

Design Science Methodology  
2015 - 2016

Questions and Assignments

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# Rules for handing in the assignments

- The deadlines for handing in assignments are on Blackboard.
- The deadlines are strict. One minute too late is too late.
- Please motivate your answers. At the same time, be brief and clear.
- Pages size A4, maximum number of pages is 5, minimal point size is 11.

# Chapter 1

## What is Design Science?

### Questions

1. Which of these research problems is a design problem, and which a knowledge question?
  - If it is a design problem, what artifact is being designed?
  - If it is a knowledge question, what is the artifact x context subject of the question, i.e. what artifact x context combination do we want to know something about?

Explain your answer using the heuristics for distinguishing improvement problems from knowledge questions. If a problem description is ambiguous, explain the ambiguity and if it is incomplete, indicate the incompleteness.

- (a) Which business goals should we support?
  - (b) How effective is telemedicine service for physical rehabilitation?
  - (c) What are the goals of these users?
  - (d) What would be a good procurement process for Office supplies?
  - (e) What is the complexity of this algorithm?
  - (f) Find an algorithm to solve this problem
  - (g) How do users interact with this system?
  - (h) How to interact with this system?
2. For each of the following design problems, identify (1) the problem context, (2) the artifact, (3) the intended interaction of the artifact with the problem context, (4) some stakeholders. Some of this information is missing from the problem statement; in those cases, supply reasonable examples of the required items.
    - (a) Can we control our environment through a brain-computer interface?
    - (b) How can we engineer energy-efficient software?
    - (c) Our organization has a handbook of software engineering methods, but it is not used. Which set of methods and techniques from this handbook are relevant for realizing IT-enabled business change?
    - (d) Logistics in our organization is inefficient. Select and implement a logistics financial package that improves efficiency and is robust to future IT developments

- (e) There are several wireless communication protocols for health care devices at home. These devices monitor vital data of home-care patients and transmit them to a wireless care station located in the home, which transmits the data to a care center where medical personnel has access to the data. Different care stations use different wireless communication protocols, such as Bluetooth and ZigBee. Design an application layer protocol that can run on top of Bluetooth as well as ZigBee.
  - (f) Design a database system for storing annotated sensor data for use in a dike monitoring system
  - (g) Improve the scalability in number of documents of lookup algorithm of web services with distributed hash tables in a P2P network.
3. An artifact has a problem context, a design science project has a social context. What is the relationship between these two contexts?
  4. Why is it important to identify the stakeholders of design research?
  5.
    - What knowledge sources would you use when doing a design science project?
    - Is the web a separate source of knowledge? Why (not)?
  6. Consider Figure 1.4 in the book. Explain why the lower-left corner (idealized case descriptions) and the upper right corner (universal generalizations that do not abstract from any condition of practice) are empty. Illustrate your explanations with examples of hypothetical sciences that could populate these corners of the diagram, but that do not exist. Why will these sciences never exist?

## Assignments for Chapter 1 (What is Design Science?)

Answer the following questions about the theses by:

- Broenink [3] (abstract, table of contents, chapter 1).
- Van der Graaf [7] (abstract, table of contents, chapter 1).

Read the indicated parts of the theses only.

1. For each of these two theses:
  - (a) What is the artifact?
  - (b) What is the context?
  - (c) What is the interaction between the two?
  - (d) What is the research problem?
  - (e) Is the research problem a design problem or a knowledge question?
  - (f) For each of the relevant heuristics in table 1.2, discuss whether the research problem satisfies it.
2. Consider the framework for design science in figure 1.3.
  - (a) Who are the stakeholders in the social context of the project?
  - (b) What background knowledge is available?
  - (c) What new knowledge does the thesis aim to produce?
  - (d) What is the claimed scope of this knowledge? (In other words, what is the class of problem contexts and artifacts to which it is claimed to be applicable?)

Read chapter 1 of Schoutsen [5].

3. Figure 1 of this thesis shows the design science framework of Hevner et al.
  - (a) Mention two similarities with the framework of the book (figure 1.3).
  - (b) Mention two differences with the framework of the book (figure 1.3).

## Chapter 2

# Research Goals and Research Questions

### Questions

1. For each of the following two problems, (i) reformulate the design problem according to the template as far as possible (don't supply missing pieces of information). Next, comment on the absence of any part of the design problem template: (ii) Is this missing information necessary to solve the problem? (iii) If so, how could it be obtained?
  - (a) Our organization has a handbook of software engineering methods, but it is so large that no one uses it. Which set of methods and techniques from our "methods cookbook" are relevant for realizing IT-enabled business change?
  - (b) Logistics in our organization is inefficient because it is still organized manually. Select and implement a logistics financial package with an eye to future IT developments.
2. Consider a database system for storing sensor data, annotated with time and data source information, for use in a dike monitoring system. The system should provide early warnings when there is a danger of dike collapse.
  - (a) Formulate the design problem for the database system (artifact) according to the design template. Do not supply missing information.
  - (b) If any information is missing, what would you do to get this information?
  - (c) Formulate effect, trade-off, and sensitivity questions for the database system.
3. Consider the design of an application layer protocol that should run on top of wireless communication technologies, such as Bluetooth and ZigBee, used for communication between medical devices in home care. The protocol is used by observation devices such as blood pressure monitors, temperature sensors and heartbeat sensors connected to a home care station, which relays this information to a medical center where nurses, physicians and medical specialists can use this to monitor the state of a patient who lives at home. The protocol should be energy-efficient because these devices are battery-powered. The system is intended to allow patients and other people needing medical attention to live at home independently. The protocol should be usable by a variety of sensor devices. Because there is no technical personnel available to

solve technical problems, the protocol should be reliable and robust. Because medical personnel is accountable for its actions, data must be traceable to the sensor that produced it.

- (a) Formulate the design problem for the protocol (artifact) according to the design template. If any item of information is missing, identify it. Would it be needed to provide missing information before you could solve the problem?
  - (b) Formulate effect, trade-off, and sensitivity questions for the protocol.
4. Consider a distributed database running on a P2P network, to be used for storing and searching web service descriptions. The lookup algorithm uses a distributed hash table (DHT).
- (a) Formulate the problem of designing the lookup algorithm according to the template for design problems.
  - (b) A researcher has designed a new lookup algorithm with a view to improving its scalability in the number of documents (web service descriptions) searched. Formulate effect, trade-off, and sensitivity questions for the lookup algorithm.

## Assignments for Chapter 2 (Research Goals and Research Questions)

Consider the abstract, table of contents, and chapter 1 of the theses by Broenink [3] and by Drenthen [4]. Answer the following questions based on these parts of the theses. In the course, we will explain for each of these two theses which artifact and which context you should take for this assignment

1. Figure 2.1 in the book shows a goal hierarchy , ranging from the low-level goal to design a research instrument, to highest-level external stakeholder goals. The top-level goal in a design science project is always an artifact design goal. Identify the top-level goal of the thesis, and formulate it according to the template for design problems.
2. Classify the research questions stated in the thesis as either design problems or knowledge questions.
  - For the design problems, rephrase them according to the template for design problems. Do not add any pieces of missing information.
  - For the knowledge questions, classify them according to the taxonomy of figure 2.2.
3. Formulate effect, trade-off and sensitivity questions for the artifact to be designed. (This may be a reformulation of questions in the thesis, or it may be the formulation of a totally new question, not in the thesis.)

The following questions refer to the thesis by Van Der Graaf [7].

4. Consider again figure 2.1 in the book. As any design science thesis, this theses has a top-level artifact design goal. What goal is this?
5. Read chapter 3 of the thesis. Classify the research questions as knowledge questions or prediction problems. If a question is vague, try to improve it.
6. Indicate for each knowledge question whether it is descriptive or explanatory.

## Chapter 3

# The Design Cycle

### Questions

1. In a thesis about data location compliance for cloud service providers (CSPs), the following research questions are listed.
  - RQ1 What are demands regarding data location compliance of the typical customers of a CSP?
  - RQ2 What technical solutions do CSPs currently have?
  - RQ3 What are the current limitations for CSPs to show compliance to customer demands regarding data location?
  - RQ4 How to make agreements about data location demands between customer and CSP?
  - RQ5 How can CSPs enforce security policies regarding data location?
  - RQ6 How can CSPs show compliance to customer demands regarding data location in public software-as-a-service cloud computing?
  - (a) Each these questions is asked in some step of the engineering cycle. For each question, indicate to which step it belongs and reformulate it accordingly.
  - (b) Some questions essential to the engineering cycle are missing. Add these questions.
2. Can problem solvers restrict themselves to designing an artifact rather than a treatment? Why (not)?
3. Describe the difference between design and specification as defined in this chapter, using an example.
4. Could you have a design of an artifact but not a specification? Or a specification but not a design?
5. Explain the relationship between implementation, technology transfer and goal realization by means of an example
6. Mention two important differences between the engineering cycle and an engineering process.

## Assignments for Chapter 3 (The Design Cycle)

For the previous assignments, you have read the abstract, table of contents and first chapter of the theses by Broenink [3] and Drenthen [4]. Now read the introduction to each chapter of these theses, as well as the one by Schoutsen [5]. (N.B. In the thesis by Schoutsen, one chapter listed in the table of contents is missing from the body of the text. All the assignments can be done without referring to this missing chapter.)

Use all information gathered to answer the following questions for each of the three theses.

1. Which parts of the engineering cycle are reported about in the thesis?
2. For those parts that are reported about, indicate in which chapter(s), or sections of chapters, it is reported about.
3. In which part of the engineering cycle does the thesis present its main contributions (in the form of new knowledge and/or a new design)? Justify your answer.

## Chapter 4

# Stakeholders and Goals

### Questions

1. Slide 4 mentions several typical stakeholders in a design research project, a development project, and in a software product. Explain why these are all instances of the same stakeholder concept.
2. In exercise 2 of chapter 1, you were asked to list some stakeholders of the following design problems. Now improve the answer you gave there by using the lists of possible stakeholders in table 3.1 of the book.
  - (a) Can we control our environment through a brain-computer interface?
  - (b) Our organization has a handbook of software engineering methods, but it is not used. Which set of methods and techniques from this handbook are relevant for realizing IT-enabled business change?
  - (c) There are several wireless communication protocols for health care devices at home. These devices monitor vital data of home-care patients and transmit them to a wireless care station located in the home, which transmits the data to a central location, which relays it to a care center where medical personnel has access to the data. Different care stations use different wireless communication protocols, such as Bluetooth and ZigBee. Design an application layer protocol that can run on top of Bluetooth as well as ZigBee.
3. See the definition of the MARP project in section 1.2 of the book. Consider a company X wanting to sell a MARP system for aircraft taxiing route planning. Which stakeholders listed in table 4.1 does it have to deal with? Give an example of each relevant stakeholder.
4. Define the different awareness levels that a stakeholder can have of a problem, including non-awareness. Give an example of each level.
5. Consider a new fancy device that has just been put up for sale in consumer electronics shops. Describe the different awareness levels of section 3.2 with respect to this device.
6.
  - (a) Define what it means for desires to be in logical conflict, in physical conflict, and in technical conflict.
  - (b) For each of the examples below, indicate whether there is a conflict between goals and if so, identify the goals, and explain whether the conflict is physical, logical or technical.

- Airports want a safe route and a fast route through the network
  - Airports want aircraft to behave in a predictable manner and respond dynamically to changing situations
  - Car owners want to equip their car with TV but have the same car battery life times as before
  - Car owners want to have a TV in the dashboard so that they can watch during driving, and obey the law
7. For each of the stakeholders of the DOA and DLC examples mentioned in section 3.1, list some desire with respect to the artifact under design, and give an example of a resource to be committed by that stakeholder to turn that desire into a goal.
8. This question is about the system introduced in chapter 2, question 3. The question is about an application layer protocol used for wireless communication between medical monitoring devices in home care and a home care station. The care station relays the data to a server in a central location, that relays the information to a care center. Motivate the following requirements for the protocol in terms of an external goal of a stakeholder. Structure your motivation by describing:
- (i) what desire is supported by this requirement,
  - (ii) which stakeholder(s) has (have) this desire, and
  - (iii) whether they would be willing to commit resources to achieve these desires (turning these desires into goals).
- (a) The protocol must use low power,
  - (b) The protocol must be reliable,
  - (c) A medical device must wait for an acknowledgment from the care station before it starts transmitting data to the care station,
  - (d) Observations relayed to the care center must be traceable to the sensor that generated them.

## Assignments of Chapter 4 (Stakeholders and Goals)

Read chapter 2 of Broenink [3] and Drenthen [4]. Answer the following questions for these theses, basing your answers on the parts of the theses that you have read so far. In the course, we will explain on which artifacts your answer should be based.

1. Give examples of each of the stakeholders of the taxonomy of Alexander (table 4.1).
2. What are their relevant desires as assumed, explicitly or implicitly, by the thesis?
3. What is the awareness level of the stakeholders with respect to these desires?
4. What conflicts exist between any pair of desires that you identified? For any conflicts, explain whether they are logical, physical, technical, economic, legal, or moral.

## Chapter 5

# Implementation Evaluation and Problem Investigation

### Questions

1. What is the difference between validating and evaluating an artifact? Discuss this in terms of the place in the engineering cycle, the nature of the research problem, and the object of study.
2. What is the difference in research goals between evaluation implementation and problem investigation?
3. In implementation evaluation/problem investigation we may ask evaluation questions. Classify these in terms of figure 2.2 in the book, explain your classification, and give an example.
4. What are the advantages and disadvantages of surveys for implementation evaluation/problem investigation?
5. What are the relative advantages and disadvantages of surveys and observational case studies for implementation evaluation/problem investigation?
6. Discuss the differences between observational case studies and single-case mechanism experiments.
7. Single-case mechanism experiments can be done in the lab or in the field. Discuss the relative advantages and disadvantages of this.
8. In which way can single-case mechanism experiments be useful for implementation evaluation/problem investigation?

## Assignments of Chapter 5 (Implementation Evaluation and Problem Investigation)

1. Consider the thesis by Drenthen [4] (chapters 1, 2, 3, 6).
  - (a) Preceding her Master's project, Drenthen has done a problem investigation. What research method has she used for this?
  - (b) Rephrase figure 3 of Drenthen [4] as an engineering cycle.
  - (c) Drenthen has performed several iterations through the design cycle, in which a prototype implementation of the artifact was improved based on the results of validation performed in the previous iteration. Which data collection methods were used in these validations?
2. Consider the thesis by Schoutsen [5] (chapters 1 and 2).
  - (a) In chapter 2, Schoutsen summarizes the known frauds to be solved. Make a list of known frauds that he identifies.
  - (b) In chapter 2, Schoutsen also summarizes problems identified during implementation evaluations. Make a list of problems found.
  - (c) Which stakeholders are listed by Schoutsen? List at least five. (You do not have to classify these according to the schemes of chapter 4).
  - (d) What research method(s) did Schouten use to identify the problems listed in (a) and (b)?
3. Consider the thesis by Van der Graaf [7] (chapters 1, 3 and 4).
  - (a) Classify the thesis as a problem investigation or an implementation evaluation. Motivate your answer.
  - (b) What is the role of theory in the research?
  - (c) Which research methods were used?

## Chapter 6

# Requirements Specification

### Questions

1. Why are treatment requirements also artifact requirements? Explain your answer.
2. What is the difference between constraints and requirements?
3. During treatment design, requirements for the treatment are specified. To justify these, a contribution argument is needed. Explain the difference between this contribution argument and the investigation of goal contribution during implementation evaluation.
4. Consider the DLC and DOA examples of section 6.1.
  - (a) Classify the requirements as functional or non-functional.
  - (b) For each example, give an example of a constraint.
5. Consider the DLC and DOA examples in section 6.2.
  - (a) For each assumption, indicate how the requirements should be changed if the assumption would change and the same stakeholder goal contribution should be achieved as before the change. (In some cases, no requirements may need to be changed.)
  - (b) For each requirement, check if any relevant assumptions are missing. An assumption is relevant if its absence would prevent the requirement to contribute to a goal.
6. This question is about the system introduced in chapter 2, question 3 and chapter 4 question 8. It is about an application layer protocol used for wireless communication between medical observation devices in home care and a home care station. The base station relays the data to a back-end server, which in turn communicates with medical personnel in a care center. Figure 6.1 shows an architectural model of the environment of the protocol.

As you found out in exercise 8 of Chapter 4, each of the following requirements contributes to a stakeholder goal and makes an assumption about the environment. (a) Which assumption does it make, and (b) what should change about the requirement if the assumption is dropped?

  - (a) The protocol must use low power.
  - (b) The protocol must be reliable.

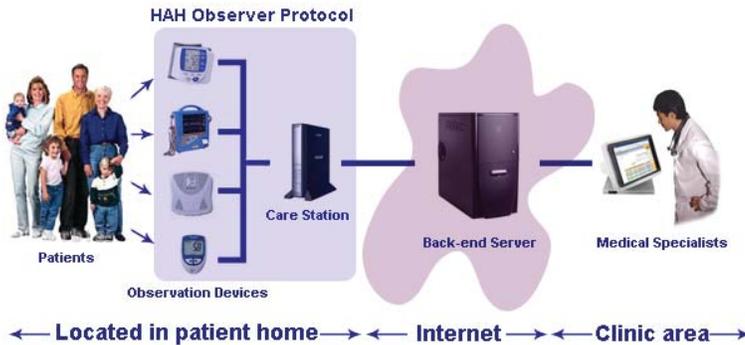


Figure 6.1: Problem architecture of Health@Home

- (c) An observation device must wait for an acknowledgment from the care station before it starts transmitting data to the care station.
  - (d) Observations relayed to the back-end server must be traceable to the sensor that generated them.
7. Consider again the protocol mentioned in question 6 above. Classify the requirements listed in that question as (a) functional requirements, (b) quality requirements, and (c) constraints.
  8. Table 6.1 defines mean time between failure (MTBF) as one indicator of reliability. A high MTBF is interpreted as an indication of high reliability. Does this mean that if MTBF is high, this *causes* reliability to be high? Explain your answer.
  9. Table 6.1 defines several indicators for most properties. Is it possible that two indicators provide contradictory information about one property? If not, explain why; if yes, give an example.
  10. A glider is an aircraft without an engine. For every kilometer of altitude lost, it can travel about 60 kilometers horizontally. By using thermals, i.e. bubbles of warm air of several hundred meters in diameter, a glider pilot can spiral up to higher altitudes and so increase horizontal reach to hundreds of kilometers. During cross-country flights of a glider, a pilot carries a mobile computer in the cockpit, that is connected to a GPS receiver and gathers information about the flight, such as location and altitude. By connecting the computer also to a transceiver that can communicate on the short range device frequency band, the computer can send this data to other devices using the same kind of transceiver, up to 40 km away in other gliders or on the ground, and it can receive up-to-date weather data from other devices.

Consider the design of a data communication protocol between computers connected this way in a mesh network (a network in which each node captures and disseminates data, as well as relays data that it receives from other nodes). A design document [2] lists the following requirements:

- The protocol should disseminate data among gliders in sparse and dense networks.
- It should cope with node mobility (nodes enter and leave the network and change their geographical position).
- Communication overhead (operations not directly related to disseminating data) should be small.

- Propagation delay should be small.
- Important messages must be prioritized over unimportant ones.
- Delivery ratio should be as high as possible.

No further information is given about the exact meaning of these requirements. The design report has defined the following indicators to measure these requirements.

- *Successful packet transmission* occurs when all bytes in a packet have been sent by a transceiver.
- *Successful packet reception* occurs when a transceiver has received all bytes in a packet and had decoded the packet.
- *Number of successful packet receivers* is the number of *successful packet receptions* divided by the number of *successful packet transmissions*.
- *Latency* is the age of a packet when it is received by a node for the first time.
- *Packet loss* is the number of successfully received packets divided by the number of packets successfully sent.
- The *delivery ratio per priority* is the number of nodes that receive packets of this priority, divided by the number of nodes.

Answer the following questions about these requirements and indicators.

- Describe for each requirement, whether and if so, how, i.e. by what test, it can be measured using these indicators.
- If an indicator's definition is still ambiguous, propose an improvement.
- If any additional indicators are missing, please define these.

## Assignments for Chapter 6 (Requirements Specification)

1. Consider the thesis by Drenthen [4] (chapters 1, 3, 9, appendices B, C, D), and consider as artifact the test automation method delivered by the project.
  - (a) What are the functional and nonfunctional requirements of the artifact?
  - (b) What is the overall contribution argument, i.e. the argument that refers to the requirements as a whole, given by the author?
  - (c) What does the author claim about satisfaction of these requirements, and
  - (d) what is the support for these claims?
2. Consider the thesis by Zarghami [8] (Abstract, Table of contents, chapters 1 and 4). This assignment rehearses material treated so far in this course.
  - (a) What is the top-level design problem? Formulate using the design problem template of chapter 2.
  - (b) Rephrase the research questions as design problems (use the template) and knowledge questions.
  - (c) Formulate the validation research questions for this project.
  - (d) Restructure the research approach (section 1.4) as a design cycle.
  - (e) For each NFR, indicate how it can be measured. If no measurement procedure has been given, provide one by defining one or more indicators.
  - (f) Relate each of the NFRs in section 4.4 to one or more FRs in section 4.3, so that it is clear of which functional requirement(s) each non-functional requirement is a property.
  - (g) Some people say that after all NFRs have been operationalized, there are only FRs. Discuss this claim.

# Chapter 7

## Treatment Validation

### Questions

1. Explain the difference between a goal contribution question in implementation evaluation, and the requirements satisfaction question of treatment validation.
2. (a) What is the central problem of validation?  
(b) What is the goal of validation research?  
(c) Can we validate an artifact after it has been implemented?
3. (a) What is the structure of a design theory? Hint: Each design theory is a scientific theory, with some additional structure.  
(b) Each design theory has a scope. Which validation research questions help in determining the scope, and how do they do that?

4. Consider again the wireless communication protocol for gliders of exercise 10 of chapter 6 [2] 1. If a node A in a wireless glider network receives messages from two other gliders, B and C, it will not receive any message if the two receptions interfere. This prevents B and C to communicate with each other through A. This is called the hidden terminal problem. Together with the dynamics of glider networks, this leads to a number of requirements on a data communication protocol as listed in exercise 10 of chapter 6 (page 17).

A design report about glider data communication protocol design lists the following design problems.

P1 What wireless communication protocol is most suitable for the exchange of information between gliders?

P2 How can the protocol deal with the hidden terminal problem?

P3 How can lossless communication be provided with the protocol?

P4 How can the protocol deal with the mobility of gliders?

Translate these problems into one design problem and validation research questions of the four types discussed in this chapter. Use the information given in exercise 10 of chapter 6. Refer to chapter 2 for the template of design problems.

5. Use the requirements listed in question 6 of chapter 6 to formulate the validation research questions for the application layer protocol mentioned in that question.

6.
  - (a) What is the purpose of validating an artifact by expert opinion?
  - (b) What are the limitations of validation by expert opinion?
  - (c) How can you mitigate these limitations?
7.
  - (a) Expert opinion and TAR can both be viewed as simulation of the effects of an artifact in a real-world context.
    - (a) Explain why they can be viewed this way.
    - (b) Explain the relative advantages and disadvantages of the two validation research methods.
8. TAR is a special kind of single-case mechanism experiment. Explain what the similarity and what the difference is compared to all other single-case mechanism experiments.
9. Scaling up to practice takes place along two dimensions.
  - (a) Describe these dimensions.
  - (b) What role do mechanism simulation experiments and statistical difference-making experiments play in scaling up research?

## Assignments for Chapter 7 (Treatment Validation)

Consider the theses by

- Broenink [3], chapter 4 until the end of section 4.1, and section 4.4 until the end of section 4.4.1;
- Drenthen [4], chapter 3;
- Schoutsen [5], the start of sections 6.1, 6.2, 6.3;
- Zarghami [8].

Answer the following questions for each thesis.

1. What validation research methods have been used?
2. For each of these methods, what validation model(s) (figure 7.2) have been used?
3. For each of these validation models, where in the progression of scaling-up (figure 7.3) is it located? Give a qualitative estimate of the position on the “robust mechanisms” axis and on the “stable generalizations” axis.

## Chapter 8

# Conceptual Frameworks

### Questions

1. Define the concepts of architecture, component, and mechanism. Illustrate your definitions with an example.
2. Figure 6.1 shows the architecture of the Health@Home problem context. The mobile devices communicate with the care station by means of protocols like Bluetooth and Zigbee. The rest of the communication is done by TCP. The goal of the Health@Home project is to design a protocol by which the applications in the mobile devices can communicate with the Care Station.
  - (a) This architecture does not represent any particular Health@Home system, but it shows a class of systems (i.e. a population) with a shared architecture. Define this class by identifying the essential elements of the architecture shared by all of these problem contexts.
  - (b) What are the capabilities that these problem components must minimally have to count as instance of this general class of problems?
  - (c) The links among components of the architecture represent a mechanism present in the problem context. Describe this mechanism.
  - (d) The artifact to be designed for this problem context should introduce another mechanism. Describe that mechanism.
  - (d) Provide a contribution argument for the desired artifact of the following form:

(An artifact that implements mechanism A) in (a context that contains mechanism C) contributes to (stakeholder goals).

Mechanisms C and A are the mechanisms that you identified in the previous two subquestions, respectively. You are free to choose a relevant stakeholder goal.
3. Read section 1-3 of the paper by Agner et al. [1]. Answer the following questions, indicating your support for your answers as follows:
  - Refer to the place in the paper where the answer can be found, as follows: (page number, column, line number), where “column” is either Left or Right and the line number starts counting from the top or from the bottom of the text column. When counting lines, you ignore tables and figures. For example, (1000, Right, 9 to 15) indicates lines 9 to 15 in the right column on page 1000. The same lines are indicated by (1000, Right, -19 to -12) when counting from the bottom of the text.

Architectural structures	Statistical structures
System class	Population
Component	Variable
Capability to behave	Distribution over population
Mechanism that produces a phenomenon	Covariance relation

Table 8.1: Architectural and statistical structures compared.

- If there is no particular place in the paper that contains support for your answer, but there is another argument for your answer, then give that argument (be brief!)
    - (a) Is this an implementation evaluation, a problem investigation, or a treatment validation? Explain your answer.
    - (b) What is the population of interest?
    - (c) Which sample of it was studied?
    - (d) What was the sampling frame?
    - (e) How was the sample selected from the sampling frame?
4. Consider again the first three sections of the paper by Agner et al. [1]. One of the variables investigated in the paper is Work Experience. Based on the parts of the paper that you have read (sections 1-3), define a chance model for Work Experience.
- Since the paper does not define a complete chance model, you will have to supply additional information. For each part of the chance model that you found in these three sections of the paper, indicate where you found it, using the location convention described above. For each part supplied by yourself, indicate the choices that you made in this part of the definition.
6. Table 8.1 compares architectural and statistical structures. Consider the population of software engineers studied by Agner et al. [1].
- (a) What is the corresponding class of systems?
  - (b) Give some examples of relevant components of these systems.
  - (c) Give an example of a relevant behavioral capability of these systems.
  - (d) Give an example of a relevant mechanism that produces or limits a capability of these systems.
7. Consider again, as in the previous questions, the research goal of finding out whether and how the UML is used in a population of software engineering projects. Consider now a case study of one of these projects.
- (a) What is the class of systems (i.e. population) of interest for this case study?
  - (b) Give some examples of relevant components of these systems.
  - (c) Give an example of a relevant behavioral capability of these systems.
  - (d) Give an example of a relevant mechanism that produces or limits a capability of these systems.

8. In a case study of the use of the UML in a software engineering project, it was decided to do a sample-based study of all the software engineers in the project. The following questions follow the main features of statistical structures listed in table 8.1.
  - (a) What is the population of this study?
  - (b) Mention two variables of interest in this sample-based study.
  - (c) Mention any assumptions about the distribution that you think are reasonable.
  - (d) What interesting covariance relation do you expect to observe for these variables?
  
9. Table 1 in the paper by Agner et al. [1] shows that many concepts common in the studied population are shared with the researchers. However, as explained in section 8.2 of the book, concepts may travel between the studied population and the research community, and during these travels they may change in meaning.
 

The concept of Model-driven engineering (MDE) originated in practice, where it was used in the 1980s by companies selling the then-new technology of computer-aided software engineering (CASE). It is now used both by researchers and practicing software engineers, but not necessarily with the same meaning.

  - (a) How is it defined by Agner et al. [1]? Indicate where you found the definition.
  - (b) Is there a danger that the concept of MDE is understood in a different way by the respondents? Explain your answer.
  
10.
  - (a) Conceptual frameworks have two uses for design problems. Describe these uses and illustrate your definition with examples.
  - (b) Conceptual frameworks have three uses for stating and answering empirical knowledge questions. Describe these uses and illustrate your definition with examples.
  
11. Shadish et al. [6] define construct validity as the degree to which our inferences from phenomena to constructs are warranted.
  - (a) What is wrong with this definition?Health
  - (b) How is the concept of construct validity defined in the book?
  - (c) The book treats constructs as mental tools, which are subject to requirements (table 8.4), and defines construct validity accordingly. Does this completely avoid the problems with the definition of Shadish et al.?
  
12. Two threats to construct validity are *inadequate definition* and *construct confounding*.
  - (a) Define these threats.
  - (b) Specify the corresponding requirements on the definition of constructs.
  - (c) Gives examples of construct definitions in which these threats have materialized (i.e. that do not sufficiently satisfy the requirements), and indicate how you would mitigate those threats.
  
13. The Wikipedia defines agile software development as

a group of software development methods in which requirements and solutions evolve through collaboration between self-organizing, cross-functional teams.

This definition is subject to the threats of inadequate definition and construct confounding. Show how it is subject to these threats, and suggest possible improvements that reduce these threats.

14. Two threats to construct validity of the definition of indicators are mono-operation bias and mono-method bias.
  - (a) Define these threats.
  - (b) Specify the corresponding requirements on the definition of constructs.
  - (c) Gives examples of construct definitions in which these threats have materialized (i.e. that do not sufficiently satisfy the requirements), and indicate how you would mitigate those threats.
15. Usability of an artifact by people is often defined in terms of the following indicators. For each indicator, we provide at least one measurement method.
  - Learnability: How easy is it for users to accomplish basic tasks with the artifact the first time they encounter the artifact?
    - Measurement method 1: Time required to learn the task.
    - Measurement method 2: Number of calls for help during learning.
  - Task efficiency: Once users have learned the design, how quickly can they perform tasks?
    - Measurement method: The time required to perform a task with the artifact, immediately after having learned how to use it.
  - Ease of remembering: When users return to the design after a period of not using it, how easily can they re-establish proficiency?
    - Measurement method: The time required to perform a task with the artifact, some time after having learned how to use it.
  - Task effectiveness: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
    - Measurement method 1: Number of errors made when performing a task with the artifact.
    - Measurement method 2: Severity of these errors, as rated by an expert on a 7-point ordinal scale.
    - Measurement method 3: Time needed to recover from these errors.
  - Satisfaction: How pleasant is it to use the design?
    - Measurement method: perceived usability, as rated by the user on a 7-point Likert scale.

Each indicator captures an aspect of the construct of usability. Consider the construct validity of this set of definitions.

- (a) These five indicators are claimed to define the concept of usability. Discuss the presence or absence of mono-operation bias in this set of definitions. The question in issue is whether the indicators jointly cover the meaning of the construct. If it does not, suggest an additional indicator that would give better coverage.

- (b) For each indicator, one or more measurement methods have been defined. Discuss the presence or absence of mono-method bias in these definitions, for each indicator. The question to be discussed here is whether or not a measurement method completely captures the meaning of the indicator. If it does not, suggest at least one additional measurement method that reduces the mismatch between the measurement and the intended meaning of the indicator.

## Assignments for Chapter 8 (Conceptual Frameworks)

Consider chapters 1, 2, 4, 7 and 8 of the thesis by Drenthen [4].

1. In chapters 2 and 4, an architectural conceptual framework for specifying the artifact and for describing its context, is introduced.
  - (a) Describe some components of this framework and their capabilities. Give 4 components and their capabilities of the proposed artifact as well as 4 components of the context.
  - (b) Describe 4 relevant interactions among the components of this framework.
2. Consider chapters 1 and 8. What is the generalization supported by the thesis, and what is the higher-level generalization to which the author aspires?
3. Drenthen develops test automation methods and techniques iteratively in a project, where after each iteration, all five project members have to fill out a questionnaire (called a survey). The results of these surveys are discussed in chapter 7. The survey requires a statistical conceptual framework.
  - (a) What is the population of this framework?
  - (b) Mention 3 variables investigated in this framework.
  - (c) What aspect(s) of their distribution are investigated? (Hint: see section 3.4 of the thesis.)
4. In chapter 1, the requirements on the artifact-to-be-designed are listed.
  - (a) How is each requirement measured?
  - (b) Discuss the presence or absence of mono-method bias for the requirements. If there is mono-method bias, what alternative measurement methods would you propose?

## Chapter 9

# Scientific Theories

### Questions

- What is a theory? Give the definition, illustrated by an example and a non-example.
  - What are the distinguishing characteristics of scientific theories compared to other kinds of theories? Give an example of a scientific and a non-scientific theory.
- What is the structure of a scientific theory? Give an example.
  - Each design theory is a scientific theory., and therefore has a scope. Which validation research questions help in determining the scope, and how do they do that?
- Define the concept of a causal explanation of a phenomenon, and give an example.
  - Define the concept of an architectural explanation of a phenomenon, and give an example.
  - Define the concept of a rational explanation of a phenomenon, and give an example.
  - If you push a sequence of buttons on a coffee machine in our office, it starts making noise, produces a cup, and pours coffee in it. Suppose I have a craving for coffee and push the right sequence of buttons. Give a causal, architectural, and rational explanation of the phenomenon that it then pours coffee.
- What is the difference between explanation and prediction? Give an example of a non-predictive explanation, and a non-explanatory prediction.
- For a design theory to be usable by a practicing designer, there is a requirement on each of the four elements of a design theory: artifact, context, effects, and requirements.
  - What are these requirements?
  - Consider the design theory that on busy airports, multiagent route planning reduces delays due to aircraft taxiing. For each of the four elements of this theory give an example of a concrete airport in which this theory would be unusable.

6. Consider again the database system of question 2 of chapter 2. Suppose you deliver a specification  $S$  of a database system that satisfies the requirements.
  - (a) You have actually delivered a design theory. What is the structure of this theory?
  - (b) By what is the scope of this theory determined?
  - (c) A scientific theory needs to be justified to a critical peer group and be tested against experience.
    - i. Regardless of the arguments, to which critical peer group would you justify this theory? How would you organize this?
    - ii. How would you test the theory against experience? Consider the research methods reviewed in chapter 7.
  - (d) The theory would have a mixed architectural and statistical conceptual framework, and so the theory would make architectural as well as statistical generalizations.
    - i. What concepts would be in the architectural theory? Give some examples of components and mechanisms that should be described in this theory.
    - ii. What would be the population of the statistical theory, and what generalizations would it contain? Give some examples.
  - (e) Design theories can be used to (1) frame a problem, (2) describe a problem, (3) specify an artifact, (4) generalize about the artifact and problem, (5) analyze the problem or artifact, (6) explain phenomena, (7) predict them, and to (8) design artifacts. Give an example of each of these eight functions of the design theory of the database system.
  - (f) Suppose a particular kind of sensor is installed because it has favorable cost/performance characteristics. After a while some sensors start sending incorrect data to the database, on account of which the database crashes. Consider the crash as a phenomenon to be explained. Give a causal, architectural, and rational explanation of this crash.
  - (g) The design theory should be able to make some predictions. Give an example of a prediction of a phenomenon that cannot be explained.
  - (h) The design theory should be usable for designers. Give the requirements on usability of the theory for designers, explaining what this means in this example.
7. Consider again the application protocol of question 3 of chapter 2. Suppose you deliver a specification of the desired application protocol that satisfies the requirements. Answer all subquestions of question 6 above for this protocol.
8. A scientific theory needs to be justified to a critical peer group and be empirically tested.
  - (a) Regardless of the arguments, to which critical peer group would you justify a scientific theory? How would you organize this?
  - (b) How would you empirically test the theory? Consider the research methods reviewed in chapter 7 and indicate in which sequence you would apply these methods if you had enough time and money to do all the research needed.
9. Suppose a particular software system crashes on receiving some input. Propose a causal, architectural, and rational explanation of this crash. Justify for each explanation, why it is a causal, architectural or rational explanation, i.e. show that it satisfies the definition of these explanations.

10. Give an example of an explanation that cannot be used for prediction.

## Assignments for Chapter 9 (Scientific Theories)

Consider the abstract and chapters 1, 2, 7, 8 and 9 the thesis by Drenthen [4].

1. What is the design theory proposed by this thesis?
2. The scope of a design theory is determined by the design freedom in the artifact and the freedom allowed by assumptions about the problem context. What is the scope of the design theory of this thesis? Discuss both the limitations to the design freedom of the artifact and limitations to assumptions about the context, and indicate uncertainties that may exist in these two components of the scope.
3. In the assignments of chapter 8, you identified architectural as well as statistical concepts in the conceptual framework of the design theory delivered by Drenthen. Give an example of an architectural generalization (a generalization about architectures) and a statistical generalization (a generalization about the distribution of a variable, e.g. about the mean or variance of a variable, over a population) based on the thesis.
4. Design theories can be used to (1) frame a problem, (2) describe a problem, (3) specify an artifact, (4) generalize about the artifact and problem, (5) analyze the problem or artifact, (6) explain phenomena, (7) predict them, and to (8) design artifacts. Give an example of each of these eight functions of the design theory of this thesis.
5. Suppose a particular software system contains many errors, some of which make the automated test system crash. Propose a causal, architectural, and rational explanation of this crash. Justify for each explanation, why it is a causal, architectural or rational explanation, i.e. show that it satisfies the definition of these explanations.
6. The design theory in the thesis should be able to make some predictions. Give an example of a prediction of a phenomenon that cannot be explained with current knowledge.
7. The design theory in the thesis should be usable and useful for designers. Give the four requirements on usability and utility of the theory for designers, explaining what this means in this example.

# Chapter 10

## The Empirical Cycle

### Questions

1. List four possible knowledge goals in the engineering cycle, and give examples.
2. For each of the following research designs, (i) indicate what the object(s) of study is/are, (ii) what the population is, and (iii) whether the research is case-based or sample-based.
  - (a) The research design for validation by expert opinion (section 7.4.1).
  - (b) The research design for single-case mechanism experiments (section 7.4.2).
  - (c) The research design for technical action research (section 7.4.3).
  - (d) The research design for statistical difference making (section 7.4.4).
3. In case-based reasoning, there are three major steps. Describe these steps and give an example.
4. In sample-based reasoning, there are four major steps. Describe these steps and give an example.
5. The validity of a research design consists of three elements. Define these elements.
6. In exercise 2 of chapter 2 you formulated a validation research question for a database for dike monitoring sensor data. As part of your research to answer these questions, you may want to do one or more single-case mechanism experiments.
  - (a) Sketch a research setup for such an experiment (define the population, OoS, sample, treatment, measurement).
  - (b) What reasoning steps would you perform on the data produced by the experiment?
  - (c) Sketch three issues that you need to check in order to assess the validity of this research design.
7. In exercise 3 of chapter 2 you formulated a validation research question for an application protocol to be used in a home health care environment. As part of your research to answer these questions, you may want to do one or more single-case mechanism experiments.

Answer the same subquestions as in the previous question.

8. Suppose that the dike monitoring database of question 6 is implemented, and you want to evaluate its performance, e.g. database size, execution speed, etc.
  - (a) Describe a sample-based research setup to answer questions like these about performance.
  - (b) Describe the four reasoning steps to infer conclusions from the raw data.

## **Assignments for Chapter 10 (The Empirical Cycle)**

Chapters 10 and 11 have one joint assignment. See the assignment of chapter 11.

# Chapter 11

## Research Design

### Questions

1. Case-based and sample-base research both sample their objects of study, but then study them in a different way. What is the difference?
2. (a) What is the difference between a random sample and a non-random sample?  
(b) What is the difference between a random sample and a simple random sample?
3. For non-random samples, the sample mean of a variable can be used as an estimation of (population mean + bias + sampling error) of the variable. Explain this equation.
4. What is the difference between an independent variable, an extraneous variable, and a confounding variable? Give an example.
5. Is a treatment a level of an independent variable, or the action of setting the level of an independent variable? Explain your answer.
6. Define the concepts of nominal, ordinal, interval, and ratio scale. Give an example of each one.
7. What is the difference between a data type and a measurement scale?
8. What scale do the following measurements have? Explain your answer in terms of meaning-preserving transformations that are and are not allowed on the scale:
  - (a) Preference for a software feature, expressed on a 5-point Likert scale.
  - (b) Software engineering effort in estimated person months.
  - (c) Software execution time in seconds.
  - (d) Student registration number.
  - (e) CPU serial number assigned by manufacturer.
9. Suppose at a party we hand out lottery tickets to the people who enter. Each ticket has a number, and we hand them out in sequence, so that the  $n$ -th entrant has ticket number  $n$ . After every participant has entered, there is a lottery in which a randomly chosen number among those handed out the participants, wins.

- (a) The numbers have a nominal scale. Explain this, by indicating the real-world meaning of the numbers, and the operations that are permissible with respect to this meaning.
- (b) The numbers also have an ordinal scale. Explain this, by indicating the real-world meaning of the numbers, and the operations that are permissible with respect to this meaning.
- (c) The numbers also have an interval scale. Explain this, by indicating the real-world meaning of the numbers, and the operations that are permissible with respect to this meaning.

## Assignments for Chapter 11 (Empirical Research Design)

Chapter 4 of the thesis by Broenink [3] reports on an experiment with the botnet identification techniques defined in chapter 3. In this joint assignment of chapters 10 and 11, assignments of this chapter and the next, we will analyze this experiment using the checklist of the empirical cycle (appendix B of the book). In the thesis of Broenink, you will find answers to most of the questions of the checklist chapter 1, chapter 2, section 3.1, sections 4.1-4.3, section 4.5.1 and chapter 5.

- (a) Answer questions 1-16 of the checklist for the empirical cycle (appendix B). If an answer is not stated explicitly, but implied by the report, please indicate this.

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