Property Lifecycle Diagram for Tracing State Machine Diagram Changes

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Keywords: Edit Log, Modeling Process, State Machine Diagram, Visualization.

Abstract: For geographically distributed systems such as IoT (Internet of Things) and CPS (Cyber-Physical System), those systems provide numerous different components. Furthermore, a lot of those components including future ones must need to interact with each other. Hence, they are designed by event-driven manners for keeping highly versatility. Meanwhile, the behavioral design of such a component is changed by changing the behavioral design of other components. Such changes thus occur frequently depending on the performance, location, etc. of those components. Therefore, diagram changes should be traceable. This paper proposes a property lifecycle diagram and a method to generate it from the edit log of a state machine model. The property lifecycle diagram visualizes the lifecycle of property values for enabling developers to intuitively trace the changes in the property values of the same state machine diagram. This study aimed to answer the following research question: "what clues can the lifecycle of properties provide to understand the changes of the diagram?" To achieve this aim, we have evaluated the proposed method by applying it to the edit log by 10 computer science students.

1 INTRODUCTION

For geographically distributed systems such as IoT (Internet of Things) and CPS (Cyber-Physical System), those systems provide numerous different components (Graja et al., 2018; Huang et al., 2010; Kraemer et al., 2009; Pencheva and Atanasov, 2016; Sanden and Zalewski, 2006). Furthermore, a lot of those components including future ones must need to interact with each other. Hence, they are designed by event-driven manners for keeping highly versatility. Meanwhile, the behavioral design of such a component is changed by changing the behavioral design of other components. Such changes thus occur frequently depending on the performance, location, etc. of those components. Therefore, diagram changes should be traceable.

Unified Modeling Language (UML) (Object Management Group, 2017) is a standardized modeling language for object-oriented analysis and design. In UML, the state machine diagram represents an event-driven behavior using discrete state transitions. A survey study (Agner et al., 2013) has reported that state machine diagrams are regularly used by more than 90% of the 209 embedded system developers.

Many studies on the traceability related to state machine diagrams have been conducted and the traceability should be kept between different types of artifacts or processes in general (Heisig et al., 2019; Horváth et al., 2020; Vidal and Villota, 2018; Sulaiman et al., 2020; Kchaou. et al., 2017; Foster et al., 2020; Kan and Huang, 2018). For instance, existing studies are focusing on the traceability between different types of state transition specifications (Horváth et al., 2020), between requirements and models (Vidal and Villota, 2018), between features and states (Sulaiman et al., 2020), between UML models (Kchaou. et al., 2017), between requirements and formal models (Foster et al., 2020) or between safety analysis and functional models (Kan and Huang, 2018). The traceability is utilized to clarify the rationales behind functions (Kan and Huang, 2018), to analyze impacts by changing requirements (Vidal and Villota, 2018) or else. Meanwhile, these studies have not focused on the changes of the same artifact in time series.

Therefore, this paper proposes a property lifecycle diagram and a method to generate it from the edit log of a state machine model. The property lifecycle diagram visualizes the lifecycle of property val-

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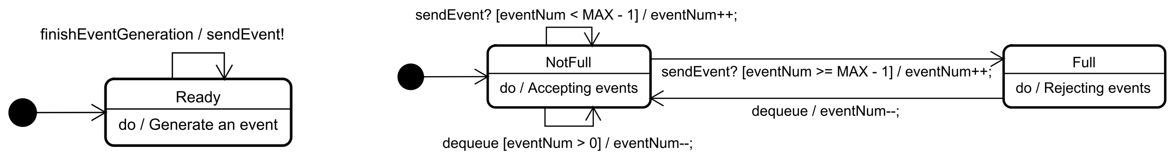
Ogata, S., Nishizawa, Y., Makihara, E., Kayama, M. and Okano, K.
Property Lifecycle Diagram for Tracing State Machine Diagram Changes.
DOI: 10.5220/0010534905210528
In *Proceedings of the 16th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE 2021)*, pages 521-528
ISBN: 978-989-758-508-1


finishEventGeneration / sendEvent!
Ready
do / Generate an event
sendEvent? [eventNum < MAX - 1] / eventNum++;
NotFull
do / Accepting events
sendEvent? [eventNum >= MAX - 1] / eventNum++;
Full
do / Rejecting events
dequeue / eventNum--;
dequeue [eventNum > 0] / eventNum--;

(a) Event generator. (b) Event queue.

Figure 1: State machine model using the concepts of glossary, communication and script.

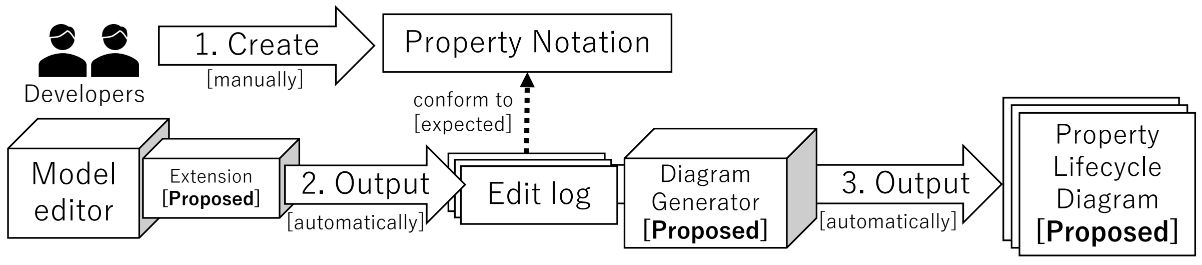


Figure 2: Overview of the proposed method.

ues for enabling developers to intuitively trace the changes in the property values of the same state machine diagram. Furthermore, we have integrated the proposed method with a method to add a glossary, etc. to the state machine diagram notation (Ogata and Kayama, 2019), so that developers can determine whether property values conform to a glossary, etc. This study aimed to answer the following research question: "what clues can the lifecycle of properties provide to understand the changes of the diagram?". To achieve this aim, we have preliminary evaluated the proposed method by applying it to the edit log by 10 computer science students.

The contributions of this paper are as follows:

- Originality: The property lifecycle diagram was proposed and then evaluated in the evaluation for the proof of concept.
- Effectiveness: As an experimental result, the proposed method enabled experimenters to intuitively trace the changing state machine diagrams. For instance, they identified the participants who misunderstood where to give terms, could not accurately use terms or changed their understandings in the middle of modeling, as the result of interpreting the traces.

2 BASICS OF UML STATE MACHINE DIAGRAM

Figure 1 presents sample UML state machine diagrams in a model. A rectangle with rounded corners indicates a state. A state can have the following properties: name, do-activity and entry and exit actions. In Figure 1, `NotFull` is the state name, and `do / Accepting events` is the do-activity that describes the behaviors during a stay in a state. An open arrowhead line indicates a transition. A transition can have the following properties: trigger, guard and effect. Figure 1, `dequeue` presents an example of a trigger that corresponds to an event, and `[eventNum > 0]` presents an example of a guard that describes transition conditions. Moreover, `/eventNum--;` presents an example of an effect describing behaviors during a traverse of the transition. A filled circle indicates an initial pseudo-state as an entry point.

3 PROPOSED METHOD

Figure 2 presents an overview of the proposed method. The edit event types triggering the logging of the model file in editing are `create`, `update`, `delete` and `move` as shown in Table 1. Each logged file is named by Unix time that indicates the time of logging the file. For the logged model files called an edit log, the proposed method analyses the difference in each pair of model files adjacent in the time series.

3.1 Property Lifecycle Diagram

A property lifecycle diagram takes the form of a state transition diagram and visualizes the lifecycles for properties. The lifecycle means that the change history of property values from creating the property until deleting it. A property lifecycle diagram shows the lifecycle integrating the lifecycles of the same type of properties extracted from all the diagram elements. In

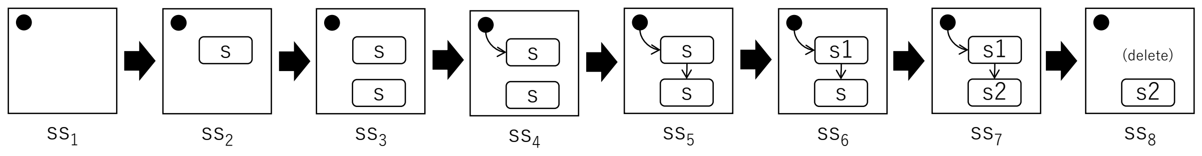


Figure 3: Edit log.

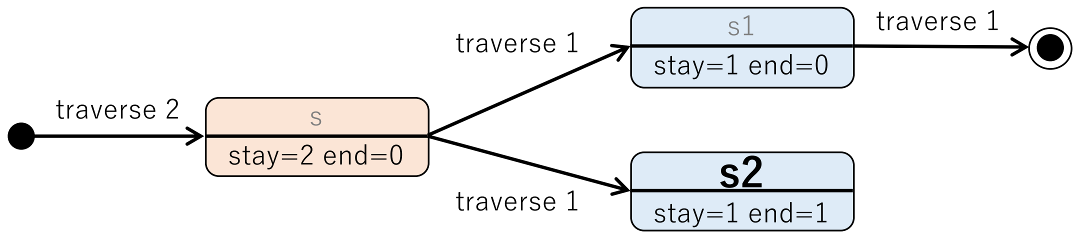


Figure 4: Property lifecycle diagram for state name.

Table 1: Edit Event Types Triggering Logging.

Type	Description
`create`	A new vertex or transition was created.
`delete`	Existing vertices and/or transitions were deleted.
`update`	Properties such as a state name were updated.
`move`	Existing vertices and/or transitions were moved.

other words, A property lifecycle diagram is created for each type of property, i.e., state name, do-activity, entry and exit actions, trigger, guard, and effect.

Figure 3 shows a simple example of an edit log starting with the snapshot SS_1. In this log, an initial pseudo-state and two states were initially created. The initial names of these two states are the same name `s`. A transition then was created between the initial pseudo-state and one state. Furthermore, a transition was created between those two states. The names of those two states then were changed to `s1` and `s2`, respectively. Finally, the state `s1` has been deleted.

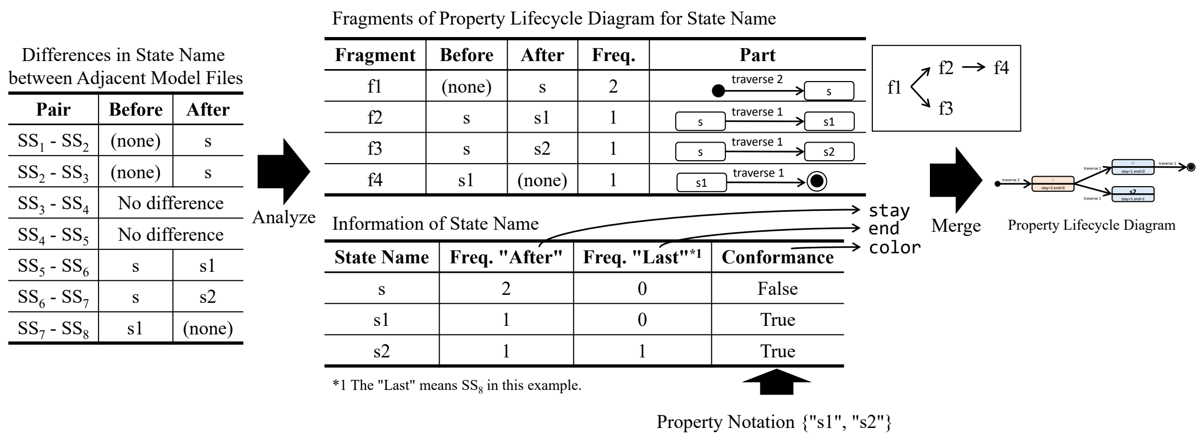
Figure 4 shows the property lifecycle diagram for the state names in the edit log of Figure 3. In this diagram, a filled circle indicates that properties were created. Meanwhile, a filled circle surrounded by a circle indicates that properties were deleted. With regard to a rectangle with rounded corners, the top region shows a property value, and the bottom region shows the passage information. `stay` means the number of times that the property value, e.g., `s`, was assigned to the property due to some change. For instance, the name `s` is assigned to `state name` properties twice in total in Figure 4. Thus, the corresponding `stay` is 2. `end` indicates the number of the values that appeared in the last model in the edit log. For instance, the `end` for `s2` is 1, since it only appeared once in the last model, i.e., SS_8. If the `end` is one or more, the font of the property value becomes bold and large. If not, the font becomes grey.

Meanwhile, an arrow indicates changes in the property value. For instance, there is the arrow from `s` to `s1` because the name of one state `s` was changed to `s1` between SS_5 and SS_6. `traverse` denotes the number of times that the property has been changed from the source value, e.g., `s`, to the target one, e.g., `s1`. For this arrow, `traverse` is 1 since the change only occurred once.

A rectangle with a blue background indicates that the property value conformed to the corresponding property notation. Contrarily, red means that the value did not conform to the property notation. If no property notation exists, all rectangles always have a blue background. The method proposed in our previous study can check whether property values conform to the property notation automatically (Ogata and Kayama, 2019). There are three types of notation element: glossary; communication; and script. The glossary is a set of terms. The communication synchronizes behaviors between different transitions. The script is executable code handling variables. However, those details are omitted in this paper due to limited space.

3.2 Property Lifecycle Diagram Generation from Edit Log

Property lifecycle diagrams are generated from the differential analysis results for each pair of model files adjacent in the time series. Figure 5 shows an overview of a property lifecycle diagram generation


Differences in State Name between Adjacent Model Files

Pair	Before	After
SS_1 - SS_2	(none)	s
SS_2 - SS_3	(none)	s
SS_3 - SS_4	No difference	
SS_4 - SS_5	No difference	
SS_5 - SS_6	s	s1
SS_6 - SS_7	s	s2
SS_7 - SS_8	s1	(none)

Fragments of Property Lifecycle Diagram for State Name

Fragment	Before	After	Freq.	Part
f1	(none)	s	2	● traverse 2 → s
f2	s	s1	1	s traverse 1 → s1
f3	s	s2	1	s traverse 1 → s2
f4	s1	(none)	1	s1 traverse 1 → ◉

Information of State Name

State Name	Freq. "After"	Freq. "Last"[*1]	Conformance
s	2	0	False
s1	1	0	True
s2	1	1	True

*1 The "Last" means SS_8 in this example.

Figure 5: Property lifecycle diagram generation.

based on the example of Figure 3. The left of Figure 5 shows a result of the differential analysis for the state name. “Pair” indicates model files adjacent in the time series. “Before” indicates the situation of the former diagram, e.g., SS_1, in the difference while “After” indicates the situation of the latter one, e.g., SS_2. “(none)” means that the state name did not exist in the former diagram but exist in the latter one, and vice versa. “s”, “s1” and “s2” indicate state names. “No difference” means that the pair was not related to the difference in the focused property type, e.g., state name.

The top middle of Figure 5 shows the fragment list extracted from the result of the differential analysis. A fragment corresponds to an arrow in property lifecycle diagrams and is identified uniquely by the pair of “Before” and “After”. In the left of Figure 5, there were two rows in which “Before” and “After” are “(none)” and “s”, respectively. Thus, a fragment “f1” shows the result of integrating the data of these two rows. The “Before” value is transformed into the source rectangle. In the case of “(none)”, it is transformed into a filled circle. Meanwhile, the “After” value is transformed into the target rectangle. In the case of “(none)”, it is transformed into a filled circle surrounded by a circle. “Freq.” indicates the frequency that the same fragment appeared in the differential analysis result, and becomes the “traverse” value. Furthermore, the graph of a property lifecycle diagram can be generated by merging each fragment pair in which the “After” value in one fragment is the same as the “Before” value in the other one.

The bottom middle of Figure 5 shows the information of state names related to the result of the differential analysis. “State Name” indicates the state names that appeared in the differential analysis result. “Freq. “After”” indicates the frequency that each state name appeared in the “After” column of the differential analysis result. Its value becomes the “stay” value in the corresponding rectangle in property lifecycle diagrams. “Freq. “Last”” indicates the frequency that each state name appeared in the last model file. Its value becomes the “end” value. In this example, The “Last” model file means SS_8 in Figure 4. “Conformance” indicates whether each state name conformed to the corresponding property notation. Its value becomes the background color, i.e., blue or red.

3.3 Prototype Tool

To support the proposed method, we have developed a prototype tool in Java. This tool uses Astah professional (Change Vision, 2020) for the logging and difference analysis and PlantUML (Plant UML, 2021) and GraphViz (Ellson et al., 2004) for the visualization. The Astah professional tool is an extensible model editor and provides Java API for reading and writing models. The PlantUML tool is a tool to render model diagrams based on texts in the PlantUML notation and partially uses the GraphViz tool to determine the model layout.

4 PRELIMINARY EVALUATION

In this study, we have evaluated the proposed method to answer the following research question: “what clues can the lifecycle of properties provide to understand the changes of the diagram?” In this evaluation, we discussed how the proposed method can be useful in practice based on the results of applying the proposed method to learners’ edit logs.

4.1 Overview

In this evaluation, each participant created a state machine model for each of the four modeling tasks in 1 day. There were a total of 11 participants, and each of them was either a fourth-year undergraduate or first- or second-year graduate computer science student. They used the prototype tool for logging their edit logs. Each participant saved the four models presented in Table 2 in one file and submitted the file, and then the edit logs were anonymized according to the experimenter's instruction. The requirements and property notations in the modeling tasks were originally written in Japanese. However, all the models in one file were written in English. Hence, the experimenters excluded that file from the 11 files. It is because the file made it impossible to validly verify many property values in the file based on the corresponding property notations.

4.2 Tasks

There were four modeling tasks. Here, we present the first two due to space constraints. The theme of the first task (Task 1) was a stopwatch. In this task, the experimenters introduced only a glossary of terms to the property notation.

- The stopwatch has the left and right buttons.
- The stopwatch is initially stopped.
- The stopwatch begins measuring the time when the right button is pressed and pauses the measuring time when the right button is pressed again.
- The stopwatch that paused resumes measuring the time when the right button is pressed.
- The stopwatch that is measuring the time keeps a lap when the left button is pressed.
- The stopwatch that is not measuring the time resets the time when and the left button is pressed.
- The stopwatch is stopped after a reset.

The theme of the next task (Task 2) was train boarding. In this task, the experimenters introduced a glossary and the script to the property notation.

- The variables `cntTrain` and `passenger` must be utilized in this task.
- The number of passengers, i.e. `passenger`, on the train is initially zero.
- The number of train vehicles, i.e. `cntTrain`, is initially one.
- The train will have a maximum of four vehicles.
- The maximum number of passengers is five per vehicle.
- The train can connect one vehicle by one connection.
- The train can disconnect one vehicle by one disconnection when the rest of the vehicles have the capacity to accommodate all passengers at the time of the disconnection.
- The train can depart at any time, regardless of the number of passengers.
- The train will arrive at the next station after a departure.
- The getting on or off the train or the connection or disconnection of the train can be done only when the train stops.

4.3 Steps

The experimenters proceeded with the evaluation as follows:

1. The experimenters elucidated how to write a state machine model to all the participants.
2. The experimenters confirmed through the participants' answers that all of them had the necessary knowledge to perform all the tasks.
3. Each participant worked on each task at the corresponding limited time. Furthermore, each participant also left notes concerning the difficulties in his/her modeling for each task.
4. The experimenters collected the anonymized artefacts of all the participants.
5. The experimenters excluded one artefact, since its type of natural language did not conform to the property notations.
6. The experimenters visualized the obtained artefacts using the proposed method to infer learners' errors. They also confirmed the notes describing the participants' difficulties.

4.4 Results

Figure 6 and 7 present the property lifecycle diagrams of the triggers and guards in Task 1, respectively. The edit logs of the 10 participants were integrated by each of these diagrams. The property notation for triggers in Task 1 accepted the terms `left button`, `right button` and `(empty string)`. It should be noted that the empty value was shown as _, depending on a prototype tool constraint. Figure 7 indicates that there was a participant who misunderstood that those terms for effects, e.g. `reset` and `keep a lap`,

Table 2: Tasks in Evaluation.

ID	Concept	Time	Theme	Diagram quantity
Task 1	Glossary	10 min.	Stopwatch	1
Task 2	Glossary and Script	20 min.	Train Boarding	1
Task 3	Glossary and Communication	20 min.	Remote Key Lock	2
Task 4	All concepts	25 min.	Producer-Consumer Problem	3

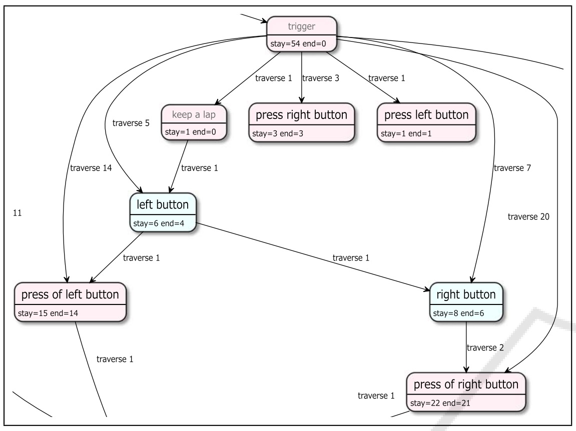


Figure 6: Lifecycle of trigger integrating the edit logs of the 10 participants in Task 1 (excerpt).

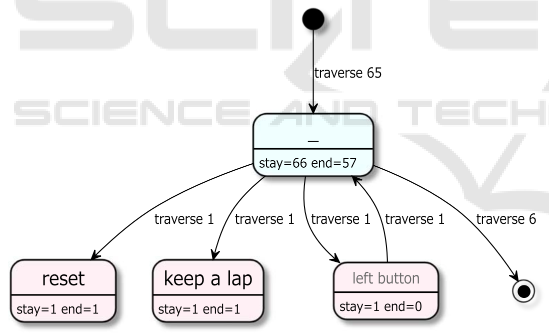


Figure 7: Lifecycle of guard integrating the edit logs of the 10 participants in Task 1.

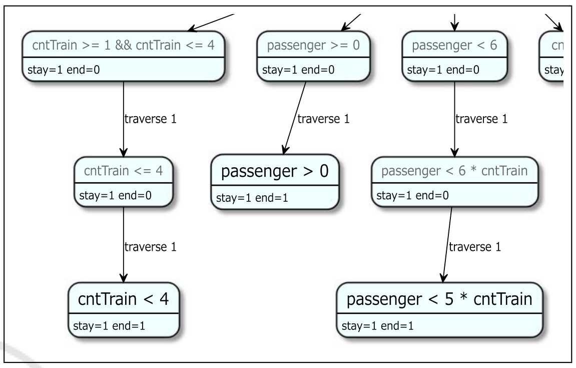


Figure 8: Lifecycle of guard based on the edit log of a participant in Task 2 (excerpt).

should be utilized for guards. Figure 8 presents the property lifecycle diagrams of the guards in Task 2. This diagram indicates the edit log of a participant. The property notation in Task 2 accepts the script in the guards and effects at least.

The number of the generated property lifecycle diagrams was 539 in total, i.e. 7 properties * (10 participants + 1 integration) * 7 state machine diagrams. Such generation result raised a issue: is it difficult to grasp the generated diagrams that integrate the edit logs of the 10 participants from the viewpoint of its complexity? This issue is important since developers create and maintain a large and complex model usually.

With regard to this issue, we investigated the variety of property values. The more the expressions of the recorded property values, the more the rectangles and arrows, and thus, the less readable the property lifecycle diagrams are. Hence, the reduction of the variety of property values enables developers and researchers to obtain property lifecycle diagrams that are easy for them to understand. For this reason, we further investigated how the presence or absence of a property notation influences the diversity of the property values. In this evaluation, six out of seven types of state machine diagrams, e.g. `stopwatch` and `train`, provided only a glossary for the `do activity` properties. Meanwhile, the six types of state machine diagrams did not provide any property notation for the `state name` properties. In other words, those diagrams accepted free-writing of the `state name` properties. Thus, we compared the property lifecycle diagrams between the `state name` and `do activity` properties and dealt with the six property lifecycle diagrams for each of the `state name` and `do activity` properties. Furthermore, each set of the six diagrams corresponds to the six types of state machine diagrams previously mentioned. We also handled the property lifecycle diagrams integrating the edit logs of the 10 participants and visualized the statistics of those diagrams using a box plot.

Figure 9 presents the box plot indicating the statistics of rectangles and arrows in the property lifecycle

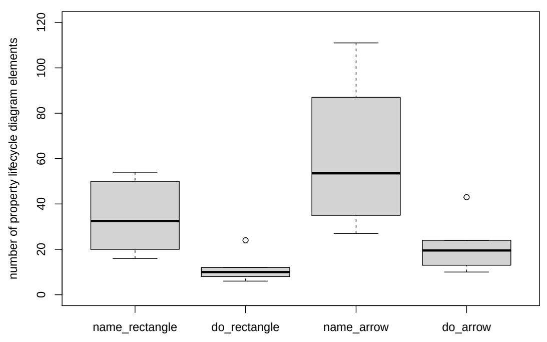


Figure 9: Comparison of the statistics of rectangles and arrows in the property lifecycle diagrams between the `state name` and `do activity` properties (N=6).

diagrams. For the labels of the x-axis, `name` and `do` denote `state name` and `do-activity`, respectively. The label of the y-axis denotes the number of property lifecycle diagram elements. As can be seen from Figure 9, the do activity property, which provides a glossary, had a significantly lower number of rectangles and arrows as well as variations compared with the state name, which does not provide a property notation. This finding indicates that the property lifecycle diagrams of the `do activity` property are small and simple, to the extent that researchers and educators can easily grasp the entire diagrams.

4.5 Discussion on RQ: What Clues Can the Lifecycle of Properties Provide to Understand the Changes of the Diagram?

As can be seen from Figure 6, there are some participants' errors in the diagram. A participant defined a trigger with `keep a lap`, which is a term for the effect but not the trigger. The participant likely misunderstood the correspondence between the property notation and properties at the beginning. However, in the final models, this error did not exist because the participant was able to fix it. What is worse is that, as can be seen from Figure 7, the participants seem to have left the wrong definition intact due to their assumptions. They have written property values in the guard what should be in the effects or triggers. A participant has noticed and removed one of the errors. These findings suggest that developers will have the opportunity to learn about past failed designs from the property lifecycle diagram and thus will be less likely to make the same mistakes. These findings also can only be obtained by analyzing the editing logs.

As can be seen in Figure 8, the participants changed the guard several times and seemed to have a hard time defining the guard. For instance, this is similar to where developers encounter difficulties in tuning parameters. Knowing where was changed many times by using the property lifecycle diagram leads developers to understand specifications that are difficult to determine. It is also difficult for developers to know without analyzing the process through edit logs, etc.

Meanwhile, as can be seen from Figure 9, the variety of the `do activity` property was explicitly lower than the `state name` property. Since each state has both properties, the numbers of properties analyzed are the same for both property lifecycle diagrams. The number of rectangles that the `end` value was over 0 was 31 for the `do activity` properties and 77 for the `state name` properties. Since the input method is the use of a keyboard, the risk of careless mistakes is considered to be similar for both properties. Thus, the provision of property notation seems to have reduced the variety of property values. Therefore, the use of the property notation reduces the number of noisy descriptions and thus avoids unnecessarily complicated and large-scale change histories, which is considered to improve the quality of traceability.

Although property lifecycle diagrams can provide useful information to developers as explained above, they may become complex and large with the size of the edit log even if the property notation aids developers in reducing the variety of words. Therefore, it is desirable to obtain appropriate feedback through quantitative analysis, however, the establishment of this method is future work.

5 CONCLUSION AND FUTURE WORK

This paper has presented a property lifecycle diagram and a method to generate it from the edit log of a state machine model. In a large-scale project, the number of traceability links becomes enormous and difficult to manage. A conventional straightforward representation of the links in the form of a matrix can be a means of management, however, it may be difficult to trace the changes in specific values. As shown in the preliminary evaluation results, the proposed method is potentially useful for tracing and understanding the changes in property values.

As future work, we consider how to use the property lifecycle diagrams for impact analysis. To achieve this goal, we will attempt to analyze the property lifecycle diagram quantitatively and also combine the proposed method with existing methods (Kchaou. et al., 2017). The proposed method can be combined with various existing methods for traceability since the concept of the proposed method can be applied to different types of diagrams. To deal with the complexities of the logs, we also plan to use process mining tools such as Disco (Fluxicon, 2021) that can narrow activities and paths in a lifecycle model.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Numbers JP16H03074 and JP20K03146.

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