Theories from Case Studies in SE and IS research

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- Based on Wieringa, R.J. (2014) *Design science methodology for information systems and software engineering.* Springer Verlag

Day 1

- 9:00
  - What is a case study (Chs 8, 17-19)
  - When to use case studies (Chs 1, 3, 5, 7)
- 10:30 Break
- 10:45
  - Scientific theories (ch 8)
- 12:15 Lunch
- 13:45
  - Scientific theories (chs 8, 9)
- 15:15 Break
- 15:30
  - Exercises, discussion (questions to chapters 8 and 9)
- 17:00 End of day 1

Day 2

- 9:00
  - Empirical research cycle (chs 10, 11)
- 10:30 Break
- 10:45
  - Case-based inference (chs 12, 14, 15)
- 12:15 Lunch
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  - Exercise (Make a case-based design of your research)
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What is a case

- A **case** is an instance of a class of systems.
  - Systems may be social, technical, and physical
  - They may be natural or artificial
  - They have a structure that produces overall system behavior
- A case displays some partly known, partly understood systematic behavior
- Examples:
  - *A software system*
  - *An information system consisting of software, hardware, roles, procedures, data*
  - *A product development project*
  - *A global SE project*
  - *An e-business network*

What is a case study

- A **case study** is a scientific investigation of phenomena in a case
- Observational case studies
  - *Study of an agile SE project*
- A single-case mechanism experiment in the field
  - *Test of a software prototype in the real world*
- Technical action research
  - *Use of an experimental development method by a researcher for a client*

Characteristics of case studies

- A **case study** is a scientific investigation of phenomena in a case
  - Takes place in the field (not in the lab)
  - May be observational or experimental
  - Purpose is to acquire knowledge and sometimes also to help a client
- Examples
  - *Observational study of political causes of IS implementation failure*
  - *Observational study of global requirements engineering*
  - *Experimental evaluation of network performance in a company*
  - *Field test of an algorithm for cruise control*
  - *Use of an experimental IT security risk assessment method to help a client*
- Non-example
  - *Simulation of different patient test scheduling algorithms (not in the field)*

Case-based versus sample-based reasoning

- Case-based reasoning:

Journalistic report
1. Describe phenomena a single instance of a class

Theory
2. Explain in terms of mechanisms, causes or reasons
3. Generalize by analogy to similar cases

- Sample-based reasoning

1. Select random sample from a population

Journalistic report
2. Describe sample statistics
3. Infer population parameter

Theory
4. Explain in terms of mechanisms, causes, or reasons
5. Generalize by analogy to similar populations

Next few slides

1. Select random sample from a population

- Sampling is drawing tickets from a box
- Population must be defined
- Sample may be simple (without replacement), this needs correction factor in the inference

- In case studies, the population is often incompletely defined.
  - We call it ``class of cases'', ``class of socio/physical/digital systems''
- Sampling is done sequentially (case by case)

2. Describe sample statistics

- Average, median, mode, variance, etc. of some variables.
  - Clean the data: outlier removal, scale transformations
- **Descriptive validity**

- In sample-based research, we are interested in sample properties
- In case-based research, we are interested in an individual's properties

3. Statistically infer population parameter

- The average, median, mode, variance, etc. of some variables in the population are unknown.
- Hypothesis testing:
  - Assume hypothesis about population parameter,
  - Compute probability of the sample data, given this hypothesis
  - Conclude about plausibility of the hypothesis
- Confidence interval estimation
  - Estimate an interval, in which the population parameter lies in 95% of the times that this resesearch will be replicated
- **Statistical conclusion validity**

- No statistical inference from cases to population

4. Explain in terms of mechanisms, causes, or reasons

- *E.g. explain difference in maintainability in terms of comments; explain this in turn by cognitive anchoring mechanisms*
- This is a theory of the researchers. Goes beyond the data.
- **Internal validity**

- Sample-based explanations often refer to causes
- Case-based explanations often refer to mechanisms.

- We return to this later

4. Generalize by analogy to similar populations

- *E.g. generalize from a study of maintainability in an SE project to all SE projects.*
- Basis of the analogy must be similarity in the underlying mechanism that produces the population property.
- **External validity**

- Analogic reasoning, same as in case studies.

- We return to this later

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When to do a case study

- When the phenomenon of interest cannot be produced in the lab
- Yin:
  - When there are more variables than data points
- Roel:
  - Then you are not focussing your research well enough

Example case studies

- Which phenomena can (not) be produced in the lab?
  - *Political causes of IS implementation failure*
  - *Coordination in global requirements engineering*
  - *Company network performance*
  - *Performance of an algorithm for cruise control*
  - *Usability and utility of an IT security risk assessment method*
  - *Performance of patient test scheduling algorithms*
  - *Your examples and non-examples …*

Elaboration for design science

- **Why** study phenomena in design science that cannot be produced in the lab?

Design science

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

To design an artifact to improve a problem context

Problems & Artifacts to investigate →

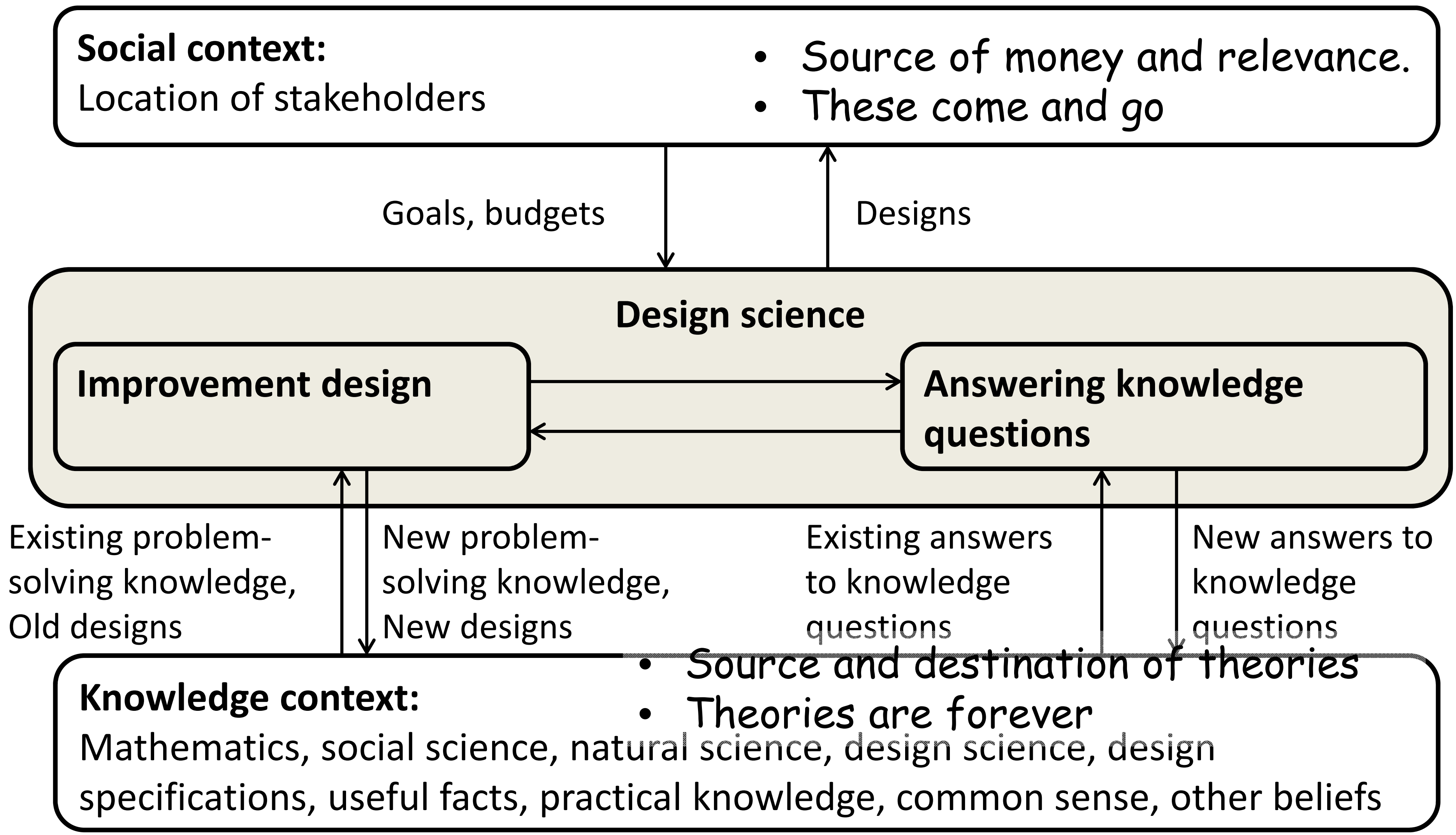
← Knowledge, Design problems

To answer knowledge questions about the artifact in context

Solving design problems;
Primary goal is utility;
Design cycle

Answering knowledge questions;
Primary goal is truth;
Empirical cycle

Framework for design science



? = knowledge question

! = action

The engineering cycle

Treatment Implementation

- Transfer to problem context!

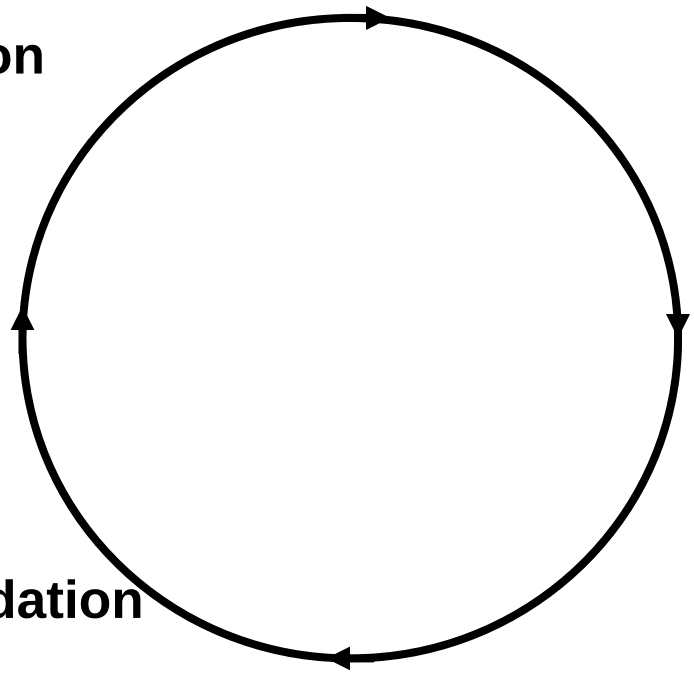
Implementation evaluation = Problem investigation

•Stakeholders? Goals?

•Conceptual problem framework?

•Phenomena? Explanations?

•Effects? Contribution to Goals?



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?

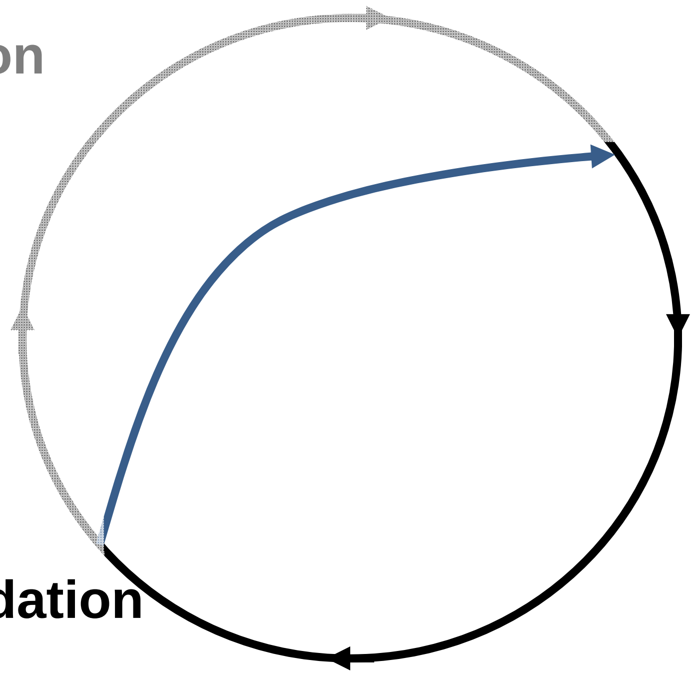
•Design new ones!

? = knowledge question
! = action

The **design** cycle

Treatment Implementation

- Transfer to problem context!



Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Explanations?
- Effects? Contribution to Goals?

Treatment design

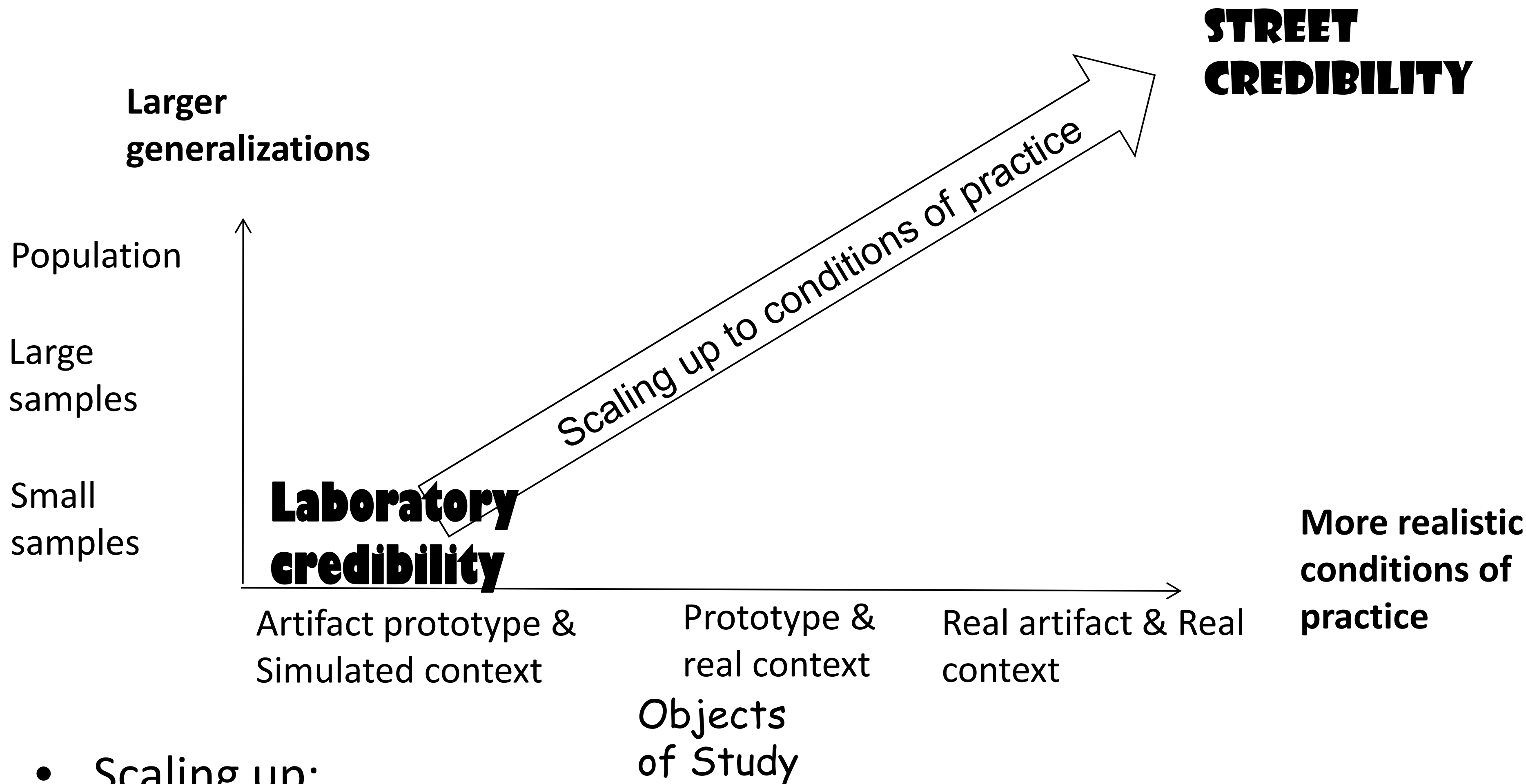
- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

Treatment validation

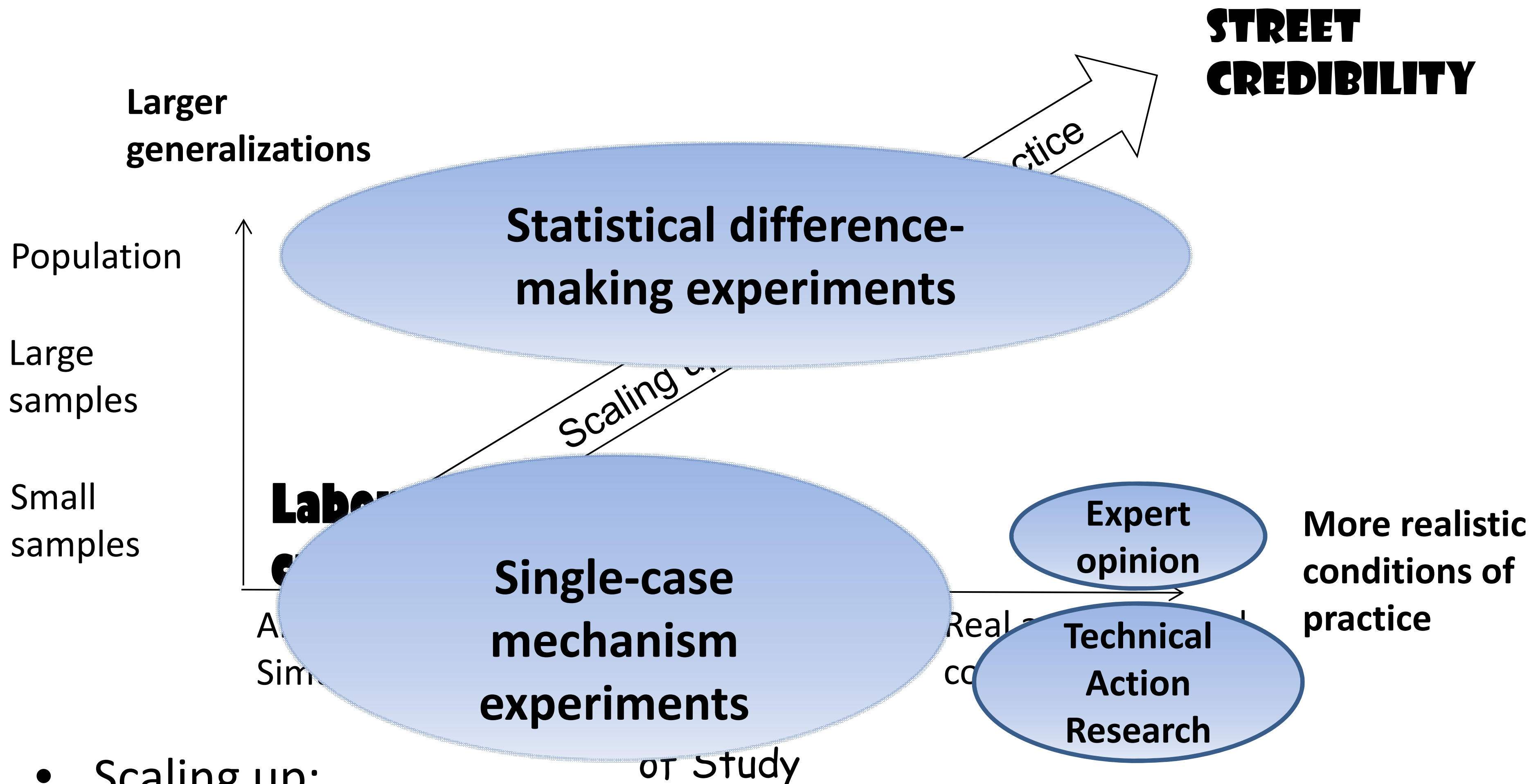
- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

When to use case studies

- Basic research spends its research budget on simulating idealized conditions in the lab
- Design science spends its research budget on approximating conditions of practice
- Case studies needed for
  - Problem investigation (**observational case study**)
  - Technology validation (simulation, **TAR**)
  - Implementation evaluation (**observational case study**)



- Scaling up:
  - Lab research: lab tests, simulation.
  - Opinion research: Expert opinion focus groups
  - Field research: Field experiments, action research (performed by researcher), pilot projects (performed by stakeholders)



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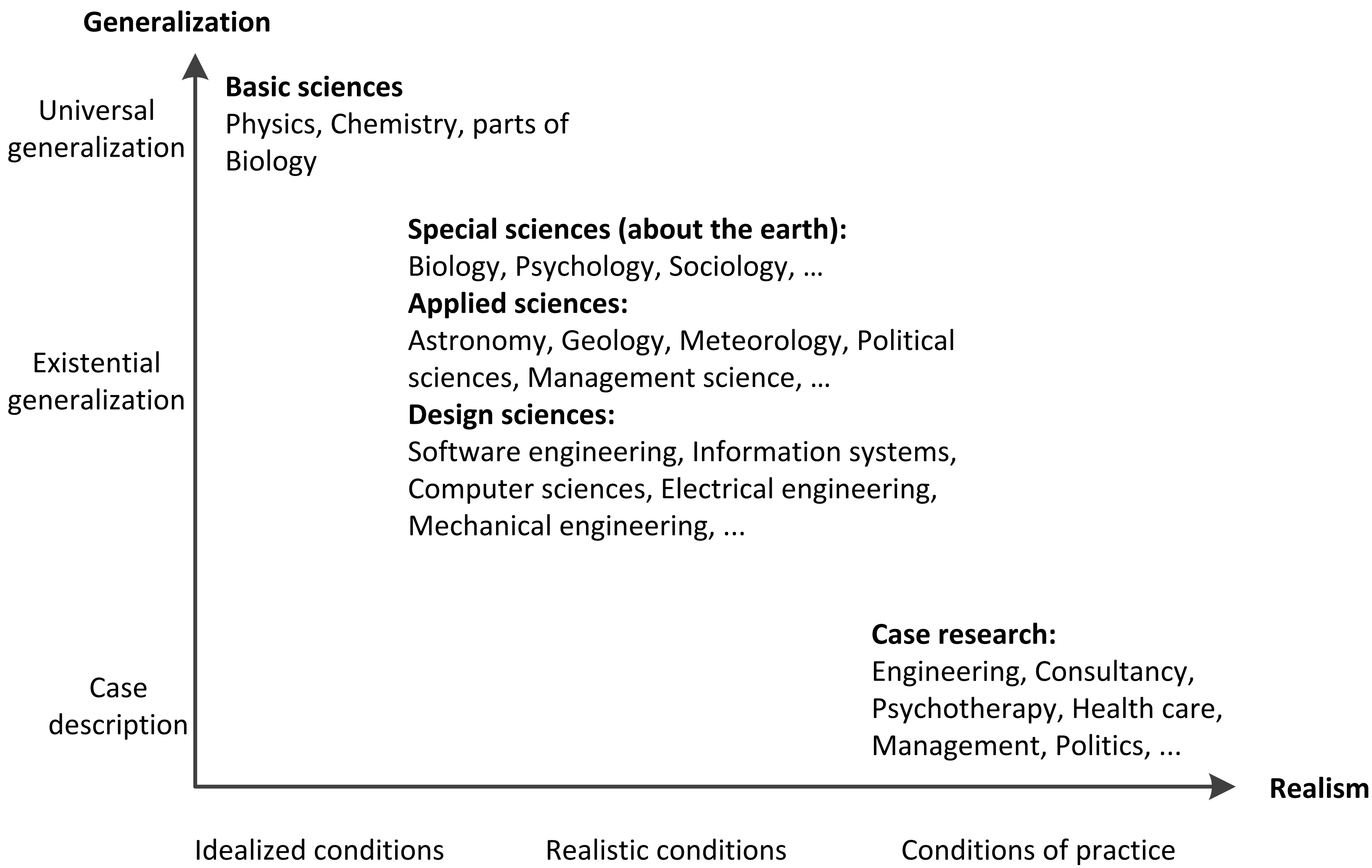
Discussion

- What reasons do you have to do a case study?
  - What phenomenon?
  - Why? Problem investigation, technology validation, implementation evaluation?

Sciences of the middle range



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- A **theory** is a belief that there is a pattern in phenomena.
  - Speculations: *“The NSA is monitoring all my email”*
  - Idealizations: *“Merging two faculties reduces cost in theory, not in practice.”*
  - Opinions: *“The Dutch lost the competition because they are not a team.’’*
  - Wishful thinking: *``My technique works better than the others.’’*
  - Scientific theories*: Theory of electromagnetism*

Scientific theories

- A **scientific** theory is a theory that
  - Has survived tests against experience
    - Observation, measurement
    - Possibly: experiment, simulation, trials
  - Has survived criticism by critical peers
    - Anonymous peer review
    - Publication
    - Replication

- Examples
  - *Theory of electromagnetism*
  - *Theory of cognitive dissonance*
  - *The Balance theorem in social networks*
  - *Theories X, Y, Z, and W of (project) management*
  - *Technology Acceptance Model*

Theories are fallible

- Fallibilism: All theories may be wrong!
  - Outside mathematics there is no certainty
  - And even there we may make mistakes (Lakatos' proofs and Refutations)
- All theories are improvable

Falsificationism

- Introduced by the philosopher Karl Popper
  - ~~Mechanical version: If the prediction of a theory is contradicted by observation, then reject the theory.~~
  - Sophisticated version: If the prediction of a theory is contradicted by observation, then
    - publish this,
    - try to replicate it,
    - try to understand it, and
    - try to improve the theory so that it can deal with the observation.

The structure of scientific theories

1. **Conceptual framework**
   – Definitions of concepts.
2. **Generalizations**
   – Express beliefs about patterns in phenomena.

Theory of electromagnetism

- *Conceptual framework:*
  - *Definitions of electric current, electric charge, potential difference, electric resistance, electric power, capacitance, electric field, magnetic field, magnetic flux density, inductance, …, … and their units.*
- *Generalizations*
  - *Electric charges attract or repel one another with a force inversely proportional to the square of their distance.*
  - *Magnetic attract or repel one another in a similar way and always come in north-South pairs.*
  - *An electric current inside a wire creates a corresponding circular magnetic field outside the wire.*
  - *A current is induced in a loop of wire when it is moved towards or away from a magnetic field*

Theory of cognitive dissonance

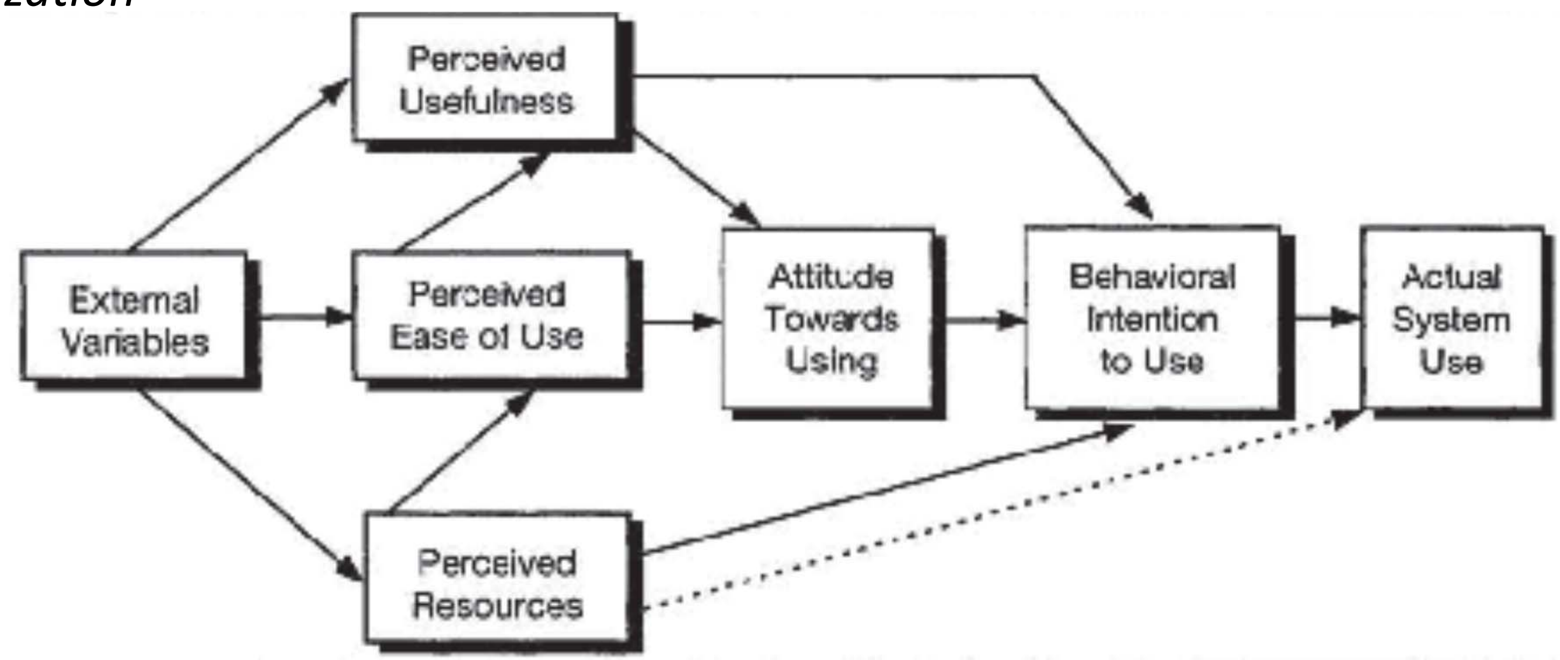
- *Conceptual framework*
  - ***Cognitive dissonance*** *is the mental stress experienced by an individual who holds contradictory beliefs or values, or is confronted by new information that conflicts with existing beliefs or values*
- *Generalization*
  - *People engage in dissonance reduction to bring their beliefs and actions in line with one another four ways:*
    - *Change behavior to agree with belief ("eat less chocolate")*
    - *Change belief to justify behavior ("occasional chocolate eating is OK")*
    - *Add new intention or behavior ("I'll work out tomorrow")*
    - *Deny information that conflicts with existing beliefs ("this is low-fat chocolate")*

The Balance Theorem in social networks

- *Conceptual framework*
  - *Definition of concepts of graph, link, friend/enemy, complete graph (each pair of nodes connected), balanced graph (no --- or ++- triangles)*
- *Generalization*
  - *Large call networks are almost balanced (V.D. Blondel, A. Decuyper and G. Krings - ``A survey of results on mobile phone datasets analysis'')*
  - *Mathematical theorem: If a labeled complete graph is balanced, then*
    - *either all pairs of nodes are friends,*
    - *or else the nodes can be divided into two groups, X and Y, such that every pair of nodes in X like each other, every pair of nodes in Y like each other, and everyone in X is the enemy of everyone in Y .*
- Idealizing assumptions **may** allow us to understand real-world phenomena

Technology Acceptance Model

- *Conceptual framework*
  - *Definitions of perceived usefulness, perceived ease of use, perceived resources, attitude towards using, behavior intention to use, actual system use*
- *Generalization*



- K. Mathieson, E. Peacock, W. W. Chin - Extending theTechnology Acceptance Model: The Influence of Perceived User Resources. SIGMIS Database, 2001.

Theories X, Y, Z, and W of (project) management

- *Theory X: By using time and motion studies, the efficiency of tasks improves.*
- *Theory Y: Output of tasks improves if people's creativity is stimulated.*
- *Theory Z: Stimulating individual creativity may create conflict; the potential for conflict can be reduced by creating a common culture.*
- *Theory W: Different organizations have different cultures. Projects involving several organizations produce their result more efficiently if every stakeholder wins something by producing the output.*

- All these generalizations make **predictions** about the effect of an intervention.
- They are embedded in theories that provide **explanations** too, and define the appropriate **conceptual framework**.

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- A **conceptual framework** consists of definitions of concepts , often called **constructs**.

- *Variables, relations among variables*
- *Populations, probability distribution of variable.*
- *Entities, attributes, relations, taxonomy, cardinality, …*
- *Events, actions, processes, procedures, constraints , …*

- We can define two kinds of conceptual structures

1. **Architectural structures**: Class of physical/social/technical systems, architecture, components with capabilities, interactions

2. **Statistical structures**: Population, variables with probability distributions, relations among variables

Architectural structures

- The world is structured as a collection of systems
  - Social, physical, technical, psychological, biological, …
  - Each system has **components** with **capabilities and limitations**,
  - that can **interact** with each other in specific ways.

Theory of cognitive dissonance

- *Conceptual framework*
  - *Class of systems: people interacting with the real world*
  - *Components: beliefs, intentions, values, facts, observations, conflict between facts and observations*
  - *Capabilities of people:*
    - *Change behavior*
    - *Change a value*
    - *Change intention*
    - *Deny observation*
    - *Deny fact*

- Conceptual framework provides a way to describe phenomena (a frame)
- but does not itself provide generalizations about phenomena
  - They cannot be falsified!
  - They can be useful, i.e. contribute to a purpose

Other examples

- In all of these examples we recognize in each case/population element an architecture consisting of components that have capabilities to interact.
  - *Theory of electromagnetism*
  - *The Balance theorem in social networks*
  - *Technology Acceptance Model*
  - *Theories X, Y, Z, and W of (project) management*

More examples

- Examples
  - *A software prototype in a simulated context*
  - *Software engineering projects in the real world*
  - *Information systems in organizations*
  - *Risk assessment methods for IT security*
  - *Business networks*
- Which architecture to recognize in a case? That depends on which generalizations we would like to be able to draw.

RJW1

History of architectural conceptual structures

- This kind of structure is used in
  - The engineering disciplines: Renaissance machines 1500
  - Astronomy: architecture of solar system; math description
  - Physics: forces among physical bodies 1600
  - Biology: structure and mechanisms in the body
  - Chemistry: composition and mechanisms of combustion 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

Slide 46

RJW1 12:15

Wieringa, R.J. (Roel); 3-11-2015

Advantages of architectural structures

Architectures can be used to decompose complex problems into simpler problems

- Study one component at a time
- Study an architecture while abstracting from internal structure of components

This in turn can be used for

- **Explanation, diagnosis, debugging**: Trace system-level phenomena to component properties.
- **Prediction, design**: Explore the effects of putting different components together.
- **Generalization**: Reason about similarity of cases or populations.

Statistical structures

- The world is structured as a population.
  - A **population** is set of all objects that satisfy a predicate, called the population predicate.
  - A **(random) variable** is an observable property of population elements
  - A **probability distribution** of a variable X is a mathematical function that summarizes the probability of randomly selecting a value of X from the population

- (``Random'' means: No systematic selection proces. Internal structure of the selection process does not provide information about the outcome of the selection.)

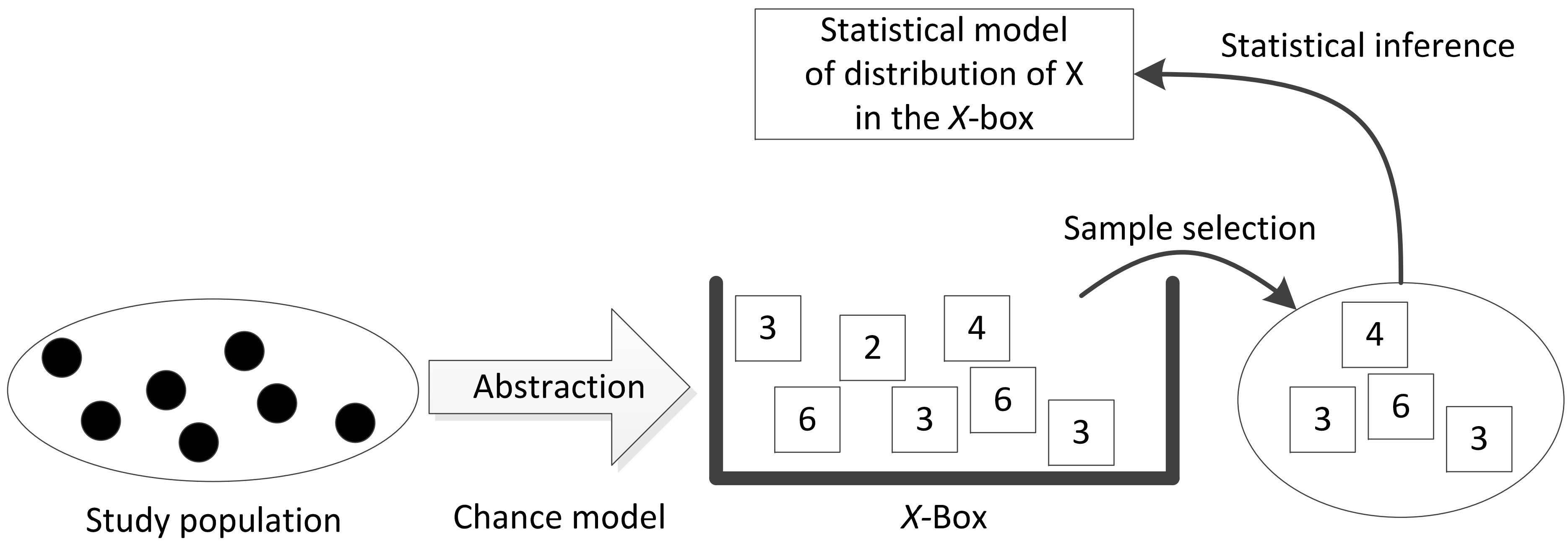
Population

- **Population** is set of all objects that satisfy a predicate, called the *population predicate*.
  – *All software prototypes in a simulated context, similar to a particular prototype & context*
  – *All agile software engineering projects in the real world*
  – *All ERP systems in large organizations*
  – *All risk assessment methods for IT security*
  – *All business networks*

- The population predicate is a **similarity predicate**

Variables

- A **(random) variable** is an observable property of population elements
- **X-box** is the multiset of values of X on a population



Statistical reasoning is about X-boxes

- A **(random) variable** is an observable property of population elements
- **X-box** is the multiset of values of X on a population
  - *Weight of people, effort of SE projects, numbers on football shirts.*
- **XY-box** is the multiset of pairs of values of (X, Y) on a population, etc.
  - *Execution time of implementations, accuracy of output, effort spent on a project, duration of a project, (effort, duration) of a project, etc.*
- In a population,
  - Each variable has properties of variation (average, variance)
  - And sets of two or more variables have relationships of covariation

Probability distributions

- **Probability distribution** of X is a mathematical function that summarizes the probability of selecting a sample of values in a random draw from the population

Chance models

- **Chance model** of X:
  1. Definition of the meaning of numbers in the X-box
  2. Assumptions about probability distribution of X
  3. Measurement procedure
  4. Sampling procedure

Example

- T. Huynh, J. Miller, An empirical investigation into open source web applications' implementation vulnerabilities. Empir. Softw. Eng. **15**(5), 556–576 (2010)
- *Population of open source web applications*
- *Random variable ImpV indicates implementation vulnerabilities.*
- *Chance model of ImpV:*
  1. *Definition: The numbers on the tickets in the ImpV-box are proportions of implementation vulnerabilities among total number of vulnerabilities in a web application. (pages 564-565)*
  2. *Assumptions: binomial distribution. I.e. ithe proportions of implementation vulnerabilities in different web applications are independent, and the probability that a vulnerability is an implementation vulnerability, is constant across all web applications*
  3. *Measurement procedure: Counting and classifying by a person.*
  4. *Sampling procedure: Not specified. 20 applications are listed.*

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

Advantages of statistical structures

- Statistical structures can be used to make large-scale population properties visible
  - Even when an individual shows no regularities

This in turn can be used to

- Describe aggregate phenomena in a sample
- Generalize from a sample to a population (sample-based)
  - Estimate patterns in the population not visible at the individual level (e.g. identify needs in a population)
  - Estimate the effect of treatments in the population (prediction of policy impact)
- Useful for policy-makers

Hybrid structures

- Statistical study within a case
  1. *Case study of a large global SE project: e.g. an architectural study of roles and interactions among software engineers;*
  2. *Contains a statistical study of the population of software engineers in this project.*

- Case study of a population element
  1. *Statistical survey of a sample of projects:*
  2. *Followed by case studies of a few projects, in order to understand mechanisms responsible statistical results.*

If the studied phenomena contain people …

They too have conceptual frameworks

Sharing and interpreting a conceptual framework

- Concepts shared by people in the domain may be adopted by researchers that investigate the domain
  - *Goal, requirement, effort, etc.*
  - Adopting these concepts in the conceptual research framework may allow additional understanding
- Concepts defined by researchers may be adopted by people in the domain
  - *(software) object program structure, agile, etc.*
  - Adopting these concepts in the domain may allow definition of additional options for action
- Concepts may even make a round trip from domain to researchers to domain

Validity of a conceptual framework

- Conceptual framework cannot be true or false
  - A definition cannot be true or false
- It is a tool
  - People may be able to use it (usability)
  - … for a useful purpose (utility)
- *E.g. the different definitions of “goal”, “requirement”, “specification”, design”.*
- *``A goal is the space between two trees”*

Construct Validity

- **Construct validity** is the degree to which the application of constructs to phenomena is warranted with respect to the research goals and questions
- ``Construct validity is the degree to which a test measures what it claims, or purports, to be measuring.”
- ``Construct validity refers to the degree to which inferences can legitimately be made from the operationalizations in your study to the theoretical constructs on which those operationalizations were based.’’

Threats to construct validity

- Inadequate definition
  - No identification and classification criterion.
  - *E.g. ``agile projects'' without instruction how to recognize and count agile projects*
- Construct confounding
  - Our cases/sample may be cases/samples from more than one population. Then what is the target of generalization?
  - *Measuring the effect of an SE method in a sample of students.*
    - *Is this a sample of novice software engineers? Well educated software engineers? Captive software engineers?*

Operationalizations

- Some constructs cannot be measured
- **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.*

Threats to validity of operationalizations

- **Mono-operation bias**
  - Defining only one indicator for a construct
  - *E.g. measuring maintainability by effort to repair a bug only (and ignoring effort to find a bug or to test the repair).*
- **Mono-method bias**
  - Indicator measured in only one way.
  - *E.g. measuring* effort to repair *by questionaires only*

Construct Validity, again

- **Construct validity** is the degree to which the application of constructs to phenomena is warranted with respect to the research goals and questions
- ``Construct validity is the degree to which a test measures what it claims, or purports, to be measuring."
  - The paradox of analysis: if a vague concept is operationalized, either the operationalization is wrong or the concept is redefined
- ``Construct validity refers to the degree to which inferences can legitimately be made from the operationalizations in your study to the theoretical constructs on which those operationalizations were based.''
  - Indicators do not *causally influence* constructs
  - Paradox of analysis: construct validity is either 0 or 100%

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  - Case-based inference
- 12:15 Lunch
- 13:45
  - Exercise (Make a case-based design of your research)
- 15:15 Break
- 15:30
  - Assignments, discusssion, wrapup (checklist application to two papers)
- 17:00 End of day 2

Target (scope) of generalization

- In case-based reasoning: defined by **similarity predicate**
  - *Agile projects: Projects following one of the recognized agile methods such as Scrum or XP. How crisp is this?*

- In sample-based reasoning: Defined by similarity predicate too!
  - Population predicate
    - *Generalize, from sample of study population of agile projects, to the study population*
  - Similar populations
    - *Generalize from study population of agile projects to the theoretical population of all agile projects.*

The structure of design generalizations

- (Artifact specification) X (Context assumptions) → Effects
  - *(UML) X (SE project) → (Less errors)*
  - *(Cross-functional teams) X (Global SE project) → (Less errors)*
  - *(Algorithm) X (Context of use) → (Faster execution)*
- Effects satisfy a requirement to some extent
  - Often, researchers have no clear requirements
  - Requirements come from stakeholder goals, so the relevance of a generalization depends on stakeholder goals

Discussion

- Do you recognize this?
- More examples …

Why do we need theories?

- With a conceptual framework we can:
  - **Frame** a problem or artifact: *choose which concepts to use*
  - **Analyze** conceptual problem structure: *analyze the framework*
  - **Describe** a problem or artifact
  - **Generalize** about problem or artifact
- With a generalization we can
  - **Explain** phenomena
  - **Predict** phenomena

Examples

- Theories:
  - *Theory of cognitive dissonance*
  - *Theory of electromagnetism*
  - *The Balance theorem in social networks*
  - *Theories X, Y, Z, and W of (project) management*
  - *Technology Acceptance Model*
- What can we do with these theories:
  - **Frame** a problem or artifact
  - **Analyze** conceptual problem structure
  - **Describe** a problem or artifact
  - **Generalize** about problem or artifact
  - **Explain** phenomena
  - **Predict** phenomena

Explanations

- An **explanation** is hypothesis about how a phenomenon came about.
  - **Causal explanations** explain the occurrence of an event by the occurrence of an earlier event
  - **Architectural explanations** explain the existence of a causal relationship by the mechanisms that produced it
  - **Rational explanation**s explain the behavior of actors by their goals.
- *E.g. why is the light on?*

Causal explanations

- Causal explanations say that an earlier event **made a difference** to a current event.
  - *Explanation of lower programnming effort: Programming effort is lower* ***because*** *we switched to UML*
    - *The earlier switch to UML resulted in the current reduction of programming effort*
    - *If we had not switched to UML earlier, our current programming effort would have been higher, other things being equal.*

- Causality is difference-making.
  - It is unobservable.
  - It may be nondeterministic

Architectural explanations

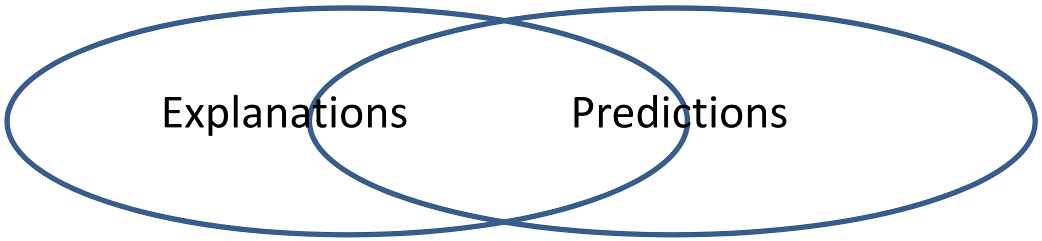
- **Architectural explanations** explain the existence of a causal relationship by the mechanisms that produced it.
  - *Explanation why UML leads to lower programming effort:*
    - *UML models resemble the domain more than other kinds of models;* → Capability of UML
    - *they are easier to understand for software engineers;* → Cognitive mechanism
    - *They allow seamless transition from domain models to software models.* → Mechanism in SW development
- A **mechanism** is the collection of interactions among components (entities, actors) that produces a response from a stimulus.
  - Mechanisms may be social, psychological, physical, technical, …
  - Mechanisms can be observed; capabilities are unobservable
  - Mechanisms may be nondeterministic

Rational explanations

- **Rational explanation**s explain the behavior of actors by their goals.
  - *Why do we have lower programming effort? Because we bid for fixed price contracts. We need to be sure that our software engineers work as efficiently as possible*
- Architectural explanation for social systems that include rational actors
  - We assume rationality in users, programmers, attackers, fraudsters, thiefs, politicians, … but their goals may not be our goals.

Predictions

- Explanations say how the present is an outcome of the past.
- Predictions look at the present and estimate what the future will be.



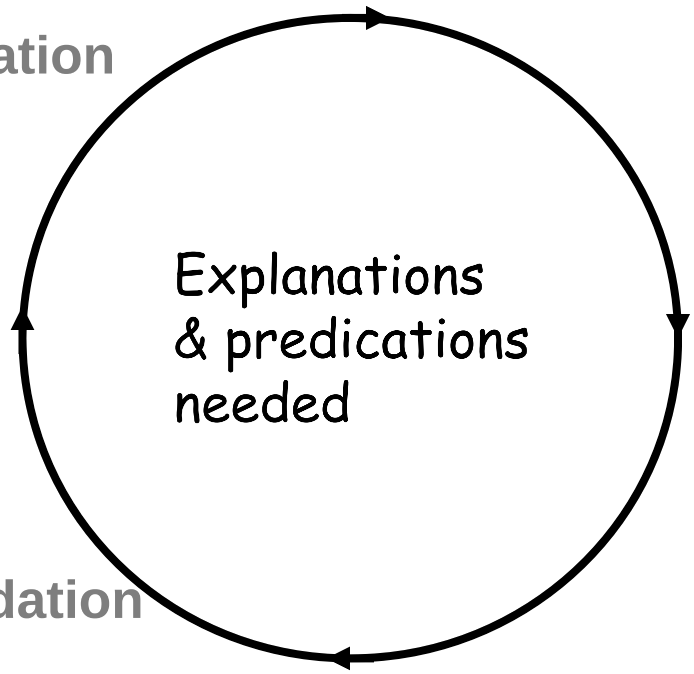
- Some explanations are too incomplete to be used as predictions
  - *Explanations of the outcome of a football match*
- Some predictions are descriptive, and do not provide an explanation
  - *In CMM 3 organizations developing embedded software, defect removal effectiveness is 98%.*
- Some explanations can be used for prediction too
  - *Most examples of explanations given so far.*

The use of theories in design

Treatment implementation

Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? **Explanations?**
- **Effects?** Contribution to Goals?



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!

Usability of design theories

- When is a design theory

  (Context assumptions) X (Artifact design) → Effects

  usable by a practitioner?

  1. He/she is capable to recognize Context Assumptions
  2. and to acquire/build Artifact,
  3. effects will indeed occur, and
  4. will contribute to stakeholder goals/satisfy requirements

- Practitioner has to asses the risk that each of these fails

Example

- *(UML) X (any SE project) → lower programming effort*

- *You are a practitioner.*
  1. *Can you recognize Context Assumptions?*
  2. *Can you acquire UML?*
  3. *Are you sure the effects will occur?*
  4. *Do they contribute to stakeholder goals?*

Discussion

- Gregor's theory of theories.
  - My book page 103.

Day 1

- 9:00
  - What is a case study
  - When to use case studies
- 10:30 Break
- 10:45
  - Scientific theories
- 12:15 Lunch
- 13:45
  - Scientific theories
- 15:15 Break
- 15:30
  - **Exercises, discussion (questions to chapters 8 and 9)**
- 17:00 End of day 1

Day 2

- 9:00
  - Empirical research cycle
- 10:30 Break
- 10:45
  - Case-based inference
- 12:15 Lunch
- 13:45
  - Exercise (Make a case-based design of your research)
- 15:15 Break
- 15:30
  - Assignments, discusssion, wrapup (checklist application to two papers)
- 17:00 End of day 2

Nutshell

- A **case study** is the study of a system in the field.
- The **conceptual framework** of a case study should define the case architecture.
- Conceptual frameworks should be assessed on the **construct validity** of the constructs and operationalizations in them
- An **architecture** consists of components that have behavioral capabilities and can interact.
- An **architectural mechanism** is an interaction among case components that produce a response from a stimulus.
- **Theories** of a case should aim to describe, explain or predict system-level phenomena in terms of architectural mechanisms.
  - Design theories: $A \times C \rightarrow E$
  - Middle range
  - Usable

Exercises

- Do question 1 of chapter 9.

Day 1

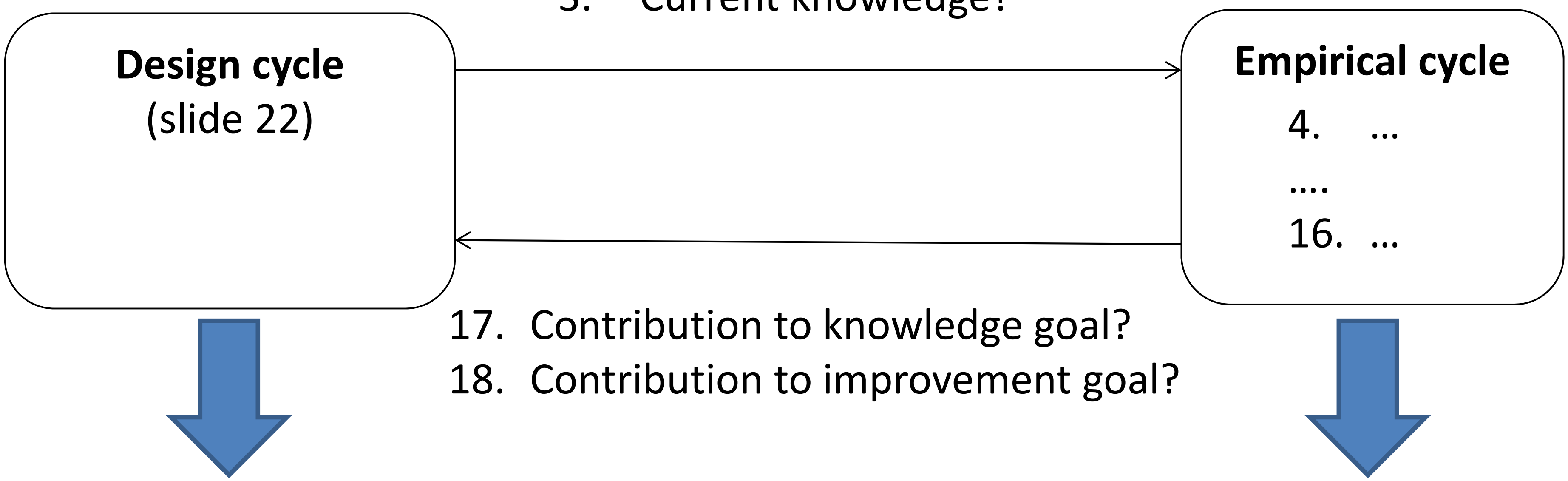
- 9:00
  - What is a case study
  - When to use case studies
- 10:30 Break
- 10:45
  - Scientific theories
- 12:15 Lunch
- 13:45
  - Scientific theories
- 15:15 Break
- 15:30
  - Exercises, discussion (questions to chapters 8 and 9)
- 17:00 End of day 1

Day 2

- 9:00
  - **Empirical research cycle**
- 10:30 Break
- 10:45
  - Case-based inference
- 12:15 Lunch
- 13:15
  - Exercise (Make a case-based design of your research)
- 14:45 Break
- 15:00
  - Assignments, discusssion, wrapup (checklist application to two papers)
- 16:30 End of day 2

Checklist for the empirical cycle: context

1. Improvement goal?
2. Knowledge goal?
3. Current knowledge?



Designing something useful

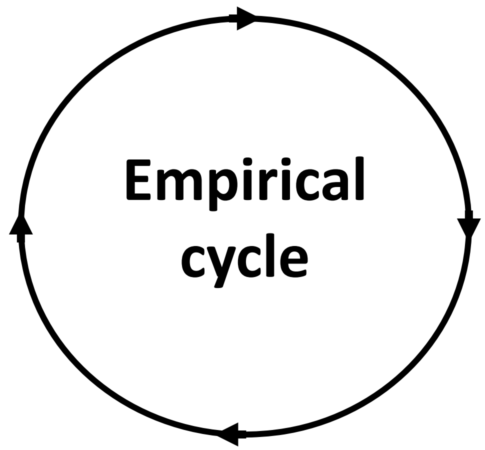
Answering a knowledge question

Data analysis

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

Research execution

11. What happened?



Research problem analysis

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

Design validation

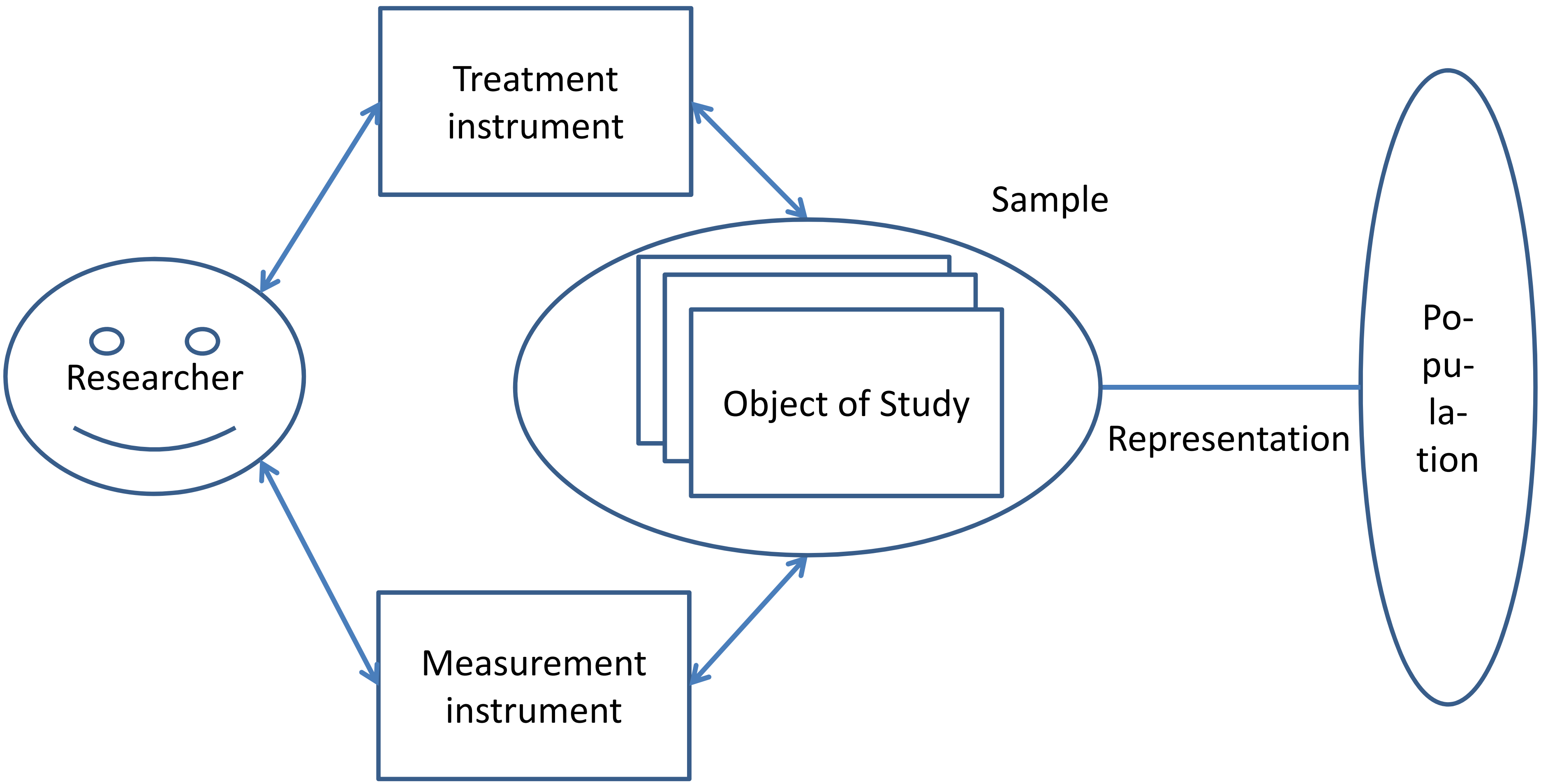
7. Object of study justification?
8. Treatment specification justification?
9. Measurement specification justification?
10. Inference justification?

Research & inference design

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

Research setup

Research setup



- In sample-based studies, ``representation'' is achieved random sampling
  - A random sample may be **dissimilar** to any other sample from the same population.
  - No analogic reasoning from random sample to population
  - Randomness guarantees long-run stability of statistical properties
- In case-based research, OoS's are studied sequentially
- In observational studies there is no treatment
  - But all instruments interact with the OoS's.
- Which inferences you can do, depends on the research setup

Examples

- What is the population, the sample of objects of study, the measurements, and the treatments (if any)?
  - *Experiment with students to test a new SE technique to see if it leads to less programming effort*
  - *Survey of the use of UML in Brazil*
  - *Case study of IS implementation failure*
  - *Experimental use of a new effort estimation technique in a pilot project to see if it is more accurate*

Kinds of empirical research methods

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

Example observational case study

An Empirical Study of the Complex Relationships between Requirements Engineering Processes and Other Processes that Lead to Payoffs in Productivity, Quality, and Risk Management

Daniela Damian and James Chisan
TSE 32(7) July 2006

Research design

- ***Research context***

1. *Improvement goal: None. Curiosity-driven research.*
2. *Knowledge goal: Fill gap between claims about RE and RE practice*
3. *Current knowledge: A few published surveys, no case studies.*

Research design

Value-word. Avoid

- ***Research problem analysis***

4. *Conceptual framework: definitions of requirements, productivity, quality, risk*
5. *Research questions:*
   - *How do improvements in RE processes relate to improvements in productivity, quality, and risk management?*
     1. *How do improvements in the RE practice impact the early stages of development?*
     2. *How do they impact the downstream development stages?*
     3. *Which components of the RE process were more significant in contributing to this impact?*
     4. *How could the interaction between REP and other processes have contributed to these results?*
6. *Population: RE processes in software development organizations*

Research design

- ***Research & inference design***

7. *Object of study: Introduction of RE at the Australian Center for Unisys Software*
8. *Treatment specification: No treatment. Observational research.*
9. *Measurement specification: Questionnaires, interviews, document inspection.*
10. *Inference:* after the break!

Example Technical Action Research (TAR) study

Morali, A. and Wieringa, R.J. (2010) *Risk-Based Confidentiality Requirements Specification for Outsourced IT Systems.* In: *Proceedings of the 18th IEEE International Requirements Engineering Conference* (RE 2010), 27 Sept - 1 Oct 2010, Sydney, Australia. IEEE Computer Society.

What is TAR?

- Using an experimental technique
  - to help a client and → Helping a client
  - to learn about its effects in practice. → Experimenting with a technique

TAR methodology

TAR

Researcher's design cycle:	Researcher's empirical cycle:	Client's engineering cycle:
Design a new technique	Validate a new technique	Solve a problem

TAR methodology

TAR

Researcher's design cycle:
- Investigate problem
- Design treatment
- Validate treatment

Researcher's empirical cycle:
- Analyze research problem
- Design research setup and inferences
- Validate
- Execute
- Analyse results

Client's engineering cycle:
- Investigate client problem
- Design treatment
- Validate treatment
- Implement
- Evaluate

TAR methodology

TAR

Researcher's design cycle:

- Investigate problem
- Design treatment
- Validate treatment

Researcher's empirical cycle:

- Analyze research problem
  - Effects?
  - Satisfy requirements?
  - Comparison?
  - Generalizable?
- Design research setup and inferences
  - Acquire a case
- Validate
  - Internal validity?
  - External validity?
- Execute
  - Do the client cycle
- Analyse results
  - Answer questions.

Client's engineering cycle:

- Investigate client problem
  - Stakeholders, goals?
  - Phenomena?
  - Causes, effects?
- Design treatment
  - Make a plan.
- Validate treatment
  - Check with client.
- Implement
  - Do it.
- Evaluate
  - Client satisfied?

Research Design

Research context

1. *Knowledge goal*
   - *To validate a newly developed confidentiality risk assessment method*
2. *Improvement goal*
   - *To develop a confidentiality risk assessment method when IT is outsourced.*
3. *Current knowledge*
   - *The method has been tested on small problems in the lab*
   - *The method has been inspected by stakeholders of a client company*

Research Design

Research problem

4. *Conceptual framework*
   – *Concepts from outsourcing and security risk assessment*
5. *Knowledge questions*
   - *Q1 Is the technique usable?*
   - *Q2 Is it less subjective than other available techniques?*
   - *Q3 Does use of the technique improve the client's understanding of confidentiality risks, better than competing techniques do?*
   - *Q4 Is the effectiveness of the techniques dependent on its context of use? If so, how?*
6. *Population*
   – *The set of all ERP outsourcing relations where the service consumer must satisfy confidentiality requirements checked by auditors and depends on the outsourcing service provider to satisfy these requirements.*

Research design

Research & inference design

7. *Object of study*
   - *large multinational industrial company with a significant corporate security staff keen on improving their procedures.*
8. *Treatment design*
   - *The RA method designed by the researcher was customized for the company.*
   - *Some software tools were used.*
   - *A schedule of interactions was agreed with the company.*

Research design

Research & inference design, continued

9. Measurement design

- *Usability measured by effort (time) to use;*
- *Subjectivity measured by number of questions in the method that require personal judgment;*
- *Client's understanding measured by debriefing interview*

– *Data sources: Architects, Chief security officer, primary documents*

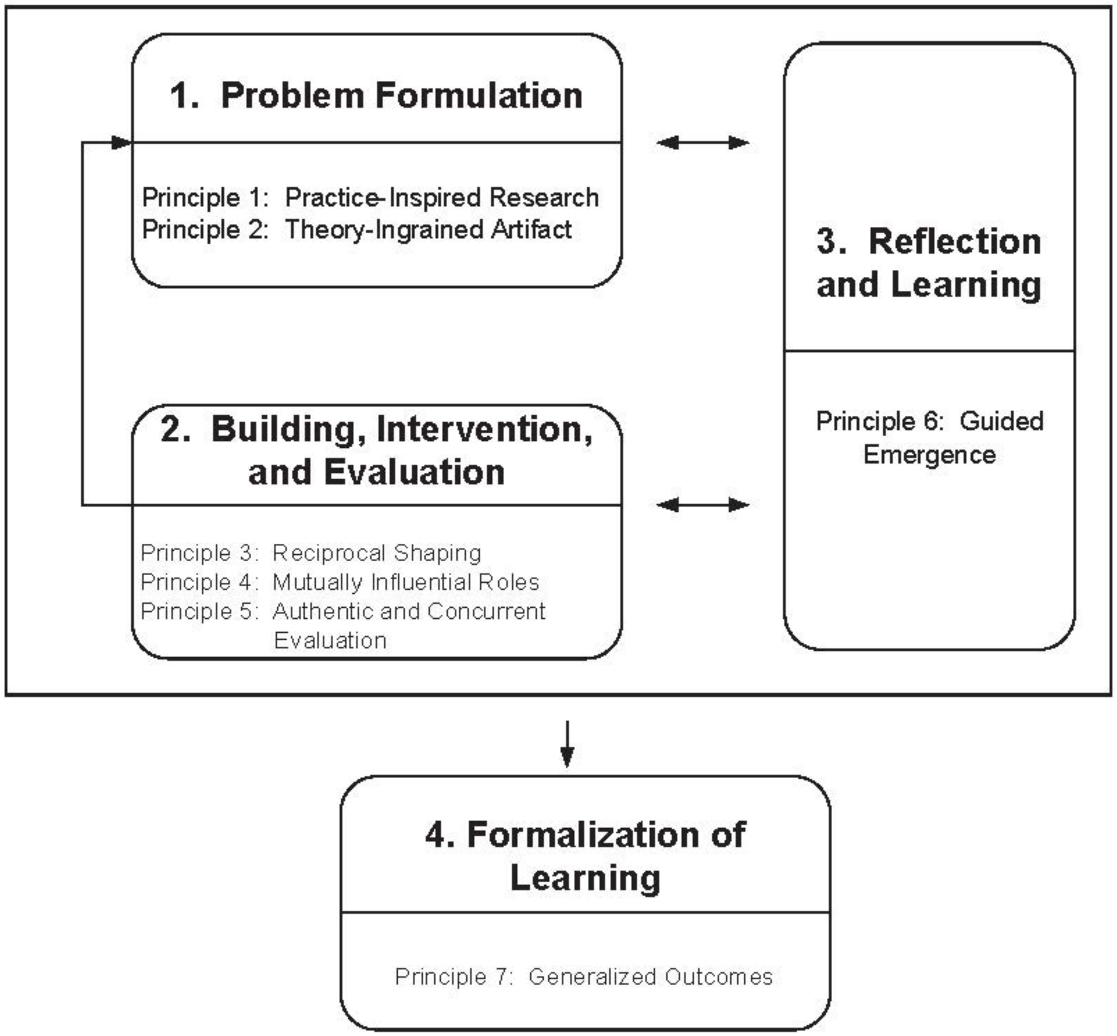
– *Instruments: Diary of researcher, Interviews with key stakeholders*

– *Measurement plan: Agreements about what data could be collected, and how*

- *Inference design:* After the break!

Discussion

- Sein, Maung, Henfridsson, Ola, Purao, Sandeep, Rossi, Matti, & Lindgren, Rikard, (2011), "Action design research", MIS Quarterly, 35(2).



- Driven by client problem

Mapping of ADR to TAR

TAR

Researcher's design cycle:

- Investigate problem
- Design treatment
- Validate treatment

2. Building

3. Reflection and learning: Need to improve the technique?

Researcher's empirical cycle:

- Analyze research problem
  - Effects?
  - Satisfy requirements?
  - Comparison?
  - Generalizable?
- Design research setup and inferences
  - Acquire a case
- Validate
  - Internal validity?
  - External validity?
- Execute
  - Do the client cycle
- Analyse results
  - Answer questions.

4. Formalization of learning: conclude, generalize, publish

Client's engineering cycle:

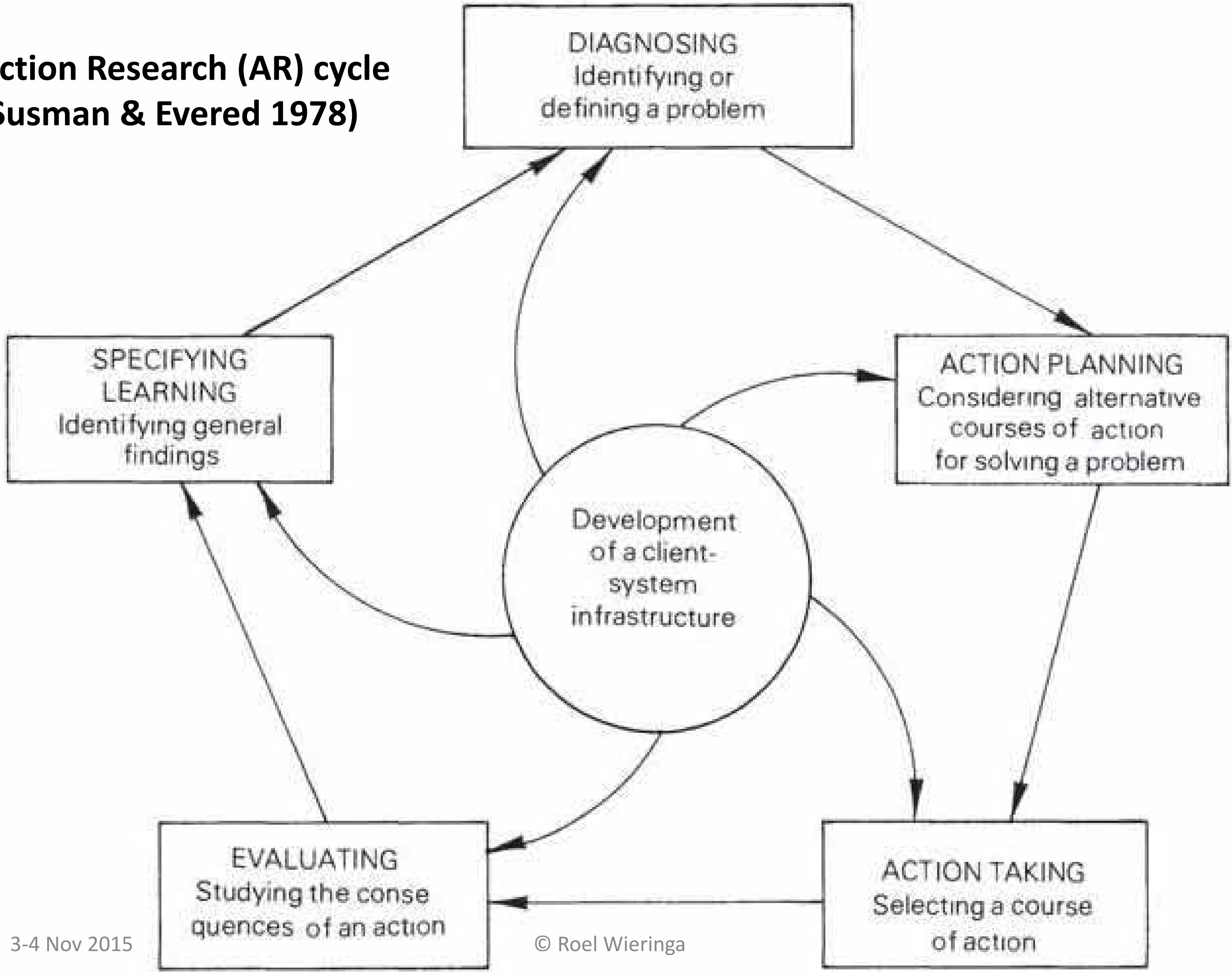
- Investigate client problem
  - Stakeholders, goals?
  - Phenomena?
  - Causes, effects?
- Design treatment
  - Make a plan.
- Validate treatment
  - Check with client.
- Implement
  - Do it.
- Evaluate
  - Client satisfied?

1. Problem formulation

2. Intervention

2. Evaluation: this cycle successful?

Action Research (AR) cycle (Susman & Evered 1978)



Mapping of AR to TAR

Researcher's design cycle:

- Investigate problem
- Design treatment
- Validate treatment

TAR

Researcher's empirical cycle:

- Analyze research problem
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  - Satisfy requirements?
  - Comparison?
  - Generalizable?
- Design research setup and inferences
  - Acquire a case
- Validate
  - Internal validity?
  - External validity?
- Execute
  - Do the client cycle
- Analyse results
  - Answer questions.

Specifying learning

Client's engineering cycle:

- Investigate client problem
  - Stakeholders, goals?
  - Phenomena?
  - Causes, effects?

Diagnosing

- Design treatment
  - Make a plan.
- Validate treatment
  - Check with client.

Action planning

- Implement
  - Do it

Action taking

- Evaluate
  - Client satisfied?

Evaluating

Day 1

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  - Scientific theories
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- 15:30
  - Exercises, discussion (questions to chapters 8 and 9)
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Day 2

- 9:00
  - Empirical research cycle
- 10:30 Break
- 10:45
- **Case-based inference**
  - **Inference design**
  - **Validity**
- 12:15 Lunch
- 13:15
  - Exercise (Make a case-based design of your research)
- 14:45 Break
- 15:00
  - Assignments, discusssion, wrapup (checklist application to two papers)
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Data analysis

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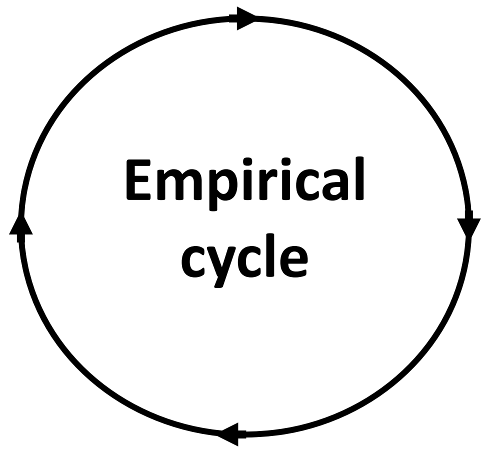
13. Observations?
14. Explanations?
15. Generalizations?
16. Answers?

Research execution

11. What happened?



Research problem analysis

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

Design validation

7. Object of study justification?
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Research & inference design

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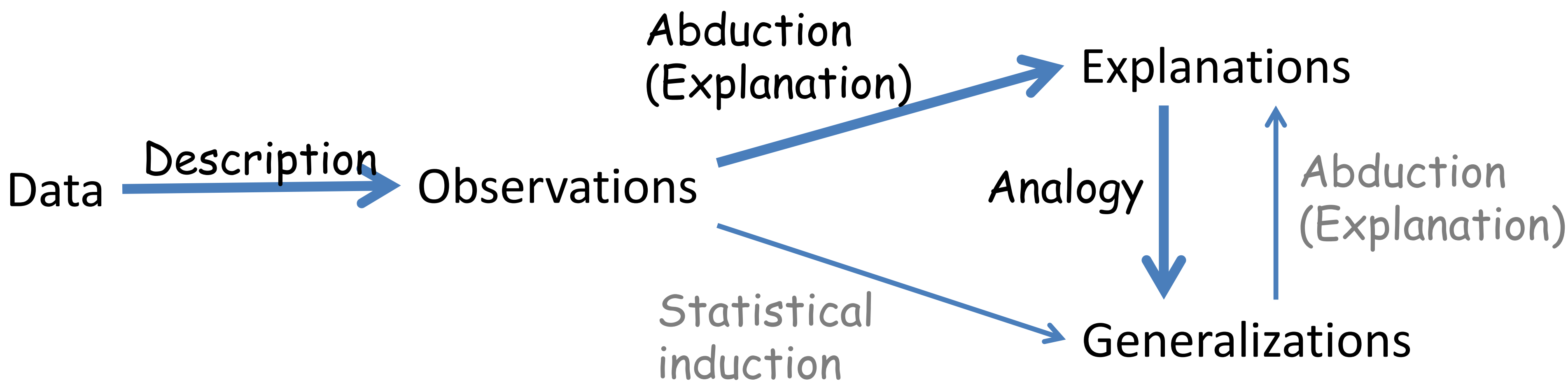
Research setup

Case-based inference design



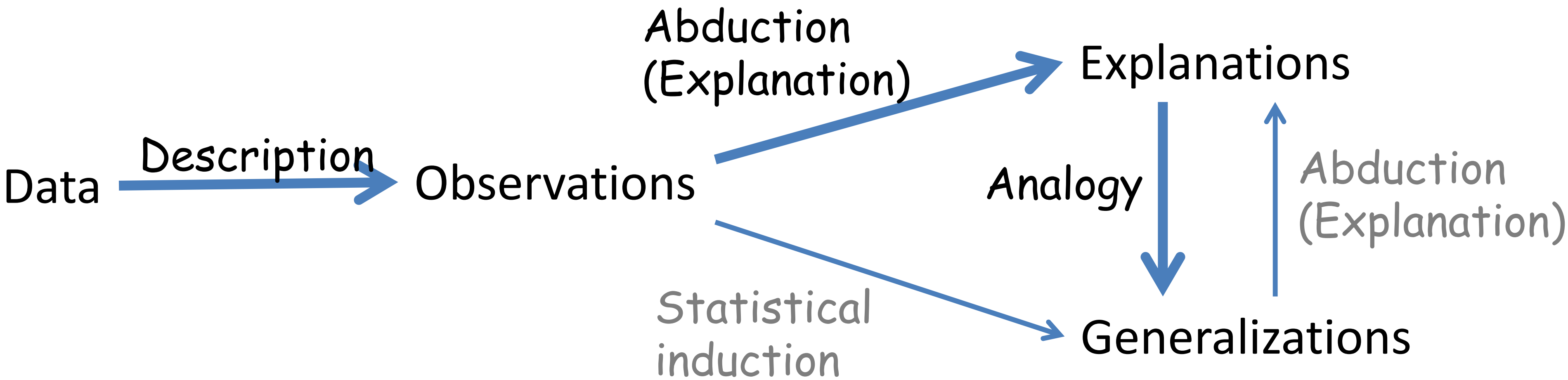
Case-based research

1. Describe
2. Explain in terms of architecture & mechanisms
3. Generalize by architectural analogy

Sample-based research

1. Describe
2. Statistically infer study population properties
3. Explain in terms of variables & causes
4. Generalize to theoretical population by architectural analogy

Case-based inference design



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Sample-based research

1. Describe
2. Statistically infer study population properties
3. Explain in terms of variables & causes
4. Generalize to theoretical population by architectural analogy

Descriptive validity

Internal validity

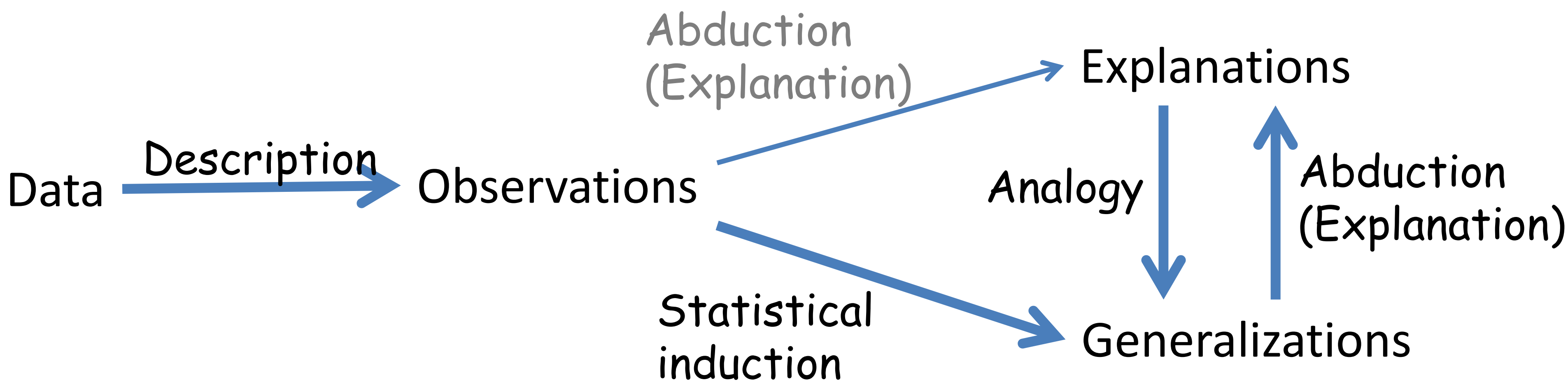
External validity

Validity

- Validity is the degree of support for your inferences
  - It is not the degree of truth of your conclusions

- Validity discussion: discuss all of the possible ways in which your inferences could be wrong
  - Legal reasoning: your opponent will try to undercut all your arguments.

Sample—based inference design



Case-based research

1. Describe
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Sample-based research

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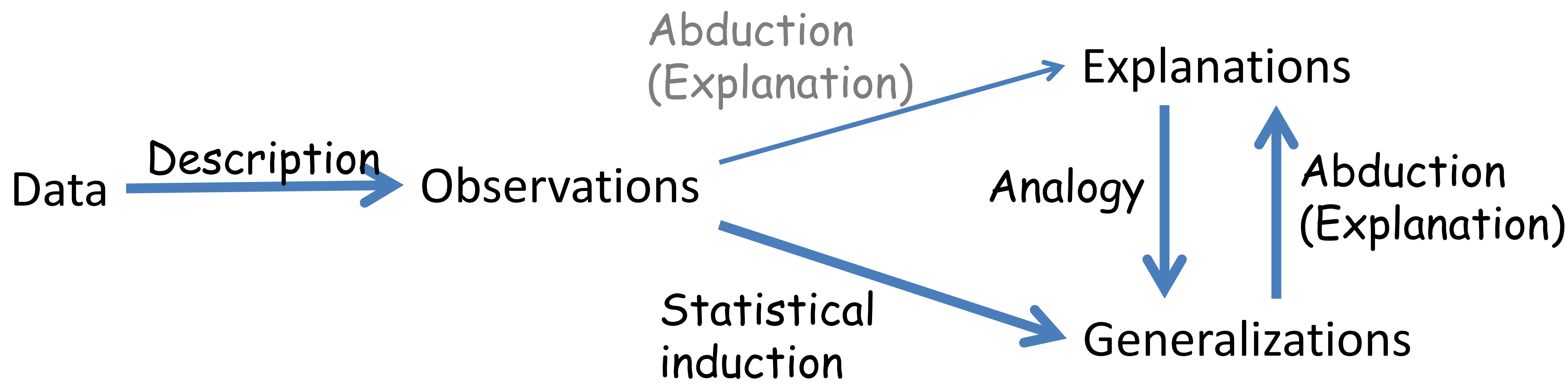
Sample—based inference design



Case-based research

1. Describe

Descriptive validity

Statistical conclusion validity

2. Explain in terms of architecture & mechanisms

Internal validity

3. Generalize by architectural analogy

External validity

Sample-based research

1. Describe
2. Statistically infer study population properties
3. Explain in terms of causes and mechanisms
4. Generalize to theoretical population by architectural analogy

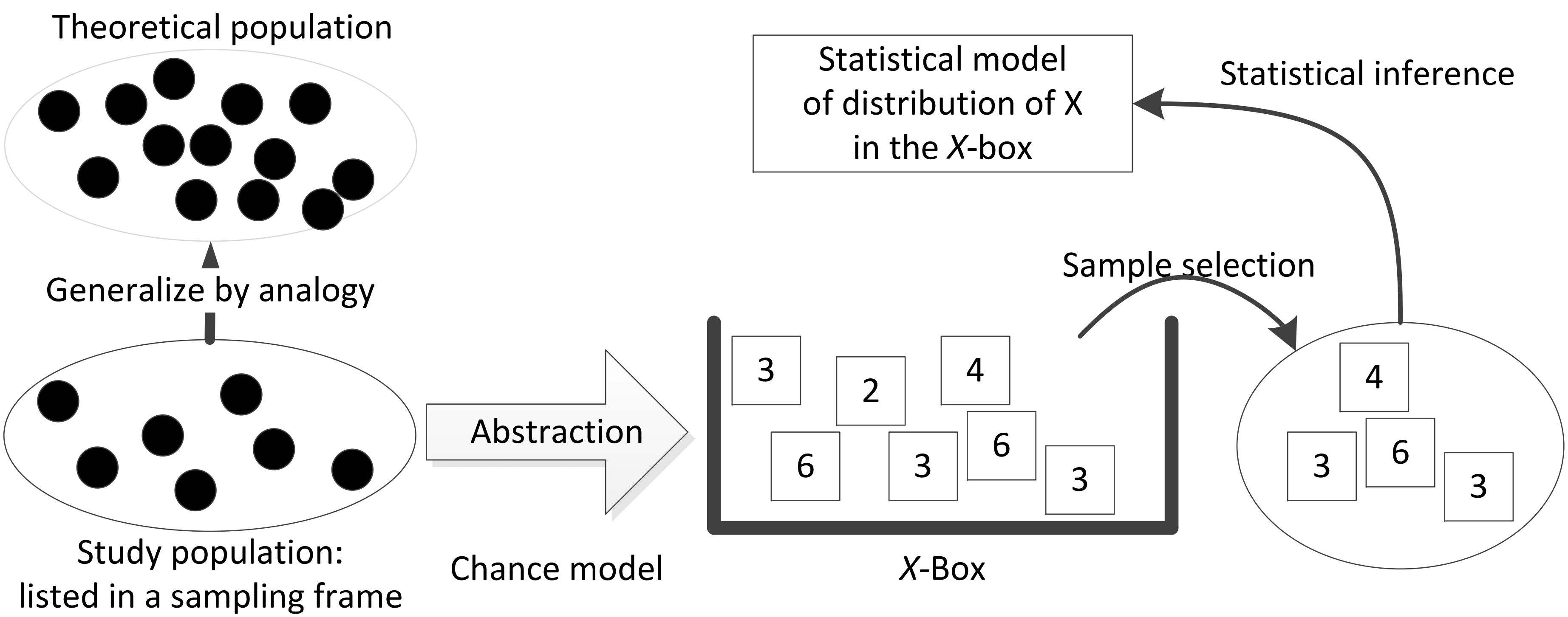
Descriptive inference design

- **Descriptive inference**
  i. Data preparation
     - Deal with missing data, outliers, perform transformations, etc.
  ii. Data interpretation
     - Conceptual analysis of text, images etc., content analysis, grounded theory, etc.
  iii. Summaries
     - Textual, numerical, graphical, qualitative.
- **Descriptive validity**
  – Triangulation (multiple sources, multiple interpretation methods, mutliple coders)
  – Member checking: check with subjects
  – Peer debriefing: check with peers

Statistical inference design

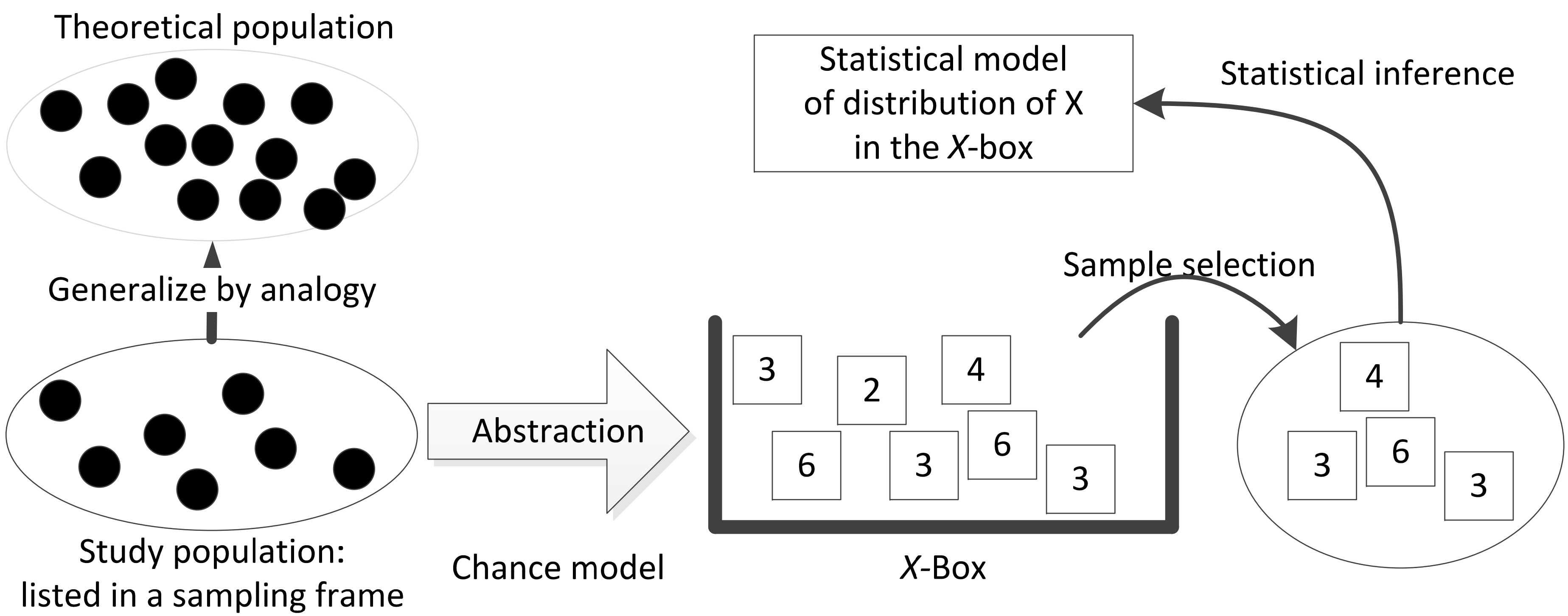
- **Statistical inference**
  – There can be no statistical inference from a sample of one or more case studies

Targets of generalization



- The study population is a subset of the theoretical population.
- What is the basis for generalizing to the theoretical population?
- Can we generalize numerical average and variance to the theoretical population?

Targets of generalization



- Case studies are about the analogies among the bullets

Abductive inference design

- **Abduction**
  - What possible explanations of case phenomena can you foresee?
    - Causes?
    - Mechanisms?
    - Reasons?
- **Internal validity**
  - What justifications of these explanations can you foresee?
  - Prior knowledge (common sense, scientific theories)

Analogic inference design

- **Generalization by analogy**
  - What is the scope of your explanation?
  - Similarity predicate of this class of cases? Shared architecture
- **Analytical induction**
  - Select a series of cases that you expect to confirm/disconfirm your generalization. If expectation is violated,
  - Redefine the similarity predicate to define away the problem or
  - Update the generalization to apply to all cases so far.
- **External validity**
  - Under which assumptions is the generalization justified?

Steps in sample-based research

- Define theoretical population (similarity predicate)
- Define study population (list of elements that serves as sampling frame)
- Define chance model
- Select sample
- Do measurements

1. Describe sample demographics & measurements
2. Statistically infer study population properties (~~test a hypothesis about~~, estimate confidence interval of, population parameter)
3. Explain in terms of causes, and explain causes in terms of mechanisms
4. Generalize to theoretical population by architectural analogy

Steps in case-based research

- Define theoretical population (similarity predicate)
- Select next case (analytical induction strategy)
- Do measurements

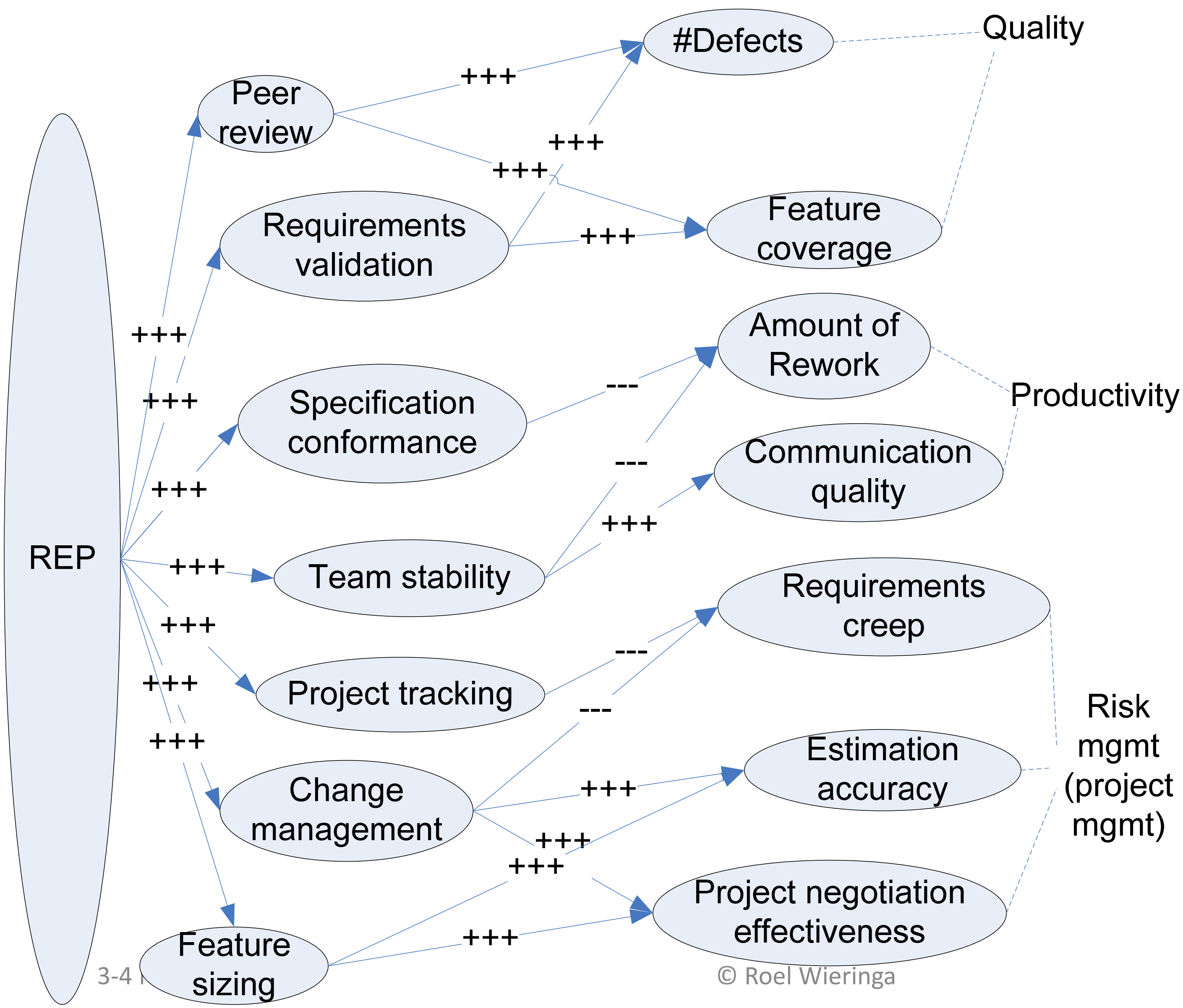
1. Describe case architecture & measurements
2. Explain in terms of architecture & mechanisms
3. Generalize by architectural analogy

Inferences in example observational case study

An Empirical Study of the Complex Relationships between Requirements Engineering Processes and Other Processes that Lead to Payoffs in Productivity, Quality, and Risk Management

Daniela Damian and James Chisan
TSE 32(7) July 2006

Damian & Chisan. RE introduction in a development company. TSE July 2006.

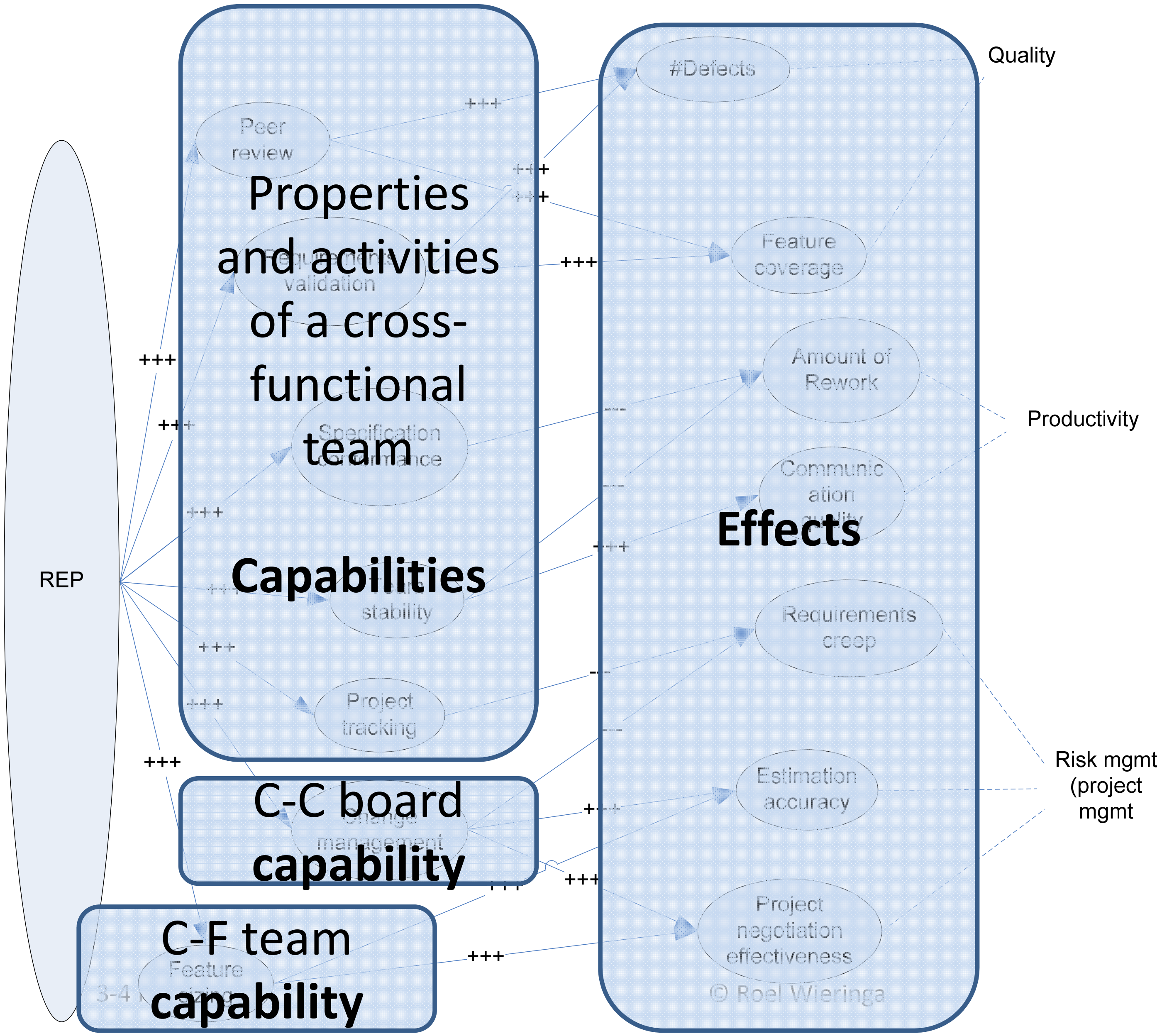


A causal model presented in the paper.

Practioners' opinions!

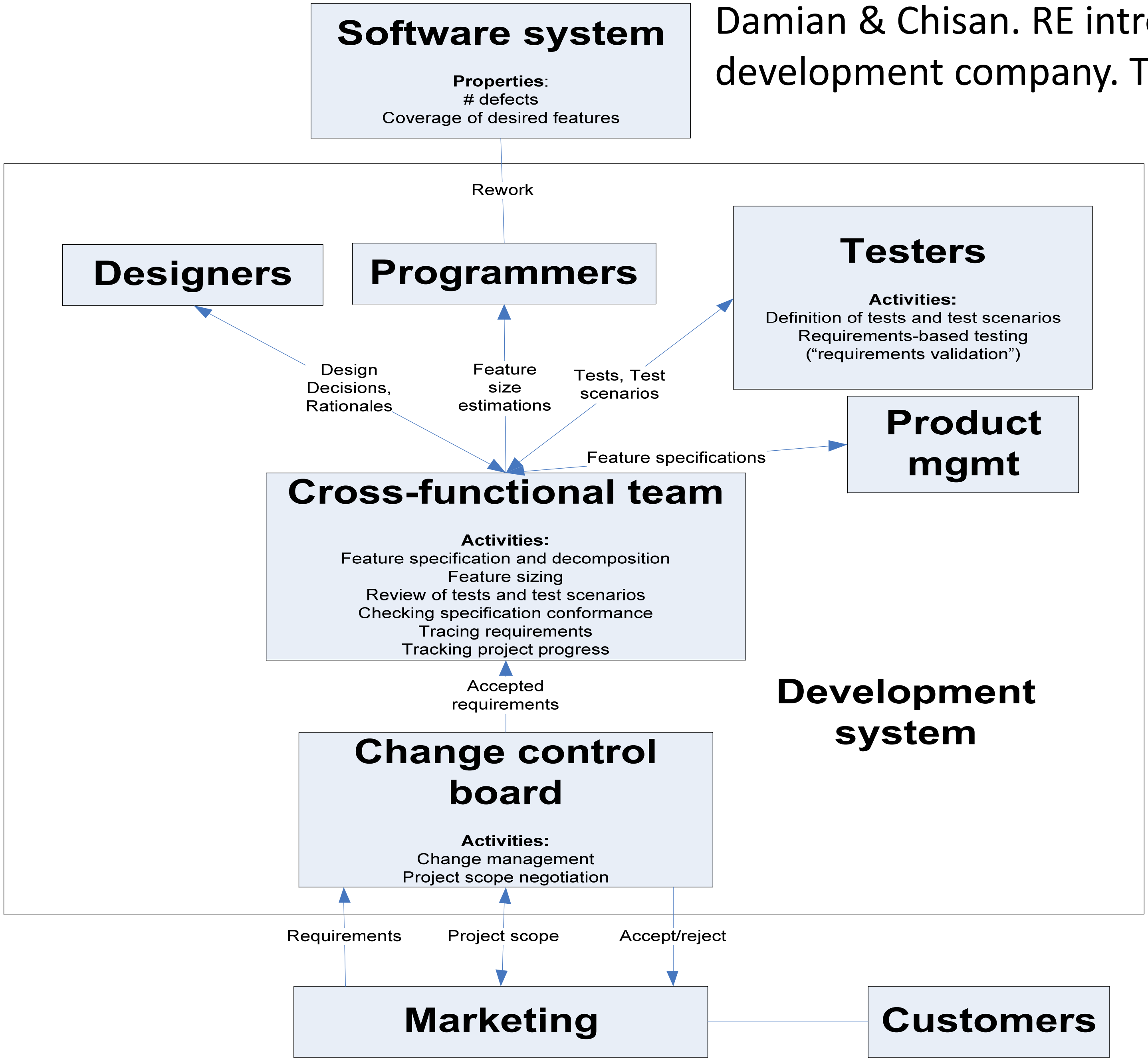
Researcher-observed practitioner-perceived correlations

Damian & Chisan. RE introduction in a development company. TSE July 2006.



The variables characterize the way of working of a cross-functional team, and its effects

Damian & Chisan. RE introduction in a development company. TSE July 2006.



An architectural model constructed from the paper.

Mechanisms that explain improved productivity, quality, risk mgmt:

C-F team

- *improves shared feature understanding,*
- *reduces rework*
-

C-C board

- *prevents requirement creep*

Which inferences can we now support?

- ***Abduction:***
  - *It is plausible that this architecture promotes these mechanisms, which contributed to the effect*
  - *Other mechanisms in this case that may have contributed to these effects:*
    - *New management may have impacted the effect variables as well*
    - *Other processes were changed too*
    - *The product was mature*
- ***Generalization:***
  - *About 150 members, small teams, tech, project, product mgrs*
  - *Ineffective customer communication*

- Need analytical induction to say more

Example Technical Action Research (TAR) study

Morali, A. and Wieringa, R.J. (2010) *Risk-Based Confidentiality Requirements Specification for Outsourced IT Systems.* In: *Proceedings of the 18th IEEE International Requirements Engineering Conference* (RE 2010), 27 Sept - 1 Oct 2010, Sydney, Australia. IEEE Computer Society.

Inference as designed

- ***Descriptive inference***
  - *Diagrams and other work products of applying the method are to be presented*
- ***Abduction***
  - *The production of the outcome (a risk assessment) is explained by the application of the method.*
  - *Treatment (the method) was applied correctly: documenting the method in advance and continuously referring to it during use*
  - *No other mechanism that could account for outcome*
  - *Other explanations: competence of the researcher who applied the method*
- ***Generalization***
  - *Scope: Large organizations; Outsourcing; Significant security department; Obligation to show that company is in control of their information assets.*

Inferences actually done

- ***Descriptions of the sample of OoS***
    - *Some of the produced diagrams are reported*
    - *A few notes from primary documents and interviews are reported.*
- ***Explanations***
    - *All products of applying the method were produced as prescribed by the method; the reason is that the researcher is the author of the method and understands exactly what needs to be done.*
- ***Generalizations***
    - *Assumptions about context that make the scope more specific:*
        - *Industrial organization, very cost-sensitive environment (they often take confidentiality risks in order to save money)*
        - *Other users would need proper tool support*

Day 1

- 9:00
  - What is a case study
  - When to use case studies
- 10:30 Break
- 10:45
  - Scientific theories
- 12:15 Lunch
- 13:45
  - Scientific theories
- 15:15 Break
- 15:30
  - Exercises, discussion (questions to chapters 8 and 9)
- 17:00 End of day 1

Day 2

- 9:00
  - Empirical research cycle
- 10:30 Break
- 10:45
- **Case-based inference**
  - **Inference design**
  - **Validity**
- 12:15 Lunch
- 13:15
  - Exercise (Make a case-based design of your research)
- 14:45 Break
- 15:00
  - Assignments, discusssion, wrapup (checklist application to two papers)
- 16:30 End of day 2

Validity

- Research setup must be valid wrt planned inferences
- Inferences actually done must be valid wrt research setup

Validity of research setup

- Inference support
  - What inferences can be supported by this research setup?
- Repeatability
  - Can other researchers repeat this research?
- Ethics
  - Does the setup satisfy ethical norms? (informed consent, no harm, fairness, confidentiality etc.)

Validity of inferences

- See chapters 12 (descriptive inference), 14 (abductive inference), 15 (analogic inference)
- Summarized in checklist B, http://wwwhome.cs.utwente.nl/~roelw/Springer-Appendix-B.pdf.

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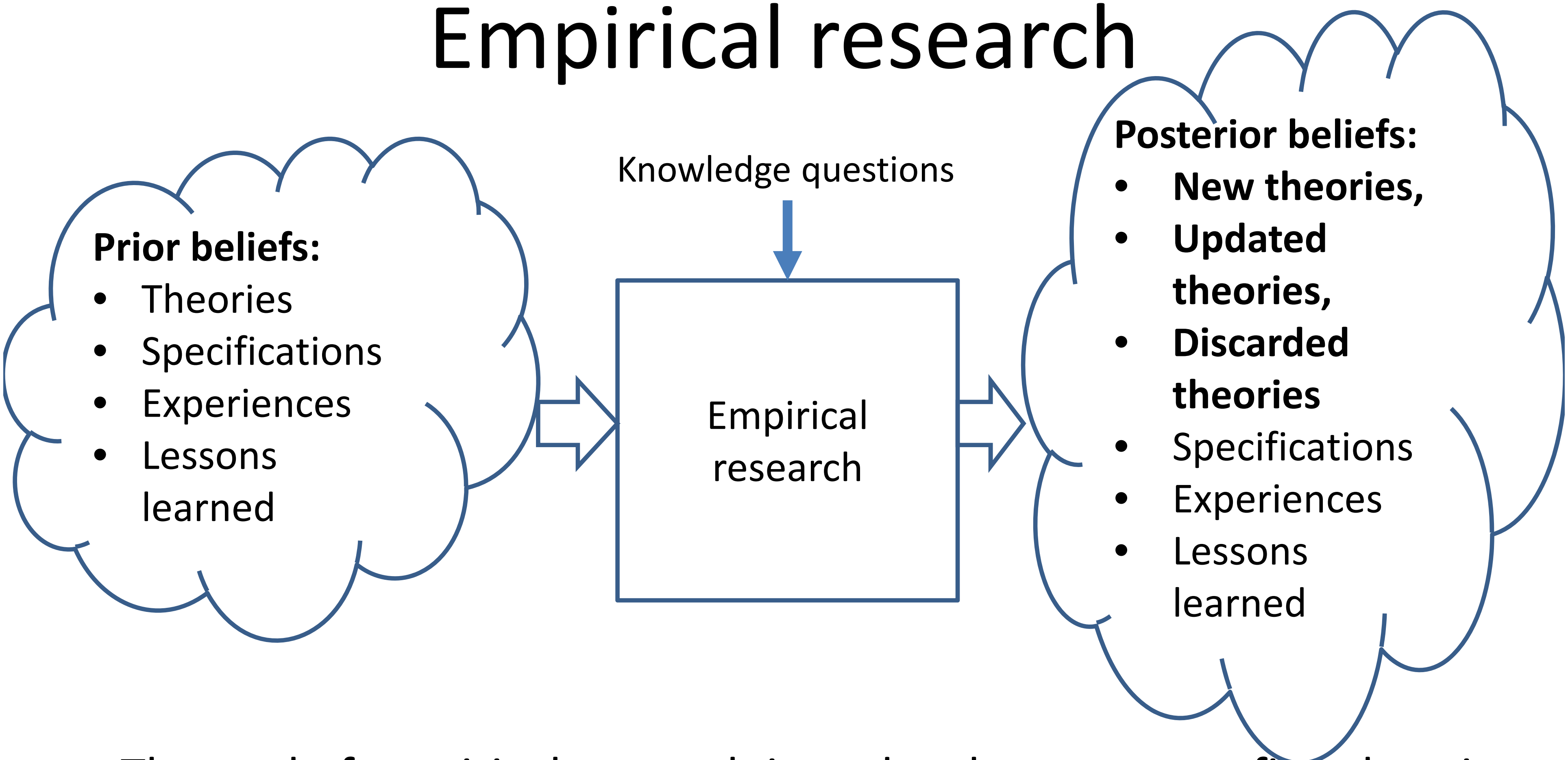
Nutshells

- A **case study** is the study of a system in the field.
- The **conceptual framework** of a case study should define the case architecture.
- Conceptual frameworks should be assessed on their **construct validity**.
- An **architecture** consists of components that have behavioral capabilities and can interact.
- An **architectural mechanism** is an interaction among case components that produce a response from a stimulus.
- **Theories** of a case should aim to describe, explain or predict system-level phenomena in terms of architectural mechanisms.
- Knowledge questions can be answered scientifically by following the **empirical cycle**
- **Research setup** can be case-based vs sample-based, and observational vs experimental.
- Observational case studies, technical action research
- **Inferences** in case-based research: descriptive, abductive, analogic
- Case selection strategy: **Analytical induction**
- **Validity** is the degree of support for your inference.
- Checklist for empirical research

Empirical research



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

Rules of the empirical research game

- **Rule of posterior knowledge**: Beliefs created by the research are present *after* execution of the research, and are absent before executing the research.
  - *E.g. formulating hypotheses after the fact, and reporting that you had them before*

- **Rule of prior ignorance**: Any beliefs present *before* doing the research may influence the outcome of the research.
  - *E.g. believing that the tested technique is better than its alternatives*

- If you violate these rules, you cheat yourself and your readers

Discussion

- Make a case-based design of your research
- Summarize on a flip-over

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Assignments

Deadline 7 december

- Read the papers
  - Daniel Karlström, Per Runeson:
    Integrating agile software development into stage-gate managed product development. Empirical Software Engineering 11(2): 203-225 (2006)
  - Lutz Prechelt, Alexander Pepper:
    Why software repositories are not used for defect-insertion circumstance analysis more often: A case study. Information & Software Technology 56(10): 1377-1389 (2014)
- Apply the checklist for empirical research to each of them
  - Be sure to distinguish prior theories and posterior theories of the authors
  - If a piece of information is missing, say so, and indicate whether you think it should/need not have been included, and why

- 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) *Design science methodology for information systems and software engineering.* Springer Verlag

- Wieringa, R.J. (2014) *Empirical research methods for technology validation: Scaling up to practice.* Journal of systems and software, 95. pp. 19-31.

- Wieringa, R.J. and Morali, A. (2012) *Technical Action Research as a Validation Method in Information Systems Design Science.* In: *Design Science Research in Information Systems. Advances in Theory and Practice 7th International Conference*, DESRIST 2012, 14-15 May 2012, Las Vegas, USA. pp. 220-238. Lecture Notes in Computer Science 7286. Springer.

- Wieringa, R.J. (2010) *Relevance and problem choice in design science.* In: *Global Perspectives on Design Science Research (DESRIST). 5th International Conference*, 4-5 June, 2010, St. Gallen. pp. 61-76. Lecture Notes in Computer Science 6105. Springer.

- Wieringa, R.J. (2009) *Design Science as Nested Problem Solving.* In*: Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology*, Philadelphia. pp. 1-12. ACM.