Theory-guided information systems engineering

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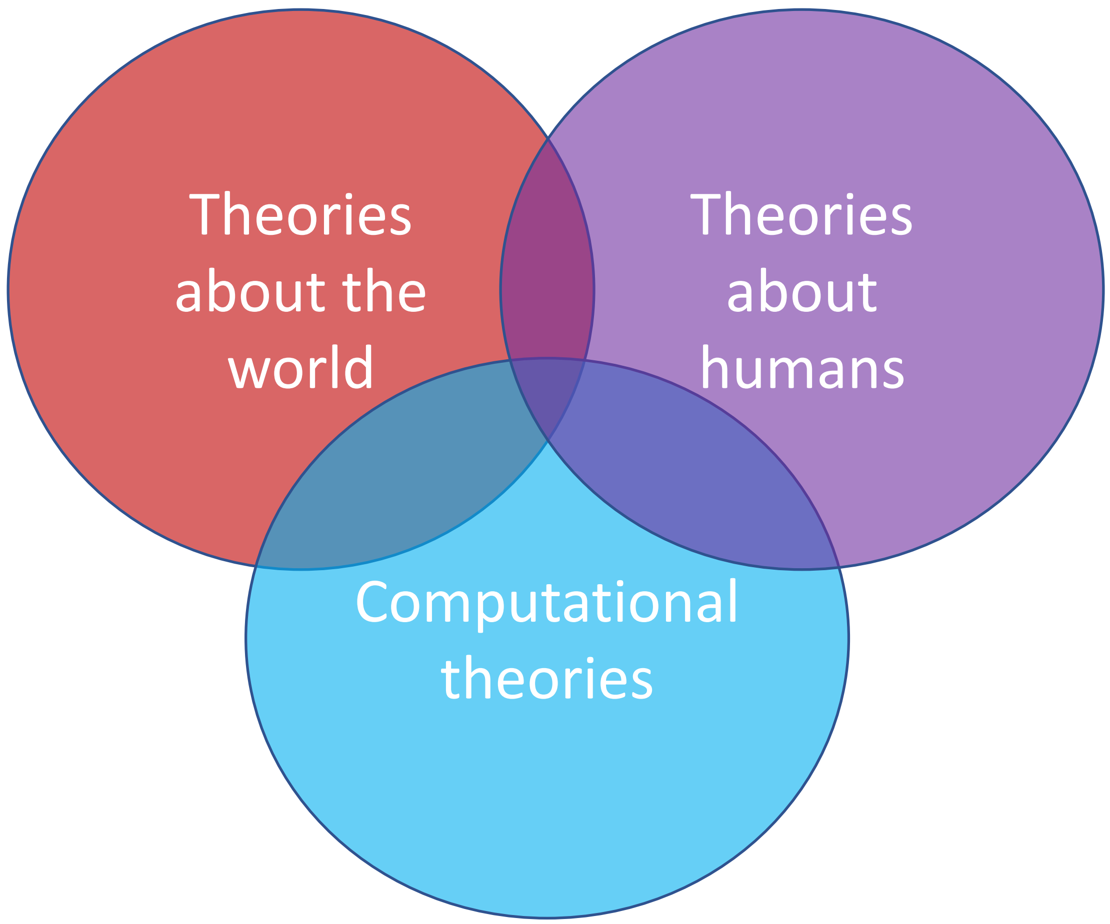
CAiSE

Zaragoza, June 2023

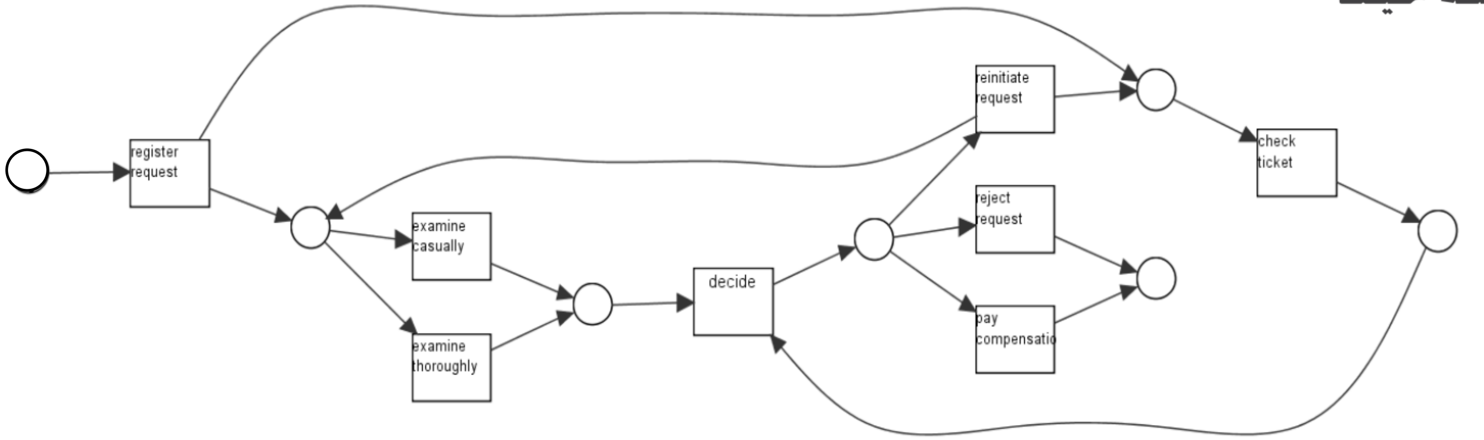
Information Systems: Cyber-human systems

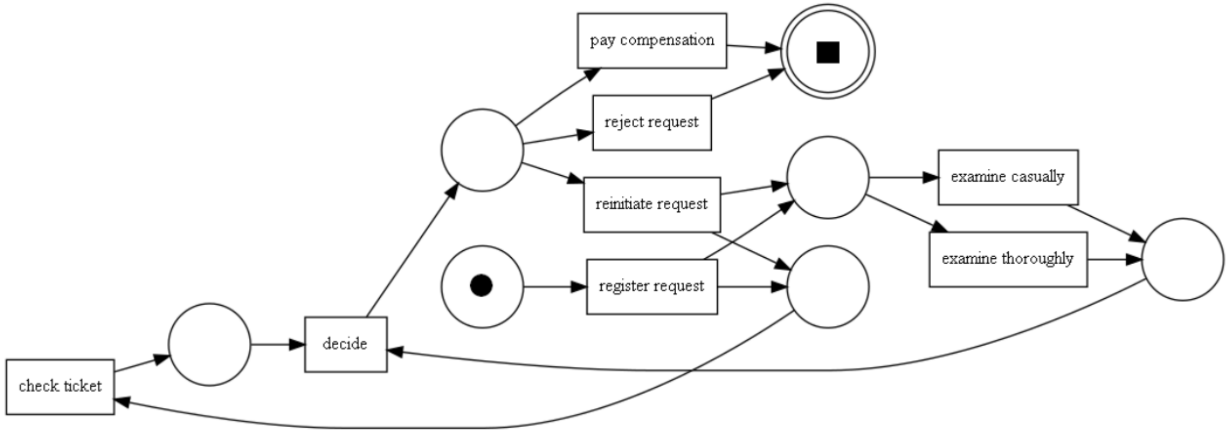


Agenda

- Why human-related theories matter for ISE
- Kinds of human-related theories
- Human-related theories in behavioral science and in design science
- Existing theories and their use along the design science process
  - Focusing on the domain of modeling and visual representations
- Two examples of my theory-guided work
  - Theory-guided artifact design: Workaround-inspired process improvement
  - Theory-guided data exploration: The process of process mining
- Research opportunities
- Challenges

Example


register request
examine casually
examine thoroughly
decide
reinitiate request
reject request
pay compensatio
check ticket


pay compensation
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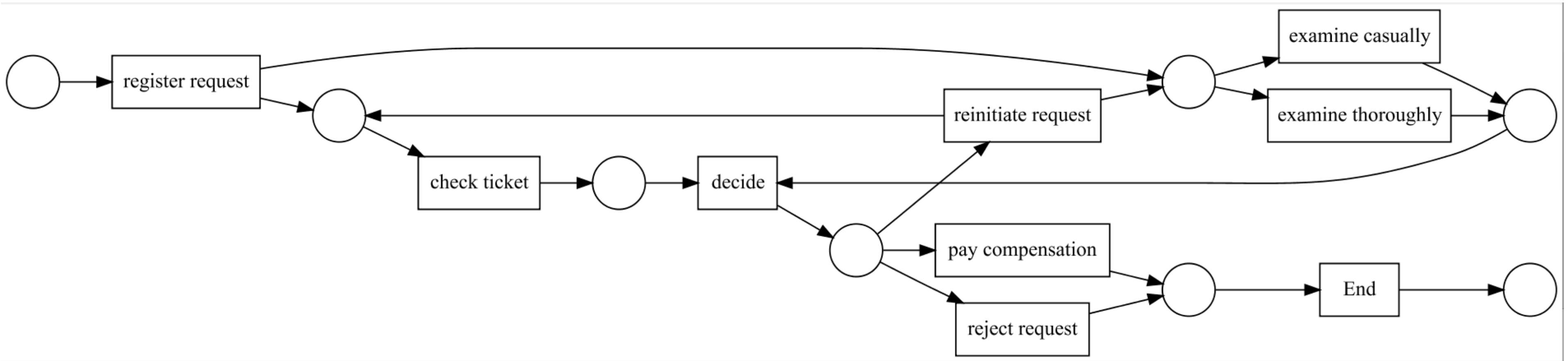
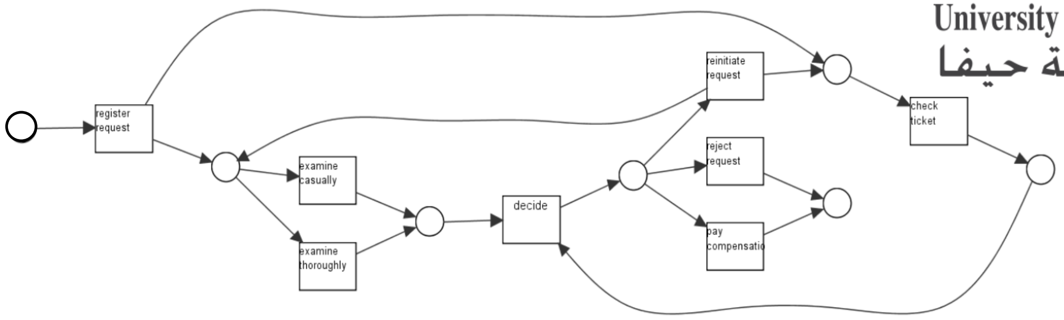
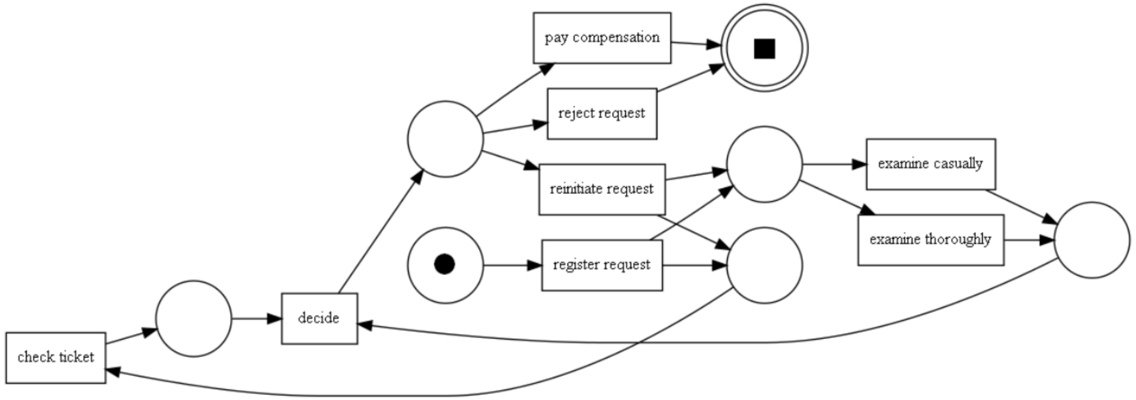
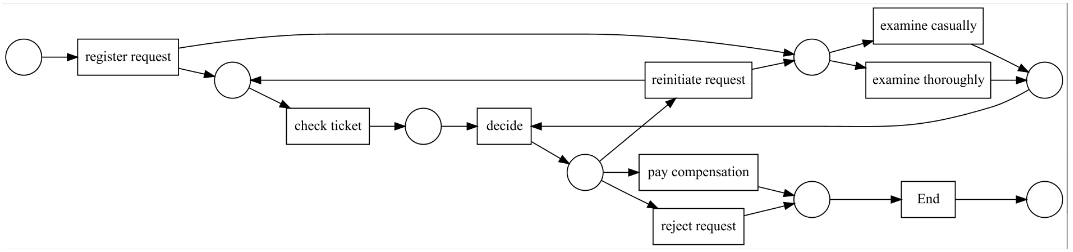

register request
reinitiate request
examine casually
examine thoroughly
check ticket
decide
pay compensation
reject request
End

- The three Petri nets are automatically generated by process discovery techniques
- Are completely identical semantically
- Have identical values of process discovery metrics: fitness, precision, generality, simplicity

- Are they identical in satisfying the goal of process discovery?
  - To provide a human-readable visual representation of the behavior captured in a log







To design artifacts for humans we need to understand human needs

5 types of theories in IS

(Gregor & Jones, 2007)

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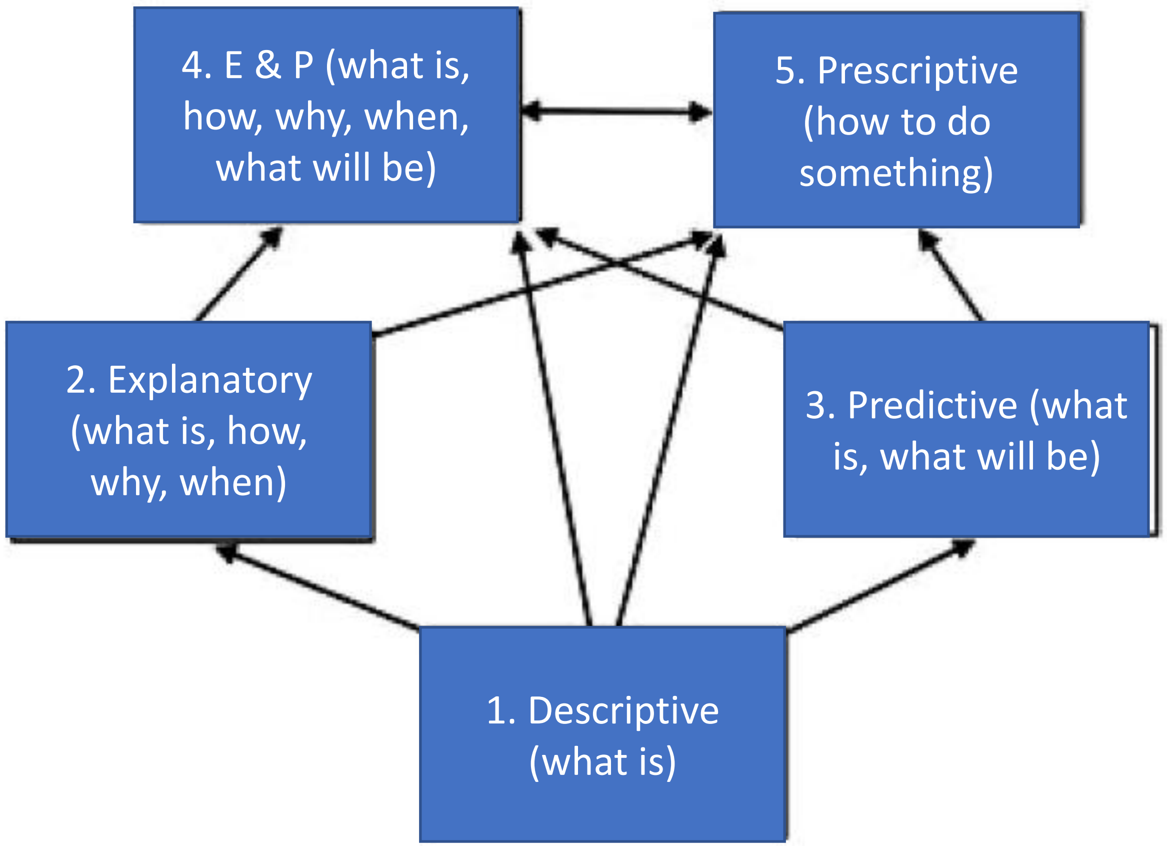
1. Theory for analyzing / describing (correlations, observations)
2. Theory for explaining (establish causality)
3. Theory for predicting (what will happen if – can be tested)
4. Theory for explaining and predicting (prediction based on causality)
5. Theory for design and action (prescription) – a special case of predictive theory concerning an artifact



Gregor, S. Jones, D. (2007). The anatomy of a design theory. *Journal of the Association for Information Systems*, *8*(5), 1.

A theory is developed

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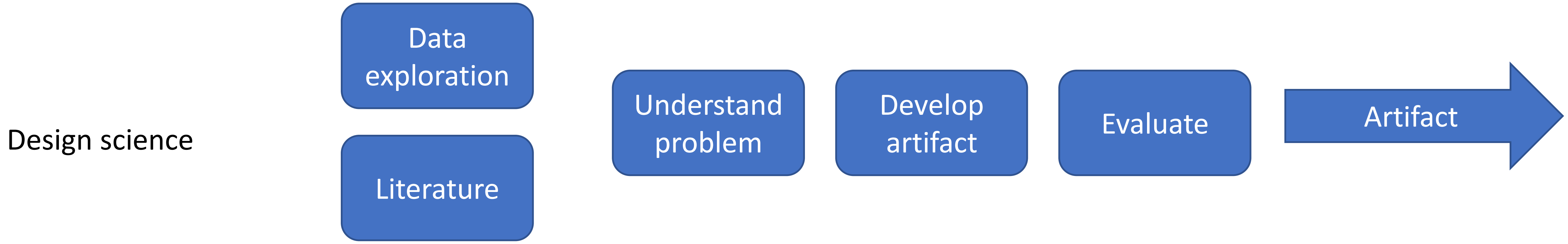
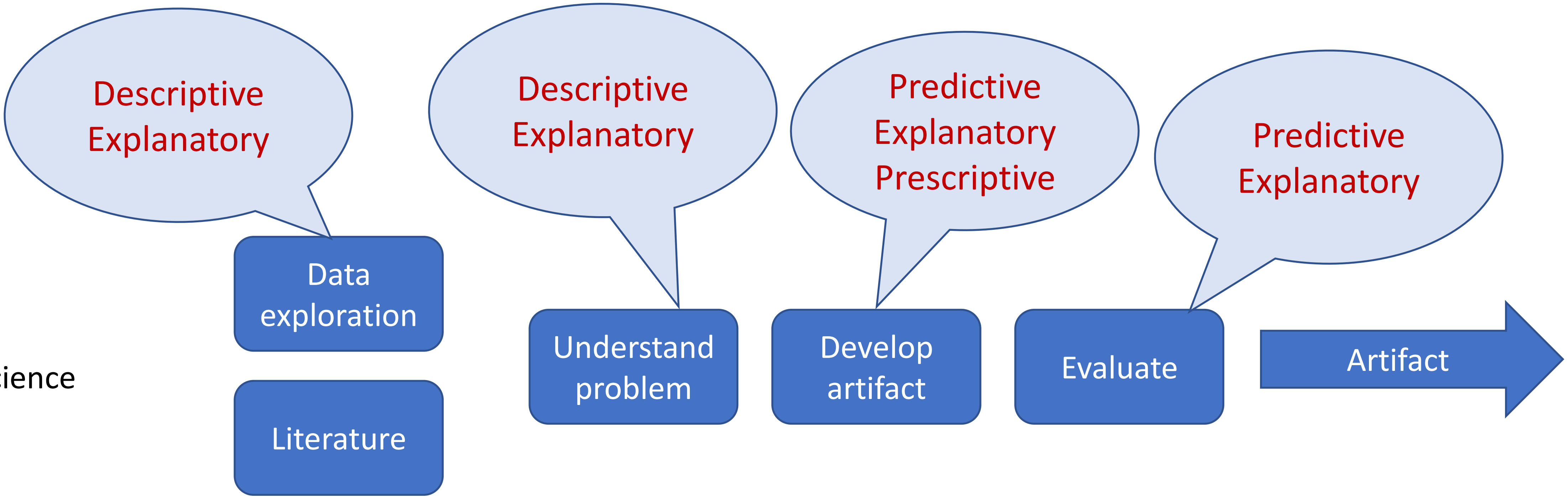
An artifact is developed



How theories can support design science



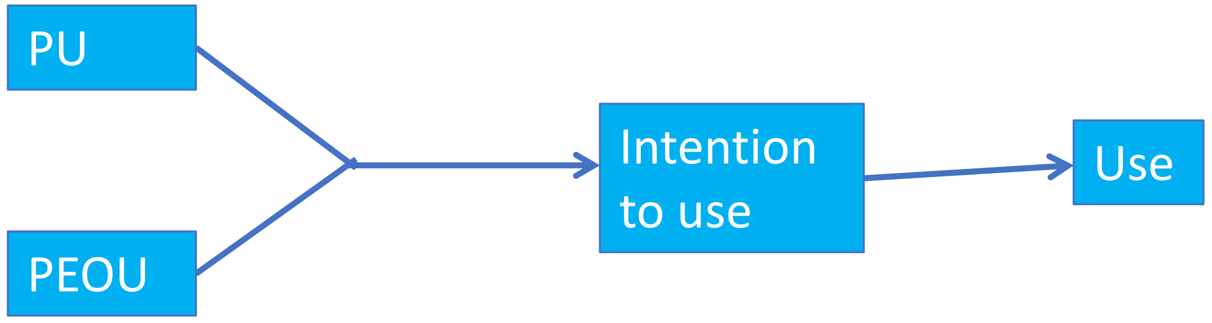
Design science

Technology Acceptance Model (TAM)

(Davis, 1989)

An individual’s intention to use a technology is determined by two major variables:

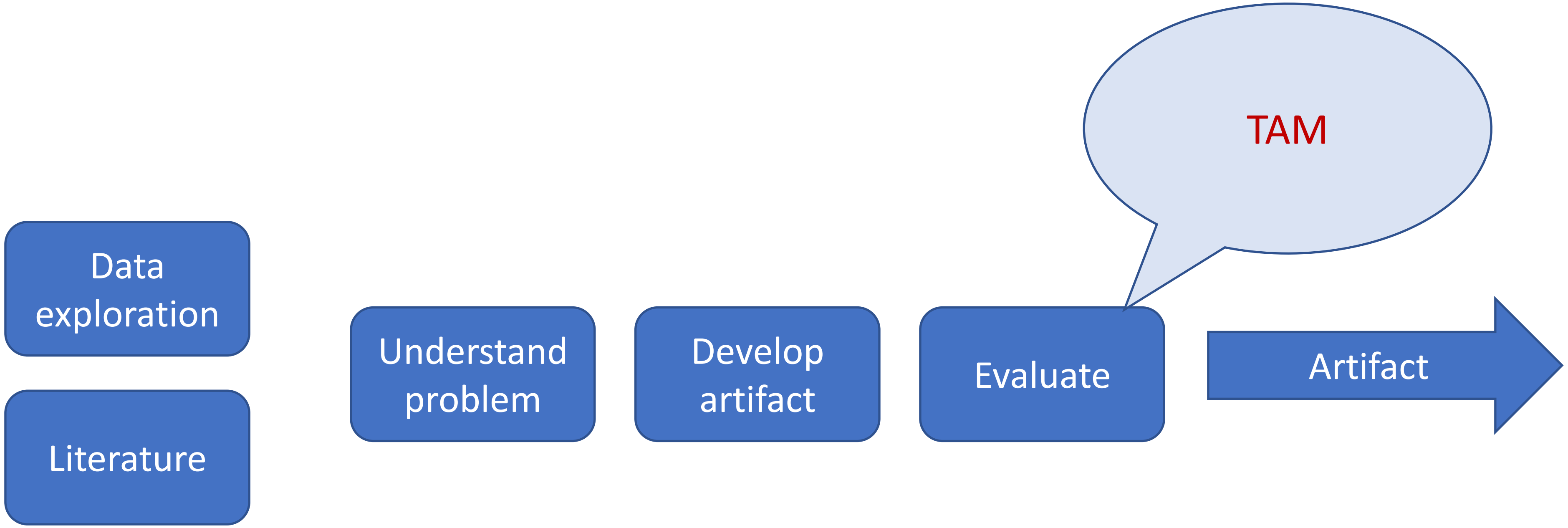
- Perceived Usefulness (PU)
- Perceived Ease of Use (PEOU).



Davis, F.D. (1989) “Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology” MIS Quarterly 13(3), pp. 319-340.

How theories can support design science

Design science

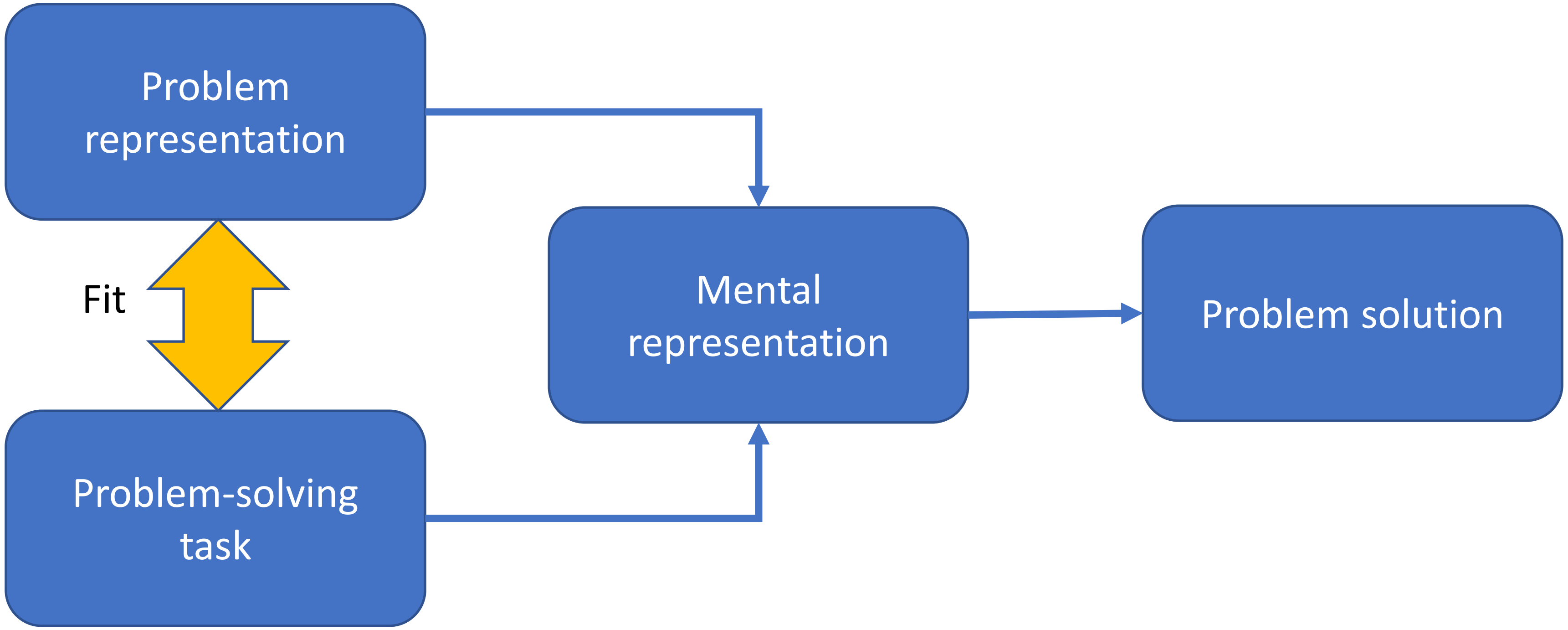


Artifact domain: information representation

- Models
- Modeling notations
- Visualization
- Diagrams, graphs

Cognitive Fit Theory

(Vessey, 1991)

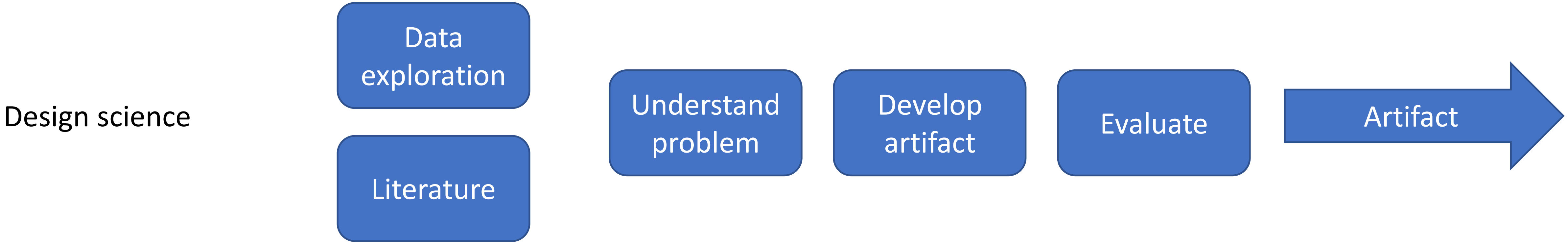


- A high fit between the problem representation and the problem-solving task will result in a high problem solution performance
  - Supporting the creation of a mental representation

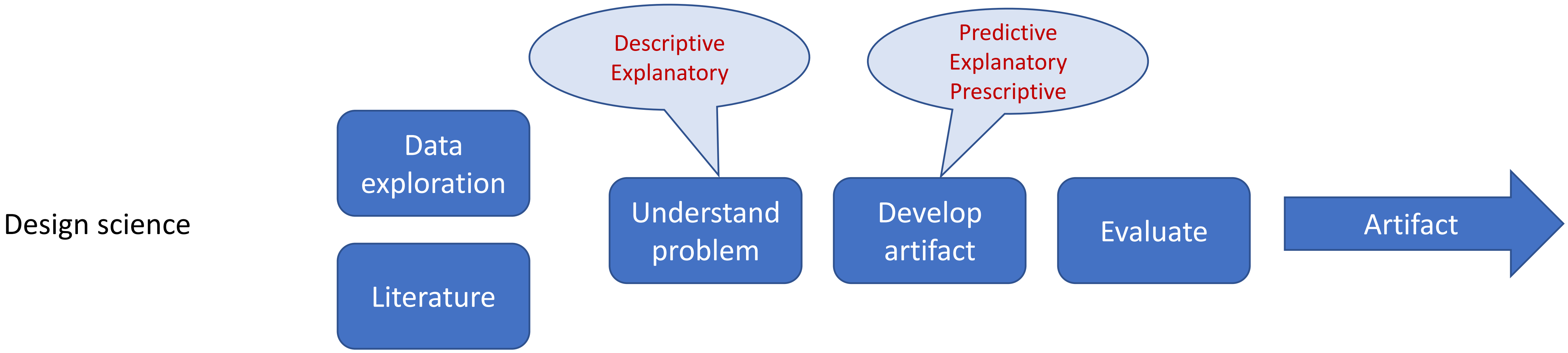
Vessey, I. (1991). Cognitive fit: A theory-based analysis of the graphs versus tables literature. *Decision sciences*, *22*(2), 219-240.

How theories can support design science

- Where does Cognitive fit theory fit?



How theories can support design science



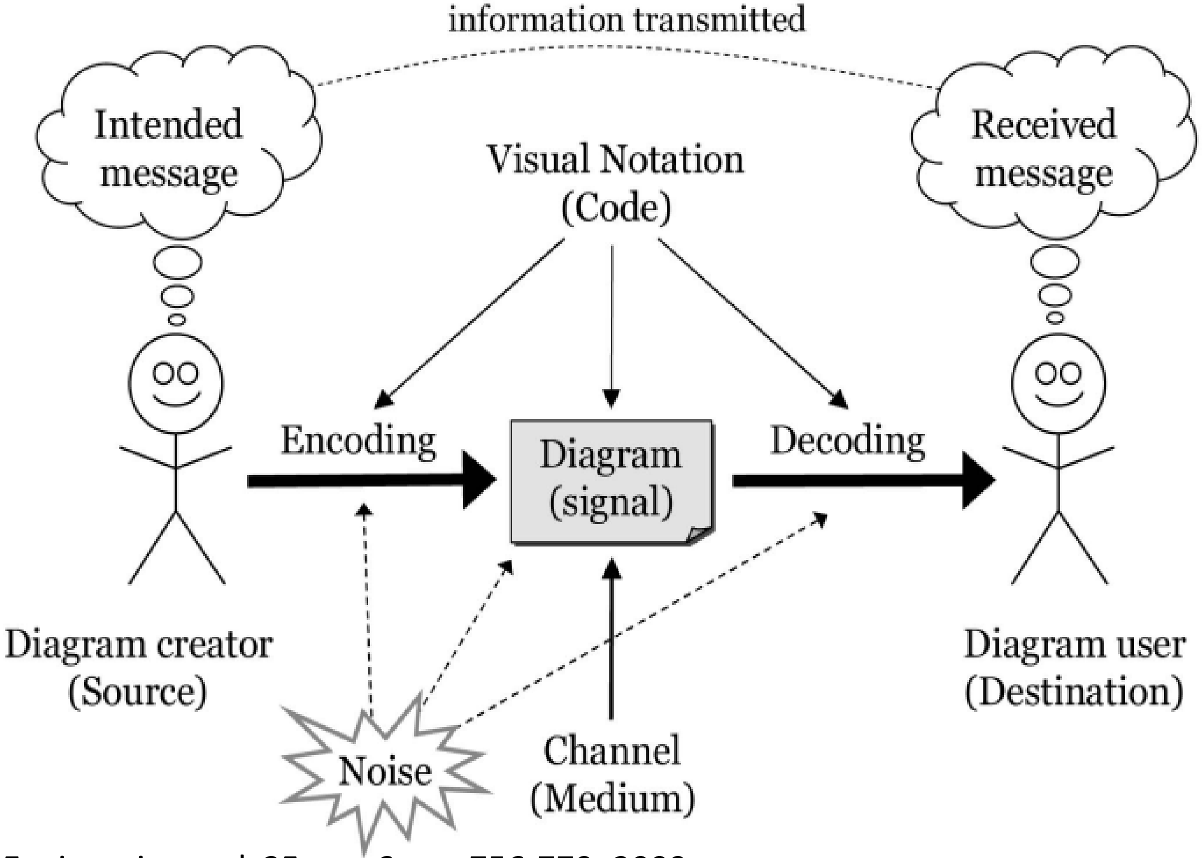
- Design develops solutions to problems
- “Solving a problem simply means representing it so as to make the solution transparent” (Herbert Simon)

For a theory to support artifact development it should be operationalized and specialized into relevant terms

The “Physics” of Notations

Moody, 2009

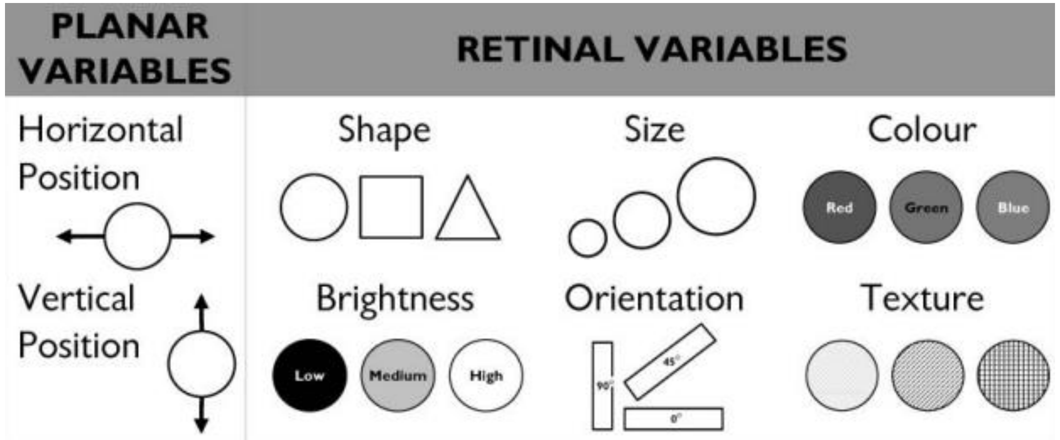
- Aim: **a design theory** for visual modeling notations
- Starting point: an explanatory theory of *how* and *why* visual notations communicate
    - Creating a specialization of Shannon & Weaver’s Theory of Communication



D. Moody, IEEE Transactions on Software Engineering, vol. 35, no. 6, pp. 756-779, 2009

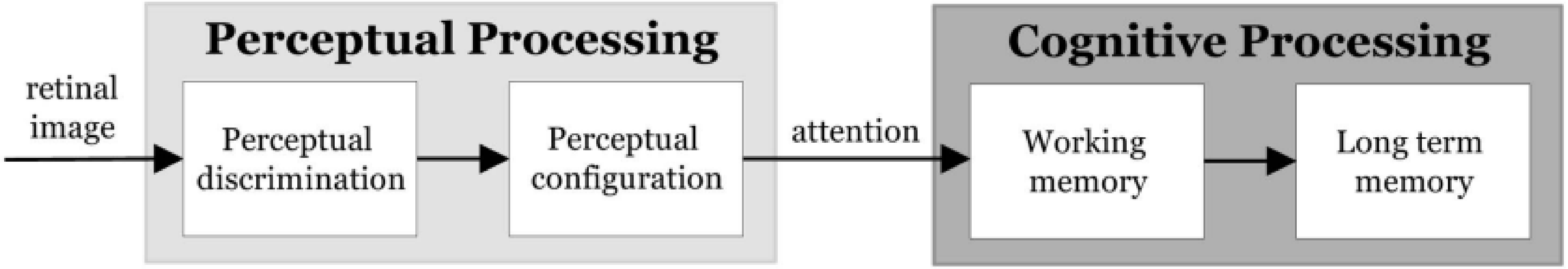
Further decomposition => operationalization

- Encoding space – (visual notation) in terms of 8 visual variables and their relations, distinguishing primary/secondary notation



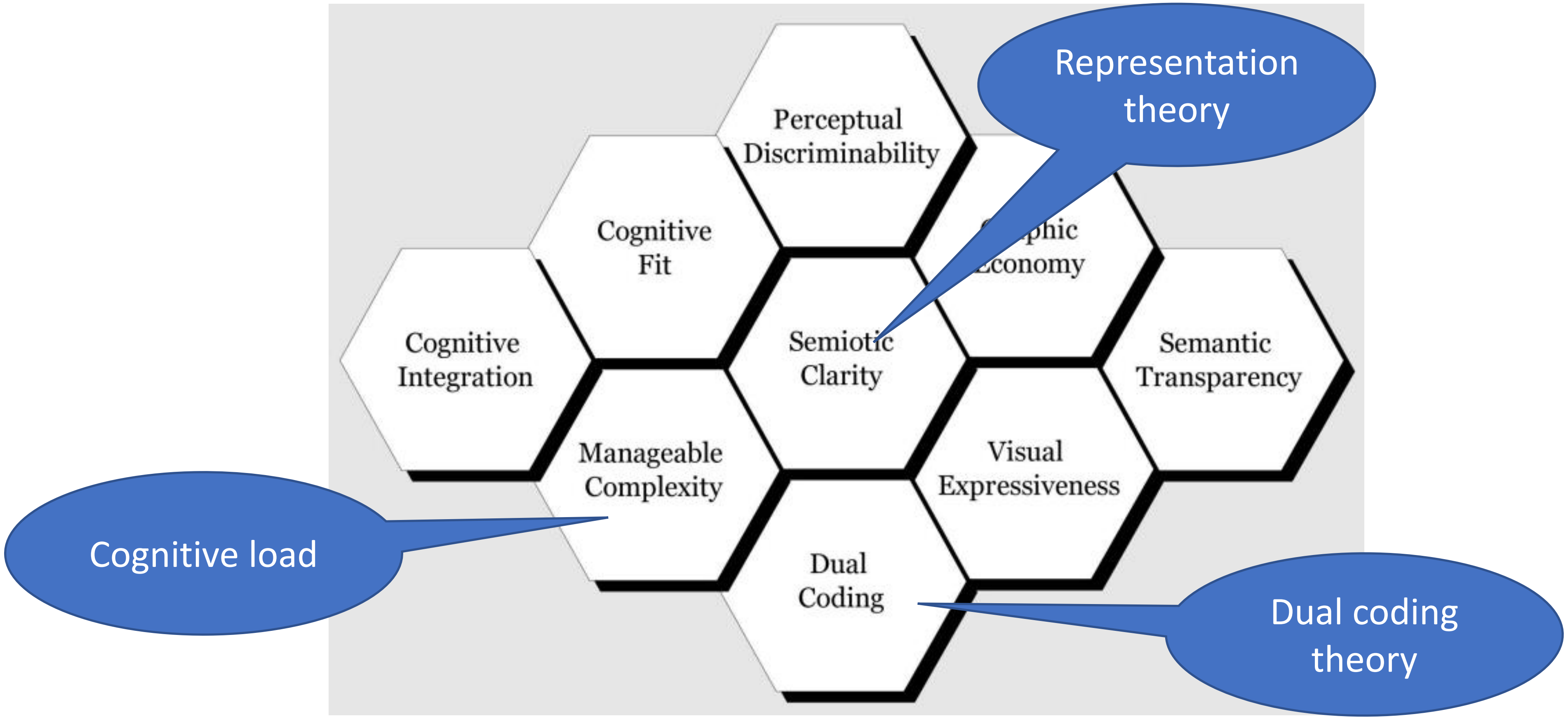
Bertin, J. (1983). *Semiology of graphics*. University of Wisconsin press.

- Decoding space – based on human information processing (Newell and Simon, 1972) – with elements associated to relevant theories



Creating a prescriptive design theory:

- Based on 9 principles derived from theories associated to decoding space elements
- Each principle is operationalized in terms of visual variables and their manipulations

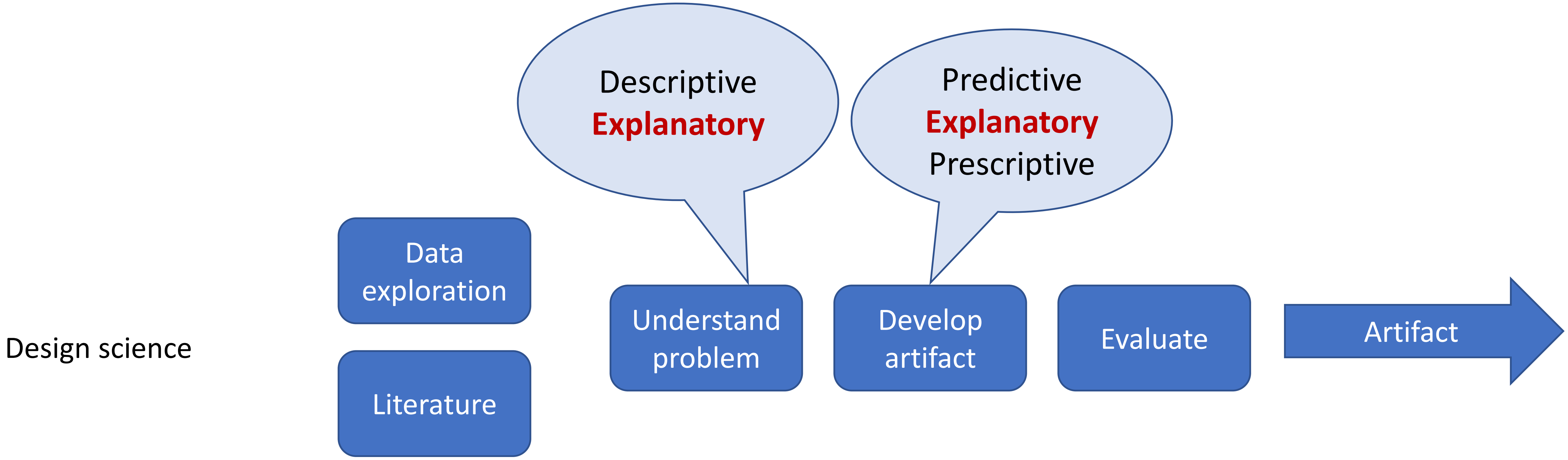


Is this all we need?

- The Physics of Notation is not perfect
  - Trade-offs among principles
  - Applicability issues
  - Need tailoring for specific purposes
- **BUT it has been used for supporting notation design**
- Additional theories exist for broader purposes (visualizations, diagrams)
  - Providing concrete operationalization of explanatory / predictive theories
  - With derived design guidelines
  - Example: CogniDia
    - Explains understanding and task performance with diagrams
    - Extends the cognitive explanatory theory
    - Provides operational criteria for effective cognitive processing of diagrams and practical guidelines

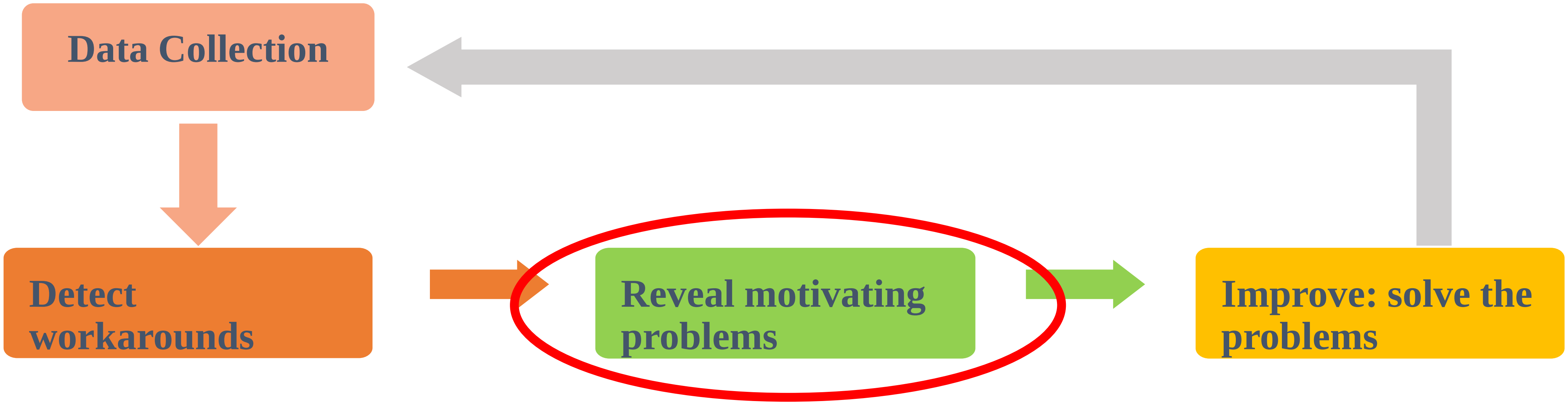
Van der Linden & Hadar (2018) A systematic literature review of applications of the physics of notations. IEEE TSE
Malinova and Mendling (2021) Cognitive diagram understanding and task performance in systems analysis and design. MIS Quarterly

How theories can support design science

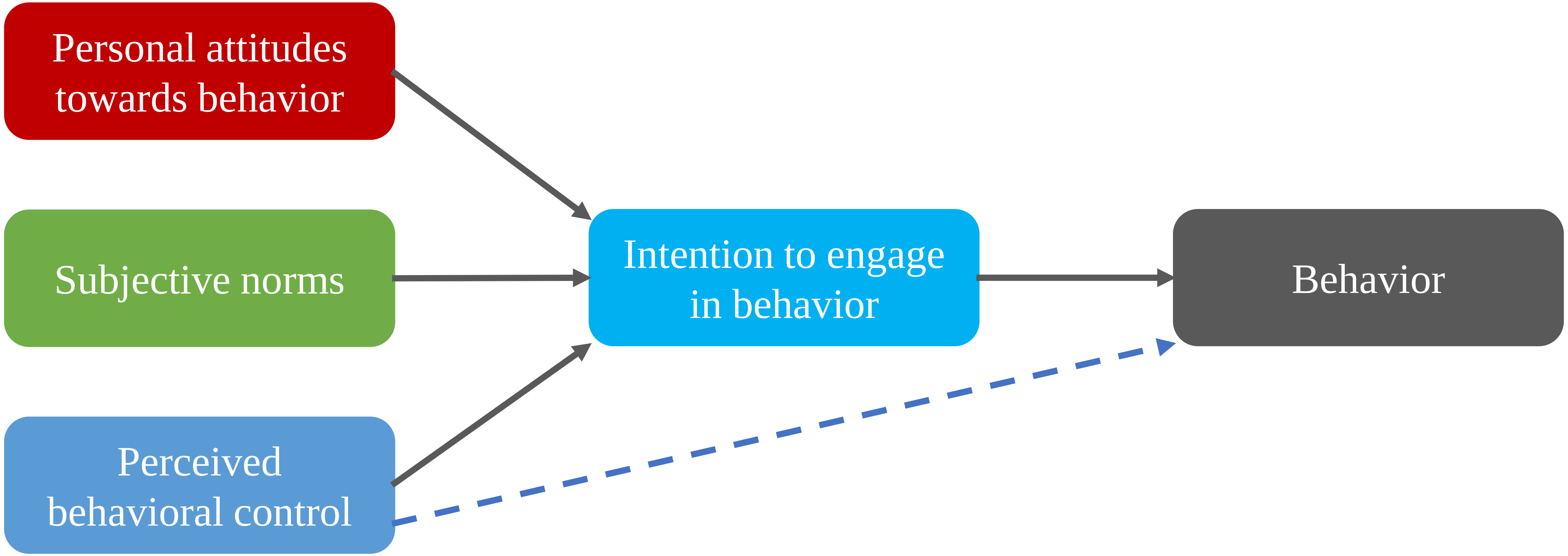


Workaround-inspired process improvement Based on the Theory of Planned Behavior

- Aim: to develop a method for process improvement based on workarounds
  - This is not new
- Current methods base improvements on observed workarounds
  - May be risky
  - May be suboptimal in global terms
  - Is only one possible solution of an underlying problem



Theory of Planned Behavior



Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179-211.

Specialization of TPB for workaround intentions

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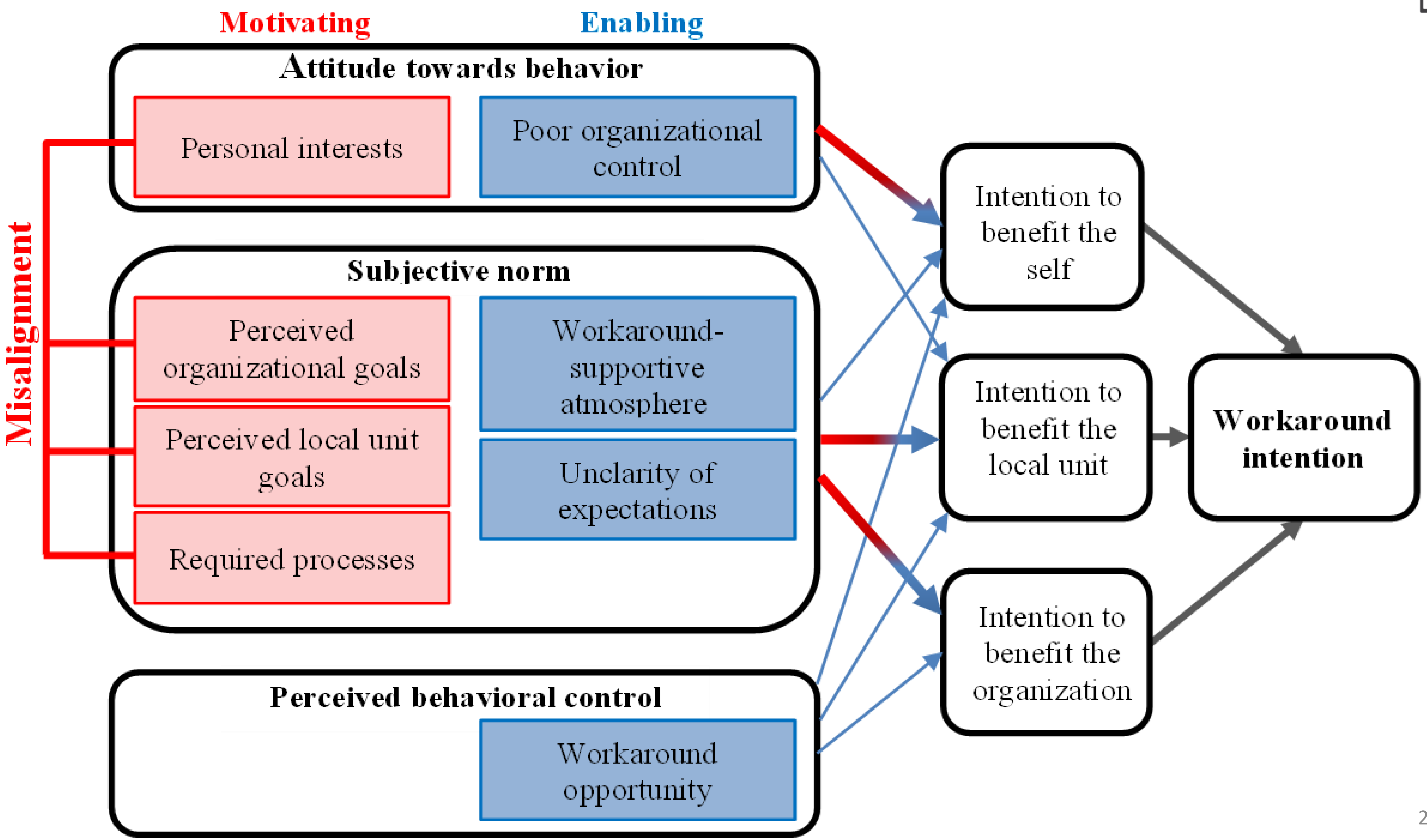
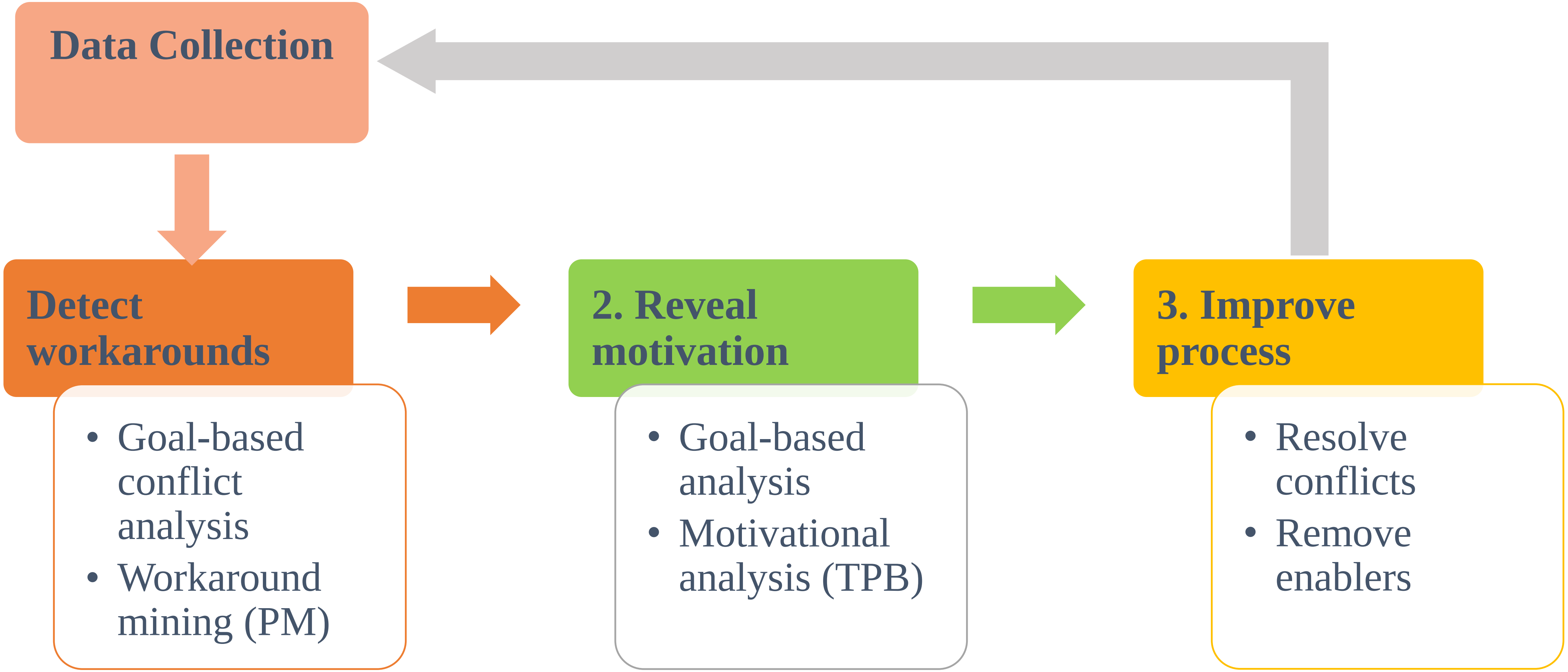


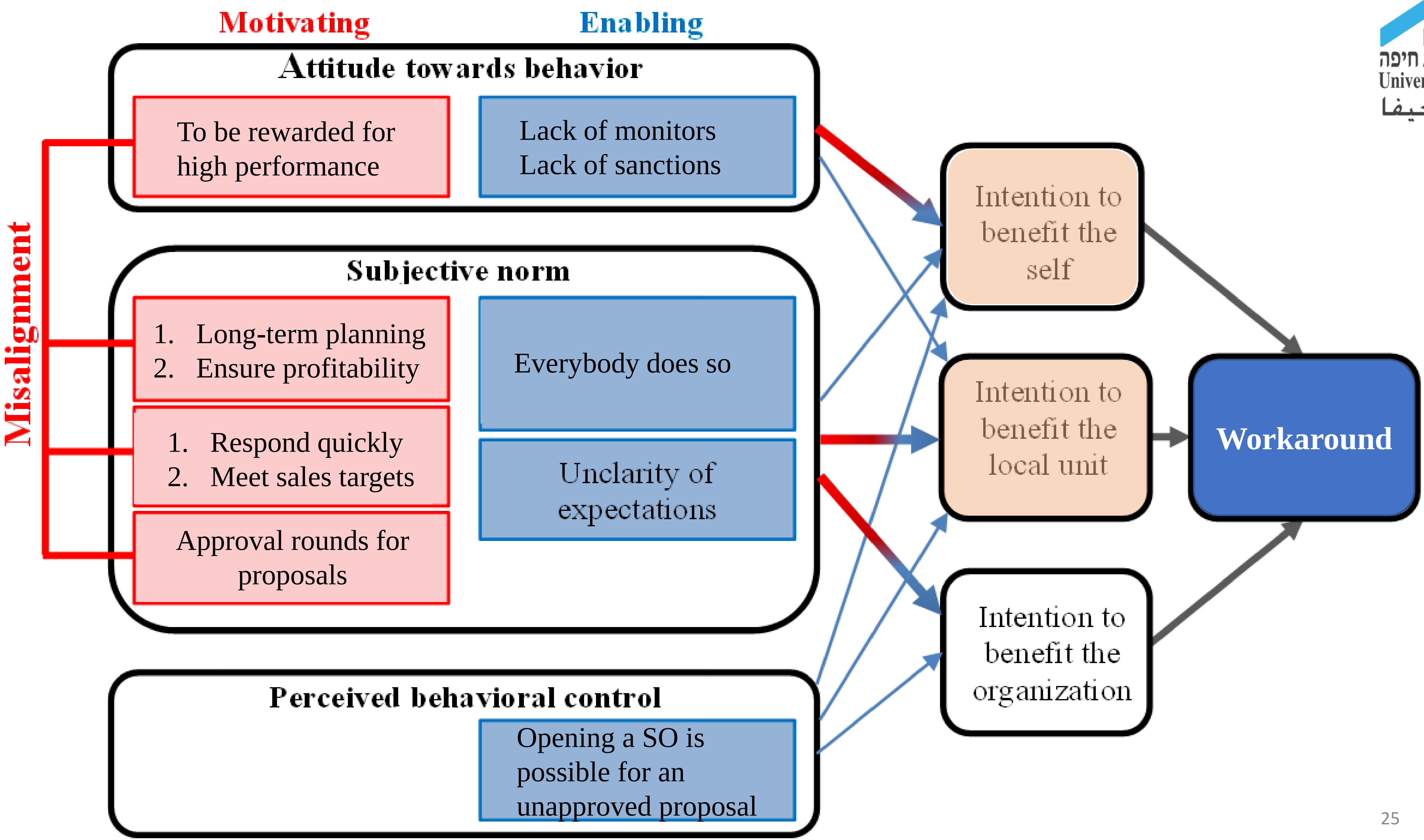
Process improvement cycle



van der Waal et al.(2022). The SWORD is Mightier Than the Interview: A Framework for Semi-automatic WORkaround Detection. BPM 2022
Outmazgin et al. (2020). Workarounds in Business Processes: A Goal-Based Analysis, CAiSE 2020

An example


Waiting for approval
APPROVED
APPROVED
VectorStock
VectorStock
VectorStock



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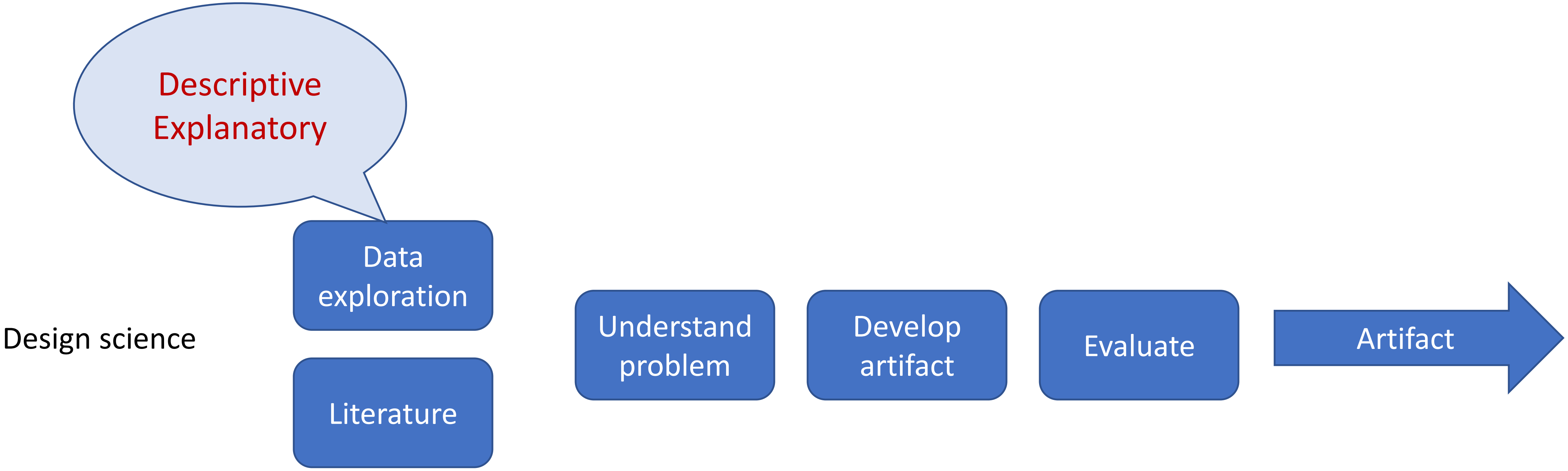
Improvement suggestions

- Change quote approval procedures
  - Introduce a SLA
  - Create “light-weight” variants based on amounts / customers / products
- Change personal rewarding system
  - Reward for proposal preparations as well as closed deals
- Change departmental KPI measurement
- Change IS so proposal approval is a precondition for opening sales orders
- Monitor exceptional process and activity durations

All improvements relate to the revealed conflicts and enablers, based on the theoretical explanation

How theories can support design science



- Data exploration – data-driven, observational in nature
- Theoretical guidance – how and what for?

Exploring the process of process mining

- Aim: to understand cognitive processes of process mining analysts
  - Identify critical steps and challenges
  - Evaluate the support given by PM tools
  - Develop methods and tools to support analysts
- Initial data collection and exploration
  - Multi-modal data of analysts performing a PM task
    - Session video
    - Tool interaction logs
    - Think-aloud text
    - Eye tracking data
    - Facial expressions (emotion recognition)
- The challenge: how to combine and abstract the data to a meaningful model?

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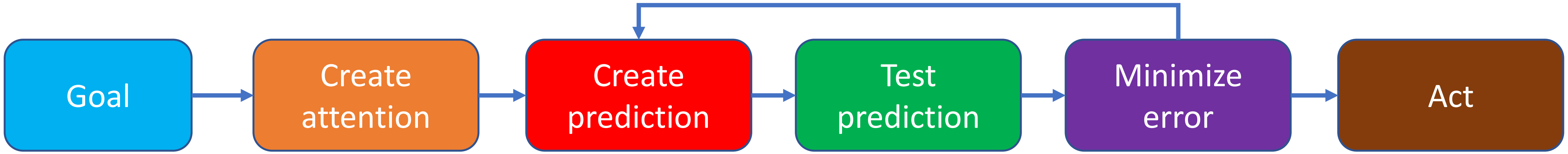
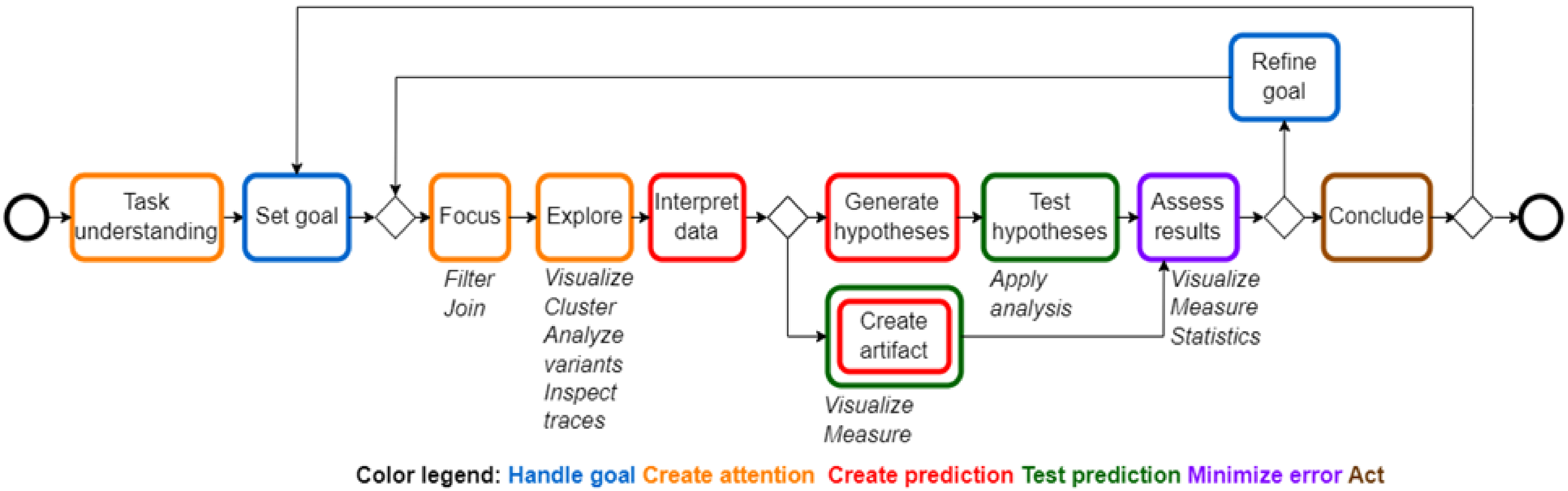
Predictive Processing
Predictive Error Minimization (PEM)



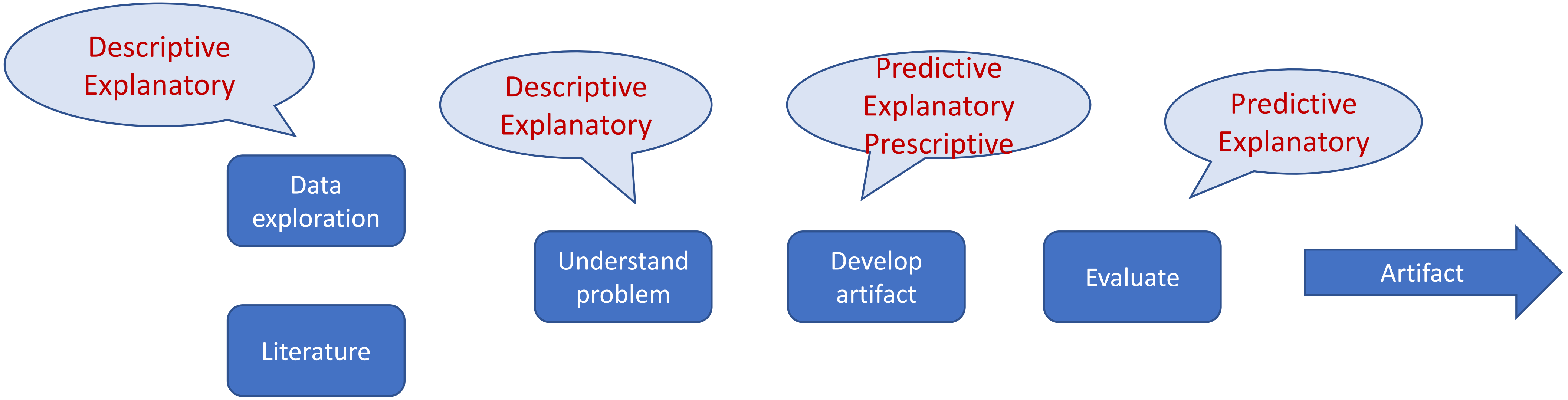
PEM4PPM


Task understanding
Set goal
Focus
Explore
Interpret data
Generate hypotheses
Test hypotheses
Assess results
Conclude
Refine goal
Create artifact
Filter
Join
Visualize
Cluster
Analyze variants
Inspect traces
Apply analysis
Visualize
Measure
Statistics
Visualize
Measure
Color legend: Handle goal Create attention Create prediction Test prediction Minimize error Act

PEM-guided data exploration

- Classify observations by PEM phases
  - A firm structure by which data can be combined and abstracted
  - Validate and refine the model
  - Currently classification is manual – can serve as ground truth for a classifier
- Based on the classification
  - Identify different strategies
  - Correlate strategies and phases with the quality of the result
  - Identify challenges and difficulties
- The vision: a theoretical support for PM artifact design
  - Indicate missing or insufficient support for specific phases
  - Explain why difficulties arise
  - Provide real-time support to analysts (based on automated phase classification)

In summary



- Theories can be useful in various design science research steps
  - Add depth and grounding
  - Address causality rather than observations
  - Highlight solution directions
- Raise many research opportunities
- And challenges

Research opportunities

- Motivational theories for artifacts where user engagement is essential
  - Example applications:
    - Software engineering (e.g., reuse, privacy & security by design…)
    - Applications for inducing behavioral change (e.g., healthy life, environmental sustainability…)
    - Crowd sourcing mechanisms (e.g., gamification, collaborative work)
  - Example theories:
    - Self Determination Theory (Intrinsic vs. extrinsic motivation) (Ryan and Deci, 2000)
    - Organizational climate (shared perceptions of individuals regarding the importance of a certain facet) (Bowen and Ostroff 2004)
    - Behavioral economics (nudge interventions) (Acquisti et al., 2007)
- Cognitive biases where user decisions or inputs are involved
  - Example applications:
    - Requirements elicitation (biases of interviewees and RE engineers)
    - Software engineering (intuition-based programming)
    - DSS (biases and decision making)
    - Explainable AI outputs (design XAI to mitigate cognitive biases)
  - Example theories:
    - Cognitive biases (kinds of biases introduced when processing information for decision making)(Kahneman & Tversky, 1973)

Research opportunities

- Cognitive information processing for representational and visual artifacts
  - Example applications:
    - Visualizations, models
    - UI design
  - Example theories:
    - Graphical perception (Cleveland & McGill, 1984).
- Extended or distributed cognition for collaborative and human-machine tasks
  - Example applications:
    - Human-in-the-loop mechanisms (overall cognitive process with delegation of steps)
    - Smart Uis (involving human body, cognition, and computer)
    - Group collaborative work (captured as one distributed cognitive process)
  - Example theories:
    - Distributed cognition (Hutchins 1995)
    - 4E cognition (Newen et al., 2018)
- Creativity theories for tasks that require creative thinking
    - Design thinking – a generic process intended to facilitate creative solutions to problems
    - Innovation in IS development
    - Business process (re)design

Challenges

- How to select a suitable theory
  - There is no one “best” theory – many explanations are possible
  - Review a number of theories
    - Can be from other disciplines: psychology, management, education, behavioral economics
  - Look for applications to the current domain or a close one
  - A bottom-up validation against data
- How to operationalize a theory
  - Top-down based on literature
  - Bottom-up based on empirical work
  - Trial and error…

Finally…

This was the story of how I learned to stop worrying and love theories…