Guest Lecture on Model-Based testing

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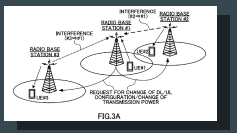
Kristian Karl, krikar@spotify.com

A little about me

- Ericsson, 1994



- Various consultant companies, 1998 -> 2010

- Spotify since 2010
- Model-based testing since 2004
- GraphWalker 2005

Model-Based Testing

I. Theory and practicalities
II. Put to the test in the industry

Model Based Testing

Theory and practicalities

Very [*and unscientific*] brief history of MBT

- **15 May, 1997**

  Software Quality Week Conference in May, 1997
  http://www.geocities.ws/model_based_testing/sqw97.pdf

- **13:52, 30 December 2004**

  First edit in Wikipedia
  https://en.wikipedia.org/wiki/Model-based_testing

- **I met Harry Robinson May 2004**

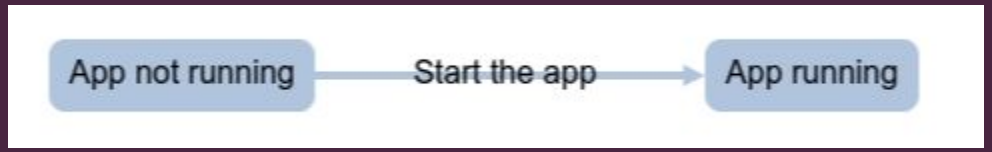
  http://www.harryrobinson.net/

What is MBT?

- **Behavior**
  Models are the **expected behavior** of a System Under Test.
- **Simplification**
  Models are **much simpler** than the the reality.
- **Automation**
  From the models, test are **automatically generated**.

State diagrams

- State diagrams are a **set of states and the relationships between them**.
- GraphWalker uses **directed graphs**.



GraphWalker history

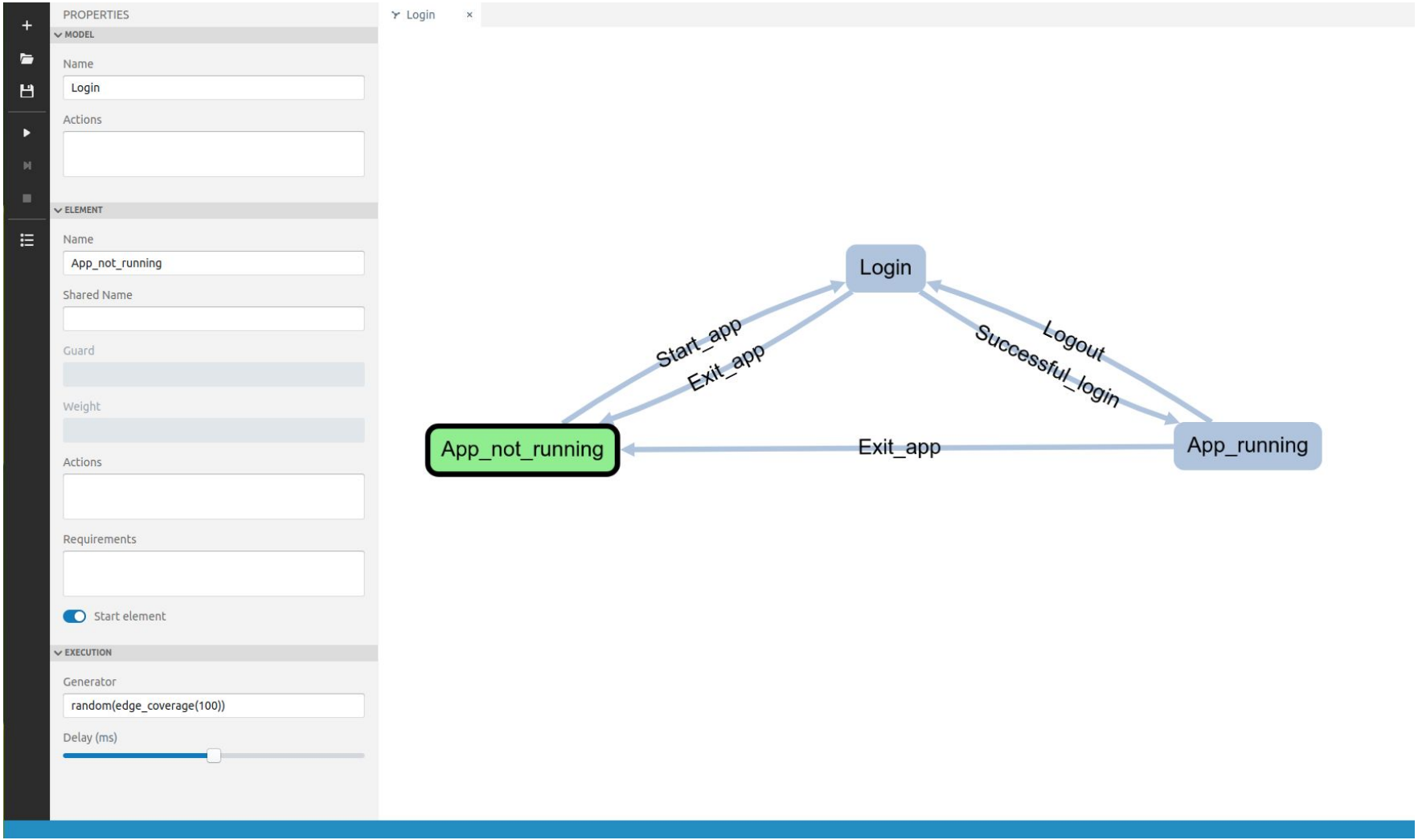
- Open source from the beginning
- 2005 - Started as mbt.tigris.org
- 2010/11 - Changed name to GraphWalker and moved to Github

States, aka nodes or vertices

- A **state represents** something that can be verified.
  - Does the app appear in a process list?
  - Does the app display a window?
  - Does a service generate a heart beat?

Transitions, aka edges or arrows

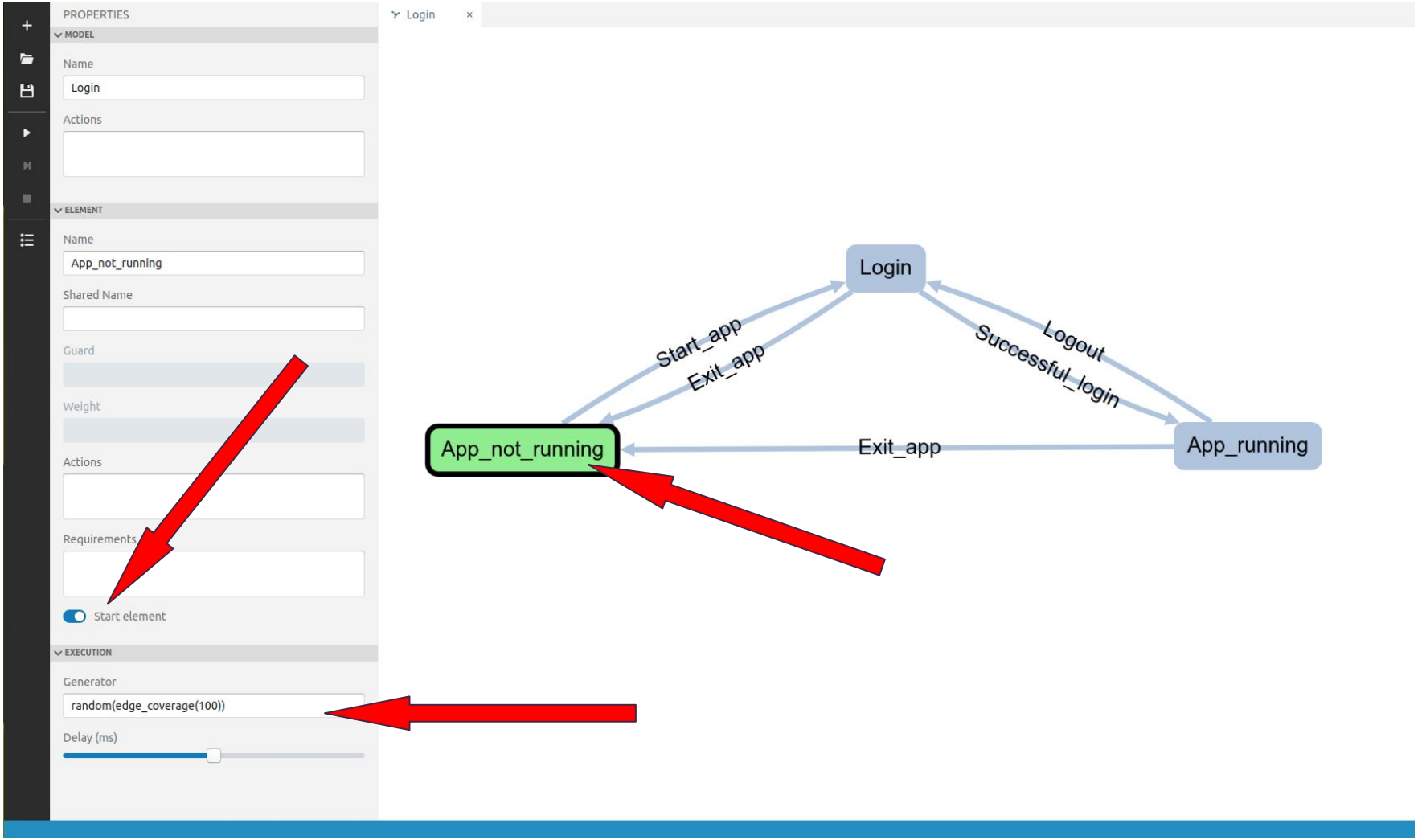
- An edge **transitions the model** to another state.
  - Launch an app.
  - Start a service.
  - Add a record to a database.


PROPERTIES
MODEL
Name
Login
Actions
ELEMENT
Name
App_not_running
Shared Name
Guard
Weight
Actions
Requirements
Start element
EXECUTION
Generator
random(edge_coverage(100))
Delay (ms)
Login
Login
Start_app
Exit_app
Logout
Successful_login
App_not_running
Exit_app
App_running

Creating tests

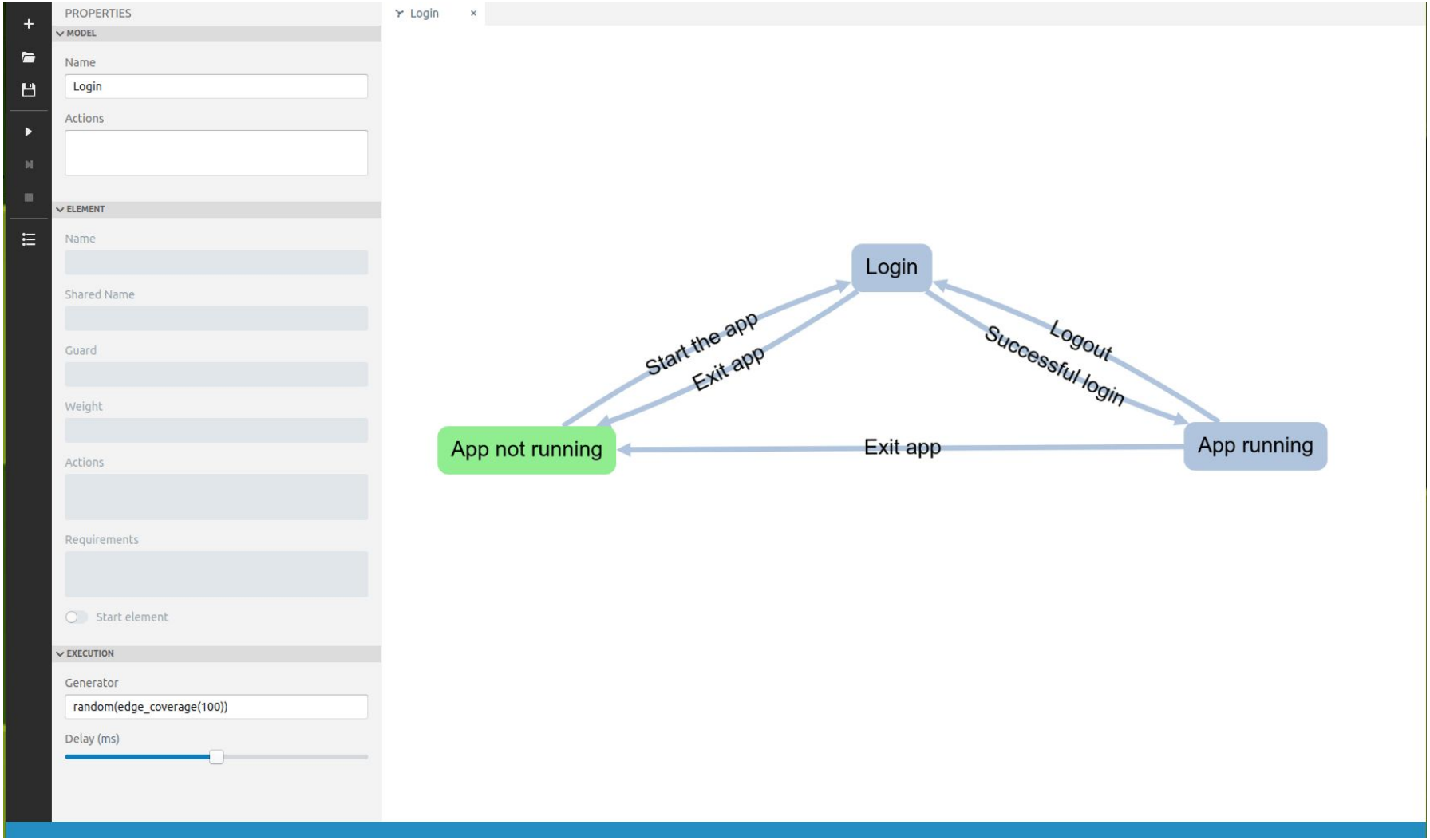
To automatically generate some test(s) from model(s) we need to tell GraphWalker:

- Where to **start**?
- How to **end**?


PROPERTIES
MODEL
Name
Login
Actions
ELEMENT
Name
App_not_running
Shared Name
Guard
Weight
Actions
Requirements
Start element
EXECUTION
Generator
random(edge_coverage(100))
Delay (ms)
Login
Start_app
Exit_app
Logout
Successful_login
App_not_running
Exit_app
App_running

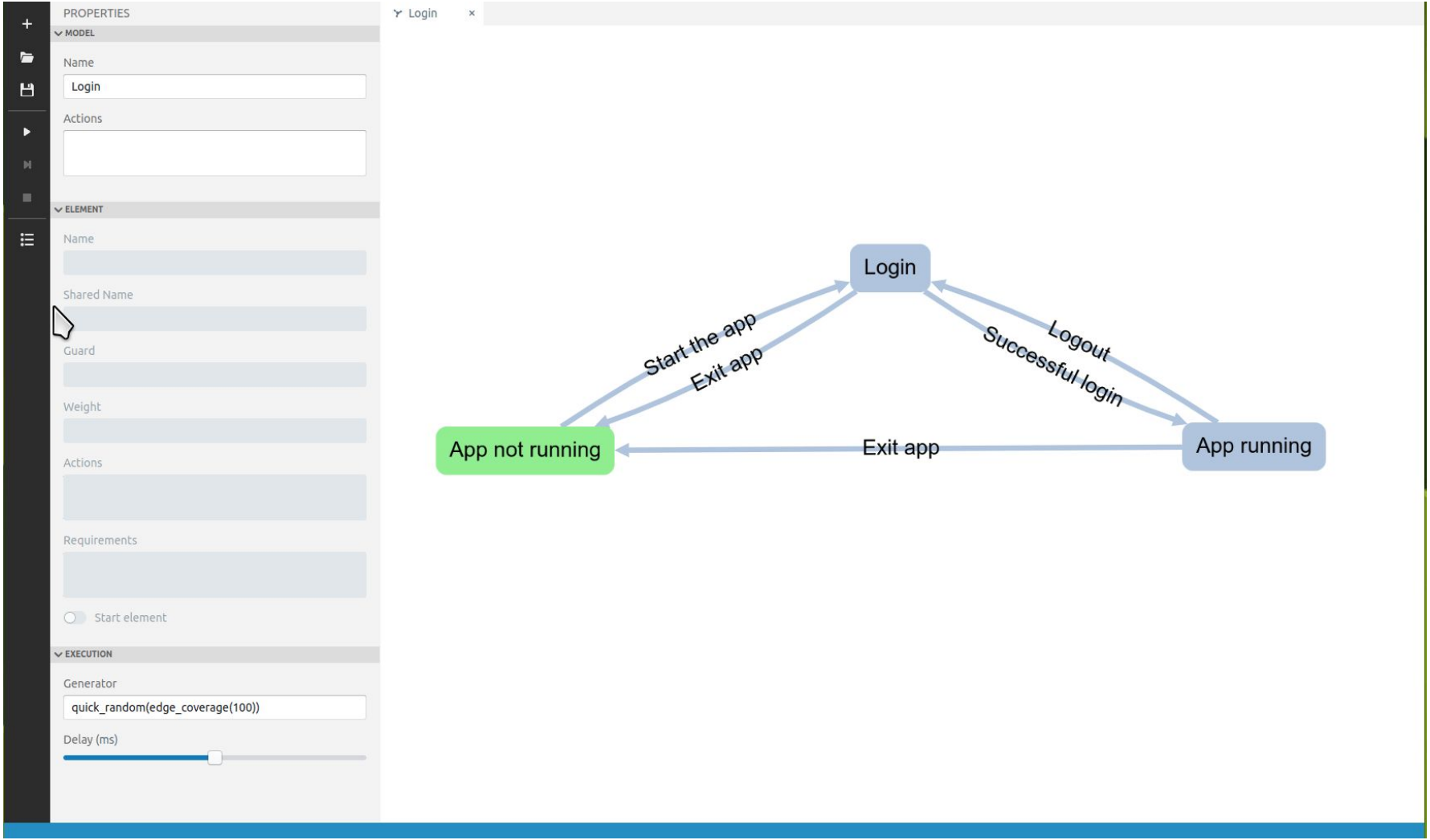
Generating paths

```
random(edge_coverage(100))
```


PROPERTIES
MODEL
Name
Login
Actions
ELEMENT
Name
Shared Name
Guard
Weight
Actions
Requirements
Start element
EXECUTION
Generator
random(edge_coverage(100))
Delay (ms)
Login
Login
Start the app
Exit app
Logout
Successful login
App not running
Exit app
App running

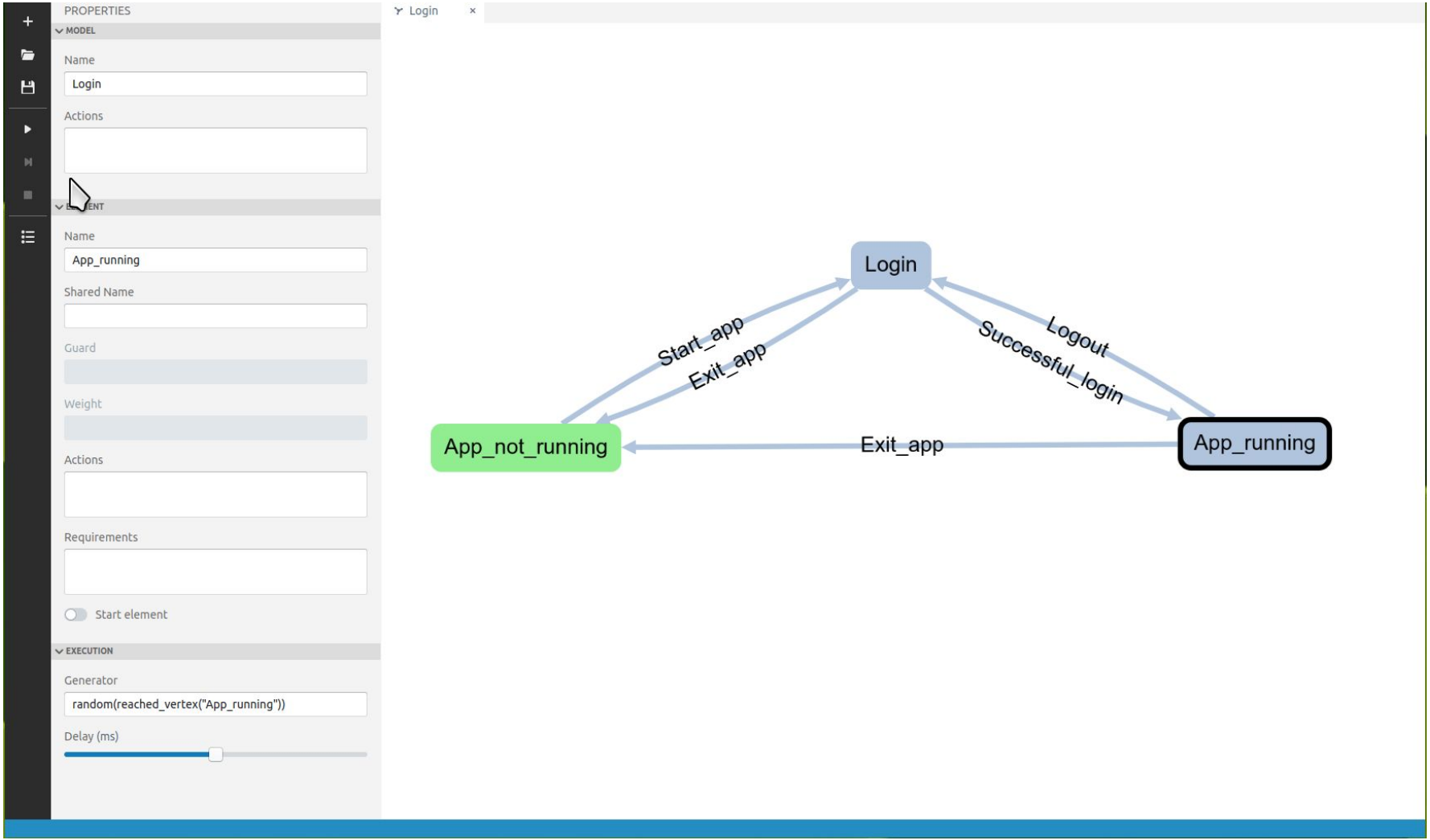
Generating paths

```
quick_random(edge_coverage(100))
```


PROPERTIES
Login
MODEL
Name
Login
Actions
ELEMENT
Name
Shared Name
Guard
Weight
Actions
Requirements
Start element
EXECUTION
Generator
quick_random(edge_coverage(100))
Delay (ms)
Login
Start the app
Exit app
Logout
Successful login
App not running
Exit app
App running

Generating paths

```
random(reached_vertex(App_running))
```


PROPERTIES
MODEL
Name
Login
Actions
Name
App_running
Shared Name
Guard
Weight
Actions
Requirements
Start element
EXECUTION
Generator
random(reached_vertex("App_running"))
Delay (ms)
Login
Login
Start_app
Exit_app
Logout
Successful_login
App_not_running
Exit_app
App_running

Generating paths - generators

- `random`
- `quick_random`
- `weighted_random`

https://github.com/GraphWalker/graphwalker-project/wiki/Generators-and-stop-conditions

Generating paths - stop condition

- `edge_coverage`
- `vertex_coverage`
- `reached_vertex`
- `reached_edge`
- `time_duration`
- `length`

https://github.com/GraphWalker/graphwalker-project/wiki/Generators-and-stop-conditions

Generating paths - generator and stop condition

```
random(edge_coverage(100))
```

https://github.com/GraphWalker/graphwalker-project/wiki/Generators-and-stop-conditions

Generating paths - combining stop conditions

```
random(edge_coverage(100) or
vertex_coverage(100))

random(edge_coverage(100) ||
time_duration(500))
```

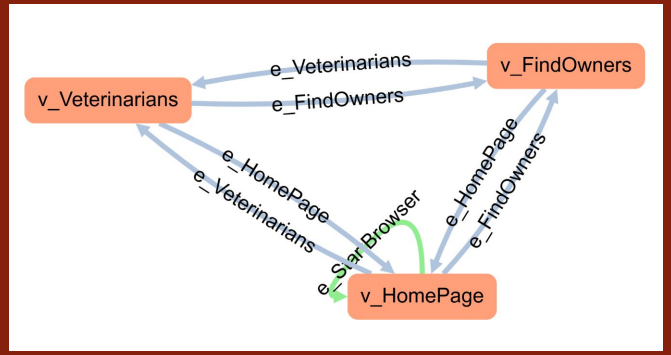
https://github.com/GraphWalker/graphwalker-project/wiki/Generators-and-stop-conditions

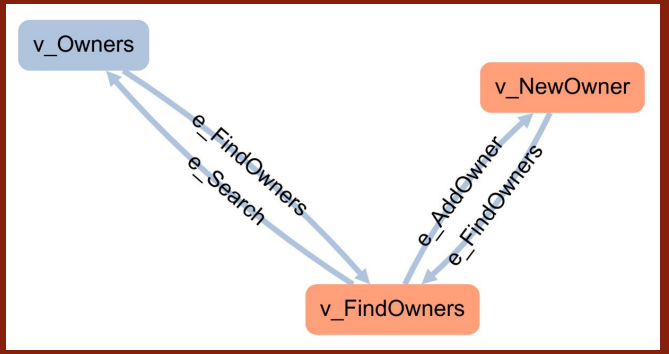
Generating paths - combining generators

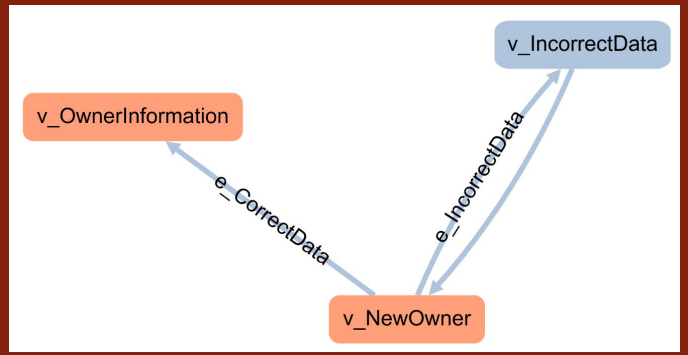
```
random(reached_vertex(v_SomeVertex)
and edge_coverage(100))
random(time_duration(3600))
```

https://github.com/GraphWalker/graphwalker-project/wiki/Generators-and-stop-conditions

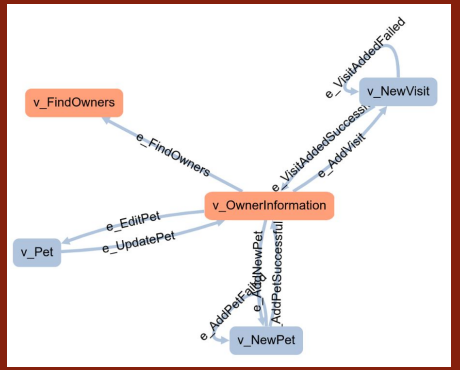
Multiple models





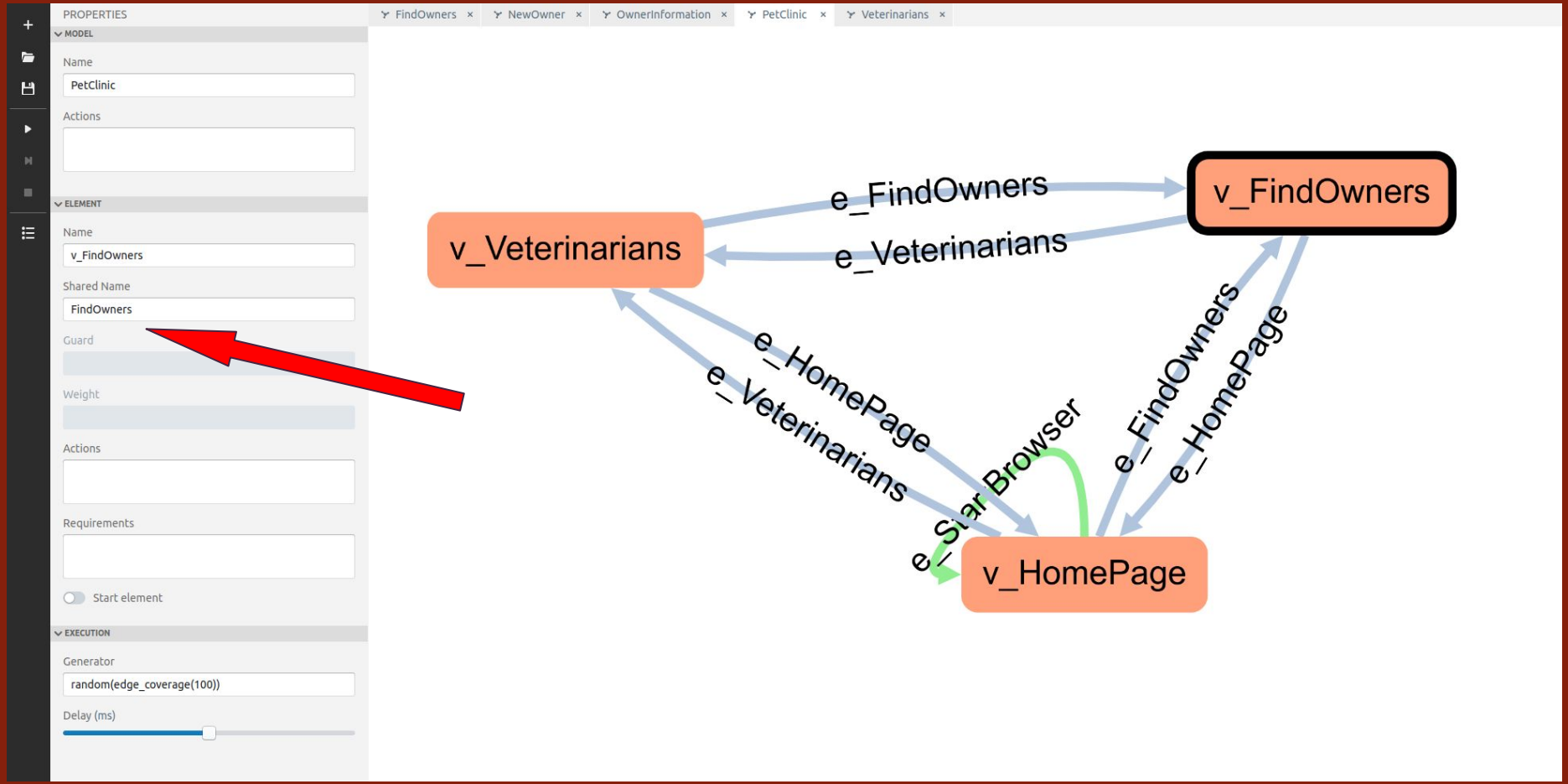


v_Veterinarians

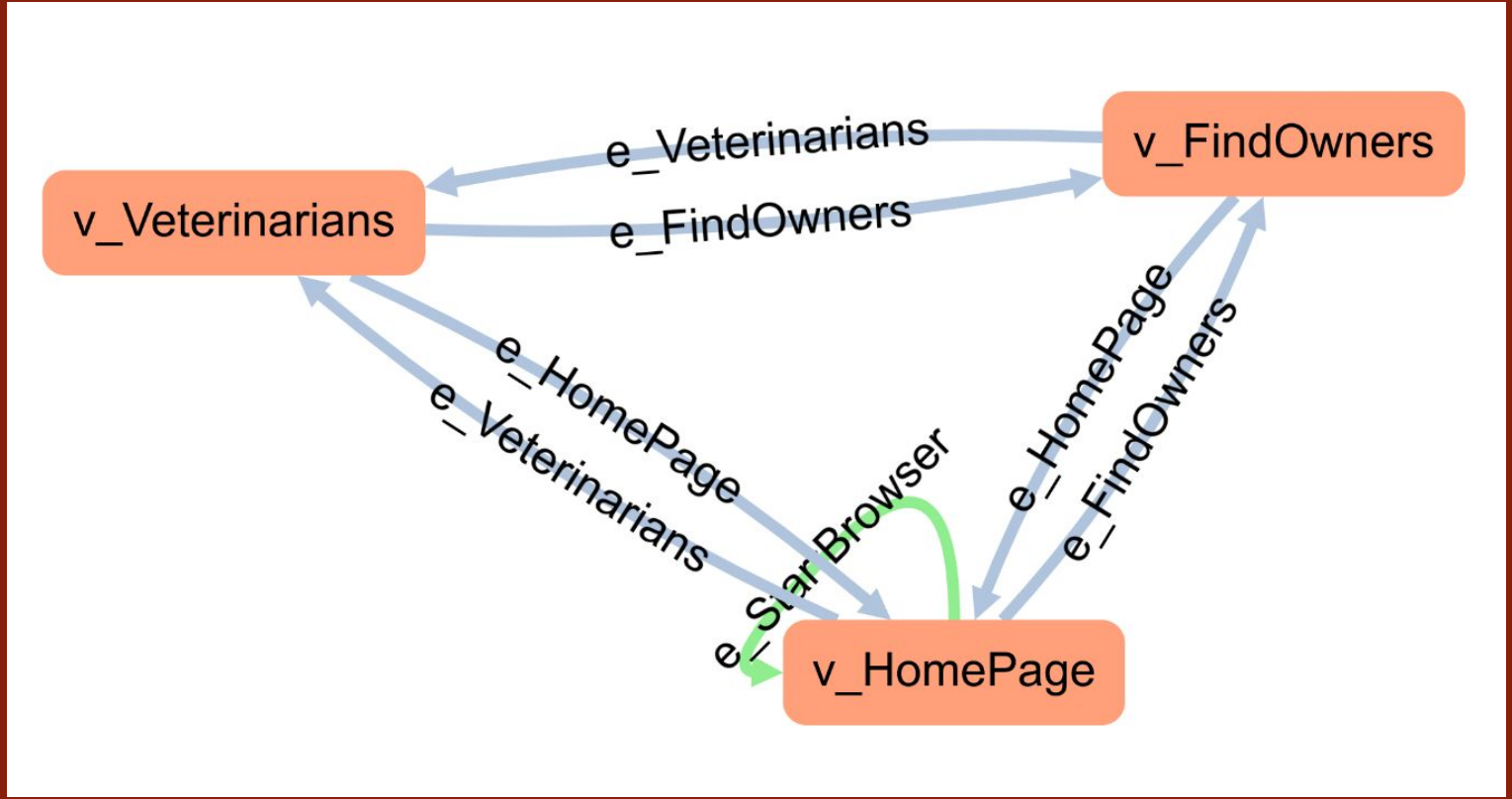


Multiple models - shared vertices

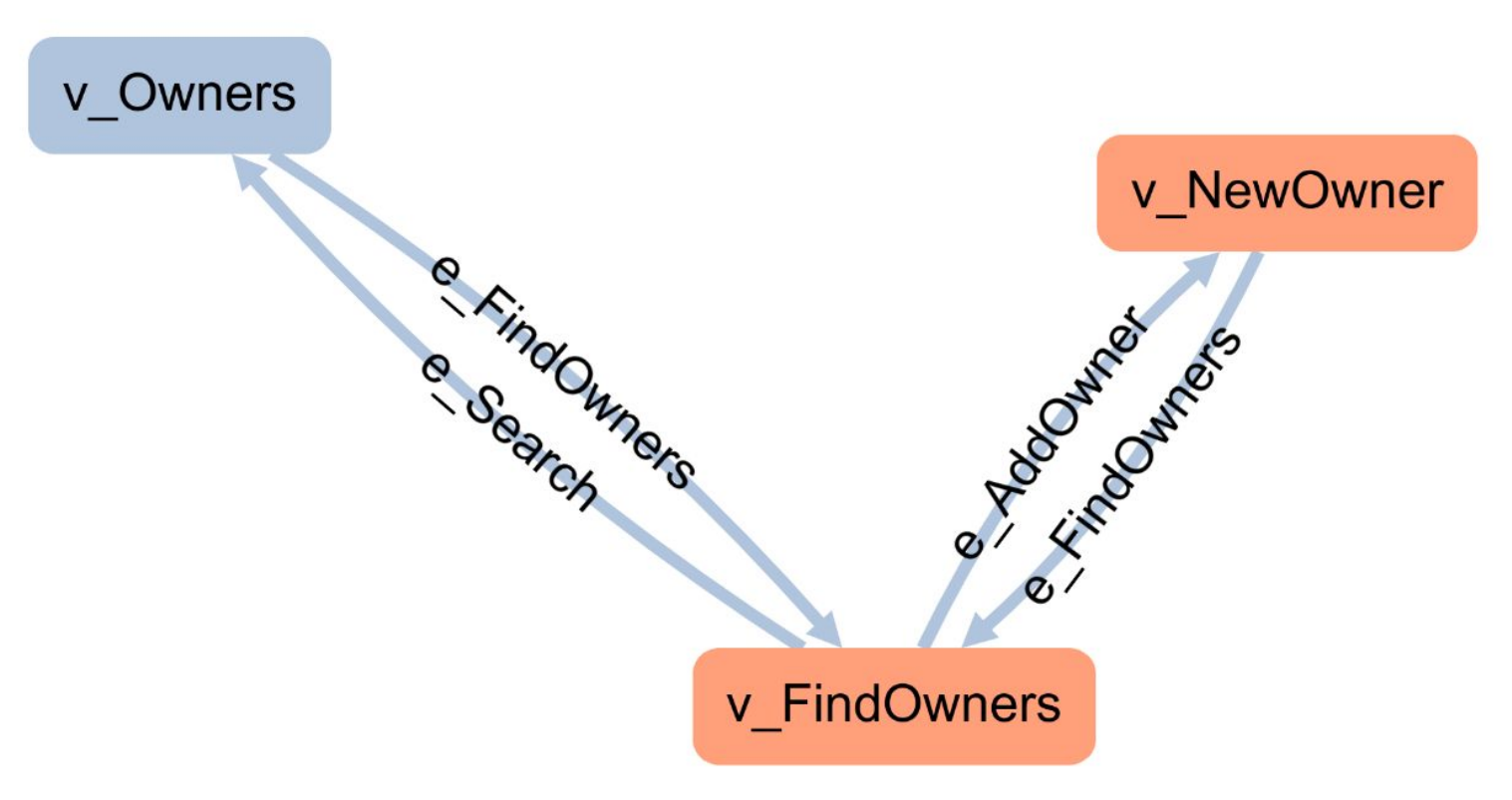
- A complex model may be **broken up** into smaller models.
- Vertices with **shared names** act like portals or bridges.


PROPERTIES
MODEL
Name
PetClinic
Actions
ELEMENT
Name
v_FindOwners
Shared Name
FindOwners
Guard
Weight
Actions
Requirements
Start element
EXECUTION
Generator
random(edge_coverage(100))
Delay (ms)
FindOwners
NewOwner
OwnerInformation
PetClinic
Veterinarians
v_Veterinarians
e_FindOwners
e_Veterinarians
v_FindOwners
e_HomePage
e_Veterinarians
e_Star Browser
e_FindOwners
e_HomePage
v_HomePage

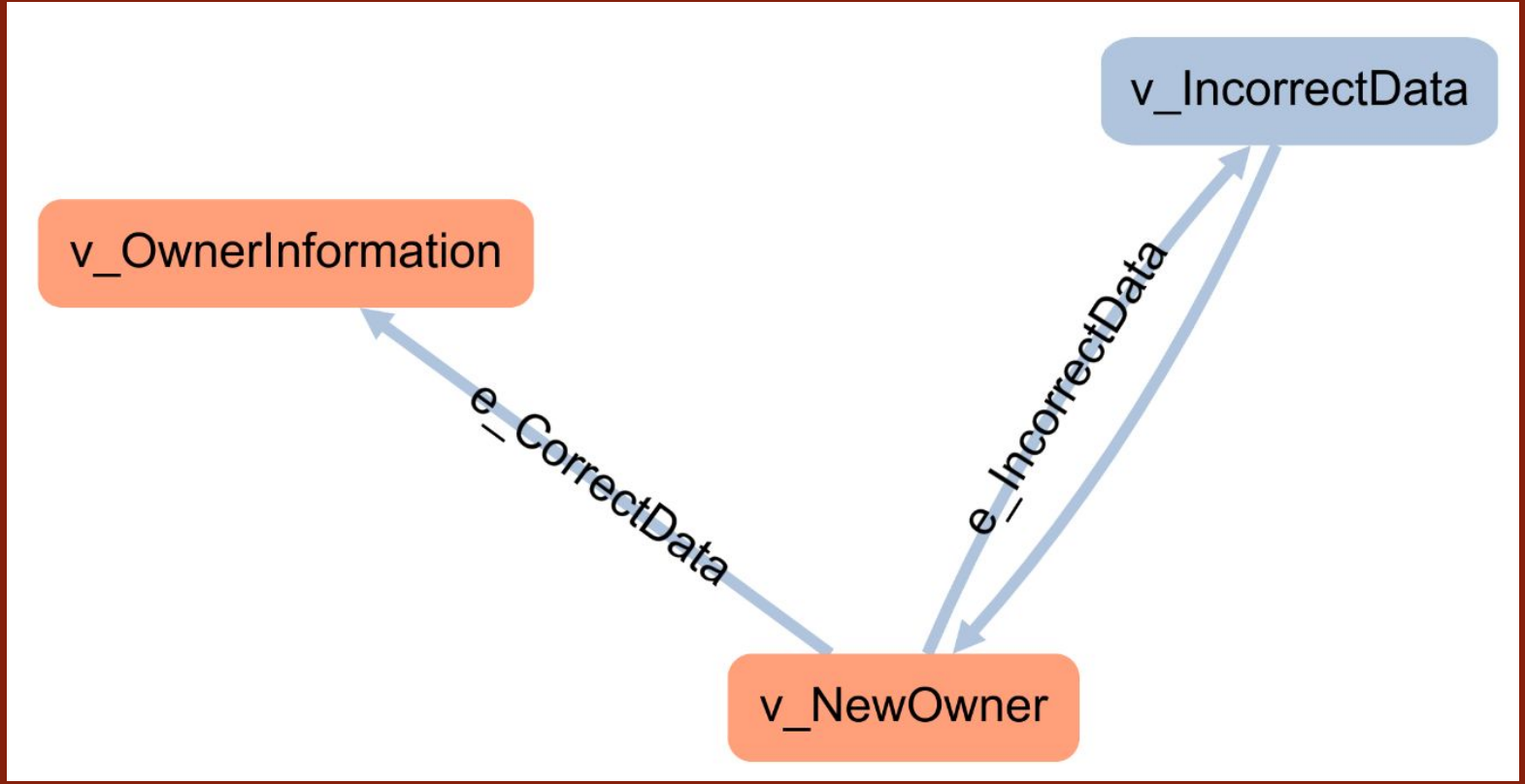
Multiple models - PetClinic



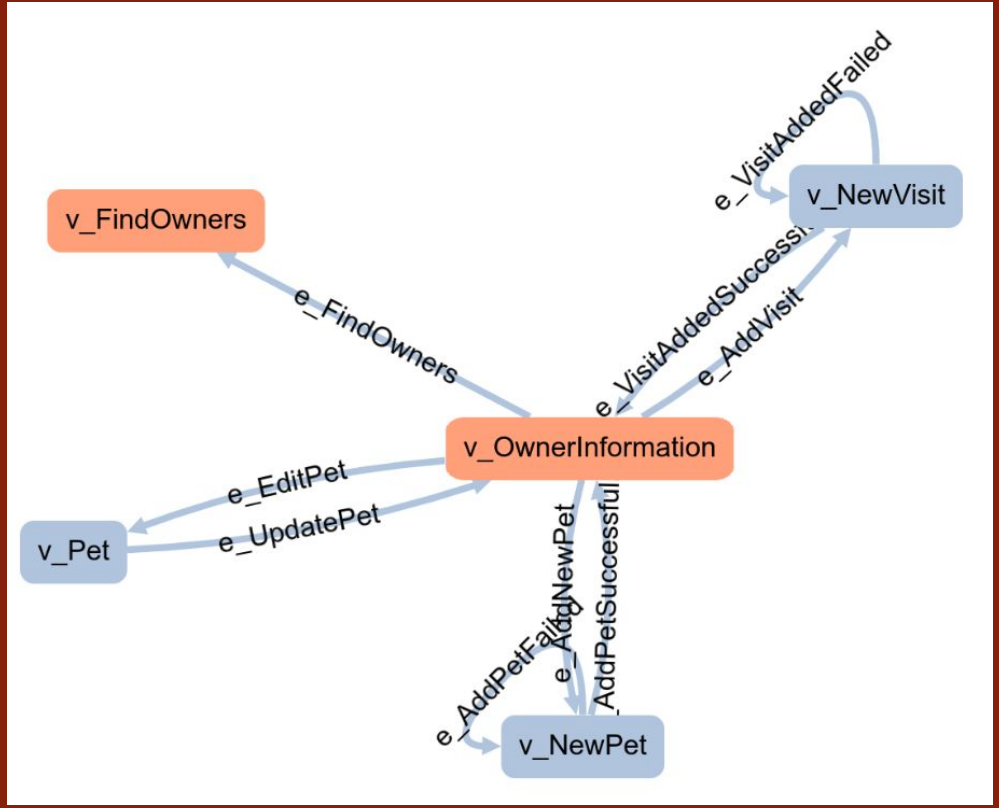
Multiple models - FindOwners



Multiple models - NewOwner

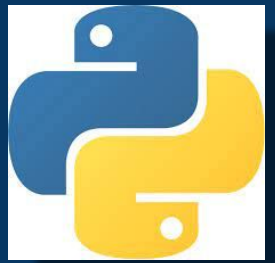


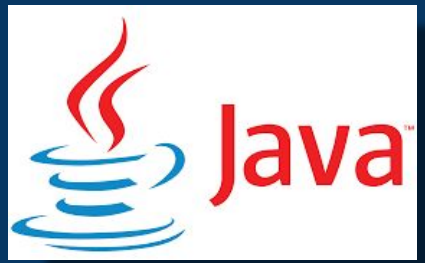
Multiple models - OwnerInformation



Connecting model(s) to code

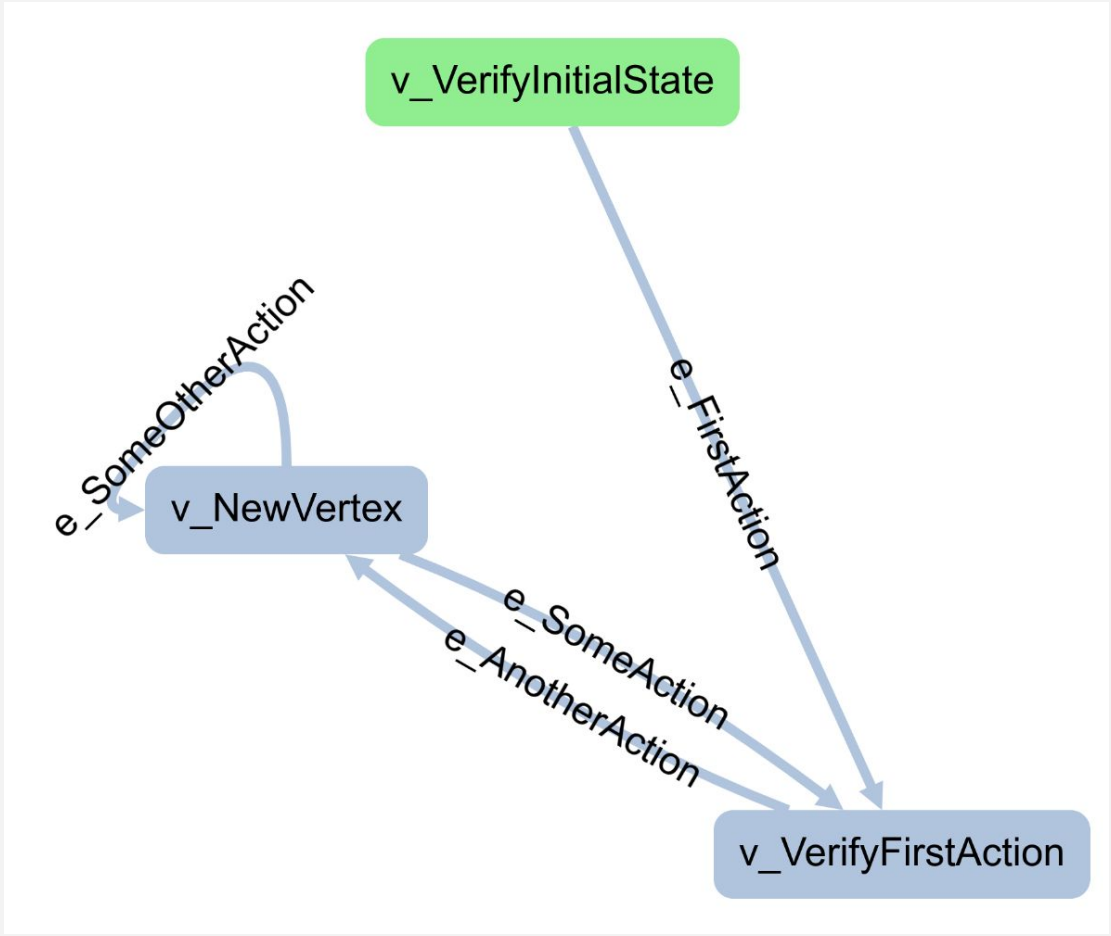
GraphWalker





Java - Connecting model(s) to code

- Graphwalker will **generate a java Interface** for each model.
- The interfaces needs to be **implemented**.
- They contain the **necessary code** that verifies or transitions the system under test to the next desired state.



https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven

```
// Generated by GraphWalker (http://www.graphwalker.org)
package com.company;

import org.graphwalker.java.annotation.Model;
import org.graphwalker.java.annotation.Vertex;
import org.graphwalker.java.annotation.Edge;

@Model(file = "com/company/SmallTest.json")
public interface SmallTest {

    @Edge()
    void e_FirstAction();

    @Edge()
    void e_SomeOtherAction();

    @Vertex()
     void v_VerifyFirstAction()
```

https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven

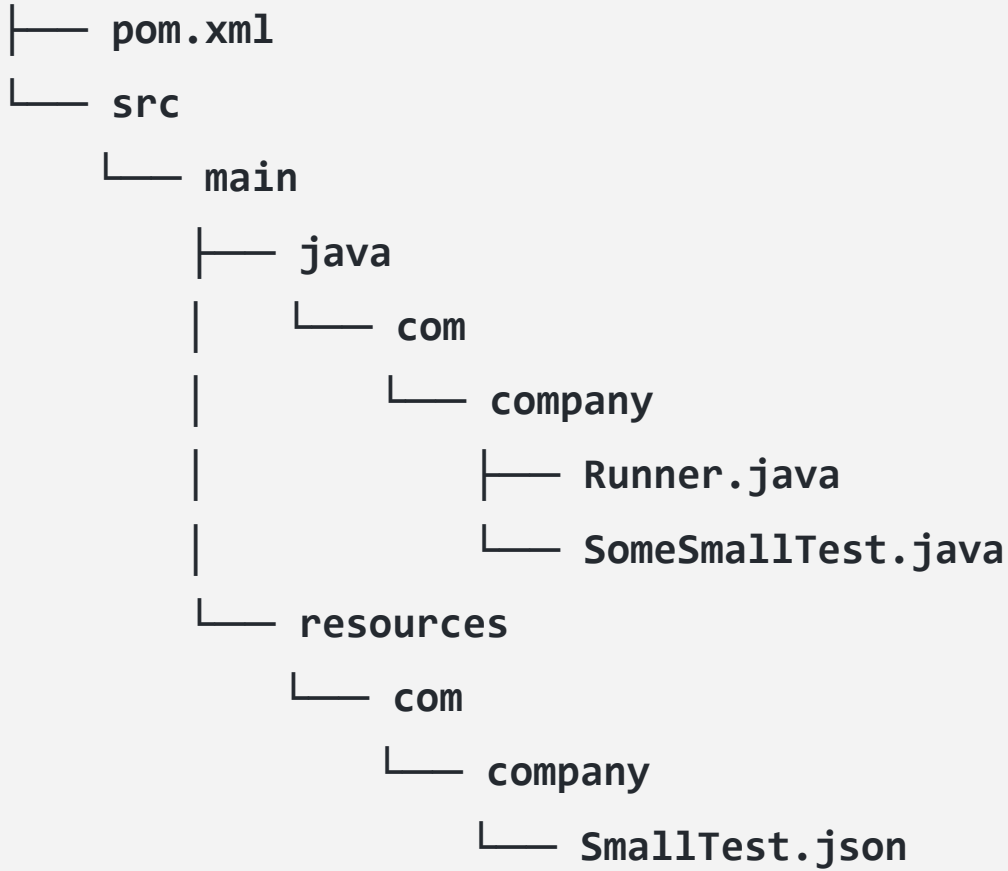
```
public class SomeSmallTest extends ExecutionContext implements SmallTest {

  @Override
  public void e_FirstAction() {
    System.out.println("Running: e_FirstAction");
  }

  @Override
  public void e_SomeOtherAction() {
    System.out.println("Running: e_SomeOtherAction");
  }
```

https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven

Boilerplate

```
mvn archetype:generate -B
-DarchetypeGroupId=org.graphwalker
-DarchetypeArtifactId=graphwalker-ma
ven-archetype -DgroupId=com.company
-DartifactId=myProject
-DarchetypeVersion=LATEST
```

https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven



https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven

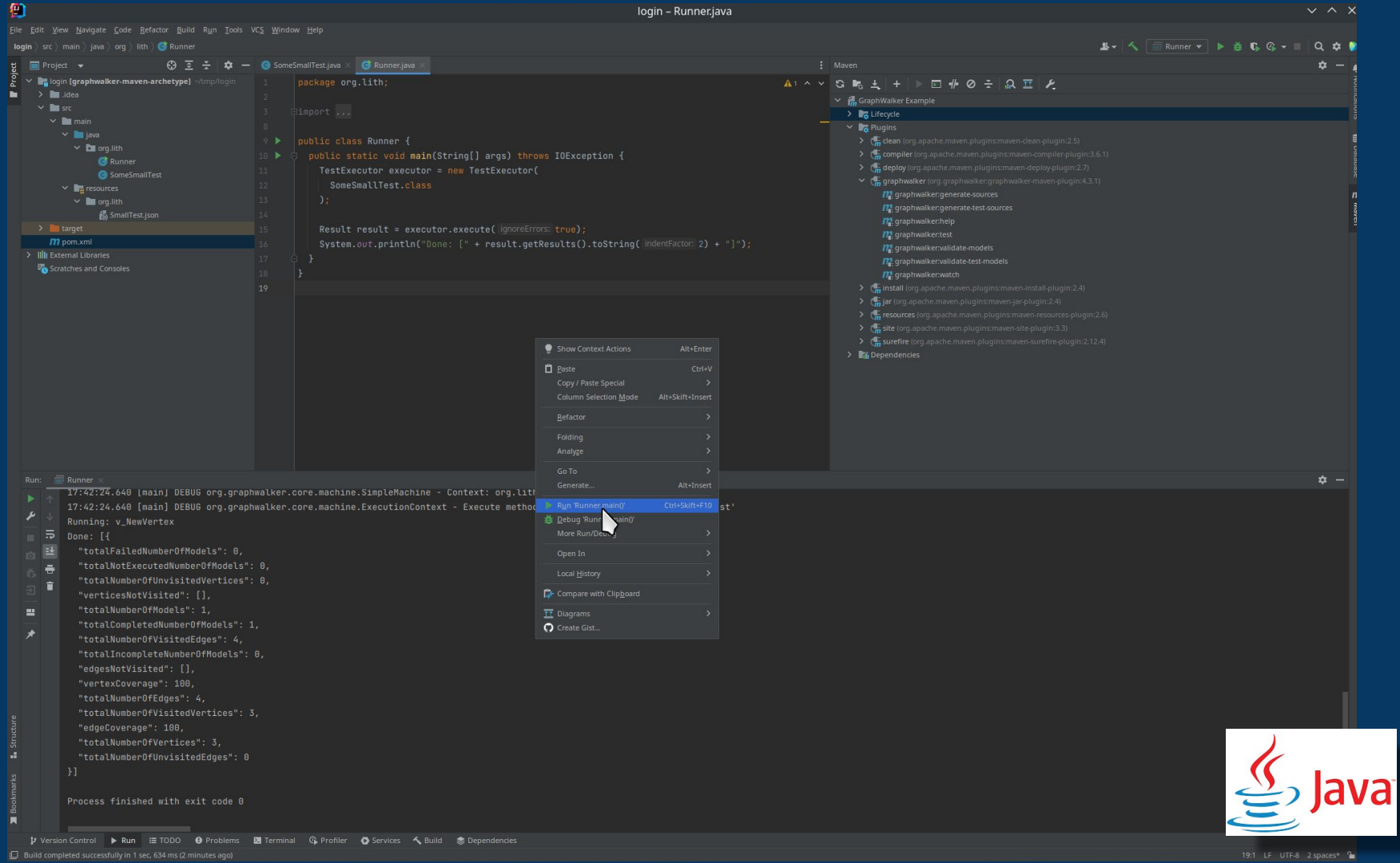
Running it

```
mvn compile exec:java
-Dexec.mainClass="com.company.Runner"
```

https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven

```
Done: [{
  "totalFailedNumberOfModels": 0,
  "totalNotExecutedNumberOfModels": 0,
  "totalNumberOfUnvisitedVertices": 0,
  "verticesNotVisited": [],
  "totalNumberOfModels": 1,
  "totalCompletedNumberOfModels": 1,
  "totalNumberOfVisitedEdges": 4,
  "totalIncompleteNumberOfModels": 0,
  "edgesNotVisited": [],
  "vertexCoverage": 100,
  "totalNumberOfEdges": 4,
  "totalNumberOfVisitedVertices": 3,
  "edgeCoverage": 100,
  "totalNumberOfVertices": 3,
  "totalNumberOfUnvisitedEdges": 0
}]
[INFO] ------------------------------------------------------------------------
[INFO] BUILD SUCCESS
[INFO] ------------------------------------------------------------------------
[INFO] Total time:  5.828 s
[INFO] Finished at: 2022-09-27T08:17:23+02:00
[INFO] ------------------------------------------------------------------------
```

https://github.com/GraphWalker/graphwalker-project/wiki/Create-boilerplate-project-using-maven


login – Runner.java
File Edit View Navigate Code Refactor Build Run Tools VCS Window Help
login src main java org lith Runner
Project
login [graphwalker-maven-archetype] ~/tmp/login
.idea
src
main
java
org.lith
Runner
SomeSmallTest
resources
org.lith
SmallTest.json
target
pom.xml
External Libraries
Scratches and Consoles
SomeSmallTest.java
Runner.java
package org.lith;
import ...
public class Runner {
public static void main(String[] args) throws IOException {
TestExecutor executor = new TestExecutor(
SomeSmallTest.class
);
Result result = executor.execute(ignoreErrors: true);
System.out.println("Done: [" + result.getResults().toString(indentFactor: 2) + "]");
}
}
Maven
GraphWalker Example
Lifecycle
Plugins
clean (org.apache.maven.plugins:maven-clean-plugin:2.5)
compiler (org.apache.maven.plugins:maven-compiler-plugin:3.6.1)
deploy (org.apache.maven.plugins:maven-deploy-plugin:2.7)
graphwalker (org.graphwalker:graphwalker-maven-plugin:4.3.1)
graphwalker:generate-sources
graphwalker:generate-test-sources
graphwalker:help
graphwalker:test
graphwalker:validate-models
graphwalker:validate-test-models
graphwalker:watch
install (org.apache.maven.plugins:maven-install-plugin:2.4)
jar (org.apache.maven.plugins:maven-jar-plugin:2.4)
resources (org.apache.maven.plugins:maven-resources-plugin:2.6)
site (org.apache.maven.plugins:maven-site-plugin:3.3)
surefire (org.apache.maven.plugins:maven-surefire-plugin:2.12.4)
Dependencies
Show Context Actions Alt+Enter
Paste Ctrl+V
Copy / Paste Special
Column Selection Mode Alt+Shift+Insert
Refactor
Folding
Analyze
Go To
Generate... Alt+Insert
Run 'Runner.main()' Ctrl+Shift+F10
Debug 'Runner.main()'
More Run/Debug
Open In
Local History
Compare with Clipboard
Diagrams
Create Gist...
Run: Runner
17:42:24.640 [main] DEBUG org.graphwalker.core.machine.SimpleMachine - Context: org.lith
17:42:24.640 [main] DEBUG org.graphwalker.core.machine.ExecutionContext - Execute method
Running: v_NewVertex
Done: [{
"totalFailedNumberOfModels": 0,
"totalNotExecutedNumberOfModels": 0,
"totalNumberOfUnvisitedVertices": 0,
"verticesNotVisited": [],
"totalNumberOfModels": 1,
"totalCompletedNumberOfModels": 1,
"totalNumberOfVisitedEdges": 4,
"totalIncompleteNumberOfModels": 0,
"edgesNotVisited": [],
"vertexCoverage": 100,
"totalNumberOfEdges": 4,
"totalNumberOfVisitedVertices": 3,
"edgeCoverage": 100,
"totalNumberOfVertices": 3,
"totalNumberOfUnvisitedEdges": 0
}]
Process finished with exit code 0
Version Control Run TODO Problems Terminal Profiler Services Build Dependencies
Build completed successfully in 1 sec, 634 ms (2 minutes ago)
Java

Graphwalker Model file:
SmallTest.json

```
mvn graphwalker:generate-sources
```

Generated Java Interface source file:
target/generated-sources/graphwalker/com/company/SmallTest.java

https://github.com/GraphWalker/graphwalker-project/wiki/Maven---generate-sources

Model Based Testing

Put to the test in the industry

https://play.spotify.com/home

Spotify BETA

Search

What's New

Radio

Playlists

Constance

Log out

New recommended albums

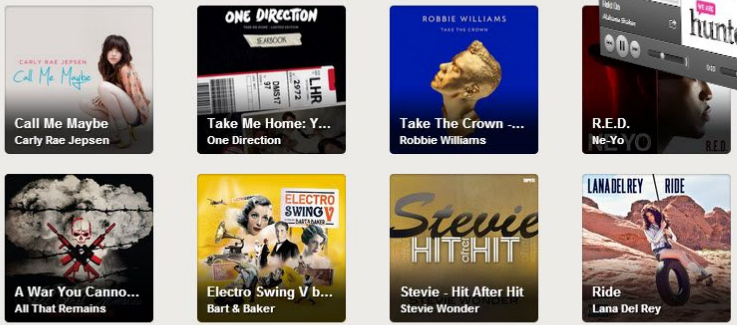
Trending playlists near you

- German Top 100 Single charts by Christian Rose
- CRo - Playlist by Christian Stößel
- CLUB SOUNDS Dancefloor Hits by Sony Playlists Germany

Top tracks near you

- Diamonds
- Lila Wolken
- Gangnam Style (강남스타...
- Sonnentanz - Original Ver...
- One Day / Reckoning Son...

New releases

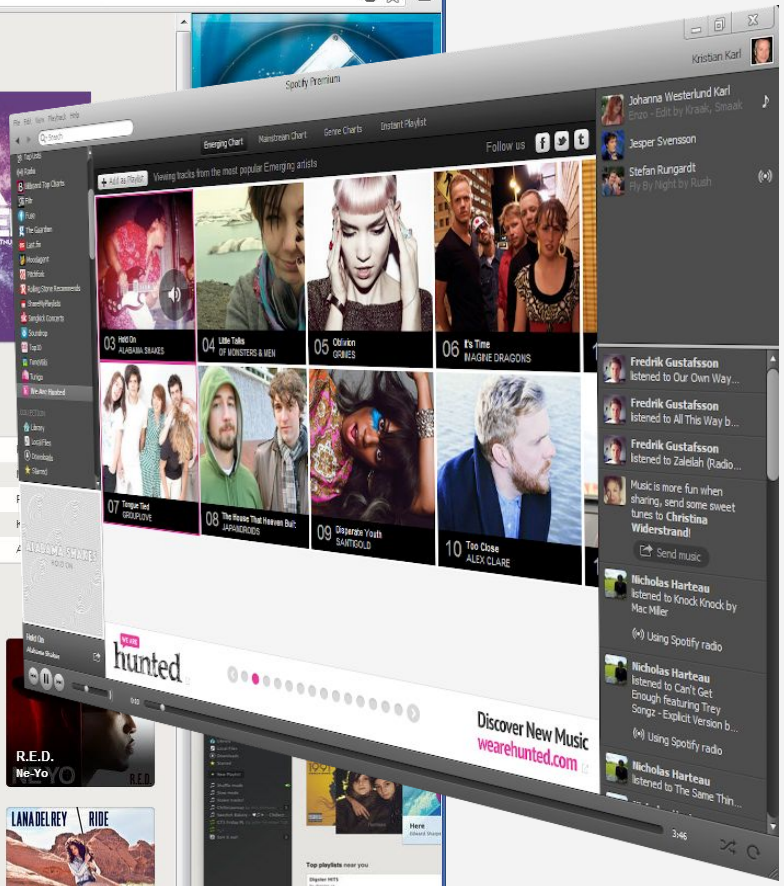


Top tracks in your country

Diamonds	Rihanna	3:45

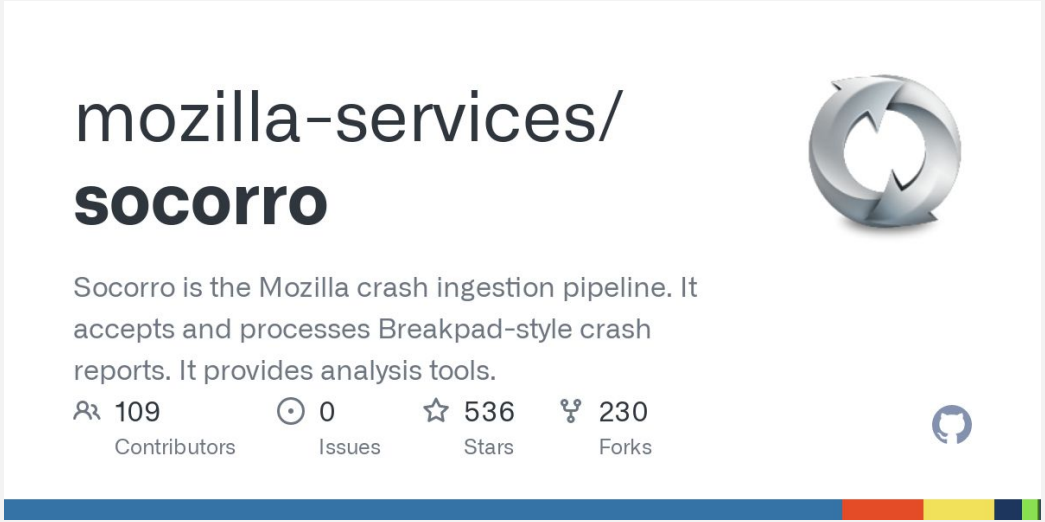
Top tracks in the world

Diamonds	Rihanna	3:45



Client crashes

…we have received ca. 12GB crashdumps in the approx. one week the Socorro installation is up and running. We received 101264 crashes, with an avg. size of 125kB each. The storage of the processed (and compressed) output takes 475MB. I think a compression to 10% of the crash dumps is possible by running gzip, so we'd end up with approx. 2GB each week at the current rate (which will of course go down soon J).



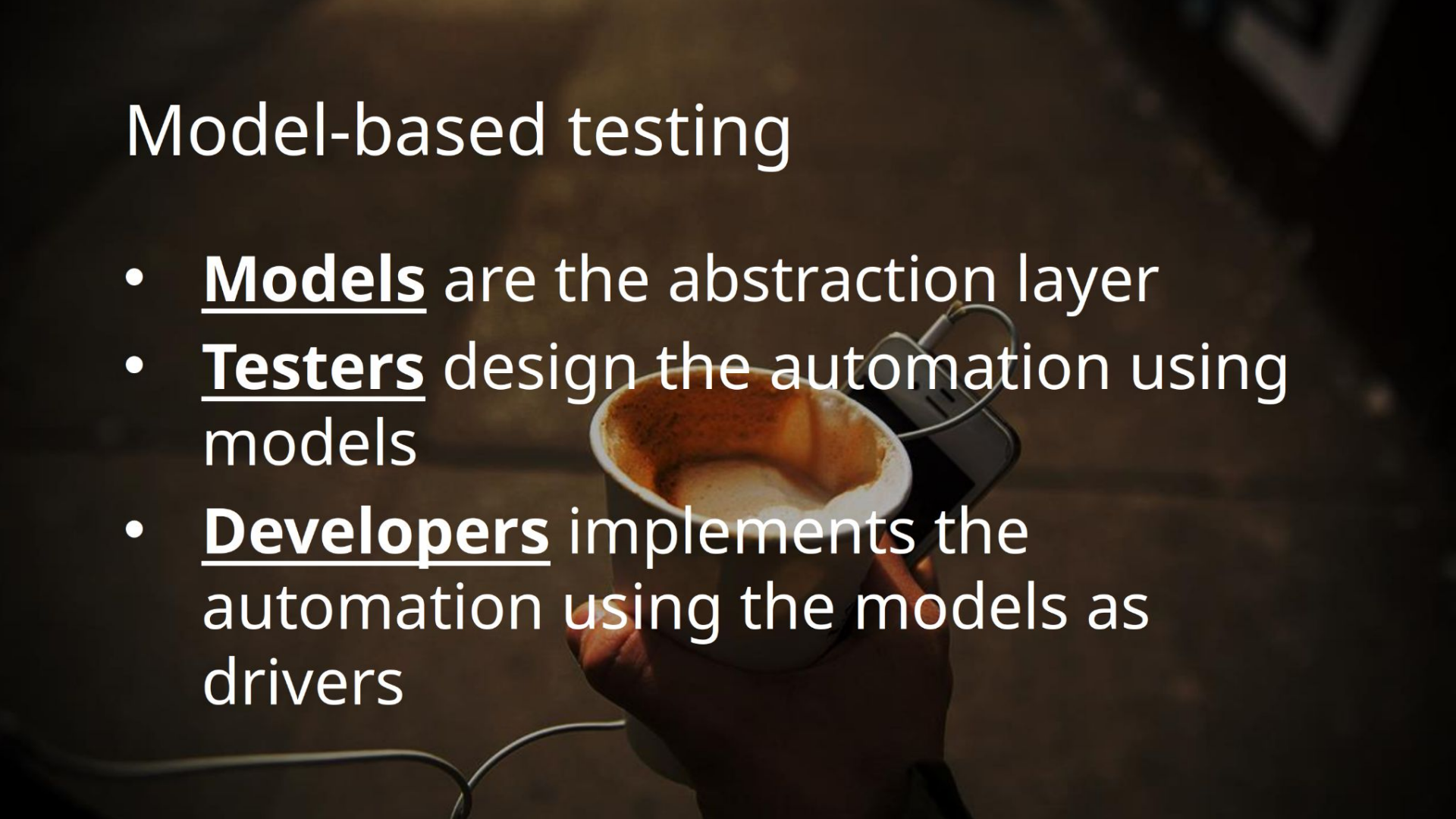
Slow Death By Regression Testing

The balance between retesting already delivered features vs testing new features.

Test automation aimed to free up the testers time to focus on new features.

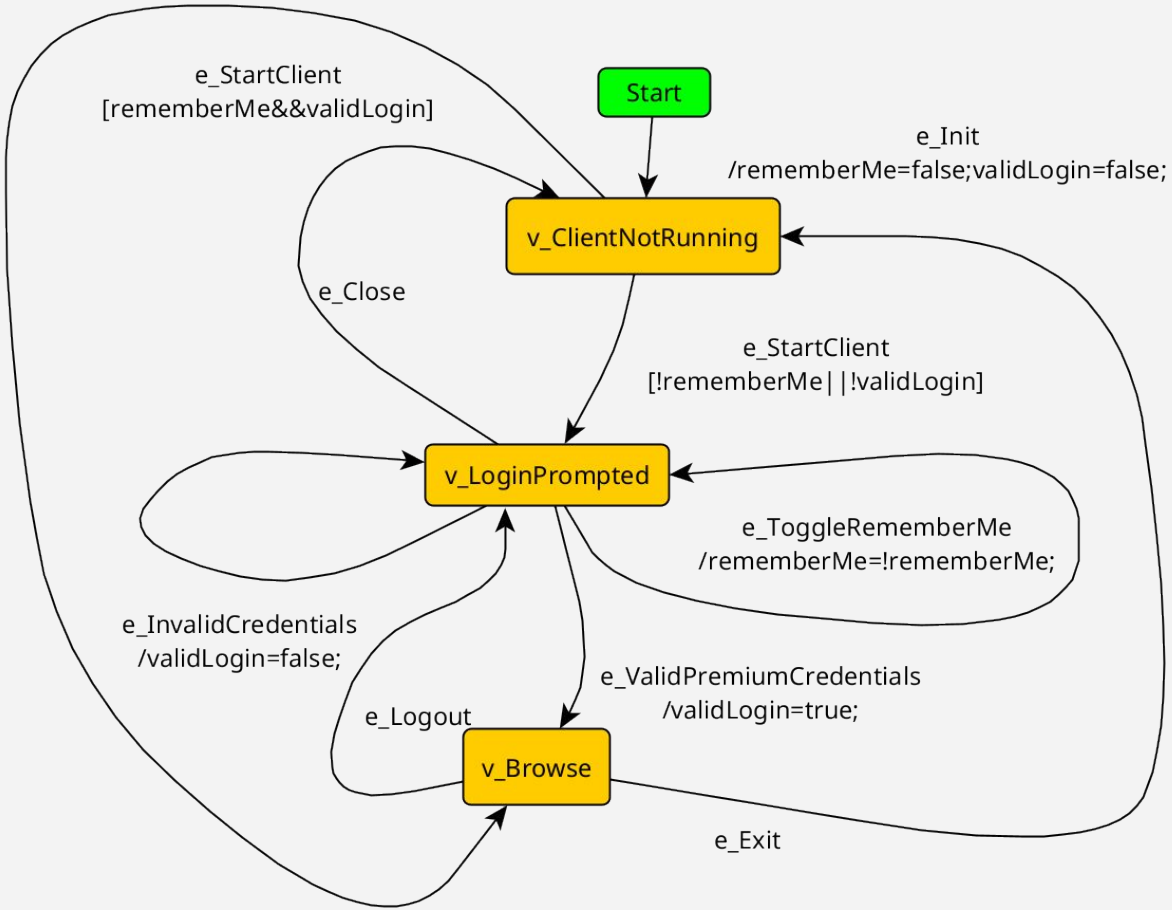
Model-based testing

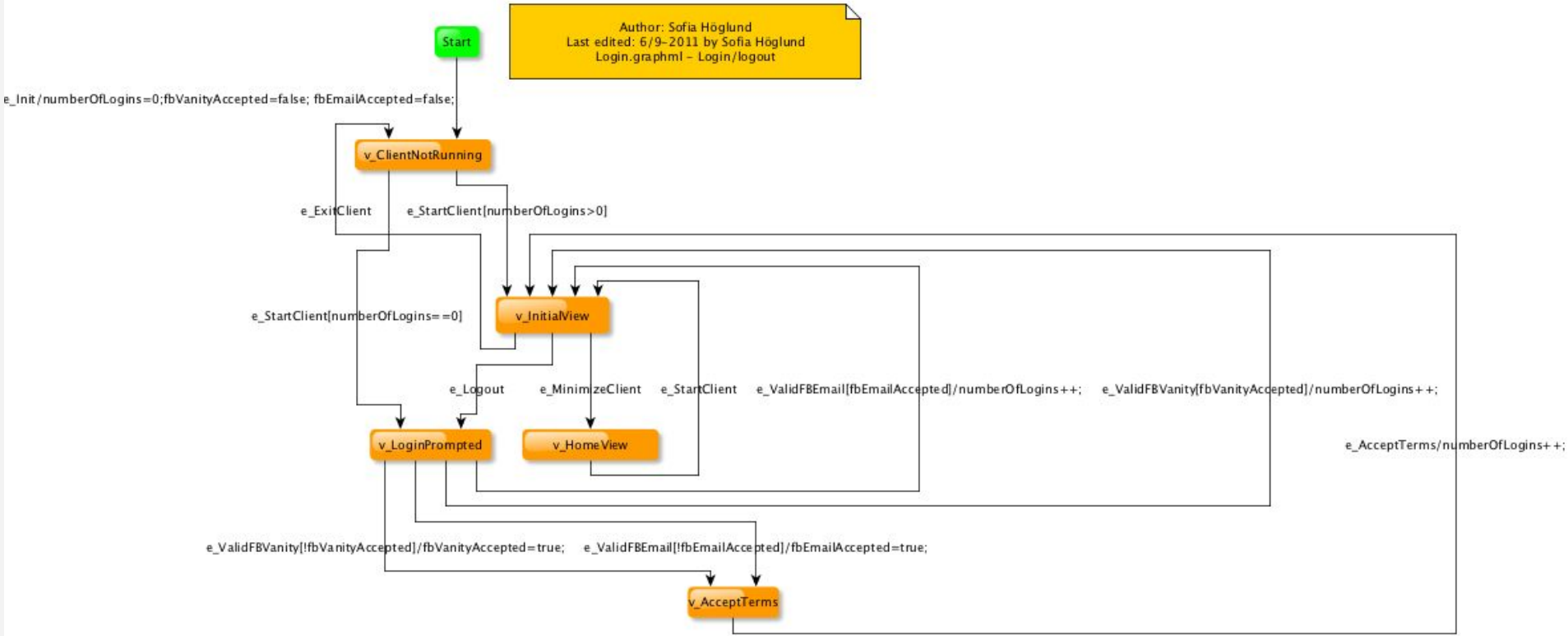
- **Models** are the abstraction layer
- **Testers** design the automation using models
- **Developers** implements the automation using the models as drivers



Model Based Testing

Models can be used to represent the desired behavior of a system under test (SUT)




Author: Sofia Höglund
Last edited: 6/9-2011 by Sofia Höglund
Login.graphml – Login/logout
Start
e_Init/numberOfLogins=0;fbVanityAccepted=false; fbEmailAccepted=false;
v_ClientNotRunning
e_ExitClient
e_StartClient[numberOfLogins>0]
e_StartClient[numberOfLogins==0]
v_InitialView
e_Logout
e_MinimizeClient
e_StartClient
e_ValidFBEmail[fbEmailAccepted]/numberOfLogins++;
e_ValidFBVanity[fbVanityAccepted]/numberOfLogins++;
v_LoginPrompted
v_HomeView
e_AcceptTerms/numberOfLogins++;
e_ValidFBVanity[!fbVanityAccepted]/fbVanityAccepted=true;
e_ValidFBEmail[!fbEmailAccepted]/fbEmailAccepted=true;
v_AcceptTerms

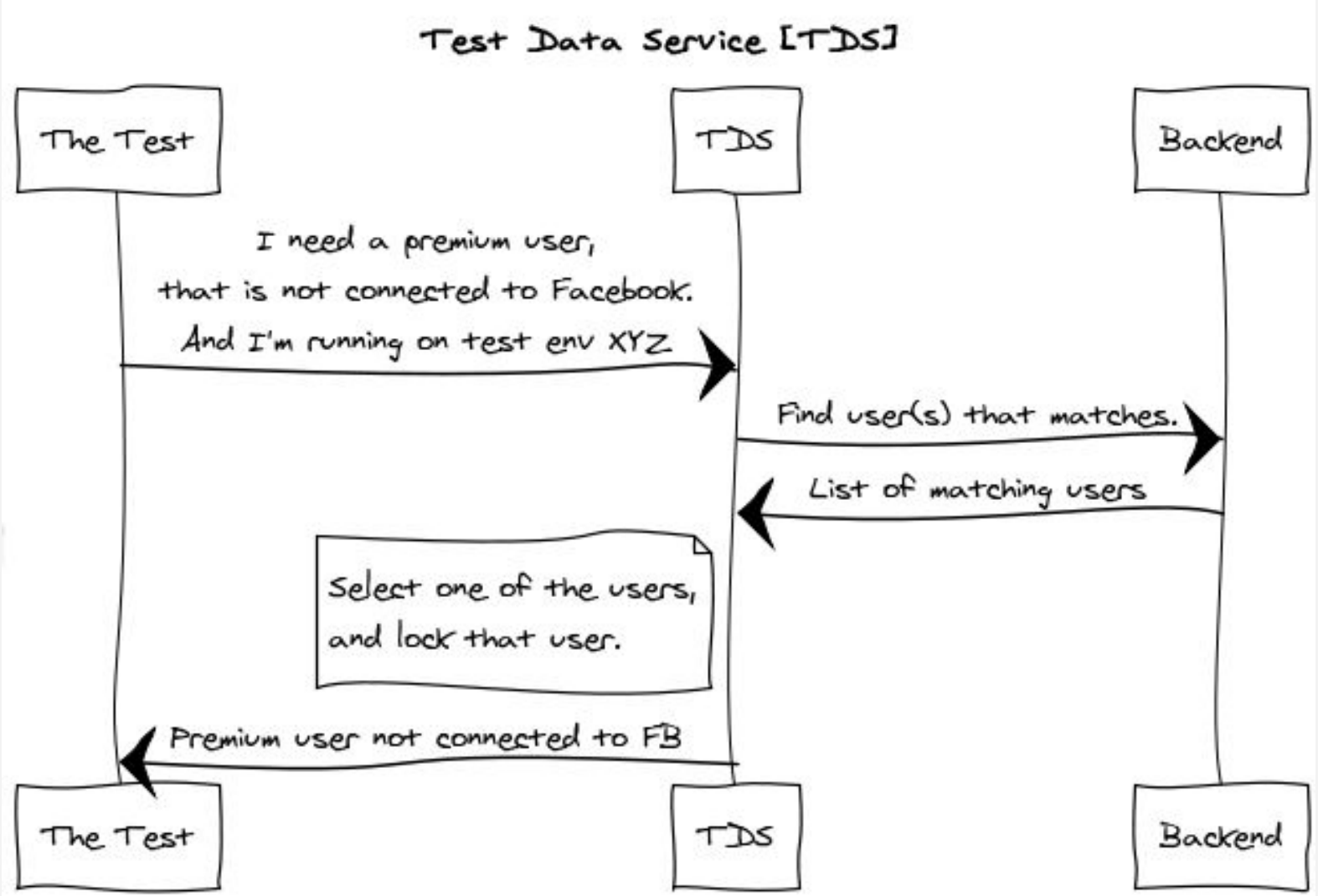
170 models

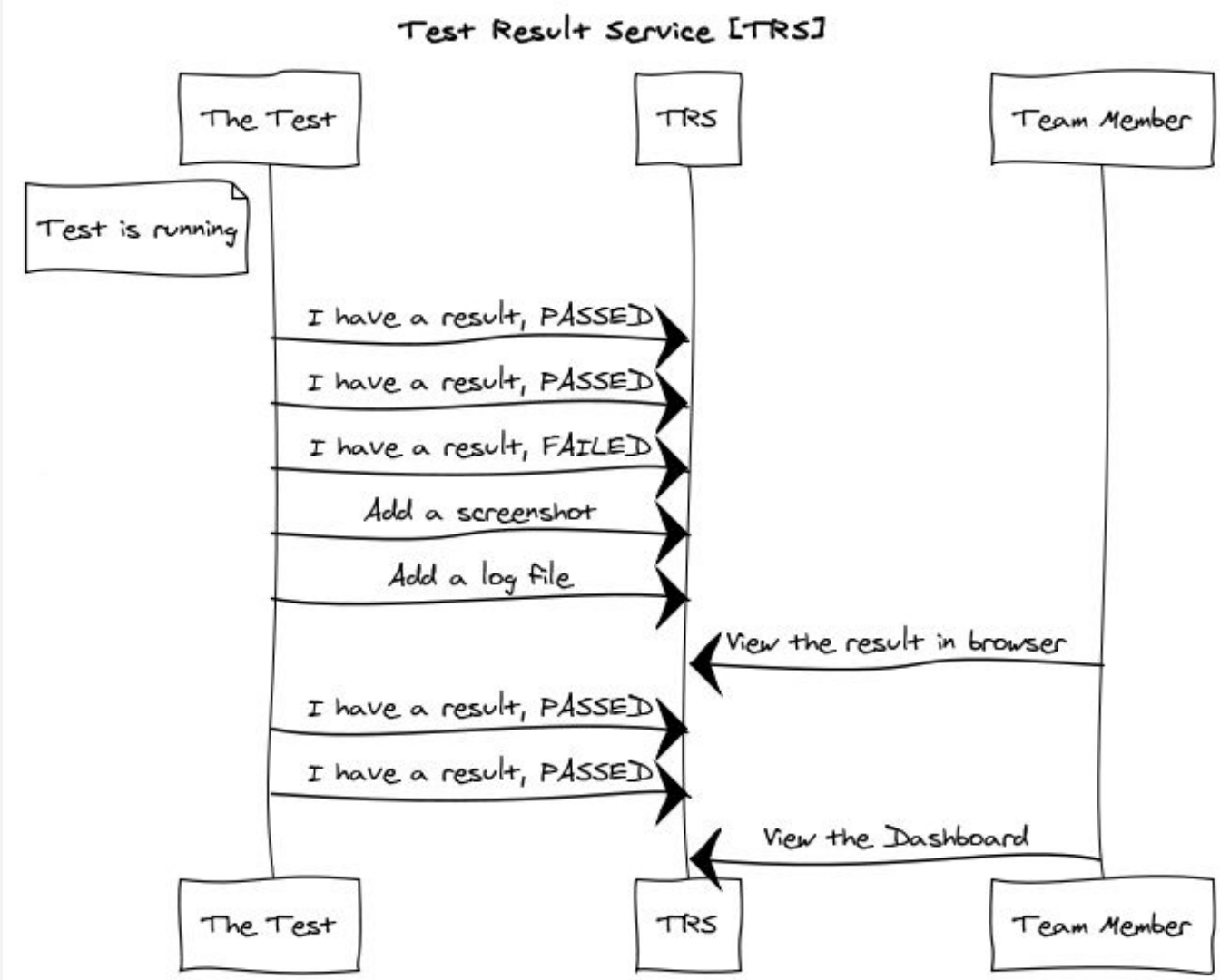
2047 states

2897 transitions

Supporting systems

test data
test results
dashboards
hardware
emulators
simulators
virtual machines
test interfaces


Test Data Service [TDS]
The Test
TDS
Backend
I need a premium user,
that is not connected to Facebook.
And I'm running on test env XYZ
Find user(s) that matches.
List of matching users
Select one of the users,
and lock that user.
Premium user not connected to FB
The Test
TDS
Backend


Test Result Service [TRS]
The Test
TRS
Team Member
Test is running
I have a result, PASSED
I have a result, PASSED
I have a result, FAILED
Add a screenshot
Add a log file
View the result in browser
I have a result, PASSED
I have a result, PASSED
View the Dashboard
The Test
TRS
Team Member

This table displays the results of the TA-tests for iOS platform, Results within 72 hours are showing.

Change the hours of the dashboard: Update Hour Suite Name Filter: ok

Edit Dashboard

	0.9.2						gerrit		master					
	iPad3 (iOS7)	iPadMini (iOS6)	iPadSim (iOS7)	iPhone4S (iOS6)	iPhone5 (iOS7)	iPhoneSim (iOS7)	iPadSim (iOS7)	iPhoneSim (iOS7)	iPad2 (iOS7)	iPad4 (iOS7)	iPadSim (iOS6)	iPhone5 (iOS7)	iPhoneSim (iOS7)	iPodTouch (iOS6)
AbroadTooLong														
AddRemovePlaylist														
AddRemoveTrack														
AdsEnabledTest														
ArtistPage														
AudioAdsSmoke														
AudioPreview														
Browse														
ContextMenu														
EmailSignup														
FacebookScrobbling														
FilterFriends														
FilterPlaylist														
FolderStructure														
Inbox														
Login														
OpenMMS_LoggedOut														
OpenURI_LoggedIn														
OpenURI_LoggedOut														
PlaybackLatencySeekOffline														
PlaybackLatencySeekOnline														
PlaybackLatencySkipOffline														
PlaybackLatencySkipOnline														
PlayContextRestore														
PlayQueue														
RadioFromContext														
RadioThumbsSkips														
RadioView														
Search														
SearchURI														
SettingsRestore														
StarUnstar														
StateRestore														
StreamNonPremium														
StreamPremium														
SyncPlaylist														
UpsellDMCA														
UpsellFreeTier														
UpsellNonDMCA														
UpsellPremium														

All tests failed
All tests passed
Failed and passed tests
No test coverage

Test Details

Go to suite

SAVE ATTACHMENTS FOR THIS TEST SAVE

Suite	JENKINS - iPhone4S - release
Result	Pass(10)/Total(11)
Start time	2013-05-05 17:53:34 UTC
TestType	AutomatedSystemTest
Target	iPhone4S
Name	com.spotify.qa.aut.client.ios.contextmenu.ContextMenuTest.TrackContextMenu
Jenkins Job	http://jenkins.spotify.net/job/Run%20test%20on%20iOS%20device%20(Mac%20Mini%202)/2461/
Platform	iOS
project	SPKVONC
Branch	release
Group	iOSContextMenu
Group	iPhoneSim
Group	iPadSim
Group	iPhoneDevice
Group	iPadDevice
Family	iPhone
Device	iPhone4S
iOS version	6.1.1
Model	Login.graphml
Test description	
Traversing style	A_STAR{VERTEX='Vertex: 'v_InitialView', INDEX=3'}
Model	TrackContextMenu.graphml
Test description	
Traversing style	SHORTESTNONOPT{EC>=100}
iOS NuRemote	Reconnect
iOS Startup Time	19626ms
iOS Startup Time	9202ms
User	qatest28
iOS Discover	What's New [qatest28, premium, SE, ab-mobile-discover=0]
Spotify version	0.6.0.671
FailStep	e_GoToPlaylist
FailFeature	ContextMenu

Device	iPhone4S
iOS version	6.1.1
Model	Login.graphml
Test description	
Traversing style	A_STAR{VERTEX='Vertex: 'v_InitialView', INDEX=3'}
Model	TrackContextMenu.graphml
Test description	
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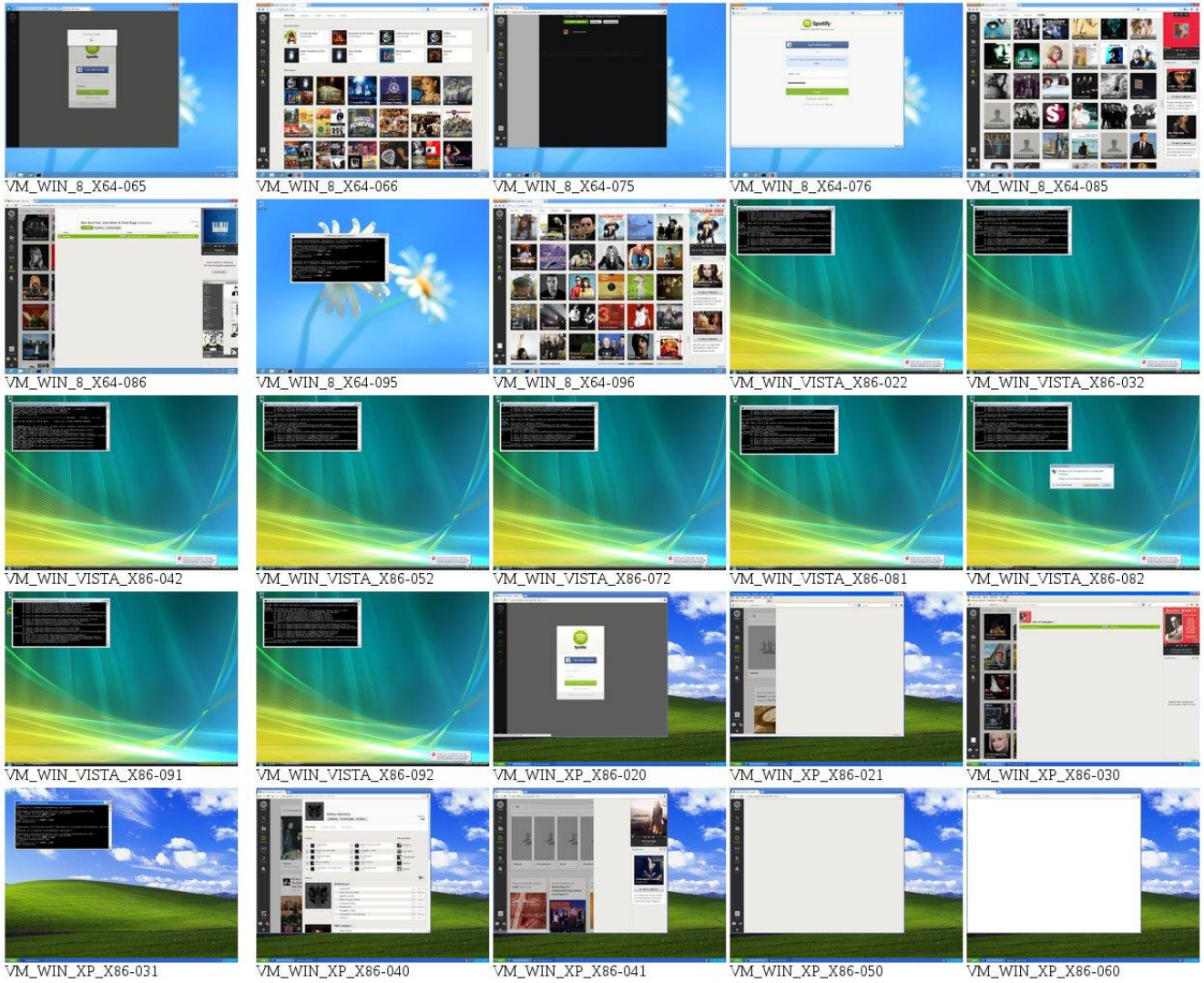
iOS NuRemote	Reconnect
iOS Startup Time	19626ms
iOS Startup Time	9202ms
User	qatest28
iOS Discover	What's New [qatest28, premium, SE, ab-mobile-discover=0]
Spotify version	0.6.0.671
FailStep	e_GoToPlaylist
FailFeature	ContextMenu
End time	2013-05-05 17:55:46 UTC
Duration	0 hours, 2 min, 11 sec

Login.jpg
TrackContextMenu.jpg
client.log
graphwalker.log

Add key value pair: Add

Test Results

Feature	Result	Model	Edge/vertex	Attachments
Login	OK	Login	e_Init	1367776465785.jpg
Login	OK	Login	v_NuxLoginPrompted	1367776470916.jpg
Login	OK	Login	e_NuxLoginHere	1367776474544.jpg
Login	OK	Login	v_LoginPrompted	1367776478662.jpg
Login	OK	Login	e_LoginSpotify	1367776482350.jpg
Login	OK	Login	v_LoginSpotifyCreds	1367776486474.jpg
Login	OK	Login	e_ValidSpotifyId	1367776495522.jpg
Login	OK	Login	v_InitialView	1367776504615.jpg
ContextMenu	OK	ContextMenu	e_Init	1367776507749.jpg
ContextMenu	OK	ContextMenu	v_InitialView	1367776510864.jpg
ContextMenu	FAIL	ContextMenu	e_GoToPlaylist	1367776543737.jpg

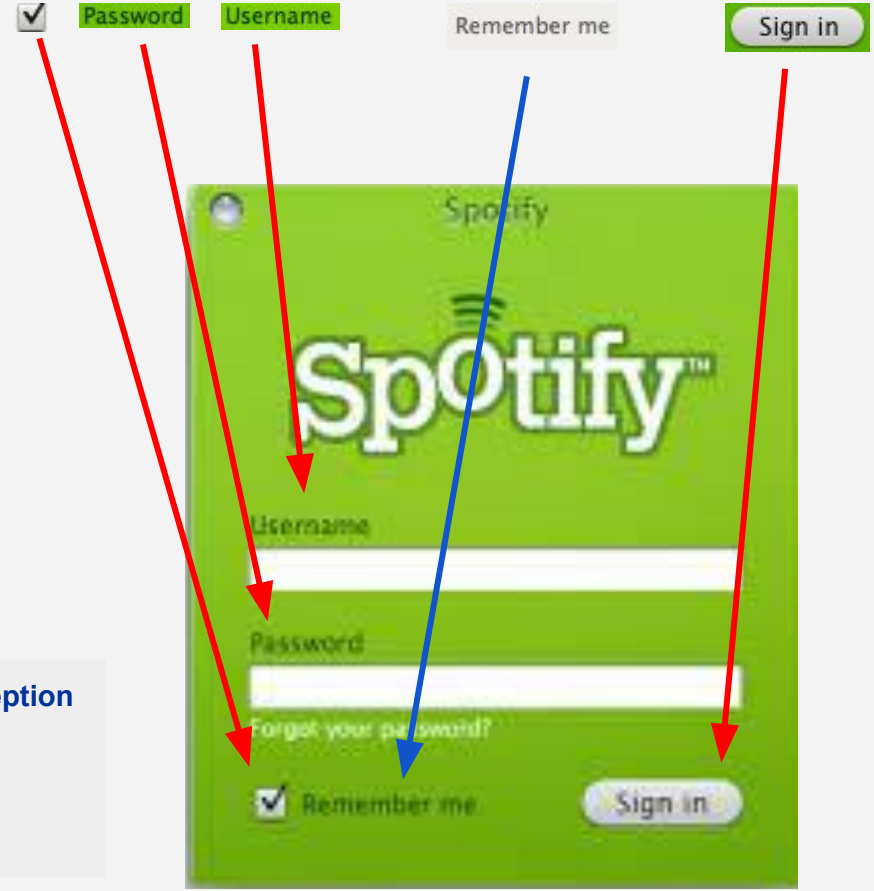


Virtual machines

Sikuli

Automates anything you see on the screen of your desktop computer running Windows, Mac or some Linux/Unix. It uses image recognition powered by OpenCV to identify GUI components.

```
public static boolean isLoginShown() throws FileNotFoundException
{
  logger.debug("Login view is currently shown");
  return checkExist("login/sign_in.png", 10);
}
```



nevyn / NuRemoting Public

Notifications | Fork 5 | Star 79

Code | Issues 1 | Pull requests 1 | Actions | Projects | Wiki | Security | Insights

master | 4 branches | 2 tags | Go to file | Code

nevyn note to self so I don't do all this work a third time — 65eb1d4 on 3 Jan 2017 — 72 commits

Controller	Bump CorePlot for Xcode 8 support	5 years ago
Examples	Move Tim's libffi out of the way	5 years ago
NuRemote	I hear ARC is nice	5 years ago
Vendor/Nu	Move Tim's libffi out of the way	5 years ago
.gitignore	CorePlot: Switch from submodule to CocoaPod	6 years ago
.gitmodules	Nope.	5 years ago
LICENSE	WIP Podspec; get iOS libffi through CocoaPods	5 years ago
NuRemoting.podspec	Could we make this work with ffi-mini instead?	5 years ago
README.md	Documenting the horrible protocol	11 years ago
TODO	note to self so I don't do all this work a third time	5 years ago

README.md

NuRemote

Put AsyncSocket, SPNuRemote and Nu.framework into your Mac or iOS project, do [[SPNuRemote new] run] somewhere, and suddenly you have magical powers. Say you did this to the standard Window+CoreData project in Xcode (as seen in the "iOS" folder in this repo), and then used your magic wand:

```
22:49:14 nevyn:~$ cat magic.nu
(set a 3)
(log "Hello #{a}")
(((((UIApplication sharedApplication) delegate) navigationController) topViewController) insertNewOb
(+ a 5)

22:49:16 nevyn:~$ nc -v 192.168.10.152 8023 < magic.nu
Connection to 192.168.10.152 8023 port [tcp/*] succeeded!
200 OK  8

22:51:01 nevyn:~$
```

About

Remote control your iOS app using Nu (lisp-on-objc)

Readme
MIT license
79 stars
4 watching
5 forks

Releases 1

Something that builds and ru... Latest
on 12 Aug 2016

Packages

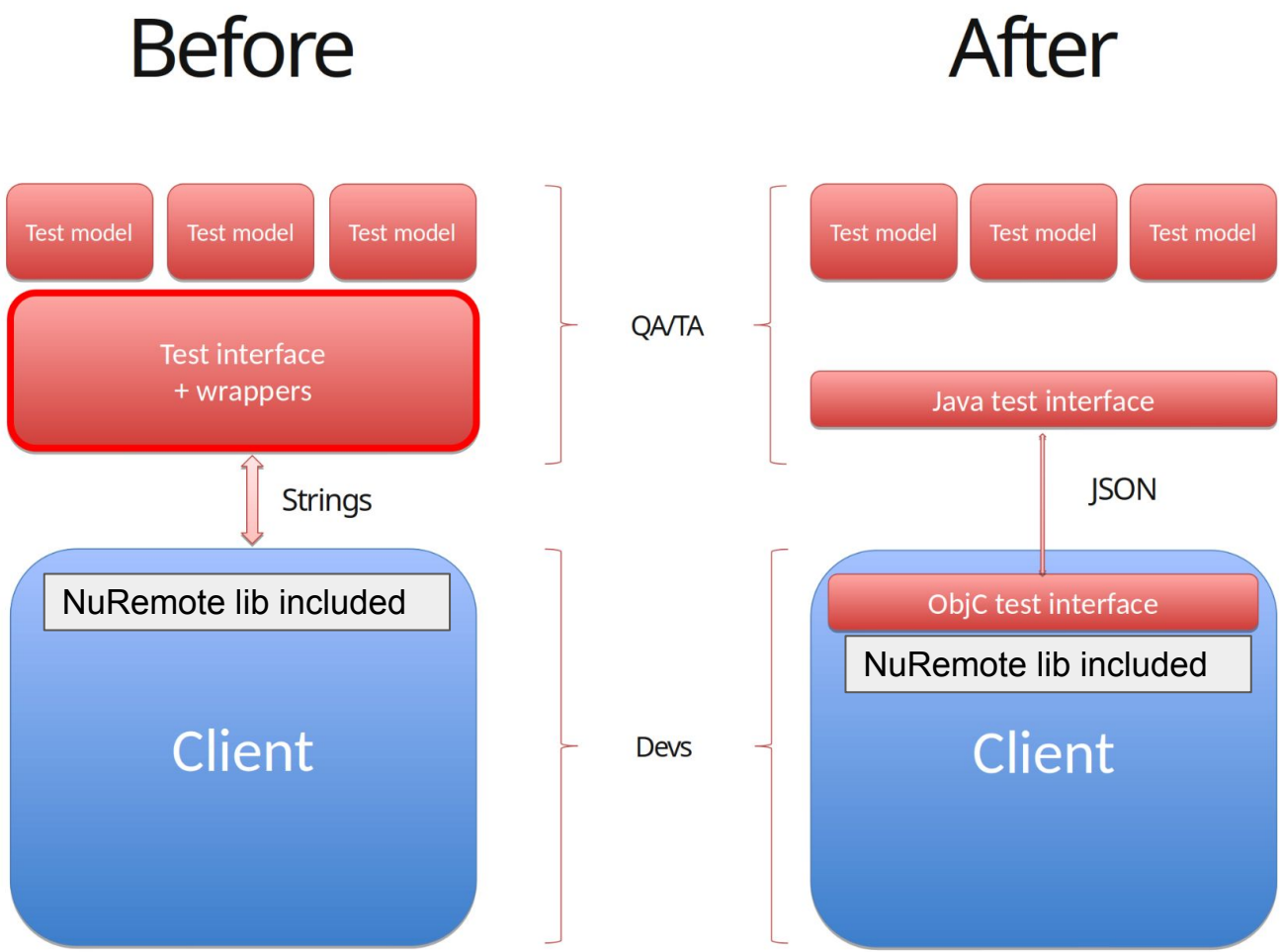
No packages published

Contributors 2

nevyn Nevyn Bengtsson
hallski Mikael Hallendal

Languages

Objective-C 98.9% Ruby 1.1%


Before
After
Test model
Test model
Test model
Test interface
+ wrappers
Strings
NuRemote lib included
Client
QA/TA
Devs
Test model
Test model
Test model
Java test interface
JSON
ObjC test interface
NuRemote lib included
Client

Before

```
String cmd = "android.view.View seekBarView =
solo.getView(com.spotify.mobile.android.ui.view.CancellableSeekBar.class,
0);";
cmd += "int[] xy = new int[2];";
cmd += "seekBarView.getLocationOnScreen(xy);";
cmd += "solo.clickOnScreen(xy[0] + 9 + (seekBarView.getWidth() - 18) * "
+ position + "f, xy[1] + seekBarView.getHeight() / 2.0f)";
BeanRemoteClient.sendToServer(cmd);
```

After

```
PlayerAuto player = Pages.remote(PlayerAuto.class);
player.seekTrack(position);
```

But it was not good enough

Moving activities upstream

Fearless Development

- Continuous delivery with quality
- Testing while coding
- Trusting the automation
- Team and products are always in a deliverable state
- ***This drives tech stacks to be testable, which usually has the benefit of a better architecture.***

The end of random long running tests?

- Automated tests has to be predictable.
- They need to deliver quick feedback.
- The need to deliver understandable feedback.
- It has to fit the CI pipelines.
- It’s a difference designing a test to find bugs than to verify functionality.

It has proven its worth

- It focuses on the desired behavior.
- It covers a lot of the system under test.
- It bridges the gap between stakeholders and engineers.
- It’s easier to maintain than similar test approaches.
- It’s interchangeable with test drivers.

Some useful links and reading

- Graphwalker
- Practitioners' best practices to Adopt, Use or Abandon Model-based Testing with Graphical models for Software-intensive Systems
- Practical Model-Based Testing — Say "Hello MBT"
- State Transition Testing – Automated Tests for Authentication Flows
- http://www.harryrobinson.net/
- What is Model-based testing