A Comparative Study on Common Errors in Rules Governing Complex Event Processing Systems

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Abstract

Despite the well-established effectiveness of Complex Event Processing (CEP) in flagging complex events for real-time decision making, the rules which define event-driven behavior can be challenging and error-prone. The problem is that creating rules for CEP systems is increasingly difficult and error-prone because the categorization of errors in CEP rules needed by Big Data Analytics practitioners to improve CEP rule development has not been established. A sample of 10 CEP rule authoring practitioners from various organizations with profiles on LinkedIn was recruited. Participants were interviewed assessing their experiences with errors in rules governing CEP. The key findings of the study were that most errors in rules governing CEP systems were related to a lack of knowledge on the part of the rule author. While more complex issues (such as temporal windows and cross-stream correlation) played a part, participants mentioned gaps in fundamental knowledge more frequently. Specifically, nine themes were identified related to errors in rules governing CEP systems. The major themes which emerged during analysis are lack of knowledge, the nature of CEP, the nature of rules, event streams, planning and design, human and team errors, complexity, and lack of testing and code reviews.

Keywords: Stream Processing, Complex Event Processing, Rule-based Systems

1. INTRODUCTION

Complex Event Processing (CEP) is a commonly used real-time processing approach enabling organizations to detect conditions such as fraud rapidly and take the appropriate action (Mousheimish, Taher, & Zeitouni, 2017). However, the process of creating rules for CEP systems is challenging. While there have been multiple attempts to address the challenge, there is not an understanding of the nature of errors in rules which govern a CEP system. This paper examines the errors which occur within CEP systems through an exploratory qualitative study with the goal of precisely describing the types and causes of errors.

Background

CEP is a form of stream processing in a Big Data environment where computation is performed in real time or on previously archived event streams (Zhou, Simmhan, & Prasanna, 2017). Real-time processing is a well-known computer science problem (Everett, 1951; Martin, 1965). Big Data has been defined using the words velocity, variety, and volume (the three Vs) to communicate the magnitude of speed, variability, and size of data being processed (Laney, 2001). Stream processing (also referred to as analysis in motion or real-time processing) is characterized by two of the three Vs: high velocity and a high variety of input (Wang, 2016). It is worth noting

that stream processing may also process a large volume of data (Ranjan, 2014).

The genesis of CEP came from the need to analyze network traffic in real time for diagnostic purposes (Luckham & Frasca, 1998). The value it could add to the business world was quickly identified (Perrochon, Mann, Kasriel, & Luckham, 1999). Initially, CEP was viewed as a means of simulating business processes, procedures, and activities (Luckham, Manens, Bhansali, Park, & Daswani, 2003). Early in the evolution of CEP, the application of the technology to financial trading was and continues to be an active research topic (Acharya & Sidnal, 2016).

Relevance

CEP is a topic of practical concern in part because it is often used in conjunction with the IoT (Dayarathna & Perera, 2018). Early in the history of IoT, CEP was applied to Radio Frequency Identification (RFID) technology as a means of converting streams of low-level events to actionable knowledge (Palmer, 2004). The use of RFID was an early driver of what would become known as the IoT (Ashton, 2009).

From its humble beginnings, CEP has become a substantial market making it a research area of importance to practical concerns (MarketsAndMarkets.com, 2016). For example, the CEP market is projected to grow from $3.08 billion in 2016 to be $13.7 billion by 2021, with a compound annual growth rate of 34.8%. CEP is being applied to many areas, including fraud detection (Correia, Fournier, & Skarbovsky, 2015), sales and marketing (Perera & Suhothayan, 2015), predictive maintenance (Hribernik et al., 2018), and risk assessment (Matko & Brezovec, 2018).

CEP Rule Errors

The rules which govern CEP systems sometimes have errors (Mousheimish et al., 2017). These errors lower the reliability of the CEP systems (Lee, You, Hong, & Jung, 2015). A better understanding of the types of errors assists in understanding the domain and aids in authoring CEP rules and constructing tools associated with CEP rules (Perera & Suhothayan, 2015).

Purpose of this Research

The purpose of this qualitative exploratory study was to explore the categorization of errors in CEP rules needed by Big Data Analytics practitioners to improve CEP rule development. The intent was to gain an understanding of causes of unexpected or undesirable events associated with using rules in a CEP system that are authored by humans through a semi-structured interview of 10 CEP rule authoring experts on LinkedIn who have encountered and resolved errors. As the participants were selected from LinkedIn, there were no geographic restrictions. The goal was to gain understanding such that subsequent research could be performed to address the identified issues.

2. METHODOLOGY

This study utilized a qualitative methodology, which was appropriate for a nascent phenomenon (Edmondson & McManus, 2007). While CEP is not a new technology, errors in the rules governing CEP are poorly understood (Palanisamy, Dürr, Tariq, & Rothermel, 2018). This lack of knowledge made quantitative methods a poor fit.

Based on the selection of the qualitative methodology, an exploratory research design (Kumar & Phrommathed, 2005) was utilized to investigate the nature of errors in CEP rules. The goal of exploratory research design is to formulate hypotheses, rather than test them. It is anticipated that the theories and hypotheses developed during this study will later be tested using a quantitative or mixed method methodology.

Selection

After IRB approval, potential participants were contacted using LinkedIn messaging capabilities and via emails obtained from the participant's LinkedIn profiles. Participants were characterized by establishing selection criteria (Flick, 2014). The selection criteria for participants was experience with CEP systems, recent active work with CEP systems, and experience with multiple CEP system implementations. There were no required demographic characteristics.

Data Collection

During data collection, semi-structured interview questions were used. A semi-structured interview enables the researcher to answer clarification questions (Griffee, 2005). The responses during the face-to-face interviews were captured using video capture software and video teleconferencing software. The researcher utilized interview questions to capture the informants' perceptions (see Appendix B). The interviews lasted approximately 30 to 60 minutes.

An interview protocol template and recording of video conferencing software were the primary data collection tools for the study. The video conferencing software was used to capture body language and context related to answers. Video

conferencing software was utilized due to geographic restrictions. The software's recording capability was utilized if available, if unavailable, video capture software was utilized to record display and audio from the video conferencing software.

As part of the data collection process, a pilot study was conducted to ensure that the questions were understandable and would likely result in reaching the goals of the study. Two experts in CEP evaluated the interview questions and protocol and determined that they were understandable and appropriate for the research question and problem. There were no modifications to the interview questions.

3. ANALYSIS OF DATA

Data analysis followed the general approach described by Saldaña (2015). Data analysis was performed utilizing Dedoose version 8.1.8, a qualitative analysis software package. The key topics and themes were identified based on transcriptions of the interview, field notes, and the researcher's observations. The transcripts were coded. The codes were organized into logical groups to support the detection of patterns and trends. Analytical memos were utilized to capture thoughts as the concepts were iteratively refined.

Demographics

The participants for the study were recruited from LinkedIn. The participants were initially contacted through LinkedIn's messaging system. Each participant self-identified as a user of CEP systems who had encountered challenges with manually created rules and had resolved those challenges.

Identifier	Use of CEP	Experience
Participant 1	Fraud and Marketing	10
Participant 2	Intrusion Detection	> 10
Participant 3	Multiple	> 14
Participant 4	Intrusion Detection	> 14
Participant 5	Multiple	> 11
Participant 6	Intrusion Detection	> 3
Participant 7	Insurance	> 3
Participant 8	Multiple	> 10
Participant 9	Multiple	> 3
Participant 10	Multiple	> 10

While the interview did not explicitly ask the participants' demographic information, such information was inferred from the participants' public LinkedIn profiles.

The participants had varying backgrounds and exposure to different CEP solutions and implementations. Over five commercial CEP systems were discussed from various perspectives. The participants utilized CEP in multiple industries and varying degrees of complexity. Saturation was reached after 10 interviews.

Overview of Analysis

While the focus of the study was on the nature of errors related to manually created CEP rules, questions were asked to engage the participants and to allow them time to evaluate the types of errors they encountered. The topic of errors in CEP rules was introduced in the second question and pursued in the third (Dennis, 2018). The last two questions revisited the topic of errors and challenges related to CEP manual rule authoring, after having allowed the participants time to consider the topic.

Codes were assigned related to types or causes of errors. Inferences were made based upon questions not explicitly asking about errors. For example, the sixth question asked what skills were necessary for a rule author to create correct CEP rules. Often the absence of a specified skill would result in an increased likelihood of a given type of error.

Words or phrases were assigned codes. During this process, as a transcript was reviewed this researcher first considered the list of existing codes if one which was sufficiently similar to the concept being encountered existed it was reused. If no such code was found, a new code was introduced. Periodically during the analysis phase, the codes were organized based on similarities. Codes were merged if such a merger did not reduce the value of the passage of interest.

4. FINDINGS

Nine themes emerged during analysis. The most frequently occurring theme was errors related to lack of knowledge. The next three themes centered on the nature and characteristics of CEP, rules, and the event stream. These three themes were not merged as the researcher viewed that the resulting merger would have diminished the clarity of the research. The fifth theme related to errors related to the lack of planning or design.

The sixth theme centered on errors related to individuals or teams. The seventh theme was errors associated with high or unnecessary complexity. The eighth theme centered on the lack of testing or code reviews. The ninth and final theme centered on errors outside of the CEP system. The nine themes will be explored in depth.

Theme 1: Lack of Knowledge

The most frequently occurring theme related to lack of knowledge on the part of the rule authors. Eight of the participants mentioned this theme once or more. Participants 4 and 10 did not explicitly mention lack of knowledge as a cause of errors in rules within a CEP system. The subthemes included lack of CEP implementation knowledge and experience, failure to use or misusing vendor tools, lack of a programming background, and not understanding the domain being addressed by the CEP system.

Lack of CEP implementation knowledge and experience was a subtheme. Seven of the participants (1, 2, 3, 5, 6, 8, and 9) indicated that lack of CEP implementation knowledge and experience was associated with errors in rules. Participant 1 addressed the lack of knowledge of the runtime behavior of CEP solutions along with not considering or understanding the implications of manipulations within the system as sources of errors.

While an appropriate background was described as useful or even necessary, generally it was not described as an essential prerequisite. Several participants mentioned training, online resources, and reference materials to address deficiencies in knowledge. There was a consensus that a rule authors' ability to successfully author rules increased as the authors became more experienced authoring rules for use in CEP systems.

The issues related to lack of knowledge were not limited to knowledge of CEP systems or programming. Participants 1, 2, 3, 5, and 6 all mentioned the importance of domain knowledge when authoring CEP rules. Participant 1 said, "if you look at it from a purely technical or mathematical perspective, you may miss some obvious event patterns that are common in the domain, but don't necessarily seem like they'd come up that frequently." The importance of understanding the problem being solved as well as how the CEP solution fits into the overall processing environment. Participant 3 said "I don't find that people have a huge problem writing the rules. I think they have a bigger problem understanding the problem they're trying to solve." Participant 6 summed up the challenges associated with lack of knowledge as "You need to know the domain. If you don't know what you are dealing, and if you don't know the product, and you don't know the exact CEP operators that will lead to reasonably bad logic."

Theme 2: Nature of CEP

The second major theme relates to errors resulting from the nature of CEP systems. This group of errors stems from the CEP system implementation or the basic nature of CEP processing. The subthemes of this theme are CEP's temporal nature, the CEP paradigm, concurrent and distributed processing, and state management.

The temporal nature of CEP was the most frequently mentioned subtheme within this theme and was mentioned by Participants 3, 4, 6, 8, 9, and 10. Participant 3 discussed challenges related to aggregation and time windows. For example, Participant 3 used an example related to a requirement of a one-second window. Participant 3 said, "You get a lot of requirements that are unclear, if you're specifying, say, an aggregation and the functional requirement that you get in from the business analyst is something like, give me a one-second average." Participant 3 explained the requirement is not sufficiently precise to enable accurate implementation. Participant 3 went on to say "is this a one-second non-overlapping window? A rolling average of one second that happens every second? Are you doing your aggregation from the time the window closes back one second?"

Participant 6 shared an example related to temporal windows in a CEP implementation. In the example, a developer had created an implementation that would occasionally fail unit tests. The failures occurred near midnight and were related to unexpected behavior in a window construct. Participant 6 also discussed that some CEP operations rely on the system time.

Theme 3: Nature of Rules

The third theme relates to the errors associated with the nature of rules. This theme is related to challenges associated with rules within a CEP system. All participants discussed this type of error. The most frequently discussed challenge associated with rules relates to threshold values and edge cases. Also mentioned were the order of rule evaluation, rule coverage and conflicts, and event sequence definition.

Participant 1 mentioned that the threshold values are often arbitrarily assigned by a subject matter expert. Participant 1 discussed the different challenges associated with threshold values. Participant 1 said, "if you had a hard-coded threshold that was very easy for the rule coverage tools to show you when one rule would fire, or another wouldn't." Participant 1 went on to say, "if you had sort of a dynamically set threshold, it became less obvious depending on how those thresholds could interact." Participant 3 went on to discuss that often threshold values are computed in scoring models and dynamically updated.

Theme 4: Event Stream

The fourth theme relates to errors associated with the event stream which the CEP system processes. Participant 1, Participant 2, Participant 3, Participant 5, Participant 6, Participant 7, Participant 8, and Participant 9 all mentioned event stream-related errors. These errors are related to Theme 9 which include integration.

The failure to test a CEP solution with production data was mentioned by the most participants as a cause of CEP errors. Participant 1, Participant 3, Participant 5, and Participant 8 each mentioned lack of testing with production event stream data as a source of errors. The responses will be explored.

Theme 5: Planning and Design

All participants, except for Participant 2, mentioned errors related to poor planning or design. The subthemes included little or no design, insufficient requirements, not planning for errors, and not understanding the overall solution.

Participants 1, 3, 5, 6, 7, 8, and 9 mentioned cases where little, or no design was performed. The result was solutions that failed to execute correctly or did so with sub-optimal performance. Participant 1 described situations where rule authors create complex rules, rather many simple rules. Participant 1 indicated that such rules were difficult to debug and maintain. Participant 1 went on to explain that poorly designed solutions were often slow because of the use of computationally expensive rules.

Theme 6: Human and Team Errors

Participants 1, 5, 10, 2, 8, 3, 7, and 9 mentioned errors related to human interaction or interactions between groups of humans. The subthemes were multiple rule authors, typographical and syntax errors, and human comprehension or retention. This subtheme included misunderstanding, misinterpretation, lack of reasoning, and forgetting details

The most common subtheme in this theme relates to multiple rule authors. Participant 1, Participant 2, Participant 7, and Participant 10 mentioned that lack of consistency in rule authoring makes it challenging to diagnose and correct errors. For example, Participant 1 said that "the more heterogeneous your development team is and the further they sit from each other, the more you get issues like rule coverage, consistency in behavior, how you consume, and how you track various events within the system." Participant 2 mentioned that often teams fail to communicate, often resulting in errors. Participant 7 discussed the need for automated tools to get the "tribal-knowledge" from users and documented, in the advent of turnover. Participant 10 mentioned issues related to "lack of consistency in the ways those rules are sort of created because we're manually creating them."

Theme 7: Complexity

Overly complicated or unconstrained systems were mentioned as a source of errors by all participants except Participant 4 and Participant 9. The subthemes related to complexity included not leveraging templates and utilizing unconstrained input, not starting simple, and utilizing overly complex rules.

Participants 2, 4, 1, 5, and 8 mentioned that complex rules were a source of errors. Participant 3 proposed "break the concepts down to be a bit simpler" as a means of addressing complexity. Participant 8 discussed how as applications grow, they often become more complex and in turn more difficult to maintain correctness.

Not using templates or frameworks was a subtheme related to complexity. Participants 1, 2, 3, 6, 7, and 8 mentioned the importance of using frameworks, templates, or other complexity reducing constructs. Participants 1 and 2 recommended the use of spreadsheet-like constructs to reduce complexity.

Theme 8: Lack of Testing and Code Reviews

Lack of testing or code reviews was identified by all but Participant 10 as a source of errors. While testing may not avoid errors, it does identify them earlier in the development process and before deployment. Participant 3 mentioned the importance of automated functional regression testing. Participant 2 described the importance of unit testing, while Participant 6 mentioned test cases as a means of combating errors. Participant

1 stated, "to avoid errors in a live CEP system, testing, testing, testing, testing, and simulation," Participant 1 also described cases where testing is not effective. Participant 1 said, "the worst type of testing I've seen was people who used their model to generate simulation data and then ran the simulation data against their model, and slightly iterated the model." Participant 1 went on to say, "because that test data was by definition, even with some reordering, basically how going to operate their model or the way they had designed it." Participant 1 cautioned "it's going to produce exactly the output you expect, which might be catastrophic when deployed into a production environment."

Participant 2 offered advice on the types of tests to execute. Participant 2 said, "correlation and simulation during unit testing and development, would really be helpful." Participant also described cases where unit testing caught issues early in the development cycle.

Theme 9: External Factors or Conditions

Participant 8, Participant 5, Participant 6, and Participant 9 described errors external to the CEP implementation. Computational resources, software failure, and integration were the subthemes related to this theme. Participant responses will be presented.

Participant 9 emphasized the importance of having appropriately sized hardware executing the CEP system. Participant 9 pointed out that lack of memory or CPU could result in runtime errors. Participant 9 said, "another set of error sources is invalid system configurations in terms of memory and CPU." Participant 9 went on to say, "if you do not basically calculate your runtime requirements, then it will eventually let the system fail."

Participant 5 mentioned that software failures, while rare, do contribute to errors in CEP systems. Participant 1 noted that "it's impossible to eliminate all errors in any sort of software system, right?" While Participant 10 did not describe instances of CEP system errors, Participant 10 did state an important requirement for CEP systems, "The biggest single thing is always reveal how the CEP system came to its conclusions."

Participant 9 and Participant 8 discussed challenges related to the integration of CEP with other systems. For example, Participant 9 mentioned the challenges associated with retrieval of reference data. It is worth noting that Theme 4 is associated with integration.

Discussion of Select Follow-On Questions

During the interview process, the participants were asked how they dealt with team members who lacked the skills necessary to author CEP rules. The question was a follow-on question to the sixth question. Select answers to that question will be presented.

Participant 1 suggested the use of tutorials to address team member deficiencies. Participant 1 also mentioned initially allowing team members to construct rules using a spreadsheet-like interface. Participant 1 indicated that as the team member progressed, they could create core operational rules.

Participant 8 mentioned that it was often beneficial to perform a code review when team members were struggling with CEP rules. Participant 8 also mentioned that training courses were often successful in increase team member capabilities. Participant 8 shared that mastery of CEP was made challenging because many "colleagues work with multi-products. None of them are particularly engaged and focused on CEP, but rather a whole portfolio of things. You do need to spend some time with it to understand, to digest the paradigm."

Participant 9 said the "best way is to basically read through the streaming material." Participant 9 went on to say, "Going through those streaming semantics is the first thing any user should do, because without that streaming semantics, understanding of that semantics, it is hard to understand the constructs, right? Hard to apply those constructs."

A follow-on to the seventh question related to the utilization of best practices. The intent was to gain insights into steps being taken to avoid errors.

Participant 1 mentioned stand-up meetings between teams to improve communication. Participant 1 also discussed the importance of identifying the author of rules. The goal was to increase awareness of the impact an individual's rules might have. Participant 1 mentioned the value in having multiple copies of event streams so that only one CEP agent consumed a given stream. Participant 1 went on to say, "So you have a core events stream coming in. And then you're basically duplicating it and feeding it to different CEP agents where you might have people operating on the same set of rules, but you don't want one behavior clobbering another." Participant 1 then discussed the importance of consolidating the output of the individual agents in a high-level abstraction. The goal was to create a separation of concerns so that one team did not impact another.

Participant 6 said, "we developed CEP rules, and we compared it to another system which is already being used in the same domain." Participant 6 went on to say, "if the data you are using is coming from a database system, you can compare the queries on top of the database and compare those with the results of a query you have written in CEP." The idea was to utilize existing static datasets, with known outcomes, and test those datasets using a stream processing model.

5. CONCLUSIONS

The problem addressed by this study was that creating rules for CEP systems is increasingly difficult and error-prone because the categorization of errors in CEP rules needed by Big Data Analytics practitioners to improve CEP rule development has not been established. Multiple personas could improve rule quality including rule authors, CEP researchers, CEP vendors, and CEP project managers. However, CEP practitioners can benefit immediately from the results of this study.

The most common theme related to this research is that lack of knowledge is associated with errors during manual rule authoring. Errors in CEP systems lower the quality of service the CEP system provides (Palanisamy et al., 2018). The implications of these finding are that when undertaking a CEP implementation assessing and potentially improving the knowledge of the team developing the solution is essential. Likewise, based upon the participant's responses, understanding the nature of the CEP processing is paramount. The participants indicated that tutorials, simple examples, and mentoring are ways to address the shortcomings in knowledge. Practical consideration of this implication is that organizations engaging consulting organizations should assign team members to CEP related activities. This level of specialization would address one of the concerns raised by a study participant.

The requirements of knowledge also vary by vendor. Not only should the creators of CEP systems understand the concepts related to CEP, but they should also be experts at the vendor's product being utilized. As it is unlikely a single individual will possess expert knowledge related to all CEP systems, finding a vendor or developer who specializes in the selected tool is critical. It is also important that the team communicate extensively. Domain knowledge was another form of knowledge which was referred to as a source of errors. When combined with the themes related to team organization and communication, it becomes apparent that those implementing CEP systems must communicate with other teams developing solutions and with the subject matter experts defining the requirements of the system. It is possible that emerging semantic oriented CEP systems may lower the risks associated with rule authoring by capturing the author's intent (Dayarathna & Perera, 2018).

While this study was limited in scope, it did identify themes which resonate with published research. It is conceivable that themes which were less frequently occurring might have a more significant impact in particular domains or industry-specific implementations. For example, while concept drift and evolution of events within the event stream (Mehdiyev, Krumeich, Werth, & Loos, 2016) was mentioned by multiple participants, it was not as frequently mentioned as lack of knowledge. To assess the extensiveness and impact of such concepts additional research should be performed.

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