
  - *Field study of the behavior of elderly at home*
- Useful to describe implementations and problems in detail, and understand the mechanics and reasons behind their effects.

Single-case mechanism experiments



- In a **single-case mechanism experiment,** we test a social or technical system
  - *Observing elderly at home*
  - *Penetration-testing the security of existing systems*
- Useful to describe the behavior of implemented technology, and to understand this in terms of underlying mechanisms

Statistical difference-making experiments



- In **statistical difference-making experiments**, we investigate whether in a sample, a difference in an independent variable X makes a statistical difference to a dependent variable Y.
  - *Apply several input scenarios to a company network and compare average behavior in scenarios with and without these inputs*
  - *Treatment group/control group experiment with software engineers to test their comprehension of UML diagrams*

Main points chapter 5
Implementation evaluation & problem investigation

- Implementation evaluation and problem investigation have different research goals but the same research questions.
  - Who are the stakeholders? What are their goals?
  - What conceptual framework shall we use to describe the phenomena?
  - What are the phenomena? Their causes, mechanisms, reasons?
  - What if we do nothing? How good/bad wrt goals?
- Useful research methods are
  - surveys,
  - observational case studies,
  - single-case mechanism experiments and
  - statistical difference-making experiments

Assignment chapter 5

- Drenthen (2014) - *Towards continuous delivery in system integration projects*
  - Artifact is a continuous delivery method using an automated test tool.
  - Context is the delivery of identity solutions by Everett.
- Schoutsen (2012) - *Fraud detection within Medicaid*
  - Artifact: data warehouse
  - Context: fraud detection within Medicaid
- Van der Graaf (2012) - *EPR in Dutch hospitals-a decade of changes*
  - Artifact: EPRs
  - Context: Dutch hospitals
- Page 15 in Q&A

Exercise

- What concepts do you need to describe your problem domain?
- What problematic phenomena are happening in the problem domain? Why is this happening? (Causes, reasons, and mechanisms behind these phenomena)
- What happens if nothing changes? How does this contribute (positively or negatively) to the stakeholder goals?

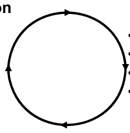
Discuss these questions

- Chapter 4 2(c)
- Chapter 5 questions 6, 7

6. Requirements Specification

Engineering cycle

! = Action
? = Knowledge question



Treatment implementation

Implementation evaluation = Problem investigation

- •Stakeholders? Goals?
- •Conceptual problem framework?
- •Phenomena? Causes, mechanisms, reasons?
- •Effects? Positive/negative goal contribution?

Treatment validation

- •Context & Artifact → Effects?
- •Effects satisfy Requirements?
- •Trade-offs for different artifacts?
- •Sensitivity for different Contexts?

Treatment design

- •Specify requirements!
- •Requirements contribute to goals?
- •Available treatments?
- •Design new ones!

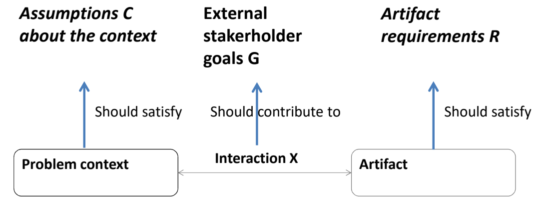
6.1 Requirements

- **Requirements** are desired properties of the treatment
  - Stakeholder goals are what the stakeholder wants to achieve
  - Requirements are what the developer must achieve
    - Special kind of goal
- Sometimes, **constraints** on the internal composition of the artifact are distinguished from requirements on the externally observable properties of an artifact.
  - *E.g. a constraint to reuse some components*

- Requirements cannot be just “elicited” from stakeholders
  - We do not know what we want
- Research projects may have very vague requirements
  - *See if you can do this (existence proof)*
  - *See if you can do this better (e.g. better execution time)*

6.2 Contribution arguments

Assumptions, requirements, goals



Contribution argument

- *(Context assumptions C) AND (Requirements R) IMPLY (contribution to stakeholder goal G)*

Example

- *Ucare contribution argument*
  - *(assumptions about patient behavior & desires, IT infrastructure of home for the elderly, national communication infrastructure, third-party services) AND*
  - *(requirements on mobile health care support technology) IMPLY*
  - *(reduce health care cost, improved health service)*

- *We need to evaluate systems **after** transfer to practice to see if this argument is correct!*

6.3 Kinds of requirements

Classifications of requirements

- By stakeholder (Who wants it? Whose goals are served by it?)
- By priority (How strong is the desire?)
- By urgency (How soon must it be available?)
- By aspect (What is the requirement about? Which property?)

Requirements by aspect (ISO 9126)

- A **function** is a terminating part of the interaction that provides a service to some stakeholder
- **Quality properties** (a.k.a. "**nonfunctional properties**")
  - Utility ("suitability")
  - Accuracy
  - Interoperability
  - Security
  - Compliance
  - Reliability
  - Usability
  - Efficiency (time or space)
  - Maintainability
  - Portability

- These are properties of functions
- They usually have global implications for artifact components and architecture

Example

- *Ucare*
  - *Functions*
    - *Medicine dispensing*
    - *Blood pressure monitoring*
    - *Agenda*
    - *Remote medical advice*
  - *Quality:*
    - *Usable by elderly and medical personnel*
    - *Reliable*
    - *Safe*
    - *Cheap*

Classify this:
- By stakeholder
- By priority
- By urgency

6.3 Indicators and norms

Operationalization

- Some properties cannot be measured directly
  - *Usability, maintainability, security, …*
- **Operationalize** them:
  - Define them in terms of one or more indicators that *can* be measured
- An **indicator** is a variable that can be measured
  - In software engineering, often called a ***metric.***

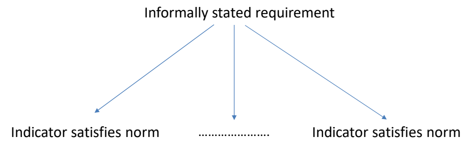
Some examples of indicators

- *Utility indicator: Opinion of stakeholder about utility*
- *Accuracy indicator: domain dependent, e.g. spatial resolution*
- *Interoperability indicator: effort to realize interface with a system*
- *Security indicators: availability, compliance to standards*
- *Compliance indicator: expert opinion about compliance*
- *Reliability indicators: mean time between failure, time to recover*
- *Usability indicators: effort to learn, effort to use*
- *Efficiency (time or space) indicators: execution time, disk usage*
- *Maintainability indicators: effort to find bugs, effort to repair, effort to test*
- *Portability indicators: effort to adapt to new environment, effort to install, conformance to standards*

See also http://en.wikipedia.org/wiki/Software_quality#Measurement

Norms

- Once we have defined indicators ("metrics"), we can operationalize requirements by means of norms
- A **norm** is a desired range of values of an indicator
  - *Average effort to learn (indicator) is less that 30 minutes (norm)*
  - *Accuracy (indicator) is better than 1 degree (norm)*
  - *Function F (indicator) must be present (norm)*
    - *When it is time to dispense a medicine, the dispenser sends an alert to the ipad*
    - *If dispensing button is pushed, the dispenser releases medicine according to protocol defined for the patient*



- Informally stated requirements may be operationalized into a set of indicator/norm pairs

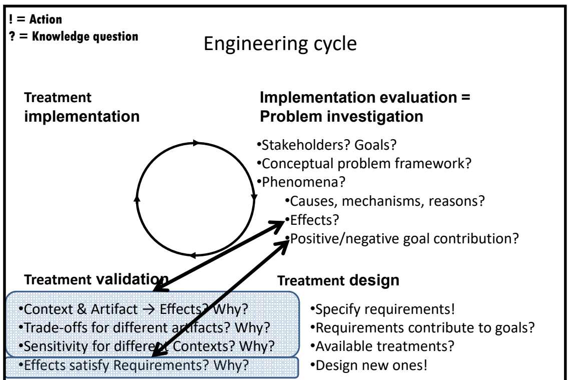
Main points chapter 6 Requirements specification

- **Requirements** are desired properties of a treatment for which there is a stakeholder budget
- Must be motivated by **contribution argument**
  - (context assumptions) X (artifact requirements) contribute to (Stakeholder goals)
- Requirements can be classified according to **stakeholder goal, priority, urgency**
- **Functional requirements** are desired functions
- **Nonfunctional requirements** (quality properties)
  - Accuracy, efficiency, security, reliability, usability, …
- Requirements may have to be operationalized
  - **Indicator** is measurable variable: measurable property
  - **Norm** is desired range of values of an indicator: measurable requirement

Exercise

- What are the requirements for a solution to your design problem?
- Classify the requirements
  - By stakeholder
  - By priority
  - By urgency
  - By aspect

7 Treatment Validation



7.1 The validation research goal

- Validation research questions are the same as implementation evaluation questions
  - But the goal is to validate new technology,
  - Not to evaluate implemented technology
- We find the validation research questions by analyzing treatment requirements (next slide)

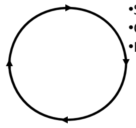
! = Action
? = Knowledge question

Engineering cycle

Treatment implementation

Implementation evaluation = Problem investigation

- •Stakeholders? Goals?
- •Conceptual problem framework?
- •Phenomena?
  - •Causes, mechanisms, reasons?
  - •Effects?
  - •Positive/negative goal contribution?



Treatment validation

- •Context & Artifact → Effects? Why?
- •Trade-offs for different artifacts? Why?
- •Sensitivity for different Contexts? Why?
- •Effects satisfy Requirements? Why?

Treatment design

- •Specify requirements!
- •Requirements contribute to goals?
- •Available treatments?
- •Design new ones!

- *Ucare requirements*
  - *Functions*
    - *Medicine dispensing*
    - *Blood pressure monitoring*
    - *Agenda*
    - *Remote medical advice*
  - *Usable by elderly and medical personnel*
  - *Reliable*
  - *Safe*
  - *Cheap*

Validation research questions

- *Does it work?*
  - *Functions*
    - *Does it perform the medicine dispensing functions?*
    - *Does it perform the blood pressure monitoring functions?*
    - *Etc.*
  - *Is it usable by elderly and medical personnel?*
  - *Is it reliable?*
  - *Is it safe?*
  - *Is it cheap?*
- *What if we change the design?*
- *What if we vary the context?*

- **To get answerable research questions, we need to operationalize the requirements!**

7.2 Validation models

The fundamental problem of validation

- We investigate the artifact outside its natural implementation context
- The artifact has not been implemented yet.
  - It has not been transferred to the real-world problem context yet
- So we study it in the lab
- Or we do a pilot study in the real world

These are more or less realistic models of a real-world implementation

Validation models

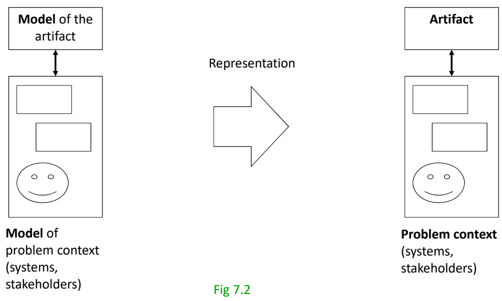


Fig 7.2

What is a model?

- An **analogic model** is an entity that represents entities of interest, called its **targets,**
- in such a way that questions about the target can be answered by studying the model.
- Examples
  - http://en.wikipedia.org/wiki/MONIAC_Computer
  - http://en.wikipedia.org/wiki/Scale_model
  - http://en.wikipedia.org/wiki/Miniature_wargaming
  - http://en.wikipedia.org/wiki/Simulation

Example validation models

- *A software prototype interacting with a simulated environment*
- *A class of students using a new software engineering method in a project that simulates a real-world project*
- *A researcher using an experimental method to solve a real-world problem*
- *Ucare*
  - *Nurses imagining how the system would function*
  - *Elderly using a prototype in their home*

Similarity

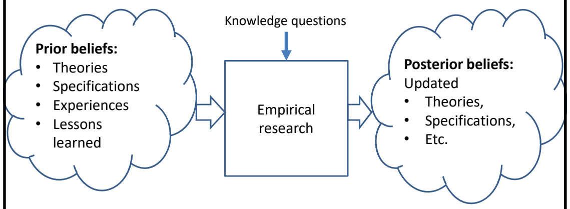
- How reliable is the generalization from the validation models to the real-world implementations?
- Positive analogy: Properties known to be similar
  - Should support transfer of conclusions about the model to conclusions about the target
- Negative analogy: Properties known to be different
  - Should block the transfer of some conclusions

7.3 Design theories

Design theories

- Design theory = a belief that there is a pattern in the interaction between the artifact and the context, tested by experiment, critically analyzed by peers
- *Design theory of the Ucare system, developed based on field tests:*
  - *The system helps elderly take their medicine, but not necessarily on time*
  - *Elderly may not use the Ucare functions but love to use the Skype function of the ipad*
  - *To provide reliable service, service providers must align the details of their interfaces as well as their maintenance procedures*

7.4 Research methods



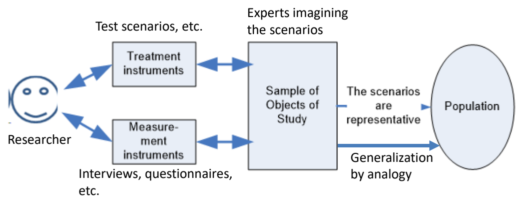
Kinds of empirical research methods

	Experimental study (treatment)	Observational study (no treatment)
Sample-based: investigate samples drawn from a population, look at averages and variation, infer population parameters	• **Statistical difference-making experiment**	Survey
Case-based: investigate cases one by one, observe case architecture and at interaction mechanisms among components	• **Expert opinion,** • **Mechanism experiments,** • **Technical action research**	Observational case study

- The methods in **bold** are useful for validation research

Expert opinion

Expert opinion

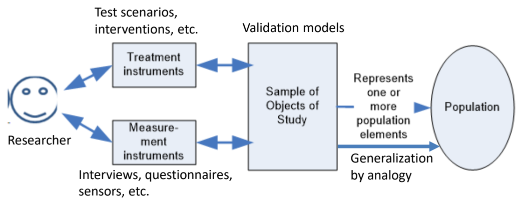


- Researcher asks experts about perceived usability and utility of new artifact in the contexts that they know first-hand.
  - *Expert opinion of nurses about U-Care functionality*
- Purpose is to weed out unrealistic ideas.

Single-case mechanism experiments

(a.k.a. simulations)

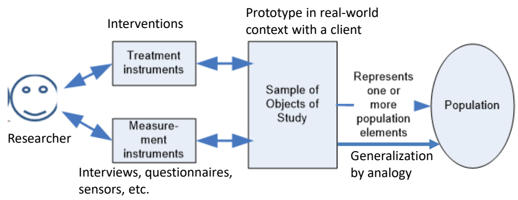
Single-case mechanism experiments



- In a **single-case mechanism experiment,** we test a social or technical artifact
  - *Testing a software prototype of Ucare using your colleagues*
  - *Testing it with volunteers in a home for the elderly*
- Useful to validate new technology

Technical action research

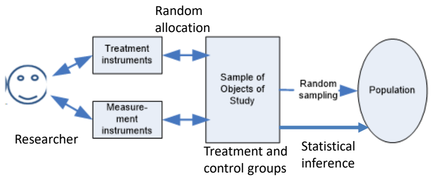
Technical Action Research



- In Technical Action research, we test a social or technical artifact by using it for a real-world problem
  - *Experimental use of a a new enterprise architecture method in a consultancy with a real-world client*
- Useful to validate new technology

Statistical difference-making experiments

Statistical difference-making experiments

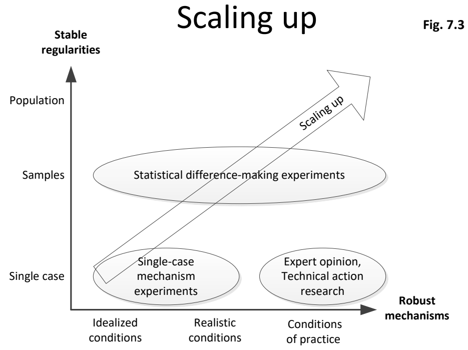


- In **statistical difference-making experiments**, we investigate whether in a sample, a difference in an independent variable X makes a statistical difference to a dependent variable Y.
  - *Compare a new software engineering technique with an existing one in an experiment with two groups of students*
  - *Compare a new algorithm with an existing one by exposing them to a set of contexts to which they are randomly allocated*

7.4 Scaling up

Scaling up

Fig. 7.3



Main points chapter 7 Treatment validation

- Validation is a prediction problem
  - What would be the effect of artifact in context?
  - Trade-offs in design of artifact?
  - Sensitivity to changes in context?
  - Satisfaction of requirements?
- Use validation models to build a design theory of A x C;
- Then use design theory to do predictions
- Research methods
  - Expert opinion
  - Single-case mechanism experiments
  - Statistical difference-making experiments
  - Technical action research
- Scale up from idealized to practical conditions

Exercise

- What artifact needs to be designed to treat your design problem?
- What are the validation research questions for this artifact?
  - Effect, trade-off, sensitivity, requirements satisfaction questions
- How will you investigate these questions?
  - Assume that you have enough time and money to do all research needed

Assignment for 21 february

- Make a poster for your research project
  - The context, the problem to be solved
  - Your research goal
  - Top-level design problem (following the template)
  - Subproblems and knowledge questions
- Table of contents