12-2-2023

How Information Systems can Support Heuristic Decision Making: A Pilot Study

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Research-in-progress

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Abstract

To answer the long-standing question of how to construct information systems to support heuristic decision making, we propose a model of decision support for tacit knowledge. Our aim is to advance a general model of how heuristics affect the quality of an interaction between a decision maker and an information system. Such a model has implications for the construction of explanations for automated decision making. In a pilot case study of shiftwork planning, we explore the use of heuristics by consultants to interpret the conditions, outputs, and quality of shiftwork and to generate recommendations for changes to the design of shiftwork in organisations. The proposed, full case study to follow this pilot study will evaluate a conceptual model of decision support to inform how heuristics can explain decisions made by human, and by extension, artificial intelligence agents.

Keywords Representation Theory, Framing Theory, automated decision making, case study.

1 Introduction

As organisations increasingly renew their decision-making processes with big data and new analytic technologies (Grover et al. 2020; Lyytinen and Grover 2017; Prat 2019) some authors hail decision makers that "…honour the power of evidence and its analytic backing and put it before personal judgment…to augment their intelligence…" (Lyytinen and Grover 2017, p. 225). Yet, cognitive scientists lament the state of our "intelligence", observing that "…none of us, thinking alone, is rational enough to consistently come to sound conclusions…" (Pinker 2021 p. xvi). To buttress their views, skeptics point to the ubiquitous adoption of heuristics as proxies for rational, evidence-based, decision making (Kahneman 2012; Pinker 2021). In contrast to the traditional focus of heuristic decision-making research on the nuances and fallibility of human judgment (Gigerenzer and Gaissmaier 2011, Tversky and Kahneman 1981), this study aims its contribution at those calling for better ways to find methodologies to describe how information systems can augment cognition to resolve complex and apparently insoluble problems (Juan et al. 2023, p. 859; Ozcetin et al. 2023).

Heuristic decision making can link data and cognition for problems that confound rational decision-making, such as problems with insufficient data or inexplicable phenomena (Gigerenzer and Gaissmaier 2011; Juan et al 2023). The potential of the new model for computer-augmented decision-making is to show that heuristics can support decision-makers as they resolve complex and apparently insoluble problems with heuristic decision making. Further, the potential of the new model for automated decisions is to show that heuristic explanations can support acceptable interpretations and explanations. Researchers and practitioners alike express concern about the cogency and veracity of automated decision making (Grover et al. 2020; Hamon et al. 2022; Newman and Mintrom 2023), a disquiet exacerbated by the recent proliferation of artificial intelligence (AI) (Nussberger et al. 2022). To facilitate greater human acceptance of automated decision making, we argue that such decisions can be described with heuristics. Such explanations would not hold machines accountable to higher standards than humans for producing interpretable or explainable representations to support decisions (Hamon et al. 2022). The field of information systems has long studied how computer representations support decision making (Recker et al. 2019; Wand and Weber 1995), nevertheless senior researchers have drawn attention to the field's lack of theoretical progress (Arnott and Pervan, 2005, 2012; Burton-Jones et al. 2017; Recker et al. 2019). A solution to this problem might be to generate a new theory that can account for phenomena associated with traditional analytic technologies but also those emerging in new fields such as AI.

Generating a new theory of computer representation and decision making requires a new conceptualisation that is both: (1) sufficiently general that it can account for multiple types of automated decision making, and (2) sufficiently grounded in the heuristics of human cognition so that it can account for heuristic decision making (Arnot and Pervan 2005, 2012; Gigerenzer and Gaissmaier 2011; Pentland 2013; Weber 2012). To demonstrate such a conceptualisation, we extend the view of information systems as representations of phenomena (Burton-Jones and Grange 2013; Strong and Volkoff 2010; Wand and Weber 1995) by showing how the cognitive framing of a phenomenon influences its consequent representations and, in turn, how such representations influence its subsequent framing (Bremhorst 2018; Fischer-Pressler et al. 2020). The conceptual model presented contributes to information systems theory by extending the representational perspective and by exploring the research question: how can information systems support heuristic decision making?

This paper proceeds as follows. The next section describes relevant background literatures, followed by a section describing a new proposed conceptual model of expertise to describe the aspects of tacit knowledge involved in decision making and its influence on how decision makers draw on decision support systems. The following section outlines the research methodology currently being used to explore the proposed conceptual model. Subsequently, this paper presents the findings from a pilot study and concludes.

2 Theoretical Background

We build our conceptual model using two bodies of theory. First, the state-tracking model (STM) from Representation Theory (Wand and Weber 1995) presents an account of how an information system can represent the states of a real-world domain (Wand and Weber 1995). Second, building on theories of cognition, including heuristics, framing, and fit (Cornelissen and Werner 2014; Gigerenzer and Gaissmaier 2011; Strong and Volkoff 2010), we propose that human perceptions of the states of real-world things emerge from cognitive frames-of-reference. Further, we propose that framing-in-practice misfit occurs when a system represents states in ways that differ from the cognitive representation of states that emerge from a decision-maker's frame-of-reference. Such framing supports both explicit and

tacit knowledge of states of the real-world. While explicit knowledge guides some of the decision-making process, it remains unclear how an individual's tacitly held knowledge also influences their final choices. Tacit knowledge involves intangible factors such as heuristics (i.e., mental shortcuts or rules of thumb) that guide an individual's behaviour without being readily available for introspection (Nonaka and Takeuchi 1995; Von Krogh et al. 2000). Table 1 presents definitions of the concepts derived from Representation Theory and cognitive science.

Constructs derived from Representation Theory (Bremhorst 2018; Wand and Weber 1995; Weber 1997)	
State tracking	Faithful tracking of the states of the real-world phenomena modelled by the information system.
Mapping	The mapping condition requires that each state in the real-world phenomena that interests us maps to at least one state in the information system intended to model the phenomena.
Tracking	The tracking condition requires that when the real-world system changes as a result of internal events that occur to it, the information system must be able to change from a state that corresponds to the initial real-world system state to a state that corresponds to the subsequent real-world system state.
External event	External-event representation requires that when an external event (input) occurs to bring about a state change in the real-world phenomena, an external event that is a faithful representation of the real-world external event must occur in the information system.
Sequencing	The sequencing condition requires that an information system processes external events in the same sequence as they occur in the real-world phenomena as perceived by the user.
Constructs derived from cognitive science (Bremhorst 2018; Cornelissen and Werner 2014; Gigerenzer and Gaissmaier 2011; Kahneman 2012)	
Heuristics	*Heuristics* internalised decision rules that can support a decision in the absence of complete information.
Framing-in-Practice	Framing-in-practice describes the frame-of-reference from which an actor learns (through their cognition) to distinguish states of a real-world thing. Thus, specific states of a real-world thing emerge within an actor's mind from their framing-in-practice.
Framing-in-Practice Misfit	*Framing-in-practice misfit* describes the misfit between information and an actor's frame-of-reference
Tacit impositions	*Tacit impositions* occur where an actor must draw on their personal experience to interpret any information already present.
Tacit deficiencies	*Tacit deficiencies* occur where insufficient information impedes efforts to generate a personal response to any information already present.

Table 1. Theoretical Constructs

The following subsection explicates Wand and Weber's (1995) state-tracking model that describes how a system models states of real-world things.

2.1 How State Tracking Models Real-World Things

Traditionally, Representation Theory acknowledged individuals' divergent conceptions of reality but assumed that a given set of states could be constructed to reflect multiple perceptions simultaneously (Recker et al. 2019; Weber 1995). Wand and Weber's (1995) state-tracking model (STM) provides a conceptual model of how information systems can represent states and state changes effectively. The STM requires the structures of an information system to demonstrate four necessary and sufficient conditions to make the states of things and their state changes apparent: the mapping condition, the external-event condition, the sequencing condition, and the tracking condition (Wand and Weber 1995). The mapping condition requires that an information system models all the states and associated state changes of interest in the thing the system represents. The external-event condition requires that a system models the states and associated state changes of interest to the system's users that occur outside

the thing the system represents. Further, the sequencing condition requires that an information system's representation of a real-world thing demonstrates the same sequence of external events as their occurrence in the real-world thing. The final condition, tracking, requires that a system models all the internal events of interest triggered by the occurrence of external events in the thing a system represents.

Although Wand and Weber (1995) describe STM's four conditions in terms that help review the faithfulness of information system scripts, the model can also describe an active information system that generates outputs to represent states of real-world things (Bremhorst 2018; Fischer-Pressler et al. 2020). When an operative system updates its outputs, its users must reinterpret its representation to support their decision-making. Such a flow of outputs generates tacit knowledge in those users who experience and learn to interpret its states correctly. By corollary, the design of an information system depends on the tacit knowledge of actors who learned to correctly interpret real-world states and articulate those states to support suitable representations of real-world things. Thus, the faithfulness of an operative system's state tracking depends on alignment with the heuristic rules that its users employ to identify and interpret a thing's real-world states. The following subsection describes how an actor's tacit knowledge enriches the state tracking apparent in any information.

2.2 How Frames-of-Reference Affect Perceptions

Actors rely on their frames-of-reference to summarise and simplify their cognition (Cornelissen and Werner 2014; Davidson 2002, 2006). Actors use framing, a personal set of *internalised rules* (Tversky and Kahneman 1981), to interpret their perceptions of both their experiences and the outputs of information systems that generate representations of those experiences. Framing helps actors to articulate rules of thumb that describe aspects of their tacit knowledge (Gigerenzer and Gaissmaier 2011) and that summarise their experience (Cornelissen and Werner 2014). Thus, actors rely on their cognitive framing to interpret information, their experiences and generate their responses (Cornelissen and Werner 2014). To describe the potential misfit between information presented in an information system's outputs and an actor's frame, we derive a new fit construct: *framing-in-practice*. Framing-in-practice describes the frame-of-reference from which an actor learns (through their cognition) to describe states of a real-world thing. Thus, specific states of a real-world thing emerge within an actor's mind from their framing-in-practice. *Framing-in-practice misfit* manifests as *tacit impositions* and *tacit deficiencies*. *Tacit impositions* occur where an actor must draw on their personal experience or direct observations to interpret the states of a real-world thing modelled by an information system. For example, a system fails to report on risk factors of sleep deprivation, so an actor must guess the risk by applying heuristic rules based on other factors. *Tacit deficiencies* occur where insufficient information impedes efforts to generate a personal response to any information already present. For example, a system's outputs report on risk factors of sleep deprivation derived by asking two employees from a team of twenty members, so an actor must refute the evidentiary validity and cannot generate valid recommendations for improvement. The theoretical arguments presented so far support the conceptual model proposed in the next section.

2.3 Conceptual Model

We propose a new conceptual model to describe how tacit knowledge manifests in actors' interactions with information systems. The proposed model (see Figure 1) holds that a system user frames real-world things to interpret and generate their cognitive responses to states of the real-world thing. Such framing creates misfits between actors' interactions with the states of a real-world thing and the information about the states of the real-world thing represented in a system's outputs. To link their frames to a system's outputs, actors rely on tacit knowledge to interpret the represented states and generate a response. Therefore, the faithfulness of a system's operative state tracking influences the level of tacit knowledge users require to interact with the system's outputs.

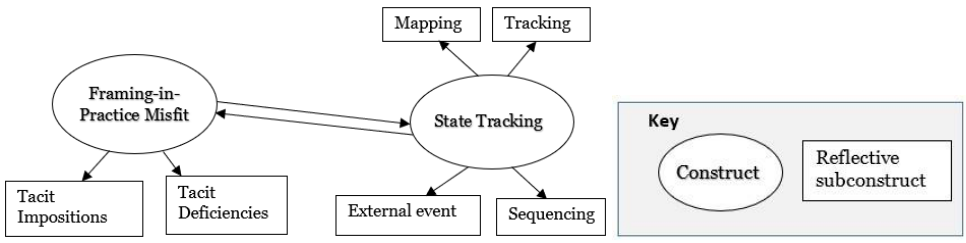

Figure 1: Conceptual model of framing-in-practice misfit and state tracking

3 Methodology

Many important practical decisions depend on heuristic decision making. For example, in managing the co-occurrence of multiple uncertain events (conjunctive risk), managers have been shown to employ a worst-first heuristic such that they attend to the greatest risk first (Lewis et al. 2023). In the context of shiftwork, decisions that mitigate conjunctive risk can lead to expensive underutilisation of production capacity, widespread employee dissatisfaction, or calamitous workplace health and safety outcomes (James et al. 2023; Rivera et al. 2022). As rostering decisions manifest more general dimensions present in many complex and insoluble managerial problems (Geaquinto Rocha 2022; Lewis et al. 2023; Juan et al. 2023), we argue the conceptual model describes heuristic decision making in many such situations.

3.1 Research Setting

We employed a case study to seek empirical support for the proposed conceptual model because this study represents a preliminary attempt to explore framing-in-practice and link it to Representation Theory's state-tracking model. We used purposive sampling to select ShiftOps as a representative case involving experts who used heuristics to assist their decision making.

3.2 ShiftOps and the Shiftwork Decision Support System

As workforce management teams increasingly adopt practices that support 24x7 operations, the work pattern known as shiftwork competes to replace "standard business hours" as the dominant work pattern among organisations that operate at every scale whether local to global. This case explores how the experts at ShiftOps employ a shiftwork information system to guide their decision making. ShiftOps maintains a specialist management consulting practice with a strong reputation for delivering insights into optimisation of shiftwork. They are a niche player in the market, spending over 30 years developing innovative solutions that streamline shiftwork operations, increase productivity, save money, and improve employee alertness and morale through the optimal design of work rosters. Their specialist team of experienced roster consultants assist workforces with as few as three to over 4000 shift workers on projects spanning a wide range of industries globally. Their extensive list of high-profile local and international clients includes many common brand names.

ShiftOps developed a decision support system to collect and analyse data acquired during client interviews, focus groups, and on-site consulting engagements. ShiftOps design and administer their own questionnaires using their vast experience in advising on shiftwork solutions. ShiftOps' database also contains benchmarks developed from statistical analysis of the records accumulated during its 30-year history. ShiftOps' consultants retain a deep understanding of diverse shiftwork practices, and the kind of data collection and information that supports good shift management decisions across all industries and many organisations' stakeholder groups.

3.3 Data Collection and Analysis

We followed Venkatesh et al.'s (2013) recommendations to improve the reliability and validity of the study. To mitigate potential problems with construct validity (Yin, 2009:116), we used multiple sources of evidence including system documentation, operating procedures, consulting reports, and interview data to triangulate our findings among the data. We provided copies of interview transcripts to interviewees for their review so they could provide corrections where appropriate. We also provided summary accounts of our preliminary findings to key interviewees. Further, we developed an interview protocol and maintained a chain of evidence. To improve internal validity, we used a pattern matching strategy by investigating the outcome of changes to state tracking on framing-in-practice misfit, and the outcome of changes to framing-in-practice misfit on state tracking. To improve reliability, we developed a case study protocol and maintained a case study database (Dube and Pare, 2003; Lee and Baskerville, 2003). Ethical clearance was granted in 12/2022.

We collected evidence of the salience of the proposed model's constructs and associations to describe the case. Our findings were based on the system's data model and user descriptions of their use of its information. Our interview questions were semi-structured because we entered the field with a specific research model. The questions were designed to cover all constructs within the research model at a holistic level. We developed and assessed a preliminary coding protocol for the constructs in the conceptual model. Following Campbell et al. (2013), we performed individual unitisation of interview transcripts, compared results, and discussed disagreements about unitisation and application to text. To reach agreement on the developing units of coded text in each transcript we discussed our respective understanding of each code's description (Appendix 1). Observations and analysis focussed on describing the state tracking produced by the ShiftOps database, design decisions during its

construction, and incidents of framing-in-practice during its use in decision support (Bremhorst 2018; Van De Ven 2007). The pilot study's findings were based on the system's database table structure, the attributes of shiftwork and workers recorded in the database tables, and consultants use of the ShiftOps' database. Analysis concluded with an operational description of the model for the case.

4 Findings

This section proceeds by describing how the proposed model's constructs operationalise in the case. Following the operationalisation of the state tracking construct and the framing-in-practice construct, this section presents supporting evidence for the conceptual model.

4.1 Salience of the State Tracking Model

In the pilot interviews, respondents described how they aim to design state tracking into the ShiftOps database. ShiftOps' proprietary database tracks the state of the shiftwork and workers in an organisation. Their database also tracks the state of shiftwork standards across all former and immediate clients of ShiftOps. This database contains ShiftOps client-organisations' employee responses collected through focus groups and individual employee survey responses. Their database outputs include summaries of the states of a workforce, the comparative states of other organisations or sectors through its benchmark measures, and any state changes. Database users can also generate outputs through query tools that help them define and answer questions about the specific states of focal areas of shiftwork in organisations.

The State-Tracking Model (STM) provides a good description of the design and operation of ShiftOps' database. The STM requires a mapping between states defined in a database and its users' perceptions of things as found in the database tables that map survey questions and responses in ShiftOps' database such as the mapping described by the database designer in his "provision" of the data schema. For example, one interviewee shared, *"…what I provided…is all the answers to questions which have been mapped to a standard or benchmark question…"* (Int1)

Related external events – labelled by representation theory as state changes initiated outside the thing an information system models – trigger activities to input and retrieve the content of database records that represent each occurrence of a survey response. Thus, the STM also requires representation of the tracking of state changes initiated by database input operations such as those that occur during the data entry processing. An interviewee describes this as, *"…so they're able to take the questionnaire online instead of having to enter manually … sometimes we do get some paper-based so then we also enter those into the database…"* (Int3)

External events receive a date/time stamp in their record(s) that satisfies the STM's sequencing condition. Individual's responses contribute to a history of survey responses that collectively produce a cross-sectional view of an organisation's shift workers and practices. The sequence of external events also enables tracking of benchmarks and long-term changes in shiftwork practices as described by the interviewees. One specific representative comment from an interviewee stated, *"…that gives us reports that we can generate and also gives us the benchmarks…"* (Int3)

Thus, preliminary findings suggests that the ShiftOps database faithfully represents state changes to produce a history of employee responses about shiftwork. Following this discussion of how state-tracking operationalised in the case, the next subsection discusses the operationalisation of framing-in-practice misfit.

4.2 Salience of the Framing-in-Practice Misfit Construct

Initial findings suggest that ShiftOps employs a consistent framing to all its engagements to mitigate framing-in-practice misfit. ShiftOps consultants applied a unique frame to shiftwork derived from their firm's experience. ShiftOps consultants framed an organisation's shiftwork practices to support the heuristic rules they used to justify their findings and recommendations. ShiftOps' consultants used interpretative heuristics to interpret database outputs and relied on generative heuristics to produce their recommendations. Such interpretative and generative heuristics developed over a long period as described by one interviewee, *"…we've been using this for over 30 [years]. So, I have some numbers back from [the firm's inception] … we were using these same questions and refining them."* (Int2)

In the following interview extract, ShiftOps consultants demonstrate their confidence in their interpretative heuristics compared to views they consider biased in local managers. This excerpt refers the poor interpretation and recommendations that followed one organisation's internal survey on employee satisfaction.

> "…what was happening was we were getting a manager saying, oh, yeah, I know what the employees want, …and they didn't, or they were just listening to the more vocal individual in the group. … So some…[questions] …sort of box them [employees] into [a] corner to get [employees] to focus on one thing at a time." (Int2)

The invalid data collection method led to tacit deficiencies. In contrast, ShiftOps' consultants framed the situation so that they could identify multiple shiftwork conditions that collectively required alternative interpretations and responses.

4.3 The Role of Heuristics in the Interaction between State Tracking and Framing-in-Practice

The empirical evidence supports the salience of the conceptual model and its associations. The state tracking construct in the model describes the unique state tracking that ShiftOps developed in its database to minimise framing-in-practice misfits. Specifically, misfits that occurred when shiftwork data about an organisation from other sources was compared to ShiftOps' consultants unique framing of the situation. The case data supports the argument that heuristics describe how the system's state-tracking and consultants' framing-in-practice interact during decision processes. As ShiftOps' consultants rely on heuristics to interpret the real-world states of shiftwork in an organisation as represented in their database, and to generate recommendations, any redefinition of state tracking led to framing-in-practice misfits. The empirical evidence showed that such misfits led to alternative perceptions of state. For example, the state of employee satisfaction cited above and its implications for follow-on recommendations. Finally, the relationship between the unique database design and its fit to Shiftops' unique framing of shiftwork demonstrates an effortful accomplishment by the database designer in comprehending the STM that faithfully represent shiftwork as framed by ShiftOps (Feldman and Pentland 2003). The next section discusses the potential contribution of the study and its implications for future research into the conceptual model.

5 Discussion

The case makes its theoretical contribution by providing initial empirical support for the salience of the conceptual model. The case demonstrates that the quality of information systems' state-tracking influences the explicability of experts' framing-in-practice, heuristics, and decisions. Further, the case provides preliminary support for the notion that experts link their framing-in-practice to a system's state-tracking to support their heuristic decision rules. The case also shows that experts explain their decisions by using interpretative heuristics to justify their use of data and generative heuristics to generate their analysis and recommendations. The salience of the conceptual model shows that heuristics can also link frames-of-reference to inexplicable decisions (such as automated decisions generated by AI) and change human awareness about potential states of real-world things.

The study makes its contribution to practice by showing that reframing real-world things (including circumstances) can improve heuristic decision making. Heuristic decision making occurs in many circumstances that depend on the co-occurrence of multiple uncertain events (Lewis et al. 2023). Such circumstances are representative of phenomena found in many human decision-making arenas. Thus, the use of interpretative or generative heuristics represents an effortful accomplishment that improves management practices (Feldman and Pentland 2003; Kahneman 2011; Tversky and Kahneman 1981).

The limitations of this study should also be acknowledged. This pilot study assesses the conceptual model against a single database, although one remarkable for its durability and longevity, that supports decisions about a sole subject matter – shiftwork. A full case study will include comparable cases with alternative empirical settings to strengthen external validity. Further, quantitative analysis will be used to identify any significant correlations among responses to ShiftOps' survey items. Confirmatory interviews will be conducted to assess whether significant correlations among responses to survey items constitute indicators of conjunctive risk.

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Appendix 1: Code Descriptions

Code Title	Decision Rules

State-Tracking Code Family	Discussion of an information system as a representation of real-world things. The interviewee demonstrates direct experience in designing, constructing, testing, or using an information system as the basis for their comments.
Mapping	Discussion of the business rules used to map real-world states into an information system's internal components and that describes which real-world states the information system can model or represent.
Tracking	Discussion of an information system's outputs that describes how an information system produces a record of attributes/variables/fields or the outputs of an information system in reports, data files, screens, queries, and other such displays of a systems' history of states or information.
External event	Discussion of an information system's input components that describes how an actor enters data into an information system or the system captures values for attributes/variables/fields.
Sequencing	Discussion of the ordering of records within an information system that describes how an information system maintains the sequence of its records of those attributes/variables/fields that are input into the system.
Framing-in-Practice Code Family	The interviewee describes their lens on a situation or scenario or decision-making process, speculates about how a decision maker might interpret or decide a course of action, or describes assumptions, beliefs, or expectations about a real-world situation as the basis for their comments.
Framing-in-Practice Misfit–Deficiencies	Discussion of inability to use or conflict caused by differences in assumptions, beliefs**,** or expectations about how information should be able to be used in decision-making or used in sense-making based on role or social function or intended use.
Framing-in-Practice Misfit–Impositions	Discussion of the mental problem-solving or processing of information and how it fits assumptions, beliefs, or expectations about how information should be able to be interpreted, used in decision-making, or used in sense-making.

Table 2: Coding Scheme

Acknowledgements

We gratefully acknowledge support from Shiftwork Solutions during the conduct of this work.

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