ATOM: Automatic Maintenance of GUI Test Scripts for Evolving Mobile Applications

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***Abstract*—The importance of regression testing in assuring the integrity of a program after changes is well recognized. One major obstacle in practicing regression testing is in maintaining tests that become obsolete due to evolved program behavior or specification. For mobile apps, the problem of maintaining obsolete GUI test scripts for regression testing is even more pressing. Mobile apps rely heavily on the correct functioning of their GUIs to compete on the market and provide good user experiences. But on the one hand, GUI tests break easily when changes happen to the GUI; On the other hand, mobile app developers often need to fight for a tight feedback loop and release often, resulting in a tight schedule for test maintenance.**

In this paper, we propose a novel approach, called ATOM, to automatically maintain GUI test scripts of mobile apps for regression testing. ATOM uses an event sequence model to abstract possible event sequences on a GUI and a delta ESM to abstract the changes made to the GUI. Given both models as input, ATOM automatically maintains the test scripts written for a base version app to reflect the changes. In an experiment with 11 commercial Android apps, ATOM maintained all the test scripts affected by the version change; the updated scripts achieve over 80% of the coverage by the original scripts on the base version app; all except one set of updated scripts preserve over 60% of the actions in the original test scripts.

I. Introduction

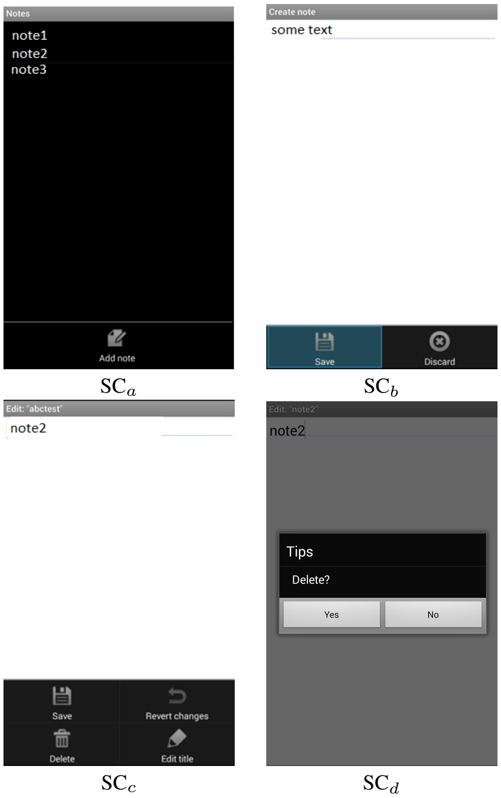
Modern software development practices like continuous integration often have regular and frequent regression testing as an integrated part to ensure that changes to a program do not break existing functionality. For regression testing to be effective and efficient, the tests need to be updated to reflect the evolved program behavior or specification. Such maintenance of regression tests, however, is expensive, largely because it often requires manual effort. Sometimes the cost is so high that engineers would rather write new tests than to update the old ones [1].

With the ever growing popularity of mobile devices, mobile applications, or apps, are becoming indispensable in our personal lives and at work. They pose new challenges to regression testing. On the one hand, regression testing is likely more important for mobile app development than for, e.g., most desktop applications. Due to fierce competition on the market, mobile app developers tend to fight for a tight feedback loop and release more often. Effective and efficient regression testing can greatly help improve the quality of mobile apps under such circumstances. On the other hand, most mobile apps interact with users through rich graphical user interfaces (GUIs), making GUI testing an essential part of the regression testing of apps. Because GUI test scripts often refer to exact sequences of actions to be performed on specific GUI widgets, they are highly sensitive to changes in the structure or workflow of the application GUI. In practice, many GUI test scripts may become obsolete after only small changes to the GUI. The high cost of manual GUI test script maintenance renders frequent regression testing much less desirable, if not impractical.

Techniques have been developed in recent years to automatically generate test scripts for mobile apps [2]–[4]. Such techniques can be used to help alleviate the maintenance problem of test scripts, but they do not outdate the requirements for maintaining GUI test scripts. First, regression test scripts often contain manually created or customized scripts that incorporate valuable expert knowledge about the application domain and are less likely to be generated automatically. Throwing away such scripts is not desirable in many cases. Second, generating enough test scripts to achieve high coverage of the code in testing is an demanding task. Always generating new test scripts for each regression testing can be prohibitively expensive.

Researchers have proposed different techniques to repair such obsolete GUI test scripts for regression testing. For example, Memon [5] present Regression Tester that uses dynamic analysis to extract an event-flow graph (EFG) to model possible event sequences that may be executed on a GUI, and repairs obsolete test scripts based on the EFG using four user-defined transformations. Due to the inherent limitations in dynamic analysis techniques and EFM models, the technique, however, does not directly apply to manually scripted test cases [6]. Gao et al. [6] present the SITAR system to *interactively* repair obsolete low level test scripts. SITAR does this by mapping low level test scripts to an EFG model for the GUI, repairing the model-level test cases, and then synthesizing low level test scripts again. If a test script action cannot be mapped to the model, e.g., due to the incompleteness of the model, user input is required. SITAR constructs the EFG in the same way as Regression Tester. A more detailed review of techniques for test script repair is included in Section V-D.

In this paper, we propose a novel approach, called ATOM,



SC_a SC_b SC_c SC_d

Fig. 1: Three screens and their corresponding menu items in the NotePad app.

to automatically maintain GUI test scripts of mobile apps for regression testing. ATOM uses an event sequence model (ESM) to abstract possible event sequences in a GUI and an delta ESM (DESM) to abstract the changes made to a GUI. Given the ESM for a base version of the app and the DESM for the changes introduced in an updated version, ATOM automatically maintains the test scripts written for the base version app. ATOM achieves this by first computing the simulations of test scripts on the model, then maintaining simulations to accommodate changes, and in the end synthesizing test scripts based on the updated simulations. Unlike SITAR, ATOM automatically searches for alternatives maps when a test action does not have a direct map in the updated model. After the maintenance, the scripts are able to test most remaining parts of the app in the updated version and preserve most of the actions.

The input models needed by ATOM may be constructed manually or through automatic mechanisms. We consider the overhead of model construction is acceptable, even when it is done manually, for two reasons. First, an ESM or DESM has a direct connection with its corresponding app or apps, making model construction a fairly straightforward task. Second, the construction of an ESM is only needed when ATOM is applied for the first time to the app. In subsequent uses, only DESMs for the changes need to be built. As differences between two versions of an app that go through adjacent regression testing are often small, they are easy to model. During test script maintenance, ATOM also merges the input ESM and DESM to produce an ESM for the updated version app. Such ESM can be used as input for the next use of ATOM.

We have implemented the approach into a tool, also called ATOM, to automatically maintain test scripts for Android apps. We applied ATOM on 11 commercial apps from a Chinese Android Market to maintain their test scripts from one version to another. As the result, ATOM was able to maintain all the test scripts affected by the version change; the updated scripts achieve over 80% of the coverage by the original scripts on the base version app; all except one set of updated scripts preserve over 60% of the actions in the original test scripts.

The remainder of this paper is organized as follows: Section II illustrates ATOM from a user's perspective using an example mobile app. Section III describes the individual steps of our approach. Section IV reports on the experiment we conducted to evaluate the effectiveness of ATOM. Section V reviews related work in GUI testing for mobile apps. Section VI concludes the paper and presents future work.

II. A ATOM EXAMPLE

In this section, we use a simple Android App named NotePad to demonstrate from a user's perspective how ATOM can be used to automatically maintain GUI test scripts during the evolution of mobile applications.

NotePad provides basic functionalities for note taking, and it is a sample app shipped with the Android SDK[1]. Figure 1 shows three screens from the GUI of NotePad and, on the bottom of each screen, the corresponding menu a user can call up by pressing the Menu physical key. Henceforth, we refer to a widget simply by the text on it when the meaning is clear from the context.

SC_a is the initial screen when NotePad is launched in a typical scenario, with previously saved notes listed. A user can click on Add note on this screen to create a new note and start editing that note on screen SC_b. On SC_b, once the editing is done the user may opt to Save or Discard the changes by clicking on the corresponding menu item and return back to SC_a. A user can also click on a note item on SC_a and open the note for editing on SC_c. Later on, the user can Save the changes, Revert changes, Delete the note, or Edit the title of the note. We refer to this implementation of NotePad as Version 1.0.

Figure 2(a) shows three test scripts written in Robot Framework[2] and Appium[3] for testing the Version 1.0 of NotePad. Each script defines a sequence of actions to be taken during the test, one action per line. All the three test scripts here start execution from SC_a. TS_1 first creates a new note, then inputs some text, and at the end saves the input. TS_2 is similar as TS_1, but the changes are discarded at the end. TS_3 assumes the presence of a note item named note1. It first opens the note by clicking on the note item, then clicks on Delete to

[1] https://developer.android.com/studio/index.html
[2] http://robotframework.org/
[3] http://appium.io/

```
TS1
Press Keycode MENU
Click Element name=Add note
Input Text id=some text
Press Keycode MENU
Click Element name=Save

TS2
Press Keycode MENU
Click Element name=Add note
Input Text id=some text
Press Keycode MENU
Click Element name=Discard

TS3
Click Element name=note1
Press Keycode MENU
Click Element name=Delete
```

(a) Version 1.0

```
TS1
Press Keycode MENU
Click Element name=Add
Input Text id=some text
Press Keycode MENU
Click Element name=Save

TS2
Press Keycode MENU
Click Element name=Add
Input Text id=some text

TS3
Click Element name=note1
Press Keycode MENU
Click Element name=Delete
Click Element name=Yes
```

(b) Version 2.0

Fig. 2: Test Scripts for NotePad

remove the note. We say a test script runs successfully if all its actions can be performed without causing any error, or fails if otherwise. On Version 1.0 of NotePad, all the test scripts run successfully.

We then modify the GUI of NotePad to produce its next version, mimicking what might happen to an app during its life cycle. The modifications include the following. First, the Add note menu button on SC$_b$ is changed to Add; Second, a confirmation modal dialog[4] with Yes and No buttons is added after Delete is clicked on SC$_c$; Third, the Discard menu item is removed from SC$_c$. We refer to this modified implementation of NotePad as Version 2.0.

Under such changes, some of the original test scripts are now broken, i.e., they do not describe acceptable action sequences by the application. In our example, TS$_1$ and TS$_2$ will both fail as SC$_a$ no longer has the menu item Add note; although TS$_3$ will not fail, it does not really delete the note either.

Taken both versions 1.0 and 2.0 of NotePad, a model describing the feasible event sequences in Version 1.0, and other information like the changes introduced by Version 2.0 as the input, ATOM then automatically evolves the existing test scripts to stay in sync with the application. During the process, ATOM preserves the actions when possible, updates them when necessary, and extends the action sequences to test new behaviors of the system. Figure 2(b) shows the result test scripts produced by ATOM, with added and modified actions highlighted. TS$_1$ is updated to reflect the change of menu item name from Add note to Add; Besides of being updated in the same way as in TS$_1$, TS$_2$ is also truncated, with infeasible events removed from the script; TS$_3$ is extended with the action of clicking on the Yes button on the confirmation dialog, and therefore successfully deletes the note test.

III. How Atom Works

Let us now describe the detailed steps in applying ATOM to maintain GUI test scripts when an app evolves from a previous version to a new version. Figure 3 summarizes the individual steps during the process.

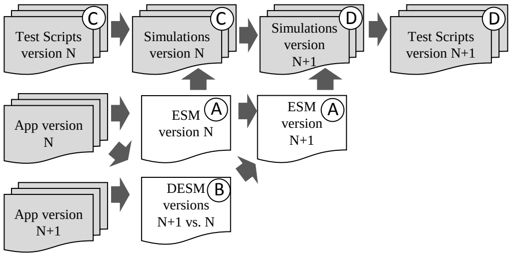


Fig. 3: Process of the ATOM Approach.

A. Event Sequence Model

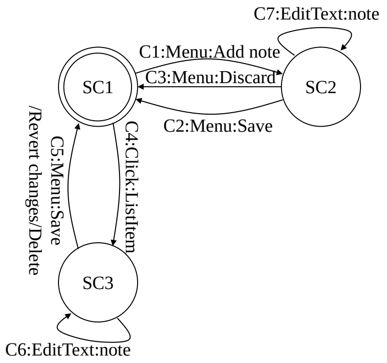


Fig. 4: Partial ESMs for Notepad versions 1.0 (ESM$_1$). SC$_1$ is the initial screen. Labels on transitions give the corresponding event types and widget names.

To achieve automatic maintenance of the test scripts, ATOM makes use of event sequence models (ESMs) to describe the behaviors of an app. To be both powerful enough to support test script maintenance and simple enough to facilitate manual or automatic construction, an ESM leaves out information about the internal states of an app (e.g., variables) and focuses on the GUI elements like widgets and screens as well as events on them.

Formally, let $\boldsymbol{W}$ be the set of widgets in an app and $\boldsymbol{E}$ the set of event types on $\boldsymbol{W}$, the ESM for the app is a deterministic finite state machine $\mathcal{M} = <\Sigma, \boldsymbol{S}, \{s_0\}, \boldsymbol{C}, \boldsymbol{F}>$, where

- $\Sigma = \boldsymbol{W} \times \boldsymbol{E}$ is the set of events in the app;
- $\boldsymbol{S} \subseteq 2^{\boldsymbol{W}} (s_i \cap s_j = \emptyset, \forall s_i \in \boldsymbol{S}, s_j \in \boldsymbol{S}, i \neq j)$ is the set of screens in the app;
- $s_0 \in \boldsymbol{S}$ is the initial screen;
- $\boldsymbol{C} \subseteq \boldsymbol{S} \times \Sigma \times \boldsymbol{S}$ is a set of *connection*s between states. Given a connection $c = <s_1, \sigma, s_2> \in \boldsymbol{C}$, we call s_1, σ, and s_2 the *source*, the *cause*, and the *destination* of the connection, respectively.
- $\boldsymbol{F} = \boldsymbol{S}$ is the set of final screens.

[4] A modal dialog is a dialog that disables the rest of the application. A user must interact with the dialog before they can go back to the parent application

In everyday use, an event may transit an app from one screen to different others based on the specific program state when the event was triggered. For example, depending on whether a mobile device is connected to the Internet through WIFI or not, a click on a link may cause the link to be opened on a new screen or a dialog to pop up to let you decide whether the link should be opened at all. The nondeterminism of the model is to reflect such possibility.

The model does not distinguish a particular set of screens as final, as a script may stop execution at any screen during testing. For example, a partial ESM for the three screens SC_1, SC_2, and SC_3 in Figure 1 is shown in Figure 4. Here Σ includes editing and clicking events on various text fields and buttons, $\boldsymbol{S} = \{\mathrm{SC}_1, \mathrm{SC}_2, \mathrm{SC}_3\}$, s_0 is the initial screen, and each connection is labeled with its ID, the event type, and widget ID.

A non-empty sequence $\epsilon = c_0c_1 \dots c_n$ ($n \geq 0$, $c_i \in \boldsymbol{C}$, $0 \leq i \leq n$) of connections is called a *path* on ESM $\mathcal{M}$, if the destination of c_j is equal to the source of c_{j+1} for all $0 \leq j < n$. And it is called a *run* of the model, denoted as $\mathcal{M} \models \epsilon$, if it also starts from the initial screen of $\mathcal{M}$. Runs of a model capture important event sequences that can be triggered on the app's GUI. For example, the sequence of connection $c_1c_7c_2$ in ESM_1 forms a run and indicates that, a click on Add note on SC_1 will bring a user to SC_2, where multiple editing events are possible without causing any screen transition; A click on Save, however, will bring the user back to SC_1.

The connection between a mobile App and its ESM is straightforward, making the model suitable to be automatically extracted from the application source code. If the model is not available already, the construction of the whole ESM is only necessary when ATOM is applied to an app for the first time. This is because, when using ATOM, the model is incrementally maintained together with the test scripts (see Section III-B) and is suitable for use in the next maintenance.

In our experimental evaluation (see Section IV), we manually created the ESMs for the subject apps. Another viable way is to first use tools like GUI Ripper [7] to build an initial model and then adjust that model to meet the requirement of ATOM. The construction of an automatic ESM extraction tool belongs to the future work.

B. Changes as a Delta-ESM

Many different reasons may cause test scripts to break during the evolution of an app from a previous version to a new one. In this work, we focus on cases where the reason is in changes to the GUI of the app. We model the changes by following a similar idea as described in Section III-A and construct a delta ESM (DESM). A DESM specifies all the changes to the connections of an ESM as well as the involved screens. Given an ESM $\mathcal{M} = {<}\Sigma, \boldsymbol{S}, \{s_0\}, \boldsymbol{C}, \boldsymbol{F}{>}$, a delta-ESM $\Delta_{\mathcal{M}}$ relevant to $\mathcal{M}$ is a septuple ${<}\Sigma_\triangle, \boldsymbol{S}_\triangle, \emptyset, \boldsymbol{C}_\triangle, \emptyset, \boldsymbol{l}, \boldsymbol{r}{>}$, where ${<}\Sigma_\triangle, \boldsymbol{S}_\triangle, \emptyset, \boldsymbol{C}_\triangle, \emptyset{>}$ is also a finite state machine similar to an ESM but with no initial or final screen; $\boldsymbol{C}_\triangle$ is the set of all changed connections with respect to $\boldsymbol{C}$; $\boldsymbol{l} : \boldsymbol{C}_\triangle \rightarrow Bool$ is a total function and it partitions $\boldsymbol{C}_\triangle$ into two groups: the set $\boldsymbol{C}_+$ of connections producing $true$ values are newly introduced by the changes, and the set $\boldsymbol{C}_-$ producing $false$ are those to be removed; A modification to a connection is modeled in a DESM as two *related* changes, one deleting the original connection and the other adding the modified. $\boldsymbol{r} : \boldsymbol{C}_- \rightarrow \boldsymbol{C}_+$ is a partial function, it maps every connection deletion to its related addition, when applicable; Screens associated with at least one of the changed transitions constitute $\boldsymbol{S}_\triangle$. Consider for example the changes to NotePad Version 1.0, as described in Section II, they can be depicted by the finite state diagram shown in Figure 5. Edges in solid line model added connections, and those in dotted line model deleted ones.

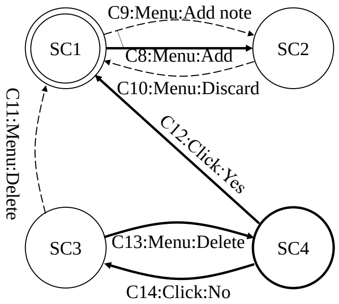


Fig. 5: A delta-ESM modeling the changes to NotePad Version 1.0.

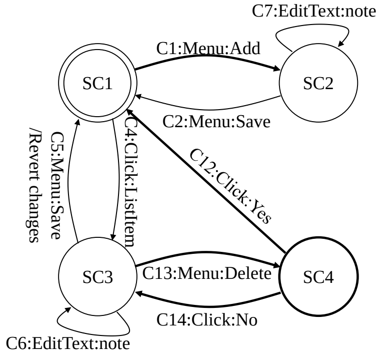


Fig. 6: Partial event sequence models for Notepad versions 2.0 (ESM_2).

An DESM captures the changes introduced by the new version to an app, relative to a previous version. Such info is valuable in both understanding the impact of the changes on test scripts and devising adjustments to the test scripts to accommodate the changes.

Once we have the ESM $\mathcal{M} = {<}\Sigma, \boldsymbol{S}, \{s_0\}, \boldsymbol{C}, \Sigma{>}$ modeling the behaviors of a previous version app and a DESM $\Delta_{\mathcal{M}} = {<}\Sigma_\triangle, \boldsymbol{S}_\triangle, \emptyset, \boldsymbol{C}_\triangle, \emptyset, \boldsymbol{l}{>}$ capturing the changes made to them, we can easily *merge* (we use $\bigoplus$ to denote the operation) the two and construct the ESM for the new version app. The new ESM can be computed as $\mathcal{M} \bigoplus \Delta_{\mathcal{M}} = {<}\Sigma \cup \Sigma_\triangle, \boldsymbol{S} \cup \boldsymbol{S}_\triangle, \{s_0\}, \delta \cup \boldsymbol{C}_+ - \boldsymbol{C}_-, \Sigma \cup \Sigma_\triangle{>}$. Note that in this process, connections from $\boldsymbol{C}_-$ first get their IDs from their matches in $\mathcal{M}$ and then pass on the IDs to their related connections in $\boldsymbol{C}_+$. Therefore, modified connections will preserve their IDs in the new model.

C. Test Scripts and Their Simulations

A test script describes a sequence of actions to be taken to exercise an app during testing. Each action has a type and a target descriptor: the type specifies the nature of the action, e.g. whether it is to click an element or to input some text; the target descriptor describes the widget on which the action is performed. The execution of a test script generates a sequence of events on the GUI of the app, which can be used to simulate its run on the ESM of the app.

In ATOM, the correspondence between ESM events and test script actions is defined in the form of mapping relation in configuration files. In this way, we can easily use higher level events in ESMs to keep the models small. For example, instead of using two low level events of pressing the Menu physical button and pressing on the Save menu item that directly match test script actions, an ESM can use just one higher level event clicking the Save menu item. Such design also makes it easy to extend ATOM to handle test scripts in other syntaxes.

Formally, let $\boldsymbol{T}$ be the set of action types and $\boldsymbol{D}$ the set of target descriptors, the set of possible actions is then $\boldsymbol{A} \subseteq \boldsymbol{T} \times \boldsymbol{D}$. Given an ESM $\mathcal{M} = <\Sigma, \boldsymbol{S}, \{s_0\}, \delta, \boldsymbol{F}>$, a test script $\boldsymbol{K} = k_0 k_1 \ldots k_h$ ($h \geq 0, k_i \in \boldsymbol{A}$ for $0 \leq i \leq h$), and a mapping relation $\boldsymbol{R} : \boldsymbol{A} \times \Sigma$, we can easily find a sequence of events $\boldsymbol{R}(\boldsymbol{K})$ on $\mathcal{M}$ by repeatedly applying $\boldsymbol{R}$ to actions in $\boldsymbol{K}$. Using $\boldsymbol{R}(\boldsymbol{K})$ we can derive a run $\boldsymbol{P}$ on $\mathcal{M}$ that models the intended execution of $\boldsymbol{K}$. We call $\boldsymbol{P}$ the simulation of $\boldsymbol{K}$ on $\mathcal{M}$. Nondeterminism in $\mathcal{M}$ can be resolved by human input or knowledge about the actual execution trace of $\boldsymbol{K}$ on the app.

D. Test Script Maintenance

The maintenance of test scripts is done in two phases based on simulations of test scripts. In the first phase, by comparing the simulation of a test script on an ESM and the changes made to that model in an DESM, ATOM first identifies how the changes affect the simulation, then synthesizes a new simulation that is in line with the changes based on the old one. In the second phase, causes, i.e., events, of the connections from the new simulation are collected and mapped to test script actions according to the mapping relation $\boldsymbol{R}^{-1}$ between GUI events and script actions from Section III-C.

Algorithm 1 shows detailed steps in the first phase. The algorithm takes as input the ESM $\mathcal{M}$ for the previous version of app, the DESM Δ of the new version with respect to $\mathcal{M}$, and the simulation $\boldsymbol{P}$ of a test script on $\mathcal{M}$, and outputs the updated simulation $\boldsymbol{P'}$. First, $\mathcal{M}$ and Δ are merged to produce the updated ESM $\mathcal{M}'$ for the new version (line 2). Then, the algorithm iterates through the simulation $\boldsymbol{P}$ and updates every event in order (lines 3 through 50). Particularly, if an event p_i is not affected by the change (line 6), it is appended to the result simulation directly (line 7 through 9); Or, if p_i is modified (line 10), then the modified connection is appended to the result simulation (lines 11 through 13).

Otherwise, p_i is changed in other ways or deleted in the new version, and the paths before and after p_i are now disconnected. The algorithm constructs an alternative path to reconnect them by finding an intermediate state $interState$ that is connected to both paths. Three different cases are considered here. Let e be the cause of p_i. First, if e transits the source of p_i to another state in $\mathcal{M}'$ (line 16), then this new destination state is used as the $interState$, and the algorithm exploits a broad first search to find a path from $interState$ to the original destination of p_i. The search is restricted to paths no longer than $MaxPathLength$ to keep the cost low and the alternative paths easier to understand, and the first hit, if any, will be appended together with the connection between the source of p_i and $interState$ to the result simulation. Then the iteration proceeds to the next connection (lines 17 through 24). Second, if e transits in $\mathcal{M}'$ another $preState$ to p_i's destination (line 25), then the algorithm tries to construct an alternative path connecting the source and destination of p_i through $preState$ in a similar way as described in the previous case (lines 26 through 33); Third, if e is not associated with either the source or destination of p_i, the algorithm searches for a short path connecting p_i's source state with any state from the path starting from p_i's destination, with the hope to preserve as many original connections as possible (lines 35 through 47). If such effort fails, the simulation is truncated (line 48).

IV. EVALUATION

To empirically evaluate the *effectiveness* of ATOM in test scripts maintenance we have conducted experiments that applied ATOM to several production mobile apps. This section reports on the experiments and provides some preliminary assessment of the approach.

A. ATOM *Implementation*

In its current implementation, ATOM automatically maintains scripts that are based on the Robot Framework to test the GUI of Android apps. The Robot Framework is a generic, keyword-driven, test automation framework. In ATOM, it uses the Appium open source test automation framework to drive the Android app under testing and it communicates with Appium through the AppiumLibrary. Our approach, however, is not limited to any specific testing framework. Support for other testing frameworks can be easily added by defining the necessary mapping between test script actions and ESM connections.

All the experiments ran on a Windows 8 machine with 3.1 GHz Intel dual-core CPU and 8 GB of memory. ATOM was the only computationally-intensive process running during the experiments.

B. Measures

One goal of ATOM is to assist test script maintenance so that the confidence provided by the test scripts in the correctness of

Algorithm 1 Maintaining an ESM Path

```
Input: $\mathcal{M} = <\Sigma, \boldsymbol{S}, \{s_0\}, \boldsymbol{C}, \boldsymbol{F}>$,
       $\Delta_{\mathcal{M}} = <\Sigma_\Delta, \boldsymbol{S}_\Delta, \emptyset, \boldsymbol{C}_+ \cup \boldsymbol{C}_-, \emptyset, \boldsymbol{l}, \boldsymbol{r}>$,
       $\boldsymbol{P} = p_0 p_1 \ldots p_l \ (0 \leq l)$ on $\mathcal{M}$
Output: Path $\boldsymbol{P'}$ on $\mathcal{M} \bigoplus \Delta_{\mathcal{M}}$

$\boldsymbol{P'} \leftarrow []$
$\boldsymbol{S'} = \boldsymbol{S} \cup \boldsymbol{S}_\Delta$, $\boldsymbol{C'} \leftarrow \boldsymbol{C} \cup \boldsymbol{C}_+ - \boldsymbol{C}_-$
$i \leftarrow 0$, $srcState \leftarrow s_0$
while $i \leq l$ do
    $destState \leftarrow p_i.destination$
    if $p_i \notin \boldsymbol{C}_-$ then                          ▷ $p_i$ not affected
        $\boldsymbol{P'} \leftarrow$ CONCAT($\boldsymbol{P'}, [p_i]$)
        $srcState \leftarrow destState, i \leftarrow i + 1$
        continue
    else if $\boldsymbol{r}(p_i) \neq$ null then                      ▷ $p_i$ modified
        $\boldsymbol{P'} \leftarrow$ CONCAT($\boldsymbol{P'}, [\boldsymbol{r}(p_i)]$)
        $srcState \leftarrow destState, i \leftarrow i + 1$
        continue
    end if
    $e \leftarrow p_i.cause$                 ▷ $p_i$ otherwise changed or deleted
    if POSTSTATE($\mathcal{M'}, srcState, e$) $\neq$ null then
        $interState \leftarrow$ POSTSTATE($\mathcal{M'}, srcState, e$)
        $path \leftarrow$ SHORTESTPATH($\mathcal{M'}, interState, destState$)
        if $path \neq$ null then
            $c \leftarrow$ CONNECTION($\mathcal{M'}, srcState, e, interState$)
            $\boldsymbol{P'} \leftarrow$ CONCAT(CONCAT($\boldsymbol{P'}$, [c]), $path$)
            $srcState \leftarrow destState, i \leftarrow i + 1$
            continue
        end if
    else if PRESTATE($\mathcal{M'}, e, destState$) $\neq$ null then
        $interState \leftarrow$ PRESTATE($\mathcal{M'}, p_i, destState$)
        $path \leftarrow$ SHORTESTPATH($\mathcal{M'}, srcState, interState$)
        if $path \neq$ null then
            $c \leftarrow$ CONNECTION($\mathcal{M'}, interState, e, destState$)
            $\boldsymbol{P'} \leftarrow$ CONCAT(CONCAT($\boldsymbol{P'}, path$), [c])
            $srcState \leftarrow destState, i \leftarrow i + 1$
            continue
        end if
    else
        $hasFound \leftarrow$ false
        for $j \leftarrow i + 1, l$ do
            $interState \leftarrow p_j.source$
            $path \leftarrow$ SHORTESTPATH($\mathcal{M'}, srcState, interState$)
            if $path \neq$ null then
                $\boldsymbol{P'} \leftarrow$ CONCAT($\boldsymbol{P'}, path$)
                $srcState \leftarrow interState$
                $i \leftarrow j, hasFound \leftarrow$ true
                break
            else
                $j \leftarrow j + 1$
            end if
        end for
        if not $hasFound$ then $i \leftarrow l + 1$ end
    end if
end while

return $\boldsymbol{P'}$
CONCAT($path_1$, $path_2$)          ▷ The concatenation of $path_1$ and $path_2$
SHORTESTPATH($\mathcal{M}, srcState, destState$)      ▷ The shortest path from
    ▷ $srcState$ to $destState$ on $\mathcal{M}$: shorter than MaxPathLength, or null
PRESTATE($\mathcal{M}, e, destState$)                  ▷ The state $s$ in $\mathcal{M}$ such that
                                ▷ $<s, e, destState>$ is a connection in $\mathcal{M}$, or null
POSTSTATE($\mathcal{M}, srcState, e$)                  ▷ The state $s$ in $\mathcal{M}$ such that
                                ▷ $<srcState, e, s>$ is a connection in $\mathcal{M}$, or null
CONNECTION($\mathcal{M}, srcState, e, destState$)               ▷ The connection
                      ▷ in $\mathcal{M}$ from $srcState$ to $destState$, with cause $e$
MaxEditDistance $\leftarrow 10$
MaxPathLength $\leftarrow 2$
```

the app, in terms of the coverage of screens and connections in ESMs, could be preserved as much as possible after the maintenance. A good coverage of the models by the updated test scripts, however, is not enough by itself. Such scripts, e.g., when produced by an automatic generation process, may exercise very different behaviors of the app than those exercised by the original test scripts, which incorporate valuable knowledge about the application. Therefore, in addition to expecting the updated test scripts to cover comparable percentage of the ESMs as before maintenance, we also prefer update scripts to retain most of the action sequences from the previous test scripts. We adopt two metrics accordingly to measure the effectiveness of the maintenance process.

Formally, let $\boldsymbol{S}_c$ be the set of screens that the updated ESM shares with the base ESM, $\boldsymbol{S}_v$ the set of screens visited by the original test scripts, and $\boldsymbol{S}'_v$ the set of screens visited by the updated test scripts. The *screen coverage preservation* (SCP), calculated as $|\boldsymbol{S}'_v \cap \boldsymbol{S}_c| / |\boldsymbol{S}_v \cap \boldsymbol{S}_c|$, measures, among all the screens the updated ESM get from the base ESM, how many percent of previously covered screens are still covered by the tests after maintenance. Understandably, the larger the screen coverage preservation the better and a value larger than 1 indicates the coverage is actually increasing after the maintenance. The increase may happen, e.g., when the alternative path found for a deleted connection visits other screens that were not visited by the existing test scripts. Similarly, we can define the *connection coverage preservation* (CCP) to measure the percentage of connections visited by the updated test scripts in all the connections the base version ESM has.

Let $\boldsymbol{A}_t$ be the set of all test actions from the base version test scripts, $\boldsymbol{A}_e \subseteq \boldsymbol{A}_t$ the set of effective test actions that will be exercised if the base test scripts are run directly on the updated app, and $\boldsymbol{A}'_e$ the set of test actions that are executed by the maintained test scripts. The *test action preservation* (TAP), calculated as $|(\boldsymbol{A}'_e - \boldsymbol{A}_e) \cap \boldsymbol{A}_t| / |\boldsymbol{A}_t - \boldsymbol{A}_e|$, measures, among all the test actions that would be lost if without maintenance, how many percent are now rescued into the updated tests.

Based on the measures, we devise our experiments to answer the following two research questions:

- **RQ1**: Does using ATOM lead to maintained test scripts with high screen and connection coverage preservation?
- **RQ2**: Does using ATOM lead to maintained test scripts with high test action preservation?

C. Subjects

We select as the experiment subjects 11 popular mobile apps from the Chinese Android market. Table I lists all the apps and briefly describes each app. Even though we deliberately select apps with various sizes and from different categories, they can hardly represent the wide range of all apps. The selection of subjects presents threats to the generalizability of our results, which we discuss in Section IV-F.

For each app, we randomly pick two adjacent releases that we can download from the market, and treat the earlier release as the base version, while the later one as the updated version. By reading the change log as well as actually playing with

TABLE I: Introduction of Mobile Applications for Evaluation

App (Acronym)	Brief Description
Bilibili (BB)	A video sharing website.
GNotes (GN)	A simple note app.
Wannianli (WN)	A calendar app.
YoudaoNote (YD)	A cloud-based note app.
Wechat Phonebook (PB)	A phonebook app.
Changba (CB)	A Karaoke app.
Baidu Music (BD)	A music player.
365 Calendar (CA)	A calendar app.
Ctrip (TR)	An online travel agent.
WizNote (WZ)	A cloud-based information management app.
TickTick (TT)	A to-do list app.

the apps, we identify for each app a list of changes to their GUI. We then asked a group of three graduate students to manually build an ESM for parts of each app that are affected by the changes. To ensure the correctness of the model, we trained the students using the NotePad app from Section II as an example and asked another student to review the models. In this step, we get a partial ESM for each of the 11 apps. Even though the models are incomplete, they are already useful in test script maintenance, as shown by the results presented in Section IV-E. This also speaks in favor for the usability of ATOM. The same group of students then constructed the DESM for each app based on the changes.

Table II lists, for each app, the base version (Base), the updated version (Updated). For each ESM of the base version, the number of screens (#S) and connections (#C) in the model are listed; For each DESM, the numbers of added (#S$_{+}$) and deleted (#S$_{-}$) screens as well as the numbers of added (#C$_{+}$), deleted (#C$_{-}$), and modified (#C$_{M}$) connections are also included in the table. In total,

We also asked another group of four graduate students to write test scripts for the apps. Table III reports on each app the total number of scripts (#K) as well as the minimum (Min), maximum (Max), average (Avg), and total (Sum) number of actions in a single script. As a measure of the quality, we also report in the table on the coverage of screens (S) and connections (C) by each set of test scripts (Cov). In total, we have XXX scripts

The focus of ATOM is to help maintain the test scripts that become broken after changes happen to an app. To avoid the influence of test scripts that were not impacted by the changes, we first run all the test scripts on the updated apps to identify the ones that need maintenance. Table III also lists for each app the number of test scripts affected by the changes (K$_{a}$), and the same statistics for the affected script files as those for all the scripts in the same table, including the minimum (Min$_{a}$), maximum (Max$_{a}$), average (Avg$_{a}$), and total (Sum$_{a}$) number of actions in a single script. The number of changed test script actions (#Chg) and the breakdown into the numbers of deleted (Del) and modified (Mod) actions are also included in the table.

In the experiment, we consider only the affected scripts.

TABLE IV: Experimental results.

APP	SCP	CCP	TAP
Bilibili	1(7/7)	1(11/11)	0.26(35/134)
GNotes	0.93(14/15)	1(23/23)	0.87(138/159)
Wannianli	1(13/13)	1(36/36)	0.95(91/96)
YoudaoNote	0.94(17/18)	1(31/31)	0.91(116/128)
Wechat Phonebook	0.85(11/13)	0.91(21/23)	0.95(37/39)
Changba	1(9/9)	1.06(19/18)	0.74(97/131)
Baidu Music	1(12/12)	1(25/25)	0.90(79/88)
365 Calendar	0.85(9/11)	0.88(22/25)	0.65(31/48)
Ctrip	0.92(12/13)	0.91(19/21)	0.96(50/52)
WizNote	1(12/12)	1.05(22/21)	0.93(82/88)
TickTick	0.92(11/12)	1(17/17)	0.73(16/22)
Total:	0.94(127/135)	0.98(246/251)	0.78(772/985)

D. Experimental Protocol

To get an idea of extend to which the changes affect the test scripts, we first calculate the screen and connection coverage of the original test scripts. Next, we apply ATOM to automatically maintain the test scripts. The updated test scripts are then compared with the original ones using the two metrics defined in Section IV-B. All the comparisons are done on individuals both as a whole and individually.

E. Experimental Results

In this section, we report the results of our evaluations, with the aim of answering the research questions listed at the end of Section IV-B.

Table IV summarizes the values of the metrics we use to measure the effectiveness. For each app, the table presents the screen coverage preservation (SCP), the connection coverage preservation (CCP), and the test action preservation (TAP) of the maintenance process. Each entry in column SCP is in form $x(y/z)$, where x is the value of the metric, while $y = |\boldsymbol{S}'_v \cap \boldsymbol{S}_c|$ is the number of screens from the base version ESM that are covered by the updated scripts and $z = |\boldsymbol{S}_v \cap \boldsymbol{S}_c|$ is the number of screens visited by the original scripts. Similar information is listed also for the CCP value of each app. Each entry in column TAP is in form $x(y/z)$, where x is the value of the metric, while $y = |(\boldsymbol{A}'_e - \boldsymbol{A}_e) \cap \boldsymbol{A}_t|$ is the number of extra test actions from the original scripts that the maintained scripts are able to perform and $z = |\boldsymbol{A}_t - \boldsymbol{A}_e|$ is the number of test actions that would be lost if without maintenance.

RQ1: screen and connection coverage preservation. From Table IV, we can easily see that ATOM managed to achieve SCP and CCP values higher than 0.80 and 0.9, respectively, for all apps. The overall SCP and CCP are also high: 0.94 and 0.98, respectively. Such results strongly suggest ATOM is effective in preserving the coverage of the ESM during test script maintenance.

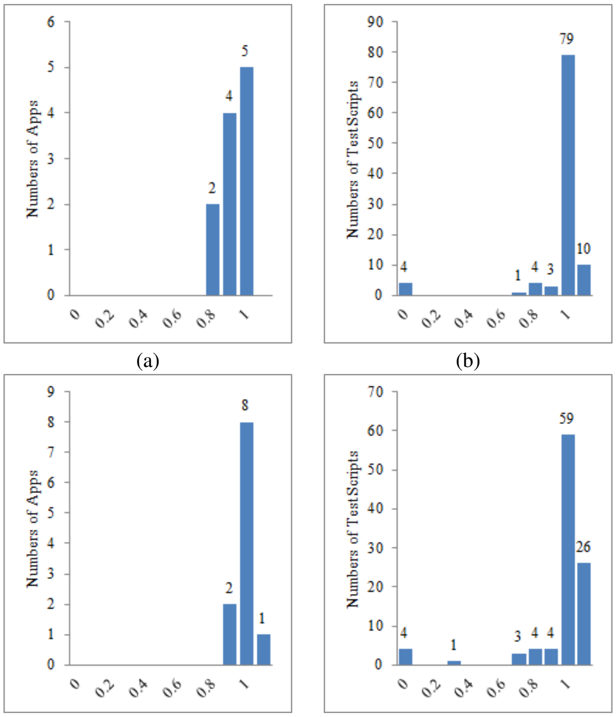
Figure 7 plots the distribution of the coverage preservation values as four histograms. The x-axis of Figure 7(a) represents the SCP value of the maintained test scripts for an app, and y-axis represents the number of apps producing such values. Figure 7(b) shows similar distribution but at the level of individual test scripts. Figures 7(c) and 7(d) are counterparts of Figures 7(a) and (b) for CCP values.

TABLE II: Basic information about different versions of the experiment subjects.

APP	Base	Updated	ESM		DESM				
			#S	#C	#S$_{+}$	#S$_{-}$	#C$_{+}$	#C$_{-}$	#C$_{M}$
Bilibili	4.12.1	4.13.0	15	36	1	5	1	16	1
GNotes	1.0.2	1.0.3	17	36	0	2	7	11	2
Wannianli	4.4.2	4.4.6	13	39	1	0	2	0	10
YoudaoNote	5.1.0	5.2.0	18	43	1	0	7	6	8
Wechat Phonebook	3.5.1	4.2.0	13	26	1	0	4	1	22
Changba	6.7.1	7.0.0	18	68	3	3	12	16	3
Baidu Music	5.6.6.1	5.7.0.3	15	33	0	2	0	5	7
365 Calendar	6.0.2	6.2.3	18	40	2	3	4	5	3
Ctrip	6.15.2	6.16.0	19	35	0	0	0	0	5
WizNote	7.1.0	7.1.6	15	30	0	2	0	4	6
TickTick	2.6.6	2.6.7	15	30	2	0	4	1	4
Total:	–	–	176	416	11	17	41	65	71

TABLE III: Basic statistics for all the test scripts and for affected test scripts only.

APP	#K	#A				Cov		#K$_a$	#A$_a$						
		Min	Max	Avg	Sum	S	C		Min$_a$	Max$_a$	Avg$_a$	Sum$_a$	#Chg	#Del	#Mod
Bilibili	15	3	20	13.93	209	100	100	12	3	20	15.67	188	59	56	3
GNotes	9	7	33	20.89	188	100	91.67	8	7	33	22.38	179	25	10	15
Wannianli	9	8	26	12.89	116	100	92.31	9	8	26	12.89	116	12	0	12
YoudaoNote	12	6	16	10.67	128	100	86.05	12	6	16	10.67	128	35	8	27
Wechat Phonebook	7	3	9	5.86	41	100	92.31	7	3	9	5.86	41	33	1	32
Changba	27	5	21	12.07	325	100	100	14	5	17	12.64	177	41	31	10
Baidu Music	20	3	13	4.7	94	100	100	18	3	13	4.89	88	23	6	17
365 Calendar	8	4	44	16.25	130	100	97.5	4	10	44	22.5	90	14	9	5
Ctrip	12	4	29	18.83	226	94.74	94.29	5	4	29	14.8	74	7	2	5
WizNote	12	15	27	20.67	248	100	96.67	8	19	27	21.5	172	15	4	11
TickTick	14	3	19	9.43	132	100	100	4	7	19	12	48	5	1	4
Total:	145	3	44	12.68	1837	99.52	95.53	101	3	44	14.17	1301	269	128	141



(a)

(b)

(c)

(d)

Fig. 7: Distribution of SCP and CCP values for the maintained test scripts.

ATOM *is effective in achieving high screen as well as connection coverage preservation when maintaining test scripts.*

RQ2: test action preservation. TAP values in Table IV are greater than 0.6 for all apps except one. A closer look at that app (BB) reveals that most changes between the two versions were deletions (as shown in Table II). In such cases, if ATOM fails to find alternative paths on the model to continue a test script, remaining test actions from that script will be truncated, resulting in a low TAP value. Majority of the individual scripts also have high TAP values ($\geq$ 0.5). Those with low TAP values (¡0.4) are mostly from apps BB and CB, where many connections were removed between versions. For better understandability of the updated tests, we restricted that alternative paths ATOM uses should not be longer than 2. We expect TAP values to be higher if this restriction is relaxed. In general, TAP values indicate ATOM is effective in preserving the test actions that would be lost if without maintenance.

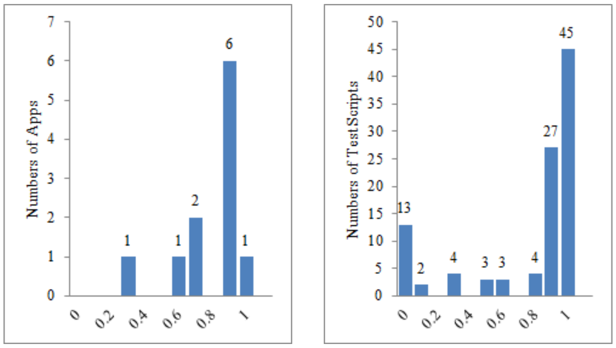
Figure 8 plots the distribution of TAP values as two histograms. The x-axis of Figure 8(a) represents the TAP value of the maintained test scripts for an app, and y-axis represents the number of apps producing such values. Figure 8(b) shows similar distribution but at the level of individual test scripts.

ATOM *is effective in achieving high test action preservation when maintaining test scripts.*

F. Threats to Validity

In this section, we outline possible threats to the validity of our study and show how we mitigate them.

Construct: We evaluate the effectiveness of ATOM based on the deterioration of code coverage and the preservation of



(a)

(b)

Fig. 8: Distribution of TAP values for the maintained test scripts.

test script actions after the maintenance. While the coverage of the updated version app by maintained test scripts is also an important metric measuring the effectiveness of the maintenance process, we did not evaluate ATOM in terms of that, as our focus in this work is on the reuse of existing test scripts. Techniques for test script generation can be easily integrated into our approach to improve the overall code coverage by result test scripts.

Internal: The main threat to internal validity lies in the possible faults in our implementation. We endeavored to minimize such threats. We reviewed our source code and manually checked the generated updates to the original test scripts to make sure ATOM faithfully implements Algorithm 1. We also cross reviewed the models among the post-graduate students to ensure the correctness of the models.

External: The main threat to external validity is the representativeness of our evaluation subjects. Mobile apps used in this study were commercial ones selected from Chinese Android market. On the one hand, such apps are likely better representatives of commercial apps than most open source apps. On the other hand, they may introduce bias to the study, as apps from the global or other local Android market may follow different patterns in their GUI and HCI design. Due to the close-source nature of the selected apps, we had to prepare models and test scripts for the subjects by ourselves. While the model we use in this work is fairly simple and has a straightforward relation with the application GUI, characteristics of the models, e.g., the comprehensiveness, may still influence the effectiveness of the approach. During the test script preparation, we instructed the students to avoid testing too many functionalities using a single script. Although this may be more desirable for test modularization, test scripts in real world projects do not always follow such design, especially when test scripts are recorded from manual testing or generated by automatic tools. Due to limited time, the evaluation was conducted only on the Android platform. More evaluations using other real-world mobile apps as subjects would help us reduce the threat.

V. RELATED WORK

In this section, we discuss on testing techniques for mobile apps that are closely related to the proposed work: regression testing, change acquisition, model based testing, as well as repair and maintenance of test scripts.

A. Regression testing techniques

Various regression testing techniques for mobile apps have beed proposed for ensuring that the changes meet the evolving requirements or fix the previous identified bugs. Gao [8] provided a review of existing testing approaches for mobile applications. Different testing approaches have beeb proposed for different testing goals and testing environments. During the development and operation process, mobile apps are upgraded or changed even more frequently than those of general software applications delivered for PC or server, which bring new challenges to software testing engineers for mobile applications. Rapid evolving mobile apps may cause existing test scripts hardly reusable and outdated during regression testing according to apps under test. To solve this problem, researchers have been working on regression testing techniques which verify old functionalities when modifications occur. The result in [9] shows that 31 regression testing techniques are applied in the past 15 years. In essence, all regression testing approaches can be divided into the following categories: minimization, selection, prioritization and optimization. Most of existing methods [10] [11] [12] [13] focus only on one part. In our work, we try to take comprehensive consideration to maintain test scripts based on changes on mobile apps under test so as to reuse existing test scripts as much as possible in the regression testing.

B. Change acquisition techniques

In regression testing, whether the previous created test scripts for old app could be reused for testing changed new one depends on the changes between two versions of the application under test. Identifying GUI changes between the two versions and analyzing their impact on test scripts is essential. So far, researchers have proposed different approaches. Grechanik and Qing [1] implemented a tool REST which mainly relies on three steps: determining the modified GUI objects base on the GUI models, detecting the affected script statements and analyzing these scripts to determine what other statements are affected as a result of using values computed by the statements that reference modified GUI objects. Raina [14] introduced an automated tool for identifying and testing only the modified parts of a web application. An HTML DOM tree generator is used to generate the DOM tree and the two DOM trees in two versions are compared to locate changes in the new version. A testing tool called GUIdiff is proposed in [15]. It runs two versions of the same application and observes the differences in the widget trees of their states. It inspired us to search for the different versions of mobile apps in our experiment. Currently, we only focus on changes in GUI widgets, such as addition, deletion and modification.

In addition, these changes were represented in the modified model for the app under test.

C. Model-based GUI testing

Traditional manual testing is time-consuming and inefficient. Automated GUI testing techniques are widely explored in the academia, and are widely used in the industry [16]. Model-based testing is one of the supporting means of GUI test automation [17]. GUI Models are employed to represent the behavior of the application under test, which then can be used to automatically generate test cases. However, modeling the GUI-based behavior of an application can be difficult. To settle the issue, GUICC [18] determines equivalence/difference between GUI states to generate GUI graph, and updates the GUI graph based on the changes. The common reverse engineering techniques for GUI testing are GUI crawling and GUI ripping [19] [7]. Model-based techniques can also be applied into regression testing. For example, Fourneret [20] presented a model-based regression testing technique based on UML/OCL behavioral models. The results show the approach is efficient. However GUI ripper may cause the automated generated model imperfect and inaccurate. In our approach, we construct the GUI model of the original application, represent the caught changes in the model, and model-based testing approach to facilitate automatic regression testing.

D. Test script reuse

Test scripts are used to perform automatic regression testing. Generally, test scripts could be manually created or automatically generated with the help of record/reply tools according to specific application under test. Because of the rapid evolving and frequent changing of mobile apps, the existing test scripts may unusable for regression testing. It is mentioned in [21] that more than 74 percent of the test cases become unusable. Test script resue is the most important and difficult problem in regression testing. To deal with this problem, Memon [5] proposed EFG model-based approach. It first selects unusable test script according to the original test scripts and the modified GUI, then repairs these scripts base on four user-defined transformations. Other approaches have been proposed to focus on automated test script repairing. Daniel [22] proposed a white-box approach that focused on GUI code. They implemented a smart IDE to record the GUI refactoring. Then, the information is used to change the GUI code as well as to repair test cases. Wen [23] proposed an IR-based method LOCUS to locate bugs from software changes. Locus only outputs the modification content of the most suspicious file in each suspicious change. Similar to our work, SITAR [6] repairs unusable low-level test scripts. It uses QTP as the testing tool. The approach has three main steps. First, GUI ripper is used to construct an EFG model. In addition, EFG model is enhanced by introducing a dominates edge. Second, the script statements are mapped to the EFG model. If a match is not found that a NULL entry is created. Final, a mapped script that has at least one NULL must be repaired. It can output a sequence of events and repaired check points. In our work, the original model is more accurate without using existing ripping tools. And we choose Appium and Robotframework without a hierarchical relationship. It makes the mapping harder but more precise. Moreover, we do not repair oracle but our test cases are generated through automatic traversal. Researchers try to repair these unusable test scripts to save cost by reusing existing artifacts while without lost efficiency. Pinto [24] pointed out that prior repairing methods that focus on assertions have limited practical applicability. All of these approached motivated us to reuse test scripts for regression testing automatically and realistically. We adopt fuzzy matching between models and scripts, employ model comparing approaches in [25] to update the modified model according to changes. The updated model are then used to maintain scripts automatically.

VI. Conclusion And Future Work

In this paper, we propose a novel method for automatically maintaining test scripts based on GUI model and version changes. First, we analyze the changes between two versions via code, change log and behaviors of the application. Then, the model of the application is updated. At last, the scripts are maintained by mapping to behavior sequence, repairing sequence based on the new model and translating to new scripts. To implement our idea, we developed a tool called MATS and exercised it on real world mobile applications. MATS shows great effectiveness and accuracy, and at the same time, it can reduce human cost.

There are still several possible enhancements to our current work. First, we find the changes between two versions manually at present. However, it's necessary to do it automatically which can significantly raise the effectiveness of our approach and reduce more human cost. Second, the coverage of test scripts may be decreasing when adding events. Although we have already developed a tool to complete the test scripts, it brings some problems such as test case explosion. Third, our approach aims at the test scripts which are generated automatically, so we don't consider test oracle. In the future, we can consider to maintain test oracle.

Acknowledgment

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