A Source Code Independent Reverse Engineering Tool for Dynamic Web Sites

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Abstract

This paper describes a tool for black box reverse engineering of web applications that reconstructs analysis models based on the concepts of form-oriented analysis. Recovering such models is motivated by requirements engineering and load testing. In particular, the paper addresses the problem of screen classification and discusses its conceptual underpinnings.

1. Introduction

This paper describes source code independent reverse engineering of dynamic web sites. The tool Revangie recovers models of dynamic web interfaces without looking at the source code. This is in contrast to other tools that perform white box reverse engineering on dynamic web sites [4, 1, 10]. Revangie can operate in three different modes: the crawl-mode, which works automatically, the snoop-mode, which is user-driven, and the guide-mode, which works semi-automatically, combining the advantages of the other two modes. We describe how these modes work, what problems come up when performing black box reverse engineering of web applications, and what solutions we found. We introduce a statistical test for determining if a classification leads to significant differences in the transition probability distributions of pages or other random variables of interest and describe how this test can be exploited for screen clustering.

Recovering models independent of source code can be advantageous because of the many platforms, architectures, and languages for the implementation of dynamic web sites. Source code dependent reverse engineering is usually restricted to a certain language, platform etc. – Revangie is independent of all those. The source code independent approach is a straightforward one because it is much easier to analyze HTML code than the generating code. It is an essential claim that the analysis of the generated HTML is sufficient to recover sophisticated models. It is not only easier to analyze HTML code than the generating code but also more convenient, because HTML code can be explored through the single point of access of an HTTP port. In contrast, the generating code can have a complex deployment structure. In the case that the source code is inaccessible analysis must be source code independent anyway, as it is the case in typical product benchmarking efforts.

The motivation for Revangie can be explained best by describing its role in the Angie tool suite, see Fig. 1. Revangie is used to recover form-oriented models from a dynamic web site. The textual description of this model in the language Angie [8] can be subsequently used for forward engineering of click dummies, i.e., executable prototypes, as they are conveniently used for requirements engineering, or customizable systems, which can help in migrating to model-driven architecture. In addition to this, Revangie can collect data about user behavior that can be used for load testing. It is further work to provide a load test tool that simulates real users on the basis of an annotated version of the Angie language.

In Sect. 2, we provide a brief overview of form-oriented analysis. In Sect. 3, we describe the different modes of operation of Revangie. Section 4 explores the screen classification problem. The paper finishes with a discussion of related work, further directions and a conclusion in Sects. 5,6 and 7.

2. Using the Form-Oriented User Interface Model

In order to perform coherent analysis we need a model that describes the user interface of web applications adequately. The form-oriented user interface model [7, 5] uses typed, bipartite state machines, in which one set of states denotes *client pages* and the other set *server actions* that generate the pages. These graphs contain all the information of page diagrams, but in addition to this, they model the relationship between server-side actions and pages. It is obvi-

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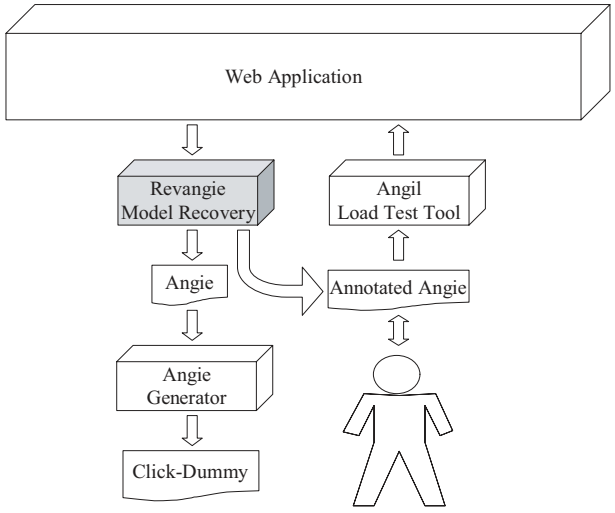

Figure 1. The Angie language related tool suite.

ous which form or link on a page uses which server action and which server action generates which page. Note that the pages in the model do not represent individual pages as seen by the user but classes of pages, of which many instances may be generated by different server actions. We call the possible instances of a page *screens*.

An important property of the model is its type system: actions as well as pages have a signature which specifies a type for the data accepted by an action and a type for the data displayed on the screens of a page. However, usually we cannot know the exact signatures of pages and actions when performing black box reverse engineering. The structure of screens can only give us some hints about their page's signature; forms contain information like parameter label names, default values and field types, which can be useful for inferring types.

For the textual representation of such models form-oriented analysis proposes the language Angie [8]. Small models can be visualized conveniently in so called *formcharts*, in which pages are represented as bubbles and actions as rectangles.

The web application depicted in the formchart in Fig. 2 starts at client page "login" which is supposed to contain a form for submitting a user name and password to server action "checkpw". If the submitted login information is invalid, the user is shown another instance of the "login" page, otherwise the user is forwarded to page "home". Here, options "buyCars" and "buyBikes" can be chosen, and the respective pages subsume all the possible screens showing lists of cars and bikes, respectively. According to the formchart, both pages use the same action "buy" to process submitted data. This points out that the same CGI program is

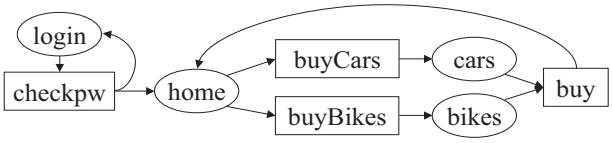

Figure 2. formchart example.

used, probably with the same set of parameters, so that the buying of a car is distinguished from the buying of a bike merely by actual parameters, like an article number.

In the context of reverse engineering we have to identify the pages and actions of a system. All we know is that each screen is instance of a page and that each form and link refers to an action. It is not always possible to say, which screen is instance of which page. The difference between pages may be a purely semantic one like in our example, where the pages "cars" and "bikes" show lists that may be structurally identical. In order to distinguish pages precisely we would have to look into the CGI programs that generate them as, for example, it is done by the tool JSpick [4]. The identification of actions can also be hard, but with the information we get from forms it is usually much easier. To put the whole matter in a nutshell, a main problem of client-side reverse engineering without the source code of CGI programs is the classification of forms and links into actions and the classification of screens into pages, the latter of which will be discussed in Sect. 4.

3. The Reverse Engineering Process

Revangie can work in different modes: the crawl mode, which works on the client side, and the snoop mode, which works at any point in the communication line between client and server. When Revangie is started, it must be told which mode it should use.

3.1. The Crawl Mode

The crawl mode works like an automated web browser: It uses an HTTP client to request pages, submit values and analyze the trace of submitted values and visited pages. It starts at a specified URL, retrieves the corresponding HTML screen and scans it for links, forms and some other tags. As mentioned in Sect. 2, links and forms are grouped to actions. As we will discuss further in Sect. 4, screens, in turn, must be classified as being instances of pages. In this way we can obtain information about which pages and actions are in the model, which action can be invoked from which page, and which page is generated by which actions.

3.1.1. Problems of Fully Automatic System Exploration

It would be naive to think that the analysis model of every

non-trivial web application could be reconstructed automatically. The problematic point is that the data submitted on a page usually has to suffice certain constraints and therefore cannot be generated generically. Sometimes this data depends on the context or its history, e.g., email addresses, credit card numbers or passwords. But still, there are web applications for which the crawl mode, which generates input data randomly, can yield satisfactory results. Think, for example, of a search engine. It is conceivable that the range of web applications feasible for the crawler can be widened by the use of simple heuristics which, for example, exploit the fact that certain field labels, e.g., "surname" or "email", correspond to well-known data types. Note that we must not generate data for the hidden parameters of forms and links; we have to use the values provided by the web application in order to guarantee consistent operation.

We cannot simply use a breadth-first or depth-first search of the bipartite graph that we are constructing because most of the more sophisticated web applications keep track of sessions, i.e., the history of action invocations triggered by a single user. The permitted protocol of a session is given by the sequence of screens as provided by the web server, and any deviation from it might cause an error. Most people have experienced that using the back and reload buttons of a browser in a form-oriented system can cause errors due to the expiry of a page.

An important question for the crawl mode is how the choice for the next action in the automated browser is made. Of course, we want to make the choice that is most likely to help us in the analysis, i.e., that leads us to the discovery of a maximum of new pages and actions. But we cannot predict which choice this will be, so we have to use heuristics like a usage counter for each form and link. The "least used" heuristic says that an action with a minimum usage counter is a good choice.

3.1.2. The Crawling Algorithm Putting it all together, this yields Algorithm 1 as the operational semantics of the crawl mode. Procedure crawlAll simulates many single-user sessions successively by invoking procedure crawl on page $entry$ as long as a significant extension of the reconstructed model takes place. $entry$ is an artificial page which contains forms for all the actions that may serve as entry points into the web application. Although page $entry$ does not appear in the actual web application, it is represented internally like any other page, only that it is marked in the model.

In order to stop exploration when no new parts of the web application are discovered any more, we calculate the value α as a ratio of the number of iterations done in crawlAll to the number of actions found in $model$, the global variable containing the reconstructed model. This gives us the average number of actions discovered in a single simulated session; and once α drops below a threshold Θ, we assume that the application has been explored sufficiently. We use the number of actions and not the number of actions and pages because the number of pages usually varies much more depending on how we classify screens. It is usually harder to find an appropriate classification for screens than it is for forms; even the simple grouping of forms by their CGI program URI works well in many cases. The number of actions in a web application is usually proportional to the number of conceptual pages and seems a satisfactory measure for how much the application has been explored. The number of pages can be too volatile depending on the notion of screen classification as it becomes apparent, for example, in a search engine: the search action may lead to innumerable screens that may be hard to classify.

Algorithm 1 Crawl Mode

```
1:  procedure CRAWLALL
2:      while α ≥ Θ do
3:          crawl(entry)
4:      end while
5:  end procedure

6:  procedure CRAWL(Page p)
7:      while |p.forms| > 0 ∧ α ≥ Θ do
8:          Set A ← {classify(f) | f ∈ p.forms ∧
                feasible(f)}
9:          for all Action a ∈ A do
10:             model ← model ∪ {(p, a)}
11:         end for
12:         if A = ∅ then
13:             break
14:         end if
15:         a ∈ A with a.usages = min_{a'∈A} a'.usages
16:         a.usages← a.usages+1
17:         Set data ← ∅
18:         for all Field f ∈ a.lastform.fields do
19:             value ←generateValue(f)
20:             data ← data ∪ {(f.label, value)}
21:         end for
22:         s ←invoke(a, data)
23:         p' ←classify(s)
24:         model ← model ∪ {(a, p')}
25:         p ← p'
26:     end while
27: end procedure
```

Procedure crawl simulates a single session which runs into a terminal set of states, i.e., a set of pages and actions that cannot be left. The existence of terminal sets of states in a web application is the reason that simulation of a single session is insufficient; a single session can only explore one terminal set. We try to cover all the terminal sets by simulating multiple sessions.

In the main loop of procedure crawl we iterate over page-action-page transitions, starting on the page p given as argument. In the condition of the while-loop in line 7 we check if the page offers any possibility of interaction at all; if not, crawl terminates. An HTML link can be regarded as a special case of an HTML form, i.e., one that does not have visible fields. Therefore, the class that represents a link is internally a subclass of class Form, and if p contains no forms it does not contain links either. The other while-condition, $\alpha \geq \Theta$, is similar to the one in procedure crawlAll and will be discussed later on. In line 8 we construct a set A which contains actions for all the forms on screen s that are feasible, i.e., that do not lead us out of the application onto other web sites. Actions for non-feasible forms could also be added to the model if desired. The following loop adds a page-action transition from p to each action in A to the reconstructed model. The model is accessible through he global variable $model$ and represents the transitions between actions and pages by a set of tuples.

Set A contains all actions that can be considered for invocation at this point. If A is empty, no action can be invoked and we terminate the session by leaving the loop in line 13. Otherwise, we choose an action a of A which has a minimal usage counter in line 15, thereby trying to maximize the likelihood of efficient exploration. After incrementing the usage-counter of the chosen action a, we generate a label-value pair for each field f of the last form classified to a in lines 17-21. Then, we can submit this data, receive a new screen s, and classify s into a page p', which can be an existing page or a new one. We add the reconstructed action-page transition (a, p') to $model$ and prepare the next iteration that uses p' as starting point.

The second condition of the while-loop in line 7, $\alpha \geq \Theta$, is there to ensure that crawl terminates when the terminal set of states it operates in seems to be sufficiently explored. Similar to procedure crawlAll, α is the ratio of the number of new actions found in a session to the number of iterations done in that session. If many iterations are preformed without the discovery of an appropriate number of new actions, crawl terminates.

3.1.3. The Quality of Crawling The quality of the constructed model depends heavily on the functions generateValue and classify. It depends on generateValue how effectively user input is simulated and therefore how well the actual set of pages and actions in the web application is covered. An action that requires data of a special form that generateValue cannot offer will probably generate an error page all the time and never reveal its real functionality. classify determines if the granularity of the reconstructed model during exploration is adequate. The classification of forms, in particular, also influences the efficacy of the crawling process because it affects the heuristic for the selection of the next action to use: A classification that is too fine leads to a redundancy of actions; many usage counters will be zero for a long time, so the least-used heuristic does not help much. A classification that is too coarse does not differentiate the functions of the system properly and leads to few actions whose usage counters will rise very fast. In extreme cases the least-used heuristic is not much better than random choice.

Classification of pages is not only, like depicted in the pseudo code, possible online, i.e., during the process of exploration. We can also perform a new classification offline, that is in a separate stage after the process of exploration. Therefore, we record the exploration history so that a classification algorithm can operate on the whole data a-posteriori and consequently use a wider range of analysis techniques.

3.2. The Snoop Mode

The snoop mode collects data of actual sessions of a web application in order to analyze it and reconstruct a model afterwards. It can either monitor the HTML communication of one or more users by taking the role of a proxy server, or monitor the communication of all users by taking the role of a facade to the web server. In the first case the user has to configure his web browser accordingly, and in the latter case the web server has to be reconfigured.

This mode allows us to collect realistic session data of one or more users. In the case of many users it can be utilized to determine certain user model parameters statistically. An analysis model with this additional data, like distributions for the turnaround time, navigation probabilities or sample input, is ideally fit for performing fully-automated realistic tests, especially load testing. Of course, the snoop mode should be used with discretion so that other's privacy is respected.

3.3. The Guide Mode

The guide mode tries to combine the advantages of crawl and single-user snoop mode: automation and the possibility to enter form data manually. The algorithm is like in the crawl mode, but at certain points the user is asked to choose the form to use next and enter appropriate values. The tool can ask for user input at every step or only at steps that are hard to handle automatically, like forms with input fields.

Besides for the selection of a form and the generation of input data, user input can also be useful for screen classification. If classification seems ambiguous according to some measure, the user can select to which page a screen should be added. If automatic classification produced unsatisfactory results, screens can be reclassified by the user. The same applies to forms and actions.

The guide mode uses an ordinary web browser for interaction and offers additional controls for computer aided re-

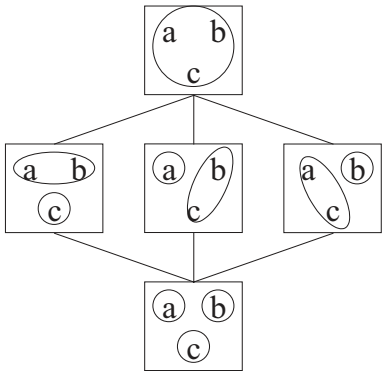

Figure 3. Cpo of equivalence relations.

verse engineering. The tool acts as a proxy for the web browser and displays session histories, usage counters, screen and form classifications and a formchart of the current model. It also suggests automatically generated data for input fields, thus making reverse engineering more convenient.

4. The Screen Classification Problem

We need to classify each received screen to a page in order to build our model properly. As depicted in Sect. 2, a page is characterized by the signatures of its targets, i.e., the actions that can be invoked on it by the user, and the signature of the data presented on its screens. Screens usually contain many hints about how these signatures look like, and there is a wide variety of possibilities for screen classification. If, for example, a target's URL has the suffix `.html` and no parameters, it is reasonable to assume that it leads to a static page of which all screens are equal by string equality. On the other hand, if a target action has parameters, it is likely to generate screens with varying content that require more sophisticated techniques to classify.

4.1. The Lattice of Classifications

Let us first look at the formal basis of classification. Formally, a classification is an equivalence relation, i.e., a reflexive, transitive and symmetric binary relation which partitions a set into disjoint subsets called equivalence classes. We denote the set of all equivalence relations over a given set S by EQ_S.

We call a classification resp. equivalence relation $A \in EQ_S$ a refinement of equivalence relation $B \in EQ_S$, denoted by $A \sqsubseteq B$, *iff*

$$\forall x, y \in S : x \sim_A y \Rightarrow x \sim_B y$$

The above definition of refinement is natural because a refining classification is conservative with respect to the refined classification, i.e., a refinement only further subdivides the classes of a given classification. This is also neatly expressed by the fact that the defined refinement is equal to the subset relationship between equivalence relations, i.e., the following holds

$$A \sqsubseteq B \textit{ iff } A \subseteq B$$

For example, given a set of screens $S = \{a, b, c\}$, the Hasse diagram in Fig. 3 visualizes the partial order $(EQ_S, \sqsubseteq)$ of equivalence relations over S.

Similarly we can define true refinement $\sqsubset$, coarsening $\sqsupseteq$, and true coarsening $\sqsupset$ by:

$$A \sqsubset B \textit{ iff } A \subset B,$$

$$A \sqsupseteq B \textit{ iff } A \supseteq B,$$

$$A \sqsupset B \textit{ iff } A \supset B.$$

We now define conjunction $\wedge$ and disjunction $\vee$ of classifications. A classification identifies elements of the set for which it is defined. Informally, a conjunction $A \wedge B$ identifies those elements that are identified by both A and B, whereas a disjunction $A \vee B$ identifies those elements that can be identified by means of A or B. Conjunction is defined by set intersection on equivalence relations; however, disjunction cannot be defined analogously just by set union, but must be defined as transitive closure of set union.

$$\begin{array}{lll} A \wedge B & =_{def} & A \cap B \\ A \vee B & =_{def} & \text{transitive-closure}(A \cup B) \end{array}$$

The partial order EQ_S together with conjunction and disjunction, i.e., $(EQ_S, \wedge, \vee)$, form a complete lattice.

A notion of classification assigns to each set a classification of this set, i.e., an equivalence relation on this set. Typically, only sets that adhere to certain criteria are considered – we can formalize this by considering subsets S of a given base set B only. The given context criteria can be exploited to argue about the refinement relation between notions of classifications defined below. All this means, that a notion of classification is a dependent product with respect to a family of sets and equivalence relations over these sets.

$$C = (C_S : EQ_S)_{S \subseteq B}$$

We now define refinement, disjunction and conjunction for notions of classification:

$$(C_S)_{S \subseteq B} \sqsubseteq (D_S)_{S \subseteq B} \quad \textit{iff} \quad \forall S \subseteq B . C_S \sqsubseteq D_S,$$

$$(C_S)_{S \subseteq B} \wedge (D_S)_{S \subseteq B} \quad =_{def} \quad (C_S \wedge D_S)_{S \subseteq B},$$

$$(C_S)_{S \subseteq B} \vee (D_S)_{S \subseteq B} \quad =_{def} \quad (C_S \vee D_S)_{S \subseteq B}.$$

Also the set NoC_B of notions of classification with respect to a base set B together with disjunction and conjunction, i.e., $(NoC_B, \wedge, \vee)$, form a complete lattice.

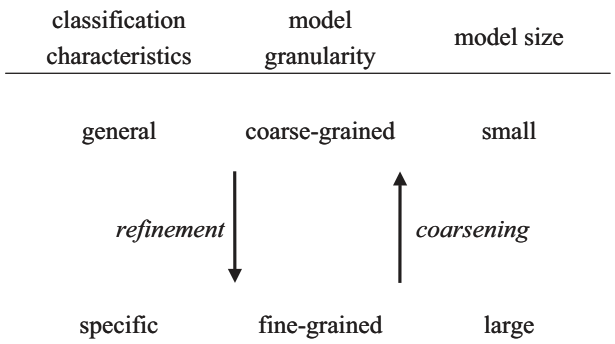

Figure 4. Terminology for classification.

We now define the concept $SNoC_B$ of *standard notions of classification* with respect to base set B. Informally, a standard notion of classification is conservative with respect to set operations on the underlying set of the equivalence relations.

$$C \in SNoC_B$$
$$\textit{iff}$$
$$\forall S,T \subseteq B.\forall x,y \in S \cap T.x \sim_{C_S} y \Leftrightarrow x \sim_{C_T} y$$

For standard notions of classification, refinement can be defined more directly as the refinement on the base set classification because the following holds:

$$\forall S \subseteq B.C_S \sqsubseteq D_S \quad \Leftrightarrow \quad C_B \sqsubseteq D_B.$$

In the sequel we use the terms *notion of classification* and *classification* synonymously. The terminology for classification used in our paper is defined in Fig. 4. It shows the effect of refinement and coarsening on classification characteristics, model granularity, and model size.

4.2. Possible Screen Classifications

Now, let us consider different notions of screen classification:

Trivial identity is the coarsest possible equivalence relation. All screens are equivalent. It is practically unimportant but forms the top ($\top$) element of our lattice.

Screen identity is the finest possible equivalence relation for screen classification and consequently forms the bottom ($\bot$) element. Each screen that is received by a web client gets its own page, even when two screens have the same HTML code.

Textual identity groups screens with the same HTML code into the same page.

Source identity groups screens into the same page that were generated by the same action.

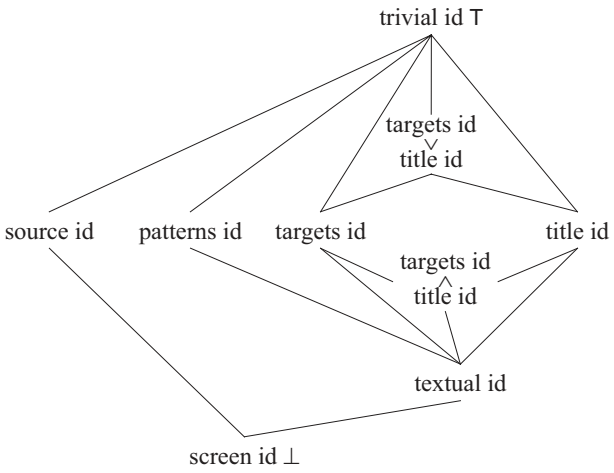

Figure 5. Lattice of notions of screen classification.

Targets identity groups screens with identical *targets signature*, i.e., the same set of signatures of the server actions targeted by a screen. Targets identity can be coarsened to **form targets identity** by excluding the signatures of links from the targets signature, or orthogonally, coarsened to **internal targets identity** by excluding forms and links that target external actions, like links to other web sites.

Title identity groups screens with identical HTML titles.

Pattern identity groups screens that match a user-defined pattern. This may be a textual pattern, a purely syntactical pattern or a mixture of both; regular or, at most, context-free patterns are usually sufficient.

Similarity or dissimilarity of screens according to some textual or structural distance metric can be used to cluster them into pages (e.g., [17]). A similarity measure suitable for clustering can also be created by combination of multiple similarity indicators, like any of the discussed ones, which can be combined, for example, by a weighted sum.

The relationship between the different notions of classifications is illustrated in Fig. 5. Note that Fig. 5 is not a complete visualization of the lattice of notions of screen classification because only exemplary disjunctions resp. conjunctions are included.

By combining and configuring classification techniques appropriately, it is possible to reconstruct an expressive model with adequate page granularity. For a maximum of flexibility, Revangie offers a system of configurable plug-ins for screen classification, with a generic default plug-in. Note that it depends on the intended usage of a model which model granularity is adequate, i.e., a given model granu-

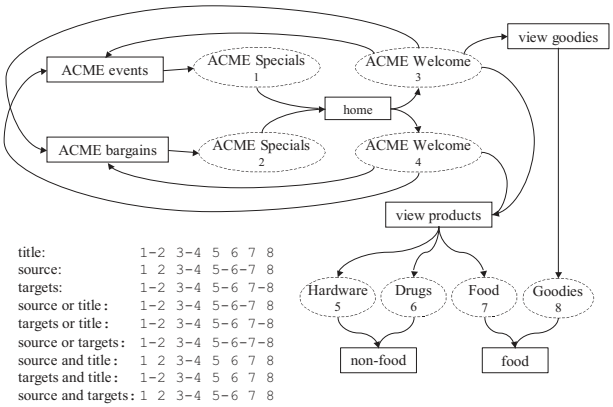

Figure 6. Example conjoined and disjoined classifications.

larity must be judged with respect to an external criterion. For example, targets identity can be considered to fit best in load testing scenarios, whereas textual identity is the classification of choice for static HTML pages. Targets identity is an important basic classification because it yields the smallest possible form-oriented analysis models without enabling conditions for targets, i.e., it yields a model where all the screens of a page offer the same server actions for interaction. We discuss this topic further in Sect. 4.6.

Our classification apparatus is especially expressive because of the notions of conjunction and disjunction. Potential candidates for conjunction are, for example, targets identity and title, or targets identity and pattern identity. Please consider the classifications resulting from conjunction and disjunction in the ACME webshop example of Fig. 6. Note, that the figure shows a modified formchart diagram where single, completely unclassified screens are drawn instead of client pages. Therefore, dashed lines are used instead of solid ones for the bubbles. The example, with its many different classifications, aims to clarify that there is no single notion of correct model granularity. All the classifications correctly group screens 3 and 4, but not all separate 1 and 2 although they are semantically different. All the screens 5 to 8 display different kinds of products, so it would be thinkable to separate them, like title identity does. It might also be more appropriate to classify them according to their targets identity, so that only food and non-food products are distinguished.

4.3. Classification and Clustering

Every classification can be reformulated as a clustering according to some metric δ, with δ being a binary function on screens that evaluates to a positive real number called distance. For purely logic predicates like the identity of targets or titles corresponding metrics would produce a distance of zero iff the predicate is true and some other fixed value if not. If the metric has a range that encompasses more than two distance values, as it is the case for dissimilarity measures, i.e., if the answer of δ whether two screens belong to the same page is fuzzy, we need to use a clustering method. Such a method partitions a set of objects – in our case, the screens – into clusters which correspond to the equivalence classes of an equivalence relation – the pages, in our case. A large variety of such methods exists; see, for example, [12].

Most clustering methods allow us to choose the number of clusters, which means in our case, the granularity of the model. This allows us also to let the user set a preferred model size and calculate a model that fits that size best. But there are also useful heuristics for determining an optimal model size: it is reasonable to assume that the fan-out of an action has a small maximum, i.e., that an action generates only a few conceptually different pages, e.g., a page that displays and requests some information and a page that shows some error message if the action's input was invalid. If the fan-out of an action exceeds the maximum, we can assume that the clustering of its generated screens is too fine and coarsen the clustering, e.g., by merging clusters. If we assume that there is some typical fan-out value for an action, e.g., that it generates either a proper result or an error, we can also steer the clustering in a way that this value is approximated best. In the same way we can also assume that a page has a limited fan-in, i.e., a limit on the actions that generate it. Remember that a link is represented by an action, not a page, so that if a link is on many screens of a web application, the corresponding action has a high fan-in, but not the page. That two different actions generate the same conceptual page is rare but occurs; so a maximum on the fan-in of a page can be used to steer the clustering, too.

4.4. Statistical Testing of Refinements

We introduce statistical methods in order to refine an equivalence relation on screens. After running Revangie in the snoop mode, we have a set S of screens. Furthermore, we may find a certain criterion suitable for distinguishing conceptually different pages. A good criterion is, for example, the target usage frequency distribution of a page, i.e., the number of screens for each target in which the respective target was invoked by a user. It is a natural assumption that pages with different usage patterns are conceptually different, and therefore, we look for classifications that partition S into pages with different usage patterns well.

We might want to know, for example, if classification by screen titles helps to distinguish pages that are used differently. In terms of statistics, every screen has random variables $target$ and $title$, with $target$ being the action that was invoked from that screen. In order to determine if $title$

helps us to distinguish between different usages, we test if $target$ depends on $title$. If so, we refine our classification by intersecting with title identity. A standard method used for testing dependency of random variables is Pearson's chi-square [13].

4.5. Clustering with Significant Refinements

We introduce a clustering method that uses Pearson's chi-square test as described in Sect. 4.4. Algorithm 2 works the following way: procedure cluster gets as input a classification, i.e., an equivalence relation, on the set S of all screens. It iterates over different other equivalence relations B on S, like target identity or title identity, and conjoins the current classification A with B using operator $\wedge_*$.

Algorithm 2 Statistical clustering of screens.

```
1:  procedure CLUSTER(EQ_S A)
2:      for all B ∈ {targets id, title id, ...} do
3:          A ← A ∧_* B
4:      end for
5:  end procedure

6:  function ∧_*(EQ_S A, EQ_S B)
7:      Set P ← ∅
8:      for all Q ∈ S/A do
9:          Set R ← Q/B
10:         while ∃r1, r2 ∈ R.r1 ≠ r2 ∧ ¬χ²(r1, r2)* do
11:             R ← (R − {r1, r2}) ∪ {r1 ∪ r2}
12:         end while
13:         P ← P ∪ R
14:     end for
15:     return A' with S/A' = P
16: end function
```

The conjunction $\wedge_*$ does not work like ordinary conjunction as defined in Sect. 4. Before splitting up a page cluster in A, it tests if the split leads to conceptually different subclusters. That is, it may preserve certain parts of A that the ordinary conjunction would take away:

$$A \supseteq (A \wedge_* B) \supseteq (A \wedge B).$$

Let us consider now how $\wedge_*$ works. In the following we will use the terms equivalence class and cluster synonymously. In line 7 we initialize set P, which will eventually contain all the clusters of $A \wedge_* B$. In line 8 we split the set of all screens S up into clusters S/A by applying equivalence relation A and iterate over these clusters. Each of the clusters, in turn, is split up by equivalence relation B in line 9, and the resulting subclusters are stored in set R. In lines 10 to 12 we examine the clusters in R and merge those that do not differ significantly. Two distinct clusters r_1 and r_2 are merged if the random variable "cluster of the screen" with possible values $\{r_1, r_2\}$ depends on a random variable that can be reasonably assumed to distinguish conceptually different screens, like usage (see Sect. 4.4), for all screens in $r_1 \cup r_2$. If the χ^2-test does not signify dependence, $\neg\chi^2(r_1, r_2)^*$, we merge the two clusters of R. If no two clusters which fulfill the condition and could thus be merged are found in R, the while-loop terminates. Afterwards, the remaining clusters are added to set P.

If equivalence relation B proves useless for distinguishing conceptually different screens, all clusters in R are reunited and A is not refined. In that case, the clusters in P – which are those of $A \wedge_* B$ – will be the same as those created by A, so $S/A = P$. In line 15 we return the desired equivalence relation A', which is defined by the set of clusters in P, i.e., by $S/A' = P$.

4.6. Examples for Refinement and Coarsening

We identify two main motivations for reverse engineering a web application with Revangie: the creation of a model of the application itself for the purpose of product benchmarking [21] or re-engineering and the creation of a model of its users for the purpose of testing the application, esp. load testing. In the following we will, for each of the motivations, look at cases where refinement or coarsening of the model is desirable.

4.6.1. Reconstruction of an Application Model For the reconstruction of an application model there is not a single recipe for screen classification. Generally, classification by targets identity is a good starting point but usually either too fine or too coarse. Consider, for example, the dynamic pages of a content-managed information system like the portal of an online newspaper. The start page of the newspaper may contain summaries of the latest articles with links to them, and although many different screens are instances of this conceptual page, they may differ heavily in the links and therefore in their targets signature. In this case, a good choice for coarsening the classification might be form targets identity. On the other hand, there may be conceptually different pages with the same targets signature, e.g., a page in a web shop to view articles and a conceptually different one, although the same in targets identity, to view special offers. In such cases, it can be useful to conjoin another classification like, for example, title identity. For some systems it may be useful to readjust the classification for certain pages a-posteriori.

4.6.2. Reconstruction of a User Model Reconstruction of a user model requires that a sufficient amount of session data has been collected in the snoop mode. The first natural classification is that by targets identity because, in a user model, we want to distinguish pages by the way they are used. Furthermore, we can use the clustering technique de-

scribed in 4.5 with target choice or user response time as second random variable in order to determine a clustering that distinguishes screens with different user behavior well. Consequently, if screens are equivalent with respect to user behavior, they can be grouped in a common page, but classifications that group screens with different user behavior have to be refined.

5. Related Work

There are a couple of elaborated approaches [15, 11, 10, 9, 14, 1] that analyze source code to recover [3] a design or analysis model of the considered system. The motivation for these systems may range from pure system navigation visualization over maintainability support to the recovery of high-level architectural descriptions. Consider the tool presented in [11, 10, 9] as a representative example for this technology class. The tool analyses source code and pages of a web application and generates an architecture diagram that visualizes the interactions between static pages, active ASP or JSP pages and other software components by arrows. A similar support is offered by the tool WARE (Web Application Reverse Engineering) [14] for ASP and PHP based systems. Thereby, flat information about actual form parameters is recovered by this tool, too. A technique for recovering navigational structure and a conceptual model from a web application without tool support is described in [1].

VAQUISTA [20, 19] offers support for the static analysis of HTML pages. However, its goal is not to reverse engineer a whole web site but to reverse engineer the user interface from individual HTML pages in order to make them accessible from other contexts, i.e., device independency is targeted. An example for a tool that can track the change history of a web site is given in [2].

A tool for source-code independent analysis of web applications is ReWeb [16, 18]. An early version of ReWeb was able to recover a navigational model of a completely static web site. However, already in this early contribution the possibility to recover models for dynamic web pages solely by analyzing the generated HTML code has been envisioned. In [18] there is an outline of the new ReWeb features for the analysis of dynamic web sites. ReWeb is different from Revangie with respect to motivation, input simulation, server action classification, and notions of screen classifications. The motivation for the dynamic features of ReWeb is regression testing in web site evolution scenarios. ReWeb works similar to our crawl mode, but input values must be given before it is started. This means that an initial knowledge of the system is required already before ReWeb can be fully utilized. However, the choice of values can be challenging because inappropriate values can lead to partial models or duplicate pages in the model. ReWeb draws a distinction between implicit and explicit state models. The explicit state model regards each invocation of a CGI program with new values as a new server action. The Revangie state model is rather an implicit state model in the sense of ReWeb. The explicit type model has a couple of flaws: interaction state cannot necessarily be distinguished through hidden parameters because recovered hidden parameter values may loose their validity over time. When ReWeb is used on a web application, hidden parameters that are generated by the system are not propagated properly but overwritten by the ones in the explicit model, which may cause dynamic errors. The distinction of actions according to hidden parameters will lead to bloated models if hidden parameters are used for session management. ReWeb offers three notions of classification for grouping screens: textual identity, syntactical identity, and identity with respect to similarity metrics. Syntactical identity groups screens that have identical abstract syntax trees, i.e., that are equal up to textual content of tags. However, we feel syntactical identity is not the appropriate generalization of textual identity: consider the insertion of a new row into a table, which causes the resulting screens to be different with respect to syntactical identity, although they might very well be instances of the same conceptual page. In this important example, syntactical identity is no improvement on textual identity. However, the example can be dealt with very elegantly by means of syntactical pattern identity.

6. Further Directions

Once an adequate model for a web site is reconstructed, it may be desirable to extract certain features in order to make it clearer or facilitate subsequent redesign. Like many other software systems, also web sites usually contain aspects, i.e., parts that cross-cut the general structure. A common example for aspects in web applications are menus, which are important for the navigation on a web site, and it is possible to extract such features from the recovered model automatically. For example, forms and links that occur on several pages can be extracted and modeled separately with so called state sets, thereby making changes much easier and allowing users to view parts of the system independently of the whole without disturbing its general structure. For an account on how this can be done using form-oriented analysis see [6].

Furthermore, we are about to implement Angil – a tool that uses the models created by Revangie in order to perform realistic load testing of web applications. The models used by Angil are annotated by additional data about typical user behavior, like transition probabilities and user response times. This data can be collected by Revangie in the snoop mode.

7. Conclusion

The tool Revangie builds a form-oriented analysis model solely from the usage of a web application. The recovered models can be, for example, exploited for the purpose of requirements engineering and load test development. Revangie can explore a given web application fully automatically or can passively record its usages. The collected data, i.e., data about screens, server-side programs, and system responsiveness, are analyzed in order to build a user interface model. The paper presented several adequate screen classifications, which are utilized to reconstruct significant models. Revangie is built on solid theoretical grounds and offers robust solutions to common problems. An implementation of the Revangie tool and a real-world example for its usage can be found on the project website at `www.revangie.formcharts.org`.

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