Decision making and cognitive biases in designing software architectures

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***Abstract*—The architecture of any software can be thought of as a blueprint of its structure. This blueprint is an artifact generated based on a series of decisions taken by software architects and determines the overall quality of the resulting software. The first part of this paper focuses on identifying and formalizing the decision-making models in the context of designing software. Three models are investigated in detail: the rational economic model, the bounded rational model, and the recognition-primed decision model. The steps of decision making are mapped to the OODA Loop (Observe, Orient, Decide and Act) decision cycle as a generic framework for decision making.**

The second part of this paper focuses on documenting cognitive biases in the context of architectural decision making. Architects, being human, are invariably subject to the influence of cognitive biases due to the cognitive limitations of the human mind, resulting in a systematic deviation from the ideal decision-making process. This leads to the design of sub-par solutions because of missing rationality behind the decisions. A two-level classification is made to modularize the extensive list of biases that influence the architectural decision-making process. As an important outcome of this research, detailed information about each bias is documented as part of a cognitive bias catalog.

***Index Terms*—Decision-making process; OODA loop; Architectural design decision; Cognitive bias.**

I. Introduction

Software architecture is a set of architectural design decisions (ADDs) [1]. Software architects and developers make these ADDs and in many cases they may not be aware of how they made those decisions [2]. Architectural decision making is a continuous process which is often implicit, complex, and knowledge intensive. It is a key factor for the sustainability of software systems. In recent years, evidence has been provided to show that architects either follow rationalistic or naturalistic decision-making process [3]. In parallel, it has also been shown that architects are biased during their decision making [4]. Architects regularly use past experiences, familiarity with technologies, trends, and other heuristics or "cognitive shortcuts" to make decisions. The resulting decisions are biased due to the use of heuristics and may lead to "sub-optimal" or "satisficing" solutions [5].

During the decision-making process, architects like all humans are constrained by their cognitive limitations which are affected by factors including information overload, complex data, and time constraints. The cognitive limitations manifest in the form of cognitive biases resulting in suboptimal solutions. Much effort has been made over the years by experts in identifying different types of cognitive biases [6]. However, not all those biases are important in the context of designing software. We have identified and documented thirty-three biases that in our opinion influence architects more commonly. As discussed in Section III, these biases are presented in a modular way using a two-stage custom classification. The information about each bias, its relevance to software architecture, and the corresponding debiasing technique is structured in the form of a cognitive bias catalog.

Furthermore, in this paper, we make the implicit decision-making process explicit by using semi-formal models that consists of a series of steps specifying the course of actions taken to reach a decision. The decision-making steps are mapped to the Observe, Orient, Decide, and Act (OODA) loop [7], which is a four-phase decision cycle used by strategists in many other domains including business, litigation, and military strategy. Three decision-making models (DMMs) along with their relationships to the OODA loop are presented in Section II which correlates them in a systematic manner.

The contribution of this paper is twofold. First, we establish a relationship between the DMMs and the OODA loop. Second, we map the cognitive biases to the OODA loop phases. This is to present the combination of three concepts (DMMs, OODA loop, and cognitive biases) in a way that can be easily comprehended by architects. By consolidating and making the aforementioned information available to architects, they will be able to (a) relate their decision-making processes to a generic process such as the OODA loop and (b) evade the common cognitive limitation pitfalls by being aware of the typical biases documented in the catalog. In essence, the cognitive bias catalog helps architects in debiasing through self-awareness and encourages them to reason about their ADDs. Our claim indeed goes with the assumption that if a person is aware of the situation where things could go wrong (anti-patterns), he or she would put an extra effort to avoid it.

II. OODA loop and decision-making models

A. OODA loop

The concept of OODA loop [7] developed by John Boyd is a generic decision-making process model. It describes how to gain competitive advantage in any situation. Within the OODA loop, an actor makes *observations* about the surrounding

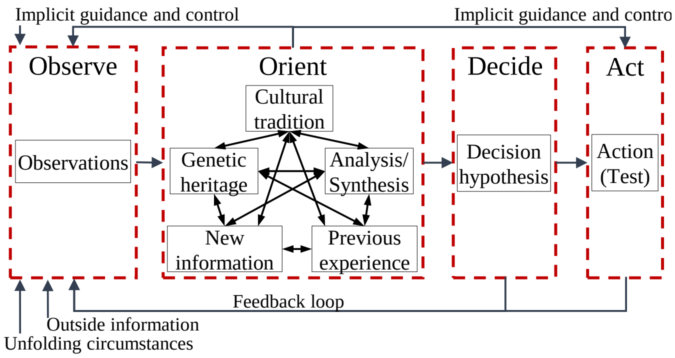

Fig. 1. The OODA Loop decision cycle; Adapted from [7]

environment, *orients* his/her thinking process by perceiving the important information based on the context, *decides* on a course of action, and finally *acts* on it. As shown in Figure 1, this process is iterative with loops providing feedback to the observe phase for constant reorientation and adaption.

Designing software architectures involve making strategic decisions keeping in mind various factors such as long-term sustainability, technical capabilities of the teams, complexity, and time constraints. In the next subsection, we present how DMMs can be used in conjunction with the OODA loop when making ADDs. These ADDs, for instance, could include the selection of architectural styles, design patterns, implementation technologies, and software components.

B. Modeling the decision-making process

There exist two main approaches to decision-making, namely *normative* and *behavioral* [9]. The DMMs belonging to the normative stream are based on sound logical reasoning. They are mostly applicable in an ideal-world scenario wherein a perfect requirements document with no future changes is available, alongside with other resources such as time, budget, and team dynamics are also available. The examples for normative approaches include the *Rational Economic model* (REM), the Brunswick's Lens model (BLM), and the Cynefin framework. The BLM is statistical in nature and requires an optimal decision to begin the process and to compare it against the actual decision. On the other hand, even though the Cynefin framework is useful for executives and policy-makers, it is hard to break it down into simple steps so as to map it with the OODA loop. However, due to the clarity of the decision-making steps in the REM, it is investigated further.

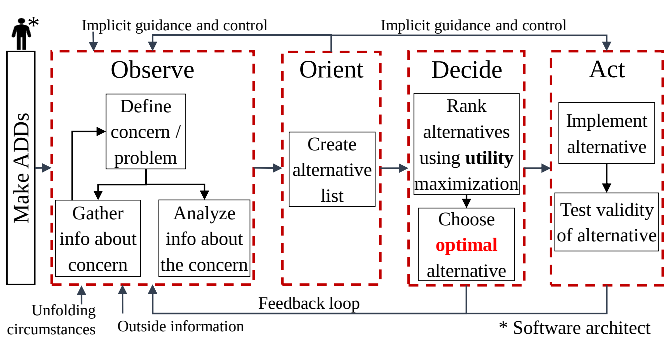

Fig. 2. The REM with the OODA Loop; REM adapted from [8]

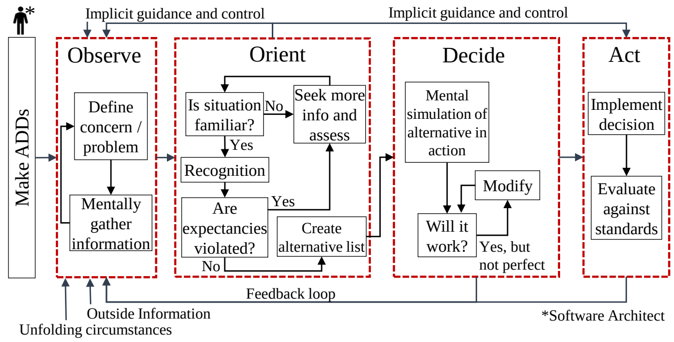

Fig. 3. The RPDM with the OODA Loop; RPDM adapted from [10]

As shown in Figure 2, in the REM, an architect meticulously defines the concerns in the *observe* phase and creates a list of *all* possible alternatives that can be used to address the concerns in the *orient* phase. In the *decide* phase, a ranking algorithm is used to choose an "optimal" alternative which is then implemented in the *act* phase. The implementation is then tested and constant feedback is sent to the observe phase for future decision making. While the REM works well in ideal situations, it is difficult for architects to use it since they work under various real-life constraints such as time, complexity, and permanently changing budget constraints.

The DMMs representing the behavioral approach are subject to cognitive biases and better reflect real-world scenarios. Two models, the Recognition-Primed Decision Model (RPDM) and the Bounded Rational Model (BRM) are selected for detailed analysis. The RPDM is derived from the naturalistic decision-making framework that relies on mental mind maps. It is generally used by inexperienced architects or in scenarios where ADDs are to be made under time pressure and other constraints which affect the decision-making quality. As shown in Figure 3, architects gather information in the *observe* phase to define concerns until they feel it is complete. In the *orient* phase, the situation is verified for familiarity and to check if any expectations are violated so as to determine if more information is needed. In the *decide* phase, a mental simulation of each alternative is made to verify if it works. The alternative that fits the situation is selected and is implemented in the *act* phase. Here, the aim of an architect is to find a "good-enough" alternative that meets an acceptability threshold.

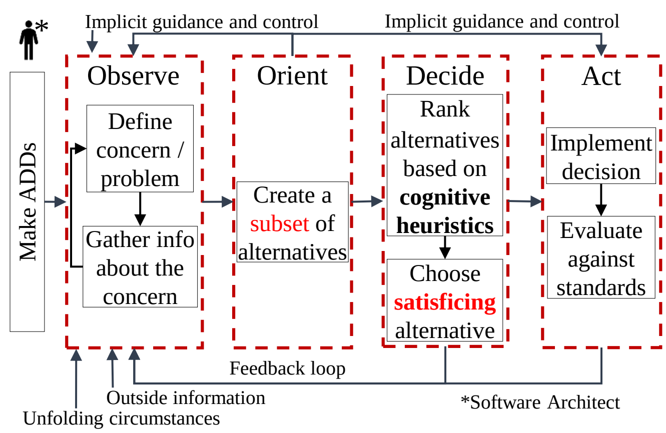

Fig. 4. The BRM with the OODA Loop; BRM adapted from [11]

On the other hand, we also observe architects making an effort in creating a subset of alternatives to *orient* themselves with the design concerns captured in the *observe* phase. Then, using heuristics such as "previous experience" and "team capabilities", architects choose a "satisficing" alternative in the *decide* phase. This corresponds to the BRM introduced by Herbert Simon [11]. The steps in this process model are shown in Figure 4. The BRM is similar to the REM but differs from it as an architect collects only a manageable subset of alternatives, ranks the alternatives using heuristics, and chooses a satisficing alternative without using any optimization algorithm, which may or may not be the optimal one.

III. Cognitive Biases

The DMMs belonging to the behavioral approach are all subject to the influence of cognitive biases. Cognitive biases manifest themselves differently in different people depending on circumstances. Even though more than two hundred cognitive biases have been identified by experts in various domains, within this study, we have selected thirty-three biases that have already been discussed in the context of software engineering from papers including [12] and [13]. As the list of cognitive biases is extensive, a two-stage classification is used to modularize the information. In the first stage, each cognitive bias is assigned to one or more phases of the OODA Loop. In the second stage, a further classification is made under each phase depending on the relationships between different biases. Figure 5 shows the two-stage hierarchical classification as well as relationships between biases (related to/similar). The selected thirty-three biases are represented as the leaf nodes.

Within the **observe** phase, since architects focus on how to gather information and how to present them in the subsequent phase, biases can be classified into two main subcategories, namely, *information gathering biases* and *information presentation biases*. Information gathering biases include for instance, search, reference, and confirmation bias. On the other hand, framing and similarity biases are classified as presentation biases. Furthermore, biases can be related to each another. For example, reference bias is related to anchoring and adjustment bias as they both establish a point of reference which sets the tone for further steps in decision making.

The **orient** phase consists of biases which influence how people interpret the information and orient themselves to the situation at hand. During this process, architects orient themselves by filtering available information and are influenced by the similarity of the situation, their previous experiences, and current trends. Hence, the subcategories under the orient phase are *biases related to semblance*, *information filtering biases*, *biases related to experience*, and *biases related to trends*.

Since the actual decision-making happens in the **decide** phase, this phase is associated with largest number of biases. The decisions are made based on the *complexity* of the problem, nature of how the solution will be invented (*trends*), *previous experience*, and *decision-making strategies*.

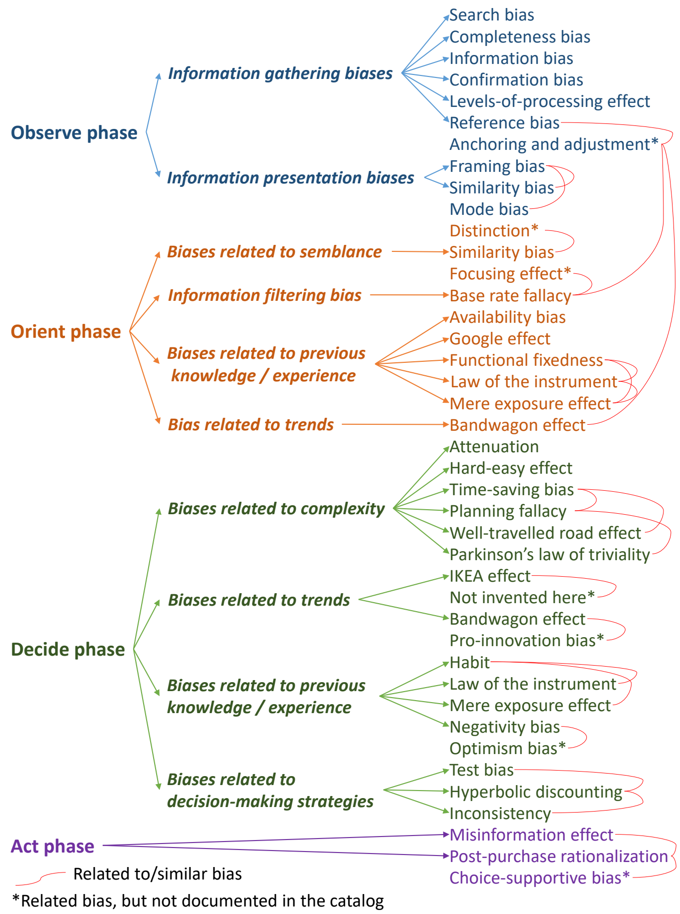

Fig. 5. Two-stage classification cognitive biases.

Corresponding to the **act** phase, since only two related biases, namely, misinformation effect and post-purchase rationalization were identified, we did not sub-classify these biases.

A catalog containing detailed information about each bias is presented in a web interface[1] as well as documented in a report [14] as part of this research project. Readers are directed to the Master thesis for a detailed description regarding the selection of specific biases and the reasons for their classification under a specific category. The **planning fallacy** bias from the catalog is presented in Figure 6. Each bias is described using the same template containing (a) definitions from different sources, (b) OODA phase to which it belongs to, (c) the subclass within the classification, (d) rationale for classification under a specific class and subclass, (d) an example from the architectural decision making context, its implications, (e) hints on how architects can debias, and finally (f) their related biases.

IV. Using the Research Artifacts

First, architects should gain an understanding of the OODA loop and how it is related to their decision-making process. Next, they should explore the three different DMMs and understand the relationships between the OODA loop and

[1] https://tum-master-thesis.herokuapp.com/

the DMMs. Following this, architects can move on to the cognitive bias catalog. To get an initial idea, it is recommended to familiarize with the bias listing and the classifications. Additionally, being familiar with the bias definitions is helpful since the names of many biases are deceptive to its actual meaning. During the actual decision-making, once architects identify the phase of the OODA loop they are in, they can read in-depth about biases related to the corresponding phase so as to reduce or eliminate the impact of the biases.

V. Conclusion and future work

This research revolves around exploring three concepts (OODA loop, DMMs, and cognitive biases) along with their relationships in the context of architectural decision making. To help architects relate their decision-making process, be it rationalistic or naturalistic, we have mapped the steps in three different DMMs to the OODA loop which is a generic DMM. These three DMMs have already been discussed in the context of architectural decision making by various researchers from a theoretical perspective. In this paper, we have made the steps in those DMMs explicit using process flow diagrams and mapped those steps to the different phases of the OODA loop. We choose the OODA loop, since it provides the right abstraction, is intuitive and relatable for architects, as well as, is one of the more popular DMMs used by successful decision makers in different domains.

Furthermore, since architects are biased during their decision-making process, to raise awareness about cognitive biases during architectural decision making we documented thirty-three important cognitive biases as part of the cognitive bias catalog and mapped those biases to the OODA loop phases and subcategories. The usage of the catalog brings the *availability heuristic* into play by ensuring greater availability of biases in the minds of architects. They can then tend to seek evidence of these biases in real-life decision-making scenarios through the *confirmation bias*. Even though awareness of biases establishes the first point for debiasing, awareness alone is *not* sufficient. The best one can expect is a discussion on cognitive biases and as described in the bias catalog some (limited) actions that architects could take to avoid those biases. Further research is required to provide substantial tool support to help architects debias during their decision making.

Planning Fallacy	
Definitions Block	
Definition 1: The tendency to underestimate task-completion times. Definition 2: It is a phenomenon in which predictions about how much time will be needed to complete a future task displays an optimism bias and underestimates the time needed.	
OODA Class: **Decide Phase**	Subclass: **Complexity**
Reasoning for classification: Time is a crucial factor in software projects. Often, the implementation times fall short of the initial estimates. The reason being underestimation of task-completion times due to lack of understanding of the complexities involved.	
Examples and impact on architecture design decisions	
Example: Choosing spring-security as the security framework: Spring is one of the most popular choice for developing Java-based enterprise applications. To meet the security requirements, spring-security would be an automatic choice as it is part of the framework itself. It is easy to assume that configuring the application security would be as easy as developing an application in spring. However, it is not an easy solution to implement without a proper understanding. If the decision-makers assumes that the security aspect is as easy as feature development, then it leads to an optimism bias resulting in time estimate errors. *Impact:* A common result is missing delivery deadlines. The added pressure resulting from the missed deadlines leads to implementation of sub-par solutions.	
Debiasing techniques	
The decision-maker must understand how to estimate time. There are many workflows for time estimation that can be used. One simple way is to add a buffer time to the initial time estimate in order to complete tasks. It is common to set the buffer time to 10% of the total estimate.	
Related biases	
Complexity bias, Parkinson's Law of triviality, Time-saving bias.	

Fig. 6. Example of a bias from the catalog

Currently with our industry partner, we are exploring different possibilities on how to further this research in a way that can be useful for architects at large. The first possibility is to incorporate the content presented in this paper into lectures such as Software Architectures in universities. Second, with the help of architects in our partner industry, we aim for half-day workshops to explain decision makers the benefits of self-awareness of decision-making process and typical biases that affect software design. Furthermore, as an alternative to workshops, we also consider the web-based training (WBT) in large organizations as a possibility, since, courses related to *biases during hiring process* are already part of the WBT.

However, it is necessary to get a critical reflection from the software architecture research community first. Then, we need to improve the catalog by extending the individual examples and collecting biases related to group-decision making as a community effort (similar to the biases list in Wikipedia). Lastly, there is a need for us to collaborate with research groups from psychology and sociology domains who can provide better insights into how we can further this research.

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