Design Science Research in Information Systems and Software Systems Engineering

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Outline

- Design science
  - Research problems
- Design theories
  - Design research methods

- R.J. Wieringa. *Design Science Methodology for Information Systems and Software Engineering*. Springer. http://www.springer.com/gp/book/9783662438381
- Slides at http://wwwhome.ewi.utwente.nl/~roelw/

Outline

- **Design science**
  - Research problems
- Design theories
  - Design research methods

- Design science is the design and investigation of artifacts in context
- A.k.a engineering science,
- Technical science

Engineering science

Technical science

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

Subjects of design science

Problem context:

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

Interaction

Artifact:

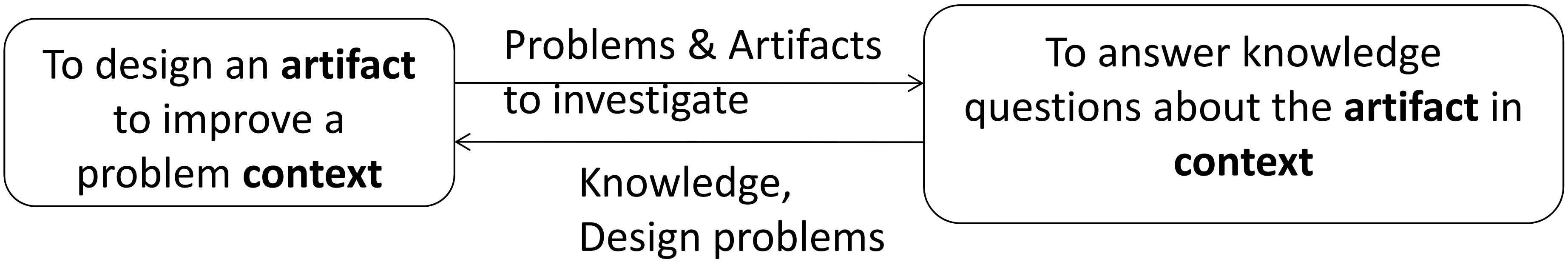
SW component/system,
HW component/system,
Organization,
Business process,
Business roles,
Service,
Method, Technique,
Conceptual structure,
...

Something to be influenced

Something to be designed

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

Research problems in design science



The design researcher iterates over these two activities

Research problems in design science

To **design** an artifact to improve a problem context

Problems & Artifacts to investigate

Knowledge, Design problems

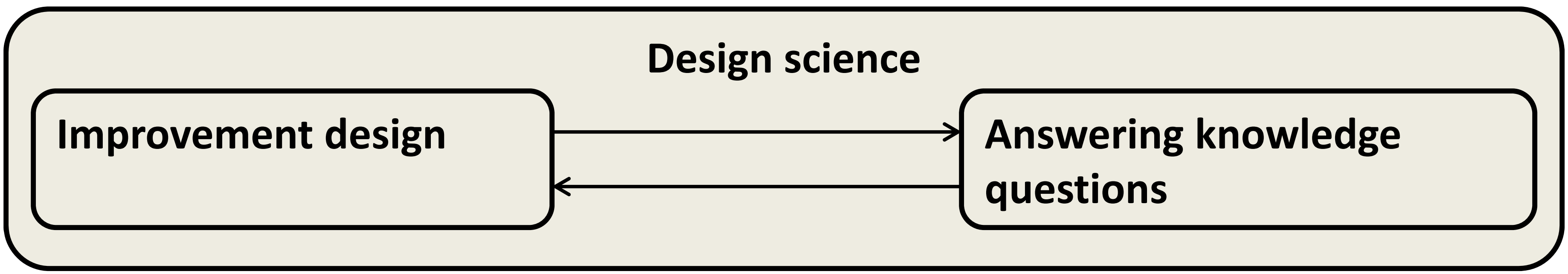
To answer **knowledge** questions about the artifact in context

- *"Design a DoA estimation system for satellite TV reception in a car."*
- *"Design a multi-agent aircraft taxi-route planning system for use on airports"*
- *"Design an assurance method for data location compliance for CSPs"*

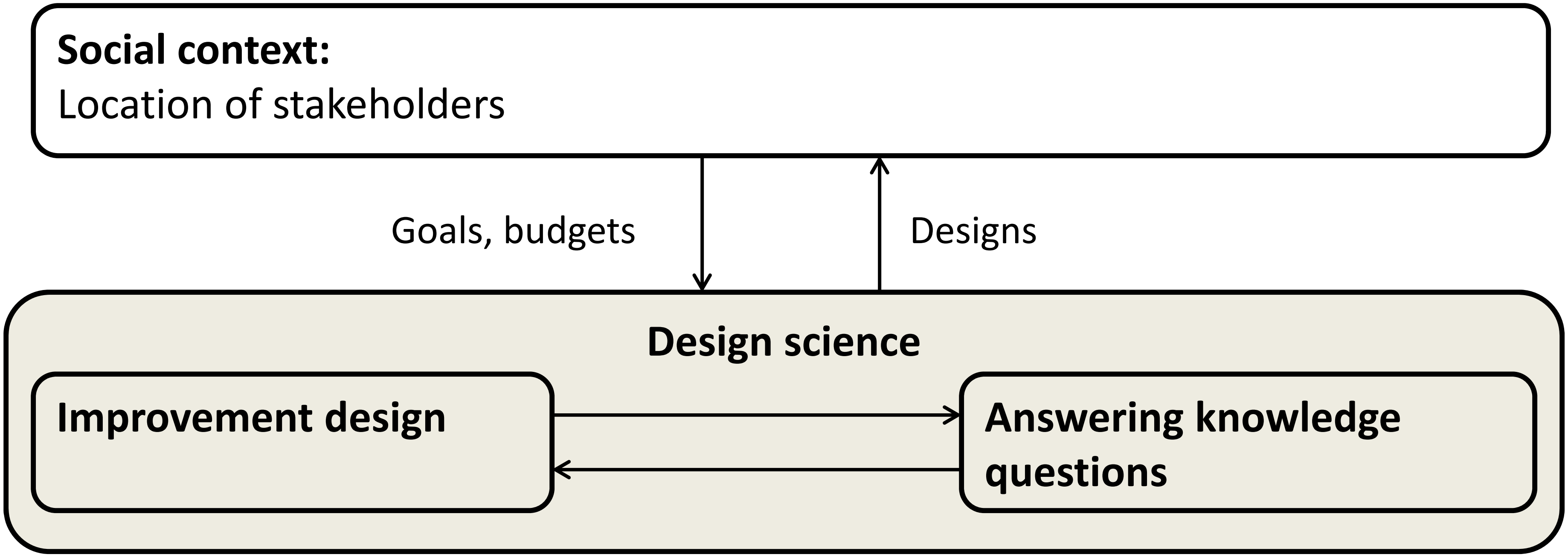
- *"Is the DoA estimation accurate enough?"*
- *"Is this agent routing algorithm deadlock-free?"*
- *"Is the method usable and useful for cloud service providers?*

The design researcher iterates over these two activities

The context of design research



The context of design research



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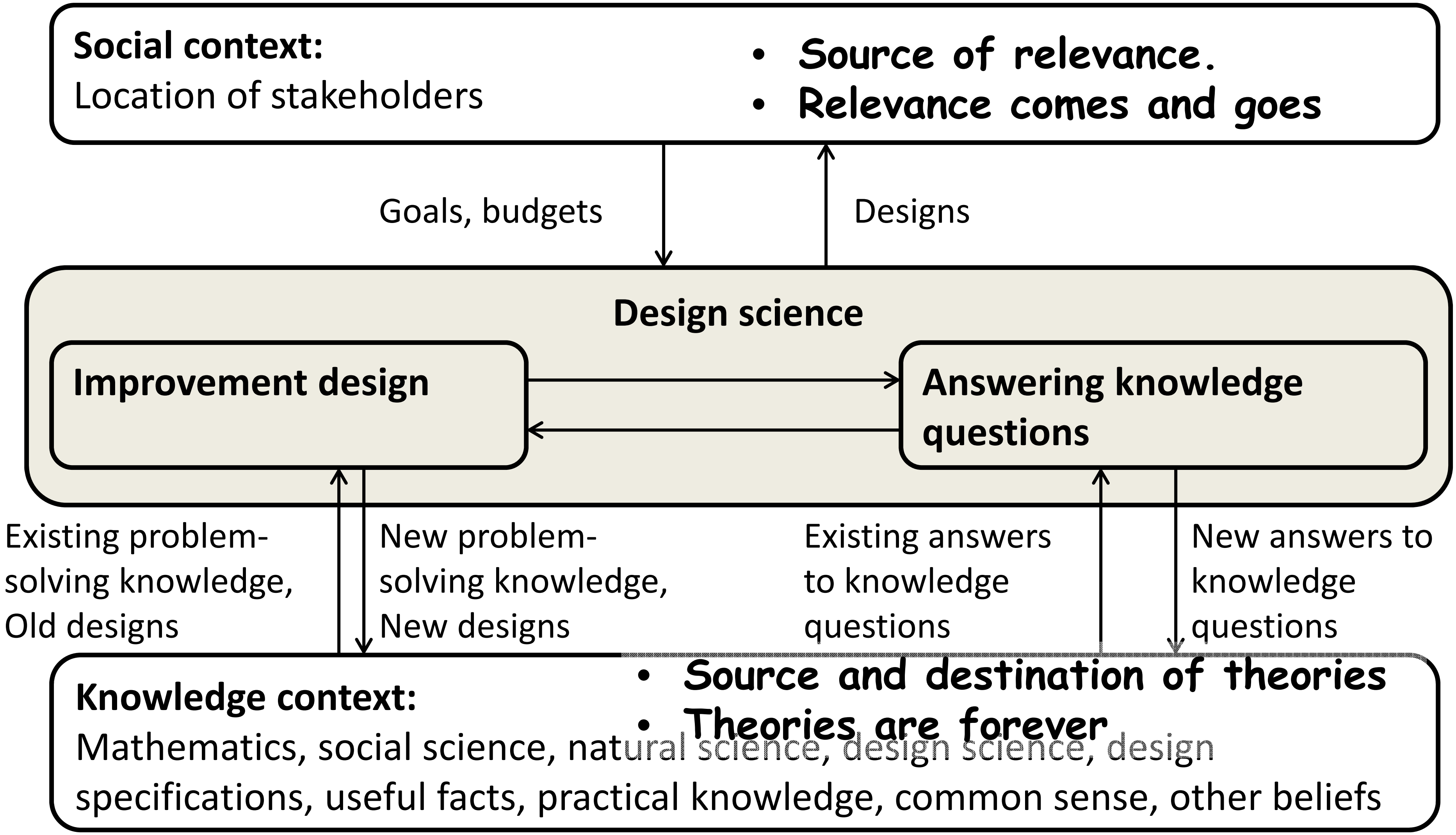

Outline

- Design science
  - **Research problems**
- Design theories
  - Design research methods

Two kinds of research problems

- Design problems
- Knowledge questions

Template for design problems

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

- *Reduce my headache*
- *by taking a medicine*
- *that reduces pain fast and is safe*
- *in order for me to get back to work*

Template for design problems

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Stakeholder language:
Problem context and stakeholder goals.

Template for design problems

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Technical language:
Artifact and its desired properties.

Template for design problems

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- *Reduce my headache*
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- *Improve the course admin*
- *By integrating with student admin*
- *Such that less data need be entered*
- *In order to reduce workload*

A problem in science communication

- Design problems are usually not considered to be research problems
- They are stated in the form of questions
  - *How to plan aircraft taxi routes dynamically?*
  - *Is it possible to plan aircraft routes dynamically?*
  - *Etc.*
- This way, stakeholders, goals, and requirements stay out of the picture!

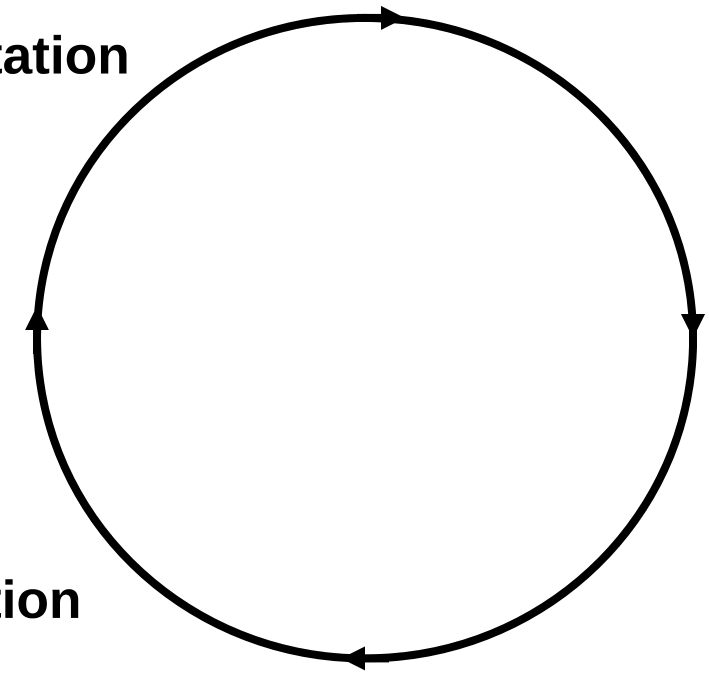
Legend: *Knowledge questions?* *Actions!*

Engineering cycle (a.k.a. regulative cycle)

Design implementation

Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes? Effects?
- Effects contribute to Goals?



Design validation

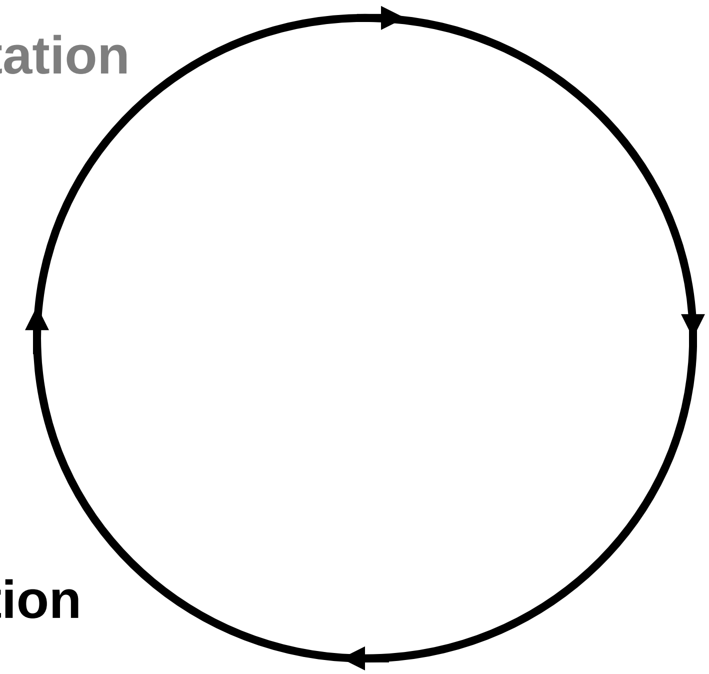
- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design

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

Implementation (transfer to problem context) is not part of research if the problem context is society

Design implementation



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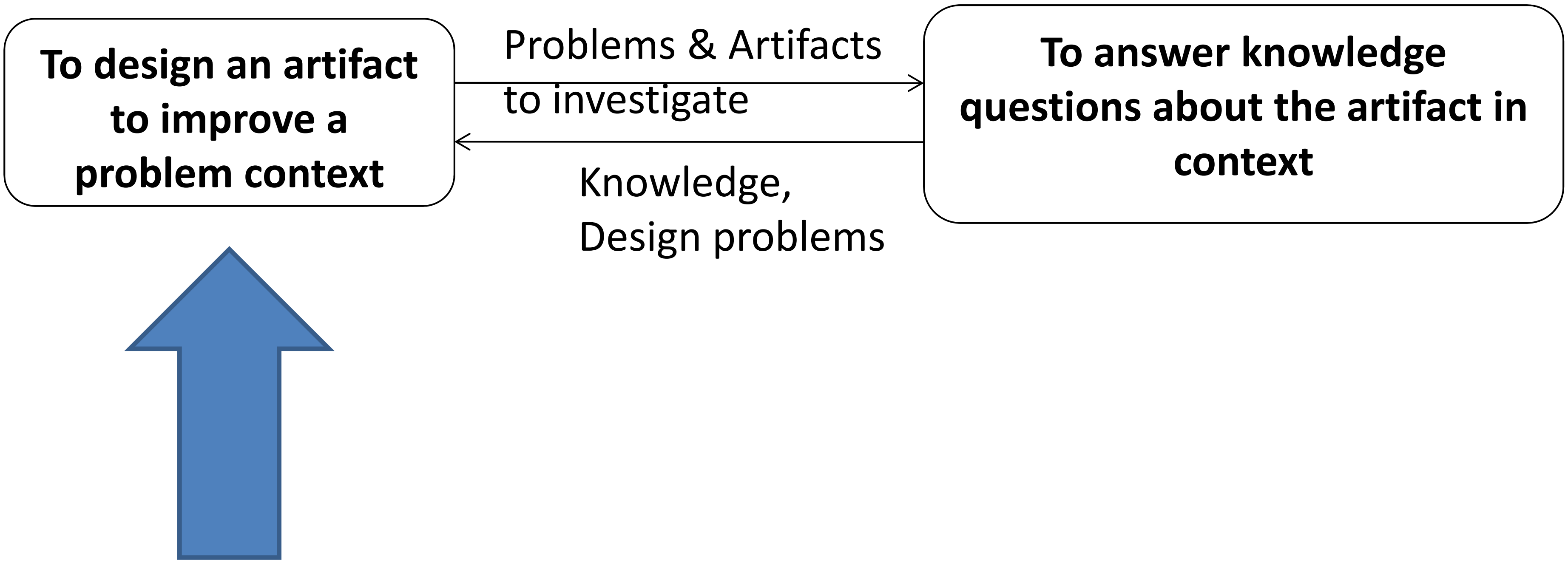
By default, the problem context of a research project is society

- Research projects may focus on
  - Implementation evaluation
  - Problem investigation
  - Treatment design and validation

Research problems in design science



Knowledge questions in (any) science

- Descriptive questions:
  - What happened?
  - When?
  - Where?
  - What components were involved?
  - Who was involved?
  - etc.
- Explanatory questions:
  - Why?
    - What has **caused** the phenomena?
    - Which **mechanisms** produced the phenomena?
    - For what **reasons** did people do this?

Journalistic questions.
Yield facts.

Beyond the facts.

- *Descriptive question: What is the performance of this program?*
  - *Execution time for different classes of inputs*
  - *Memory usage*
  - *Accuarcy,*
  - *Etc. etc.*
- *Explanatory question: Why does this program have this performance?*
  1. *Cause: because it received this input (and not anothyer input)*
  2. *Mechanism: because it has this architecture with these components*
  3. *Reasons: Because users use it for tasks for which it was not intended*

Effect questions

- Central effect question
  - **Effect question:** Context X Artifact → Effects?
  - Descriptive or explanatory
- Generalizations
  - **Trade-off question:** Context X ***Alternative artifact*** → Effects?
  - **Sensitivity question:** ***Other context*** X artifact → Effects?
  - Descriptive or explanatory

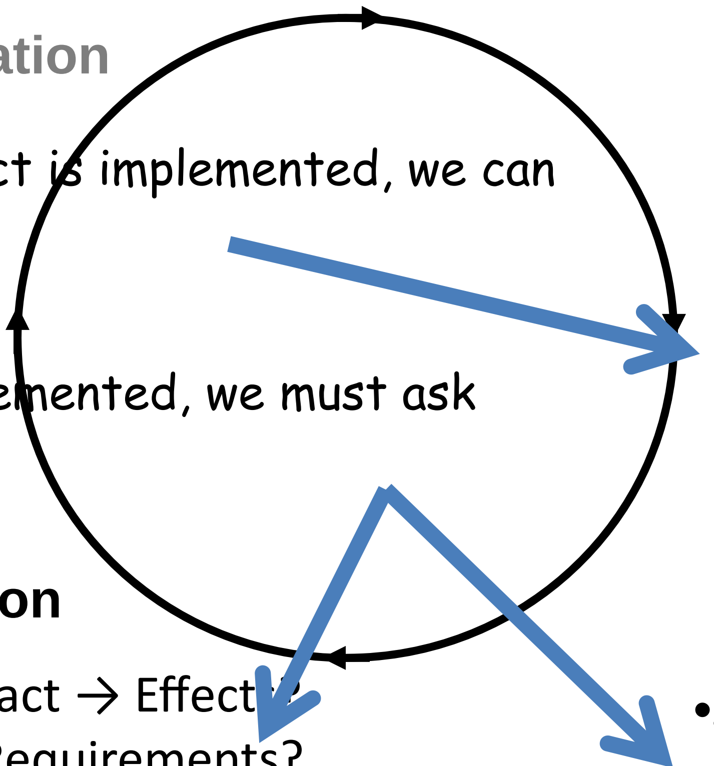
Contribution questions

- Preliminary questions:
  - **Stakeholder question:** Who are the stakeholders?
  - **Goal question:** What are their goals?
  - Descriptive or explanatory
- Central contribution question:
  - **Contribution question:** Do Effects contribute to Stakeholder goals?
  - Descriptive or explanatory

Example knowledge questions

- ***Effect:***
  - *What is the execution time of the DoA algorithm?*
  - *What is its accuracy?*
- ***Trade-off:***
  - *Comparison between algorithms on these two variables*
  - *Comparison between versions of one algorithm*
- ***Sensitivity:***
  - *Assumptions about car speed?*
  - *Assumptions about processor?*
- ***Stakeholders:***
  - *Who are affected by the DoA algorithm?*
- ***Goals:***
  - *What are their goals?*
- ***Contribution evaluation (after DOA algorithm is in use)***
  - *How well does the DoA algorithm contribute to these goals?*

Societal implementation (transfer to societal problem context) is not part of research



Design implementation

After the artifact is implemented, we can ask this question

Before it is implemented, we must ask these questions

Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes? Effects?
- Effects contribute to Goals?

Design validation

- Context & Artifact → Effects?
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Treatment design

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Outline

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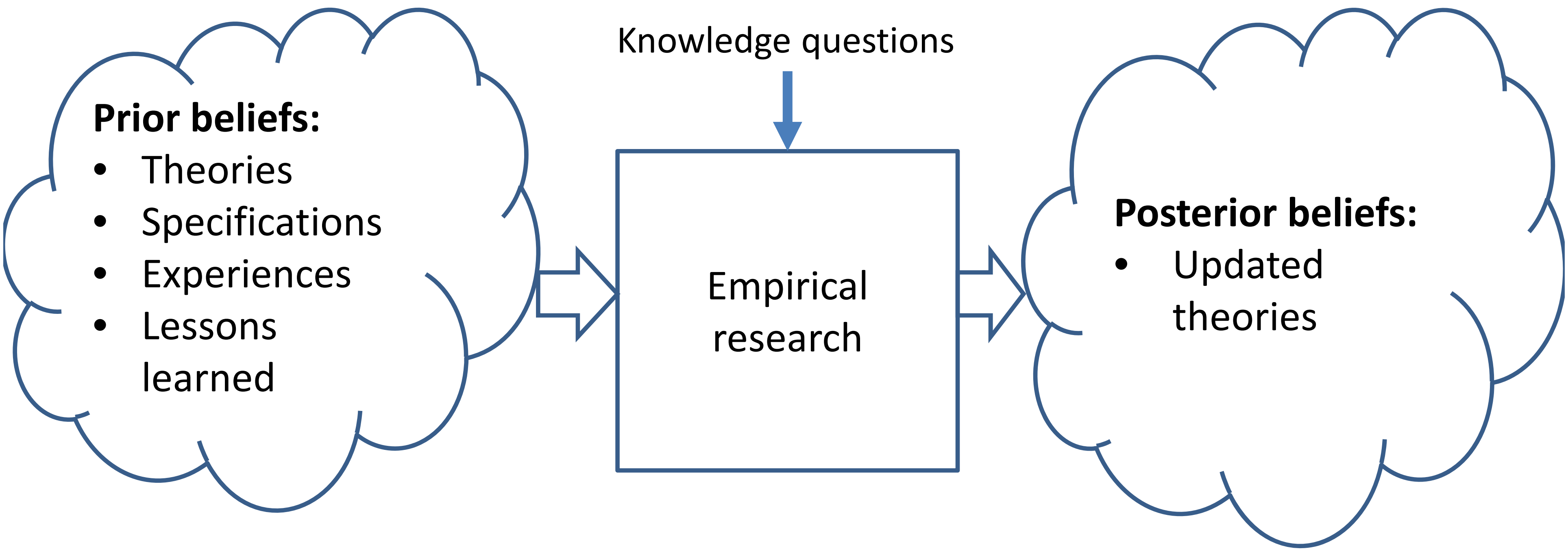
  – Research problems
- **Design theories**
  – Design research methods

Empirical research



- The goal of empirical research is to develop, test or refine theories
- We never start empty-handed

- A **theory** is a belief that there is a pattern in phenomena
  - Speculations
  - Opinions
  - Ideologies
  - …
- A **scientific** theory is a theory that
  - Has survived tests against experience
  - Has survived criticism by critical peers
- All theories about the real world are fallible

The structure of scientific theories

1. **Conceptual framework**
   - Constructs to frame, describe, specify, analyze, generalize about phenomena
   - Descriptions can be case-based or sample-based
2. **Generalizations** about patterns in phenomena
   - Statements that explain phenomena.
   - Explanations can be causal, architectural, or rational
   - Scope.

The structure of

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The structure of design theories

1. **Conceptual framework**
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The structure of design theories

1. **Conceptual framework**
   – Constructs to frame, describe, specify, analyze, generalize about ***artifacts in context***
   – Descriptions can be case-based or sample-based
2. **Generalizations** about patterns in phenomena
   – Statements that explain ***interactions between artifact and context*.**
   – Explanations can be causal, architectural, or rational
   – Scope.

The functions of scientific theories

- To **analyze** a conceptual structure
- Use a conceptual structure to **describe** phenomena

- Use generalizations to **explain** phenomena or
- to **predict** phenomena

The functions of scientific theories

- To **analyze** a conceptual structure
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- to **predict** phenomena

- Some phenomena can be explained but could not be predicted
  - *Outcome of elections*
  - *Outcome of organizational change*
  - *Diseases*

- Some phenomena can be predicted without explanation
  - *Performance parameters of a machine*
  - *The weather*

- Designers need at least the ability to predict A & C → E

Statistical theories

- Statistical conceptual framework:
  - Population, variables
  - Probability distributions over the population
- Explanations are causal, causality is difference-making.
  - If a change in X on the average results in a change in Y, then X on the average causes Y.
  - There is an average difference in Y, which can only be attributed to the average difference in X.
- Examples:
  - *DOA descriptive theory: e.g. performance graphs*
  - *DOA causal theory: e.g. change in angle of incidence causes change in phase difference*
  - *Causal theory of agile software development: Introduction of agile development causes customer satisfaction to increase*

History of statistical conceptual structures

- Statistical conceptual frameworks are used in
  - Social sciences: human populations
  - Physics: statistical mechanics
  - Biology: populations of animals, plants
  - Psychology: groups of people
  - Information systems: populations of organizations
  - Empirical software engineering: populations of projects, software engineers

1800
- Population-based statistics (descriptive, including regression)

1900
- Sample-based statistics (statistical inference)

2000
- Very large sample (population)-based statistics

- In the field, the causal influence of X on Y may be swamped by many other causal influences.
  - Lab research (controlled) versus field research (almost no control)
  - Scaling up to practice

Architectural theories

- Architectural conceptual framework
  - Components, capabilities
  - Interactions among components
- Explanations are architectural
  - Phenomenon Y occurred because components C1, …, Cn interacted in this way (technical, social, psychological, biological mechanism)
  - Rational explanations: Actor A did this because A had this goal
- Examples:
  - *DOA mechanistic theory: e.g. input-output relation is explained by structure of the algorithm*
  - *In agile development for SME, the SME does not put customer on-site, because SME resources are limited and focus is on business.*
  - *Introduction of change control board reduces requirements creep.*

History of architectural conceptual structures

- This kind of structure is used in
  - The engineering disciplines: Renaissance machines 1500
  - Astronomy: architecture of solar system; math descriptipon
  - Physics: forces among physical bodies 1600
  - Biology: structure and mechanisms in the body
  - Chemistry: composition and mechanisms of compustion 1800
  - Sociology: structure and mechanisms of of society, organizations,
  - Psychology: cognitive mechanisms 1900
  - Economy: structure and mechanisms of markets
  - Sociology, economy, computer science, Structure & mechanisms of networks and games 2000

- In the field, different mechanisms may interfere, to give unpredictable result (but explainable in individual cases).
  - Lab research versus field research

Hybrid theories

- Investigate a sample (statistical), analyze a few cases in the sample in-depth (architectural)
- Investigate a case (architectural), do a survey within the case (statistical)

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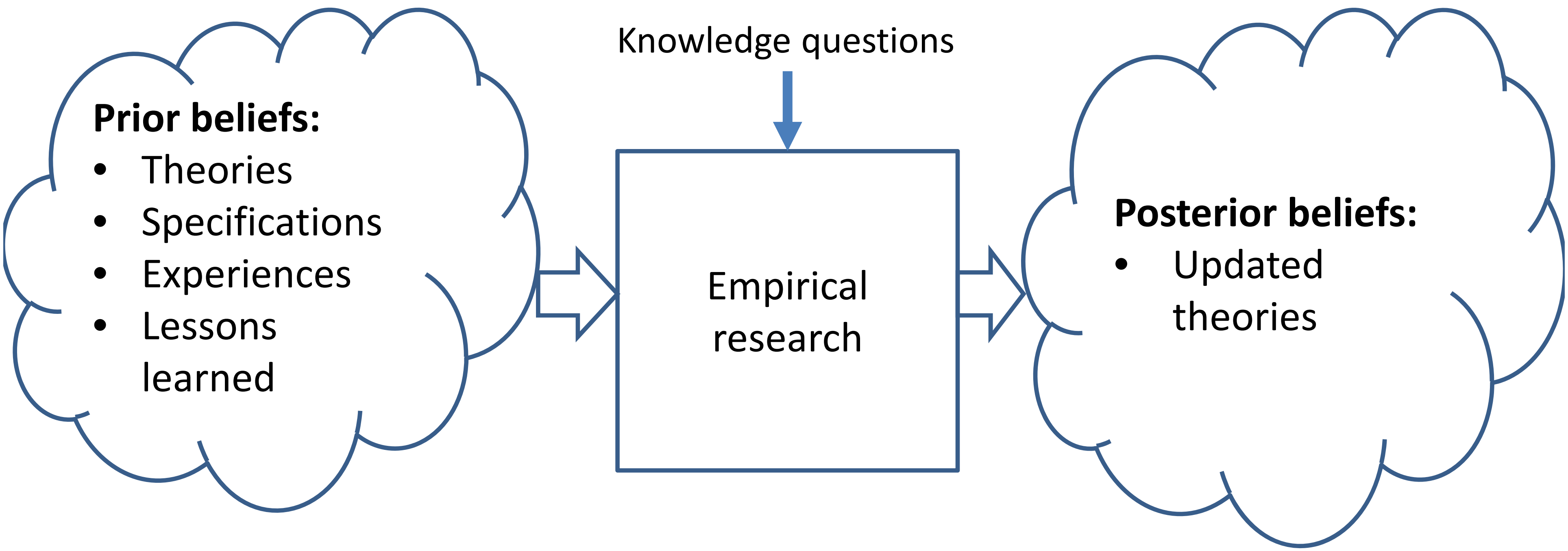
  - **Design research methods**

Empirical research



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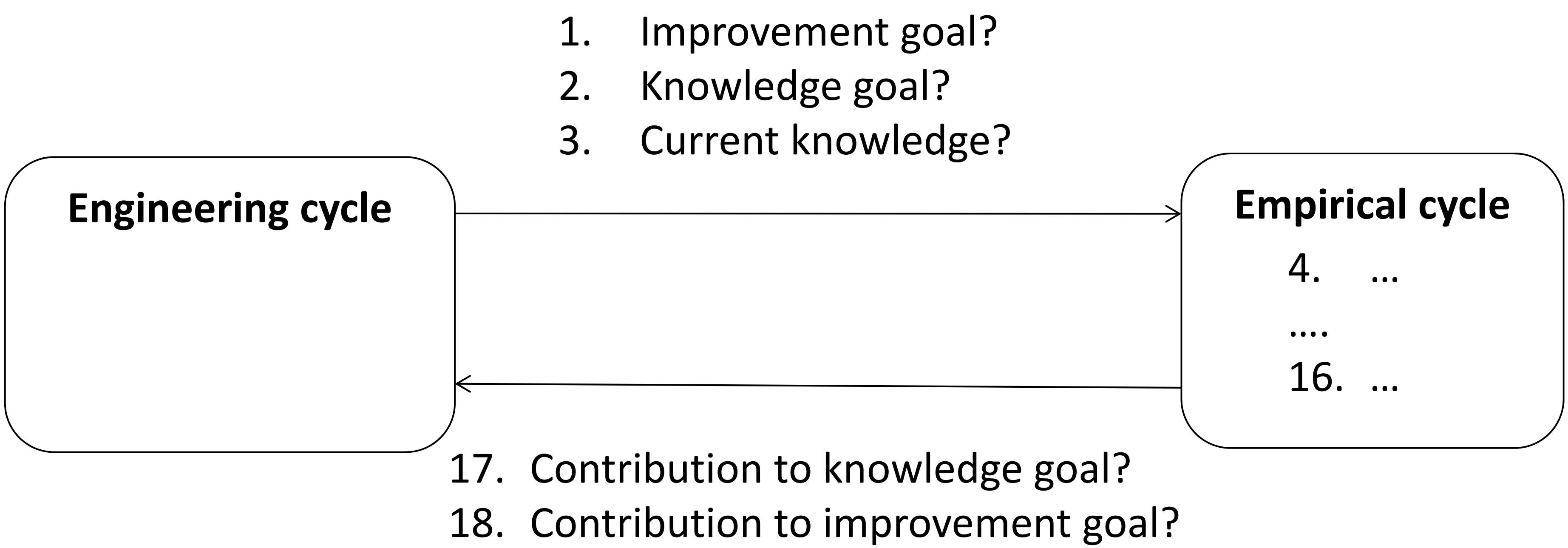
Checklist questions about research context



- A research paper should answer all questions in the checklist.

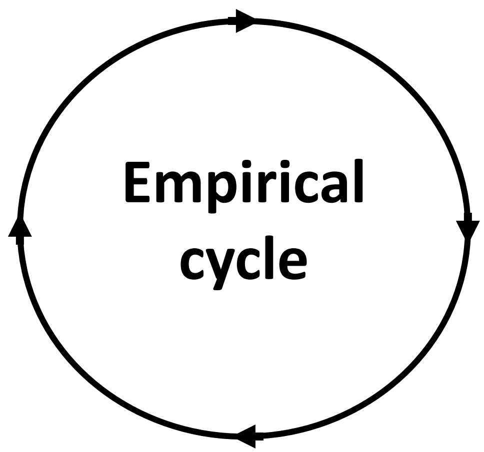
Data analysis

12. Data?
13. Observations?
14. Explanations?
15. Generalizations?
16. Answers?

New research problem

Research execution

11. What happened?



Research problem analysis

4. Conceptual framework?
5. Research questions?
6. Population?

Source of rigor

Validition

7. Validity of Object of study?
8. Validity of treatment specification ?
9. Validity of measurement specification?
10. Validity of inference design?

Research & inference design

7. Object of study?
8. Treatment specification?
9. Measurement specification?
10. Inference?

Data analysis

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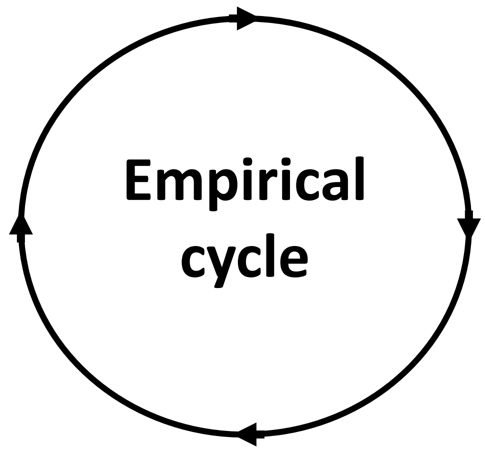

Research problem analysis

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Research & inference design

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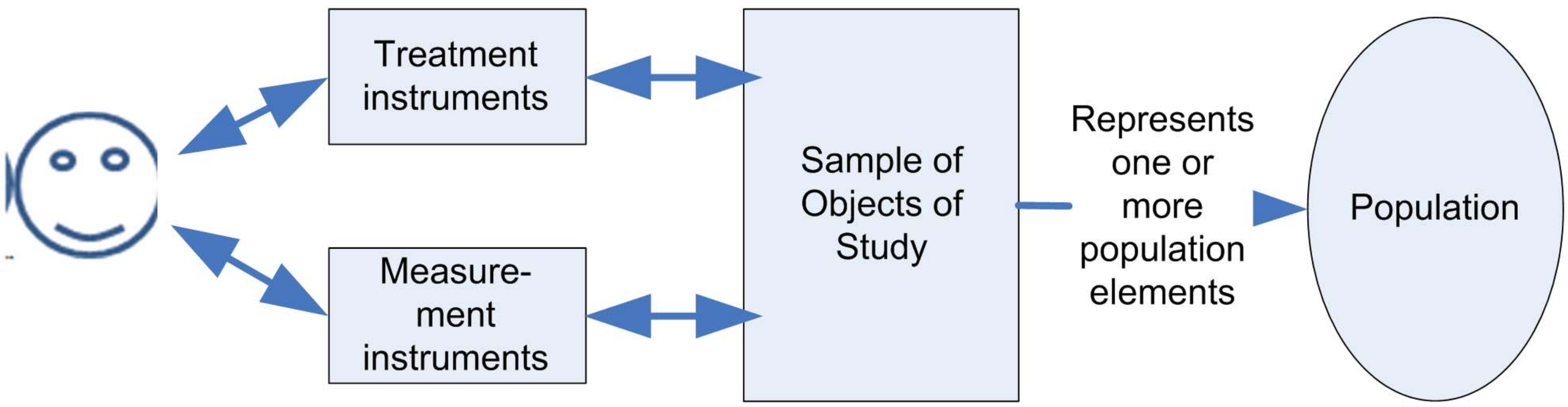
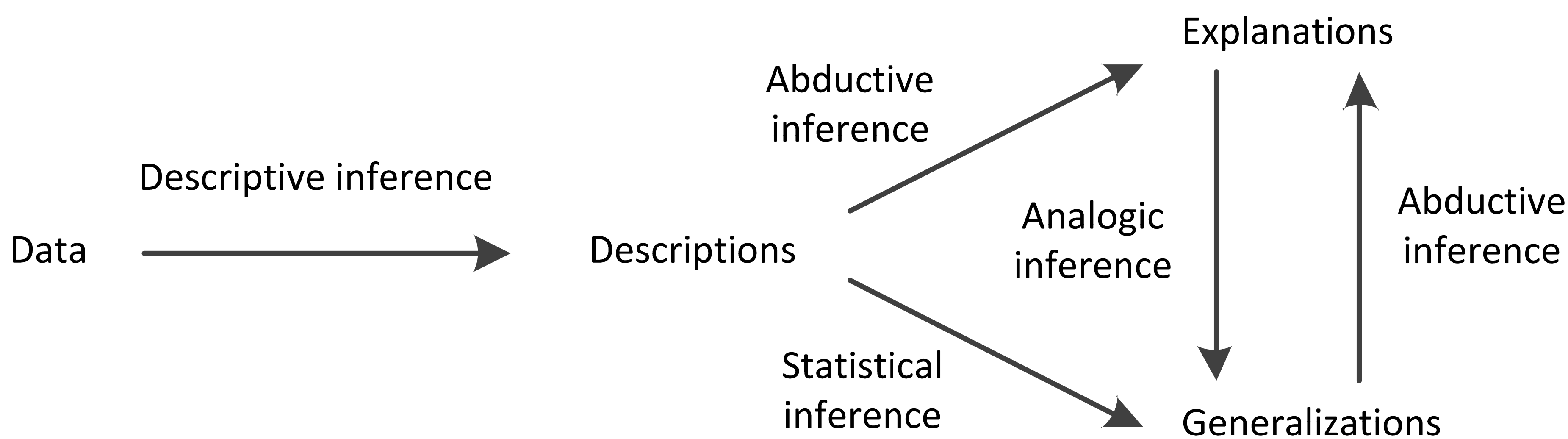
Research setup

The empirical research setup



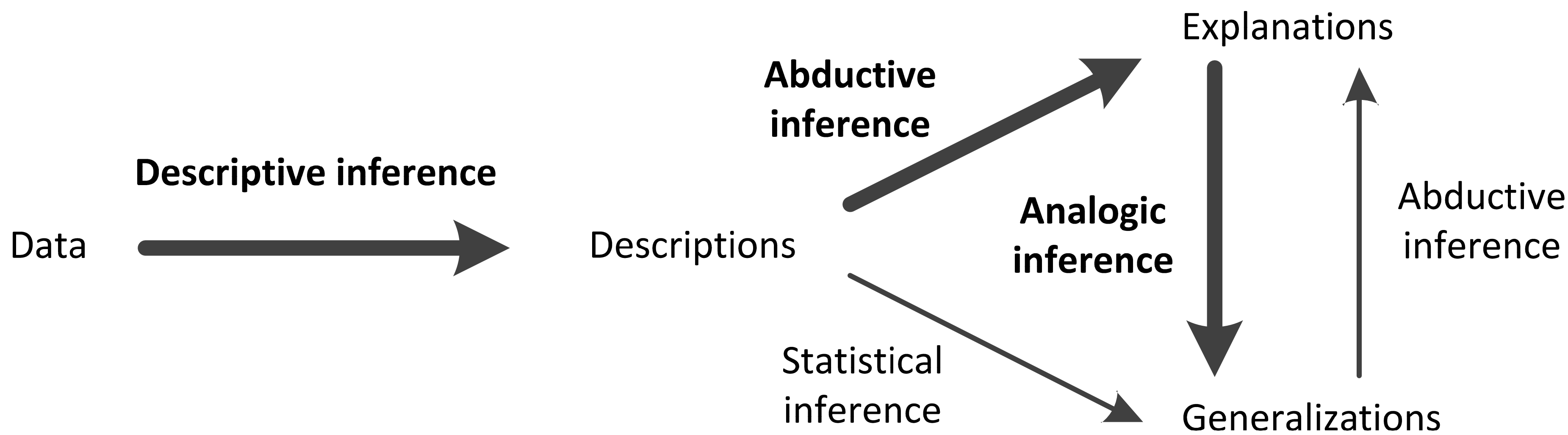
- Example
  - *Validating a new enterprise architecture design method*
  - *Validating a new model-based software testing method & tool*
  - *…..*

Four kinds of inference



- All inferences are fallible. **Validity** is degree of support for the inference.

Case-based inference



- Describe, explain, generalize

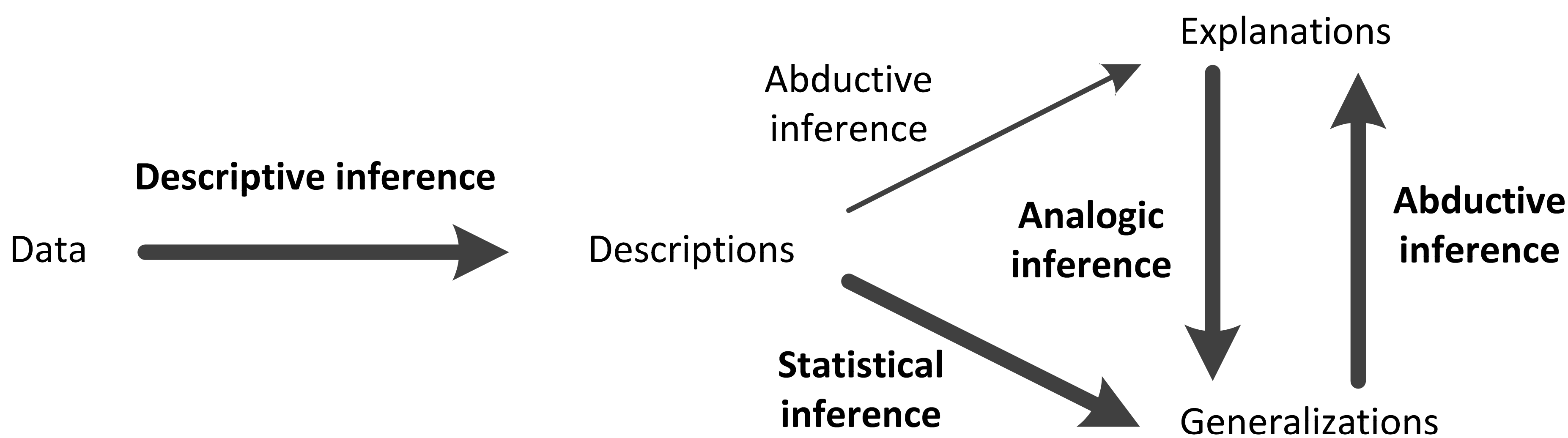
Case-based inference

1. **Descriptive inference:** Describe the case observations.
   - Discuss **descriptive validity**.
   - *In a study of a global SE project, describe the organizarional structure and communication & coordination processes based on data obtained from project documents, interviews, email and chat logs.*
2. **Abductive inference:** Explain the observations architecturally and/or rationally.
   - Discuss **internal validity.**
   - *Explain reduction of rework by the capabilities of the cross-functional team in the project.*
3. **Analogic inference:** Assess whether the explanations would be true of architecturally similar cases too.
   - Discuss **external validity**.
   - *Reason that similar teams will produce similar effects, other things being equal.*

Case-based reasoning should be architectural

- Architecture gives a basis for generalization by analogy

Sample-based inference

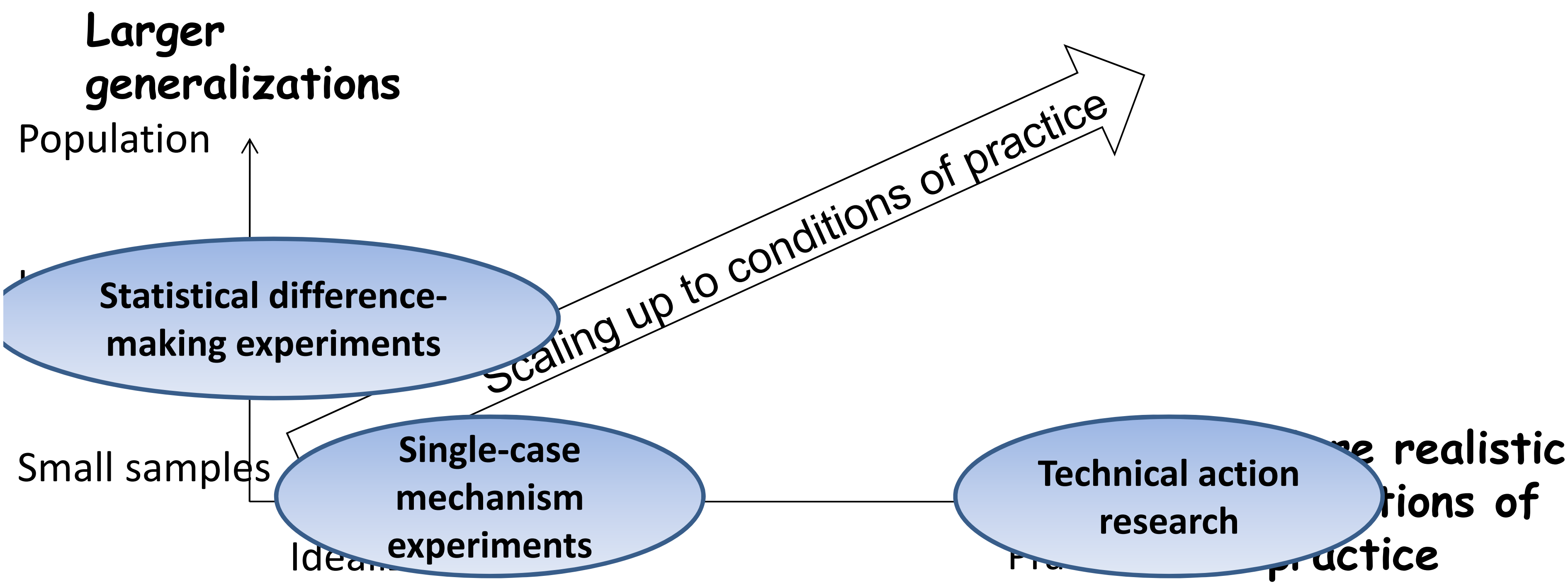


- Describe, aggregate, explain, generalize

Sample-based inference

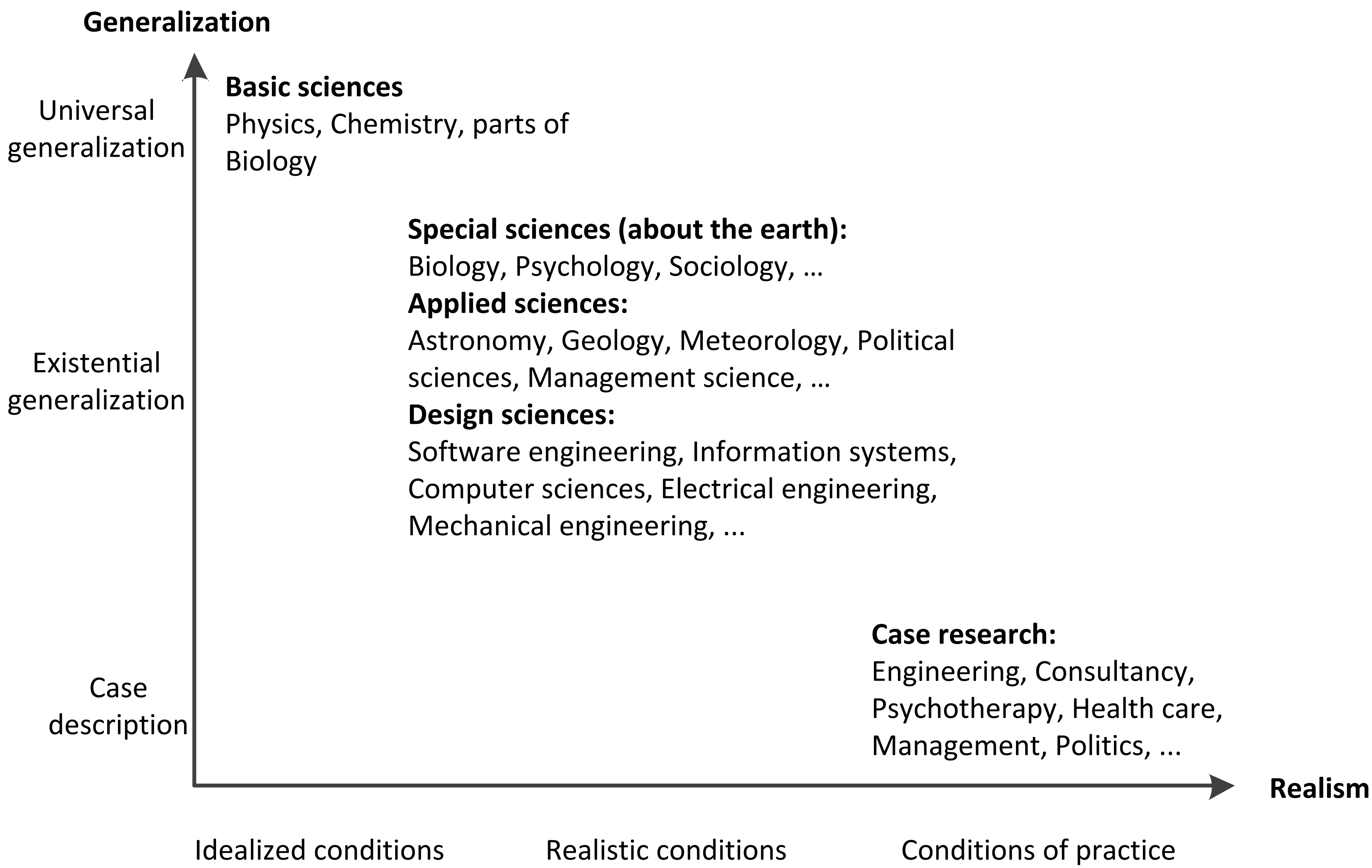
1. **Descriptive inference:** Describe sample statistics.
   - **Discuss descriptive validity.**
   - *In an experiment with a new programming technique, describe average #errors in treatment and control groups of students.*
2. **Statistical inference:** Infer a statistical model of the population.
   - **Discuss conclusion validity.**
   - *Estimate a confidence interval of difference of averages in population.*
3. **Abductive inference:** Explain the model causally or architecturally
   - **Discuss internal validity.**
   - *Argue that difference is caused by difference in technique. Explain by psychological mechanisms.*
4. **Analogic inference:** Assess whether the statistical model and its explanation would be true of architecturally similar populations
   - **Discuss external validity.**
   - *Argue that same effect will be obtained in (junior) practitioners*.

	Case-based inference	Sample-based inference
No treatment (observational study)	Observational case study	Survey
Treatment (experimental study)	Single-case mechanism experiment, Technical action research	Statistical difference-making experiment



- If all population elements were identical, statistical inference would not be needed

Sciences of the middle range



Take-home

- Design science
  - Design problems and knowledge questions
- Design theories
  - Effects of artifact in context
- Design research methods
  - Case-based and sample-based research
  - Architectural and statistical reasoning
  - Scaling up from lab to practice

Further reading

- Wieringa, R.J. and Daneva, M. (2015) *Six strategies for generalizing software engineering theories.* Science of computer programming, 101. pp. 136-152
- Wieringa, R.J. (2014) *Empirical research methods for technology validation: Scaling up to practice.* Journal of systems and software, 95. pp. 19-31.
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