Design Science Methodology

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0. Introduction

Goal of the course

- Improve some of your problem-solving capability
  - Improve your capability to **justify** your solution
  - Help you **structure** your Master's thesis

- Not a creativity course

Material

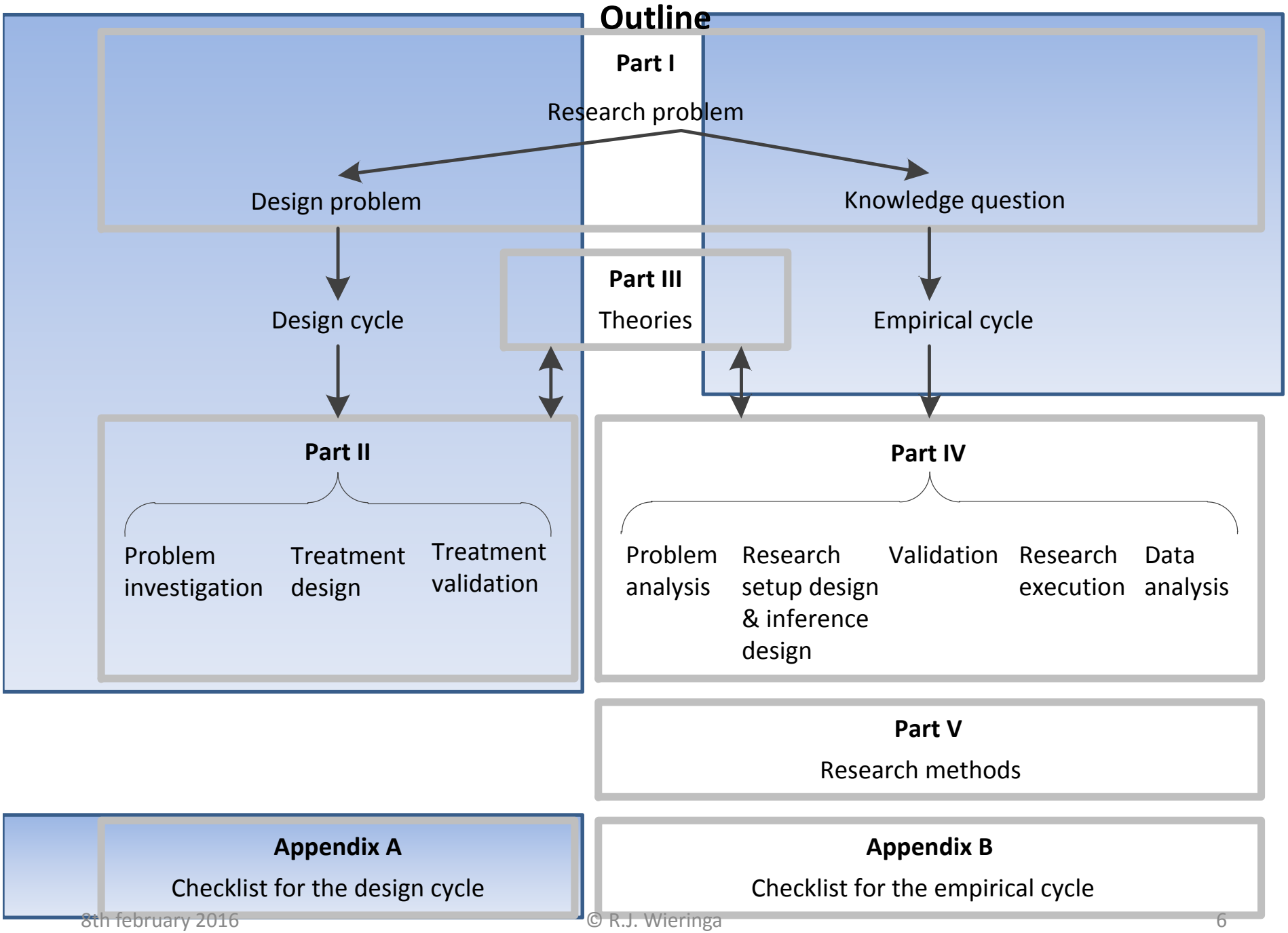
- Slides on my web site
- Book http://link.springer.com/book/10.1007/978-3-662-43839-8

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**
  - **Utility is the goal**
  - Knowledge is a side-effect
  - ``Technical research problems''

- (2) Knowledge questions
  - *Describe, explain, predict*
  - Knowledge questions, research design, research execution, data, analysis
  - **Empirical research cycle**
  - **Truth is the goal**
  - Utility is a side-effect

Outline


Part I
Research problem
Design problem
Knowledge question
Design cycle
Part III
Theories
Empirical cycle
Part II
Problem investigation
Treatment design
Treatment validation
Part IV
Problem analysis
Research setup design & inference design
Validation
Research execution
Data analysis
Part V
Research methods
Appendix A
Checklist for the design cycle
Appendix B
Checklist for the empirical cycle

Schedule

chapter	schedule
0 Intro	9:00 - 10:30
1 What is design science	
2 Research goals and questions	
3 The design cycle	10:45 - 12:30
4 Stakeholder and goal analysis	
5 Implementation evaluation and problem investigation	13:30 - 15:00
6 Requirements specification	
7 Design validation	15:15- 16:30

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 topic of your Master project?
- Design of conceptual / physical / software / social structures

Subject of design science

Artifact:

SW component/system,
HW component/system,
Organization,
Business process,
Service,
Method, Technique,
Conceptual structure,
...

Interaction

Problem context:

SW components & systems,
HW components & systems,
Organizations,
Business processes,
Services,
Methods, Techniques,
Conceptual structures,
People,
Values, Desires, Fears,
Goals, Norms, Budgets,
...

Something to be designed

Something to be influenced

Where is the system boundary?

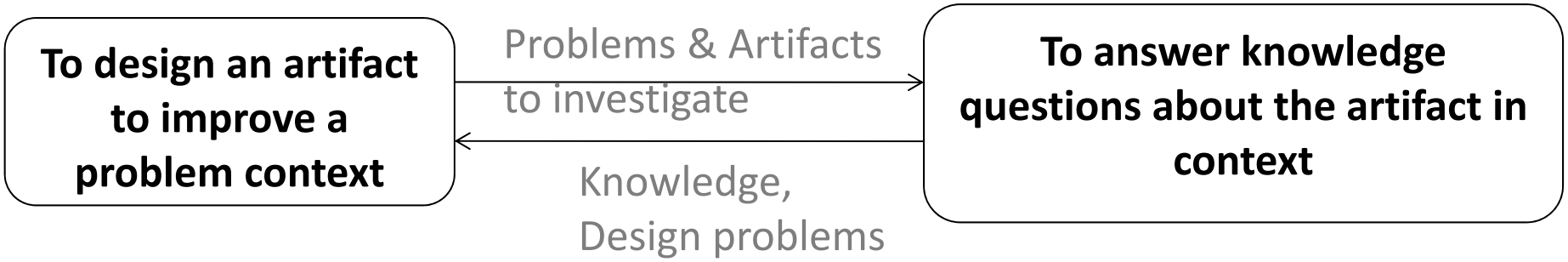
- The **problem context** is given to you
  - It is not designed by you
- The **(renewed) artifact** is (re)designed by you
  - It is not given to you
  - An older version of the artifact may be given to you

Interaction with the artifact 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
- Design science studies
  - behavior of artifacts in context
  - and its contribution to stakeholder goals

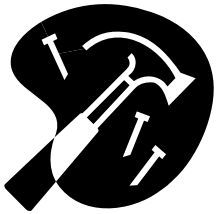
2.2 Research problems in design science

Research problems in design science



Heuristics

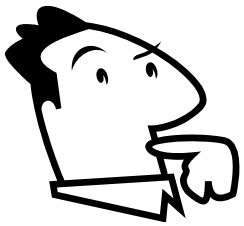
- Design problems
  - √ Call for a change of the world
  - √ Solution is design
  - √ **Many solutions**
  - √ **Evaluated by utility**
  - √ Many degrees of utility
  - √ What is useful depends on stakeholder goals



Doing

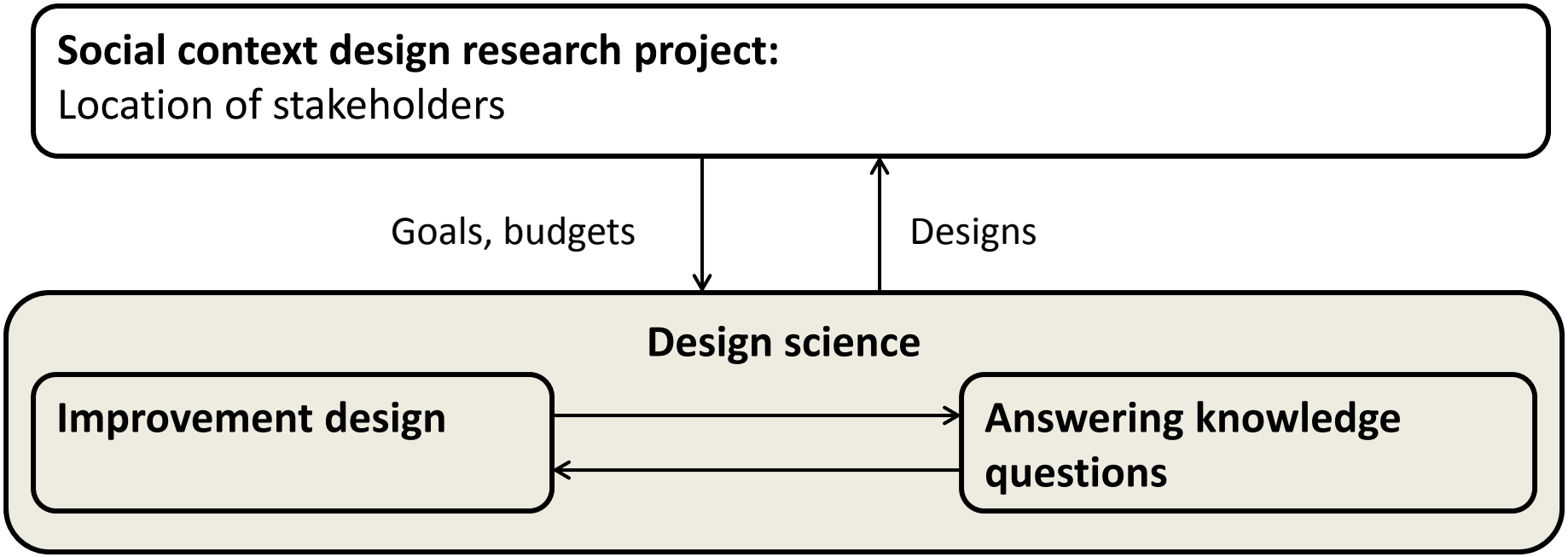
- Knowledge questions
  - √ Ask for knowledge about the world
  - √ Answer is a proposition
  - √ **One answer**
  - √ **Evaluated by truth**
  - √ Many degrees of certainty about the answer
  - √ What is considered "true" does not depend on stakeholder goals

Thinking



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":

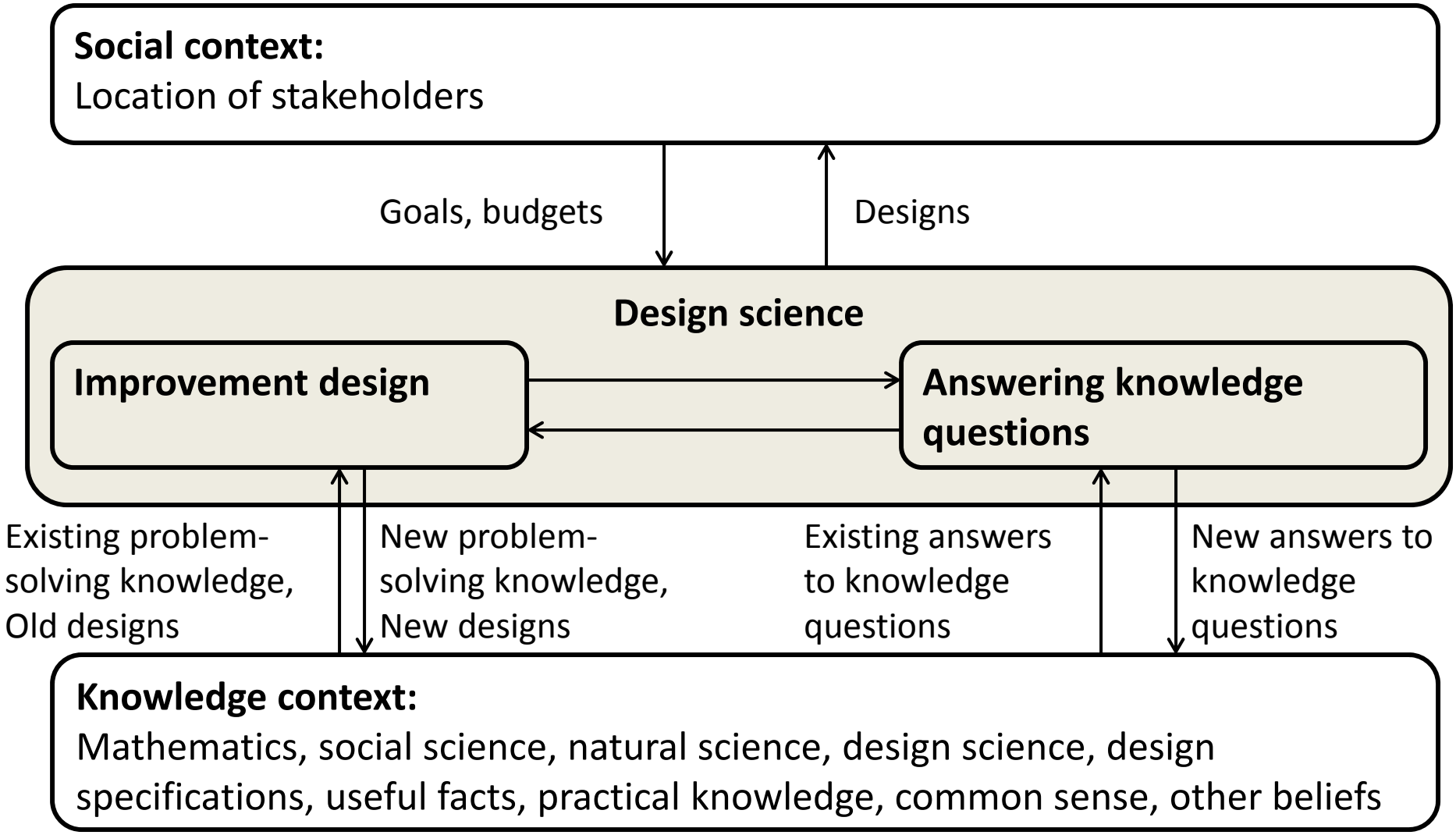
Stakeholders: Researchers, NXP (sponsor), component suppliers, car manufacturers, garages, car passengers

"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?

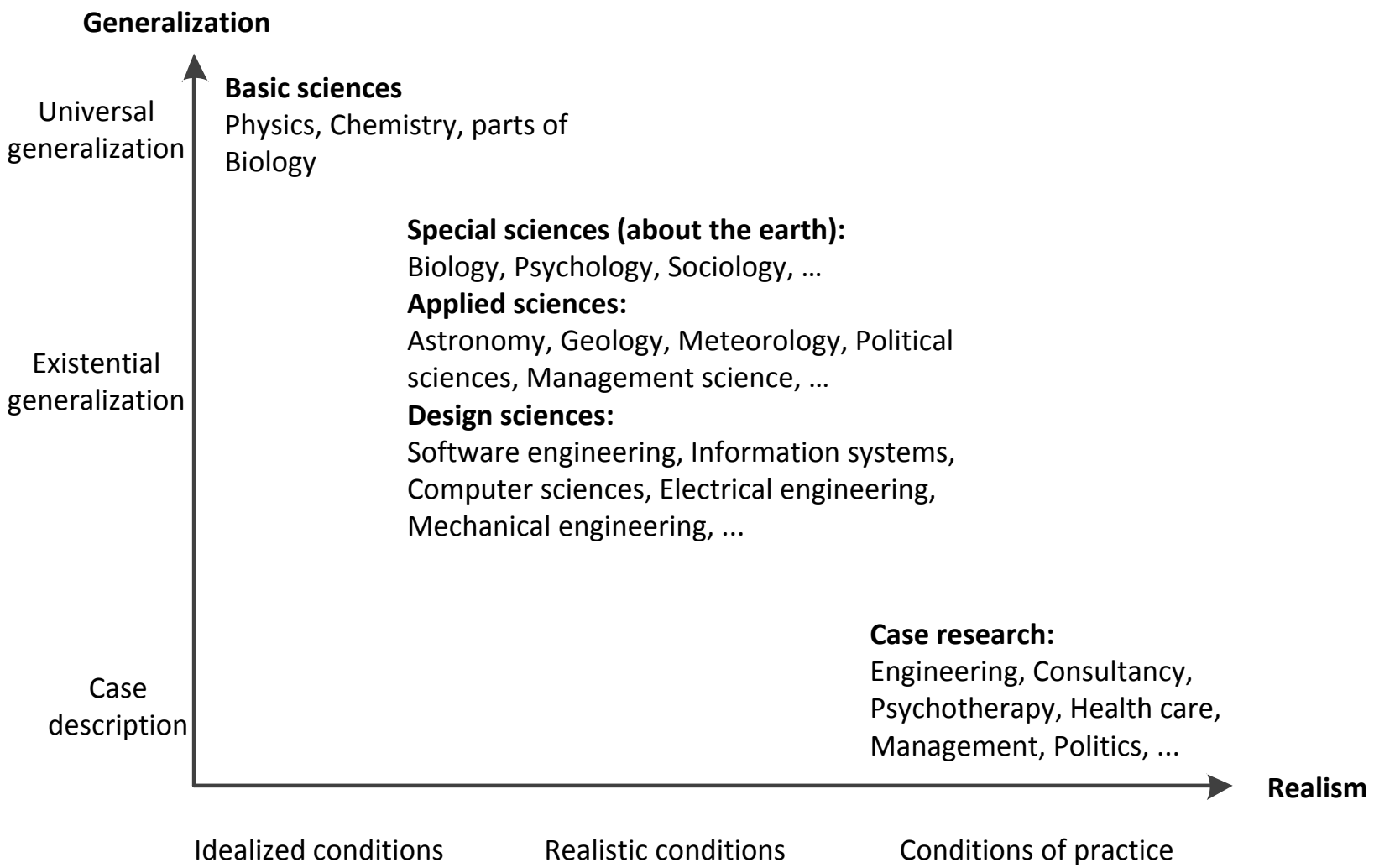
- The Web is a communication channel, not a source of information
- Sources are more diverse
  - Scientific literature
  - Technical literature
  - Professional literature
  - On-line databases
  - Social networks
- Did the information survive
  - Empirical tests?
  - Critical judgment of peers?

Your research aims at theories

- Knowing the relevant properties of an artifact in context is not enough
  - Theories are general

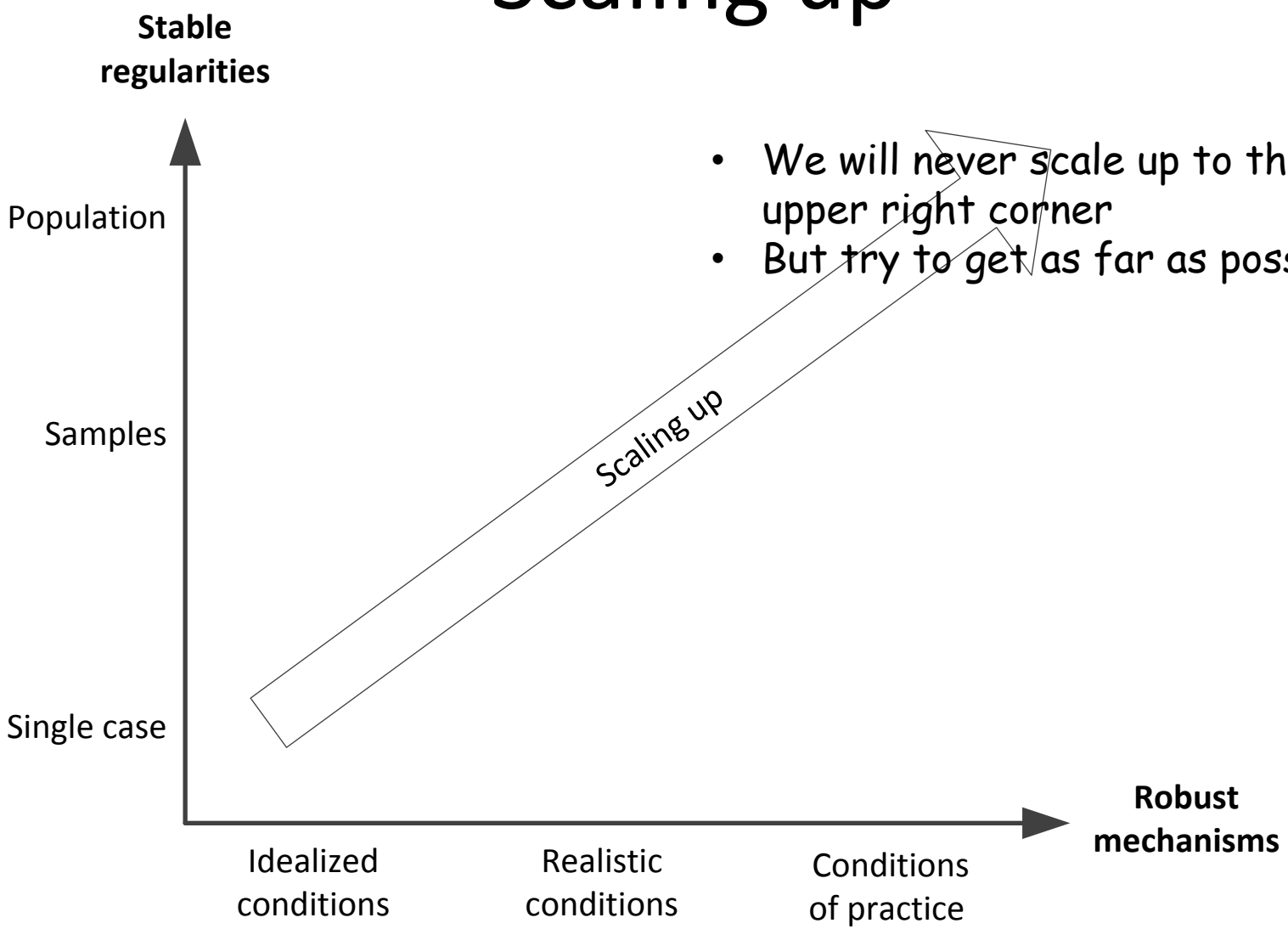
- If the artifact prototype that you built disappears, what is the knowledge remains?
  - Tested, critiqued knowledge

Sciences of the middle range



- 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
  - …

Scaling up



- We will never scale up to the upper right corner
- But try to get as far as possible

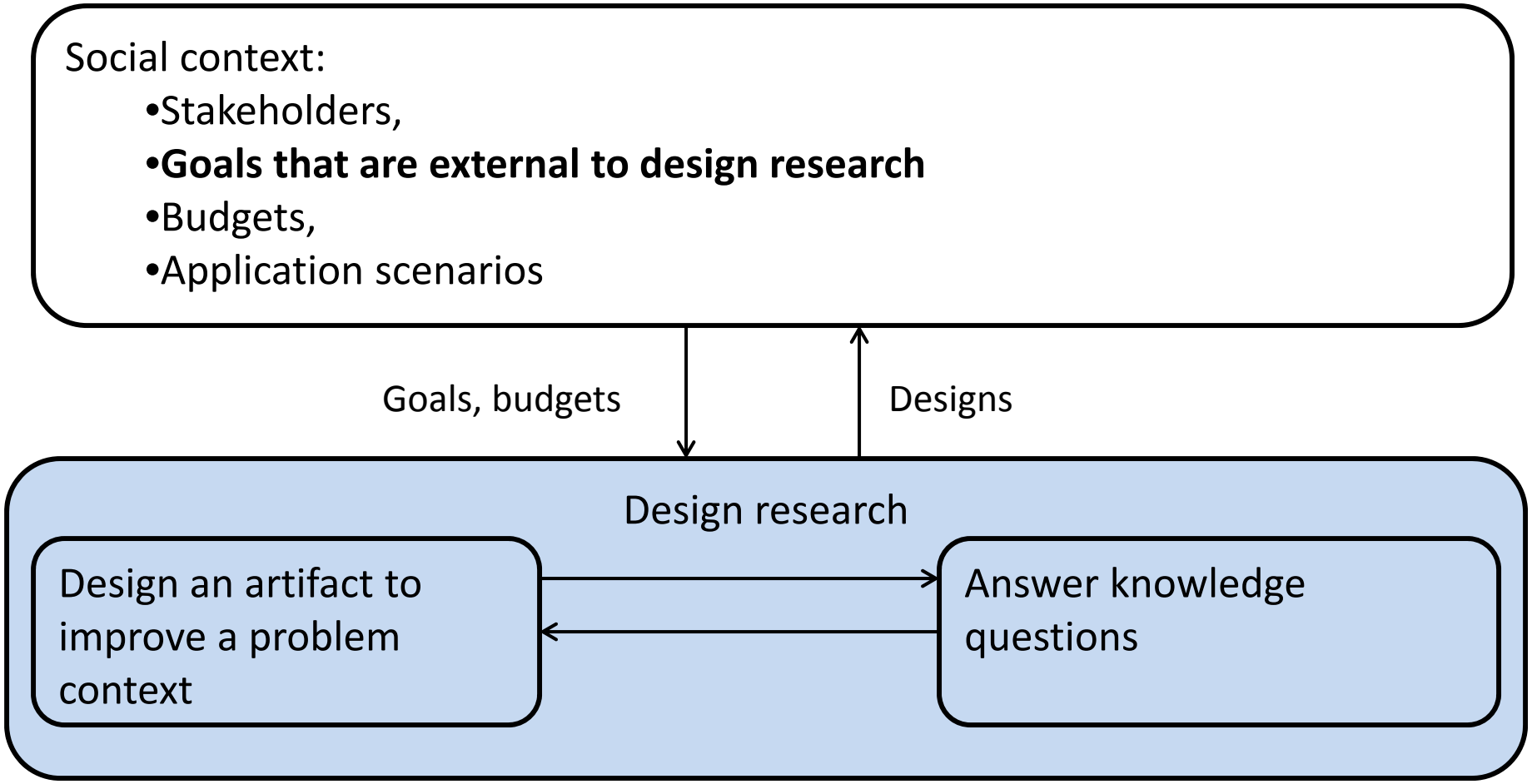
Main points chapter 1
What is design science

- 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 of stakeholders and their goals and budgets.
- The **knowledge context** consists of scientific knowledge, design specifications, useful facts, practical knowledge, common sense, etc.
- The design sciences are **middle-range sciences** aiming for partial generalizations about realistic conditions.
  - Need to scale up from idealized to practical conditions

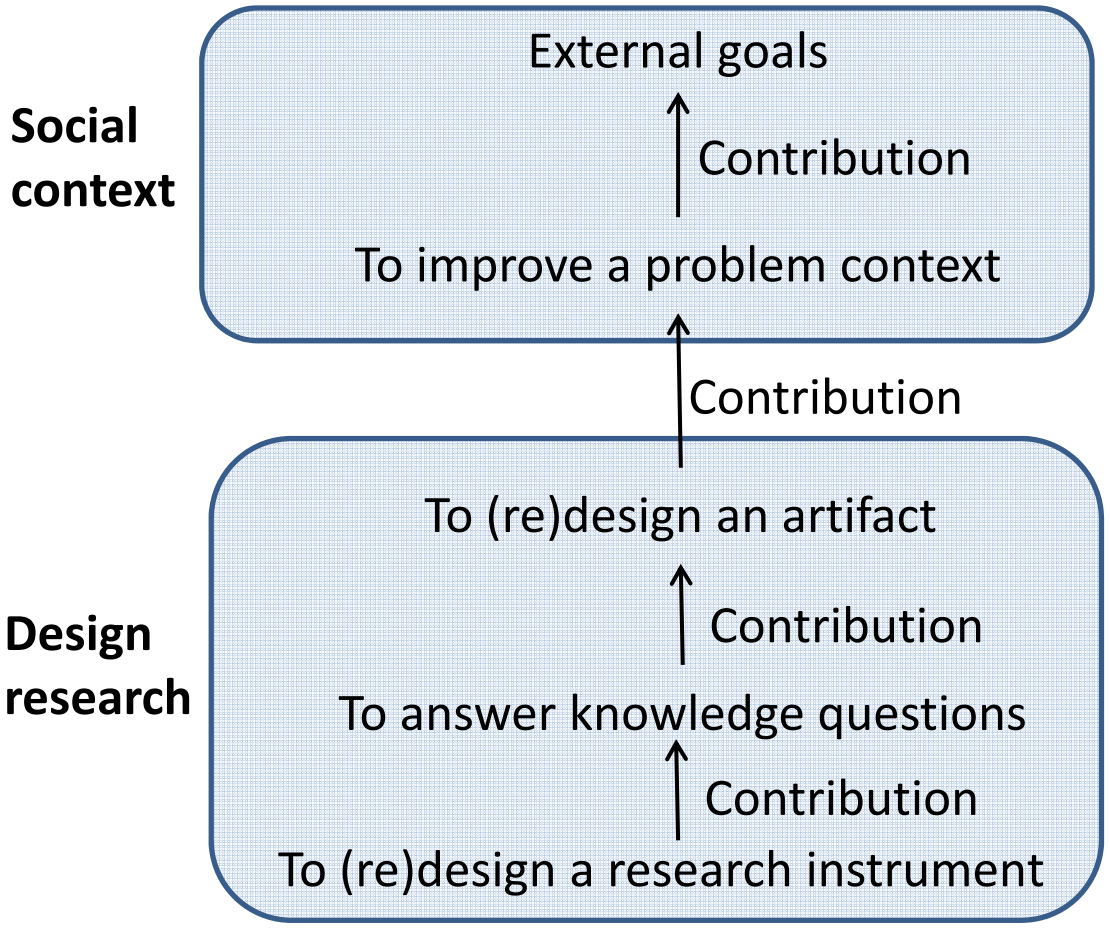
2. Research Goals and Research Questions

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 he 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 questions

- 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 relieves my headache*
- *in order for me to get back to work*

Template for design problems

- Improve <problem context>
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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***
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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 relieves my headache*
- *in order for me to get back to work*

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

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 theory that tells us what usually 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 is 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

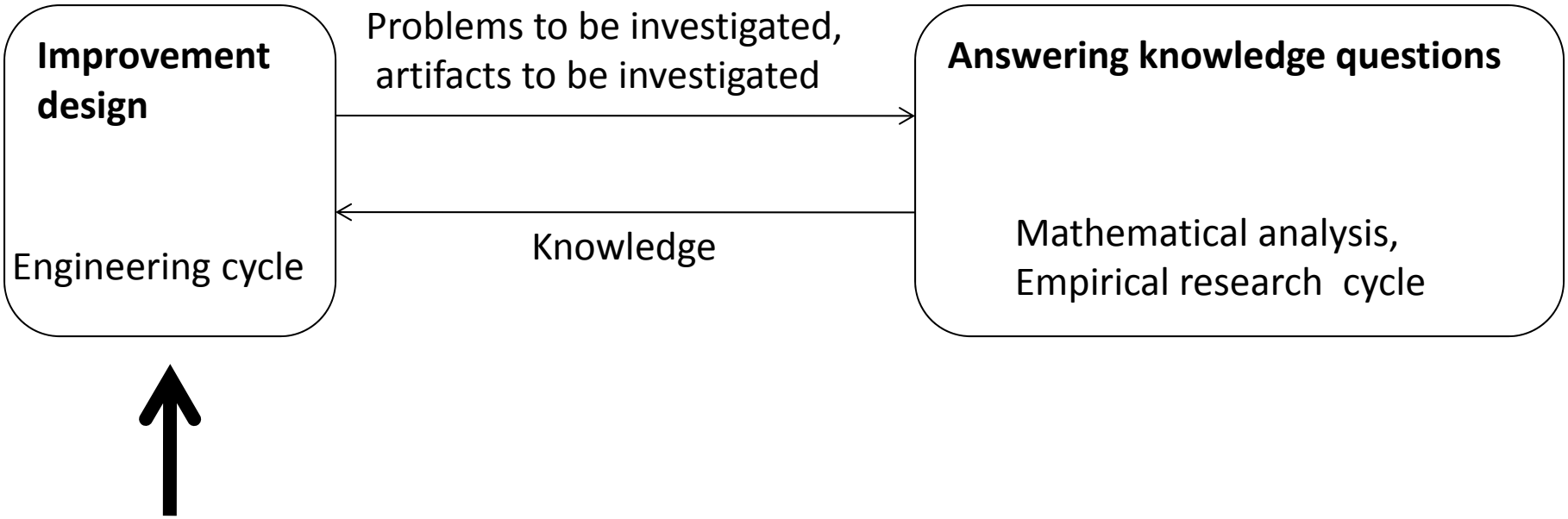
- *Open descriptive effect questions: What is the performance of the Ucare system?*
  - *Accuracy of output*
  - *Reliability of communication infrastructure*
  - *Usability of interfaces*
  - *Etc. etc.*
- *Open descriptive trade-off questions*
  - *What happens to the performance iof we change the 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).
  - The highest-level research goal is to (re)design an artifact
  - This may be decomposed into design problems, prediction problems, and knowledge questions
- Knowledge questions may be analytical or empirical.
  - Empirical knowledge questions may be
    - descriptive or explanatory,
    - open or closed,
    - effect-related or requirement-related
- The answers to knowledge questions may be used to solve design and prediction problems

3 The design cycle

Activities in design science

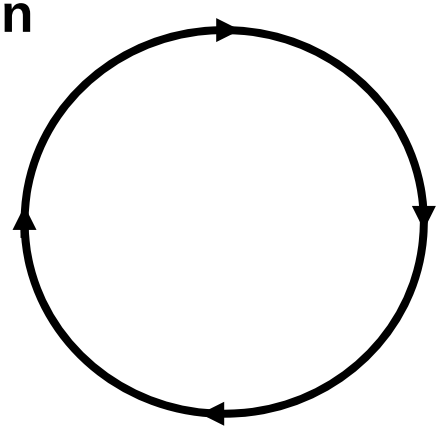


3.1 The design and engineering cycles

Engineering cycle

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

Design 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?

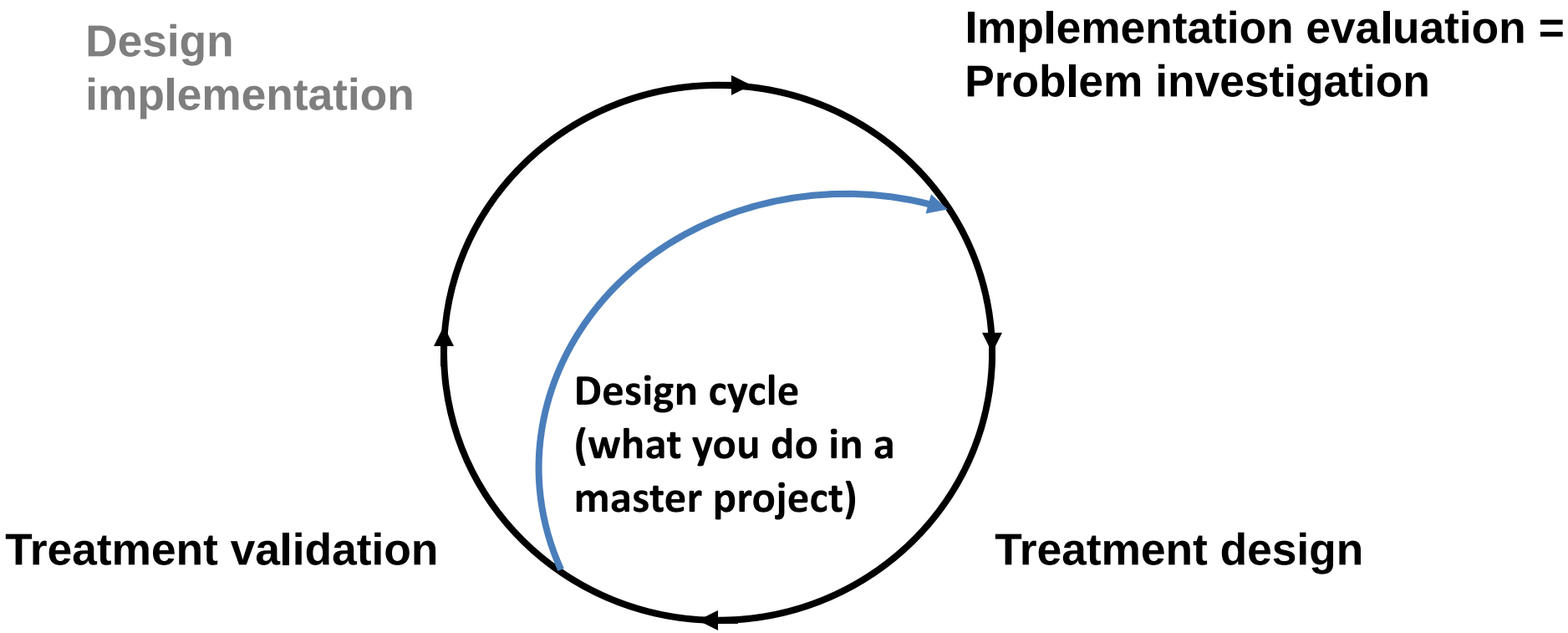
- Depends on who you talk to
  - *For a software engineer, this is writing and debugging a program until it works.*
  - *For a mechanical engineer, this is assembling the physical machine until it works*
  - *For the manager, this is introducing the machine in the organization until it works*
  - *For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

Implementation

- **Implementation** = introducing an artifact in the 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



- Design research projects iterate one or more times through the design cycle.

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

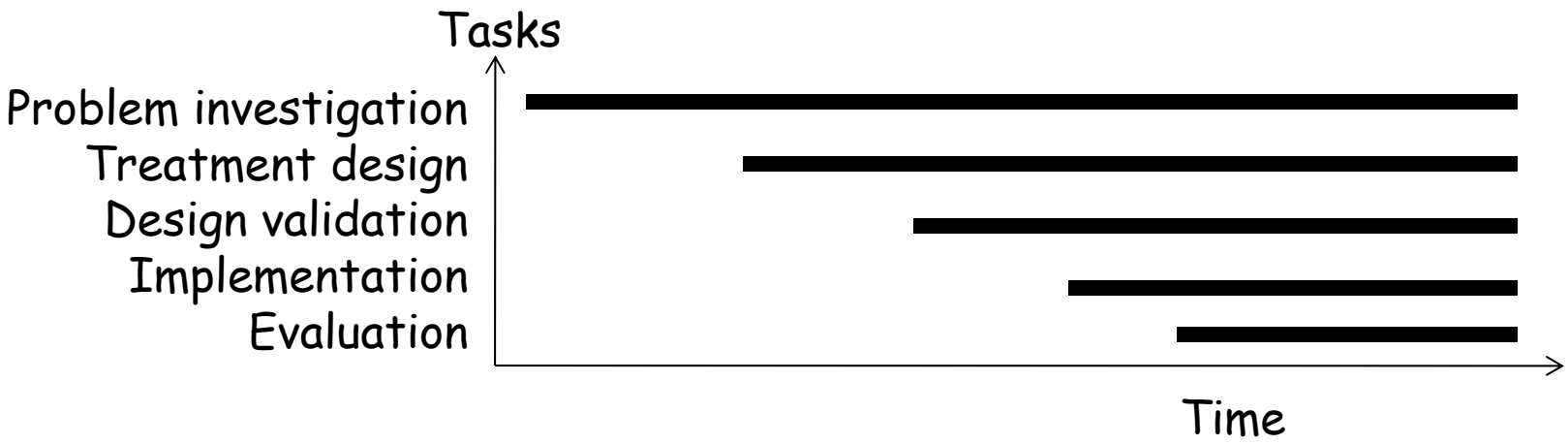
3.2 Design and engineering processes

- 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



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

However, you have to manage yourself ☺

Main points chapter 3
The design cycle

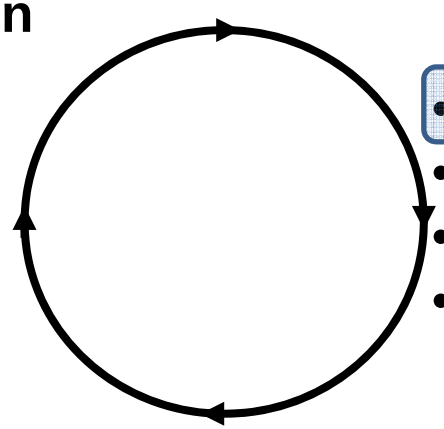
- The engineering cycle is a rational decision cycle:
  - Problem/evaluation: Look where you are and what you want to do;
  - Design possible treatments;
  - Validate treatments without executing them;
  - Choose one and do it;
  - Evaluation/problem: Look where you are and what you want to do.
- The 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)

4. Stakeholder and Goal Analysis

Engineering cycle

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

Design implementation



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- Available treatments?
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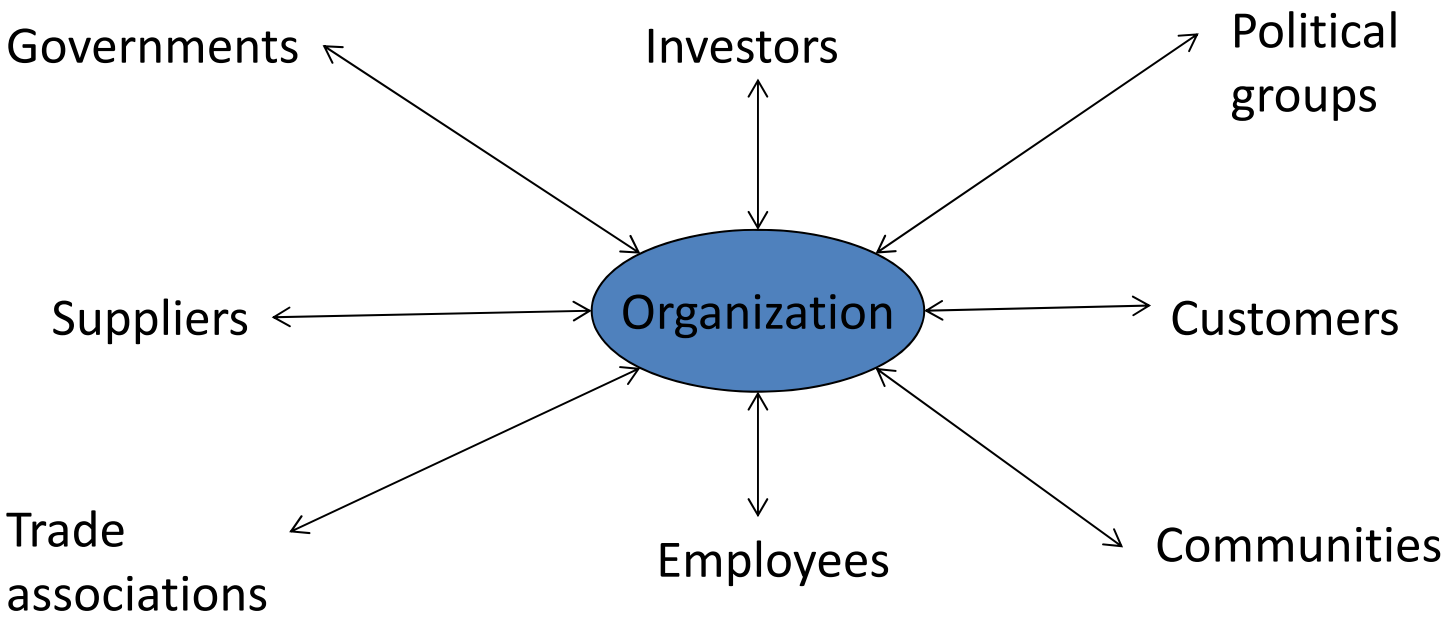
4.1 Stakeholders

Stakeholders

- A **stakeholder** of a problem is a biological or legal person affected by treating a problem.
  - *People, organizations, job roles, contractual roles, etc.*

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

- *Ucare: Design a system that provides health care support for elderly people at home.*
  - *Services:*
    - *Medicine dispensing*
    - *Blood pressure monitoring*
    - *Agenda*
    - *Remote medical advice*
- *Your project*

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 interested enough to commit resources (money, time)

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

Indifferences, Desires, Fears

Stakeholder makes resources (time, money) available

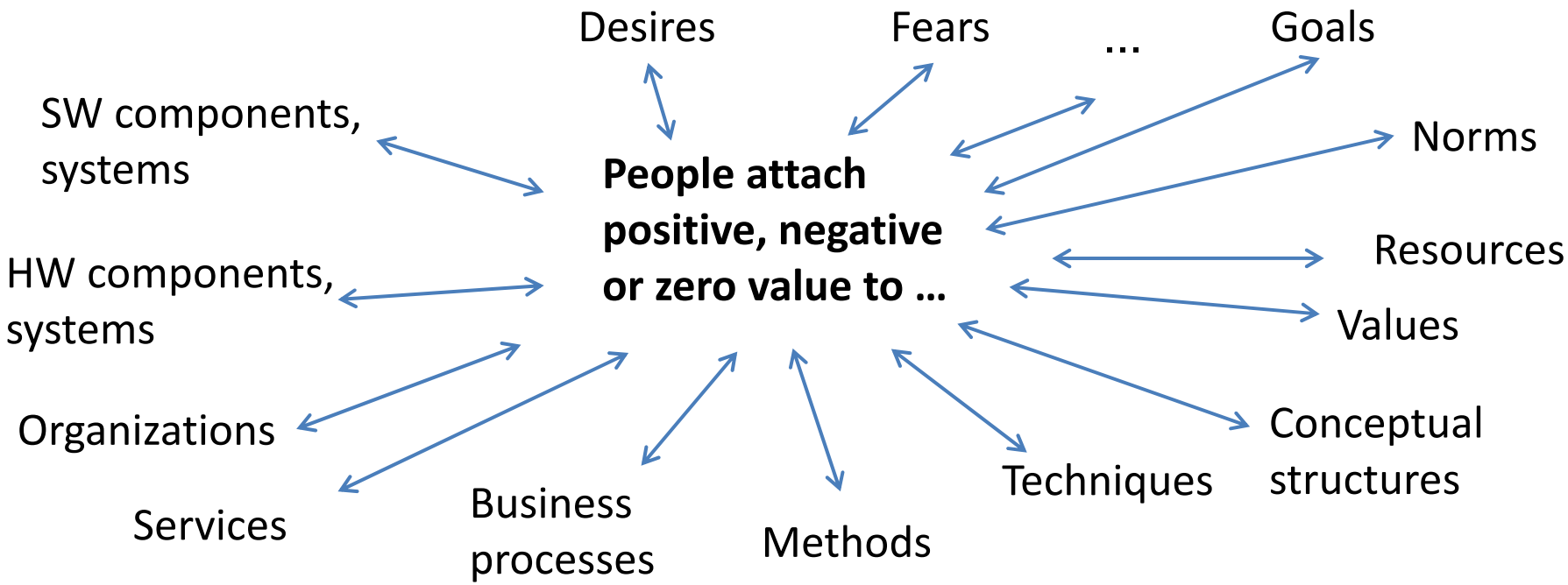
Aware & Committed:
Resources committed to act for a goal

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

Goals

- 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

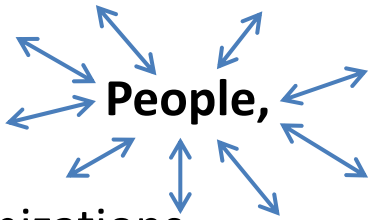
Anything can be the object of desire, fear or indifference



- 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

Problem context

SW components & systems,
HW components & systems,



Organizations,
Business processes,
Services,
Methods, Techniques,
Conceptual structures,
Values, Desires, Fears,
Indifferences, Goals, Norms,
Resources, ...

Interaction

Artifact

SW component, system,
HW component,
system,
Organization,
Business process,
Service,
Method,
Conceptual structure,
...

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.

Main points chapter 4
Stakeholder and goal analysis

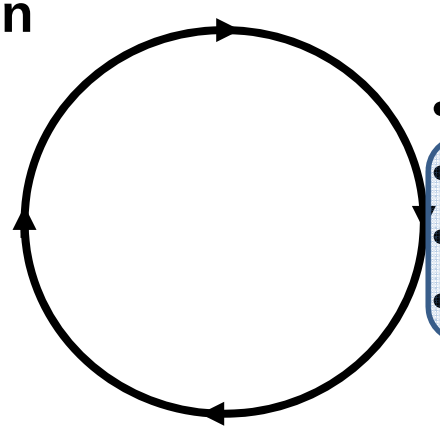
- A **stakeholder** of a problem is a biological or legal person affected by treating a problem
  - Positively or negatively affected
  - There are checklists of possible stakeholders
- A **goal** of a stakeholder is a *desire* to the realization of which the stakeholder has *committed* resources (time,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

5 Implementation Evaluation and Problem Investigation

Engineering cycle

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

Design implementation



Implementation evaluation = Problem investigation

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

Design 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 top-level goals

- **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*

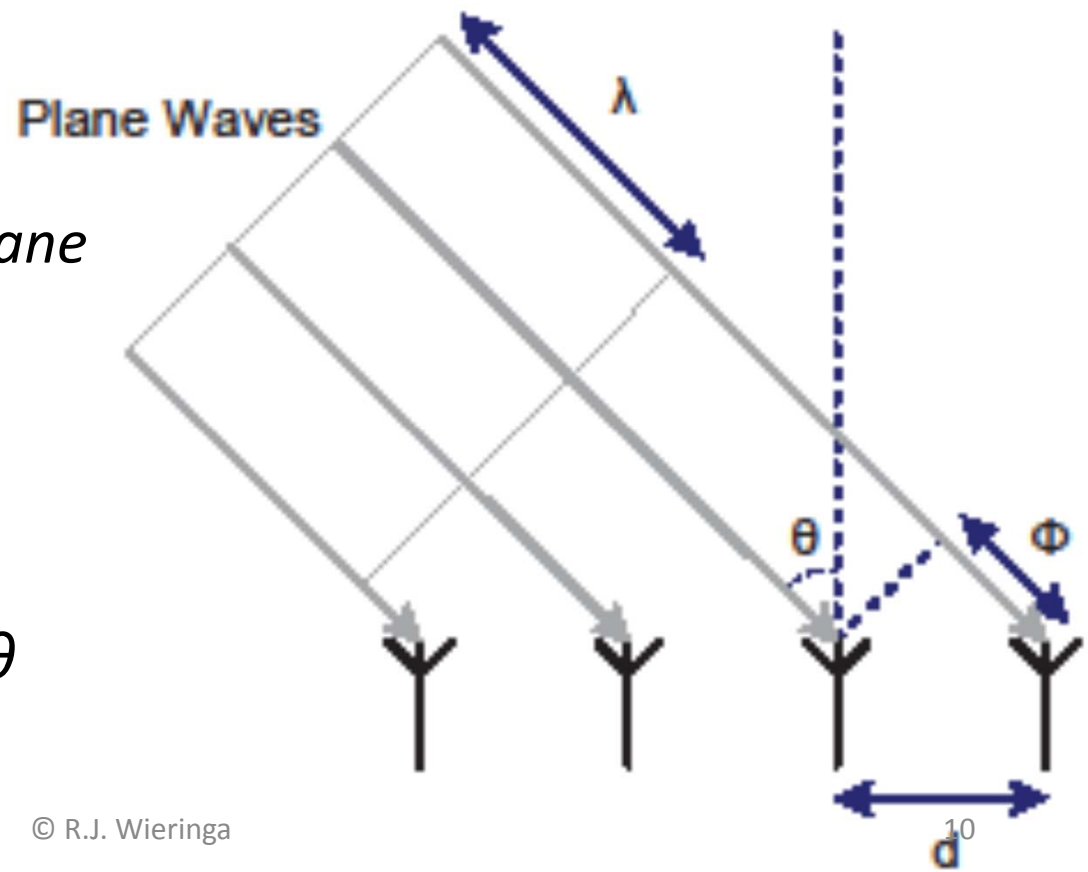
Problem theories

- 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*
  - *…*

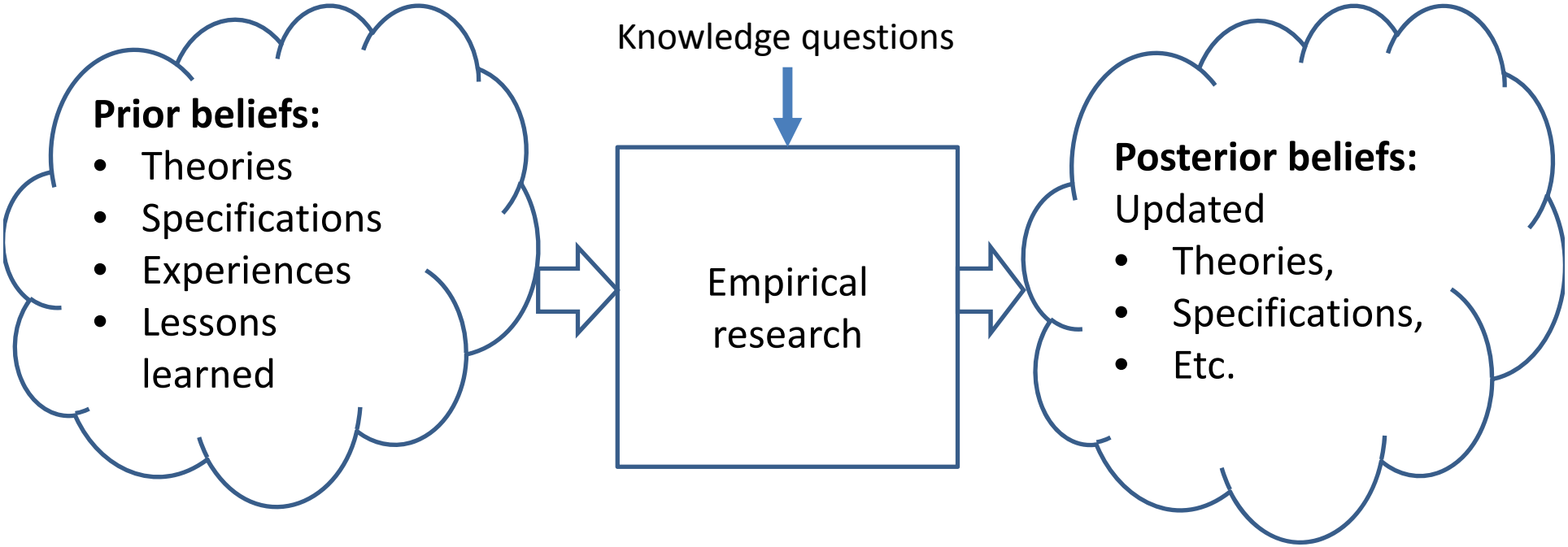
Satellite TV reception system for a car, contains an antenna array. Problem to be solved by a software system: recognize direction of arrival of plane waves.

Problem theory:



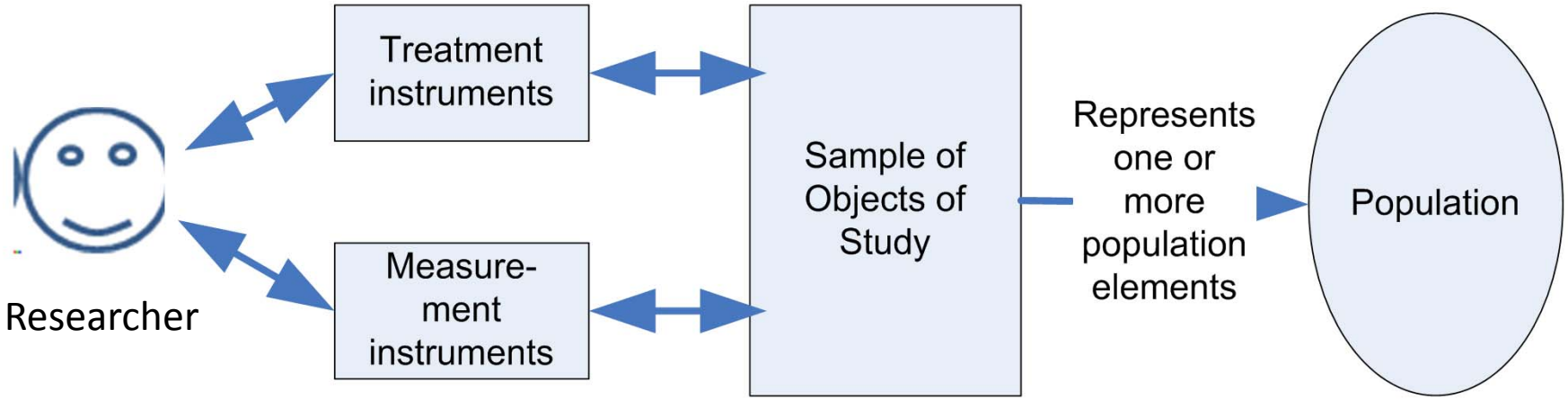
- *Definitions of concepts: Plane waves, wave length, bandwidth, etc.*
- *Generalization about the problem: $\varphi = 2\pi\,(d/\lambda)\sin\theta$*

5.3 Research Methods



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

The empirical research setup



You

The instruments that you need to provide input to the OoS and to collect data

The laboratory simulations or field cases that you want to study

All problems similar to the one you want to treat

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

Surveys

- **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.
- Generalization by statistical inference

- E. Babbie – *The Practice of Social Research.* 11th Edition, 2007. Chapter 9.
- C. Robson. *Real World Research.* 2nd Edition. 2002. Chapters 8 (Surveys) and 9 (Interviews)
- P. Runeson et al. *Case Study Research in Software Engineering.* 2012. Chapter 4 (Interviews and Focus Groups)

Observational case studies

- **Observational case study** of instances of an implementation or problem (small sample)
  - *Case study of power politics in the decision about acquisition of an ERP system*
  - *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.
- Generalization by analogy

- Chapter 17

Single-case mechanism experiments

- In a **single-case mechanism experiment,** we test a social or technical system
  - *Software testing*
  - *Investigating a patient*
  - *Simulation of a real-world system*
  - *Penetration-testing the security of existing systems*
- Useful to describe the behavior of implemented technology, and to understand this in terms of underlying mechanisms
- Generalization by analogy
- Chapter 18

Statistical difference-making experiments

- In **statistical difference-making experiments**, we investigate whether in a sample, a difference in an independent variable X makes a difference to a dependent variable Y that can be generalized to the population.
  - *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*
- Generalization by statistical inference
- Chapter 20

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

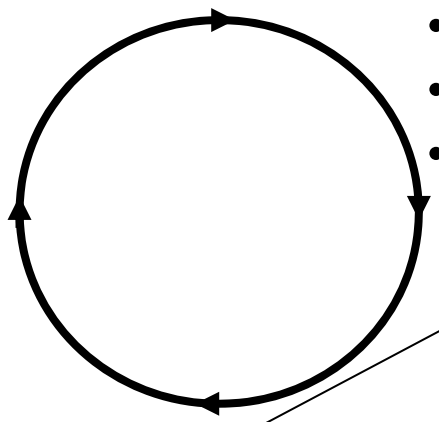
7 Treatment Validation

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

Engineering cycle

Design implementation

Implementation evaluation = Problem investigation



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

Design 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!

7.1 The validation research goal

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

- *Validation research questions*
  - *Functions*
    - *Does it perform the medicine dispensing functions?*
    - *Does it perform the blood pressure monitoring functions?*
    - *Etc.*
    - *Etc.*
  - *Is it usable by elderly and medical personnel?*
  - *Is it reliable?*
  - *Is it safe?*
  - *Is it cheap?*

Follow-up questions:

- *Does this satisfy our requirements?*
- *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

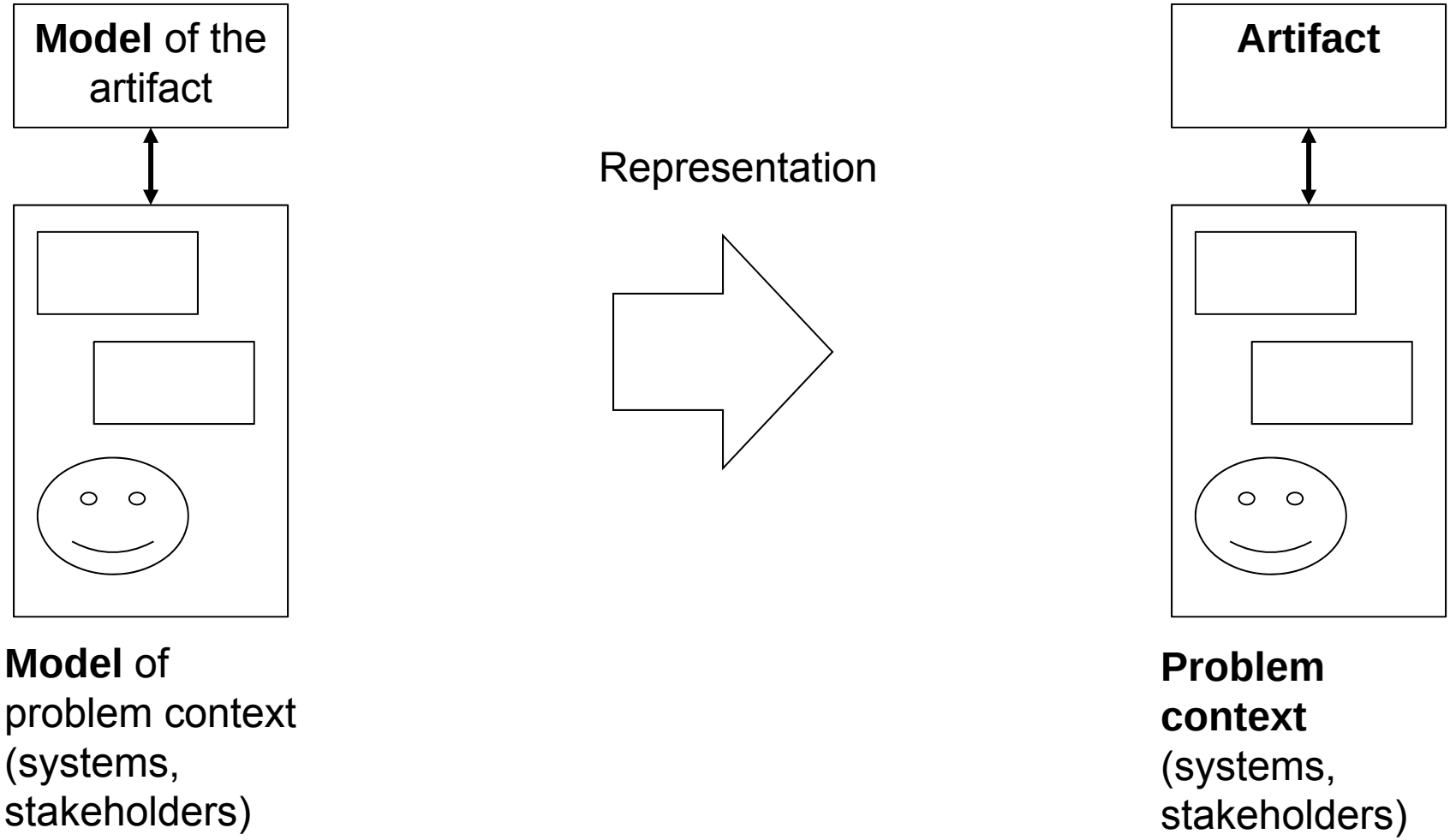
The fundamental problem of validation

- 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



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 not block the transfer of conclusions

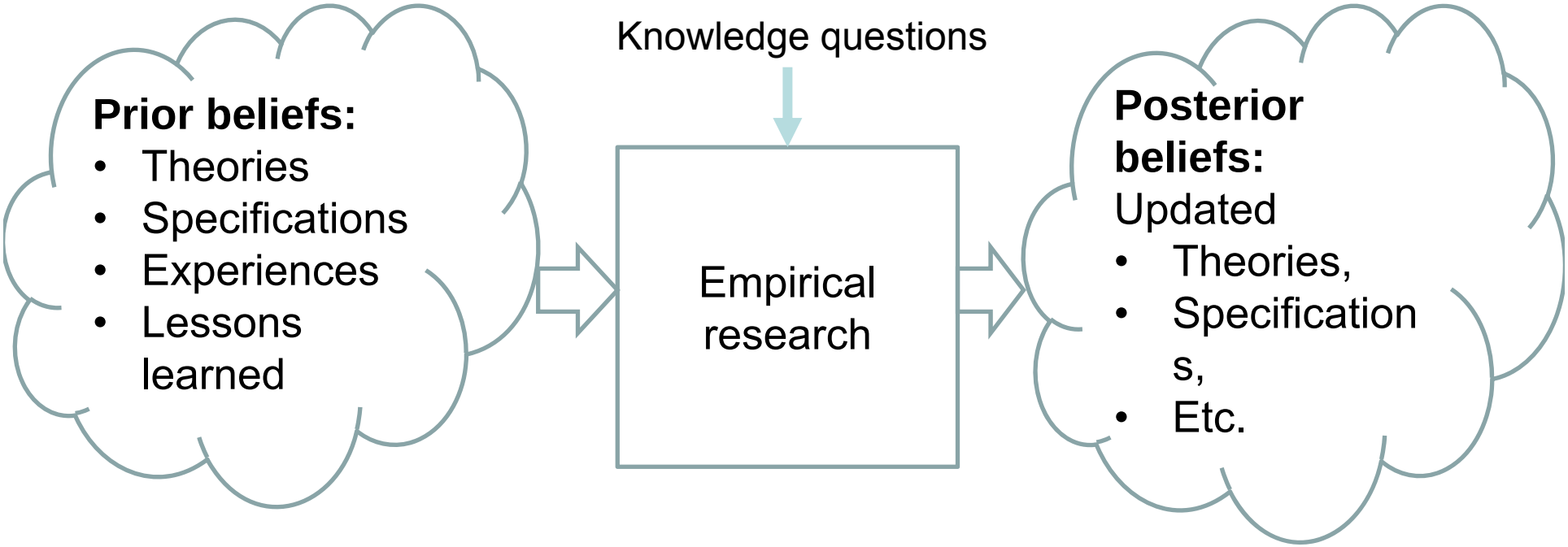
7.3 Design theories

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


Knowledge questions
Prior beliefs:
• Theories
• Specifications
• Experiences
• Lessons learned
Empirical research
Posterior beliefs:
Updated
• Theories,
• Specifications,
• Etc.

Kinds of empirical research methods

- The methods in bold are useful for validation research

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

- Researcher asks practitioners about perceived usability and utility of new artifact in the contexts that they know first-hand.
  - Interview and/or
  - Questionnaire and/or
  - Focus group
- Purpose is to weed out unrealistic ideas.
- Example
  - *Expert opinion of nurses about U-Care functionality*

Single-case mechanism experiments

(a.k.a. simulations)

Mechanism experiment

- Single-case mechanism experiments are simulations, tests etc.
  1. Build a validation model
  2. Experiment with it
  3. Describe and explain results
  4. Generalize by analogy to similar cases
- Examples
  - *Testing a software prototype of ucare using your colleagues*

Technical action research

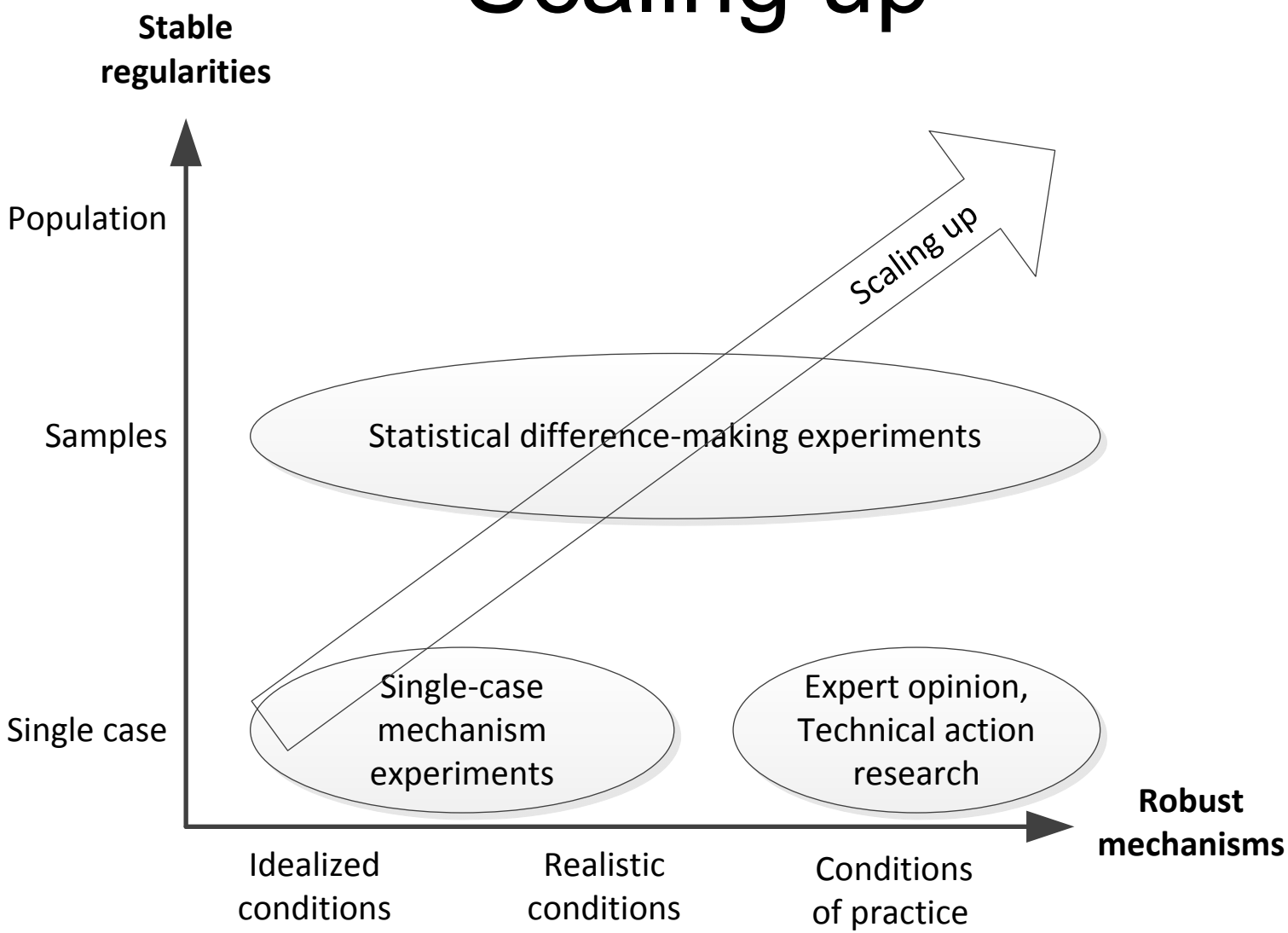
Technical action research (TAR)

- TAR
  1. Build an artifact prototype and acquire a client
  2. Treat the client's problem with the artifact
  3. Describe and explain results
  4. Generalize by analogy to similar cases
- Examples
  - *Test a prototype of Ucare with volunteers in a home for the elderly*

Statistical difference-making experiments

7.4 Scaling up

Scaling up



Main points chapter 7
Treatment validation

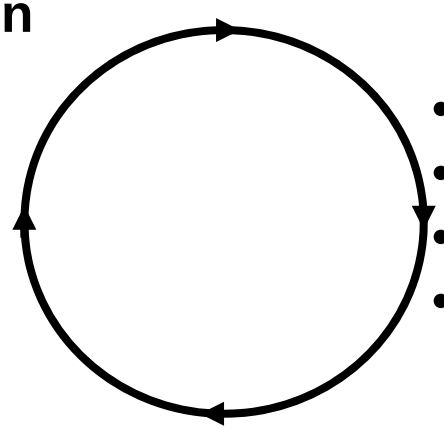
- Validation is a prediction problem
  - What would be the effect of artifact in context?
  - Trade-offs in design of artifact?
  - Sensitivity to changes in context?
  - Satisfaction of requirements?
- Use validation models to build a design theory of A x C;
- Then use design theory to do predictions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

6. Requirements Specification

Engineering cycle

! = Action
? = Knowledge question

Design implementation



Implementation evaluation = Problem investigation

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Design validation

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- 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!

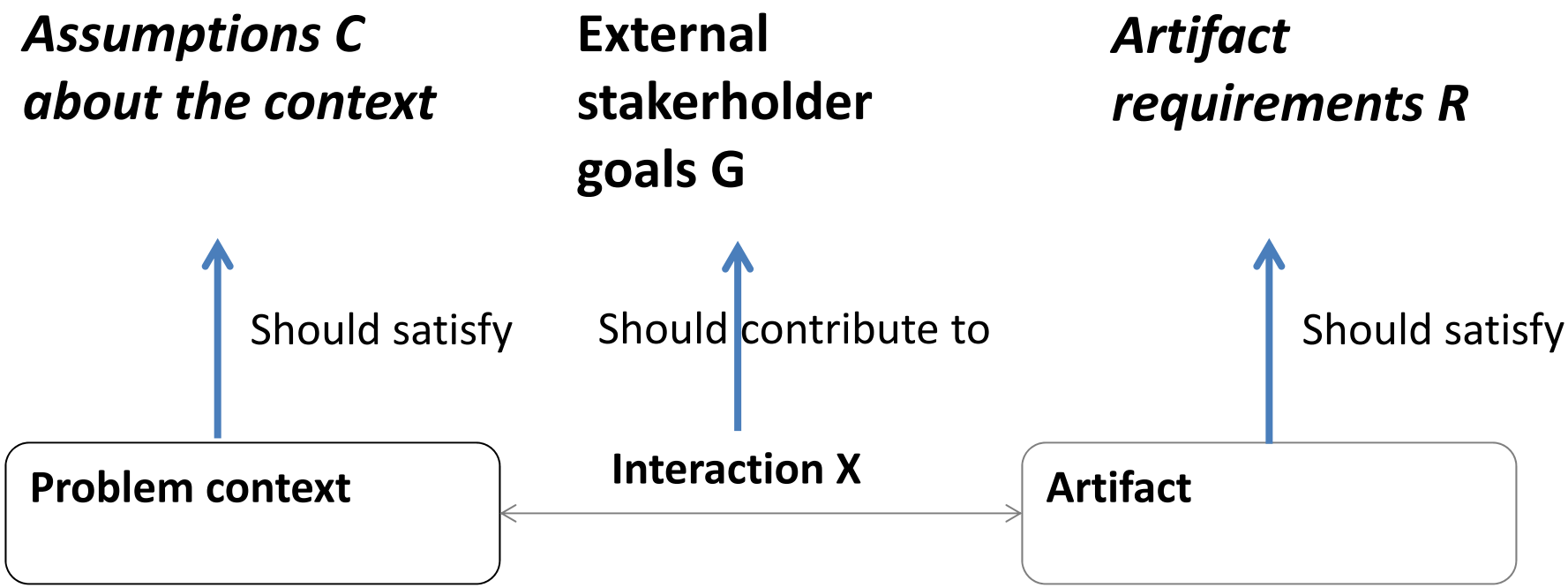
6.1 Requirements

- **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

- 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)*

Examples

- *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 evaluated 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?)

Kinds of artefact requirements (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

Examples

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

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*

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)
- **Functional requirements** are desired functions
- **Nonfunctional requirements** (quality properties)
  - Accuracy, efficiency, security, safety 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