Mining Oracles for Fully Automated Test Generation

Andreas Zeller
Saarland University, Saarbrücken, Germany

UNIVERSITÄT DES SAARLANDES

max planck institut informatik

Max Planck Institute for Software Systems

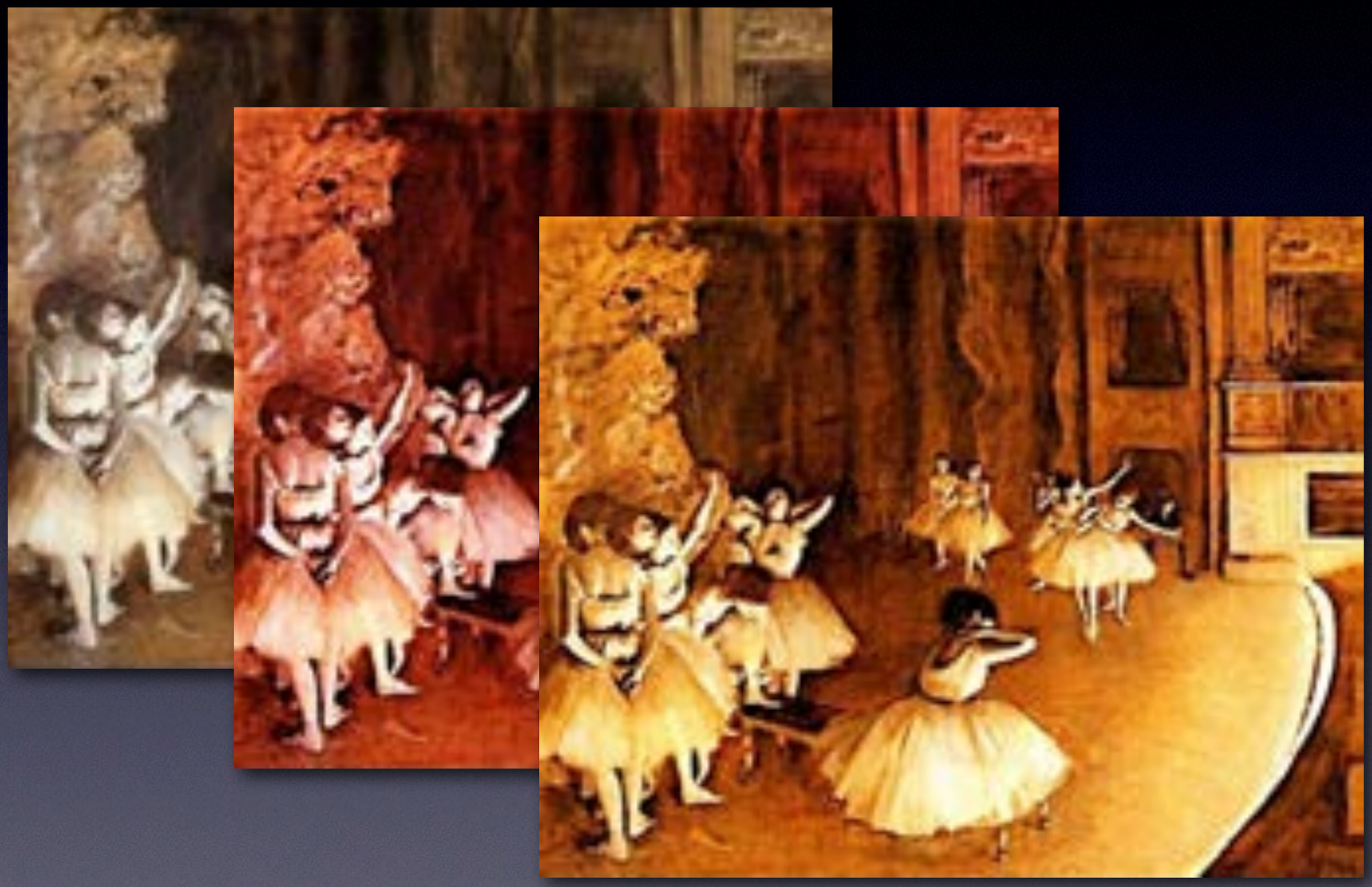
DFKI

intel Visual Computing Institute

CISPA Center for Information Security, Privacy and Accountability

Testing

Software is manifold



Software is manifold

Software is manifold

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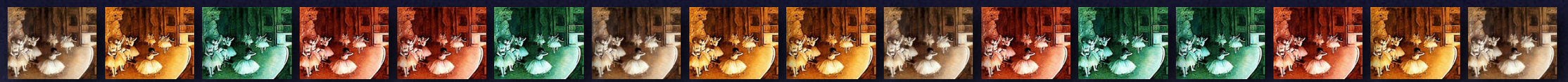
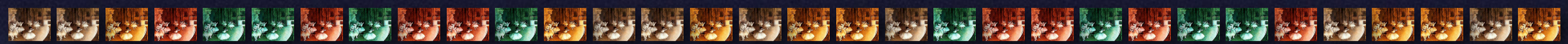
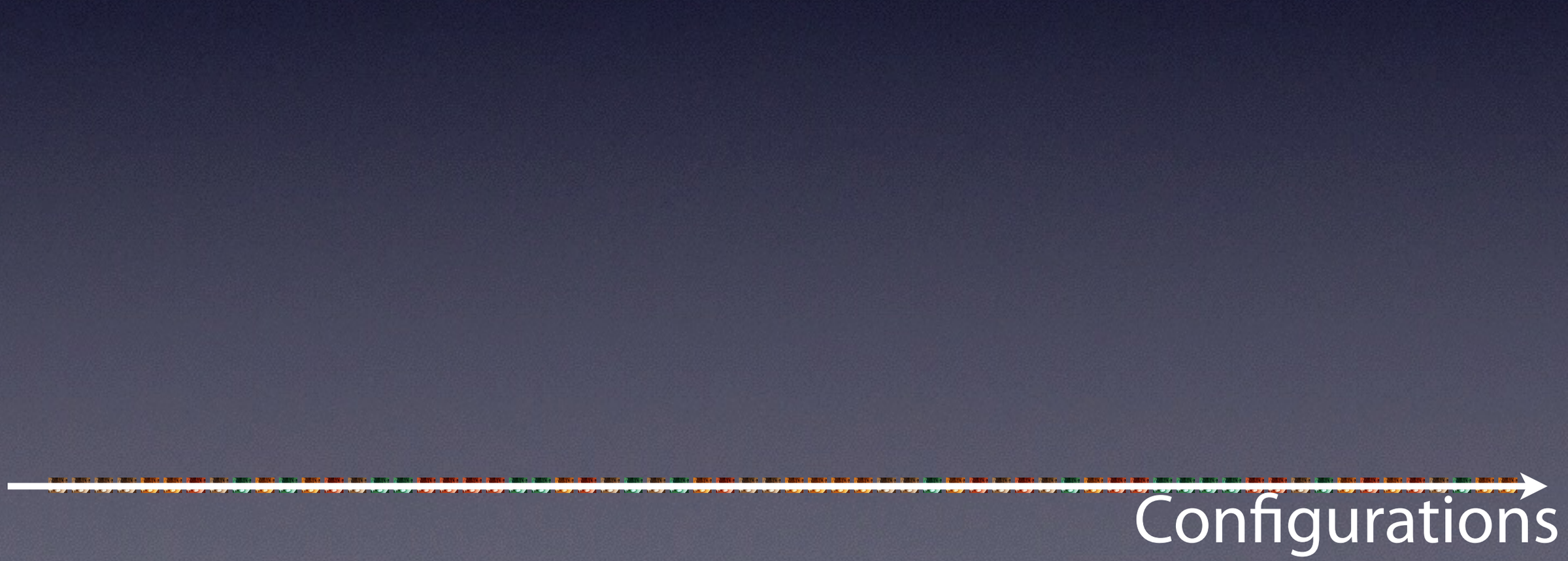


Software is manifold

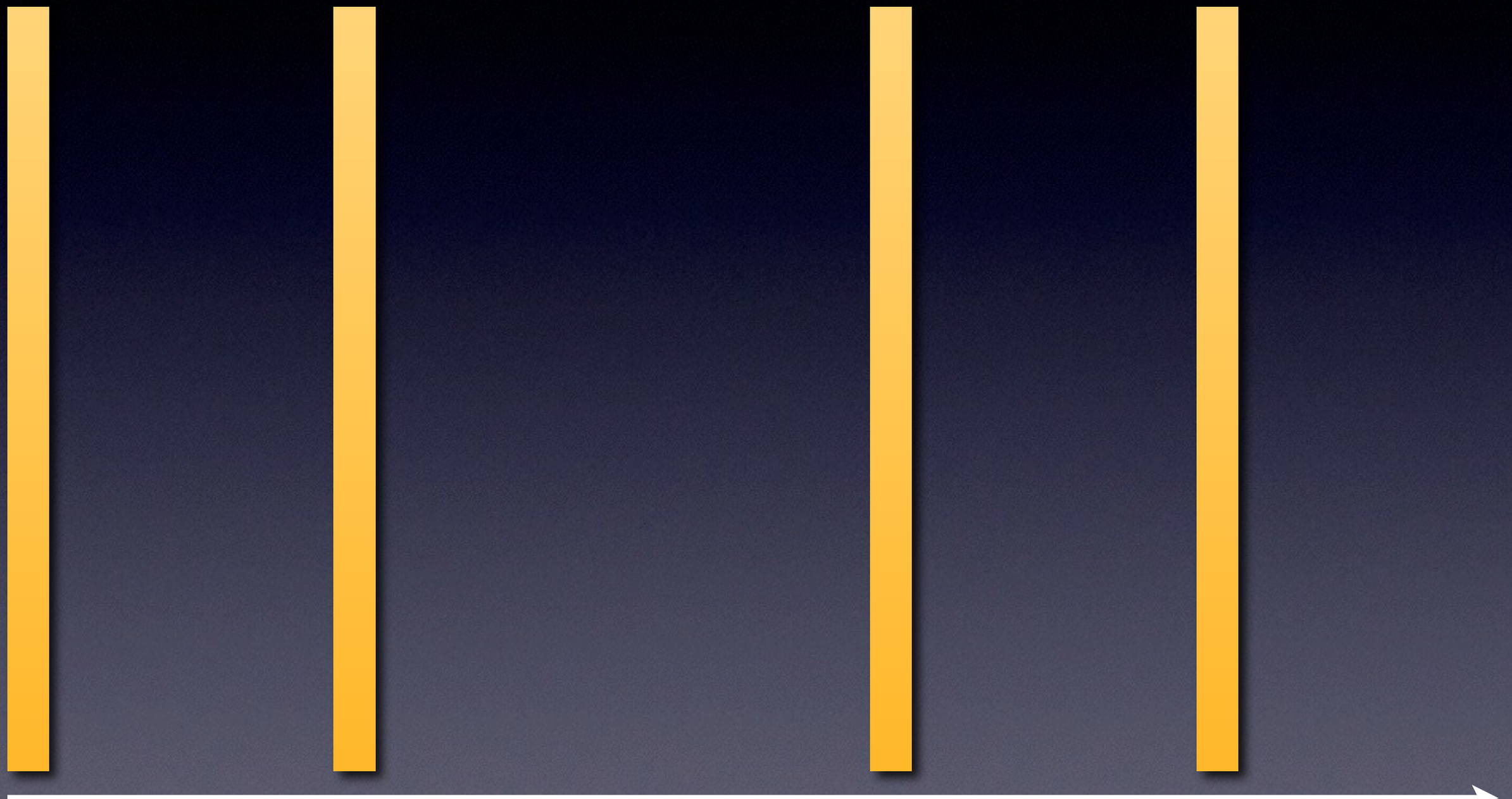


Software is manifold

Testing



Testing



Dijkstra's Curse

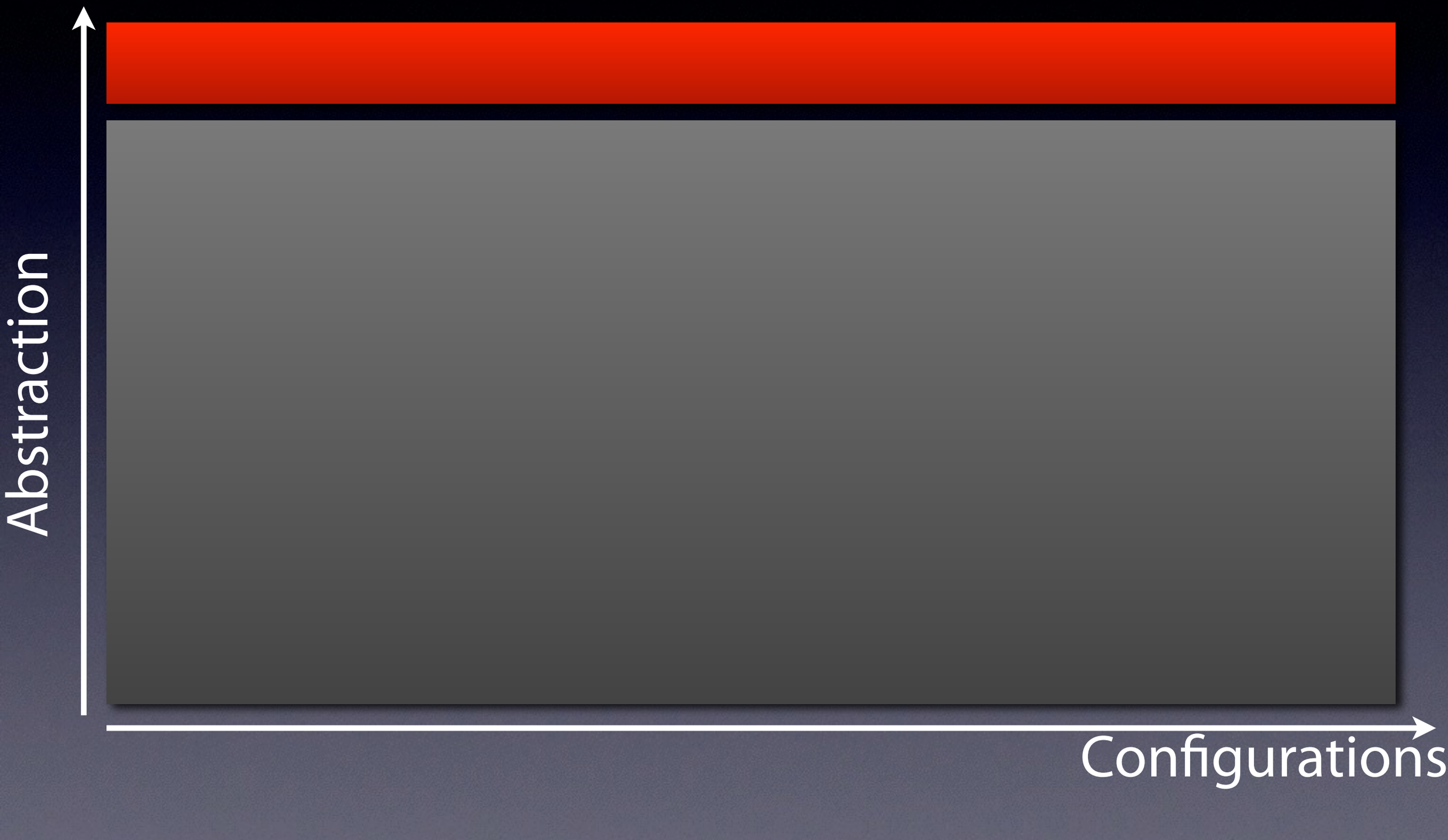
Testing can only find the *presence* of errors, not their *absence*

Configurations

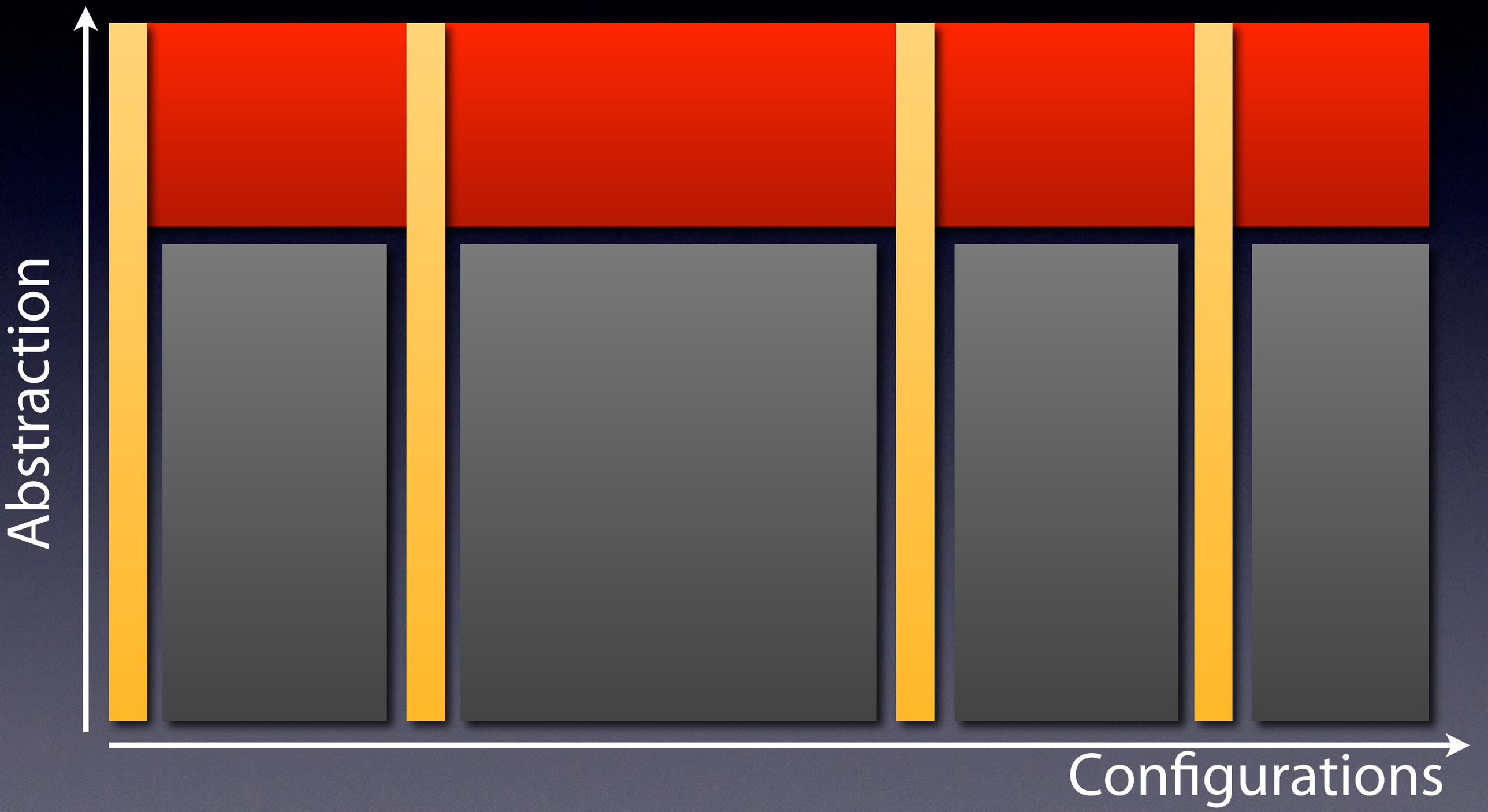
Formal Verification

Formal Verification

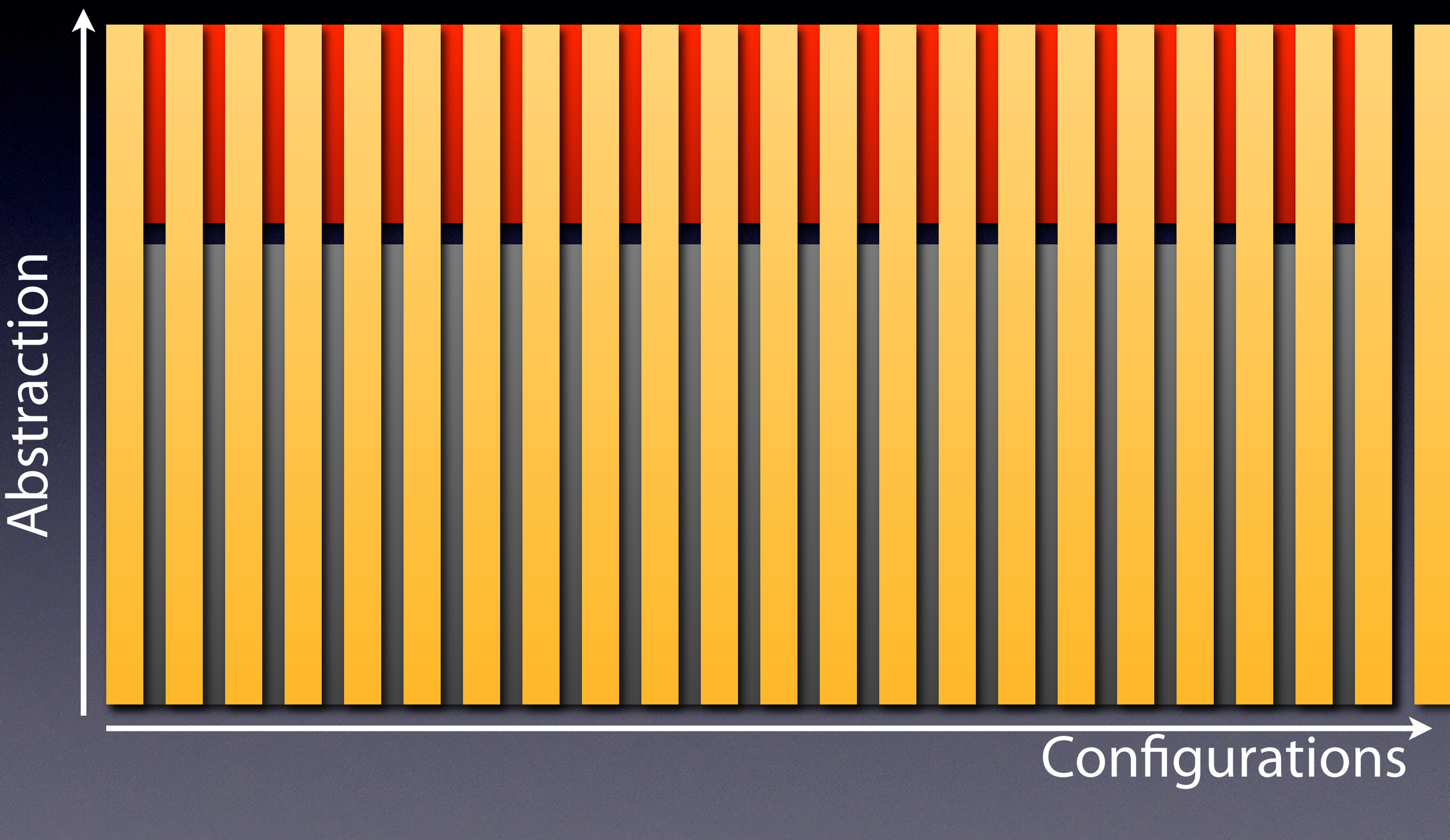
Formal Verification



The Best of two Worlds



Generating Tests



Address Book

New contact

New category

First name	Last name	E-mail	Phone	Mobile
James S.	Roebuck	JamesSRoe...	561-888-...	561-888-...
Naomi D.	Long	NaomiDLo...	390-12-5...	390-12-1...
Karen L.	**Lloyd**	**KarenLLlo...**	**228-76-1...**	**228-76-...**
Jean R.	Voigt	JeanRVoigt...	610-344-...	610-344-...
Douglas L.	Green	DouglasLG...	612-615-...	612-615-...

- All
  - Contractors
  - Customers
  - Employees
- Suppliers
  - Europe
  - U.S.

First name: Karen L.

Last name: Lloyd

Phone: 228-76-1230

Mobile: 228-76-8710

E-Mail: KarenLLloyd@ex

Second e-mail: Karen@CreditCa

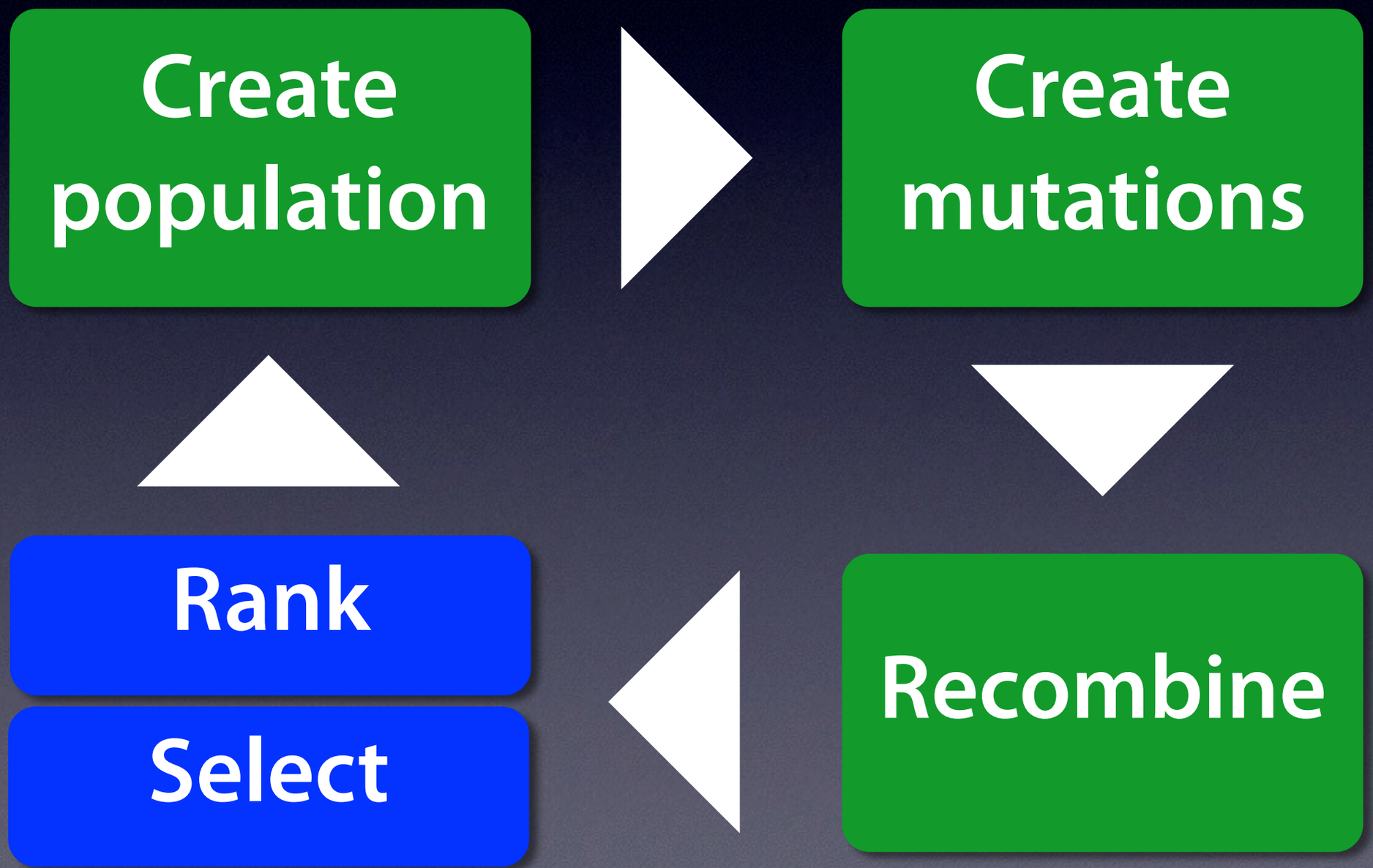
URL: http://www.crec

Apply

Notes:
1673 Jehovah Drive
Fredericksburg, VA 22408

Infinite Monkey Theorem

Evolutionary Algorithms



Create population

“fdsakfh+ew%3gfhdi%4f”

“fwe8^ru786234jä”

Mutation

“fdsakfh+br%3gfhdi%4f”

“fwe8^ru&26234jä”

“fdsakfh+ew%4gfhdi%4f”

“xb3#ru786234jä”

Recombine

“fdsakfh+ew%4gfhdi%4f”

“xb3#ru736234jä”

Create population

“fdsakfh+ew%3gfhdi%4f”

“fwe8^ru786234jä”

Mutation

“fdsakfh+br%3gfhdi%4f”

“fwe8^ru&26234jä”

“fdsakfh+ew%4gfhdi%4f”

“xb3#ru786234jä”

Crossover

“fdsakfh+ew%4gfhdi%4f”

“xb3#ru786234jä”

“xb3#ru7%4gfhdi%4f”

Selection and Ranking

if (angle = 47 ∧ power = 532) { … }

“fdsakfh+ew%4gfhdi%4f” angle = 31

“xb3#ru786234jä” angle = 48

“xb3#ru7%4gfhdi%4f” angle = 65

Selection and Ranking

if (angle = 47 ∧ power = 532) { … }

angle = 51

“xb3#ru786234jä”

angle = 48

angle = 47

EXSYST

Florian Groß, Andreas Zeller

Address Book

New contact

New category

First name	Last name	E-mail	Phone	Mobile
James S.	Roebuck	JamesSRoe...	561-888-...	561-888-...
Naomi D.	Long	NaomiDLo...	390-12-5...	390-12-1...
Karen L.	**Lloyd**	**KarenLLlo...**	**228-76-1...**	**228-76-...**
Jean R.	Voigt	JeanRVoigt...	610-34...	
Douglas L.	Green	DouglasLG...	612-61...	

All
Contractors
Customers
Employees

First name Karen L.

Last name Lloyd

E-

Second e-

Calculator

1,245

C

7 8 9 +

4 5 6 -

TerpWord - quotes2.html

File Edit View Font Format Search Insert Table Help

New Document ^N
Open Document... ^O
Print... ^P
Recently Opened
Save ^S
Save As...
Save RTF...

quotes2.html
quotes.html

Roman

Quotes

TerpSpreadsheet Graph

Copy

TerpPresent

Datei Bearbeiten Ansicht Format TPBook Zelle Markierung Fenster Hilfe

n b i

- 1993

24

X

Neuer Graph*

Slide 1

Today's Keynote:

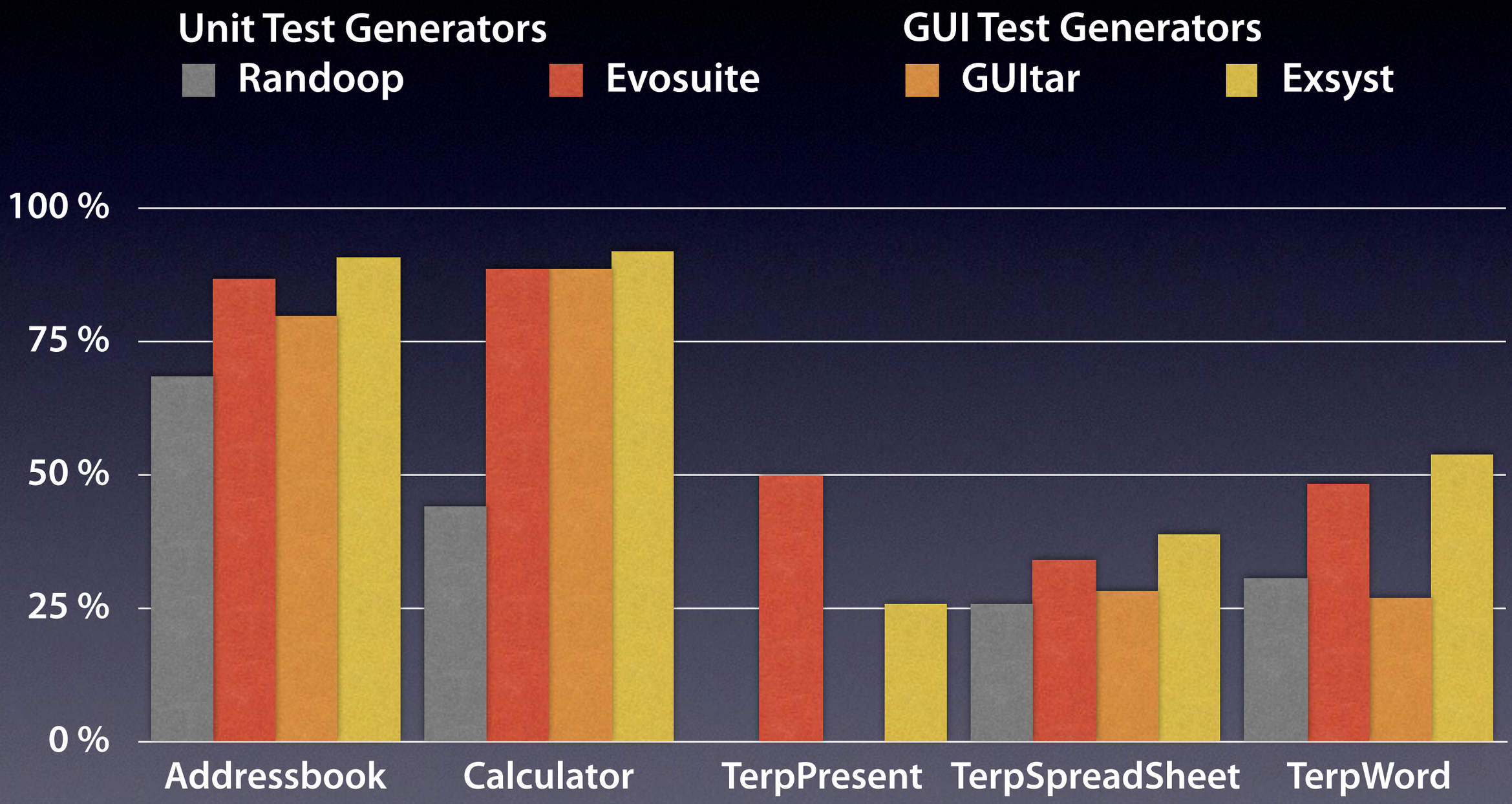
Search-Based Program Analysis

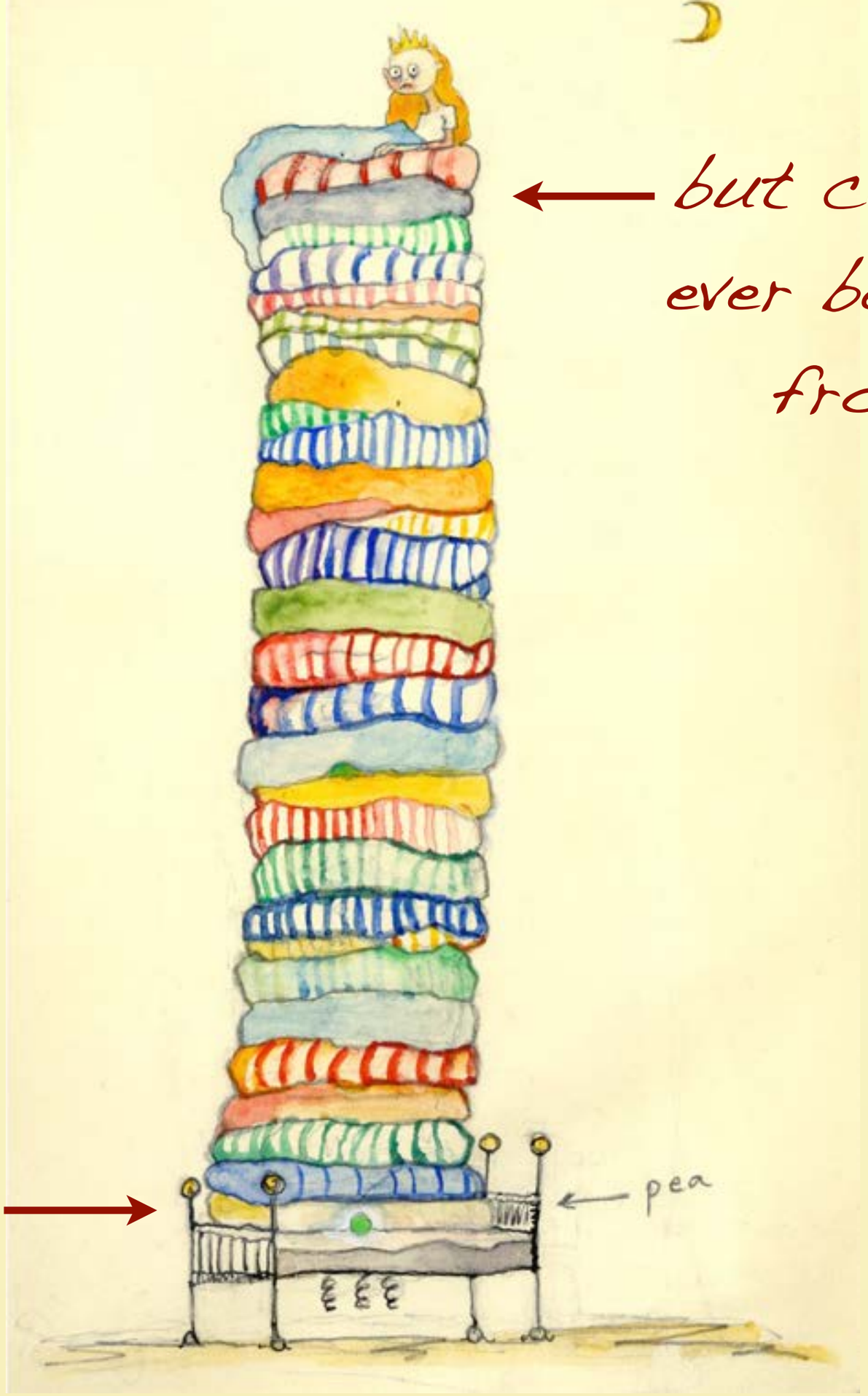
Jeffrey B.

James M

Plays Pleasant and

Test Coverage





← but can these ever be invoked from here?

testing may detect errors here... →

← test generation
at the system level

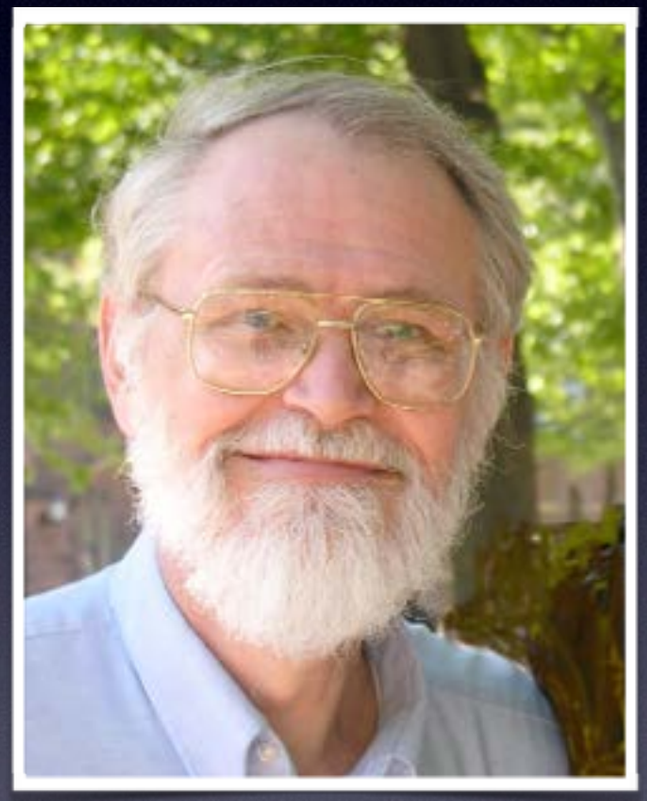
← test generation
at the system level

anything that
happens here
is <u>real</u> →

The Oracle

The Oracle

" Without specification, there are no bugs— only surprises"



Brian Kernighan

Specifications

removeChild

$\Delta XMLElement$

$child? : XML\_ELEMENT$

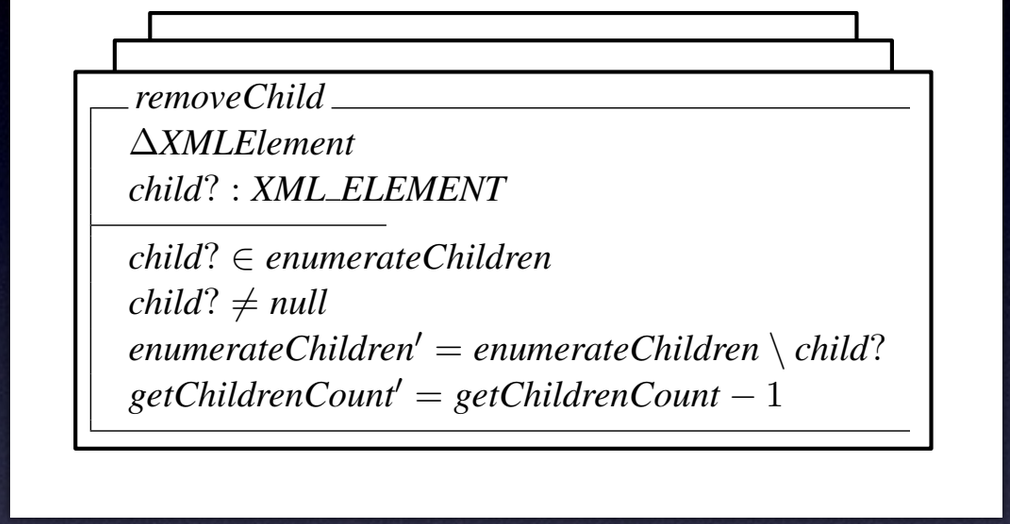
$child? \in enumerateChildren$

$child? \neq null$

$enumerateChildren' = enumerateChildren \setminus child?$

$getChildrenCount' = getChildrenCount - 1$

Specifications



removeChild

$\Delta XMLElement$

$child? : XML\_ELEMENT$

$child? \in enumerateChildren$

$child? \neq null$

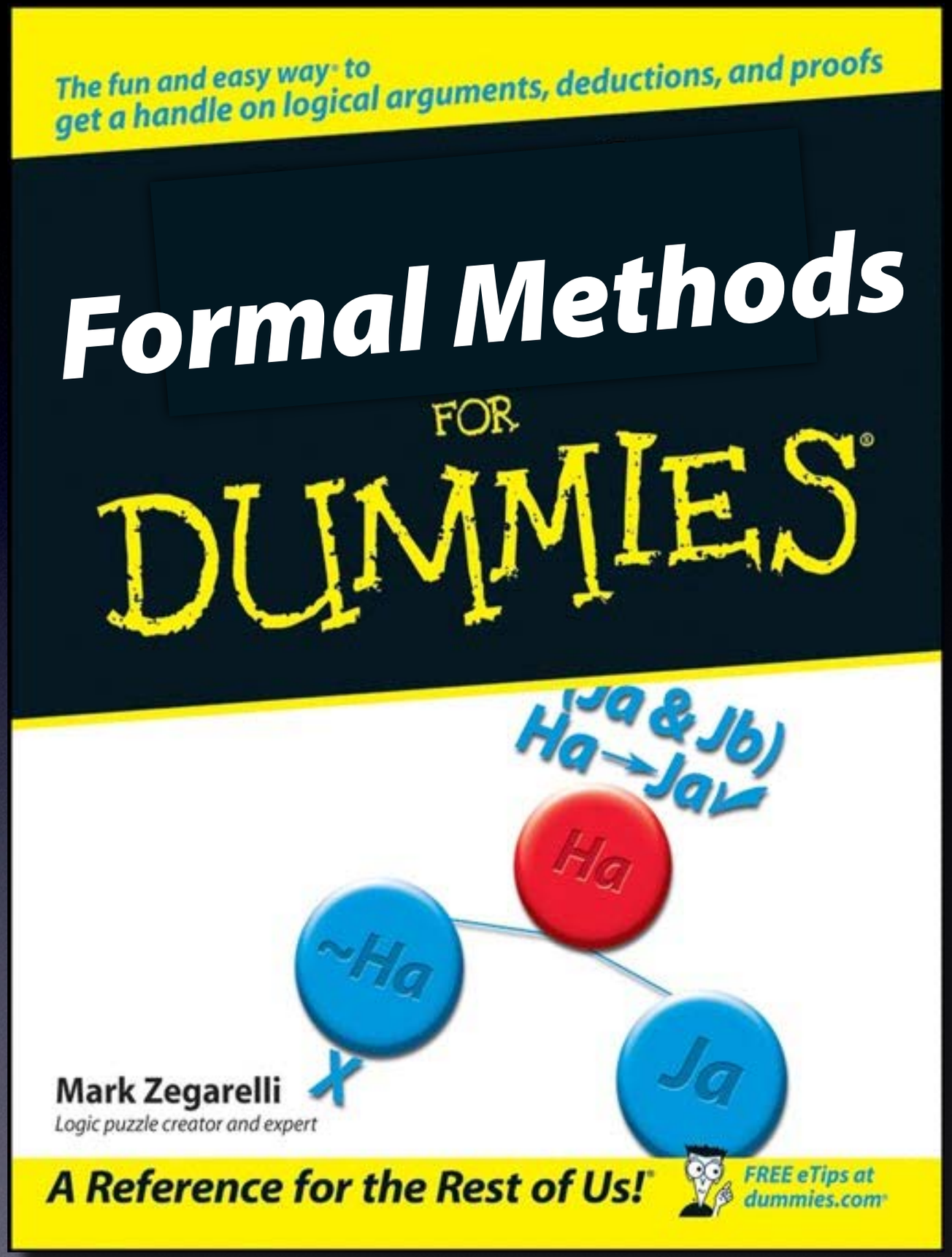
$enumerateChildren' = enumerateChildren \setminus child?$

$getChildrenCount' = getChildrenCount - 1$

fully automated testing

fully automated debugging

widely automated verification


The fun and easy way® to
get a handle on logical arguments, deductions, and proofs
Formal Methods
FOR
DUMMIES®
(Ja & Jb)
Ha → Ja
Ha
~Ha
Ja
X
Mark Zegarelli
Logic puzzle creator and expert
A Reference for the Rest of Us!®
FREE eTips at
dummies.com®

The Oracle


Microsoft Outlook
Unknown error
OK
Was this information helpful?

Specifying Correctness

removeChild

$\Delta XMLElement$

$child? : XML\_ELEMENT$

$child? \in enumerateChildren$

$child? \neq null$

$enumerateChildren' = enumerateChildren \setminus child?$

$getChildrenCount' = getChildrenCount - 1$

Normality

Mining Normality

removeChild

$\Delta XMLElement$

$child? : XML\_ELEMENT$

$child? \in enumerateChildren$

$child? \neq null$

$enumerateChildren' = enumerateChildren \setminus child?$

$getChildrenCount' = getChildrenCount - 1$

Top Sites

Go to this address

Google

News (8) More Work Fun Papers Research Apple Travel Shop Money Search Comics Todo

Top Sites | History

Log In | Facebook

http://www.facebook.com/home.php

Edit

Search History

Willkommen bei Facebook - anmelden, registrieren oder mehr erfahren - Mozilla Firefox

Datei Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe

Willkommen bei Facebook - anmelden, regist...

www.facebook.com/index.php

facebook

E-Mail Passwort Anmelden

Angemeldet bleiben Passwort vergessen?

Facebook ermöglicht es dir, mit den Menschen in deinem Leben in Verbindung zu treten und Inhalte mit diesen zu teilen.

WEBMATE

Martin Burger, Valentin Dallmeier, Andreas Zeller

Registrieren

Facebook ist und bleibt kostenlos.

Vorname:

Nachname:

Deine E-Mail-Adresse:

E-Mail nochmals eingeben:

Neues Passwort:

Ich bin: Geschlecht auswählen:

Geburtstag: Tag: Monat: Jahr:

Warum muss ich meinen Geburtstag angeben?

Wenn du auf „Registrieren" klickst, akzeptierst du unsere Nutzungsbedingungen und erklärst unsere Datenverwendungsrichtlinien gelesen und verstanden zu haben.

Registrieren

Erstelle eine Seite für eine Berühmtheit, eine Band oder ein

WebDriver

Normality: Platforms

Abnormal Behavior

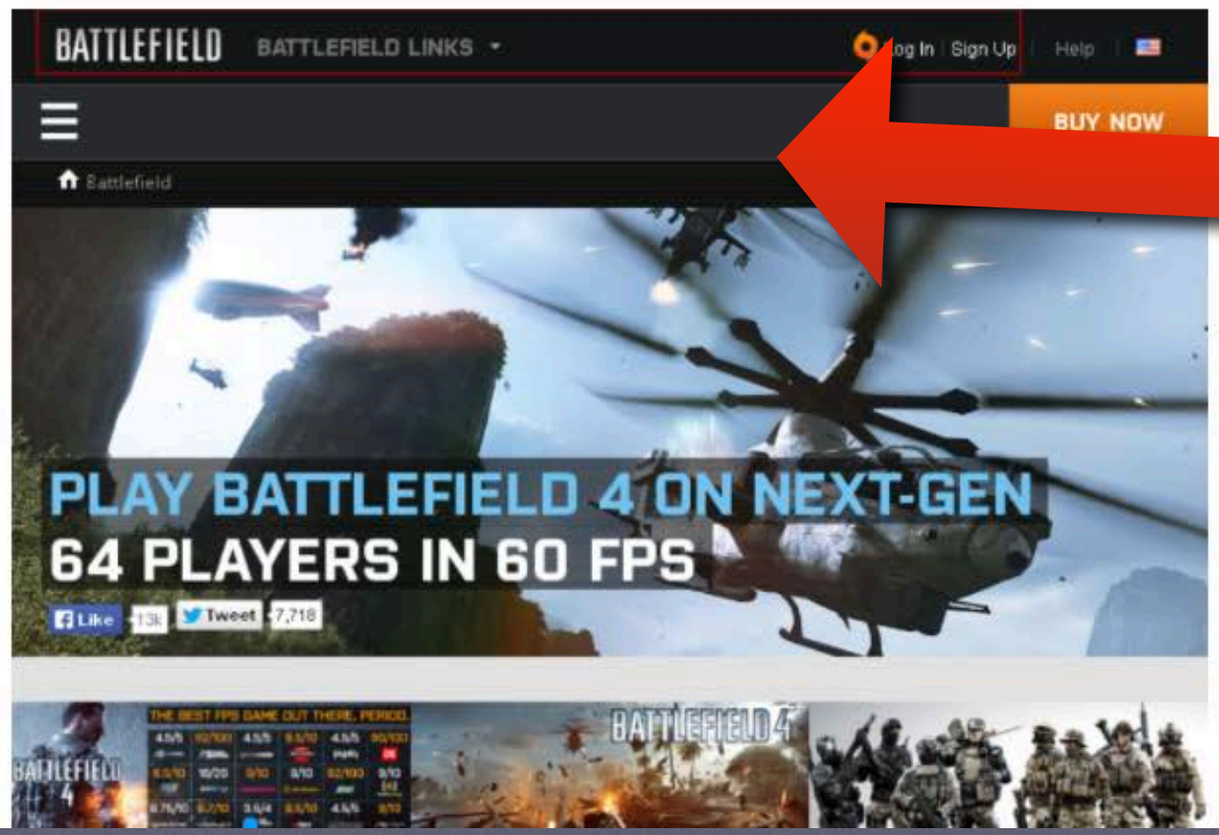
Dashboard / Test: http://www.battlefield.com/ / State: e7b5f462538c372 / Issue: 50135

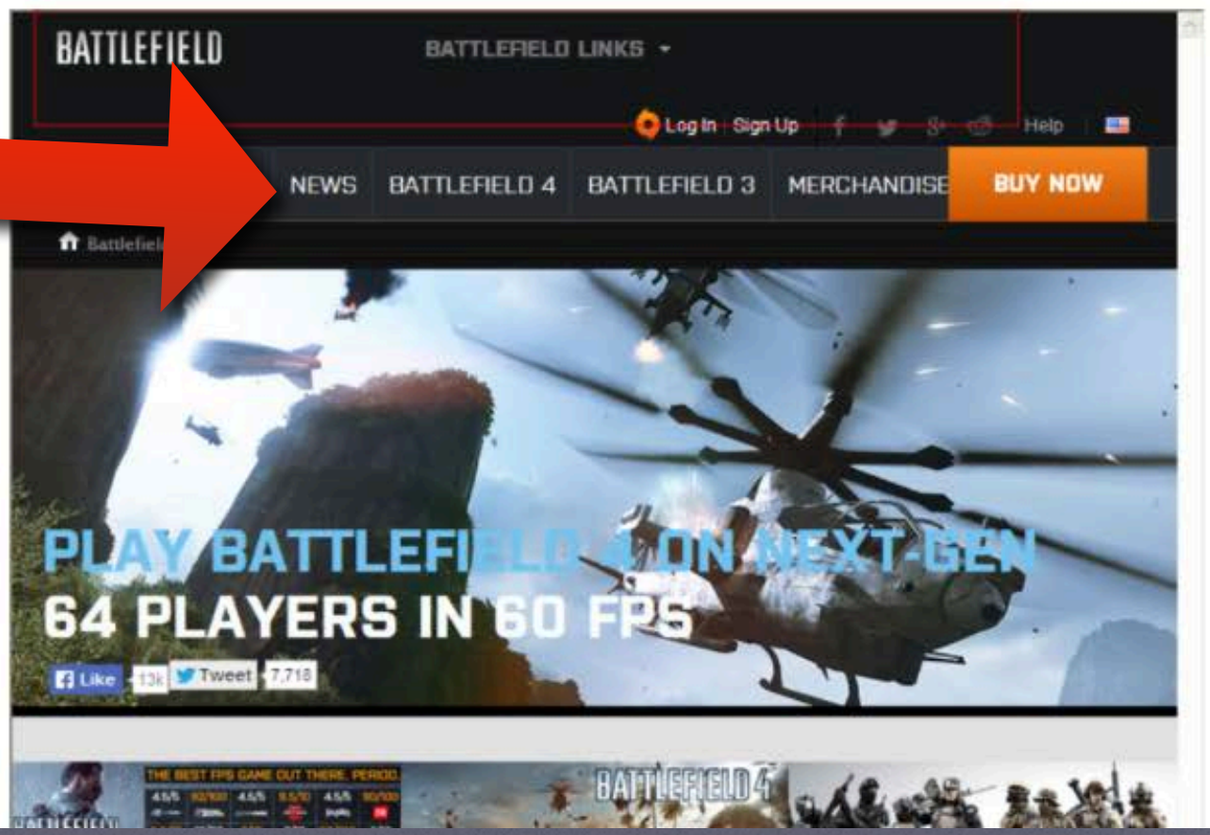
Incorrect Dimensions: //div[@id='gus-wrapper']/div[1]/div

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

Reference Browser
Mozilla Firefox 17 / Windows XP

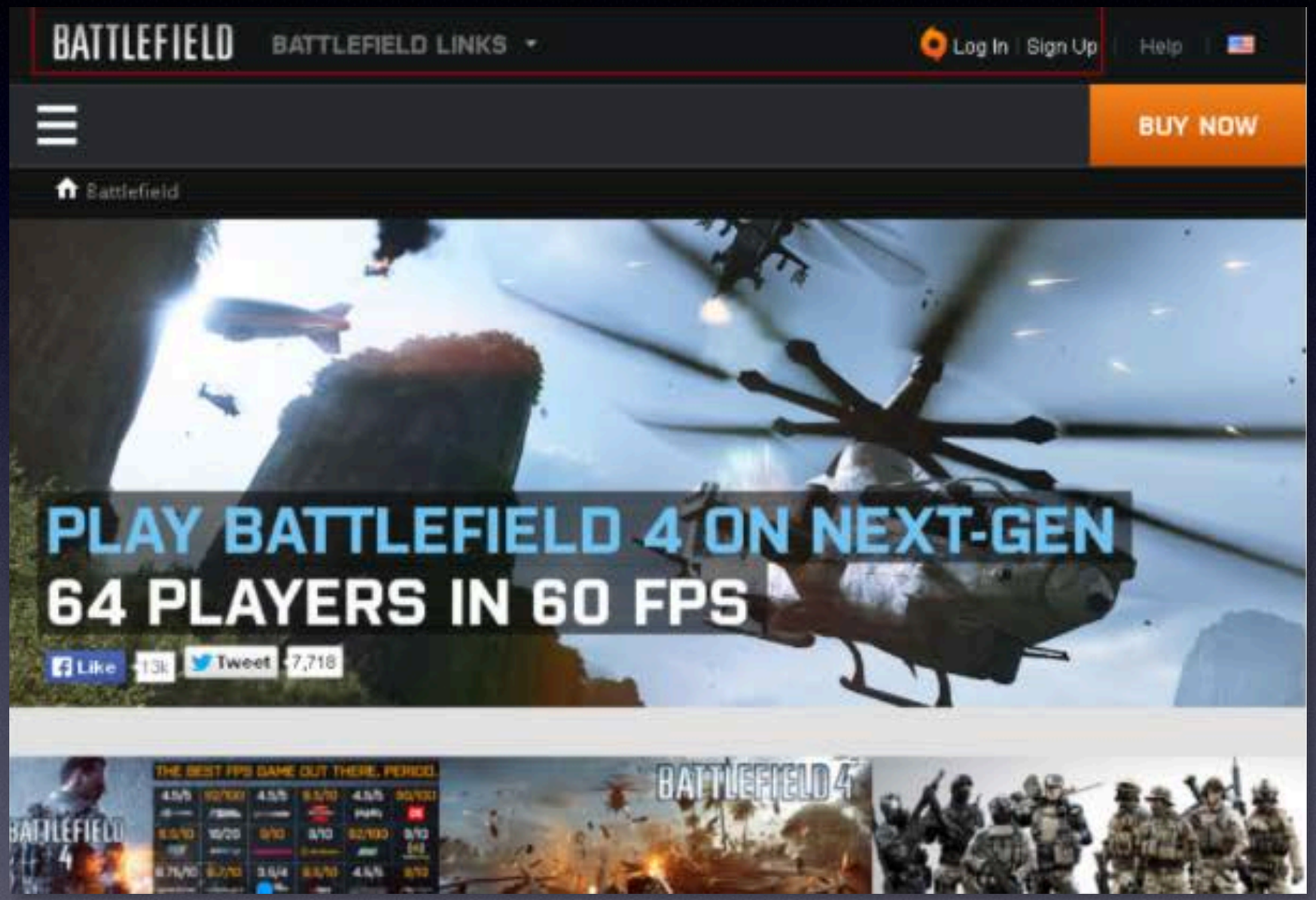
X-Browser
Internet Explorer 8 / Windows 7





Presence of *interactive* elements

Presence of *non-interactive* items

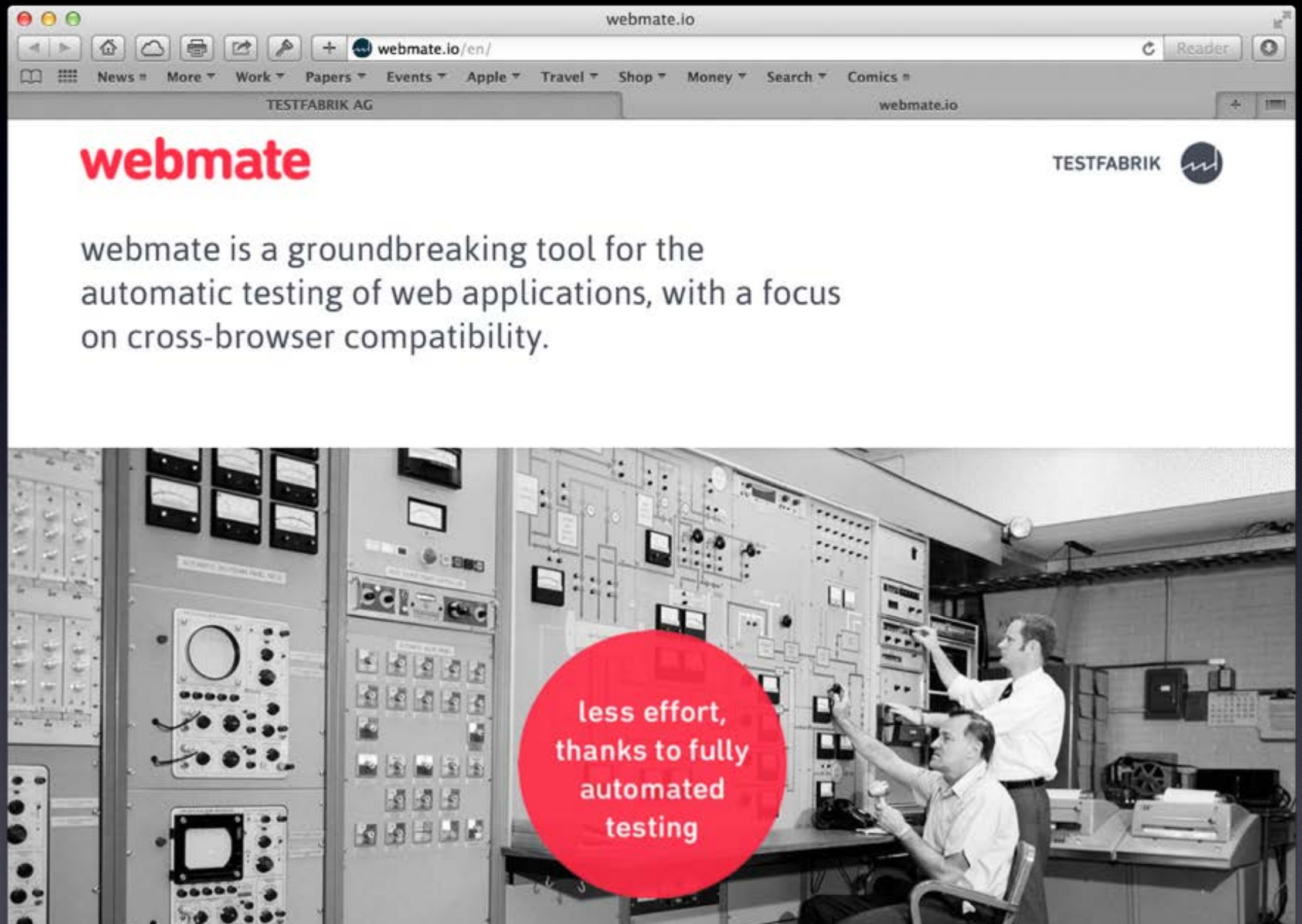


Dimension

Position

Pixels

webmate.io

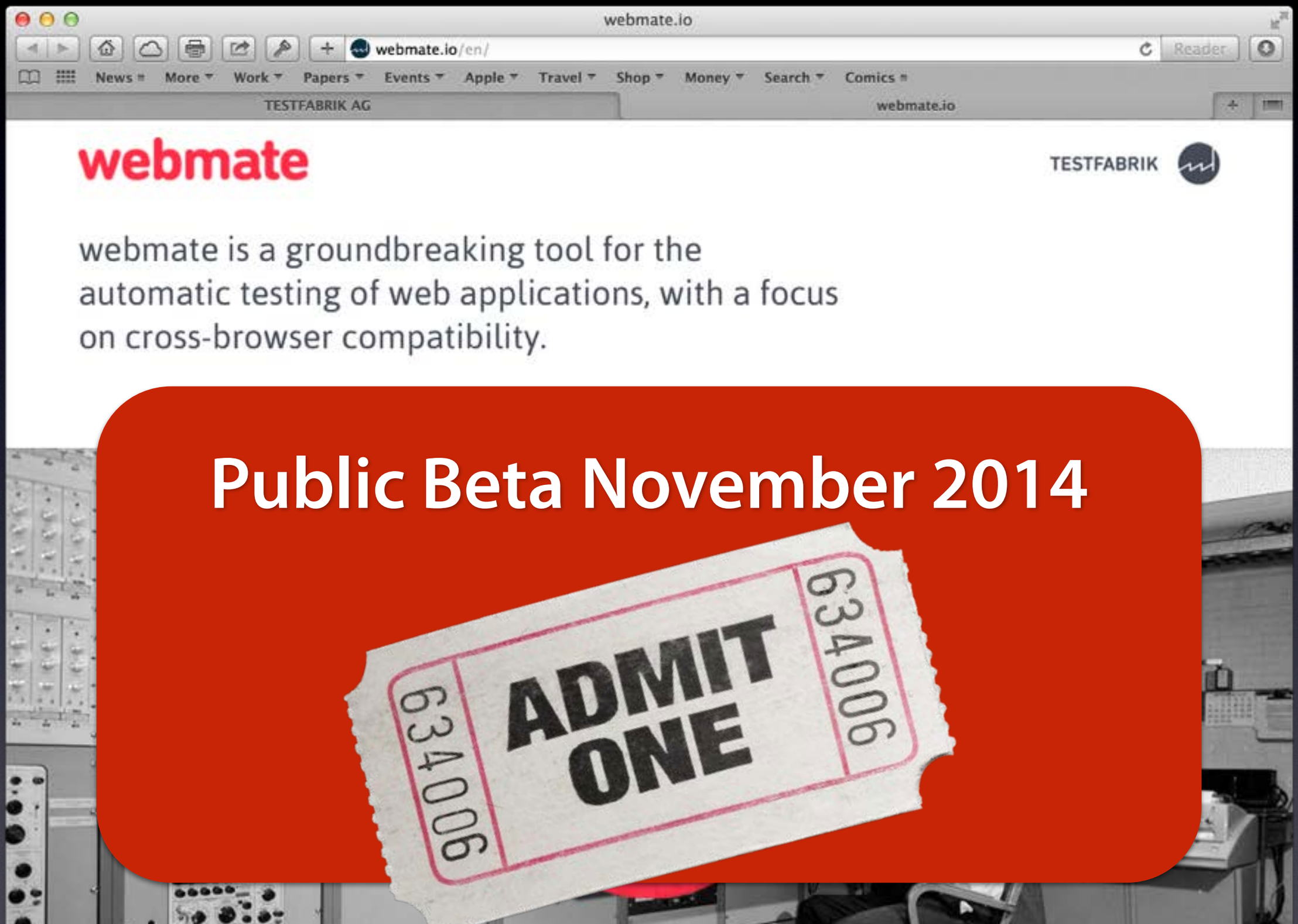

webmate.io
webmate.io/en/
Reader
News
More
Work
Papers
Events
Apple
Travel
Shop
Money
Search
Comics
TESTFABRIK AG
webmate.io
webmate
TESTFABRIK
webmate is a groundbreaking tool for the automatic testing of web applications, with a focus on cross-browser compatibility.
less effort, thanks to fully automated testing

Normality: Time

Yesterday

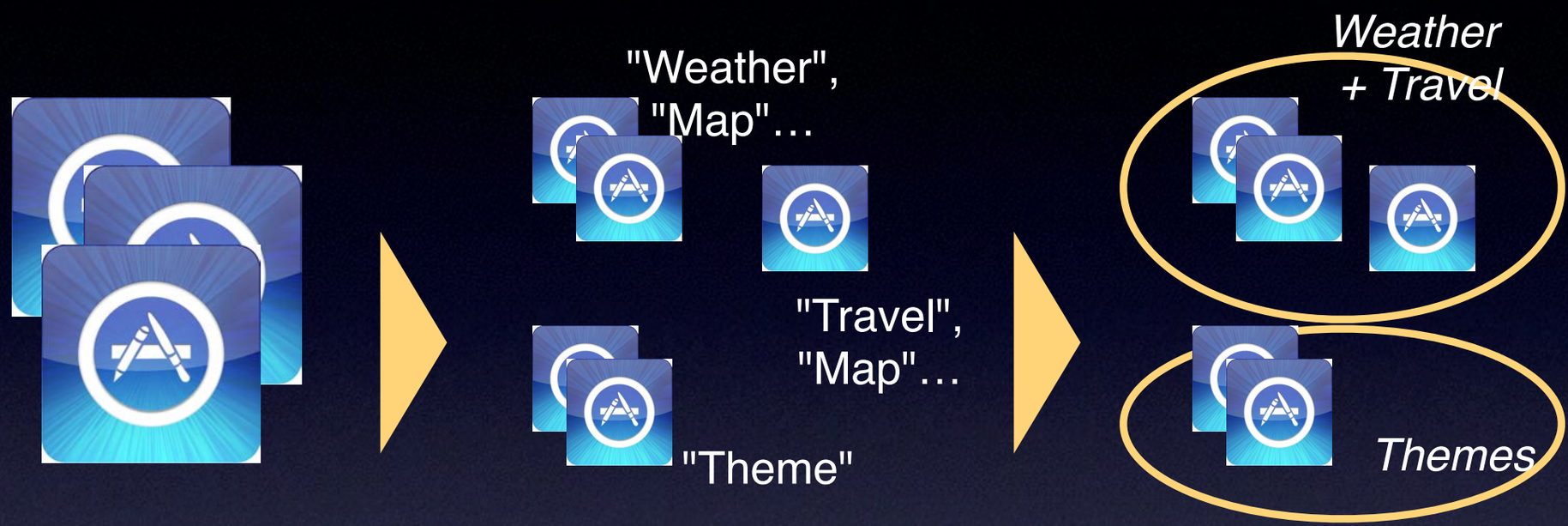
Today

webmate.io

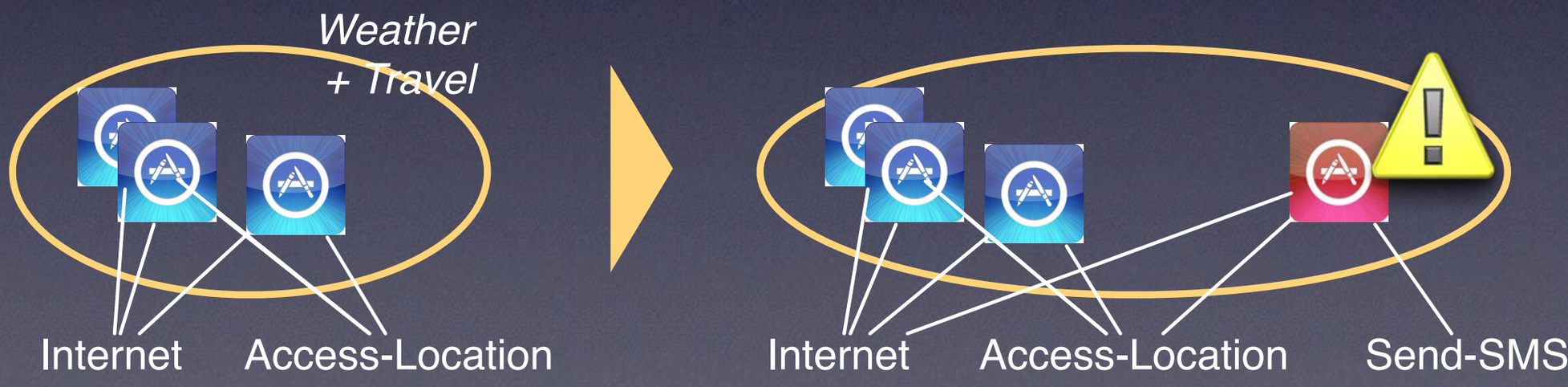

webmate.io
webmate.io/en/
Reader
News
More
Work
Papers
Events
Apple
Travel
Shop
Money
Search
Comics
TESTFABRIK AG
webmate.io
webmate
TESTFABRIK
webmate is a groundbreaking tool for the automatic testing of web applications, with a focus on cross-browser compatibility.
Public Beta November 2014
ADMIT ONE
634006
634006

Normality: Apps

CHABADA

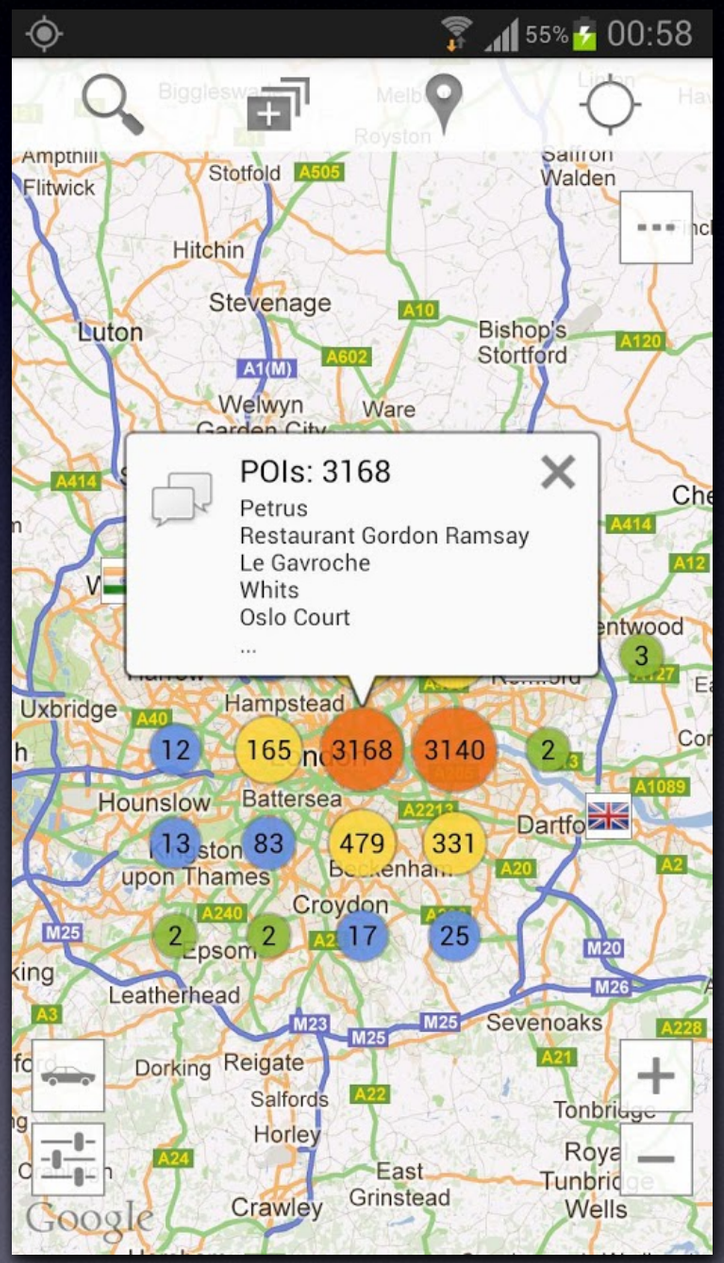


1. App collection **2. Topics** **3. Clusters**



4. Used APIs **5. Outliers**

London Restaurants

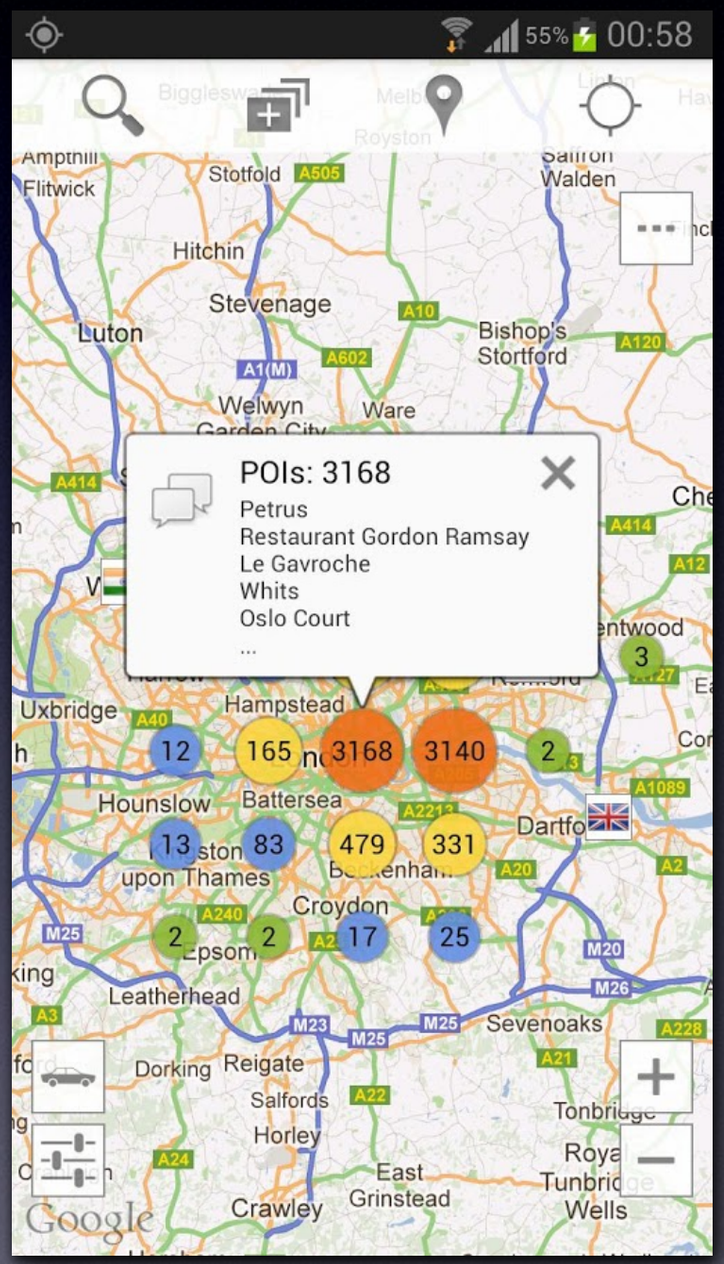


looking for a restaurant, a bar, a pub or just to have fun in london? search no more! this application has all the information you need:

- 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

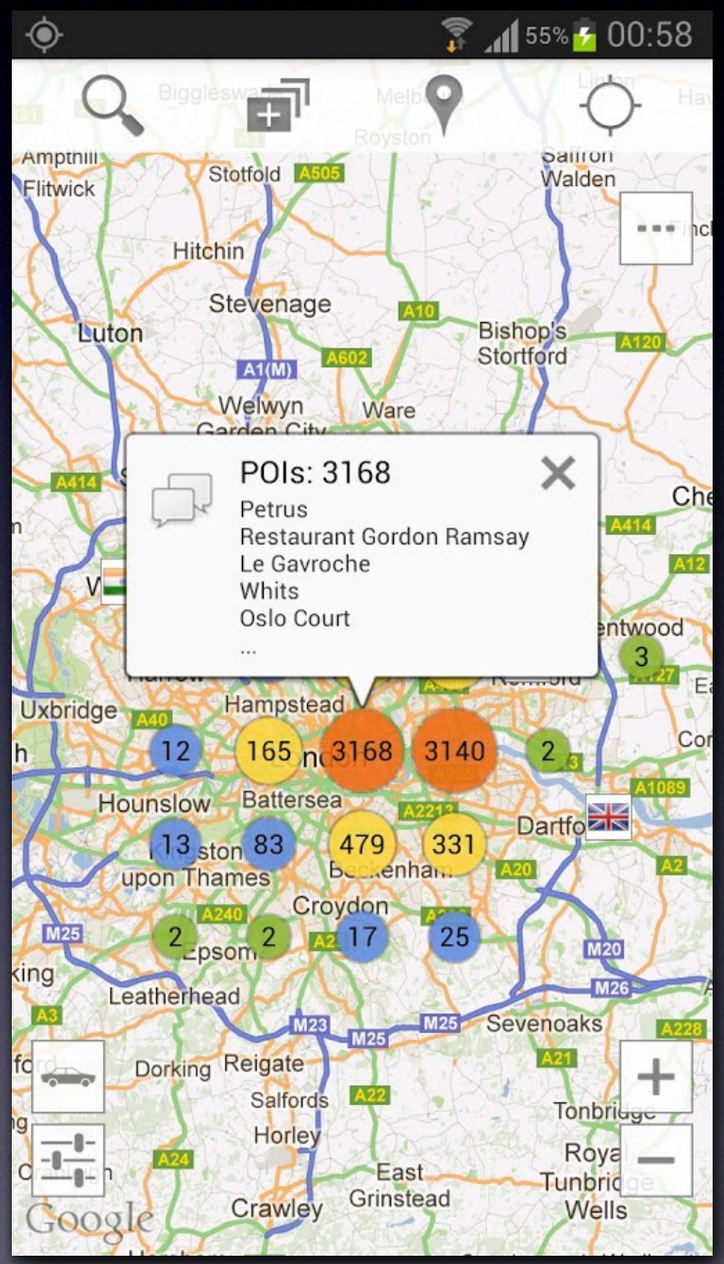


looking for a restaurant, a bar, a pub or just to have fun in london? search no more! this application has all the information you need:

- 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)
- you can use it with street view
- you can use it with navigation

keyword: london restaurants, bar, pub, food breakfast lunch dinner meal eat supper street view navigation

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

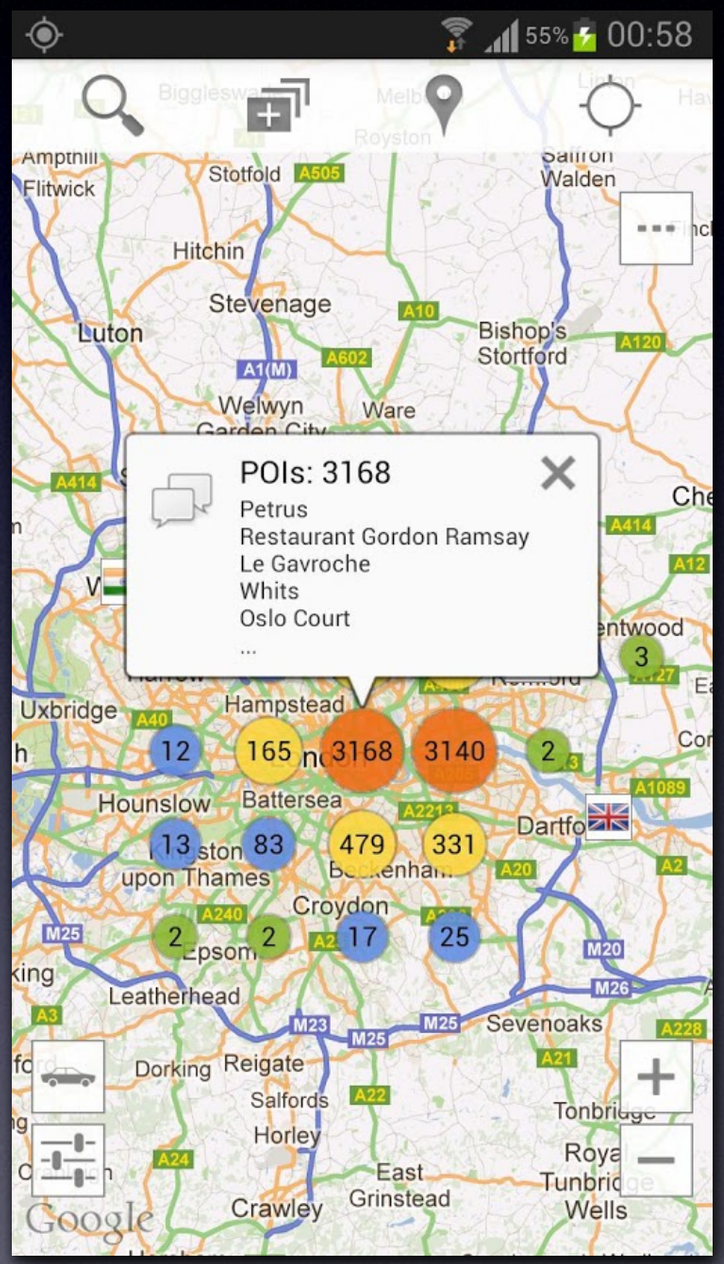
durat can view direct object near

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%)

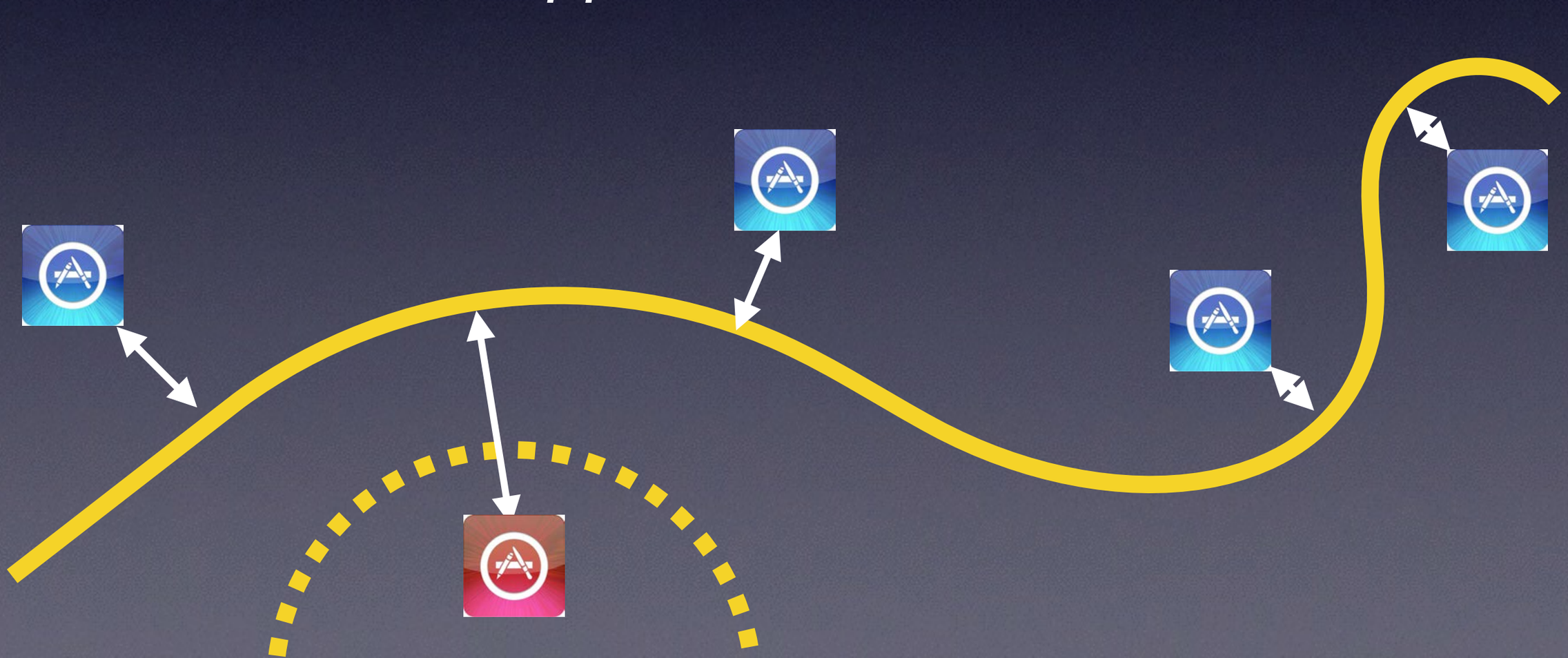
Clusters

Id	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%), design 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**

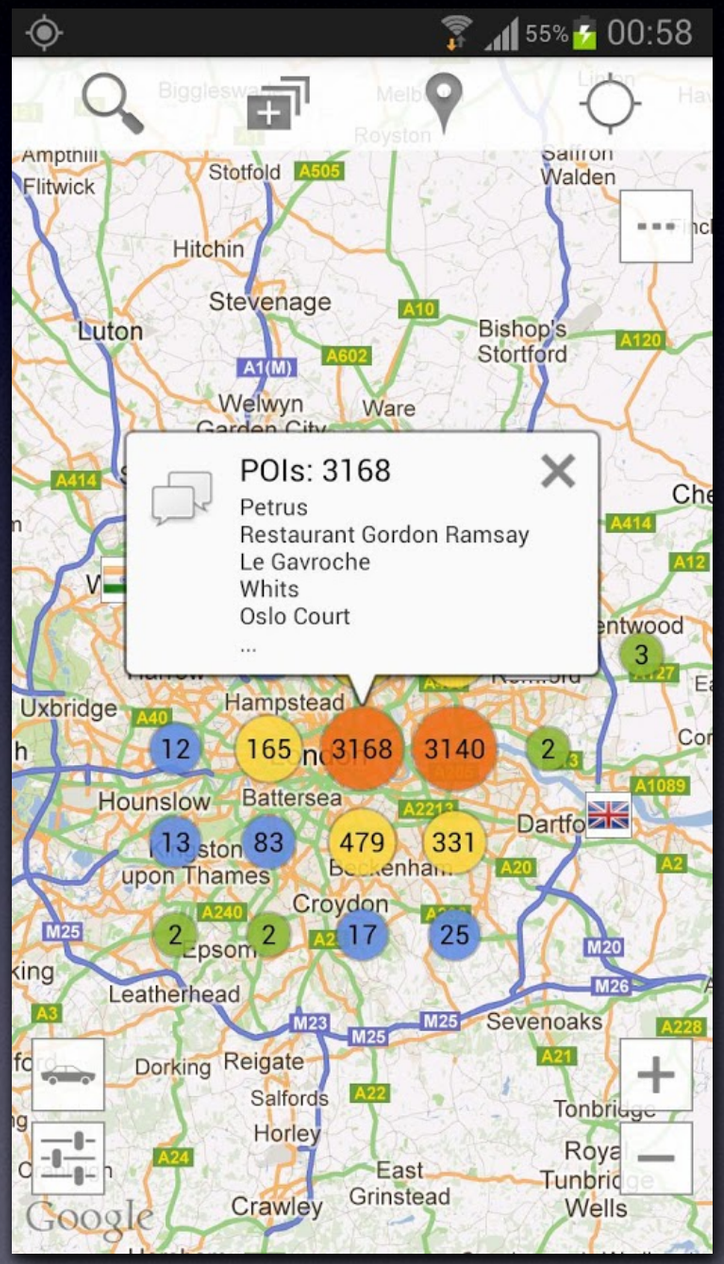
19	“sports”	580	**sports** (62%), share, popular media
20	“files and videos”	679	**files and videos** (63%), share, settings and utils
21	“search and browse”	363	**search and browse** (64%), game, puzzle and card games
22	“advertisements”	380	**policies and ads** (97%)
23	“design and art”	978	**design 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%), wallpapers, 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, settings and utils
32	“settings and wallpapers”	251	**settings and utils** (37%), **wallpapers** (37%), personalize

Outlier Analysis

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



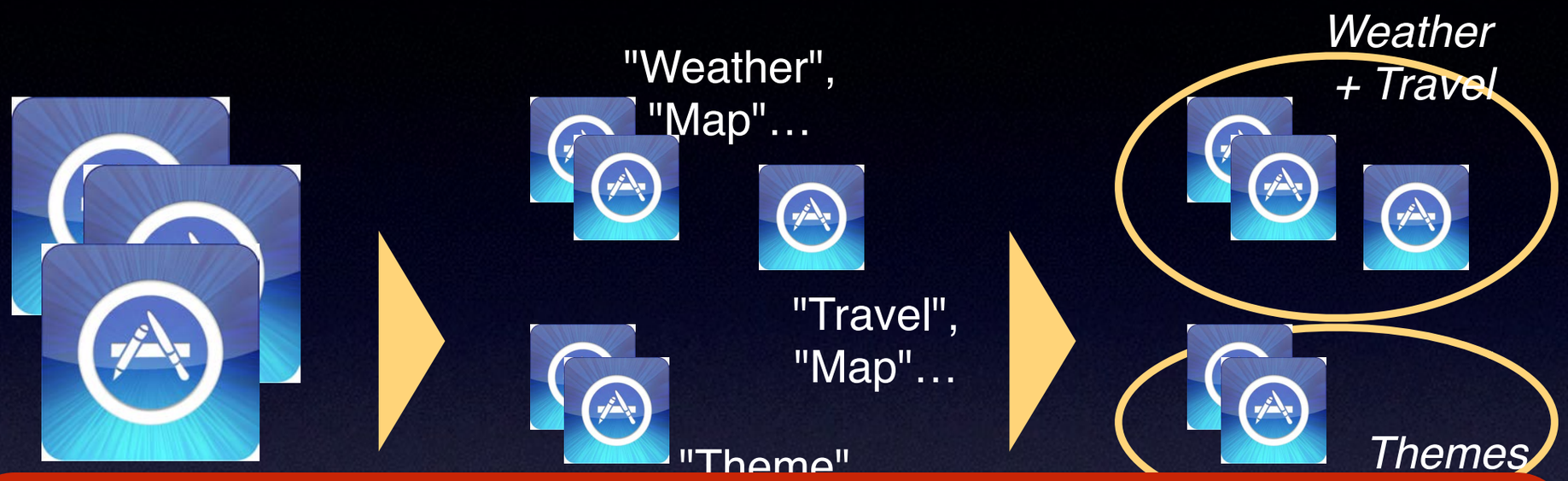
London Restaurants



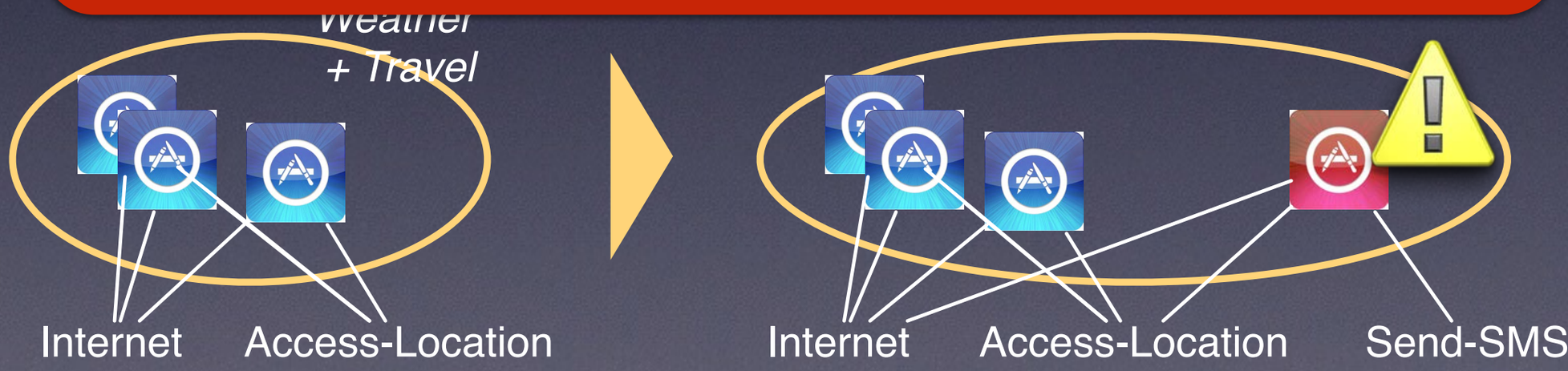
android.net.ConnectivityManager.getActiveNetworkInfo()
android.webkit.WebView()
java.net.HttpURLConnection.connect()
android.app.NotificationManager.notify()
java.net.URL.openConnection()
android.telephony.TelephonyManager.getDeviceId()
org.apache.http.impl.client.DefaultHttpClient()
org.apache.http.impl.client.DefaultHttpClient.execute()
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%



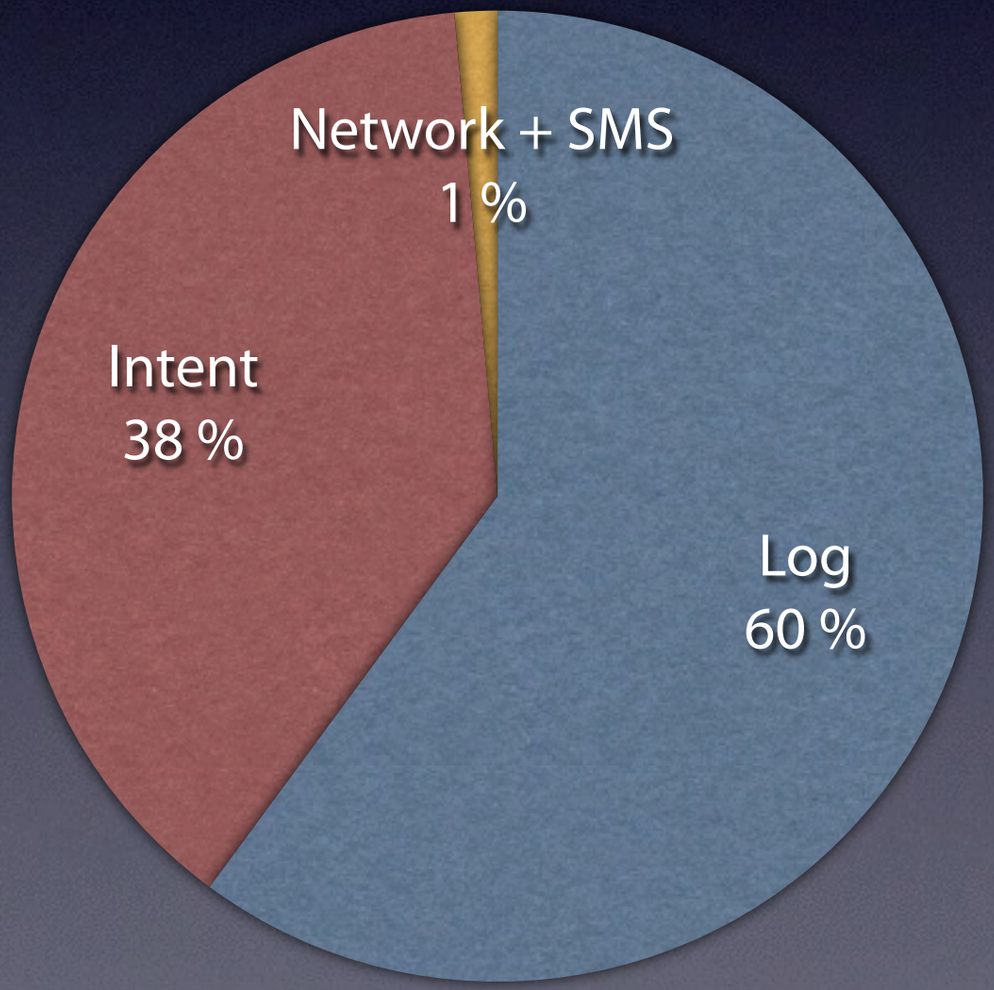
4. Used APIs

5. Outliers

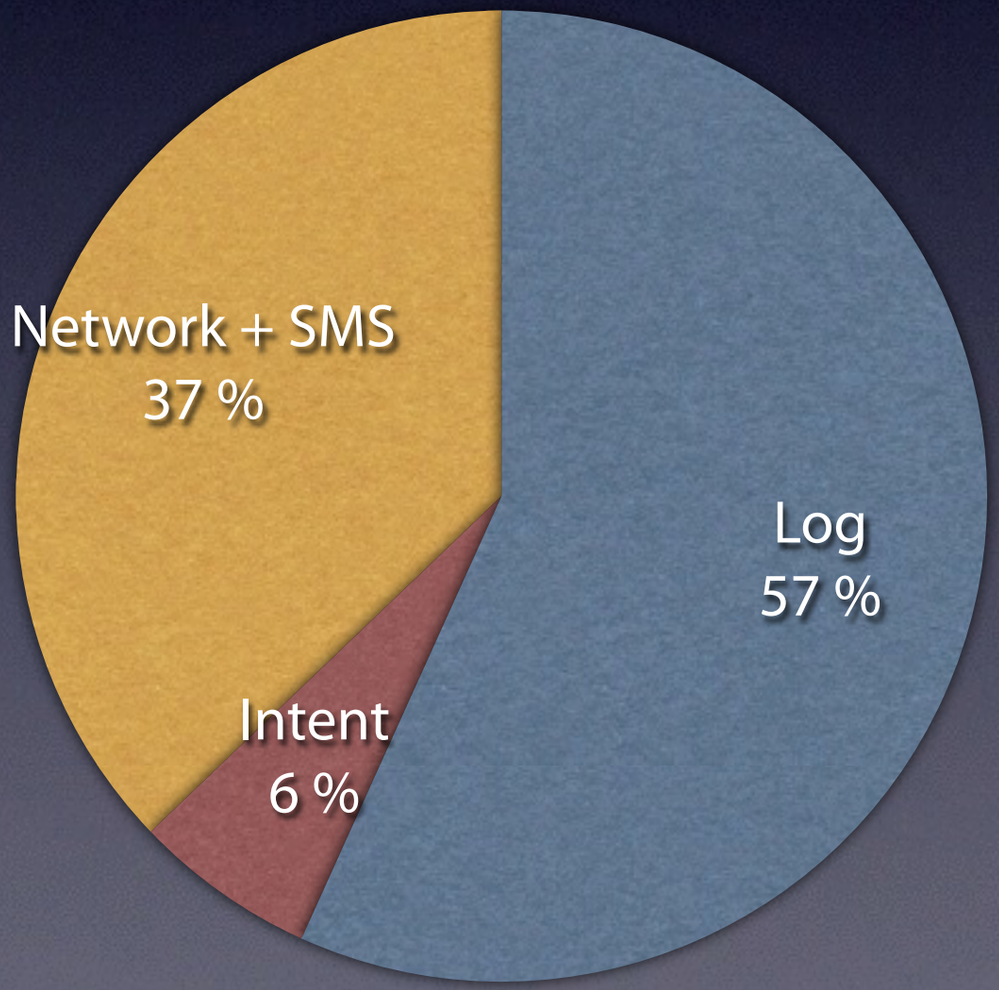
Information Flow

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

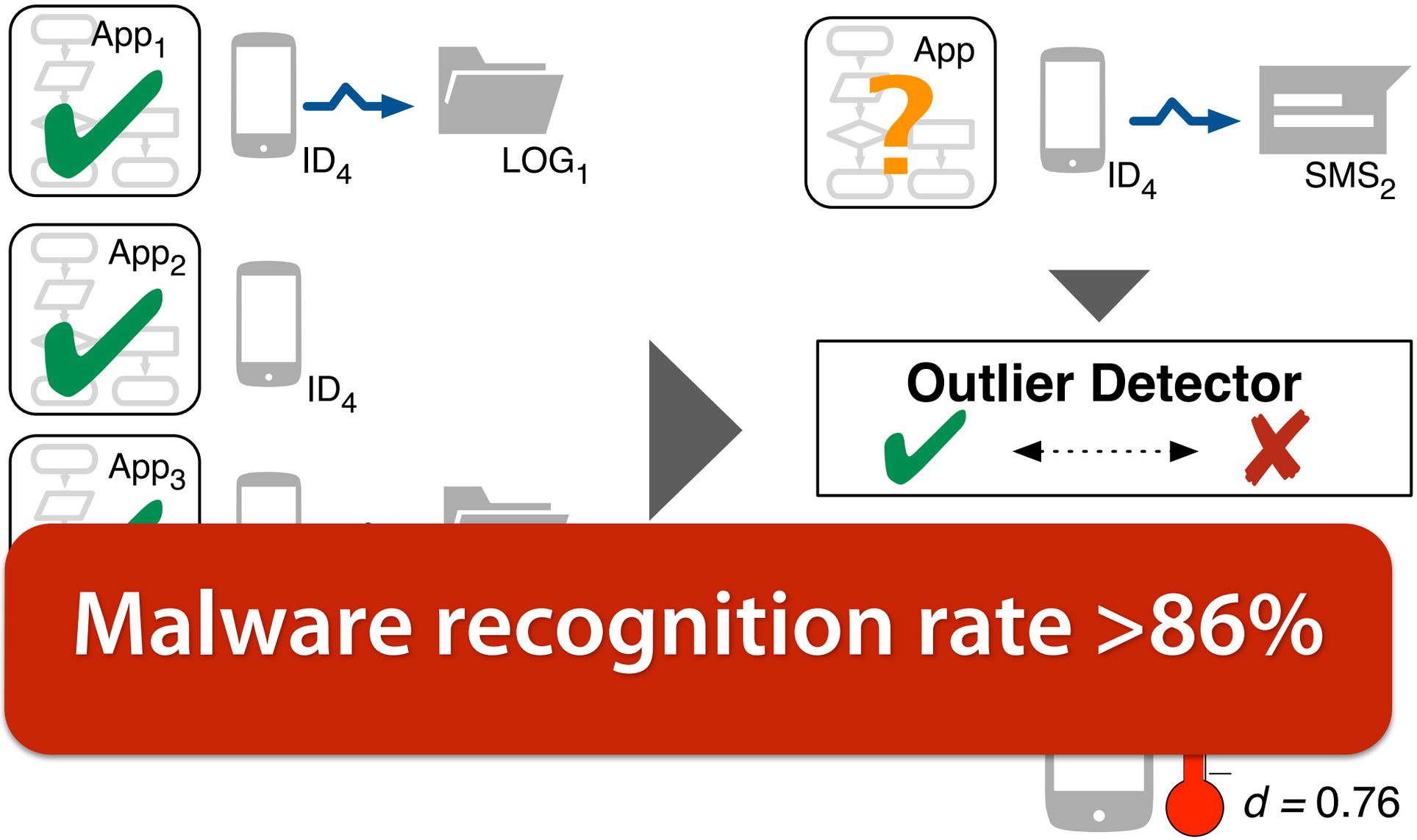
Benign Apps



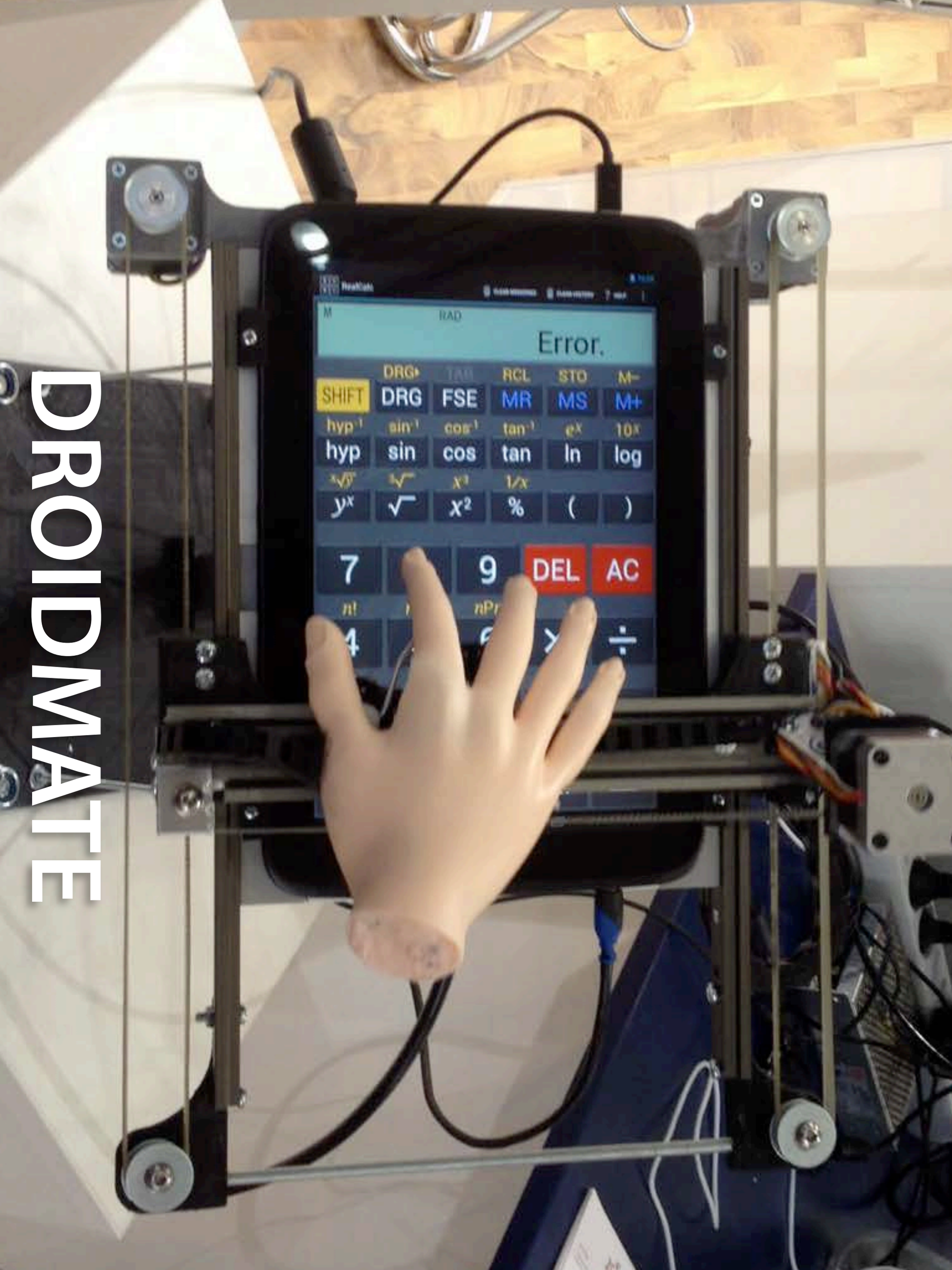
Malicious Apps



MUDFLOW


App1
ID4
LOG1
App2
ID4
App3
App
?
ID4
SMS2
Outlier Detector
Malware recognition rate >86%
d = 0.76
Training
Outlier Detection

DROIDMATE


RAD
Error.
DRG▸
RCL
STO
M−
SHIFT
DRG
FSE
MR
MS
M+
hyp⁻¹
sin⁻¹
cos⁻¹
tan⁻¹
eˣ
10ˣ
hyp
sin
cos
tan
ln
log
x³
1/x
yˣ
√
x²
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7
9
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Normality: Apps

Normality: Apps

connect to
adserver.com

connect to
exploit.com

Mining Normality

removeChild

$\Delta XMLElement$

$child? : XML\_ELEMENT$

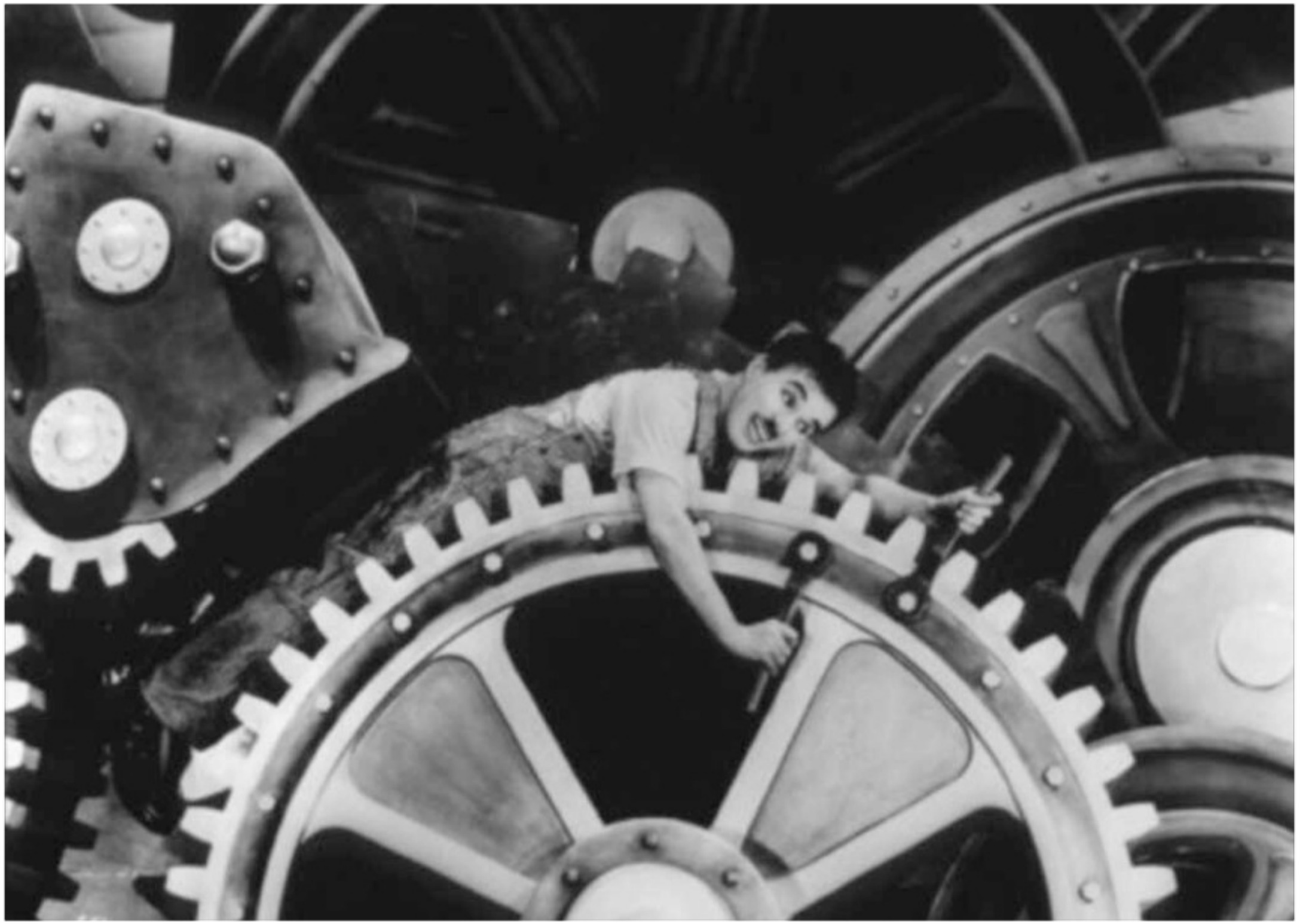
$child? \in enumerateChildren$

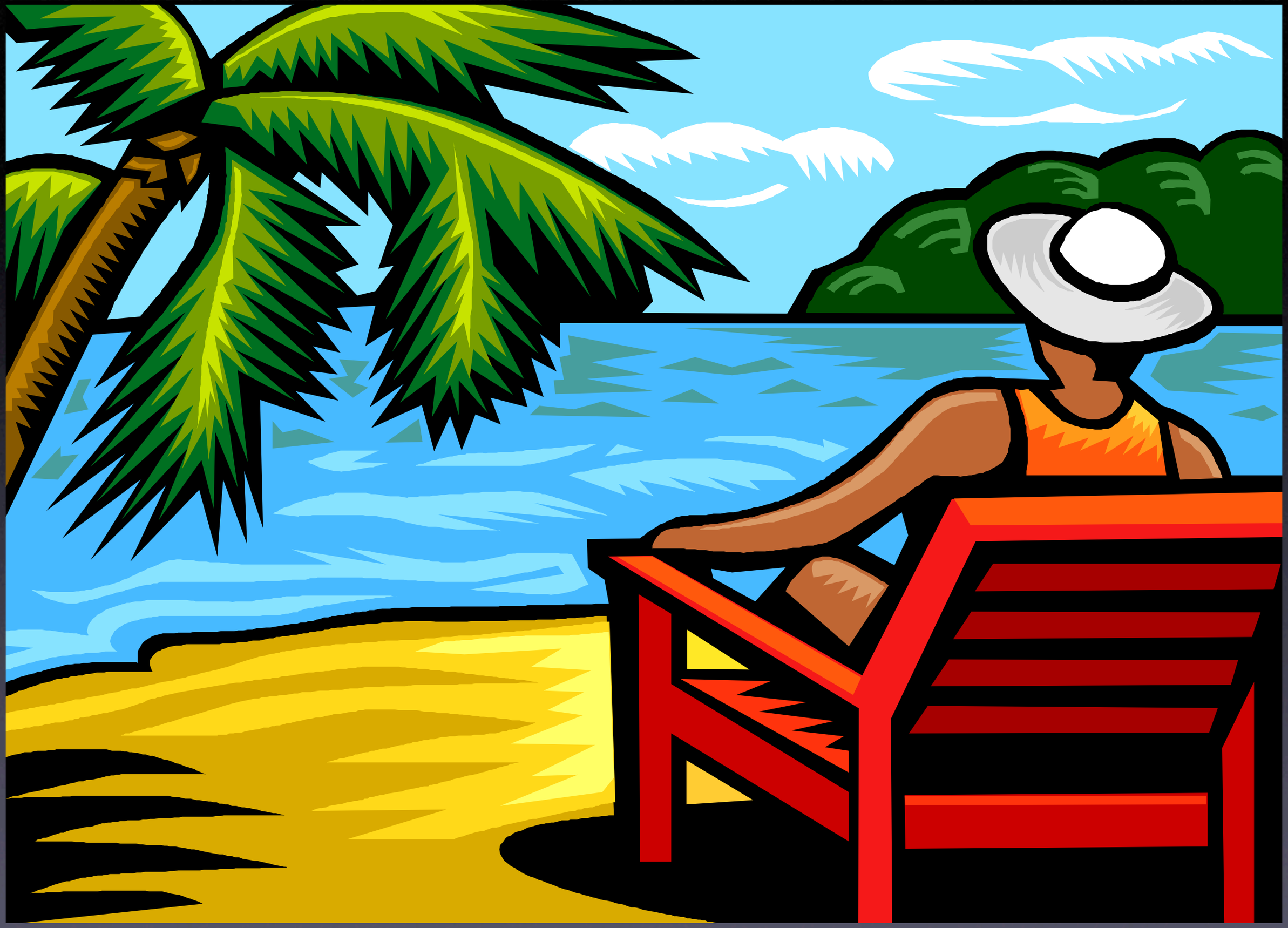
$child? \neq null$

$enumerateChildren' = enumerateChildren \setminus child?$

$getChildrenCount' = getChildrenCount - 1$

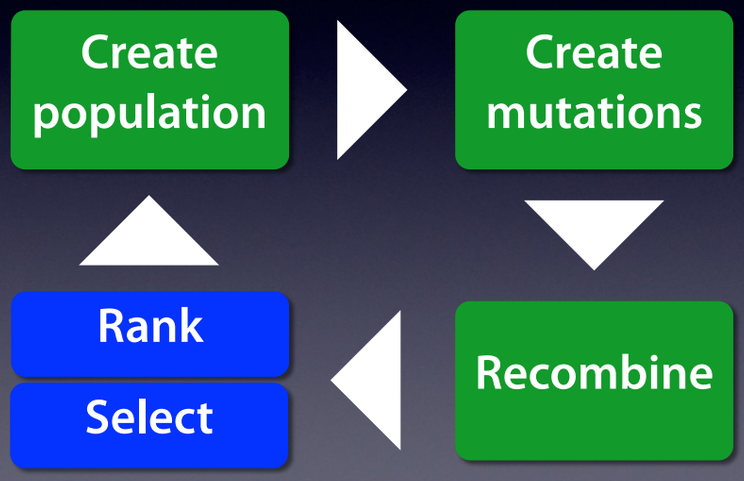
Úlfar Erlingsson



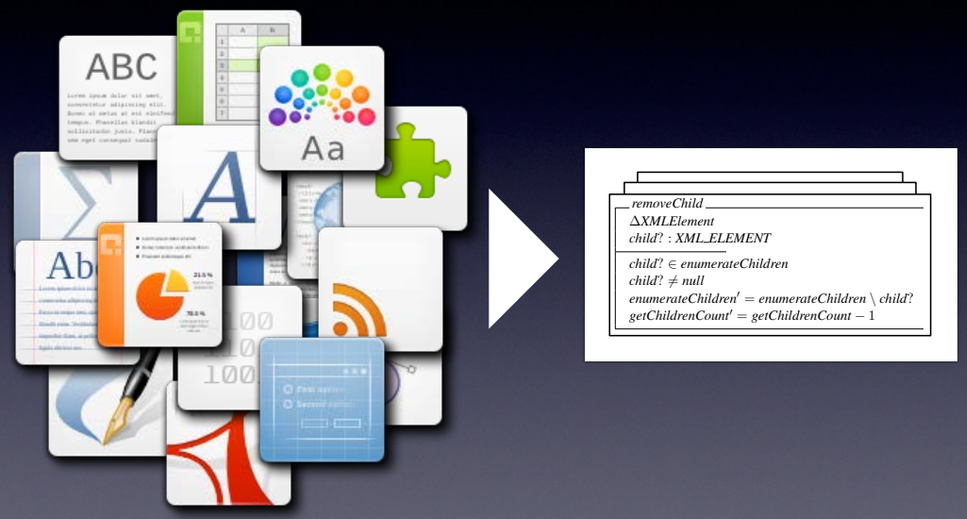



A Rau
V Dallmeier
S Just
E May
F Gross
K Herzig
C Hammacher
A Zeller
A Tarasevich
M Burger
K Streit
M Höschele
B Pohl
M Mirold
I Tavecchia
G Reibold
J Rößler
K Jamrozik
JP Galeotti
K Becker
A Gorla

Evolutionary Algorithms

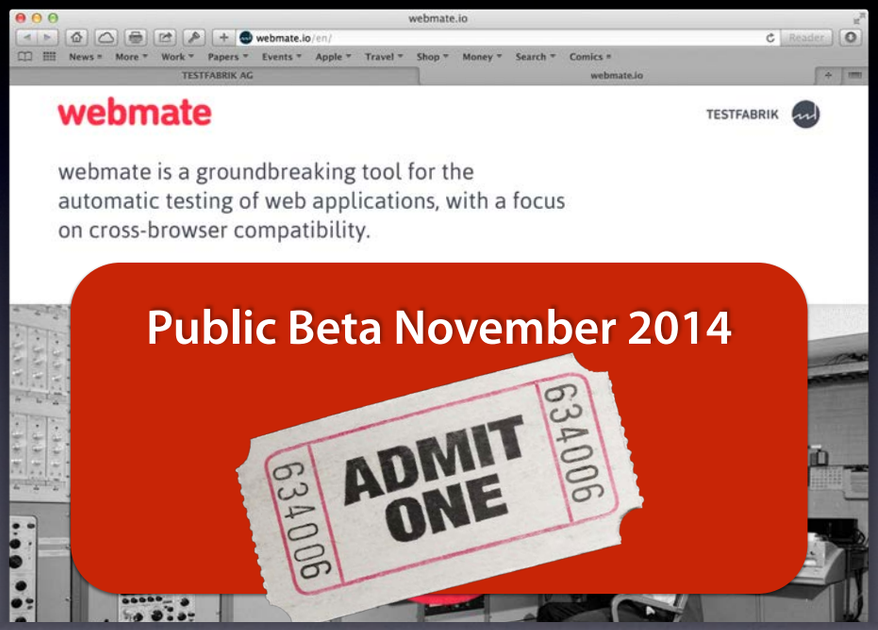


Mining Normality



http://www.st.cs.uni-saarland.de/

webmate.io



CHABADA