Empirical Activity: Assessing the Perceptual Properties of the Size Visual Variation in UML Sequence Diagram

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ABSTRACT

Recent empirical studies about UML showed that software practitioners often use it to communicate. When they use diagram(s) during a meeting with clients/users or during an informal discussion with their architect, they may want to highlight some elements to synchronise the visual support to their discourse. To that end, they are free to use color, size, brightness, grain and/or orientation. The mentioned freedom is due to the lack of formal specifications of their use in the UML standard and refers to what is called the secondary notation, by the Cognitive dimensions framework. According to the Semiology of Graphics (SoG), one of the main references in cartography, each mean of visual annotation is characterized by its perceptual properties.

Being under modeler's control, the 5 means of visual annotations can differently be applied to UML graphic components: to the border, text, background and to the related other graphic nodes. In that context, the goal of this research is to study the effective implementations, which maintain the perceptual properties of, especially, the size visual variation. This latter has been chosen because it is considered as the "strongest" among the other visual means, having all the perceptual properties.

The present proposal consists of a quantitative methodology using an experiment as strategy of inquiry. The participants will be the ˜ 20 attendees of the HuFaMo workshop. They must be experts on modeling and they know UML. The treatment is the reading and the visual extraction of information from a set of UML sequence diagrams, provided via a web application. The dependent variables we study are the responses and the response times of participants, that will be validated based on the SoG principles.

CCS Concepts

•Software Engineering → UML modeling; •Software visualization → *Semiology of Graphics;*

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Keywords

UML, Secondary notation, Size visual variable, Empirical activity.

1. INTRODUCTION

The Unified Modeling Language (UML) is the visual language for specifying, constructing and documenting software intensive systems. Recent empirical studies about UML in practice [14] [4] showed that UML artefacts are mostly used for communications. Stakeholders of these communications might be familiar with UML (e.g. members of the technical team) or not (e.g. clients) [9]. In such situations, modelers may need to highlight information that they deem relevant for the discussion (e.g. the main class in a class diagram; model, view and controller elements; a modeler's own subsystem; distribution of tasks between technical members; project progression). This is to synchronize the visual support with their discourse. In that context, while the UML specification describes exhaustively its primary notation, its semantics, it lacks highlighting abilities for such contextual information. The secondary notation, defined by the Cognitive Dimensions framework [11], may deal with such concerns. It refers to the free use and change of the possible means of visual annotations: size, brightness, grain, color and orientation. The previously mentioned five means of visual annotations are relatively rapidly perceived because the reader's eye can detect their variation without moving the visual brush. According to the Semiology of Graphics (SoG), one of the main references in cartography, each mean of visual annotation is characterized by its perceptual properties. In fact, it can be selective: allows readers to distinguish groupings (e.g. all green marks), ordered: allows readers to perceptually order marks (e.g. from dark to light or from light to dark but never in another order) and/or quantitative: allows readers to visually quantify ratio between marks (e.g. three times larger).

In UML, as the means of visual annotations are under modeler's control, there exist different ways to vary their values into a UML graphic component: graphic node or graphic path.

The combinatorial explosion of the possible implementations is due to four reasons. First, UML graphic nodes mostly include: a border, a text and a background. Second, some UML graphic nodes are composed of multiple shapes (e.g. a lifeline is composed of 3 components: a rectangle, a dashed line and sometimes an execution specification).

Then, graphic nodes might be related to other nodes via graphic paths, forming the diagram. Finally, a UML graphic component might contain/be contained in other graphic nodes (e.g. a fragment in a sequence diagram can contain one or more messages).

It may seem obvious that some implementations of variations are more effective in highlighting elements than others. But what we can gain in effectiveness might be anecdotal. To be sure that there exist (or not) implementations that are more effective, we have to dress an exhaustive list of implementations and test them. This means that we have to rigorously decompose all UML graphic components and see, for each sub-element, if the value of a mean of visual annotation can vary and how. Consequently, the purpose of this research is to study the effective implementations, which allow viewers to fully benefit from the performances of a mean of visual annotation. This is a purpose for which the number of related works is small. As the field of study is wide, we propose to focus here only on the variation of the size mean of visual annotation and on one type of diagram : UML sequence diagram. The size visual variation has been selected in this study because it is the only mean of visual annotation, belonging to the UML secondary notation, which has all the perceptual properties. In addition, we propose to target, especially, the UML sequence diagram because it belongs to the three first mostly used UML diagrams in practice.

For each type of graphic component, being composed of multiple shapes or a component itself, container of other graphic nodes or contained in other graphic nodes, this research aims at finding patterns of effective implementations of the size visual variation. In this study, we assume that the latter patterns depend on the information to be highlighted. It can concern only one graphic component (e.g. a lifeline) or more than one (e.g. two or more than two lifelines). For the first assumption, the size variation will surely highlight the concerned graphic component [5]. But, we aim at finding the effective implementations, which allow viewers to relatively rapidly perceive all significant details about the concerned graphic component. For the second assumption, the size visual mean is selective, ordered and quantitative [5]. In this case, we want to find the effective implementations which maintains valid the selective, ordered and quantitative perceptive attitudes of its variation.

To that end, we want to study the impact of the possible implementations on the perceptual properties of the size visual mean. The latter impact will be controlled by the size of the UML diagram containing the implementation. It can be small, medium or large. The studied impact will also be controlled by the layout of the diagram. We will especially focus on the horizontal and vertical distance between the related graphic components.

This paper presents a proposal of a quantitative methodology using an experiment as strategy of inquiry. The participants will be the ˜ 20 attendees of the HuFaMo workshop. They must be experts on modeling and they know UML. The treatment is the reading and the visual extraction of information from a set of provided UML sequence diagrams, via a web application. The outcome variables we study are responses and response times of participants, that will be validated based on the SoG principles.

2. EXPERIMENT DEFINITION

This section reports on the delimitation of the study, the research questions that it attempts to answer and its hypothesis.

2.1 Delimitation of the study

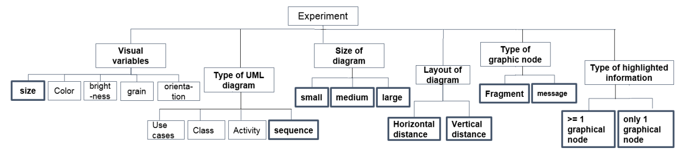

Figure 1: Delimitation of the study.

Figure 1 resumes the delimitation of the experiment. Following are justifications for each choice.

Size, brightness, grain, color and orientation represent powerful means to highlight information, to make it relatively rapidly perceived in a third dimension [5]. Each mean of visual annotation is characterized by its perceptual properties. The SoG distinguishes three perceptive attitudes that viewers can take in front of a mean of visual annotation.
Selectivity: the reader can perceive groupings (e.g. all red colors, all marks having the same size).
Order: The human eye can perceive order (e.g. from dark to light, from the smallest mark to the biggest).
Quantity: The viewer can perceive ratio between marks (e.g. this mark is 5 times bigger than another).

The size is the only mean of visual annotation allowing the three perceptive attitudes. To benefit from its interesting performances, we made the choice to begin by studying its effective implementation in UML. We chose to be limited to three categories of size. This number can be extended to more than three categories in a future empirical study. We argue that exceeding three categories of size in UML diagrams will overload the diagram, especially if it contains a lot of graphic components (i.e. large diagram). In addition, we note that sizes of graphic nodes depend on the contained text (eg. the width of a UML class varies depending on the length of its name, its attributes or its methods). Therefore, we will assume that all graphic nodes, in a diagram, have the same initial size (i.e. the size of the biggest node, containing the largest text).

According to [9][8], sequence diagram is ranked among the three first frequently used UML diagrams in practice. It is mostly used for clarifying understanding among technical members of the project team [8]. In such informal meetings, highlighting information might be promising to ease the communication [10]. In addition, contrarily to class diagrams, we note a lack of works in the literature, studying the effective visualization of sequence diagrams. Those are the main reasons behind the specific choice to begin by the UML sequence diagram.

In practice, the graphic nodes will be connected to each others, forming the diagram. The resulting diagram can be small, medium or large. We chose to cover all the 3 alternatives in the present study.

The graphic notation of the sequence diagram is described by 11 graphic nodes and 4 graphic paths [1](p. 594-596). As we chose to exhaustively study the UML sequence diagram., we will take into account all of them in the present experiment.

We observe that information to highlight might concern only one graphic component (e.g. one message, one lifeline, one coregion). It can also concern more than one graphic component (e.g. multiple lifelines, multiple coregions, multiple execution specifications). The present study will cover both alternatives.

Finally, we observed that distance between related graphic components can vary in two directions, horizontally and vertically for instance. We will experiment with both possibilities.

2.2 Research questions

After delimiting the study, we will define the research questions for the resulting scope. In fact, we observe that, for a single graphic component of the sequence diagram, there are different possible implementations of the size mean of visual annotation. This is due to the following facts.

UML graphic nodes are mostly made of a border, a background and a text. Changing only its area can be seen as obvious, but we want to explore the effectiveness of varying the size of its border and text also. Moreover, some graphic components include multiple shapes. *Lifelines* include a rectangle and a dashed line. *LostMessages* and *FoundsMessages* include an edge and a black point at the extremity. Varying the size of such graphic components might consist of changing the size of all its elementary shapes or some of them. We wonder about the most effective implementation.

In addition, some graphic nodes can be embedded in other graphic nodes. An *execution specification*, a *coregion*, *DurationConstraint*, a *DurationObservation* and a *StateInvariant* are always embedded to a lifeline. *Continuations* might be embedded to more than one lifeline. Changing their size can affect the size of graphic nodes to which they are embedded. We want to infer the most effective implementation.

Furthermore, graphic components are semantically linked to each others. *Lifelines* are linked via graphic paths, graphic paths having source and destination graphic nodes. Highlighting them with the size variation might mean highlighting its semantically related graphic components also.

Finally, some graphic nodes may contain other graphic components. A Frame, an *InteractionUse*, a *CombinedFragment* and a *coregion* can contain *executionSpecifications, messages*. They may also contain each others. Applying the the size to such graphic nodes might concern the contained other graphic nodes and vice versa.

As a result, the following research questions arise.

RQ1: What are the effective implementations of the size visual variation to all types of graphic components of the UML sequence diagram (i.e. container, contained, embedded to a graphic node, complex graphic node (composed of multiple shapes))?
Where effectiveness can be measured by the capability of each implementation to preserve all the perceptual properties of the size, allowing viewers to relatively rapidly detect the accurate information that they are searching for.
RQ2: How the effectiveness of each implementation can be controlled by the type of information to highlight (i.e. concerns only one graphic component, more than one component).
RQ3: How the effectiveness of each implementation can be controlled by the size of the diagram containing the implementation and its layout.

2.3 Hypothesis formulation

2.3.1 Variables

The experiment has 4 independent variables and two dependent variables.
Independent variables
Implementation **I** (**alternatives**: Effective Implementation **I**, Other Implementation **I'**).
Size of the sequence diagram **S** (**alternatives**: small, medium, large).
Its layout **L** (**alternatives**: Horizontal distance **HD**, Vertical distance **VD**).
Type of information to highlight **TI** (**alternatives**: concerns only one graphic component **TI1**, more than one graphic component **TIn**).
Dependent variables
Responses of participants **R** (**alternatives**: true, false, complete, incomplete).
Response time of participants **T**.

2.3.2 Hypothesis

Table 1: Hypothesis

Dependent variables	Null hypothesis	Alternative hypothesis
Response time T	∀ (S, TI, L); H0: T(I) > T(I')	∀(S, TI, L) H1: T(I) < T(I')
Response R	∀ (S, TI, L); H0: T(I) > T(I')	∀ (S, TI, L) H1: T(I) < T(I')

The hypothesis for assessing the effectiveness of the **I** size variations with the independent variables are given in table 1. The alternative hypothesis H states that the proposed effective implementations take less time to let participants give the right and complete answer to a given question. The experimented effective implementation **I** is proposed for each possible combination of (S, TI, L). Figures in appendices illustrate the different implementations that we deem effective and the experiment aims at validating. They also illustrate an example of a question that concern one graphic path (a message) with different implementations.

3. EXPERIMENT DESIGN

3.1 Population, sample, and participants

The sampling method used in this study is the convenience sampling [6]. In fact, the target population of this study is the community of UML users: practitioners, researchers, students. The HuFaMo attendees are a naturally formed and might be a representative sample of the target population. They include students, researchers, UML practitioners and maybe some tool vendors. They are a part of the MoDELS community, interested in modeling and/or contributors on MDE. We assume that we will have ˜ 20 participants, considered as experts on UML.

3.2 Data collection and materials

A web application will be used in the present experiment. This is to be aware of the complexity of modeling tools (i.e. not all participants are familiar with the same modeling tool). Moreover, installing the same modeling tool to all participants will be time consuming, especially in the workshop (same timeslot as a presentation). If accepted, the web application will be developed between the acceptance notification and the workshop date. It will be coded by the first author and tested before its use in the experiment. The web application will first ask participants about their gender, level of experience and if they have visual deficiency(ies). Then, it will display a question on a white page. After its reading and comprehension, the participant is able to click a button to switch to the next page. A sequence diagram, visually annotated with an implementation of the size will appear, along with its corresponding question on the bottom. Parallelly, the application will trigger a time counter. When the response to the question is found by the participant, he can click a button to navigate to another white page (without the sequence diagram), where he will be able to enter his response. At the same time, the application will stop the chronometer and save the time spent to answer. It will also save the corresponding response entered by the participant. Sequence diagrams that will be used in the experiment will be extracted from a models repository [12] [2]. Visual annotations using implementations of the size variations and questions will be manually proposed.

3.2.1 Method

One day before the experiment, the HuFaMo participants will receive an e-mail requesting them to bring their laptops. The first author will ensure the availability of an internet connection during the experiment day. The experiment will begin by an introduction phase and a training session related to the experimental task. The first author will present the web application that will be used in the experiment, for which details are mentioned in the previous subsection. Then, the link of the web application will be sent to the HuFaMo attendees via the workshop mailing list. The second step consists of the experiment's task. This latter will individually be performed by each participant. The main treatment will consist on the reading and the visual extraction of information from a visually annotated sequence diagram. The estimated time for the whole experiment is 30 minutes.

3.3 Data analysis procedures

In the analysis procedure, we will report on the number of the HuFaMo attendees who didn't participate to the study. We also plan to give a descriptive analysis of data for all independent and dependent variables of the study. At the end of the experiment, we want to analyse the relationship between the independent and dependent variables. This is to find patterns of effective implementations, depending on a combination of (S, TI, L). For each combination of the three independent variables, we will determine the effective implementation **I**, which has a minimum T and a complete and true values of **R**. Therefore, we select the correlation/regression statistic tests.

4. ANTICIPATED ETHICAL ISSUES IN THE STUDY

This section will report the internal and external threats to validity.

4.1 Internal validity

The first internal threat to validity is the possible gain of maturity by the participants during the study. That may happen because of the unicity of the studied type of UML diagram: sequence diagrams. As well as the uniqueness of the studied visual variation. Therefore, we will ensure that diagrams will be randomly proposed so that questions concerning the same graphic component will not be successive. In addition, as mentioned before, participants might have some visual deficiencies. This additional input will be mentioned before beginning the task, so that we can take into account its influence on the results. We also note that each participant will have a different screen with different characteristics. We will ensure that at least the same value of luminosity is set up and that the same web navigator is used to open the web application. Finally, one of the outcomes of the study is the response time of participants. It is automatically saved when the participant finds the response by clicking a button. Late clicking the button will bias the results. We will stress on the importance of this step to participants in the introduction phase. We will also try to add a voice recorder, so that participants can speak out loud when finding the response. Then, we will have to find mechanisms to manage the simultaneous voices of participants, placed in the same setting.

4.2 External validity

The HuFaMo participants are not only experts on modeling but also interested in Human Factors in Modeling. So, they may know about the scope of this research, especially the perceptual properties of the means of visual annotations, which can bias the study. To limit the latter threat to validity, we will not inform them about the research questions of the study nor its hypotheses. Moreover, the participants are not in a natural setting, using their own modeling tool and moving naturally to their UML sequence diagrams. As a result, we will perform further additional empirical study (e.g a case study in a natural setting) in order to be sure that the obtained result can be generalized to the whole population.

5. LITERATURE REVIEW

The free use of additional means of visual annotations in software engineering has been recognized as theoretically advantageous. This is via the secondary notation by the cognitive dimensions framework [11]. A few empirical studies aiming at assessing its benefits in UML visual notation have been conducted. However, if they considered the need of empirical validations, they focus only on two axis: layouts and colors. The other means of visual annotations (i.e. size, brightness, grain and orientation) have not been yet discussed, despite of their great performances on highlighting information, known in cartography [5] and psychology [13] [18].

Concerning layouts, there exist several empirical studies aiming at finding effective layouts in UML diagrams. [19] [16] [15] use experiments to assess effective layouts for diagram comprehensions, user preferences, program understanding, etc. [20] uses eye tracking in an experiment involving 12 participants to identify the impact of layout, color and stereotypes on comprehension of UML diagram. Most of the mentioned researches [16] [15] [20] focus on UML class diagram. [17] focusses further on UML activity diagram and use case diagram. While the sequence diagram belongs to the three most used UML artefacts in practice, we note few works on it [7] [3].

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APPENDIX

Considering all independent variables, 12 sequence diagrams are required for each implementation of the size variation. We argue that at least two diagrams are needed for each implementation. Therefore, for all 14 graphic components of the UML sequence diagram, at least 336 diagrams are required for this study.

A. EFFECTIVE IMPLEMENTATIONS AND AN EXAMPLE OF A QUESTION WITH DIFFERENT IMPLEMENTATIONS

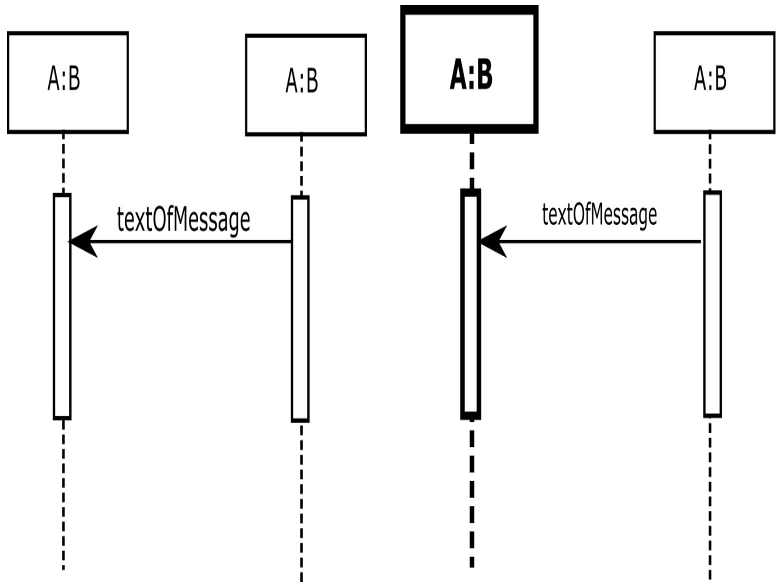

Figure 2: Effective implementation of a "lifeline" I, (TI=TI1, T=S)

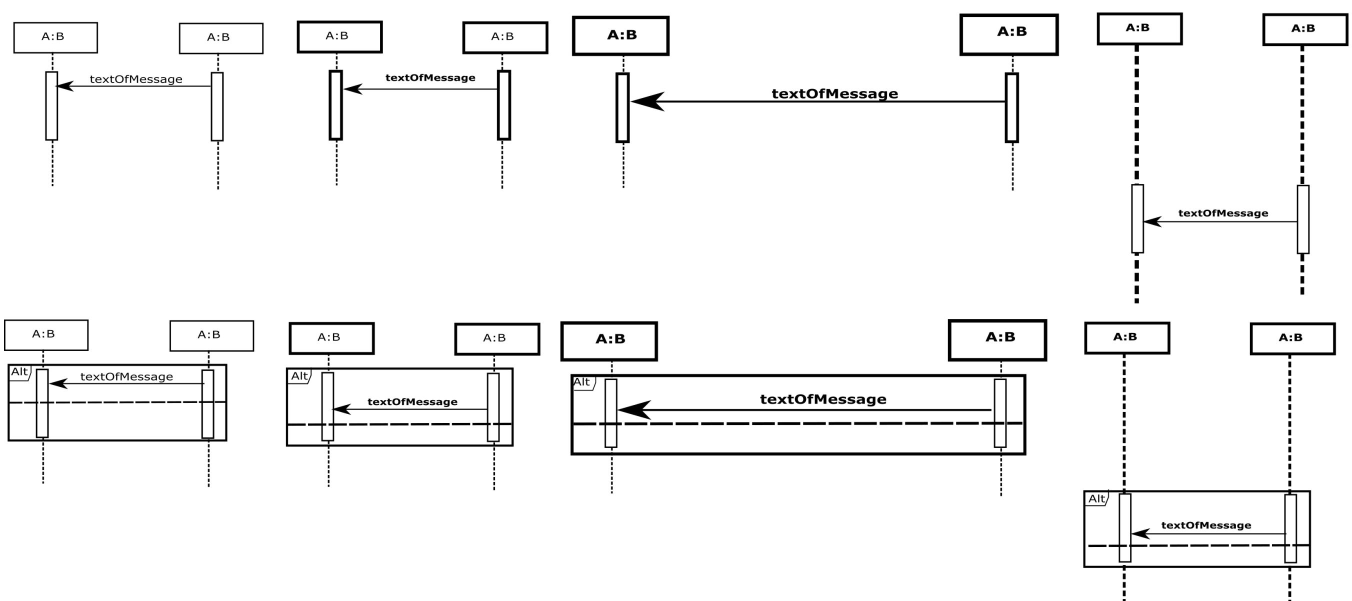

Figure 3: Effective implementations of "message" I, (TI=TI1, T=S)

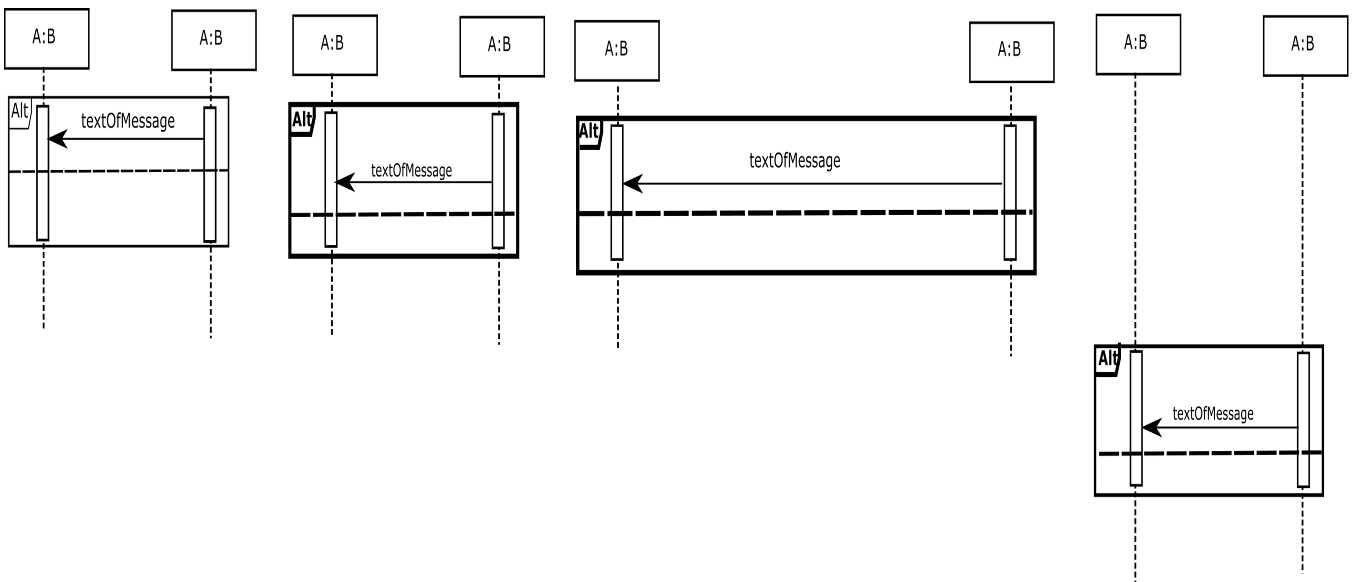

Figure 4: Effective implementations of a ”fragment” I, (TI=TI1, T=S)

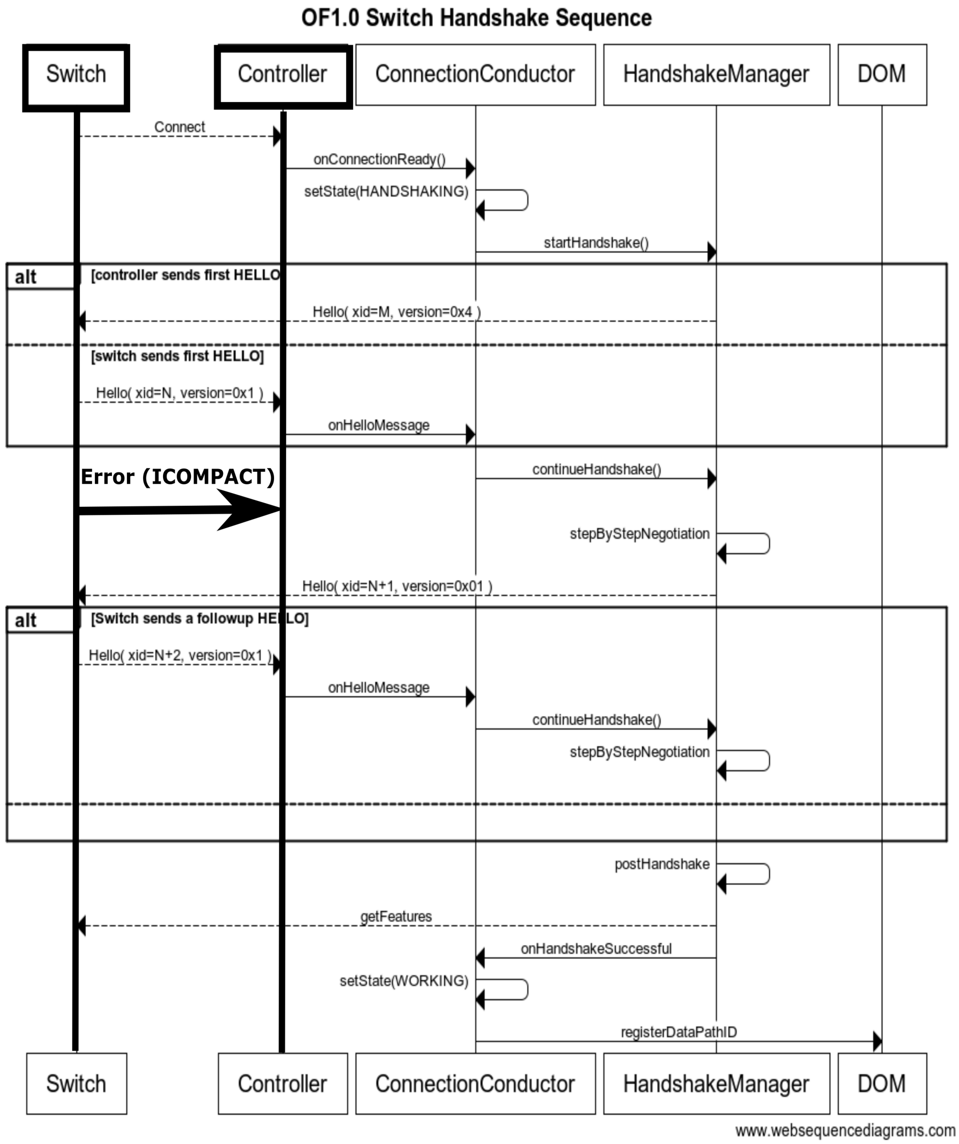

Figure 5: Response to the question: What happens if the controller sends first hello? with the implementation I

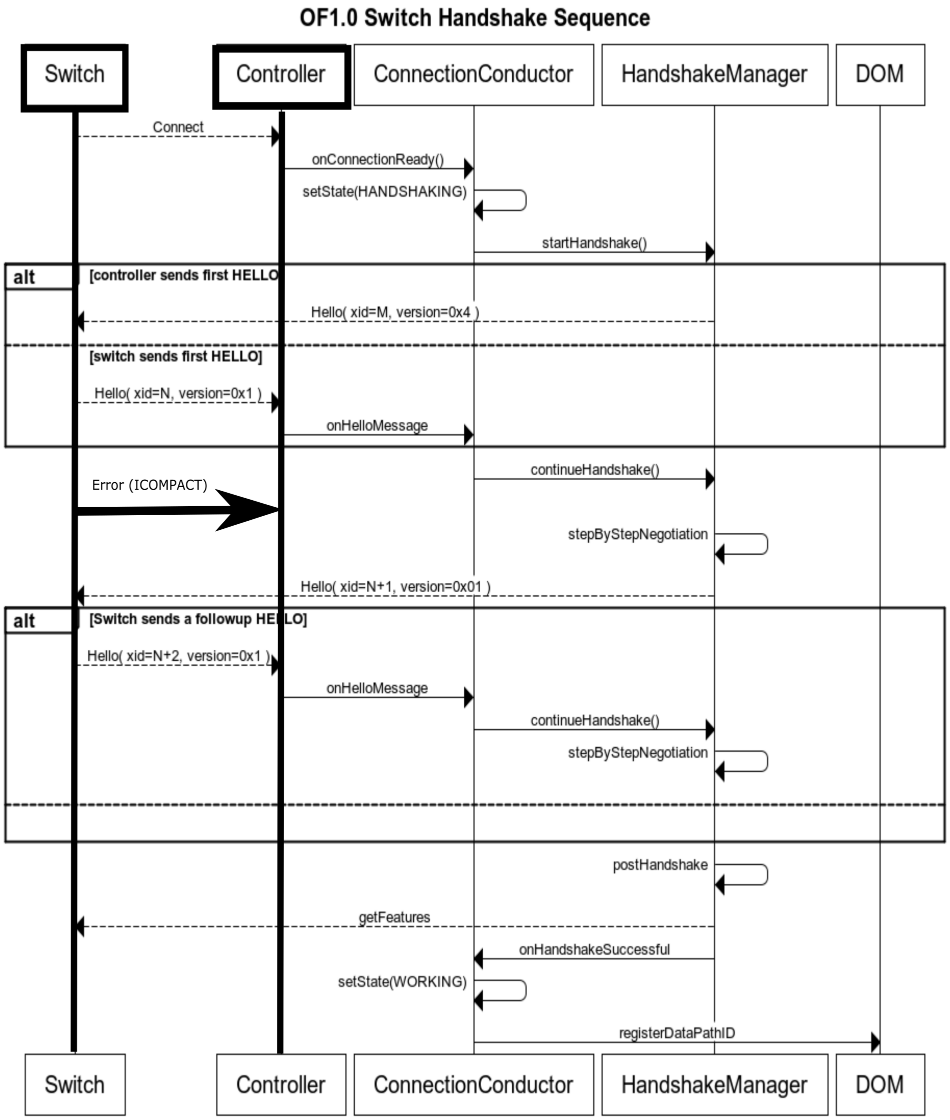

Figure 6: Response to the question: What happens if the controller sends first hello? with an implementation I'

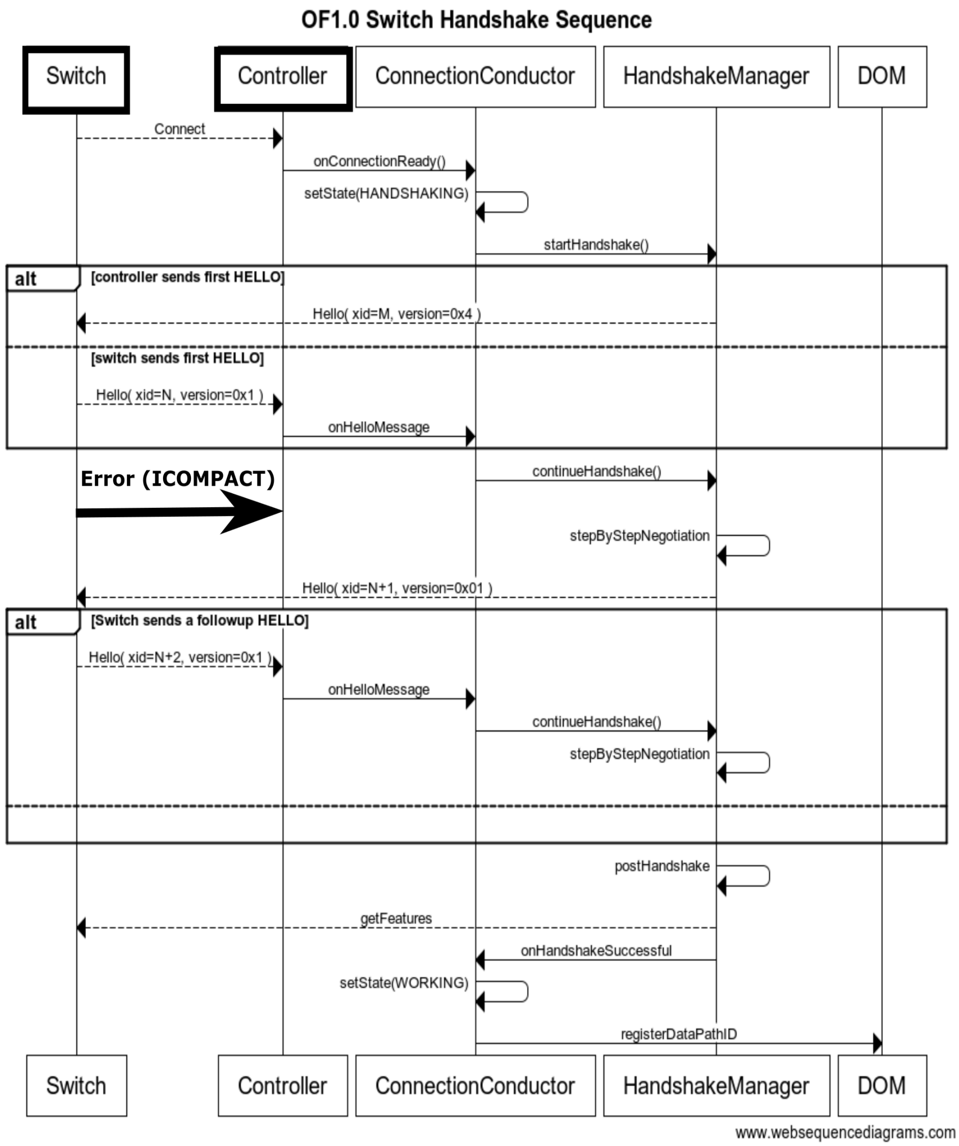

Figure 7: Response to the question: What happens if the controller sends first hello? with an implementation I'

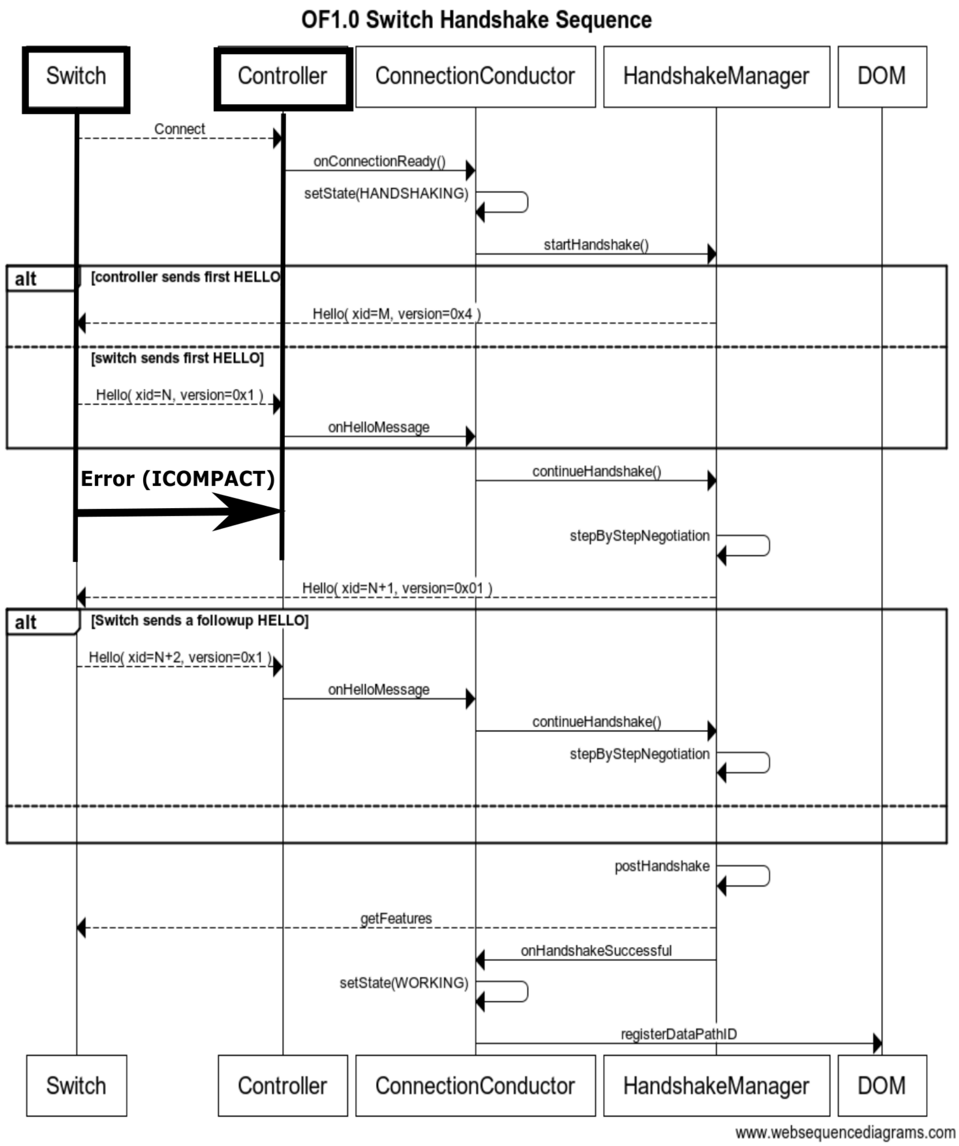

Figure 8: Response to the question: What happens if the controller sends first hello? with an implementation I'