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Mining Oracles for Fully Automated Test Generation

 $child? \in enumerateChildren$ $child? \neq null$ $enumerateChildren' = enumerateChildren \setminus child?$ getChildrenCount' = getChildrenCount - 1

Andreas Zeller Saarland University, Saarbrücken, Germany















Testing







Testing



Testing





Dijkstra's Curse



Testing can only find the *presence* of errors, not their *absence*



Formal Verification



Formal Verification

Abstraction



Formal Verification



Abstraction

The Best of two Worlds



Configurations

Generating Tests Abstraction

Configurations

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| First name James S. Naomi D. Karen L. Jean R. Douglas L. | Last name Roebuck Long Lloyd Voigt Green | E-mail JamesSRoe NaomiDLo KarenLLIo JeanRVoigt DouglasLG | Phone 561-888 390-12-5 228-76-1 610-344 612-615 | Mobile 561-888 390-12-1 228-76 610-344 612-615 | All Contractors Customers Employees Suppliers Curope U.S. |
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| Mobile | 228-76-8 | 3710 | | | |
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Infinite Monkey Theorem



Evolutionary Algorithms



Create population

"fdsakfh+ew%3gfhdi%4f"

"fwe8^ru786234jä"

Mutation

"fdsakfh+br%3gfhdi%4f"

"fdsakfh+ew%4gfhdi%4f"

"fwe8^ru<mark>&2</mark>6234jä"

"<mark>xb3</mark>#ru786234jä"

Recombine





Create population

"fdsakfh+ew%3gfhdi%4f"

"fwe8^ru786234jä"

Mutation

"fdsakfh+br%3gfhdi%4f"

"fdsakfh+ew%4gfhdi%4f"

"fwe8^ru<mark>&2</mark>6234jä"

"<mark>xb3</mark>#ru786234jä"

Crossover



Selection and Ranking

if (angle = 47 \lapha power = 532) { ... }



Selection and Ranking

if (angle = 47 ^ power = 532) { ... }

angle = 51

angle = 48

angle = 47

"xb3#ru786234jä"

Coverage Progress



EXSYST

Florian Groß, Andreas Zeller



Test Coverage



but can these ever be invoked from here? testing may detect errors here. pea 260

test generation

at the system level



The Oracle

The Oracle

"Without specification, there are no bugsonly surprises"



Brian Kernighan

Specifications

_removeChild

 $\Delta XMLE lement$

child? : XML_ELEMENT

 $child? \in enumerateChildren$ $child? \neq null$ $enumerateChildren' = enumerateChildren \setminus child?$ getChildrenCount' = getChildrenCount - 1

Specifications

_removeChild __

∆XMLElement child? : XML_ELEMENT

 $child? \in enumerateChildren$ $child? \neq null$ $enumerateChildren' = enumerateChildren \setminus child?$ getChildrenCount' = getChildrenCount - 1

fully automated testing

fully automated debugging

widely automated verification The fun and easy way to get a handle on logical arguments, deductions, and proofs





The Oracle



Specifying Correctness





| Г | |
|---|---|
| | removeChild |
| | $\Delta XMLE lement$ |
| | child? : XML_ELEMENT |
| | $child? \in enumerateChildren$ |
| | $child? \neq null$ |
| | $enumerateChildren' = enumerateChildren \setminus child?$ |
| | getChildrenCount' = getChildrenCount - 1 |

Normality



Mining Normality



| | _ |
|--|----|
| | |
| removeChild | |
| $\Delta XMLE lement$ | |
| child? : XML_ELEMENT | |
| $child? \in enumerateChildren$ | |
| $child? \neq null$ | |
| $enumerateChildren' = enumerateChildren \setminus child$ | !? |
| getChildrenCount' = getChildrenCount - 1 | |



Q Search History

Edit

| Bearbeiten Ansicht Gwonik Lesezeichen Egtras Hilfe | | | | | |
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Normality: Platforms



Abnormal Behavior

Dashboard / Test: http://www.battlefield.com/ / State: e7b5f462538c372 / Issue: 50135

Incorrect Dimensions: //div[@id='gus-wrapper']/div[1]/div

(http://www.battlefield.com//e7b5f462538c372)

Reference Browser Mozilla Firefox 17 / Windows XP



Presence of *interactive* elements

Presence of non-interactive items



Dimension

Position



webmate.io



webmate is a groundbreaking tool for the automatic testing of web applications, with a focus on cross-browser compatibility.



Normality: Time





Yesterday







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Saarbrücker Informatik

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Excellerocluster Multimodel Computing and Interaction

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Excelleractivater Multimodel Computing and Interaction



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webmate.io



Normality: Apps



CHABADA





London Restaurants



looking for a restaurant, a bar, a pub or just to have fun in london? search no more! this application has all the information you need:

• you can search for every type of food you want: french, british, chinese, indian etc.

• you can use it if you are in a car, on a bicycle or walking

- you can view all objectives on the map
- you can search objectives
- you can view objectives near you
- you can view directions (visual route, distance and duration)
- you can use it with street view
- you can use it with navigation
- keywords: london, restaurants, bars, pubs, food,

breakfast, lunch, dinner, meal, eat, supper, street view, navigation

Stemming



looking for a restaurant, a bar, a pub or just to have fun in london? search no more! this application has all the information you need:

 you can search for everi type of food you want: french, british, chinese, indian etc.

you can use it if you are in a car, on a bicycle or walking

- you can view all objectives on the map
- you can search objectives
- you can view objectives near you

you can view directions (visual route, distance and

duration)

can use the street view

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keyword london restaur bar pub food breakfast lunch dinner meal eat supper street view navig

Stemming



look london restaur search bar pub just applic fun inform can search need everi type food want french british chines indian etc car bicycl walk can us can view object map visual rout can search object search can view distanc durat can view direct object near can us street view can us navig keyword london restaur bar pub food view breakfast lunch dinner meal eat supper street navig

London Restaurant Topics



look london restaur search bar pub just applic fun inform can search need everi type food want french british chines indian etc car bicycl walk can us can view object map visual rout can search object search can view distanc durat can view direct object near can us street view can us navig keyword london restaur bar pub food view breakfast lunch dinner meal eat supper street navig



"navigation and travel" (59.8%) "food and recipes" (19.9%) "travel" (14.0%)

Clusters

| ld | Assigned Name | Size | Most Important Topics |
|----|---------------------------|-------|---|
| 1 | "sharing" | 1,453 | share (53%), settings and utils, navigation and travel |
| 2 | "puzzle and card games" | 953 | puzzle and card games (78%), share, game |
| 3 | "memory puzzles" | 1,069 | puzzle and card games (40%), game (12%), share |
| 4 | "music" | 714 | music (58%), share, settings and utils |
| 5 | "music videos" | 773 | popular media (44%), holidays and religion (20%), share |
| 6 | "religious wallpapers" | 367 | holidays and religion (56%), de- sign and art, wallpapers |
| 7 | "language" | 602 | language (67%), share, settings and utils |
| 8 | "cheat sheets" | 785 | game and cheat sheets (76%), share, popular media |
| 9 | "utils" | 1,300 | settings and utils (62%), share, connection |
| 10 | "sports game" | 1,306 | game (63%), battle games, puzzle and card games |
| 11 | "battle games" | 953 | battle games (60%), game |

| 19 | "sports" | 580 | sports (62%), share, popular me- dia |
|----|---------------------------|-----|--|
| 20 | "files and videos" | 679 | files and videos (63%), share, settings and utils |
| 21 | "search and browse" | 363 | search and browse (64%), game, puzzle and card games |
| 22 | "advertisements" | 380 | policies and ads (97%) |
| 23 | "design and art" | 978 | design and art (48%), share, game |
| 24 | "car games" | 449 | cars (51%), game, puzzle and card games |
| 25 | "tv live" | 500 | tv (57%), share, navigation and travel |
| 26 | "adult photo" | 828 | photo and social (59%), share, settings and utils |
| 27 | "adult wallpapers" | 543 | wallpapers (51%), share, kids and bodies |
| 28 | "ad wallpapers" | 180 | policies and ads (46%), wallpa- pers, settings and utils |
| 29 | "ringtones and sound" | 662 | ringtones and sound (68%), share, settings and utils |
| 30 | "theme wallpapers" | 593 | wallpapers (90%), holidays and religion, share |
| 31 | "personalize" | 402 | personalize (86%), share, set- tings and utils |
| 32 | "settings and wallpapers" | 251 | settings and utils (37%), wallpa- pers (37%), personalize |

Outlier Analysis

- For each app, determine the APIs used
- In each cluster, identify outliers through one-class support vector machine (OC-SVM)



London Restaurants



android.net.ConnectivityManager.getActiveNetworkInfo() android.webkit.WebView() java.net.HttpURLConnection.connect() android.app.NotificationManager.notify() java.net.URL.openConnection() android.telephony.TelephonyManager.getDeviceId() org.apache.http.impl.client.DefaultHttpClient() org.apache.http.impl.client.DefaultHttpClient.execute() android.location.LocationManager.getBestProvider() android.telephony.TelephonyManager.getLine1Number() android.net.wifi.WifiManager.isWifiEnabled() android.accounts.AccountManager.getAccountsByType() android.net.wifi.WifiManager.getConnectionInfo() android.location.LocationManager.getLastKnownLocation() android.location.LocationManager.isProviderEnabled() android.location.LocationManager.requestLocationUpdates() android.net.NetworkInfo.isConnectedOrConnecting() android.net.ConnectivityManager.getAllNetworkInfo()

→ An Outlier in the "Travel" Cluster

CHABADA



Malware recognition rate >80%



Information Flow

• Which sensitive APIs does the *device ID* flow to?



MUDFLOW





Normality: Apps



Normality: Apps





connect to adserver.com

connect to exploit.com

Mining Normality



Úlfar Erlingsson







Evolutionary Algorithms

Mining Normality

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| Ľ | removeChild |
| 11 | $\Delta XMLE lement$ |
| 11 | child? : XML_ELEMENT |
| | child? ∈ enumerateChildren |
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webmate.io

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• :

webmate is a groundbreaking tool for the automatic testing of web applications, with a focus on cross-browser compatibility.

Public Beta November 2014

ADI

CHABADA

Malware recognition rate >80%

4. Used APIs

5. Outliers