A User-centered Approach for Modeling Web Interactions Using Colored Petri Nets

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Abstract: Interactions are communication acts which take place between at least two agents and result in information interchange. To represent these activities, formal methods can be used to model interaction flows and Colored Petri Nets (CPNs) are a handy formal language with graphical notation for modeling systems. This paper introduces *wiCPN* (Web Interaction Modeling Using Colored Petri Nets), a language based on CPNs for representing Web interactions with improved notation. Our proposal is first presented with its proper refinements over traditional CPNs. Next, we have applied the approach for modeling the interaction of Classroom eXperience's (CX) Web front-end, a real u-learning environment. As CX is an educational system developed to assist instructors and students during academic activities, we verified the developed model's reachability to ensure it was able to represent users different access levels. We also validated our proposal with user experiments, comparing it with UML. Our designed model represented CX's interaction correctly, considering user access levels and maintaining an understandable notation. Results indicate advantages of *wiCPN* over UML for modeling interactive interfaces. By gathering strengths of Petri Nets with a higher level graphical notation, *wiCPN* propitiated better understanding of the model, representing interaction in a structured and intuitive way.

1 INTRODUCTION

Interactive issues tend to go far beyond creating nice layouts, addressing relevant aspects such as usability features, ways of presenting information correctly and cultural characteristics of users (Clemmensen, 2012). To perceive such requirements and to develop products that work properly when in touch with users, interaction modeling is a software engineering activity able to assist software production process, being significant during specification phases and over development and verification steps of systems deployment processes (Sommerville, 2010).

Application of formal methods for modeling interactions can provide benefits, including the guarantee of consistency across platform designs and the incorporation of a user interface design phase into the formally-based procedure of software development (Bowen and Reeves, 2007). In this scope, a Petri Net is a formal and mathematical graphic language, appropriate for modeling distributed and concurrent systems (Jensen, 1994). Colored Petri Nets (CPNs) are high level Petri Nets whose *tokens* have colors and can represent data values. This extension increases the descriptive power of modeling, since the triggering of transitions is made depending on the availability of these *colored tokens* (Jensen et al., 2007).

A CPN model describes the possible states a modeled system can reach and the transitions which may occur among these states. Therefore, they are an effective formalism for describing concurrency, synchronization and causality, being suitable for modeling, analyzing and prototyping dynamic issues of interactions (Jensen, 1994). CPNs have been studied in a wide range of application areas and many projects have been documented in the literature while implemented in industry, e.g., hardware and software designs (Kim et al., 2012), security analysis of network protocols (Choosang and Gordon, 2014), parallel file systems (Nguyen and Apon, 2012) and distributed computing systems (Weidlich et al., 2013).

In this work, we applied CPNs as a conceptual basis, since they have relevant characteristics for modeling interactions, such as: *(i)* well-defined semantics, *(ii)* graphical portrayal, *(iii)* possibility of formal analysis and *(iv)* hierarchical modeling. Thereby, we introduce *wiCPN* (Web Interaction Modeling Using Colored Petri Nets), a language for representing in-

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teractions between users and Web interfaces which extends traditional CPNs to better depict Web interactions in a dynamic and uncomplicated way.

As a practical example of *wiCPN*'s use, we modeled the Web interface of a real U-Learning Environment (ULE) system. To validate our proposal, we compared *wiCPN* with UML by running user experiments and, according to results, *wiCPN* evinced to be a concise notation, without losing expressiveness. With *wiCPN*, only a single diagram is required to represent the same interactive flow that, in UML, would require multiple diagrams, overwhelming the design team and potentially generating inconsistencies in case of changes in one diagram that would need to be propagated to other ones. Within this situation, *wiCPN* notation enables a mapping between an interactive element (e.g., a given screen or a Web page) and its functionality, allowing users to identify their exact location, context and interaction options.

The remaining of this article is structured as follows: in Section 2, we detail CPNs components and usage; in Section 3, we present *wiCPN*, a language developed for representing Web interactions; in Section 4, we first introduce Classroom eXperience (CX), our educational platform, and then we utilize it as a case study for demonstrating *wiCPN* proposal; in Section 5, we present user experiments and results, comparing our technique with UML; in Section 6, we discuss related work; and, finally, in Section 7, we present our conclusions and final remarks.

2 COLORED PETRI NETS

CPNs provide a full abstraction to design, specify and validate systems (Jensen, 1994). Like ordinary Petri Nets, they are represented as graphs with *places*, *transitions*, *arcs* and *tokens*. However, in CPNs *tokens* are not blank markers, but have data attached to them. A *token*'s color is a type's specification. *Places* are assigned with one or more colors (called sets or multisets) and *arcs* are either specified with schemas or associated to boolean conditions. Also, as *arcs* simultaneously enter and exit *places*, they have functions to determine which set or multiset elements shall be removed or put into places they are bound. Besides, there are boolean expressions, named *guards*, which are associated with *transitions* and enforce conditions over CPN elements.

Figure 1 shows a model's slice in which it is possible to observe two places (*Login* and *LoginScreen*), a transition (*inLog*) and some arcs with schemas. Places *Login* and *LoginScreen* are, respectively, assigned with a set *Active* and a multiset *LoginScreen*. The former holds *act*, a token which belongs to color *Active*. The latter possesses three tokens, being two of them (*dUserTrue* and *dUserFalse*) parts of set *dUser* – which pertains to color *UserData* –, while the other one (*newUser*) is related to set *nUser* – and is associated to color *newUserData*. As place *LoginScreen* can be filled with tokens of different colors, it is assigned with a homonym multiset composed by the union of colors *UserData*, *newUserData* and *Active*. Also, transition *inLog* is connected to both places through arcs that can only transport a single token, *act*, in accordance with their schemas.

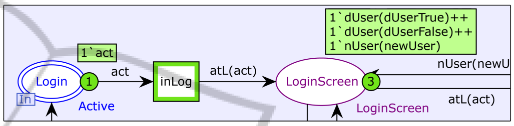

Figure 1: A model's slice with places, arcs and a transition.

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CPNs also can be organized into hierarchic modules (Jensen et al., 2007). This concept is settled on a many-level structural mechanism, which sustains both a top-down as well as a bottom-up working manner. New associated modules can be created from prevalent ones and reused in other parts of models.

Figure 2 shows a hierarchy where two slices of a model can be spotted: (a) an upper part where transition *LanguageScreen* is highlighted and (b) a lower module containing the whole activity that takes place inside of *LanguageScreen*.

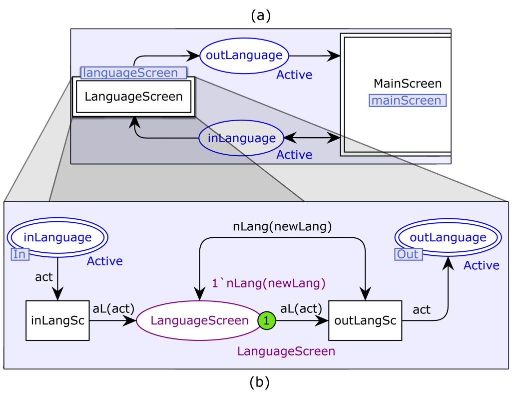

Figure 2: Two hierarchic modules.

The formal definition of a Colored Petri Net (Jensen, 1994) is represented as a 9-tuple: CPN = (Σ, P, T, A, N, C, G, E, I); where: Σ denotes a finite and non-null set of colors or types, *P* retracts a finite set of places, *T* represents a finite set of transitions, *A* portrays a finite and disjunct set of arcs, *N* denotes node functions, *C* retracts color sets and multisets, *G* represents guards, *E* portrays expression functions (or arc schemas) and *I* is an initialization function.

CPN models can be used to verify system features and properties, i.e., to demonstrate that desirable attributes are accomplished or unwanted characteristics are absent. Verification of system properties is sustained by a set of *State Space Methods*, which are automatically generated and with them it is possible to respond a large set of verification issues related to system behaviors, such as absence of deadlocks, assurance of always reaching a certain state and the guaranteed delivery of determined services.

Practical application of CPN modeling and analysis leans deeply on the existence of tools which support creation and manipulation of models. In this context, *CPN Tools*[1] is a tool suite for creating, editing, simulating and analyzing CPN models (Gehlot and Nigro, 2010). This suite was chosen for its possibility of creating graphical representation of models – as it possesses an editor that allows users to create and arrange CPN components – and for having tooling that calculates state space of models and verify their properties automatically. Figures 1 and 2 – as well as all others figures that illustrate system modeling in this paper – were designed making use of CPN Tools.

3 wiCPN: WEB INTERACTION MODELING USING COLORED PETRI NETS

Our work focused on creating a method for representing interactions that take place between users and Web front-ends. Thus, a couple of interactive issues were considered while elaborating a model that would support these needs, such as the way interactive flows occur in Web interfaces (Rogers et al., 2011) and the fact that determined screens and functions must only be accessed by certain users (Sommerville, 2010).

To figure out these needs, we considered an organizational aspect that propitiated better understanding of CPN modules. In this scope, models must support both flows – presenting links among system screens – and navigation – indicating actions associated to possible flows –, what allows the models to present interaction in an uncomplicated and dynamic way.

As a result, to better depict Web interactions while making use of CPNs, we present *wiCPN (Web Interaction Modeling Using Colored Petri Nets)*, a language for representing interactions between users and Web interfaces. *wiCPN* is an extension of CPNs, maintaining several of its characteristics, but with refinements such as: classification of places into resources, system screens and ports; differentiation between ordinary and conditional transitions and usage of a color to represent interactive flow. Explaining our model accurately, a *Web Interaction Modeling Using Colored Petri Nets* is a 9-tuple: wiCPN = (Σ_{wi}, P_{wi}, T_{wi}, A_{wi}, N_{wi}, C_{wi}, G_{wi}, S_{wi}, I_{wi}); where:

- $\Sigma_{wi} = <$ Col, *Active* $>$, a non-null set of colors and types, compound by *Col* – a finite group of colors or types that determines the functions which can be used in the net – and *Active* – a reserved color that must be used in the modeling;
- $P_{wi} = \{ < r_1, r_2, ..., r_t > \cup < s_1, s_2, ..., s_b > \cup < p_1, p_2, ..., p_r > \}$, a set of places formed by three subsets: *available resources* (r), *system screens* (s), and *input/output ports* (p);
- $T_{wi} = \{ < f_1, f_2, ..., f_m > \cup < c_1, c_2, ..., c_n > \}$, a set of transitions formed by two subsets: *flow transitions* (f) and *conditional transitions* (c);
- A_{wi} = a finite and disjunct set of arcs, such that $P_{wi} \cap T_{wi} = P_{wi} \cap A_{wi} = A_{wi} \cap T_{wi} = \emptyset$;
- $N_{wi} : A_{wi} \to P_{wi} \times T_{wi} \cup T_{wi} \times P_{wi}$, a set of nodal functions that maps every arc into a resulting pair whose first element is the source node and the second one is the destination node;
- $C_{wi} : P_{wi} \to \Sigma_{wi}$, a group of color functions which map each *place* into color sets or multisets;
- G_{wi} : c $\to$ *bool*, a set of guards which map each *conditional transition* into a *boolean expression*;
- $S_{wi} : A_{wi} \to$ *colSet* $\subset \Sigma_{wi}$, a set of arc schemas that map each *arc* into a *color set expression* subset of Σ_{wi};
- I_{wi} = an initialization function which maps each place into an expression whose result is a multiset over the places' colors.

After these descriptions, it is possible to recognize some elements' characteristics in nets modeled with the *wiCPN* approach using CPN Tools:

- *Places* are specified as (a) *resources*, (b) *system screens* or (c) (d) *input/output ports* – which are depicted in Figure 3 and distinguished by green, purple and blue colors, respectively. *Resources* represent conditions and system requirements, such as security issues that enable users to access specific *system screens*. *Input/output ports* can be stylized in two ways: (c) with a single border – while appearing in upper parts of the model – or (d) with a double border and an in/out tag – in lower parts of the model, representing interconnectivity among modules. *Input/output ports* represent paths that connect *system screens*, such as interface buttons and links.

[1] http://cpntools.org/

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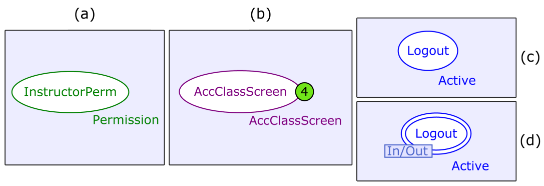

Figure 3: Some places modeled using *wiCPN*.

- *Places* can depict resources and input/output ports simultaneously (Figure 4(a)) or system screens and input/output ports (Figure 4(b)). This happens when resources or system screens are bound to hierarchic transitions and, in this case, they are stylized with a double border while appearing in lower modules of the model.

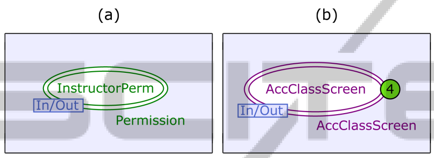

Figure 4: Places portraying a double role.

- Color *Active* is reserved and must be assigned only in two cases: to *input/output ports* connected to hierarchical transitions – as seen in Figures 3(c) and 3(d) – and to a single *token* that controls the interaction activity of the model. Both cases can be observed in Figure 5, where (a) portrays *Login* assigned to color *Active* and (b) depicts the color's declaration while being attributed to *act*.

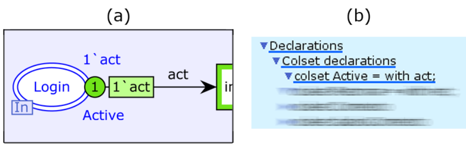

Figure 5: Declaration and usage of color Active.

- Lastly, *transitions* (Figure 6) depict two kinds of flows: ordinary ones, which are stylized in black and called *flow transitions* (e.g., *chkLogin*), and those that depend on conditions, which are depicted in red and named *conditional transitions* (e.g., *loginFalse* and *loginTrue*). *Flow transitions* show up in the whole modeling in order to depict existing common fluxes, while *conditional transitions* appear in circumstances where system resources are checked by the model.

With these refinements, it is possible to observe that *wiCPN* approach proposes a new manner of representing interactions during software modeling activities. While using this extension, generated models are visualized as navigation maps, able to illustrate existing interactive flows in systems interfaces.

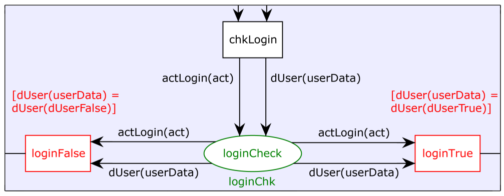

Figure 6: Some transitions modeled using *wiCPN*.

4 PUTTING wiCPN TO WORK

In order to validate *wiCPN*, we modeled the Web front-end interaction of *Classroom eXperience* (CX), a ubiquitous educational system that currently is used in a real ULE. To explain how it proceeded, we first present CX and then demonstrate how we applied *wiCPN* to model CX's interaction, verifying the developed model by making use of a state space method.

4.1 Classroom Experience

CX[2] is a ubiquitous computing platform for capturing, storing and accessing content from educational environments (Ferreira et al., 2012). CX allows instructors to lecture in a dynamic and unobtrusive way, also assisting students while accessing captured content (Araújo et al., 2013). As a typical Capture and Access (C&A) platform, CX aims at recording live experiences and making their information available for later access. Currently, CX has been used in classrooms equipped with video cameras, microphones, projectors and electronic whiteboards (Figure 7).

Figure 7: Classroom equipped with camera, microphone, multimedia projectors and an electronic whiteboard.

Instructors are able to interact with the electronic whiteboard as if they were using a traditional whiteboard or a chalkboard. During a regular interaction flow of the system, instructors could, for instance, access CX's Web front-end and set up some information before the class, such as lecture title, keywords, abstract, duration and slides file. When arriving into classroom to start lecturing, they access

[2]http://cx.facom.ufu.br/

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the Web front-end and download the lecture content to present it to students. At this moment, they teach without changing their conventional style while CX captures content being presented by means of specialized hardware and software components. After the recording phase, captured media streams are synchronized, stored and made available for students.

CX provides a customized access based on personal information to display lectures according to user needs. Students can interact with captured content through tags and comments made over the lecture content. Such annotations are shared with other students, thus extending and enriching the originally captured information. Moreover, instructors are able to register the assignments' dates and subjects, which will be displayed to students and used for content recommendation and personalization.

As can be noticed, students and instructors are distinct user roles, implying in different system permissions. While the former can solely get enrolled in courses to access captured lessons and interact with other users, the latter can also create courses, register lectures and perform their capture, besides being able to register metadata such as the lesson difficulty level or the aforementioned assignments calendar.

4.2 Modeling CX's Interface

With *wiCPN*'s refinements in mind, we modeled the interaction of CX's Web front-end, employing our method's characteristics to achieve better visualization and understanding of the model. As a result, Figure 8 depicts the high modeling level. Hierarchical transitions (e.g., *LoginScreen*, *MainScreen*, among others) represent screens and are composed by subnets which contain the whole activity that takes place inside of each transition. This happens because every system screen becomes hierarchical – as each one of them has an inherent flow with particular conditions – and these characteristics are substantial in order to enable the correct modeling of CX's interactions.

It is also possible to recognize the input/output ports in Figure 8. As they are currently in the top level of the modeling, they are directly connected to the module's hierarchical transitions. Nevertheless, when the abstraction level goes deeper, input/output ports get stylized with double blue borders, in addition to their *In*, *Out* and *In/Out* markings, which can be observed in Figure 9. Indeed, Figure 9 depicts the whole interaction flow which happens inside of *MainScreen*. As already depicted in Figure 8, *MainScreen* is connected to many other pages, so in Figure 9 it is assigned with a homonym multiset composed by the union of colors which lead to each one of the other system screens presented in the module.

Exemplifying an ordinary interaction flow, the first thing a user does during a common attempt to login into CX is to access the interface login page – represented in Figure 8 as the hierarchical transition *LoginScreen*. When this action happens, *LoginScreen* becomes active, as the token "*act*" sensitizes a transition named *inLog* – previously shown in Figure 1 (which illustrates a slice of *LoginScreen* module's interaction flow).

After being authenticated, the user reaches the input port *Initial* – identifiable on Figure 8 as the place just after *LoginScreen*'s transition and on Figure 9 as the first element of *MainScreen*'s module. At this moment, the flow proceeds to another validation, where the system checks whether the user is a student or an instructor. In case the user is a student, the conditional transition *StuAut* becomes sensitized, carrying the token "*act*" to the leading screen of the system – represented as place *MainScreen* in the model. However, if the user is an instructor, transition *InstAut* becomes sensitized instead and the token "*act*" reaches the system's leading screen at the same time the token "*perm*" arrives into place *InstructorPerm*, filling it with resources and enabling instructors to access more features than students.

In this scope, a student can never access the functionality for creating a new class – since this activity is an instructor's duty only –, and our model fully supports this restriction, as the *In/Out* port *inAddClass* (visible in Figure 9) is not reachable by students, because the transition *inAddC* never gets sensitized.

4.3 Verifying the Model

While making use of *CPN Tools*, it is also possible to explore the modeled system's behaviors using net simulations, model checking and state space methods (Jensen et al., 2007). In fact, a full state space can portray all practicable executions of an analyzed model, computing every reachable state and their changes, while representing these in a directed graph. The fundamental concept behind a state space is to set up a graph which has an arc for each binding element and a node for every reachable marking. A modeling's state space is calculated automatically and this enables to prove with mathematical meanings that it possesses determined formal properties.

Figure 10 presents the graph we generated using *CPN Tools'* state space tool. The first node depicts the marking previously shown in Figure 1 (the moment when a user accesses the login page). After this, in *node 2*, user information can be inserted in order to log into the system or introduced to register a new

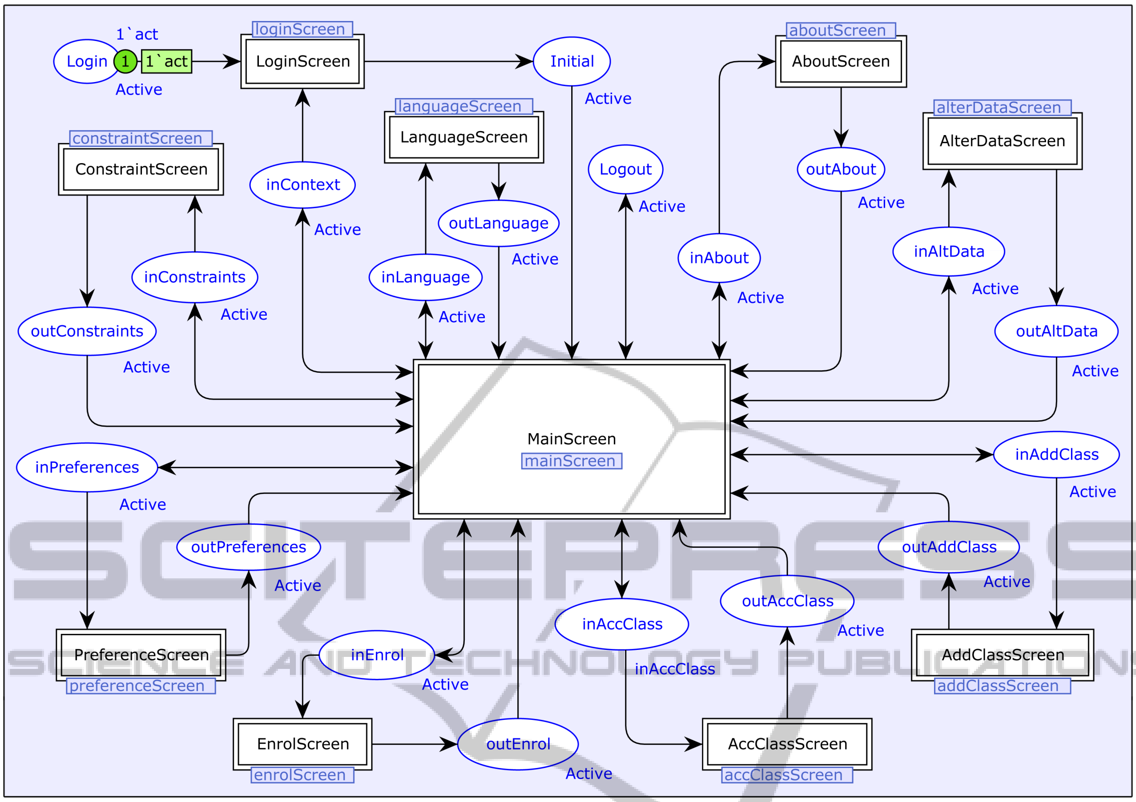

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Figure 8: The top level of the modeling.

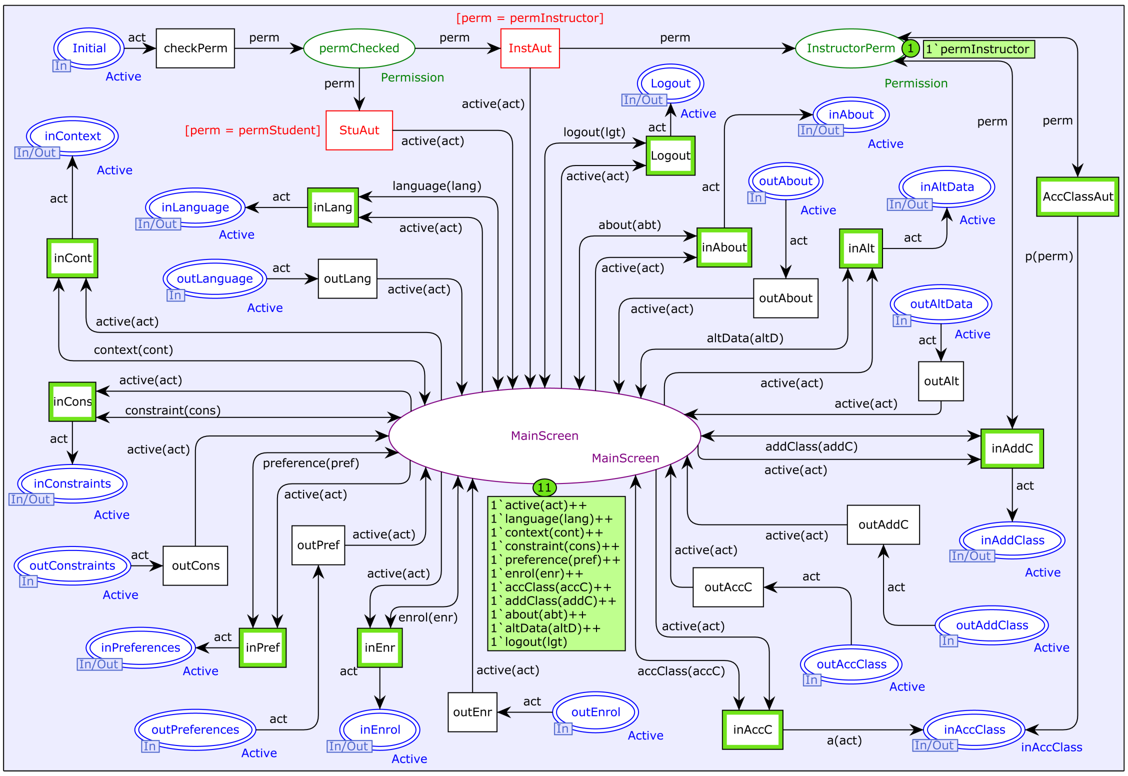

Figure 9: The MainScreen's interaction flow when the user is an instructor.

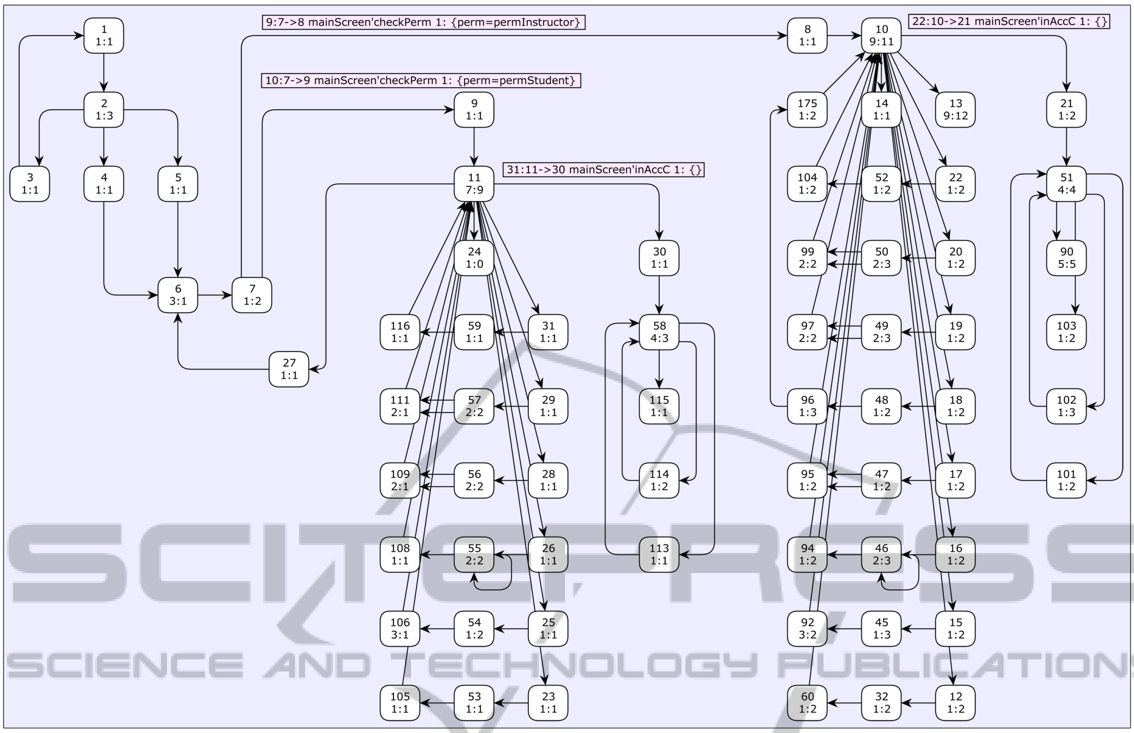

Figure 10: CX's graph of reachability.

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user – that is why the graph trifurcates. Consequently, while *nodes 4* and *5* respectively denote a successful login and a new user registration – proceeding to *node 6* –, *node 3* represents an unsuccessful login and returns the user to the login page (*node 1*).

Right ahead, *node 7* represents when the system validates whether the user is a student or an instructor, as depicted in Figure 9. In case he/she is an instructor, the interaction proceeds to *node 8*, while a student flow would advance to *node 9*. At this moment, it is perfectly clear to notice that a student reachability is inferior if compared to the states an instructor can reach. Also, *nodes 10* and *11* illustrate the system's main screen, but in different user perspectives. While in *node 10* an instructor can access every system screen, *node 11* shows that students reach a reduced amount of pages.

5 USER EXPERIMENTS

For the user-based experiments, we applied a questionnaire to 30 undergraduate Computer Science students enrolled in a Human-Computer Interaction (HCI) course. Students were used to work with interactive flows on a regular basis, in the context of the HCI course. A few of them have had previous experience with UML language, but no student have had previous contact with Petri Nets.

We separated students into two groups of 15. To the first group, we presented a 15-minute briefing about UML language and then presented a couple of interactive flows modeled with UML activity and use case diagrams (some of the models that were used can be seen in Figures 11 and 12). To the second group, we also presented a 15-minute briefing about *wiCPN* and presented the same interactive flows, but modeled with *wiCPN*. Since we aimed to analyze users understanding capability of several interactive issues, we did not employ swimlanes, but instead we modeled activity flows as clear as possible in UML diagrams.

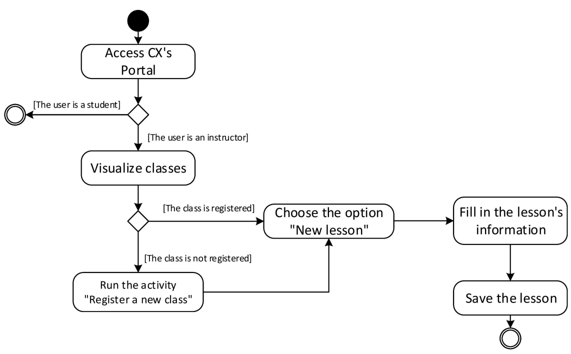

Figure 11: "Register a new class" UML activity diagram.

After studying their corresponding (either UML

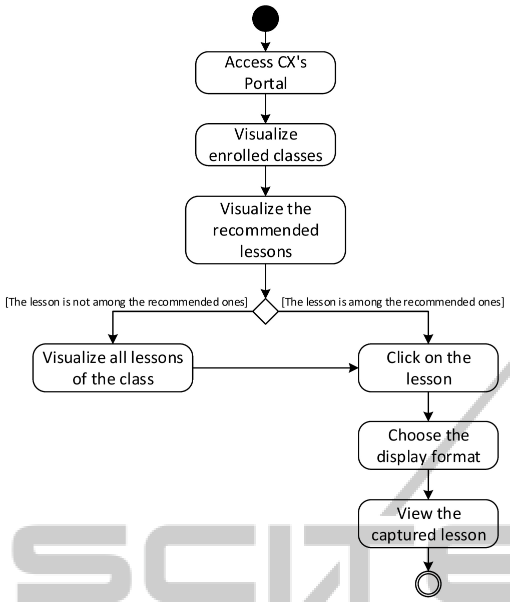

Figure 12: "Access captured lesson" UML activity diagram.

or *wiCPN*) diagrams, each student answered a questionnaire to assess his/her understanding about the modeling of the interactive flows. The questionnaire comprised 12 affirmatives to which the student should mark his/her agreement level in a 1-to-7 Likert scale (being 1 - Completely disagree, 2 - Disagree, 3 - Partially disagree, 4 - Neutral, 5 - Partially agree, 6 - Agree, and 7 - Completely agree):

1. The modeling of the interactive flows is intuitive.
2. In the presented modeling, there are screens without well-defined purposes.
3. I can understand which activities are available for each type of user.
4. Information about my current screen is not always available in the model.
5. From my current screen, I can always realize which other screens I can access.
6. It is not possible to implement all functions presented in the model.
7. I cannot understand the interactive flow represented in the model.
8. I can understand the purpose of all screens in the presented modeling.
9. The permissions granted for each type of user are not clear.
10. I always know my current screen in the model.
11. I cannot figure out which screens I can access from my current screen.
12. The modeling provides all information necessary to implement the presented functions.

We employed a reversed and negated items method for detecting insufficient effort in responding our survey in order to legitimate user answers (Huang et al., 2012). As can be noticed in our questionnaire, pairs of different affirmatives express the same ideas with opposite meanings: pair 1-7 examines general understanding of the modeling, pair 2-8 verifies the intended purpose of screens, pair 3-9 is related to the proper identification of user options and permissions, pair 4-10 contemplates current user location in the interactive flow, pair 5-11 covers the screen reachability, and pair 6-12 regards model completeness.

We assumed that students would respond to each pair with opposite opinions. This way, to evaluate the questionnaire items properly, the second affirmative of each pair should be reversed in the Likert scale (i.e., a 1 becomes a 7, a 2 becomes a 6, and so on). After invalidating contradictory answers, we then computed the mean ($\bar{x}$), standard deviation (s) and coefficient of variation (CV) for each pair of answers among the two groups of students. Results are presented in Table 1.

Table 1: Mean, standard deviation and coefficient of variation of students' responses to questionnaires.

Affirmatives[1]	*UML*		*wiCPN*	
	$\bar{x} \pm s$	$CV(\%)$	$\bar{x} \pm s$	$CV(\%)$
1 and 7	4,20±2,01	47,79	5,40±1,06	19,55
2 and 8	5,13±1,85	35,97	2,40±0,83	34,50
3 and 9	5,33±1,72	32,22	6,00±0,85	14,09
4 and 10	3,20±1,08	64,91	2,27±0,96	42,40
5 and 11	4,87±2,10	43,15	6,27±0,70	11,23
6 and 12	3,60±2,03	56,34	2,33±1,35	57,65

[1]Each pair's second affirmatives had their results inverted and incorporated into the first ones, in order to nullify or highlight responses given in first items; *UML*: Unified Modeling Language; *wiCPN*: Web Interaction Modeling Using Colored Petri Nets; $\bar{x} \pm s$: Mean and standard deviation; *CV*: Coefficient of variation.

Results show that students from the second group (*wiCPN*) presented mean values with higher partiality and lower deviations than students from the first group (UML). Besides that, for most pairs, CV values were lower for *wiCPN* – except for the last pair, which surpassed it in 1.31%. Such results demonstrate that *wiCPN* scored adjacent and uniform levels, ensuring high homogeneity in opinions and reinforcing that our approach was well-accepted and evaluated among students that used it.

Figure 13 shows the frequency of answers ob-

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tained in questionnaires. Since the affirmatives presented in questionnaires alternated positive and negative ideas, we expected students to express agreements in pairs 1-7, 3-9 and 5-11, while pairs 2-8, 4-10 and 6-12 were expected to be susceptible to disagreements. Following the same order of pairs in both samples, scores given by students that used *wiCPN* were more tendentious than those from students that used UML. While in the first column (UML) student opinions appear to be divided, the second column (*wiCPN*) shows strong trends (either to agreement or disagreement) in each pair of given answers.

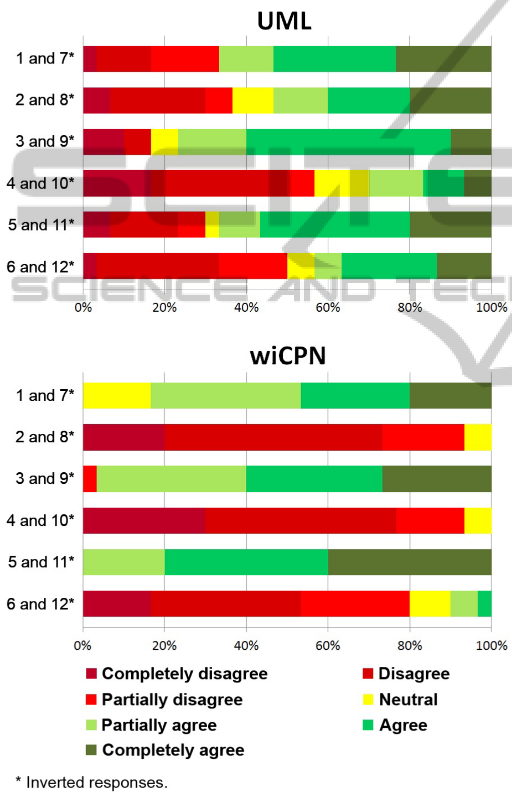

Figure 13: Frequency of answers obtained in student questionnaires. UML scores showed divided opinions, while *wiCPN* presented clear tendencies for agreement in pairs 1-7, 3-9 and 5-11, and disagreement in 2-8, 4-10 and 6-12.

More than 30% of students from the first group (UML) affirmed that the modeling of interactive flows was not intuitive. In the same group, half of the students informed that screens had no clear purpose – no similar answer was observed among students from the second group (*wiCPN*). Furthermore, almost 20% of the students that used UML declared they could not understand which activities were available for each type of user, while only 5% of students that used *wiCPN* reported the same difficulty.

Among those who used UML, about 30% revealed having trouble to identify their current screen and, from there, to which other screens they could move in the modeling. No student using *wiCPN* reported such problems. Finally, more than 40% of students asserted that it was not possible to implement all the functionalities using only the provided UML diagrams, something pointed out by less than 5% of the students that used *wiCPN*.

6 RELATED WORK

An interesting work found in literature is *UITD (User Interface Transition Diagram)*, a modeling notation for representing shifts that happen in interfaces, being also able to trigger determined transitions based on their specific conditions (Gómez and Cervantes, 2013). *UITD* notation results in pseudo-digraphs (directed graphs whose transitions have a possibility of looping), where vertexes denote user interface presentations and directed edges depict transitions.

Since *UITD* is a variation of well-acquainted *State Transition Diagrams* – also known as *State Charts* (Harel, 1987) – and its notation extends State Charts' modeling scope to an interaction range, existing tool support (such as *Yakindu*[3]) is not able to fully represent *UITD*'s graphs. Noticeably, the approach we introduce in this work is also based on an existing modeling language: CPNs. Nevertheless, *wiCPN* makes use of a specific tool suite for generating, editing, simulating and making full analysis of CPN models. As *UITD* does not have an exclusively CASE tool for supporting its generated graphs, its modeling activities end up being performed on applications originally developed for other purposes or, even, without making any use of proper tools.

MoLIC (Modeling Language for Interaction as Conversation) comprises a model focused on HCI specifications (Sangiorgi and Barbosa, 2009). Proposed to be incorporated into the UML family, *MoLIC* represents interactions as conversation topics. However, since each conversation thread is represented by scenes constructed using natural languages and user perspectives, the model is subjugated to ambiguity and subjectivity.

Another approach for modeling applications by making use of UML and with focus on representing mobile Web interfaces was also encountered (Vera et al., 2012). Based on processes defined by *OOHDM (Object Oriented Hypermedia Design Method)*, their work unified activities of interaction modeling by using two UML diagrams: a component diagram for

[3]http://statecharts.org/

representing interface navigation and a class diagram for the domain modeling. Both diagrams were expanded by making use of tag values and stereotypes. As a conclusion, these extensions added further information to models and allowed their configuration, what contributed to make code generation an easier task during the development process. Although their proposed methodology clearly brought formalization gains, it is focused merely on the specification of mobile Web applications. Otherwise, *wiCPN* method configures a different scope, focusing on user interactions which may originate from several different devices, such as computers, notebooks, cellphones and tablets – requiring only the need of a Web browser installed in these equipments.

Being recently adopted as a new standard by *OMG (Object Management Group)*, *IFML (Interaction Flow Modeling Language)* was developed to represent user interactions, application contents and control behaviors of software front-ends (Rossi, 2013). *IFML* includes a set of graphical notations capable of generating visual models which aim at depicting interaction flows and interface behaviors, with a main focus on structure and front-end activities perceivable by users. An *IFML* diagram consists of *view containers* that represent user interface windows or Web pages. These containers can have elements called *view components* which can hold input and output parameters. Both containers can be associated with events, in order to express their support to user interactions. However, despite being dedicated to specify user interaction dynamics in interface applications, *IFML*'s hypertext modeling is recent and lacks an appropriate and organized base of notations, conceptions and design methods (Gal-Chis, 2013). Also, *IFML* does not address the modeling of presentation issues, e.g., layouts and styles of application front-ends (Rossi, 2013). This may have occurred because *IFML* is an extension of WebML (Web Modeling Language), a Web designing notation first defined in early 2000's and which experienced just about ten years of use. As *IFML* is currently in Beta version, adjusts are likely to be performed for giving the language more confidence in its field. Our approach, on the other hand, makes use of CPNs – which are based on Petri Nets, a language for describing systems first documented in 1962 (Petri, 1962) and widely spread and extended since then (Silva, 2013) –, what quite reinforces the strengths and breadth of usage that Petri Nets bring to the systems modeling domain.

Another work found in the literature presented an interaction model of a smart community cyber-physical system called *Net-in-Net* (Ma et al., 2010). As elucidated by the authors, cyber-physical systems are environments which integrate physics with Internet in order to provide efficient, confidential and opportune interactions between applications and users. Since their work aims at representing interaction flows of a complex system characterized by security, stability and reliability issues, it should have been formalized by making use of a proper robust and verifiable language. However, *Net-in-Net* interactivity was modeled by making use of simple flow charts, resulting eventually in subjective models.

This subjectivity also happens in another work, where a vocabulary for web user interface design is proposed (Tena et al., 2013). As it compiles terms that are constantly changing and being substituted, its reuse becomes nearly impractical (since the result is at the mercy of time misconceptions) and the generated vocabulary has wispy usage for other researches. A cognitive model for representing interactions between drivers and vehicles was also found (Ciardelli et al., 2011). Proposed to consider user behaviors and detect potential dangerous situations, the work presented an approach to the analysis and modeling in automotive applications and exploited a simulation platform and a sensor network assembled in vehicles. As a conclusion, authors showed preliminary results demonstrating the method practicability and discussed how a continued research could bring improvements for human safety oriented applications.

With a few resemblances to our approach while concerning to Petri Nets theory, *ICOs (Interactive Cooperative Objects)* is an object Petri Nets-based interface description language for engineering and development of applications (Martinie et al., 2014). *ICOs*' associated CASE tool, named *Petshop* (which stands for *Petri net workShop*), is able to provide support for the design, specification, prototyping, and validation processes of interactive software.

While sharing the benefits of a concrete basis in formal language notations, *ICOs* also makes use of concepts borrowed from the object-oriented paradigm, such as dynamic instantiation, encapsulation and inheritance. For a correct use of such paradigm, an object Petri Net dialect had to be used in order to comprehend the object-orientation's whole scope. Therefore, plenty of skills – not only in user interface design, but also in object-oriented programming, Java language, implementation and Petri Nets-based modeling – are required to represent correctly the interactive applications while using *ICOs*, what inevitably induces a high learning curve for making engineers able to work on the projects.

In another work, a Petri Net based framework to support design, implementation and verification of animated interfaces in a two-levels process is presented (Mirlacher et al., 2012). While the higher level view of the approach focuses on interactive objects, considering their properties and composition of animations, the lower level stands for temporal aspects, caring about usage of interpolation and possible connection issues with rendering hardware. This model gets rather complex as it handles both inter-objects' animated properties and the whole orchestration of animation shifts that may happen when systems performance is lower than expected. Designing interfaces that concern about potential degradation is a heavy burden for engineers who have to be aware of computer animation issues and numeric analysis application, to distinguish in a quick and efficient way which and how animations should be degraded.

Unlike these last works, *wiCPN* approach was made to be visual and intuitive – while making use of a formal modeling language capable of verification. This way, our work comprehends a method for generating models that professionals from various fields can understand and clearly see how their interaction flows behave, thus being able to contribute better with the underlying processes of systems modeling.

To synthesize the discussions held in this section, Table 2 presents all related works concerned to interaction modeling that were perceived throughout the text. A criteria-based evaluation conducted by our researchers was able to show that all approaches have positive traits and certain gaps that justify why they are used in more specific contexts. The approaches were judged based on six different criteria: (a) existence of a specific *CASE* Tool that fully supports the method; (b) approach's ability of modeling the interaction of Web front-ends; (c) generated models' ease of understanding; (d) no prior obligation to learn other contents to properly use the technique; (e) if the approach was based on a formal language; and (f) method's ability to comprise security requirements, such as user authentication. For measuring each criterion, three levels of incidence were stipulated: an empty circle (○) for approaches that lack a specific criterion; a circle in half (◐) to works which partially fulfill a criterion; and a full circle (●) to those ones that entirely comprehend a established criterion.

As noted in Table 2, the approaches of (Ma et al., 2010), (Tena et al., 2013) and (Ciardelli et al., 2011) do not have exclusive *CASE* Tools for applying their methods. This absence may lead to inconsistencies, such as erroneous representations of interactive flows, inducing problems of misunderstanding models. Furthermore, most works demonstrate some ability to represent interactions of *Web* interfaces, even if partially. However, several details of interactivity are lost in some studies – such as in (Sangiorgi and Barbosa, 2009), (Vera et al., 2012) and (Ciardelli et al., 2011) – and this occurs because not all formalization methods were exclusively created for this purpose.

Table 2: Evaluation of analyzed approaches.

Works	(a)	(b)	(c)	(d)	(e)	(f)
(Gómez and Cervantes, 2013)	●	◐	◐	◐	●	●
(Sangiorgi and Barbosa, 2009)	●	◐	◐	◐	○	●
(Vera et al., 2012)	●	◐	●	◐	○	●
(Rossi, 2013)	●	●	◐	◐	●	●
(Ma et al., 2010)	○	◐	◐	●	○	●
(Tena et al., 2013)	○	◐	●	●	○	○
(Ciardelli et al., 2011)	○	○	◐	◐	○	○
(Martinie et al., 2014)	●	◐	○	○	●	●
(Mirlacher et al., 2012)	●	●	○	○	●	●
wiCPN	●	●	◐	◐	●	●

Among listed approaches, (Martinie et al., 2014) and (Mirlacher et al., 2012) were the ones that generated models with the highest difficulty level of understanding. This is justified by the fact that these works also involve the greatest amount of knowledge required in different areas to be previously understood by professionals who aim to use them. Furthermore, half of the works did not present any grounding or usage of formal methods in their approaches. During cases of complex systems specification, such as in (Ma et al., 2010) and (Ciardelli et al., 2011), the use of verifiable formalizations shows up as a relevant practice, thanks to the possibility of perceiving and fixing errors during early stages of software development processes.

7 CONCLUSION

This paper introduced *wiCPN* (Web Interaction Modeling Using Colored Petri Nets), a language for representing Web interactions with improved notation and semantics. Designed as an extension of CPNs, *wiCPN* brings together the strengths of CPNs with a high level graphical notation that was able to refine the model components and represent interaction in a structured and intuitive way. By allowing the creation of hierarchies, *wiCPN* stimulates the refinement and better organization of the generated models.

As a case study, our approach was tested in a real ULE with modeling and verification of Classroom eXperience's Web front-end. Generated models were replicated in UML and, together, served as a basis for a detailed user experiment. Results from user experiments demonstrated *wiCPN* to be a concise and intuitive notation, capable of simplifying the design process and, thus, avoiding redundancies and inconsistencies. With good expressiveness, our language was able to propitiate better understanding of the whole interactive process, by presenting both the connections among the system screens and the actions associated to every possible flow.

Furthermore, *wiCPN* was also capable of portraying the many access levels of different user types, respecting the roles they play in the system and the content and activities they are allowed to see and perform. This point demonstrated the language's capability of comprehending issues that concern to systems security requirements and can also serve as a basis for future work in this scope.

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