Requirements Engineering, Human Factors

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Abstract

This report describes a number of cognitive biases that likely affect the requirements engineering activities. The effects of these biases should be investigated and, when possible, mitigated in order to improve the process in which software requirements are produced as well as the end product of that process.

1. Introduction

Requirements engineering is a human centered process that affects many software development and management activities such as cost estimation, project execution, verification and validation activities, etc. When requirements are engineered information needs to be elicited from stakeholders, analyzed and documented in order to be communicated to the developers who then develop the product and together with the customers verify that the product responds to the stakeholders' needs [21]. The human centered nature of this process makes it vulnerable to cognitive decision making biases.

In this report I will focus on biases that can affect engineering of requirements (extracted from the list of cognitive decision making biases in [24]). Further, I will focus on interview as the data gathering technique, other techniques might include observation, questionnaires, etc.

The biases included in this report were chosen in two steps. First the biases that were deemed to fit the subject based on the brief description provided in the list [24] were extracted. The selected biases concern:

1. **Memory**, and affect *elicitation of requirements* since many of the requirements are based on existing or previous needs or ways to handle a system, as well as *requirement analysis* where the requirements engineer needs to recall the details about data collected in the conducted interviews. These biases may also affect *requirements validation* where

the stakeholders need to recall the details of the initial requirements, as well as *requirements specification* where the gathered requirements are documented by the requirements engineer.

2. **Data processing** that both data collector and data source need to do in all parts of the requirement engineering process that they are involved in.

In second step the scientific articles that describe biases included in step one were used for deeper analysis. In this step biases that are unlikely to affect requirement engineering activities were excluded. For example, some biases that were included in step one affect activities that might be similar to, but are not related to requirements engineering. *Barnum effect* is one such bias. It describes individual's tendency to find descriptions of their personalities as fitting for them, and only them, even though such a description might be very general (for example fortune telling, horoscopes, etc.). Cognitive biases that affect project decisions related to requirements engineering, but not requirement engineering it self were also excluded in step two. An example of such bias is *Planning fallacy*, which is a tendency to underestimate task-completion times and affects cost and effort estimation of development projects.

The final list of biases is in this report is grouped in five categories: 1)requirements elicitation, 2) requirements analysis, 3) requirements specification, 4) requirements validation, and 5) requirement management (in accordance with figure 1). Each bias is described in relation to the source of the bias (requirements engineer or customer) and activity where it originated, see Table 1 for summary. It is assumed that requirements are elicited through interviews, analyzed and specified by the requirements engineer alone and validated by the requirements engineer and customers together. Later changes are assumed to be made on request from the customer. No assumptions are made of whether the requirements engineer is a part of the customer's organization or is employed by a contractor.

2. Cognitive decision making errors in requirements engineering

In this section a list of cognitive decision making biases that could affect the process and outcome of requirements engineering will be presented, subsections correspond to the activities in Table 1.

Table 1: Cognitive decision making biases in requirements engineering

Requirements engineering activity	Elicitation	Analysis	Specification	Validation	Management
Biases related to requirements engineer (data gatherer)	Anchoring Confirmation bias Curse of knowledge Focusing effect	Anchoring Confirmation bias Focusing effect Over-expectancy bias	Curse of knowledge	-	-
Biases related to customers and users (data sources)	Anchoring Ambiguity effect Availability heuristic Bandwagon effect Curse of knowledge Conjunction fallacy Functional fixedness Focusing effect Negativity bias Neglect of probability Normalcy bias Social desirability bias	-	-	Social desirability bias Outcome bias	Backfire effect Irrational escalation

2.1. Requirements elicitation

Requirements elicitation or requirements gathering is the activity in which information about the proposed system is collected from stakeholders such as customers and users. The actors consist of (very simplified) the *data gatherer* (requirements engineer in Table 1) and the *data source* (customer in Table 1). These expressions will be used in this report when referring to these two parties.

The success of requirements elicitation depends on two main factors: the ability of the data gatherer to ask the right questions and the ability of the data source to provide useful information (both possess the correct information and to communicate it).

2.1.1. The ability of the data gatherer to ask the right questions

There is a number of biases that could affect the ability of the data gatherer to ask the questions needed to extract the right information during an interview:

Anchoring. The tendency to rely too heavily on a single piece of information when making decisions, even though that information might not be correct [1]. In the requirements elicitation an anchor might originate from data

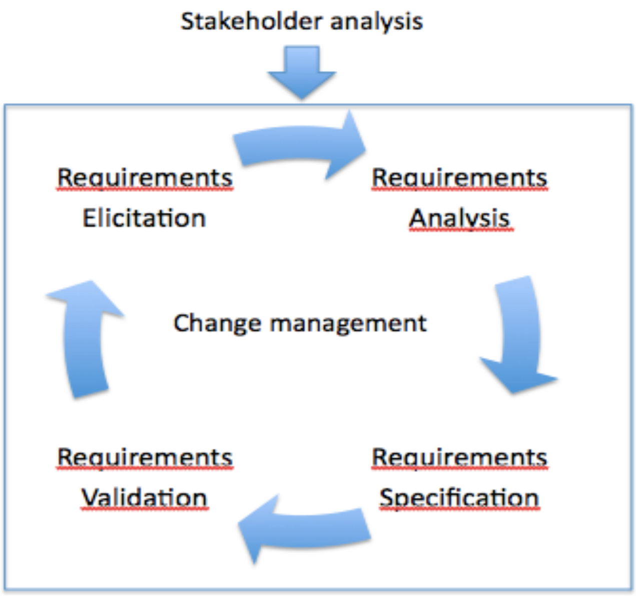

Figure 1: Requirements engineering activities (modified from [21]), focus of this report is marked in the figure.

collected in one interview and affect questions asked in later interviews. Also, information from the ongoing interview might be given too much importance and therefore be explored too heavily leaving less room for other important aspects.

Confirmation bias. The tendency to search for or interpret information in a way that confirms one's expectations [13]. If the data gatherer has has a personal interest in the system it might lead him/her to ask questions that will lead to answers corresponding to their expectations.

Curse of knowledge. Knowing too much about a topic leads to lack of ability to see things from a less-informed perspective [12]. The data gatherer might experience difficulties in asking the right questions if the stakeholders have much lower understanding of the new system's domain than the data gatherer him/her self.

Focusing effect. This bias causes an inaccurate prediction of future events as a person believes that one aspect of an event is more important than others

[16]. This bias might lead the data gatherer to focus on questions about features that are not relevant for the system missing other relevant features. However, this effect has been disputed by Cherubini et al. [5] who's results show that their subjects indeed were able to chose relevant information to focus on.

2.1.2. The ability of the stakeholder to provide correct information

Cognitive biases that could affect the stakeholders' ability to provide correct information are described below.

Anchoring. This bias was described in the previous section as the tendency to rely too heavily on a piece of information when making decisions [1], which during an interview can affect both the data gatherer and the data source. The data source might anchor on either information provided by the data gatherer or even unconsciously be affected by the information present in their surrounding during the interview. For example, it has been shown that people can be affected by completely unrelated information when they are deciding what they would be willing to pay for a product, where one such anchor was two last numbers of the subjects' personal numbers. This example is unrelated to requirements engineering, but it shows how irrelevant information that people unconsciously take into account when making decisions can be.

Ambiguity effect. The tendency to avoid options for which information is missing, in favor of options where information is available, even if choosing the option with less available information would be more beneficial than the other way around [15]. This bias might affect the data source towards what they consider to be the "safe option", for example opting for features they are familiar with instead for more user friendly features they have rarely encountered before. Especially in companies where innovative features are important this bias would cause problems.

Availability heuristic. Believing something is more likely to happen because it is to a higher degree available in memory, often biased towards unusual, or emotional situations [4]. This bias might cause the data sources to see unusual events that have affected them emotionally as more common (e.g. being annoyed by the system overloads or crashes). Thus they might provide incorrect information about usual flow of events to the data gatherer.

Bandwagon effect. The tendency to do things because other people do [19]. This bias might be caused by discussions between stakeholders prior to the interviews and lead to lack of diverging perspectives, and thus also loss of necessary information about the system.

Curse of knowledge. Described previously as lack of ability to see things from a less-informed perspective due to too much knowledge about a topic [12]. This bias might lead to difficulties in explaining every-day tasks to an outsider (data gatherer) and eventually causing the data gatherer to interpret the gathered information incorrectly.

Conjunction fallacy. The tendency to assume that a combination of several specific conditions is more probable than one general condition [9]. This bias could affect the data source to provide unlikely course of events when asked how they use an existing system, or how that system behaves.

Functional fixedness. The tendency to use an object or a system only in the way it is usually used [18]. This bias might pose a threat to the safety of the system as the users might also be unable to come up with alternative scenarios for how a system could be used. For example, the catastrophic malfunction of radiation therapy machine Therac-25 was caused by the unexpected sequence of commands fed in by the medical personnel that was handling the machine [17]. This situation might have been easier to foresee and handle if it was discussed during the requirements gathering.

Focusing effect. Described previously as a cause of inaccurate prediction of future events due to belief that one aspect of an event is more important than others. This bias might lead the data source to put too much emphasis on uncommon ways to use the system leading to inaccurate description of the stakeholders' needs [16].

Negativity bias. The tendency to focus on negative rather than positive or neutral experiences [20] could affect the data source to focus on events that have bothered them or in other ways been annoying or difficult to overcome, instead of positive or even every day events.

Neglect of probability. The tendency to disregard probability of an event when making a decision under uncertainty might lead the data source to believe that certain effects are more likely to happen than not, especially events that might have catastrophic consequences [22], for example people might believe that flight crashes are more likely to happen than they actually are. As a consequence of this bias development of certain systems could become overly expensive due to excessive development of safety or security features.

Normalcy bias. This bias is the opposite of the neglect of probability bias above and it describes how people might refuse to plan for a disastrous event because it has never happened before [14]. For example, in the case of Fukushima Daiichi Nuclear power plant disaster in 2011 the officials did not plan for high enough dams as the probability of waves being as high as 10,2 meters was deemed highly improbable, even though this problem was was pointed out as a possibility by a study conducted in 2008.

Social desirability bias. The tendency of a person to report what they believe to be socially desirable information in order to please the person they are communicating with, in this case the data gatherer [7]. This could lead to gathering of inaccurate or incomplete information if the data source wants to please the data gatherer or if they do not want to admit to embarrassing events or inability to use certain parts of the system.

2.2. Requirements analysis

Requirements analysis concerns the ability of the data gatherer to interpret the gathered information correctly, to organize the interpreted data and to prioritize and handle negotiation of the requirements (modified from [21]). The cognitive factors that could affect these activities will be described in this section.

Anchoring. The tendency to rely too heavily on a past reference or a piece of information when making decisions [1]. This bias might lead the data gatherer to interpret the collected information incorrectly by putting too much focus on information that was highlighted by only one or few individuals but might not be relevant for the system.

Confirmation bias. The tendency to search for or interpret information that confirms one's expectations [13]. This bias might lead the data gatherer to interpret the collected data in a way that will support their ideas about what the system should look like rather than having a neutral perspective that is needed in order to develop a system that will suite its users.

Focusing effect. Causes inaccurate prediction of future events due to belief that one aspect of an event is more important than others [16]. This could affect the data gatherer to focus on aspects of the elicited information that might not be relevant. However, as stated earlier, this effect has been disputed by Cherubini et al. [5] and might thus not affect the interpretation of the collected data to a large extent.

Observer-expectancy effect. The researcher expects a given result and therefore unconsciously manipulates an experiment or misinterprets data in order to find it [2]. However, this bias could also affect a person that is gathering and analyzing requirements for a new system if they have personal interest in how the system should be developed or designed.

2.3. Requirements specification

Specifying requirements means transforming the elicited and analyzed information into a written document. While the result of this activity is, of course affected by its input with all the biases present during elicitation and analysis, there is one main cognitive bias that affects the activity of requirements specification it self:

Curse of knowledge. Lack of ability to see things from a less-informed perspective due to too much knowledge about a topic [12]. This bias might lead to difficulties in specifying requirements that to the data gatherer seem to be "common knowledge". This could cause insufficient explanations of the specified requirements and might lead to misinterpretation by both customers and developers.

2.4. Requirements validation

Requirements validation, including agreements in the beginning of the project (after the requirements have been specified) as well as at the end of the project (or end of the iteration) might be affected by the following cognitive bias:

Social desirability bias. The tendency of a person to report what they believe to be socially desirable information in order to please the person they are communicating with, in this case the data gatherer [7]. This could cause the stakeholders to agree on requirements or developed system that is not what they initially required.

Outcome bias. The tendency to judge a decision by the outcome instead of the quality of the decision at the time it was made [3]. If the stakeholders' needs change or the market changes during the development of the system the stakeholders might expect the system to include functionality that was not specified in the initial requirements. This behavior might also be connected to the *Consistency bias*, which is incorrect remembering of past attitudes and behaviors as being the present attitudes and behavior [11].

2.5. Requirements management

Requirement management is management of changes in requirements that "restarts" the entire requirement engineering loop. The biases that affect this activity are described below.

Backfire effect. The tendency of people to react to disconfirming evidence by strengthening their beliefs [8], which is connected to *Irrational escalation*, the tendency to justify increased investment in a decision, based on the increased prior investment, despite new evidence suggesting that the decision was probably wrong [23]. This might lead the stakeholders to hold on to the previous, faulty decisions although the system would benefit from a change. However, the backfire effect has been disputed showing evidence of people being able to make logical choices that are not affected by discomforting evidence [6], which means that these biases likely have low or no effect on the requirements engineering.

3. Discussion and Concluding remarks

This report shows a number of cognitive biases that could affect the process and results of requirements engineering. Cognitive biases affect all parts of this process - elicitation, analysis, specification, verification and management of requirements. It is likely that they lead to biased requirements which in turn affect other important project activities such as cost estimation, planning, execution, verification and validation as well as assessment of the project success. Thus, these biases should be considered and in cases where it is possible, mitigated when requirements are engineered.

3.1. Why are some biases included in several categories while others are not?

While cognitive biases affect the entire requirements engineering process are several factors that might lead to differences in which ones are included or excluded from different categories:

1. Requirements elicitation is in this report considered to include both data source and data gatherer, all other categories include only one of them.
2. Data gatherer is considered in two ways, they could be a part of the organization that the system is developed for, or they could be part of another organization. Both of these roles are considered in this report.
3. Data source is considered to be a user or a customer. These will likely be more invested in the system's functionality than the data gatherer since they will be using the developed system (or including it as a component in a larger system).
4. Data source needs to recall how the previous systems were used if the new system will be replacing an old one, and/or suggest new functionality. This is a source of many biases that the data gatherer is not affected by.

3.2. How can cognitive biases be avoided in requirements engineering?

Cognitive biases are caused by what Kahneman and Shane [10] suggest are rules that are simple for the brain to compute but introduce systematic decision making errors. Thus, these errors are difficult to perceive in one's own behavior and many of them are therefore difficult to mitigate. In this section possible ways to mitigate the cognitive biases included in this report will be discussed.

3.2.1. Requirements elicitation, data gatherer

If the data gatherer is a professional requirements engineer some of the cognitive biases (s)he could be subject to can be mitigated through training, tools and experience. For example, while the data gatherer still might focus too heavily on certain information due to *anchoring*, a checklist prepared prior to the interview would be a good way to make sure no important aspects are overlooked. Further, while technical experience of the system that requirements are engineered for is important for the data gatherer to have, it is even more important to have training and experience of communication with stakeholders in order to avoid the *curse of knowledge*.

Confirmation bias will only affect data gatherers who have interest in how the system will be used and/or developed. One way to mitigate this bias could be to make sure that the data is elicited by a competent person that will not be affected by the use or a development of the system. *Focusing effect* is somewhat related to the confirmation bias, however this bias has been disputed and question is if it would have any effect on requirements elicitation at all.

3.2.2. Requirements elicitation, data source

Anchoring is a difficult bias to avoid since even the most irrelevant information in the surrounding where the interview is conducted could become an anchor for the data source. The data gatherer should thus remove all evidence of past interviews, such as notes or drawings on a white-board so that the most obvious anchors can be avoided.

Ambiguity effect can affect the gathering of requirements for new, innovative systems negatively. Its effects might be lessened if the data source is trained in facilitating the data source's brainstorming beyond features they are familiar with. This approach would also be beneficial in order to minimize the effect of the *availability heuristic*. However, the data gatherer must be cautious in order to not introduce anchors instead.

Bandwagon effect is caused by people's wish to do what everybody else does, so one of the ways to mitigate this bias would be to ask the stakeholders to not discuss the requirements for the new system with other stakeholders prior to the interviews. However, since the system's pros and cons are probably often informally discussed, this might be of little help.

Further, it is important to train the data gatherer in order to avoid errors in requirements due to *curse of knowledge* that data source is affected by. The data gatherer needs to be able to extract the information, but also make sure that (s)he has understood the elicited information correctly.

Conjunction fallacy might be avoided if the data gatherer asks the data source to recall actual events instead of general system behavior. However, this might affect the data source towards the *functional fixedness* and *normalcy bias* instead, forgetting or refusing to discuss unusual events that are possible but do not occur often, or haven't occurred yet. To avoid this the data gatherer needs to ask the data source specific questions about such events. However, the *neglect of probability* might affect the data source in the opposite direction where they believe that unusual events would be more probable than they really are. *Focusing effect* is another bias that could affect the data source towards similar thinking, where they would assign too high weights to events that they believe are more important than other events. The effects of these biases are difficult to mitigate in an ongoing interview, instead the data gatherer needs to compare the data collected in all interviews to see if they are any clear trends and outliers and discuss the differences with the stakeholders before the system is implemented.

To mitigate effects of *negativity bias* the data gatherer needs to remind the data source to tell them about positive or neutral behavior or features of the system, not only the ones that frustrate them. Also, as already suggested above, if the data source is asked to tell the data gatherer about actual course of events instead of more general ones they would more likely include all types of events and not only those who bother them.

And lastly, due to *social desirability bias* the data sources' answers might be skewed towards what they believe would be pleasing the data gatherer, thus it is important that the data gatherer remains neutral as to which features should be included and how the system should be implemented when they are communicating with the data sources.

3.2.3. Requirements analysis

In this report it is assumed that requirements analysis is conducted by the data gatherer. In order for them to avoid *anchoring* towards an unusual answer they need to actively look for inconsistencies in the data sources' answers, note those inconsistencies and discuss them with the stakeholders. For example, an event or property that is brought up by only one person might be overlooked by the other interviewees, misunderstood by the data gatherer, or simply unimportant. Whichever is the case, inconsistencies like that need to be resolved.

Since *confirmation bias* as well as *focusing effect* and *observer-expectancy effect* are caused by vested interest in the system they could be mitigated by choosing a data gatherer that has no interest in which features are developed and how. *Focusing effect* could also be caused if the data gatherer assigns more weight to answers from certain data sources than others, thus (s)he needs to consciously analyze the differences in data elicited from different stakeholders and understand what causes them.

3.2.4. Requirements specification

During requirements specification the data gatherer is supposed to transfer the results of the data analysis into a written report or another type of document that can be understood by developers and other stakeholders. As stated previously, the input to this activity is already affected by an number of biases. The end product of the specification process can also be affected by the *curse of knowledge* if the data gatherer has more knowledge of the system that is being developed than what the data sources have. This would lead to a document that is difficult for data sources to comprehend due to unfamiliar terminology, or explanations that are too technical or otherwise difficult to understand. Mitigation of this bias would require training of the data gatherer, as well as them having experience of similar tasks.

3.2.5. Requirements validation

During requirements validation the data gatherer communicates with the data sources in order to understand if the specified requirements correspond to their needs. The result of this process might be biased by the *social desirability bias* where the data sources find it difficult to go against what they believe the data gatherer expects from them. In order to mitigate this bias the data gatherer needs to remain as neutral as possible with regard to the specified functionality as well as the implementation process and ask followup questions to assure that necessary changes are made in order to develop a system that the stakeholders will be pleased with.

On the other hand, the data sources might, affected by the *outcome bias* unconsciously change their minds when they see the specified requirements. This can of course be positive, if the requirements include all or even additional requirements that the stakeholders believe are important, but also negative if they overlook that some of the requirements are missing or have been misunderstood by the data gatherer. This bias could be mitigated if the data sources are asked to recall their interviews prior to seeing the requirements specification, or even better, if they are given access to transcripts or recordings of their interviews.

3.2.6. Requirements management

During the implementation or maintenance of the system changes or additions to the system might be desirable or necessary, which would "restart" the requirements loop described in this report. The result of this activity might be affected by *backfire effect* and *irrational escalation* leading the stakeholders to keep on developing wrong or unnecessary functionality. To mitigate this bias the stakeholders need to question usefulness of the included functionality and improvements that are being made. To do this properly a diverse group of stakeholders would need to participate in such discussions in order for make the escalation visible.

3.3. Final recommendations

There are many cognitive biases that affect the process of requirements engineering and I have for each one of the biases included in this report

How to avoid cognitive biases in requirements engineering
Prior to the requirements elicitation the company should:
1. Provide the data gatherer with proper training and tools, or choose one that has them.
2. Choose a data gatherer with experience of requirements engineering.
3. Choose a data gatherer with no vested interest in the system.
4. Ask the stakeholders to not discuss requirements prior to the interviews.
During the interview the data gatherer should:
1. Ask explorative questions first.
2. Follow up with specific questions prepared in beforehand.
3. Ask about specific events instead of general usage of the system.
4. Ask about positive as well as negative properties of the existing system.
5. Keep own opinions and interest to them selves.
6. Remove possible anchors from the environment.
When analyzing the requirements the data gatherer should:
1. Note differences in different stakeholder's answers.
2. Bring up those differences and discuss them with the stakeholders.
When specifying the requirements the data gatherer should:
1. If possible have previous experience from requirements engineering.
When validating the requirements the data gatherer should:
1. Send the transcription or recording of their interview to each data source.
2. Remain neutral with regard to the requirements that are being validated.
In requirements management the stakeholders need to:
1. Openly question and discuss existing functionality in diverse groups.

Table 2: Recommendations for avoiding cognitive biases in requirements engineering

described mitigation strategies, summery of which is presented in Table 2.

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