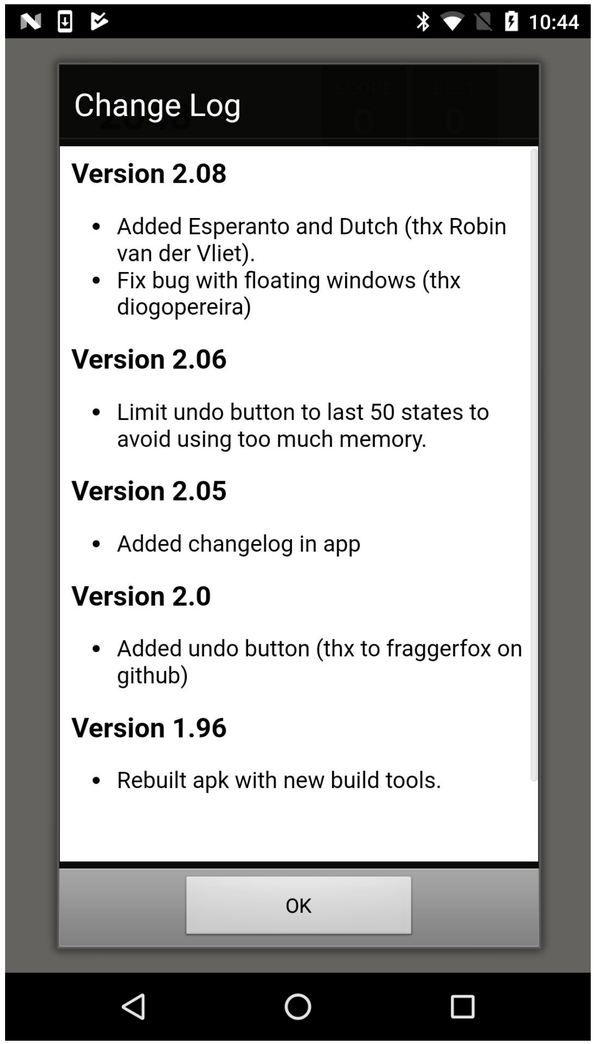
CISPA
HELMHOLTZ-ZENTRUM i. G.

Learning UI Element Interactions

Christian Degott
Nataniel Borges Jr.
Andreas Zeller

UNIVERSITÄT DES SAARLANDES

Introduction



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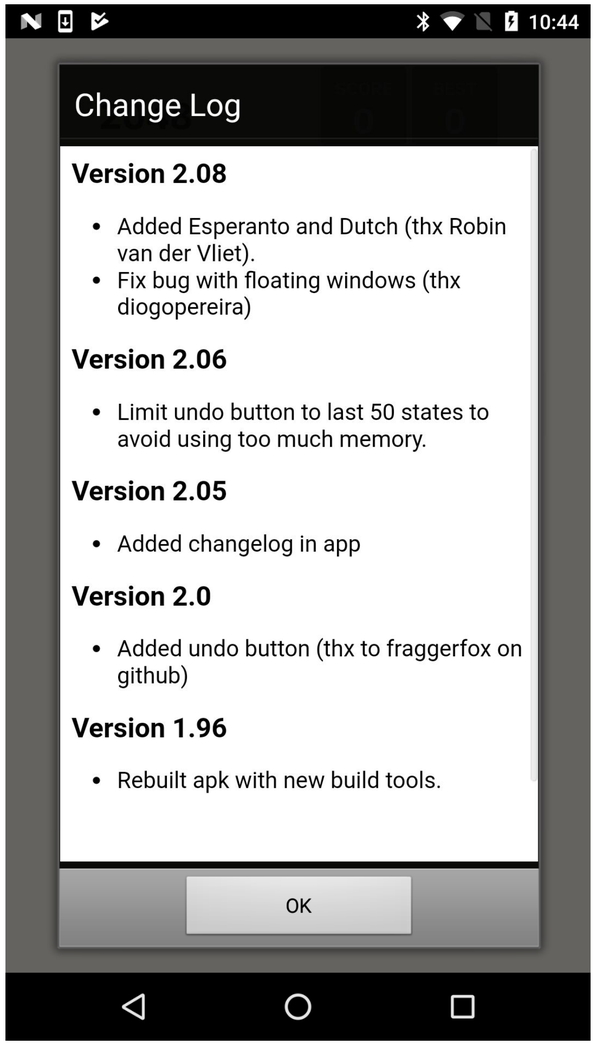
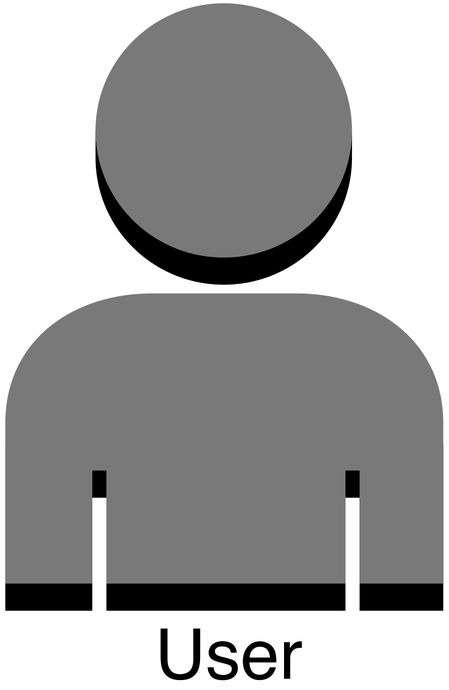


User vs GUI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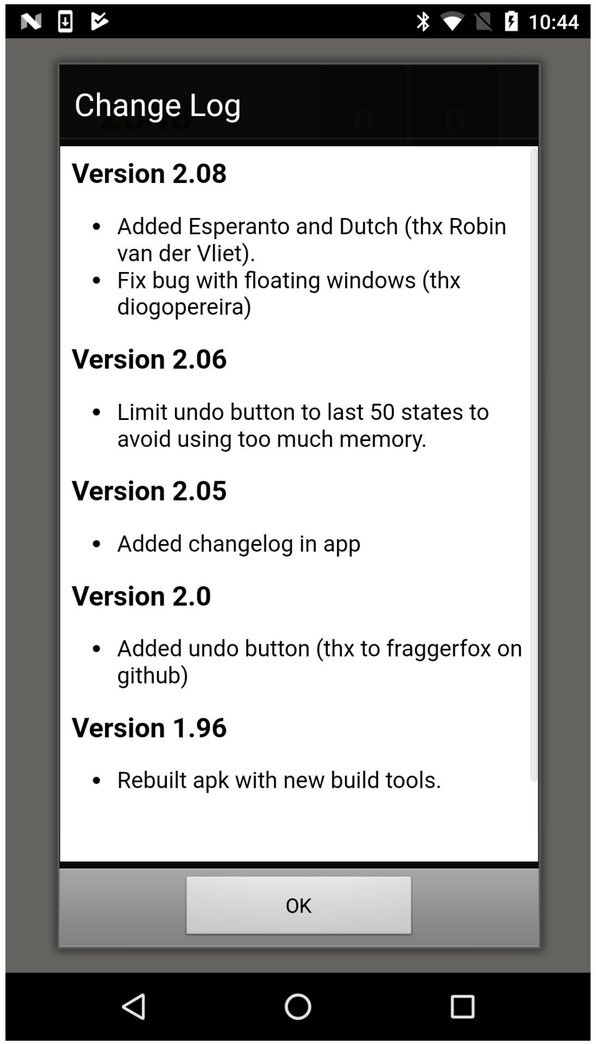
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Change Log
Version 2.08
Added Esperanto and Dutch (thx Robin van der Vliet).
Fix bug with floating windows (thx diogopereira)
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Limit undo button to last 50 states to avoid using too much memory.
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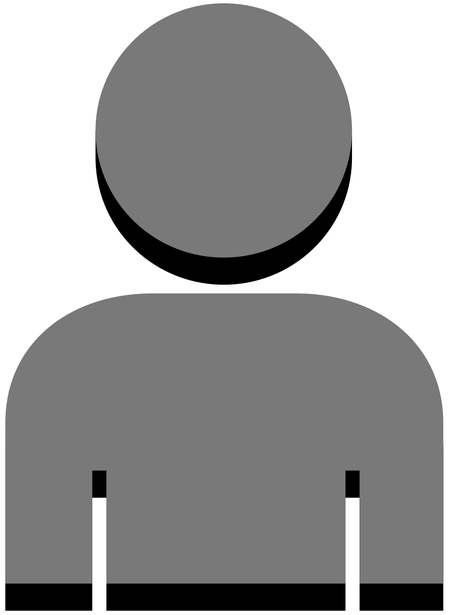
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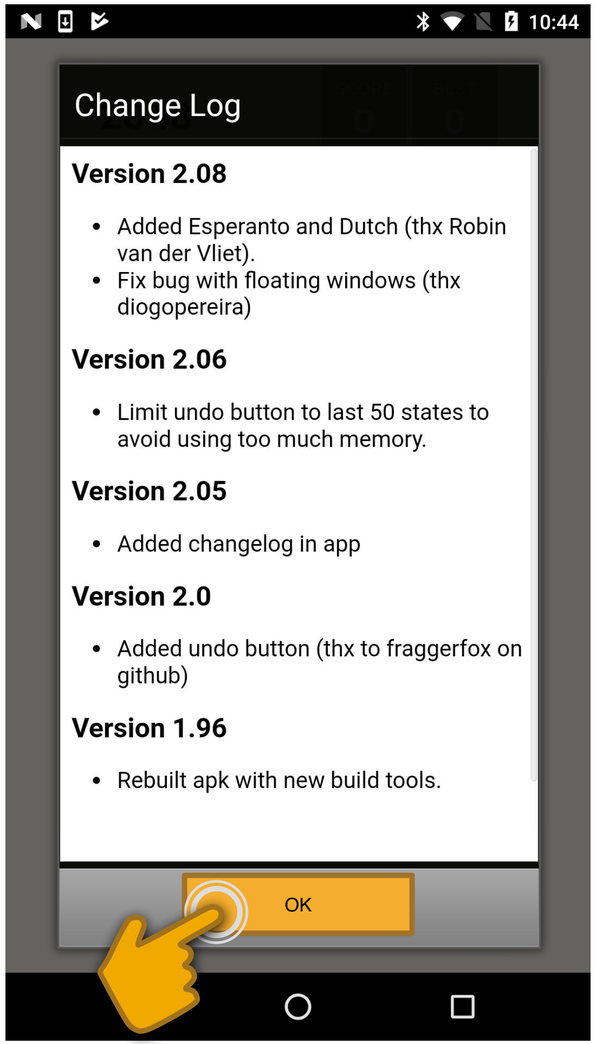
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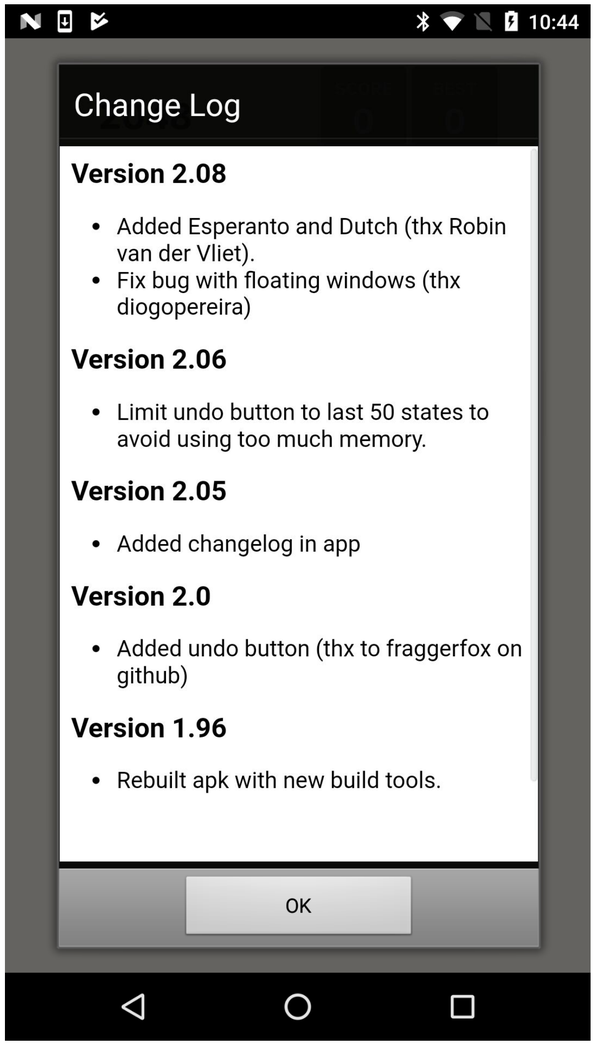
Test Generator vs GUI

Test Generator



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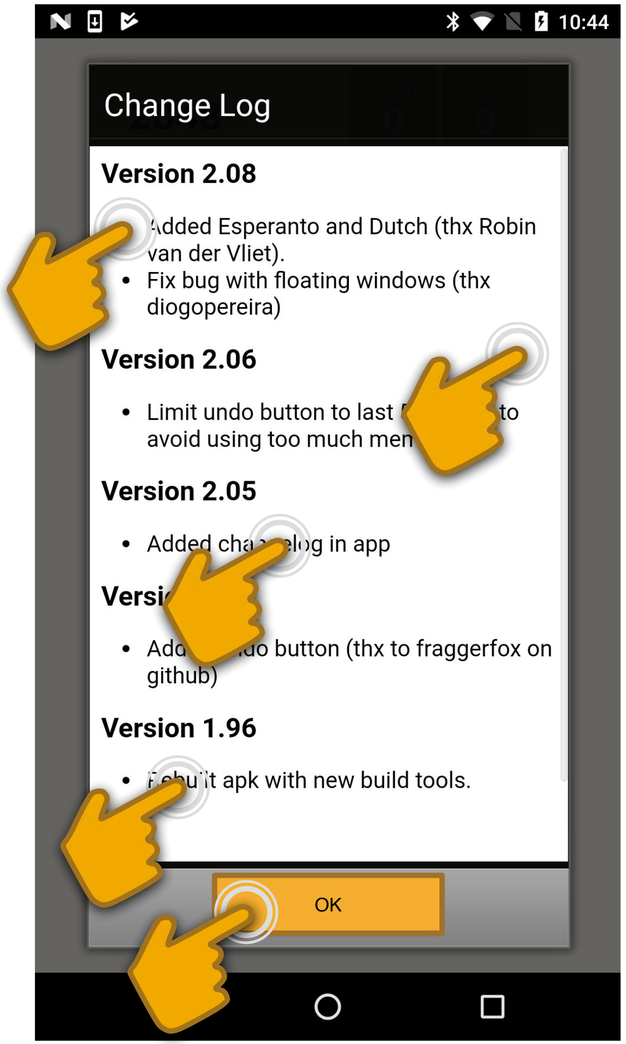
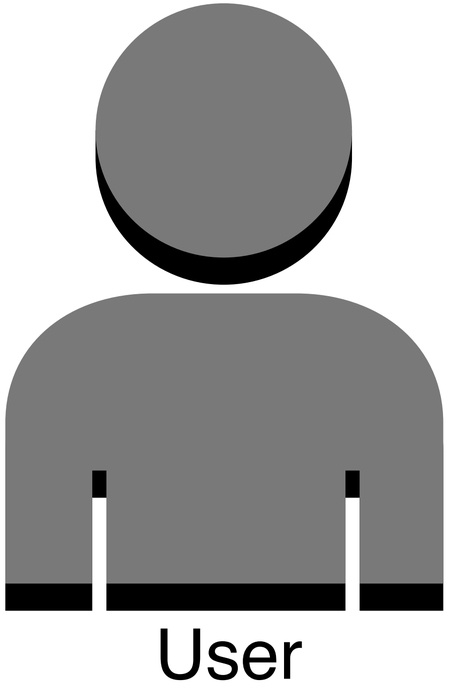
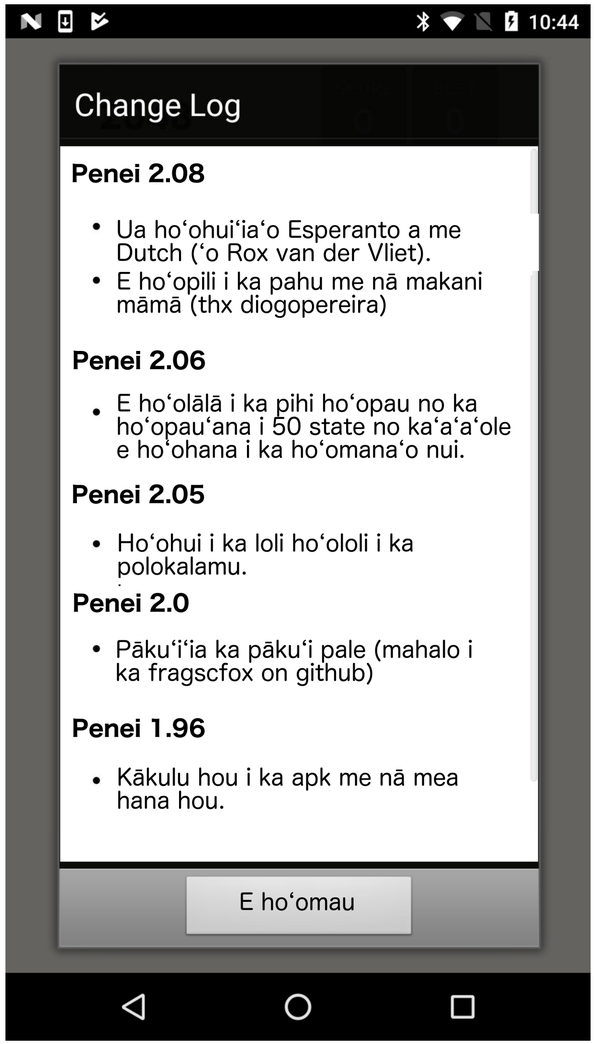


User vs (Unreadable) GUI





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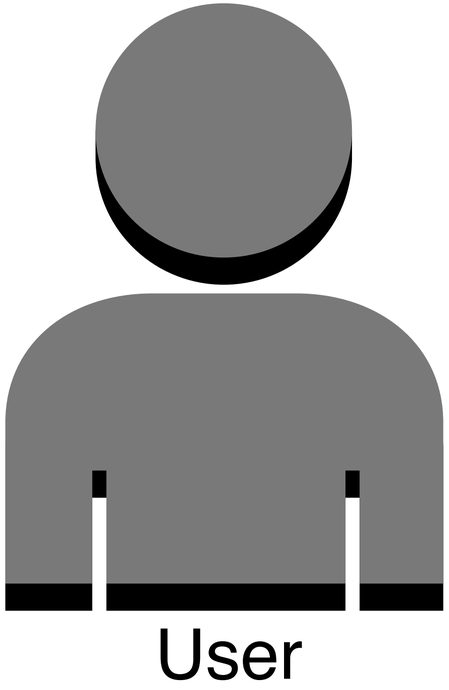

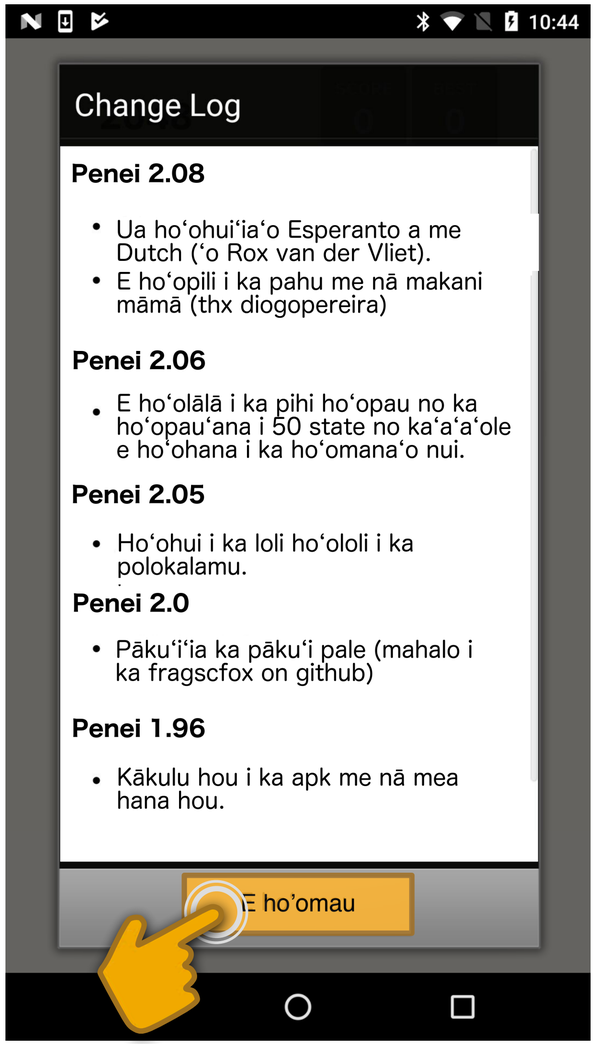

Motivation — User vs GUI vs Test Generator

Apps follow **interaction patterns**

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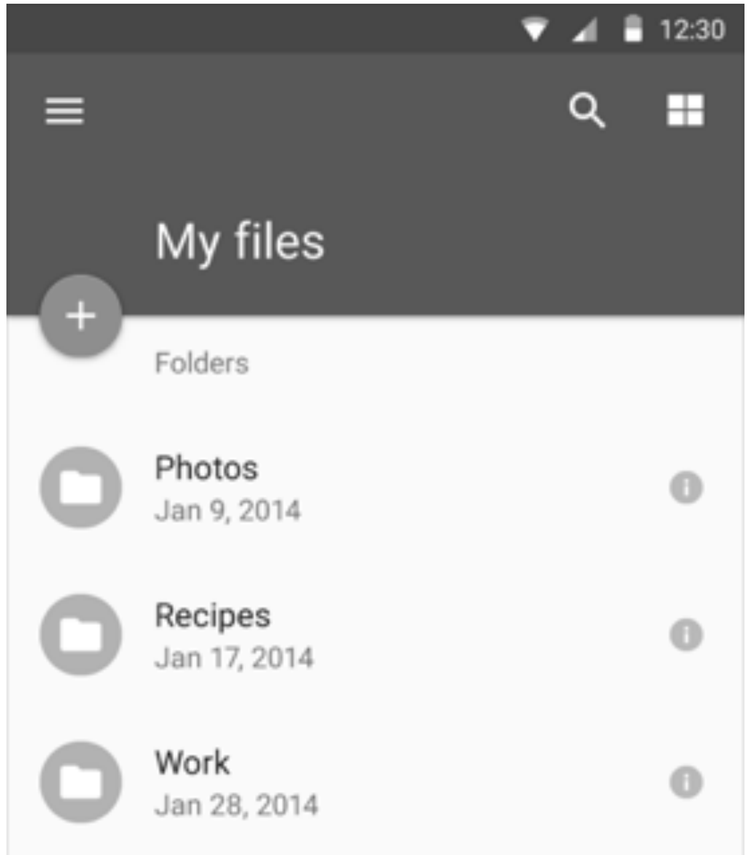
Apps follow **interaction patterns**

Simple | Context-aware | Imperceptible

- *Buttons can be clicked*
- *Hyperlinks can be clicked*



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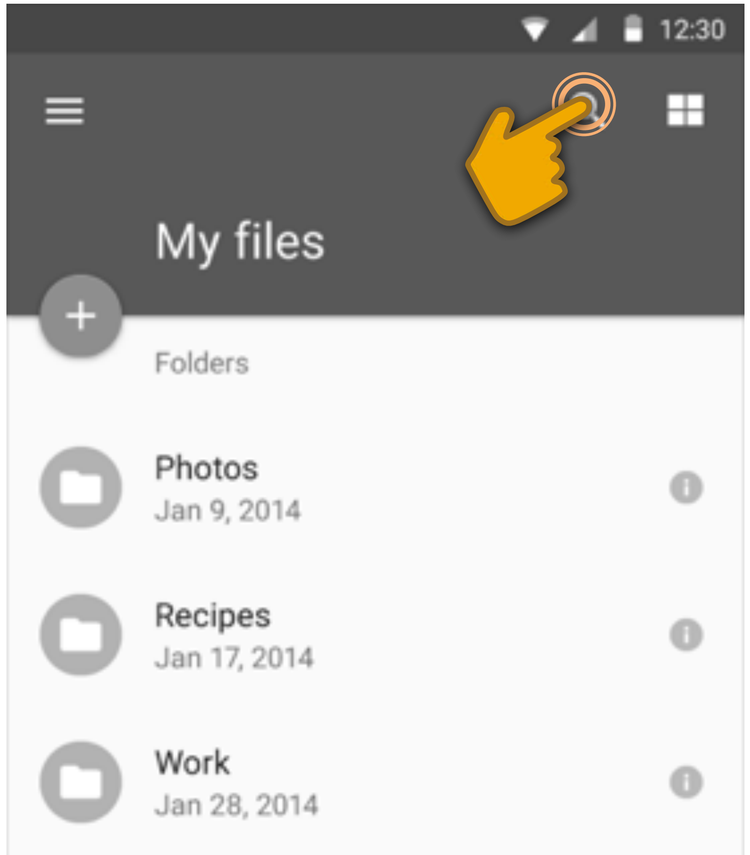

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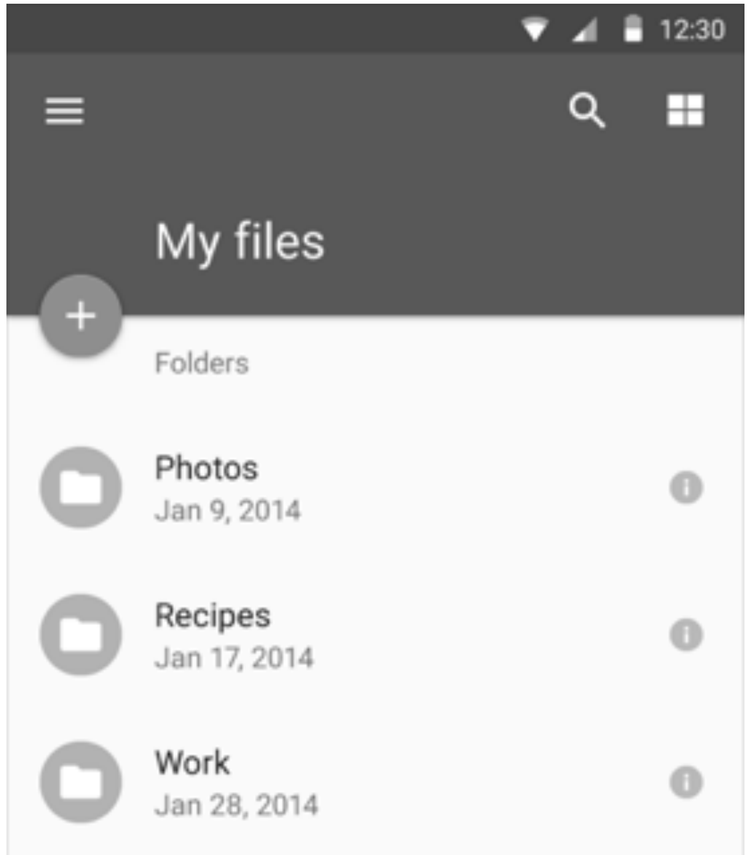
- *Labels within a layout inside a list view can be clicked*



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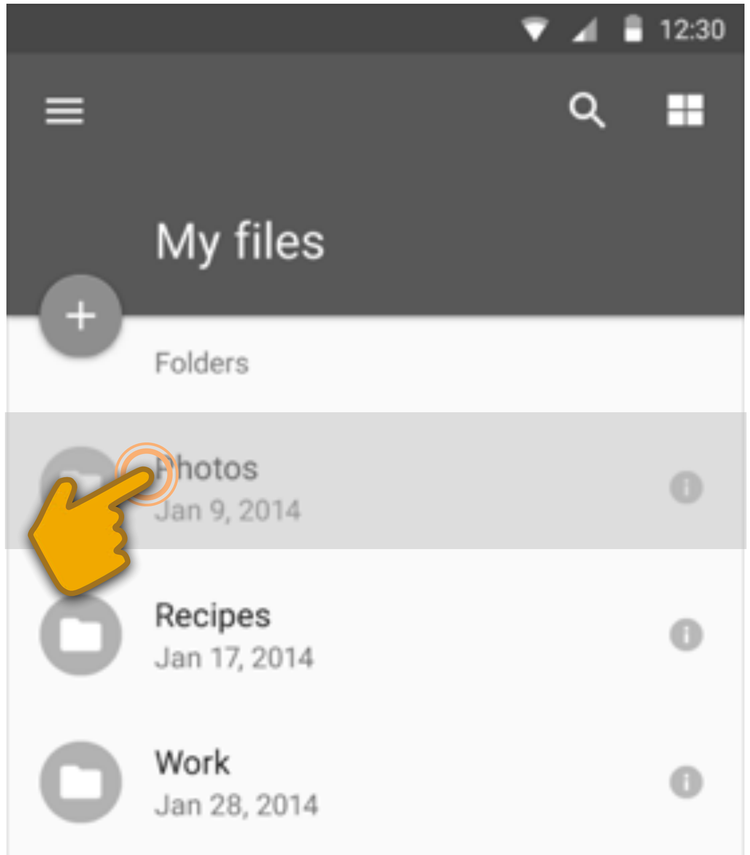
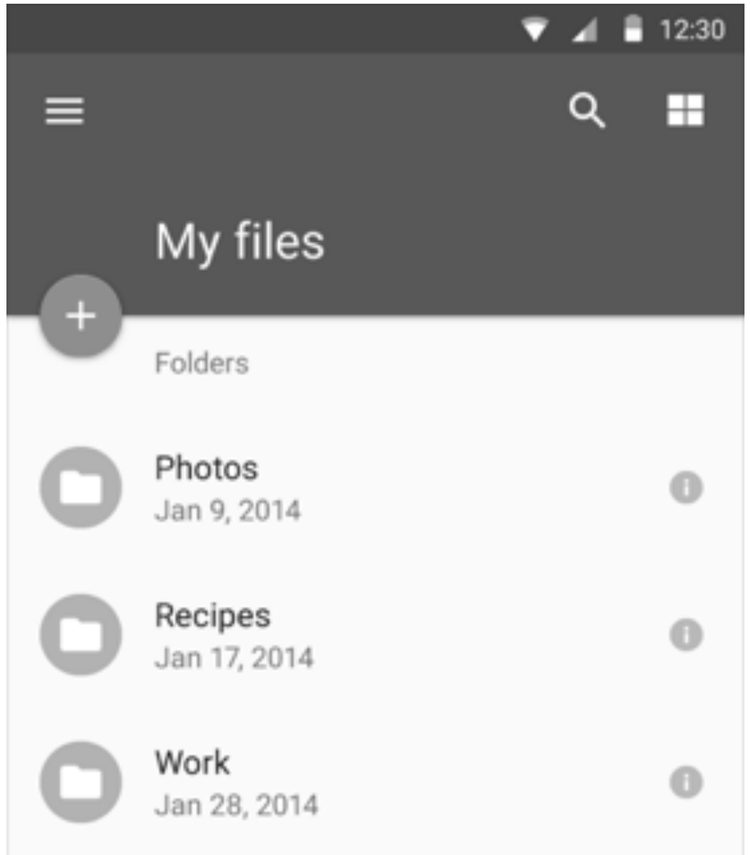


Motivation — User vs GUI vs Test Generator

Apps follow **interaction patterns**

Simple	Context-aware	**Imperceptible**

- *Layouts containing an image button can be clicked*



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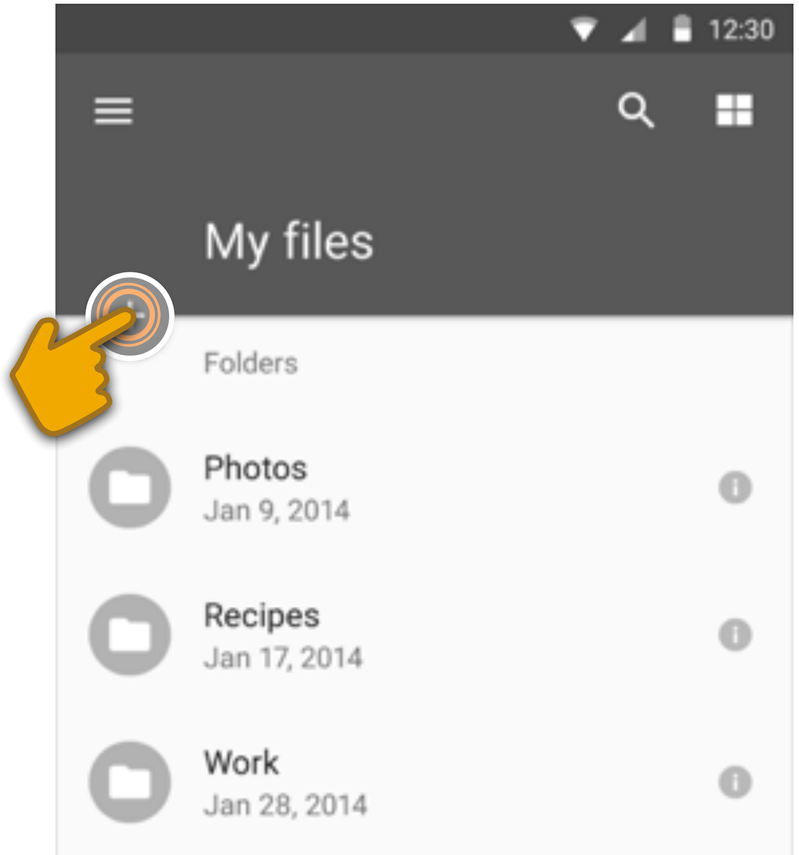

Motivation — User vs GUI vs Test Generator

Apps follow **interaction patterns**

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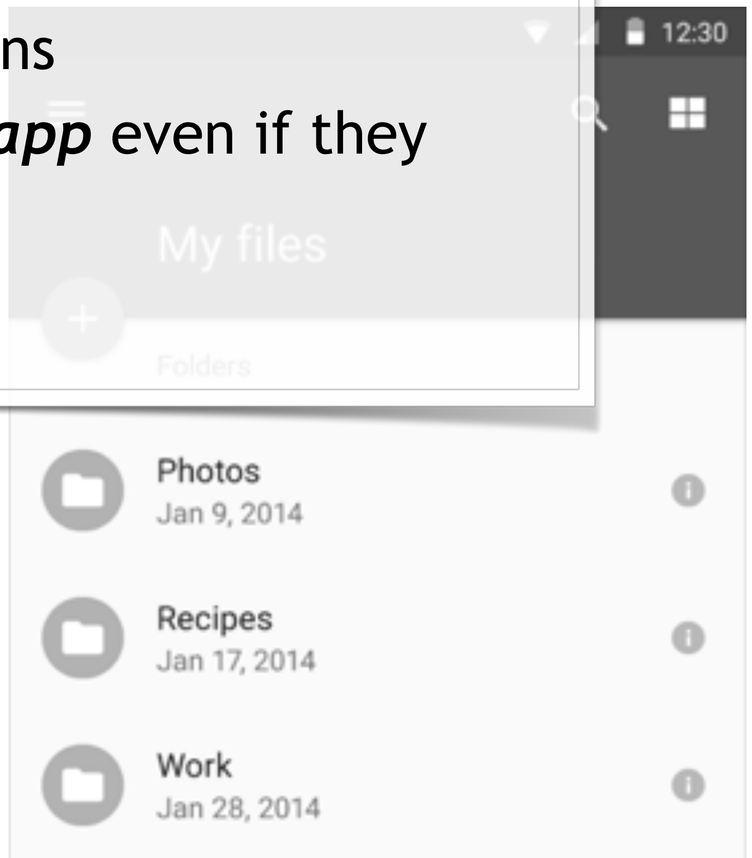
Users

- **Learn** and **identify** these patterns
- Know ***how to interact with an app*** even if they cannot identify its semantics



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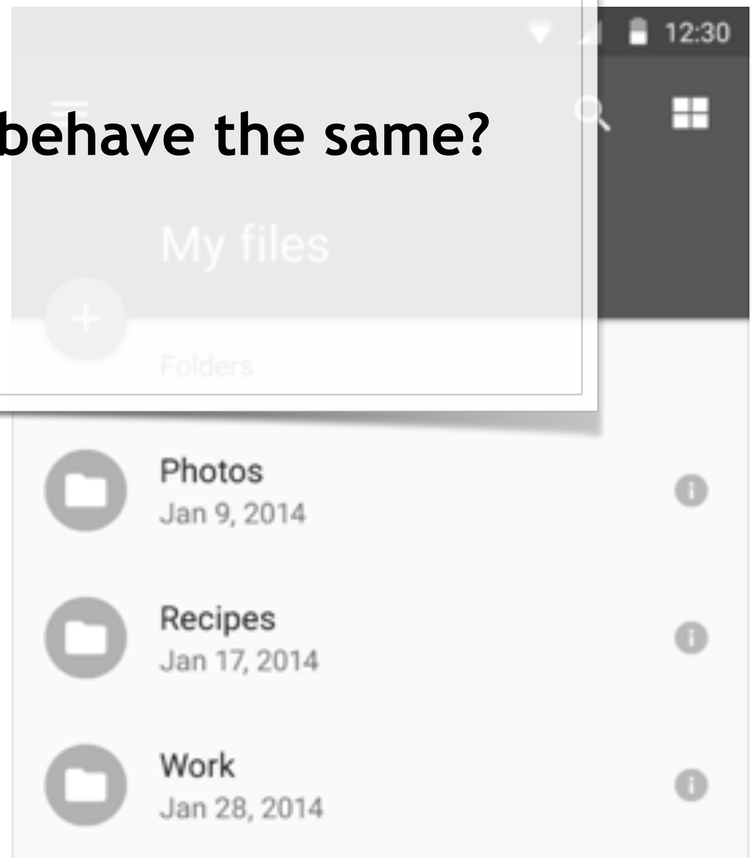
Simple **Context-aware** **Imperceptible**

How to teach a test generator to behave the same?



Testing and the Multi-Armed-Bandit Problem

Given a budget and a set of competing slot machines, a player must decide which one to play.

By interacting with one machine as a time and observing its rewards it can learn, after some time, which slot machines it has to pull to maximize its profits.

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Given a number of actions and a set of competing UI elements, a test generator must decide which one to interact with.

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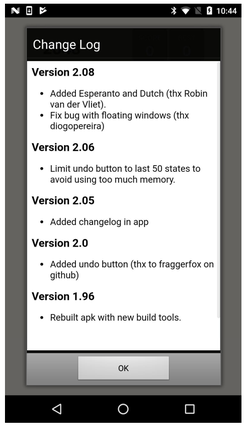
Given a number of actions and a set of competing UI elements, a test generator must decide which one to interact with.

By interacting with one UI element as a time and observing its rewards it can learn, after some time, which UI elements it has to interact with to maximize its reward.

Classic reinforcement learning problem

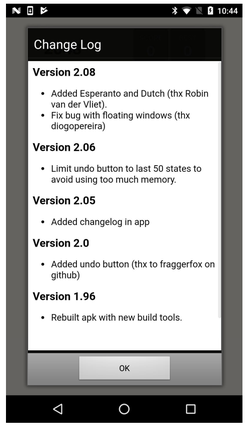
Testing with Reinforcement Learning

Testing with Reinforcement Learning



Inspect the UI

Testing with Reinforcement Learning



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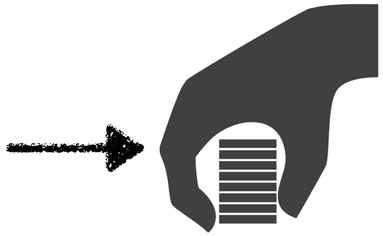
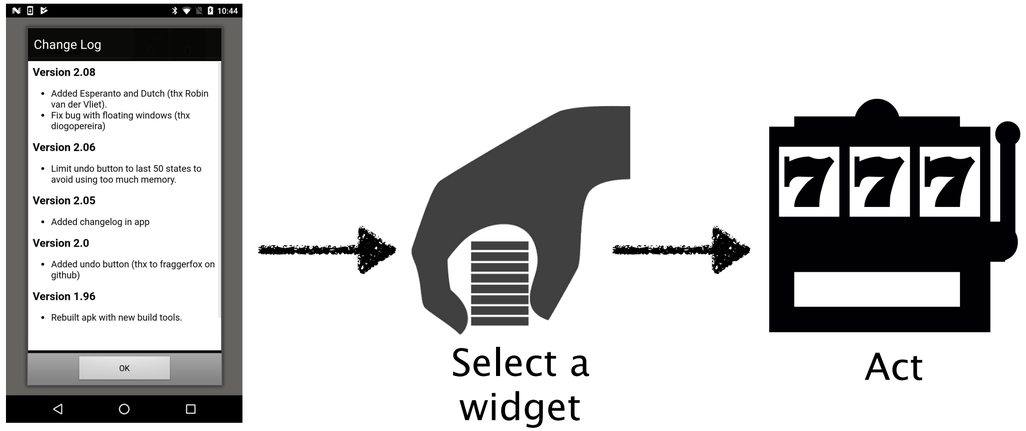


Select a widget

Testing with Reinforcement Learning



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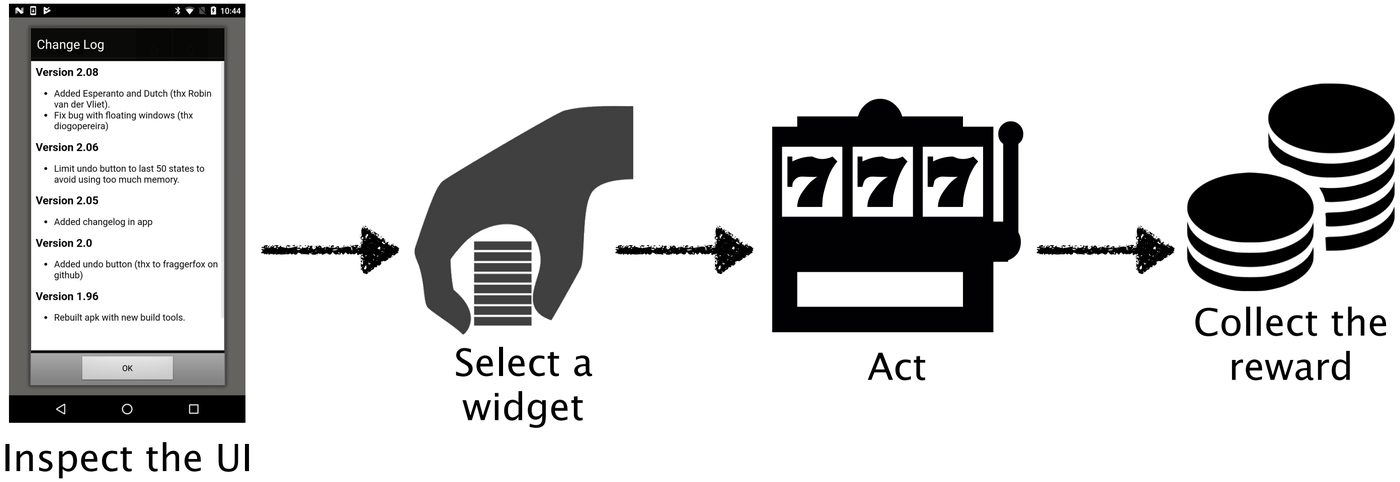

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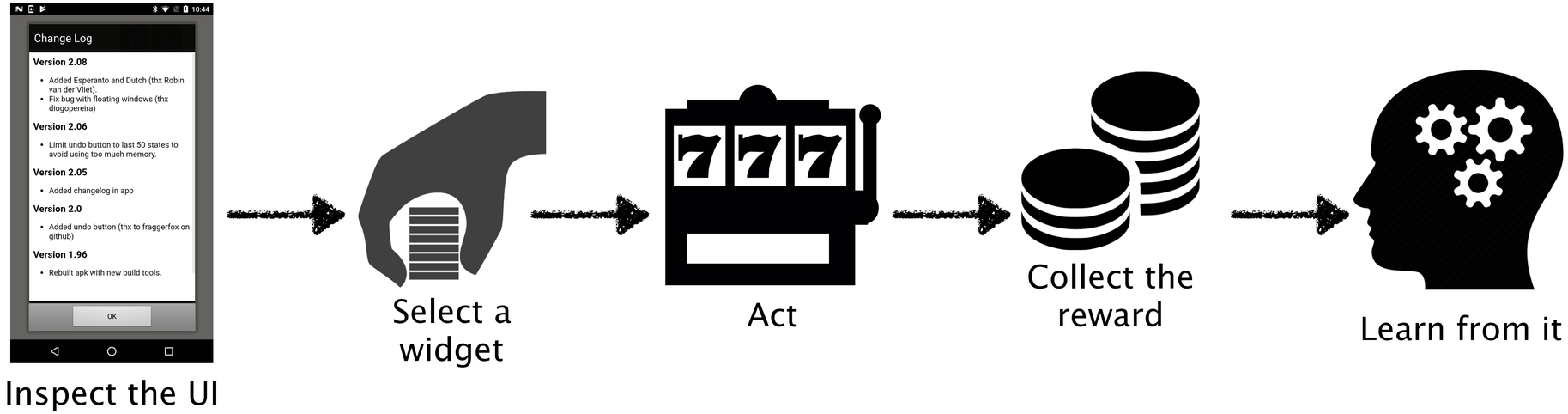

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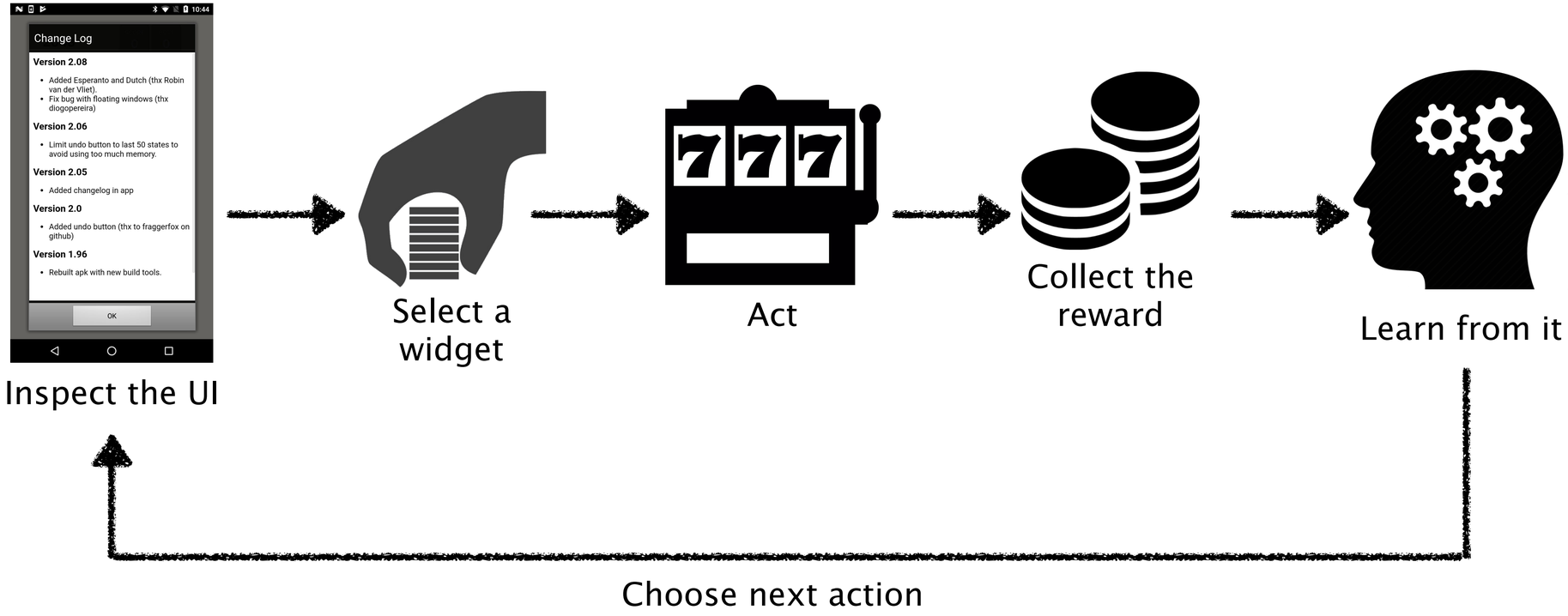

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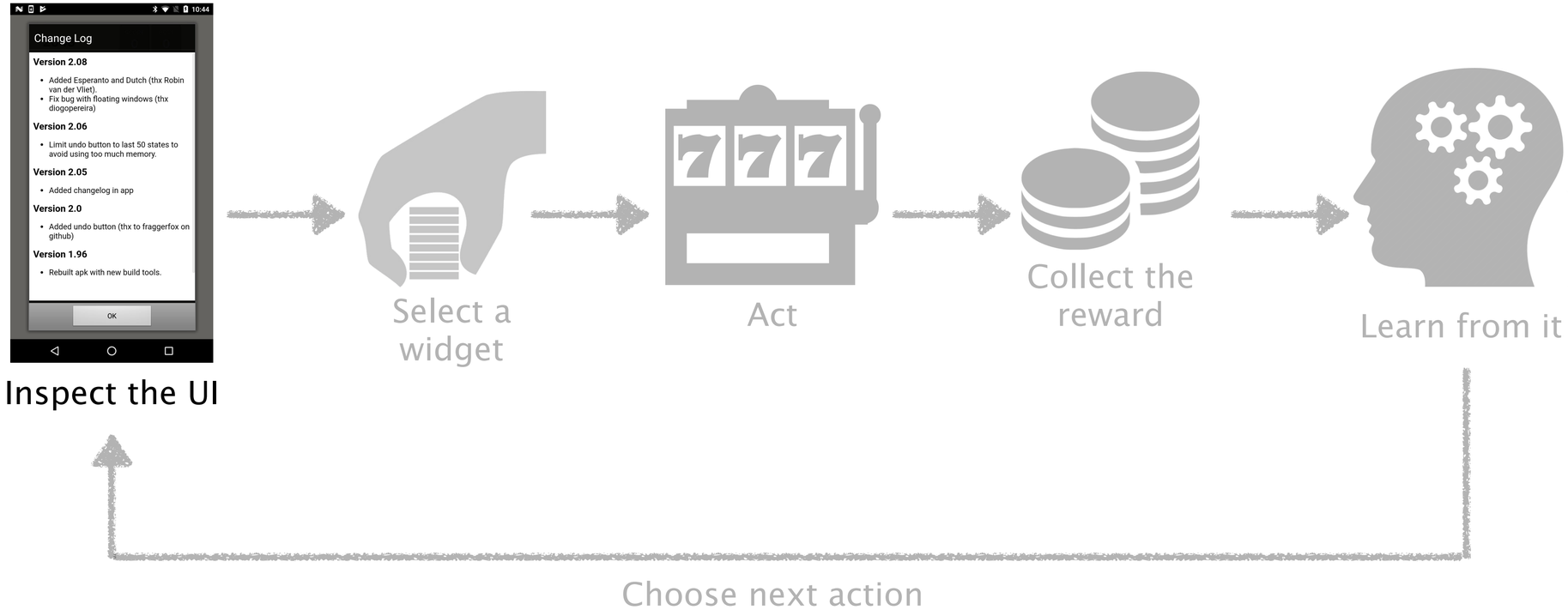

Fetch UI Elements

- All actionable UI elements
  - Extracted from the Accessibility Service

- All possible action types for each element
  - Clickable
  - Long Clickable
  - Scrollable
  - Tick-able
  - Swipe-able

Widget Classes

- Cluster features:
  - class type, parent type and children types

- Probabilities for each:
  - class and action type

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Class	Parent Type	1st Children	2nd Children
Button	Linear Layout	—	—
(…)			
Label	Linear Layout	—	—

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Class	Parent Type	1st Children	2nd Children	Action Type
Button	Linear Layout	—	—	**Click**
Button	Linear Layout	—	—	**Long Click**
Button	Linear Layout	—	—	**Swipe**
		(…)		
Label	Linear Layout	—	—	**Click**
Label	Linear Layout	—	—	**Long Click**

Widget Classes

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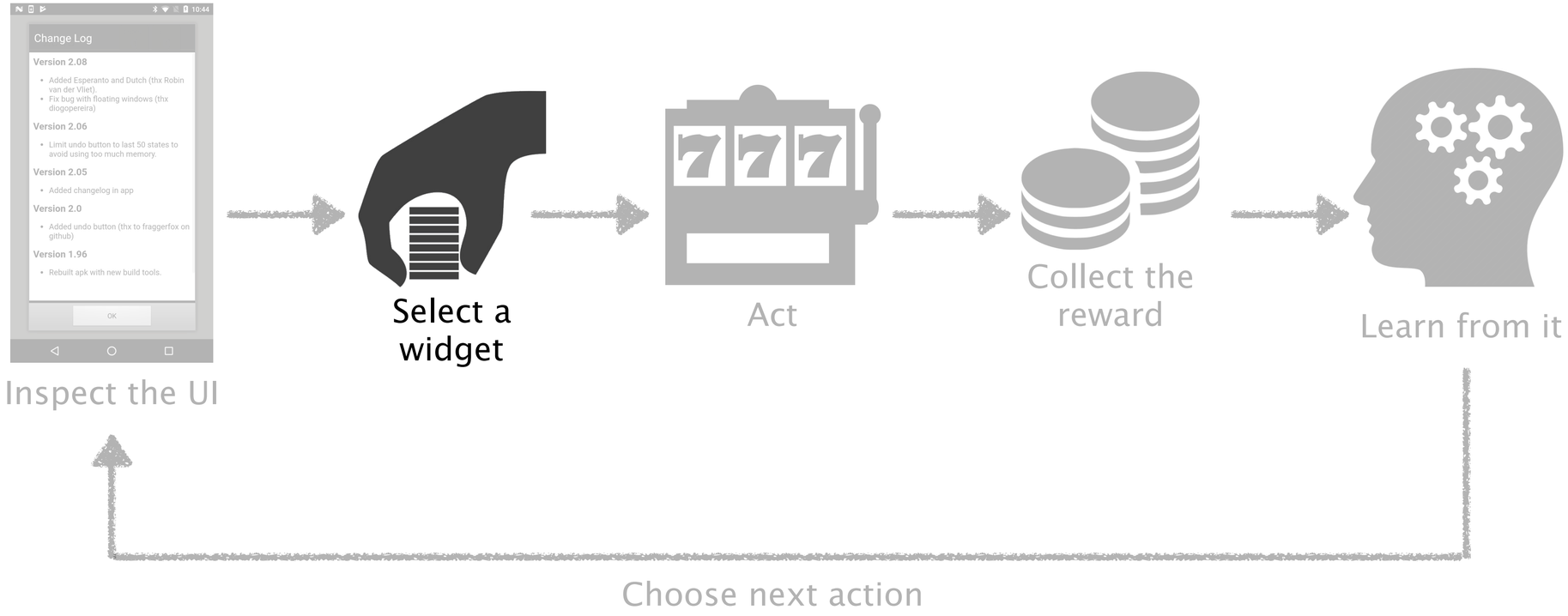
Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	**Click**	**x**	**X**
Button	Linear Layout	—	—	**Long Click**	**x’**	**X’**
Button	Linear Layout	—	—	**Swipe**	**x”**	**X”**
		(…)				
Label	Linear Layout	—	—	**Click**	**y**	**Y**
Label	Linear Layout	—	—	**Long Click**	**y'**	**Y’**

Testing with Reinforcement Learning



Reinforcement Learning Strategies

- ϵ-Greedy

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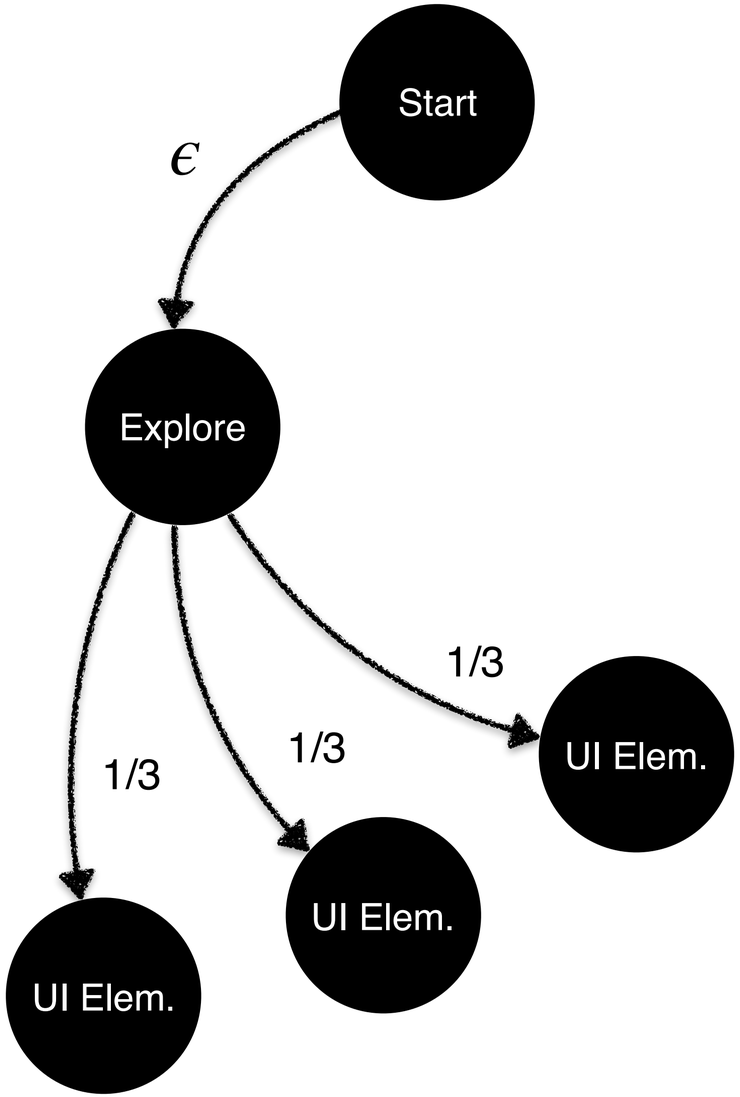
  - ϵ chance of randomly selecting a UI element



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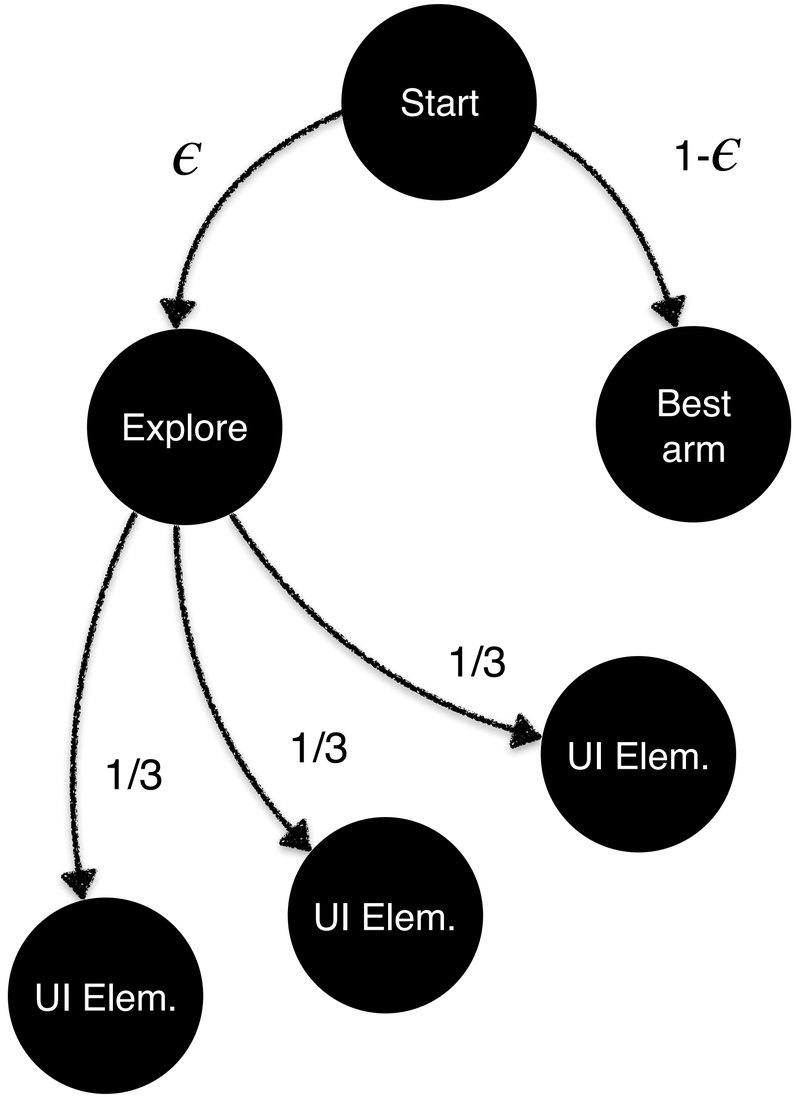
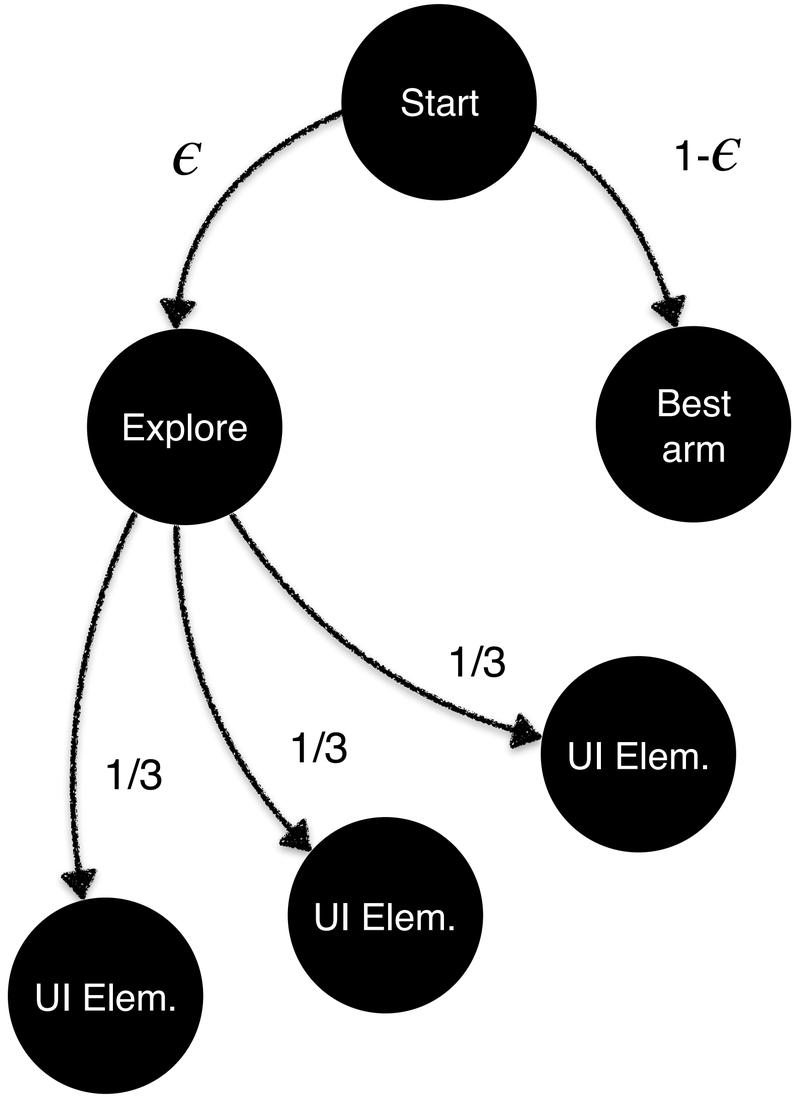


Reinforcement Learning Strategies

- ϵ-Greedy
  - ϵ chance of randomly selecting a UI element
  - 1-ϵ chance of selecting the best UI element
- ϵ balances between *exploration* and *exploitation*

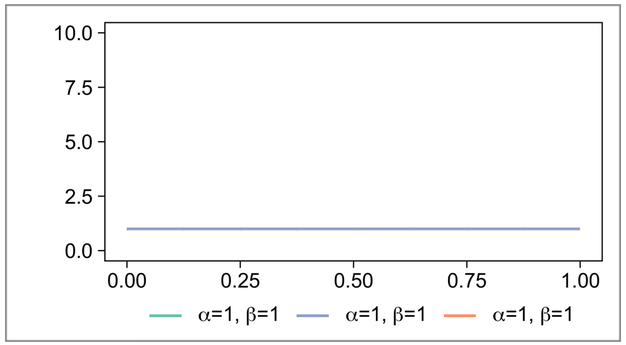


Reinforcement Learning Strategies

- Thompson Sampling

Reinforcement Learning Strategies

- Thompson Sampling
  - Wins and trials
  - β distribution



Reinforcement Learning Strategies

- Thompson Sampling
  - Wins and trials
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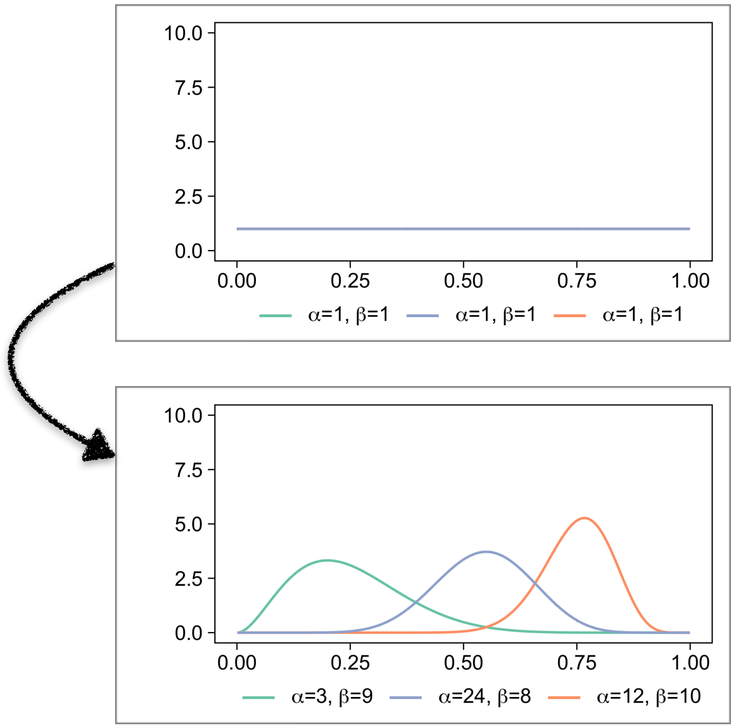
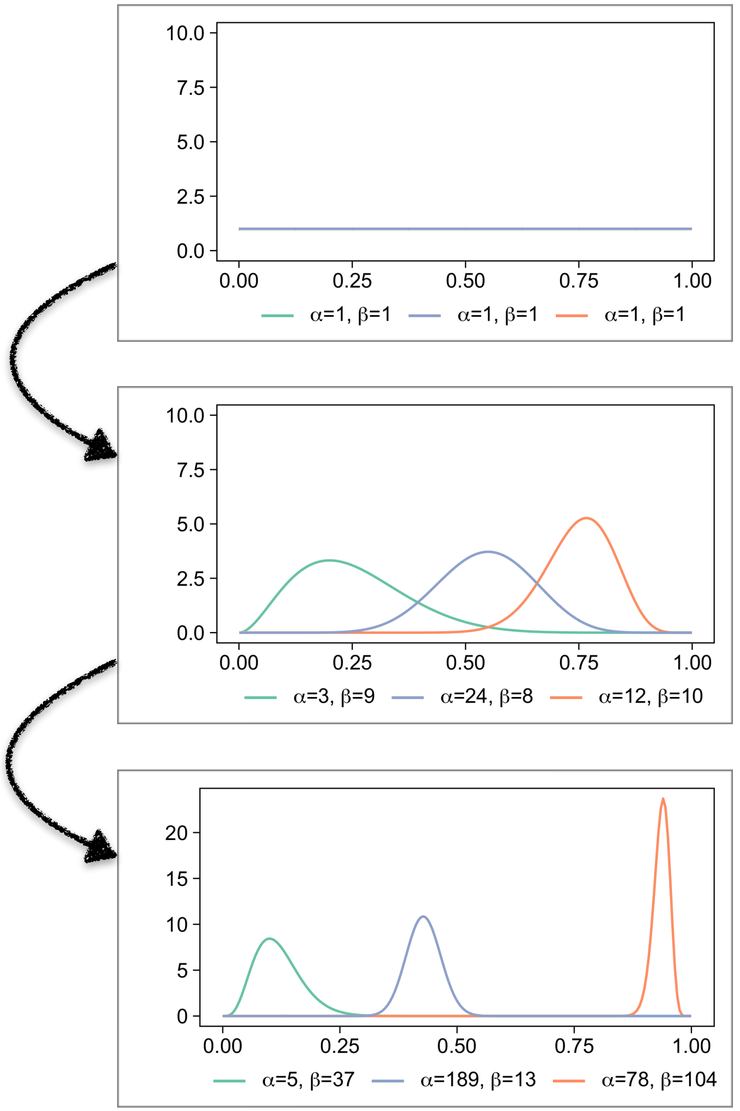
  - Random sample
  - Select class with best sample

  - Increase trials and wins after each action

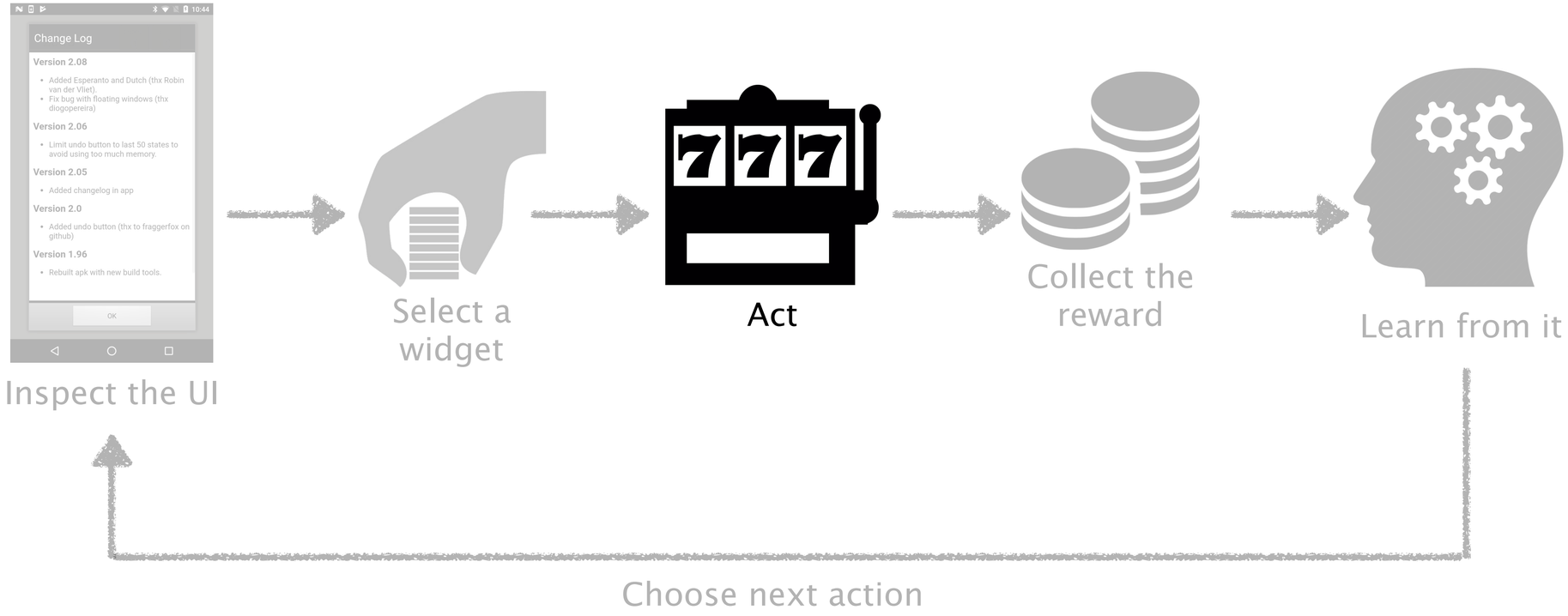


Reinforcement Learning Strategies

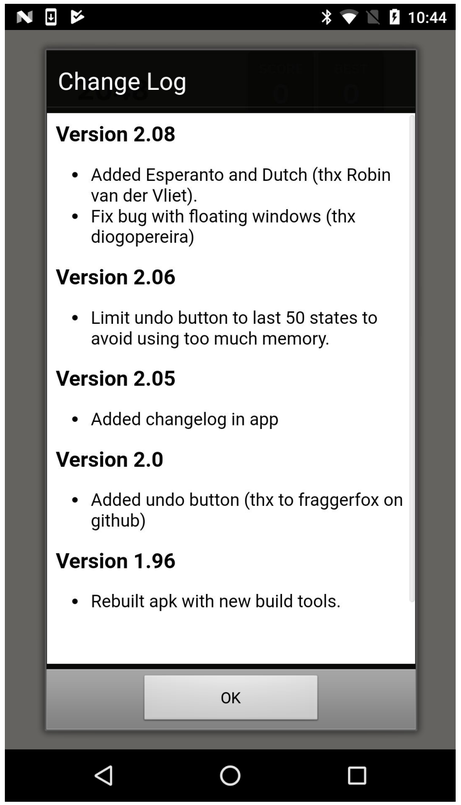
- Thompson Sampling
  - Wins and trials
  - β distribution
  - Random sample
  - Select class with best sample
  - Increase trials and wins after each action
- Distributions adjust over time



Testing with Reinforcement Learning



Convert Chosen Widget—Class into Action



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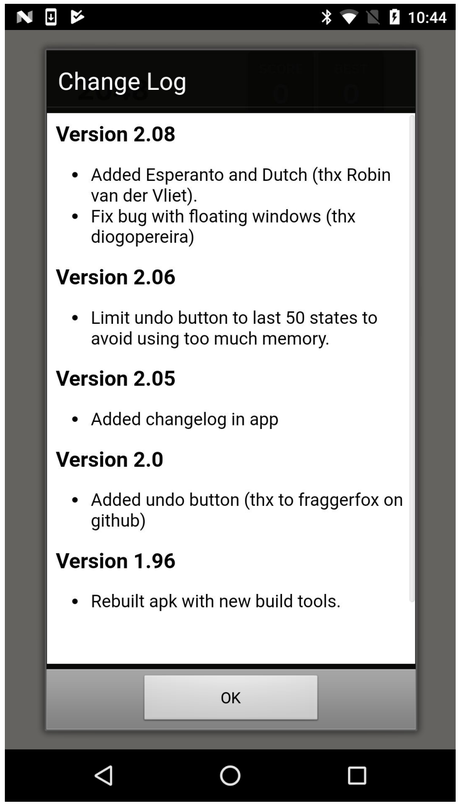

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Button	Linear Layout	—	—	**Click**	**x**	**X**
Button	Linear Layout	—	—	**Long Click**	**x'**	**X'**
Button	Linear Layout	—	—	**Swipe**	**x''**	**X''**
		(…)				
Label	Linear Layout	—	—	**Click**	**y**	**Y**
Label	Linear Layout	—	—	**Long Click**	**y'**	**Y'**

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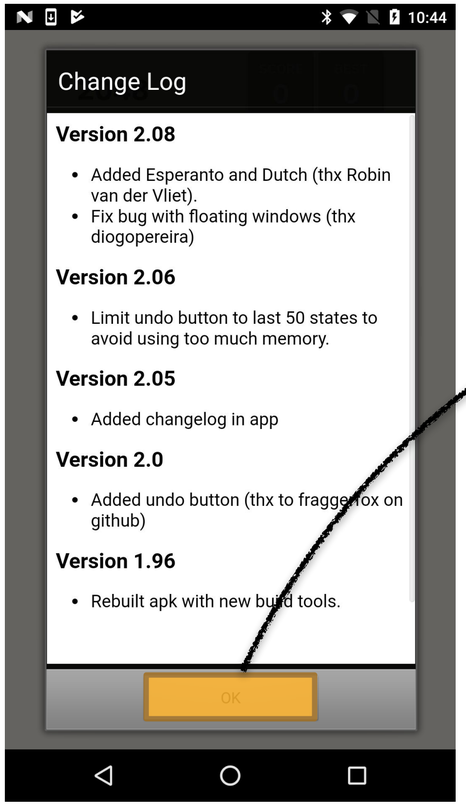

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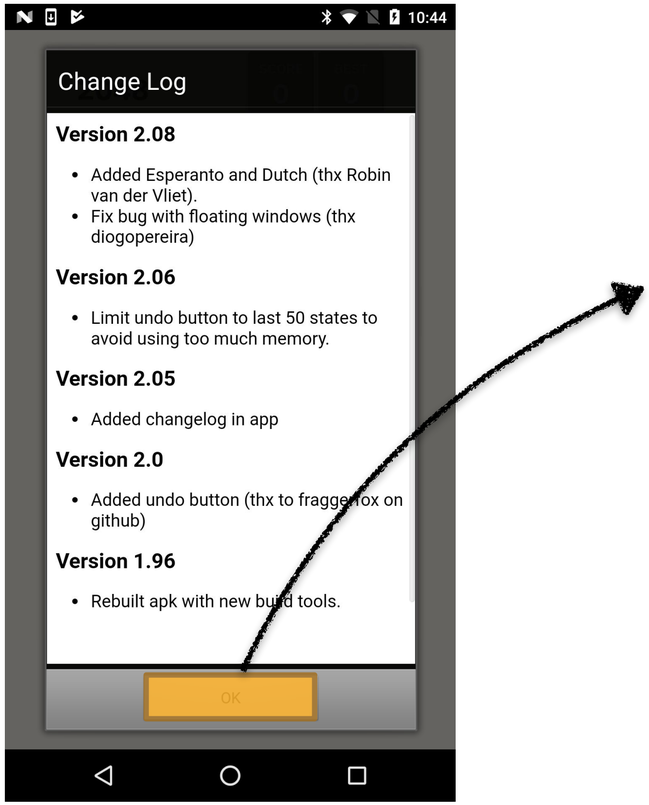
		(…)				
Label	Linear Layout	—	—	**Click**	**y**	**Y**
Label	Linear Layout	—	—	**Long Click**	**y'**	**Y'**

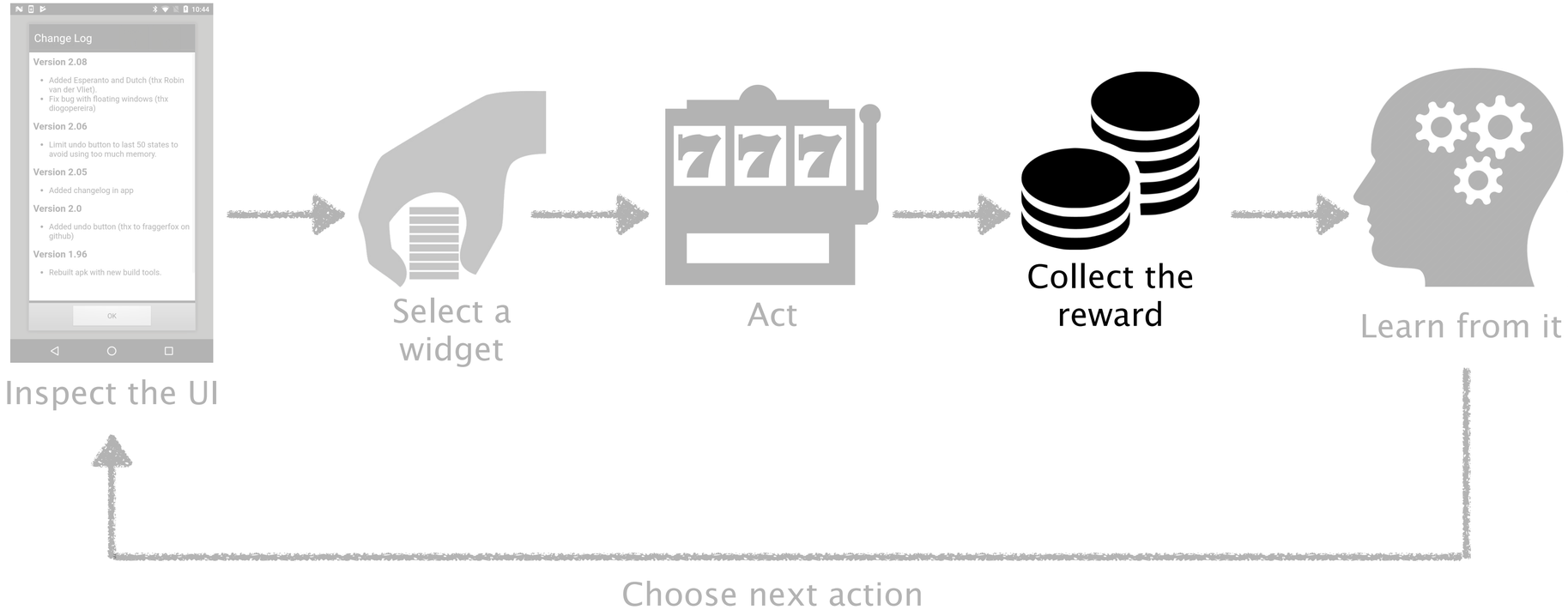
Convert Chosen Widget—Class into Action



Click on “OK" button

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	**Click**	**x**	**X**
Button	Linear Layout	—	—	**Long Click**	**x’**	**X’**
Button	Linear Layout	—	—	**Swipe**	**x”**	**X”**
		(…)				
Label	Linear Layout	—	—	**Click**	**y**	**Y**
Label	Linear Layout	—	—	**Long Click**	**y'**	**Y’**

Testing with Reinforcement Learning



Binary Reward (Bernoulli Multi-Armed Bandit)

Reward	Condition
1	If app state changed
0	Otherwise

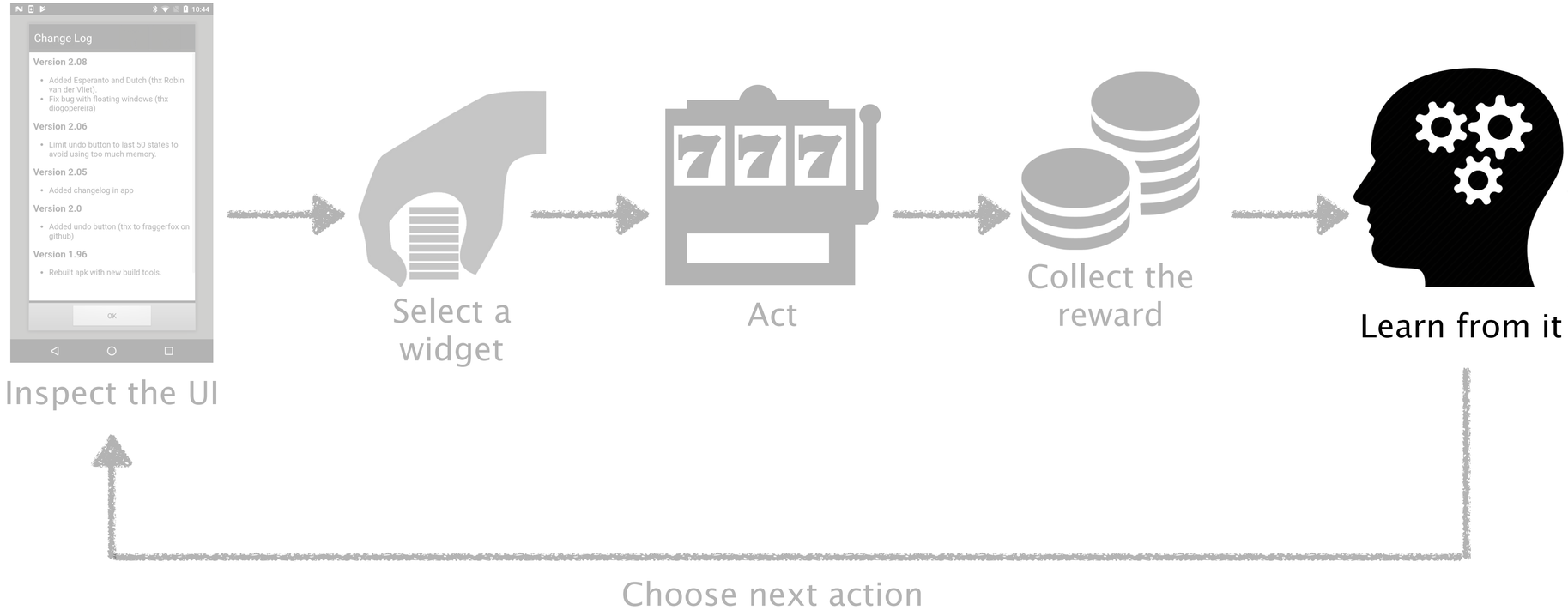
Binary Reward (Bernoulli Multi-Armed Bandit)

Reward	Condition
1	If app state changed
0	Otherwise

A state changes if any UI element is

added, removed, moved, resized, changes text (non-input)

Testing with Reinforcement Learning

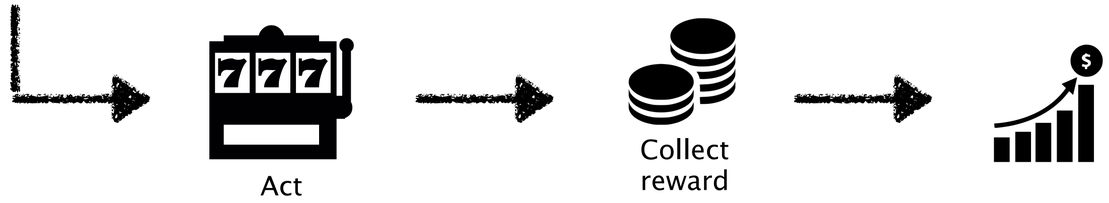


Learn from Rewards

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1

Learn from Rewards

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1



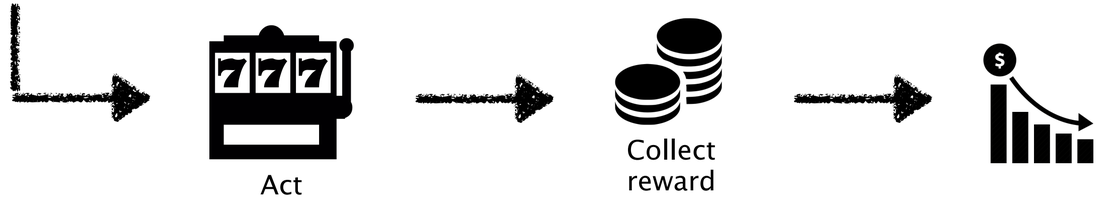
Learn from Rewards

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1
						
Button	Linear Layout	—	—	Click	**2**	**2**

Learn from Rewards

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1

Button	Linear Layout	—	—	Click	2	2



Learn from Rewards

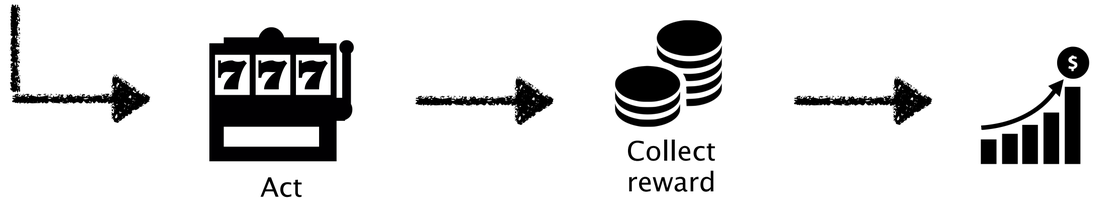
Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1
						
Button	Linear Layout	—	—	Click	2	2
						
Button	Linear Layout	—	—	Click	2	3

Learn from Rewards

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1

Button	Linear Layout	—	—	Click	2	2

Button	Linear Layout	—	—	Click	2	3



Learn from Rewards

Class	Parent Type	1st Children	2nd Children	Action Type	Wins	Trials
Button	Linear Layout	—	—	Click	1	1
Button	Linear Layout	—	—	Click	2	2
Button	Linear Layout	—	—	Click	2	3
Button	Linear Layout	—	—	Click	3	4

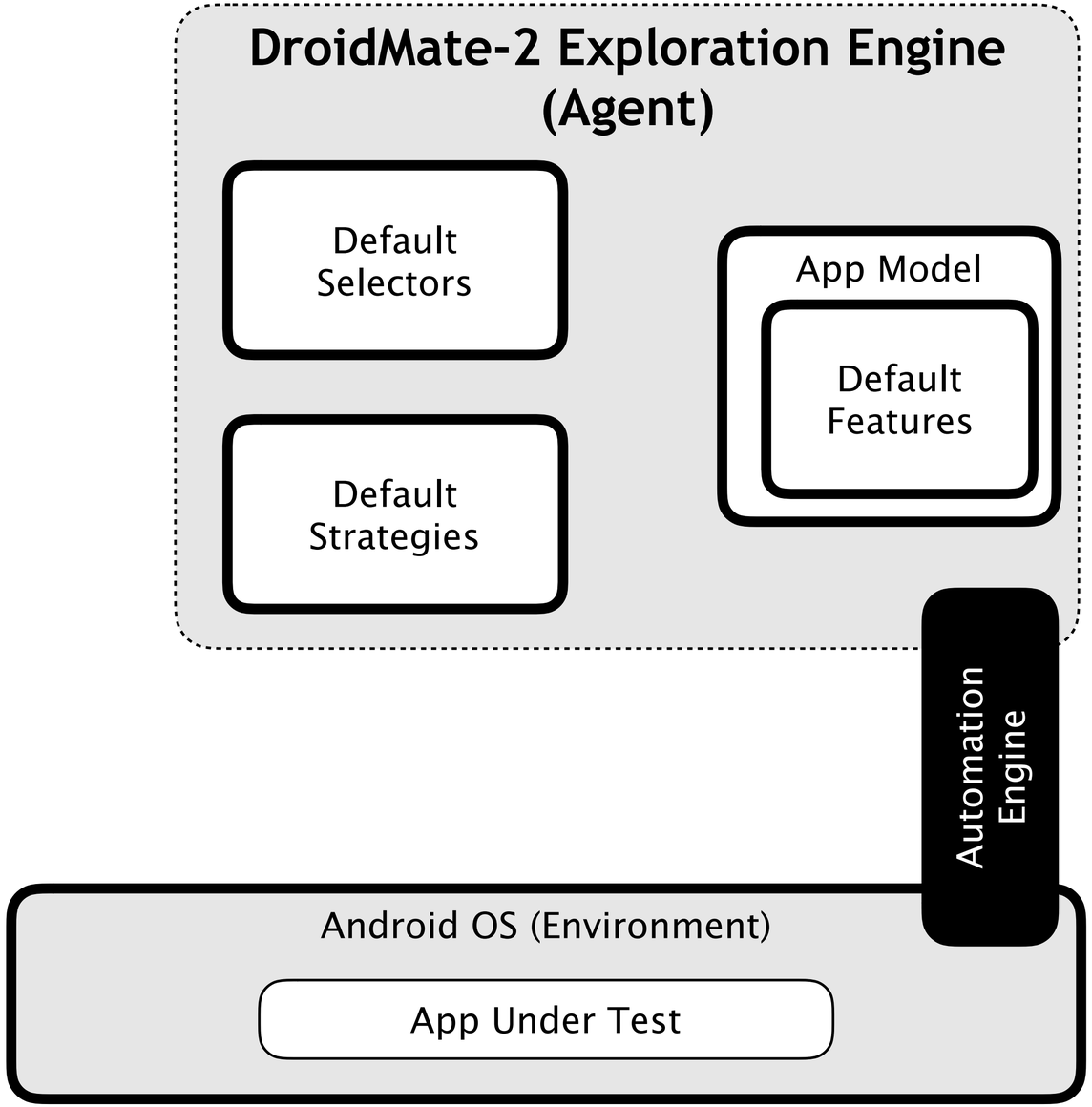
Evaluation

1. Can Multi-Armed-Bandit approaches effectively test apps?

2. Is dynamic knowledge more beneficial to testing than static models from other apps?

3. Can Multi-Armed-Bandit approaches be used to enhance static models?

Design: Exploit DroidMate-2 Exploration Engine



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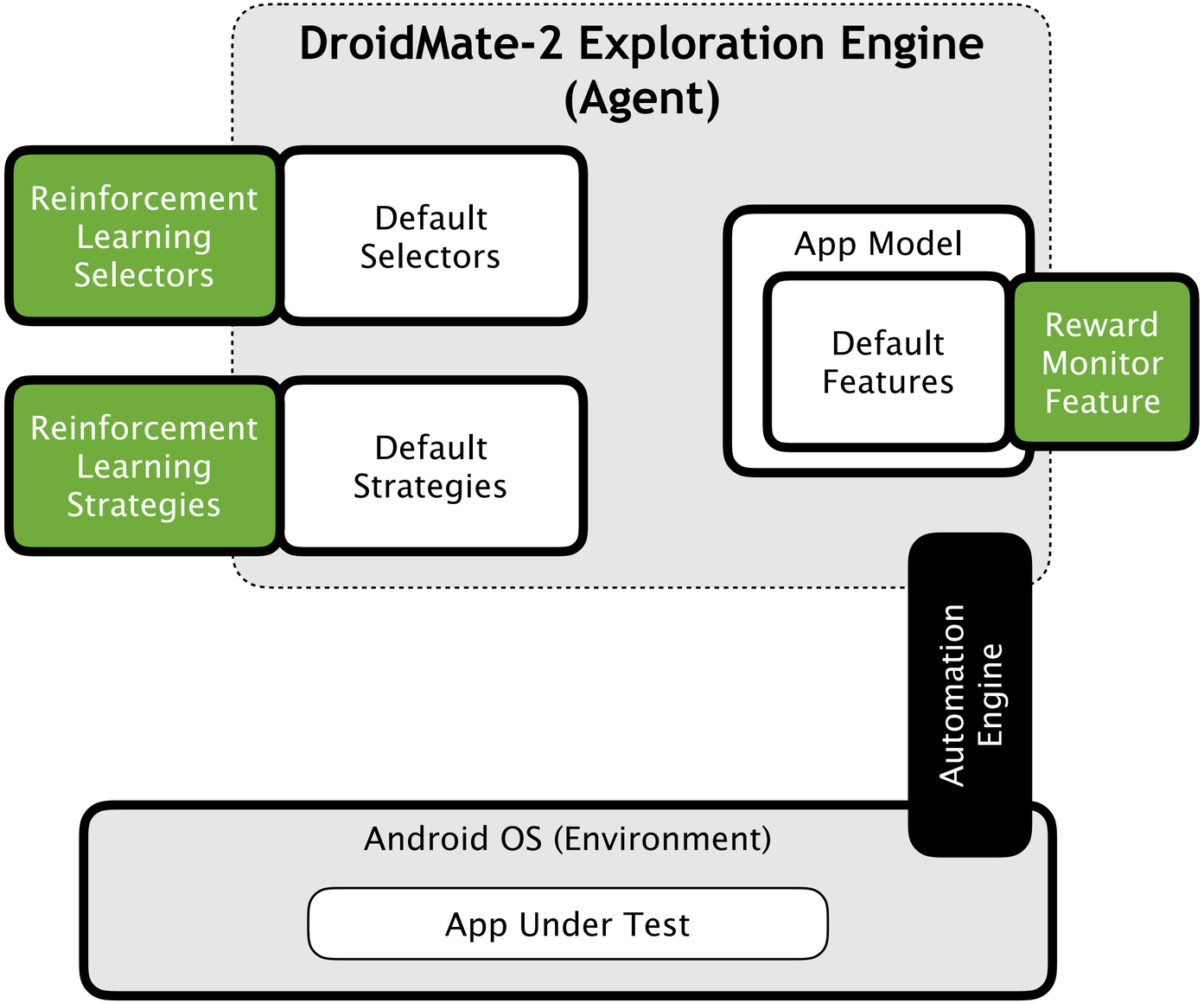

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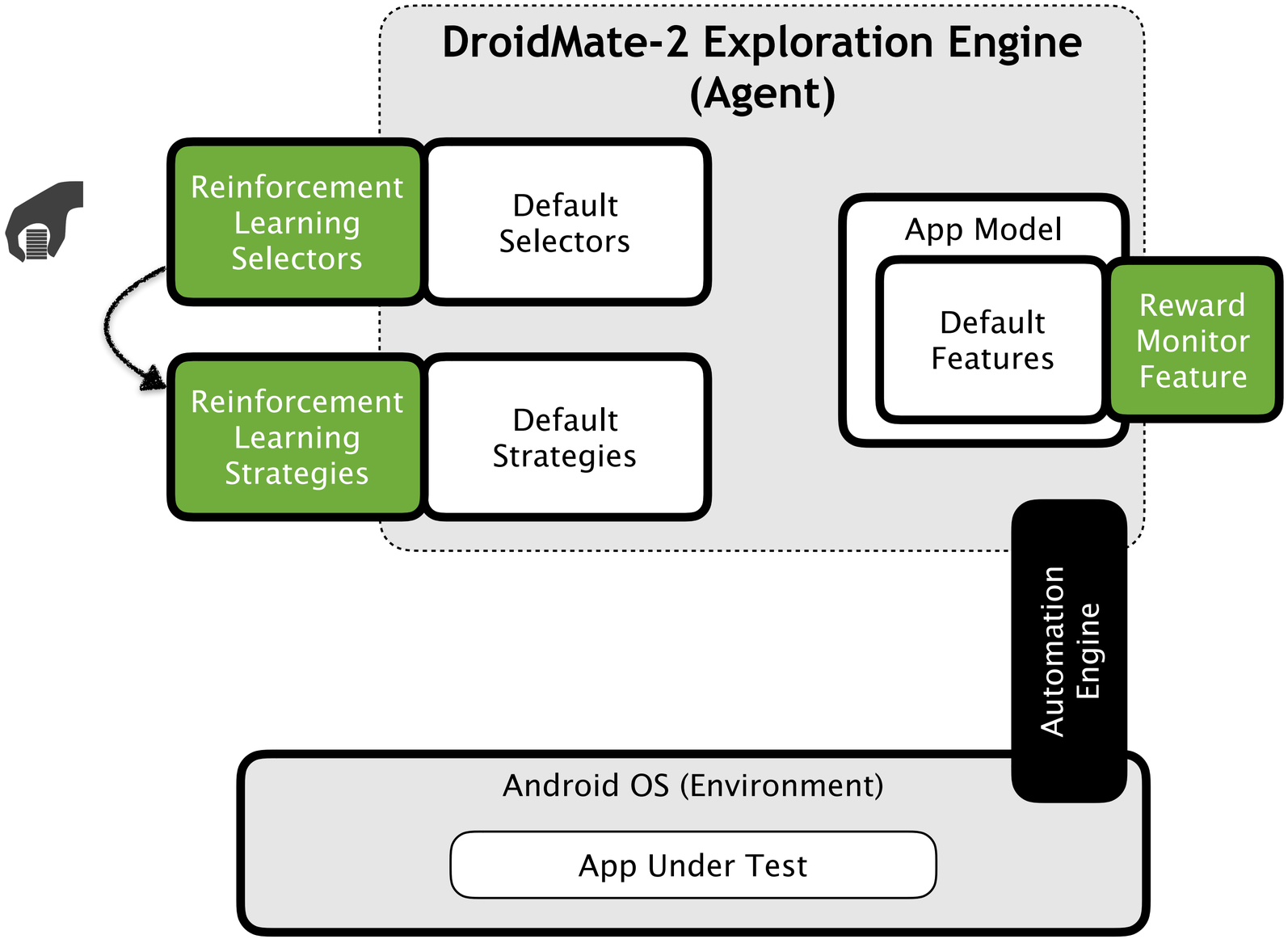

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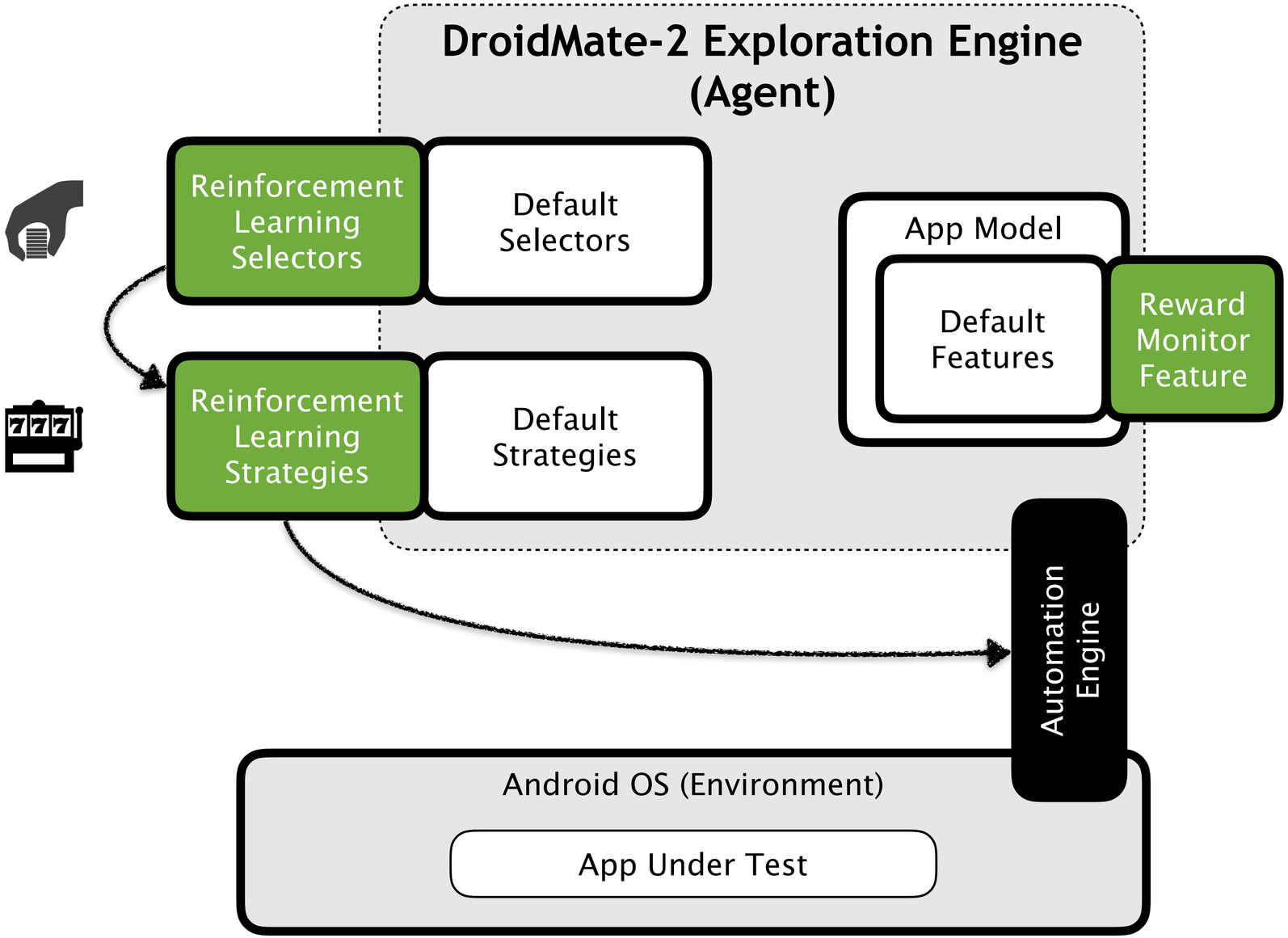

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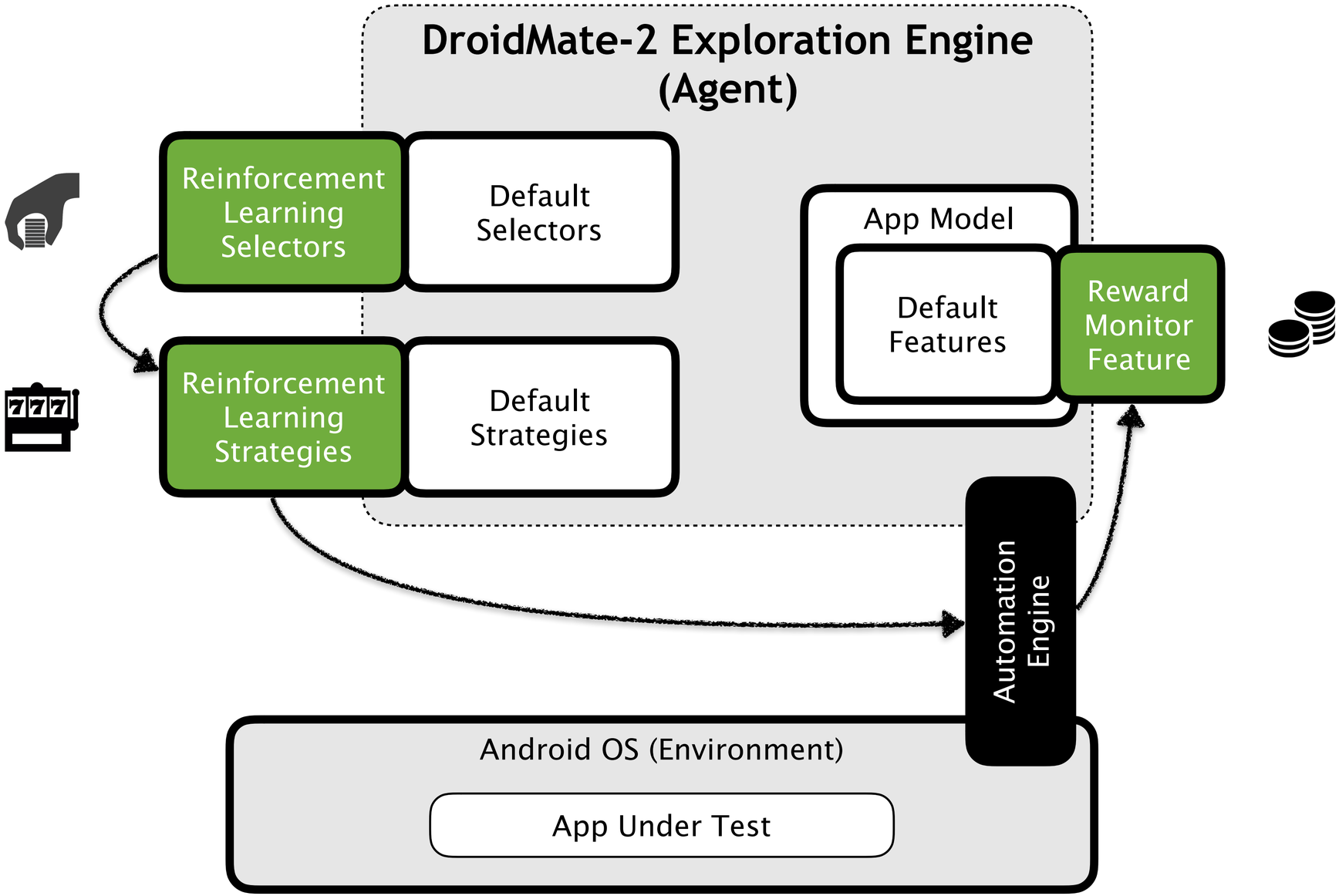
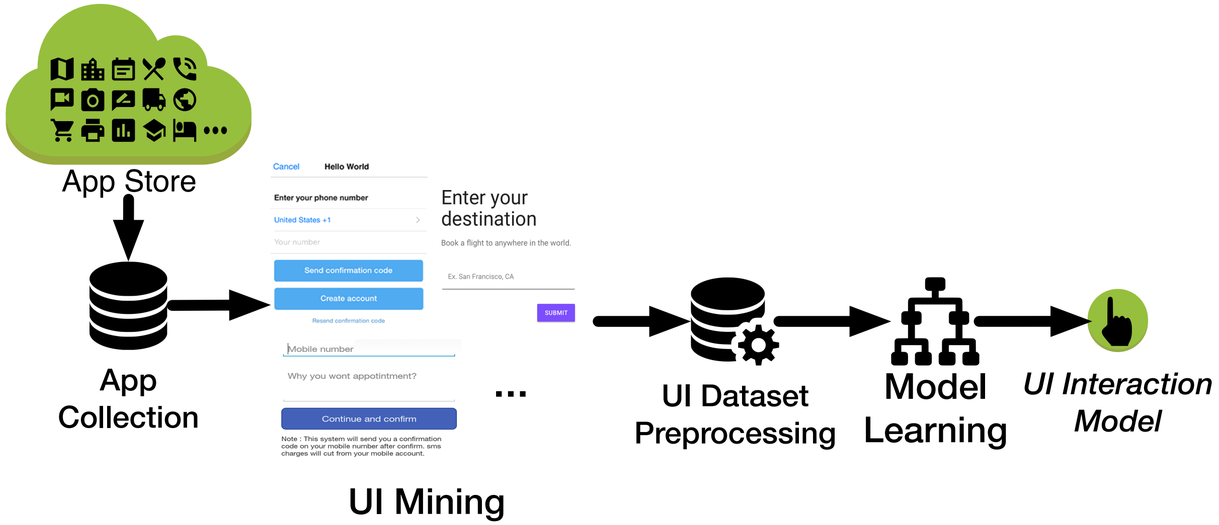


Baseline

- Crowd-Model to Predict Events
  - Static analysis to build a prediction model from multiple apps
  - Reuse the model to test arbitrary apps without any further analysis

- ~19% improvement when compared to random on the same tool

- Reused all possible apps from the original experiment



Evaluation — Can Multi-Armed-Bandit approaches effectively test apps?

- **Statement coverage**
  - Baseline vs ϵ-Greedy vs Thompson Sampling
  - ϵ = 0.3
  - 10 runs per app

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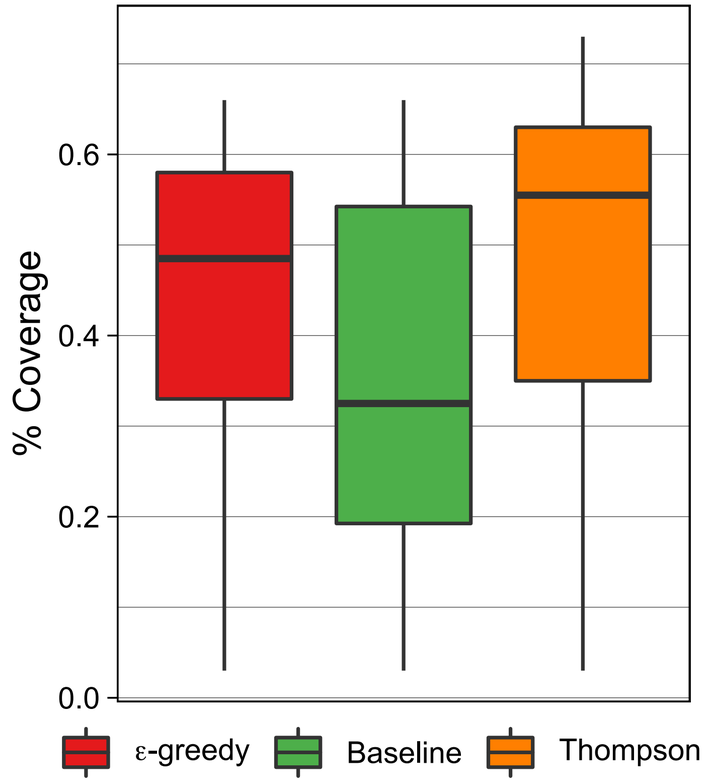

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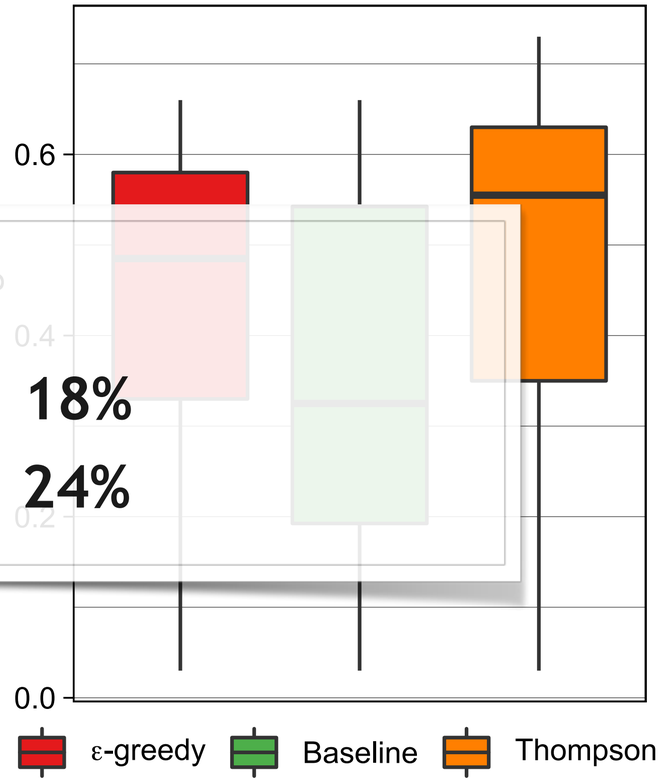
Average coverage increase:

ϵ-Greedy → **18%**

Thompson Sampling → **24%**



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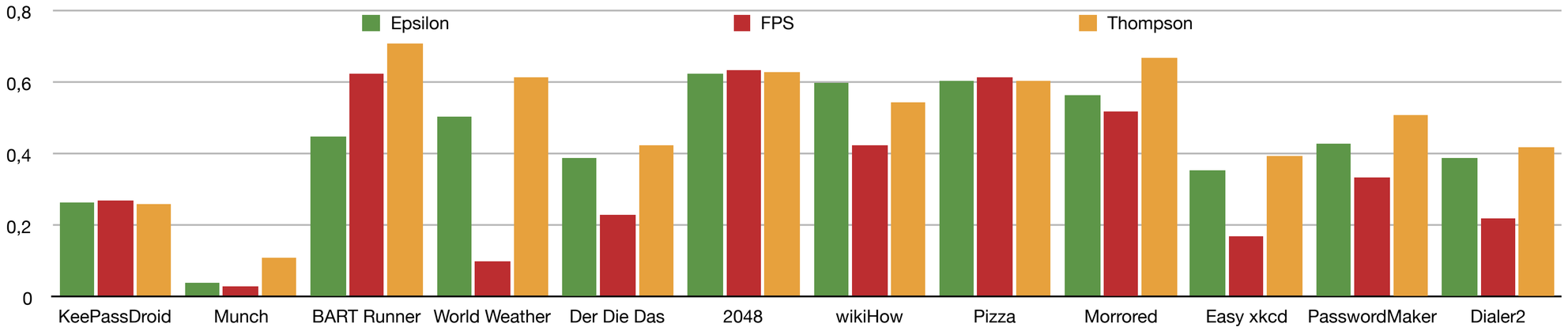

Evaluation — Can Multi-Armed-Bandit approaches effectively test apps?

- **Statement coverage**
  - Baseline vs ϵ-Greedy vs Thompson Sampling
  - ϵ = 0.3
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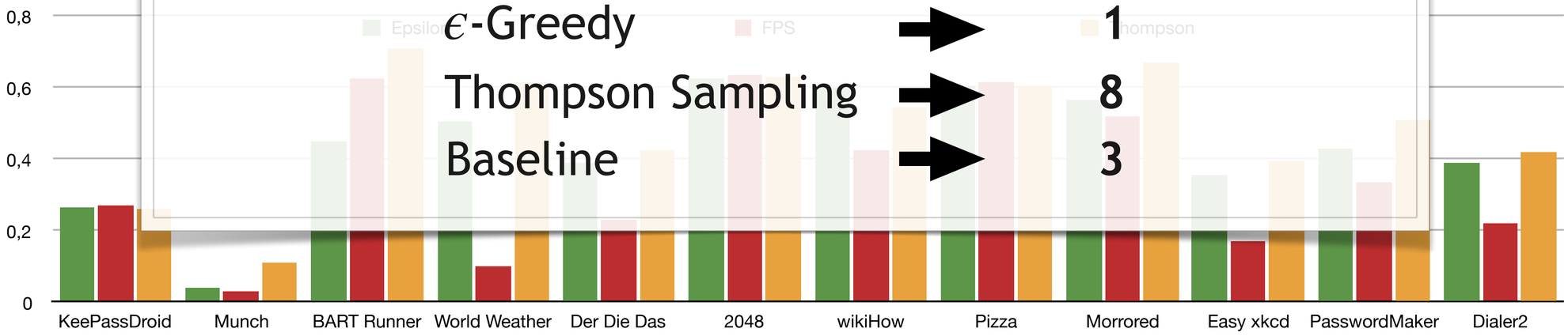
Most coverage:

ϵ-Greedy	→	1
Thompson Sampling	→	8
Baseline	→	3



Evaluation — Dynamic vs Static Knowledge?

- **Statement coverage**
  - ϵ-Greedy vs ϵ-Greedy+K
  - Thompson Sampling vs Thompson Sampling+K
  - 10 runs per app

  - Initialized trials and wins based on crowd model probabilities

Evaluation — Dynamic vs Static Knowledge?

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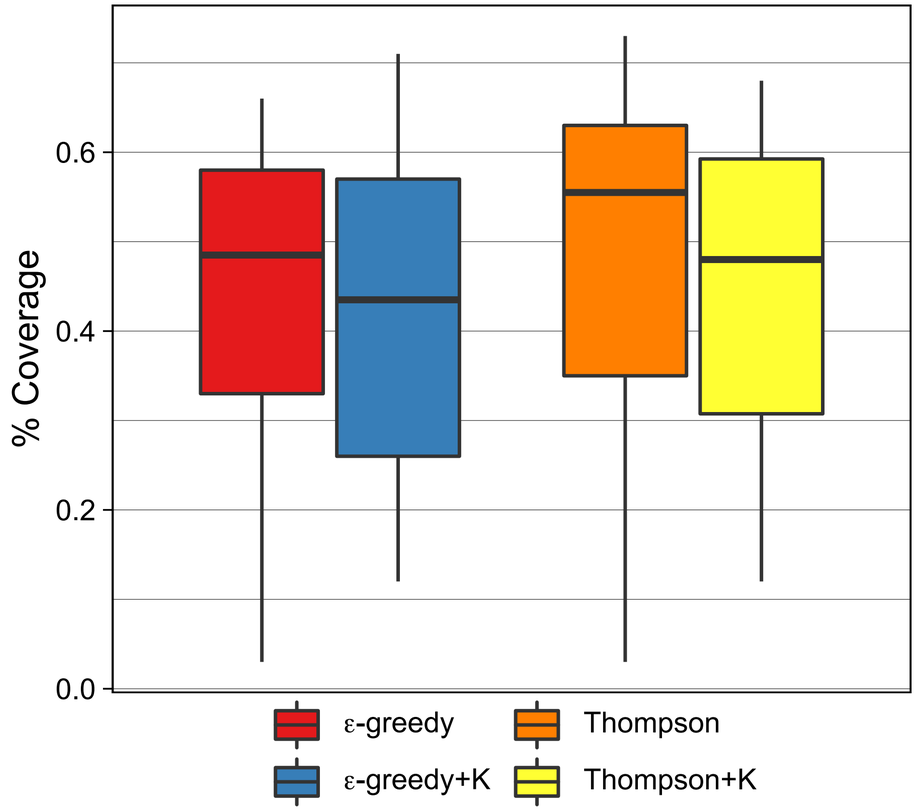


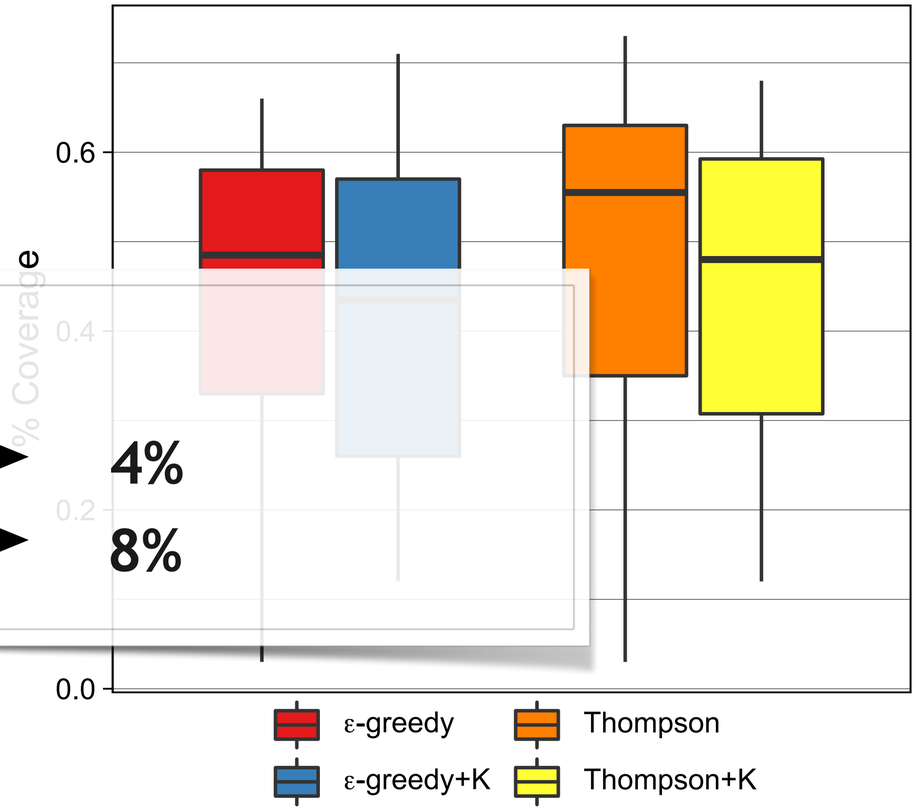
Evaluation — Dynamic vs Static Knowledge?

- **Statement coverage**
  - ϵ-Greedy vs ϵ-Greedy+K
  - Thompson Sampling vs Thompson Sampling+K
  - 10 runs per app
  - Initialized trials and wins based on crowd-model probabilities

Static models decrease coverage by:

ϵ-Greedy → **4%**

Thompson Sampling → **8%**



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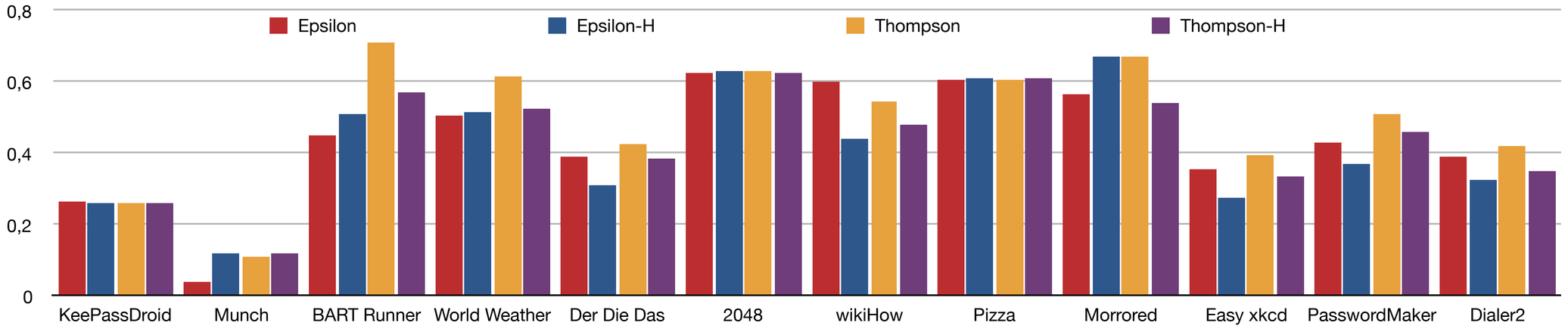

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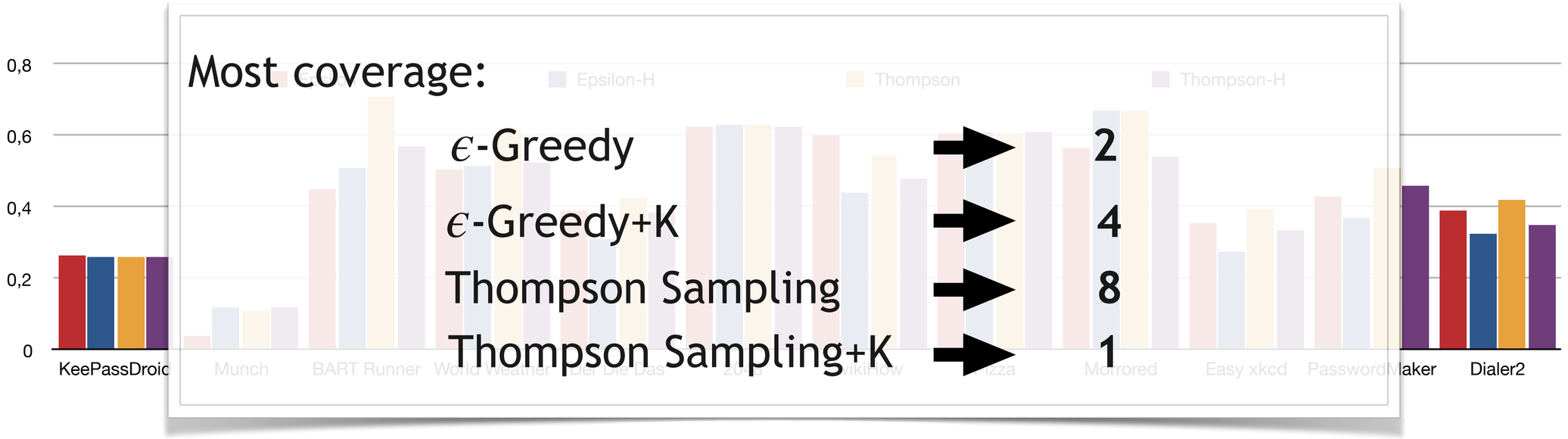

Evaluation — Multi-Armed-Bandit approaches to enhance static models?

- **Statement coverage**
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  - Roulette wheel selection algorithm from Baseline+RL
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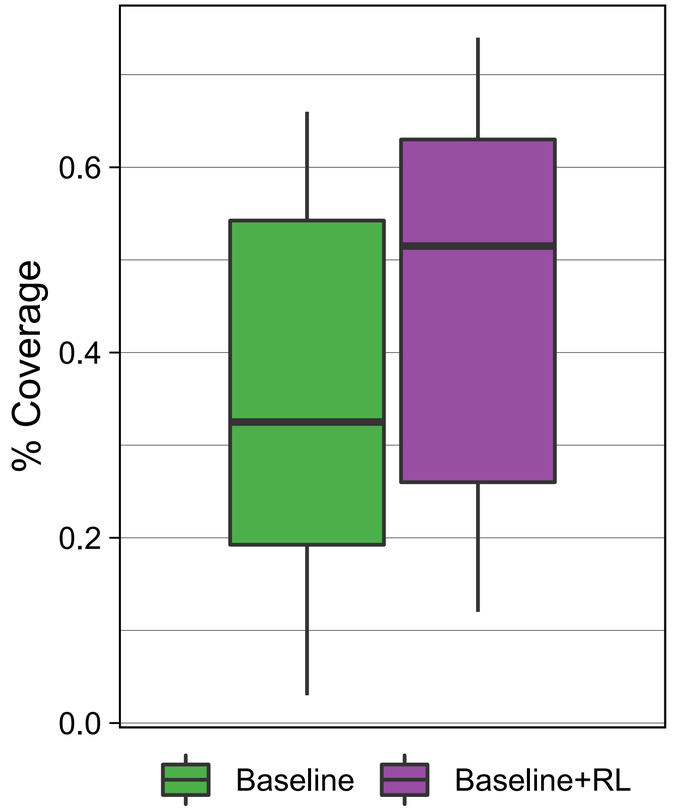

Evaluation — Multi-Armed-Bandit approaches to enhance static models?

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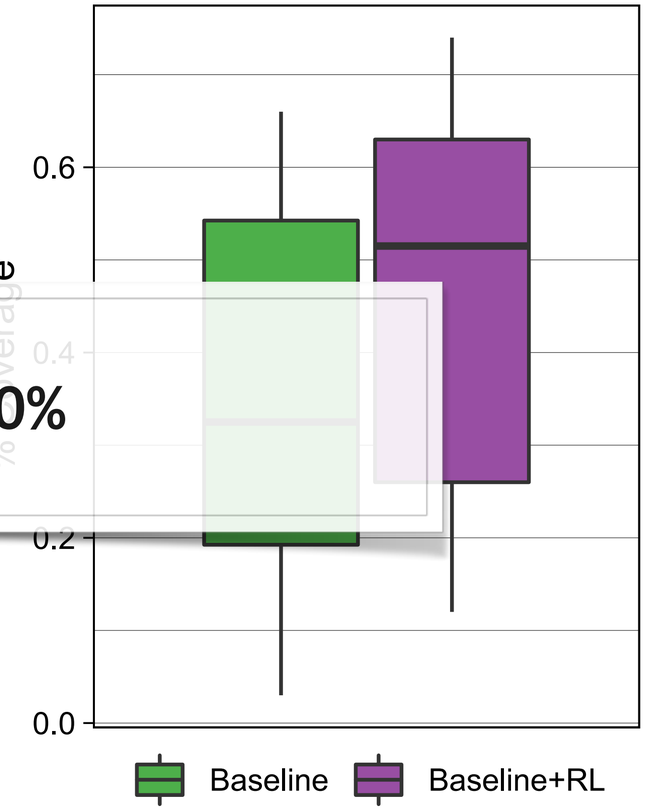
  - 10 runs per app

RL improved the baseline by **20%**



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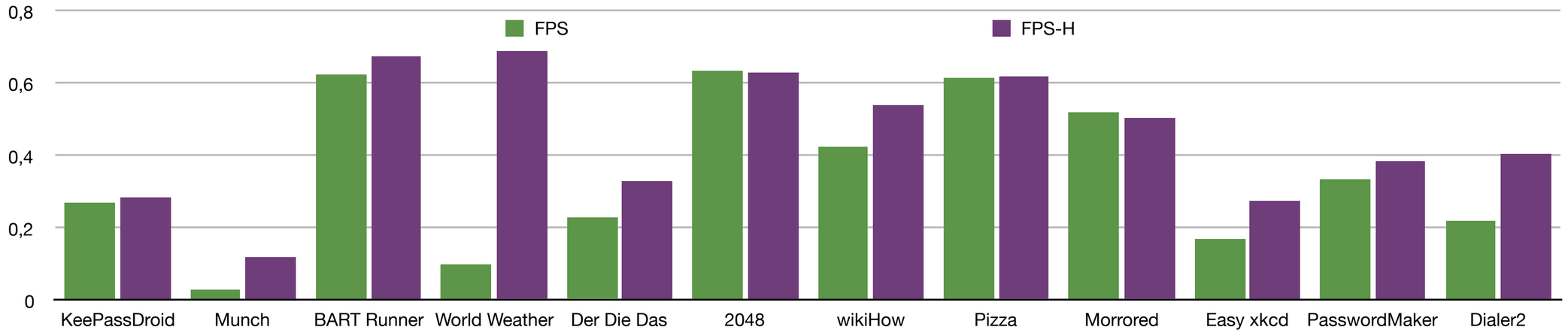

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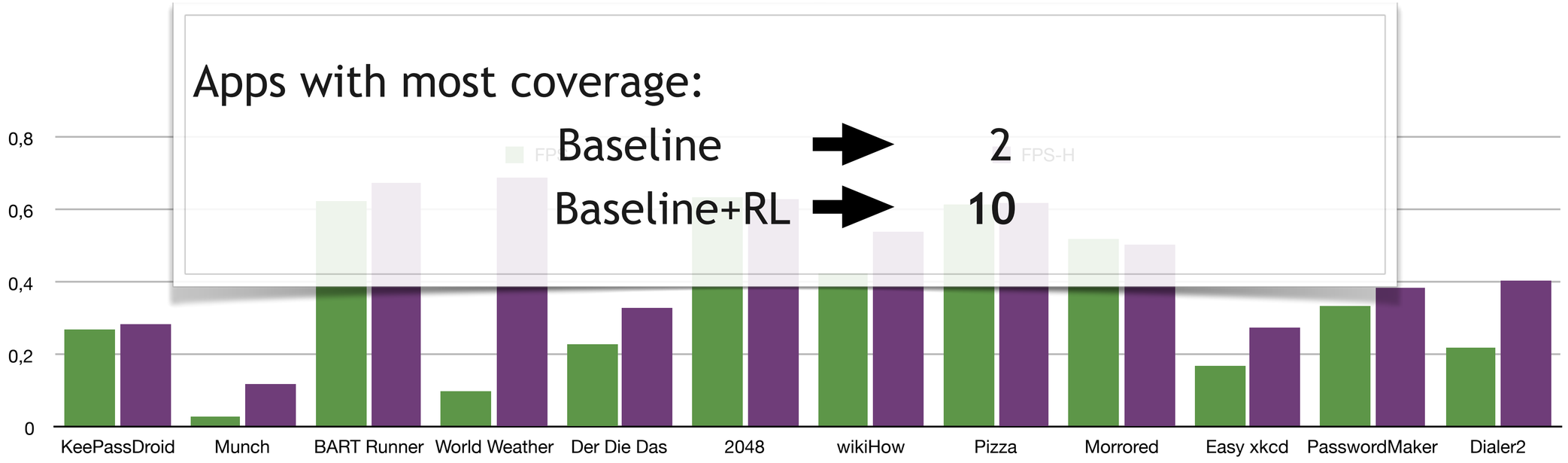

Summary

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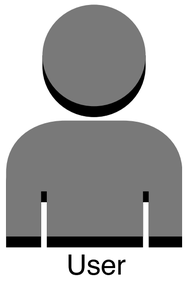
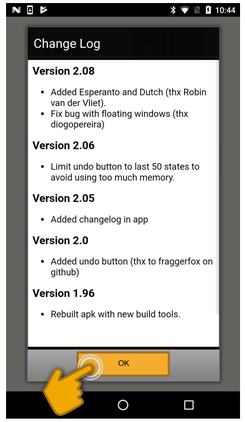
SAARLANDES

Summary

User vs GUI





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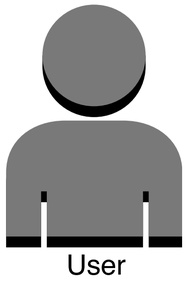
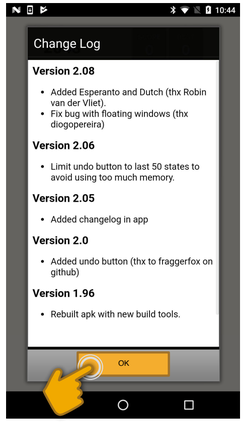
Summary

User vs GUI





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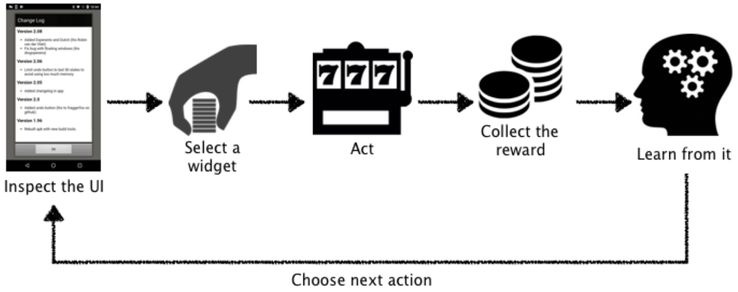
Testing with Reinforcement Learning



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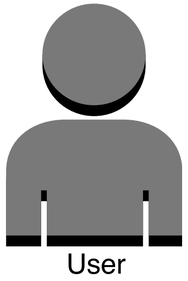

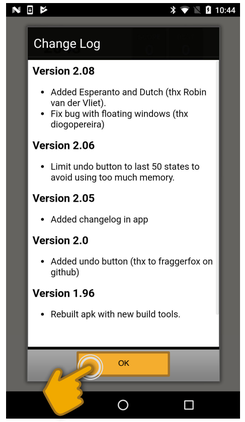

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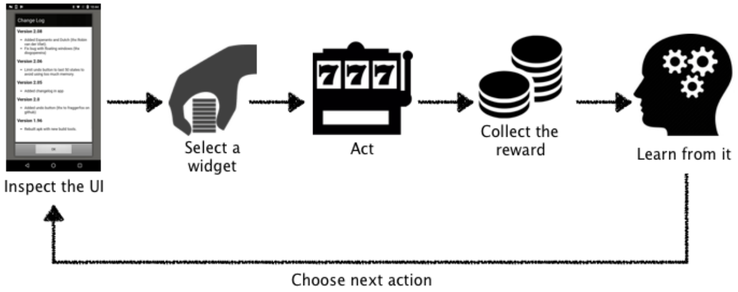
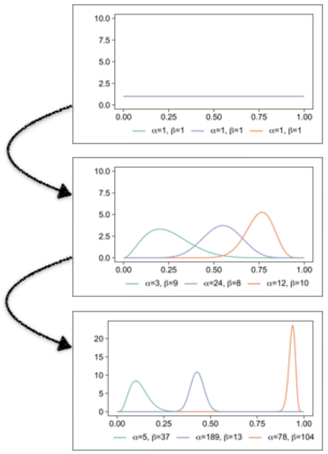


Reinforcement Learning Strategies

- Thompson Sampling
  - Wins and trials
  - β distribution
  - Random sample
  - Select class with best sample
  - Increase trials and wins after each action
- Distributions adjust over time



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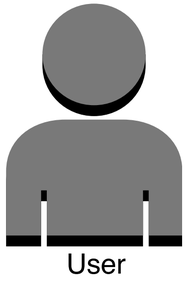

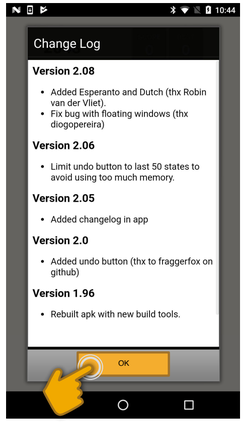

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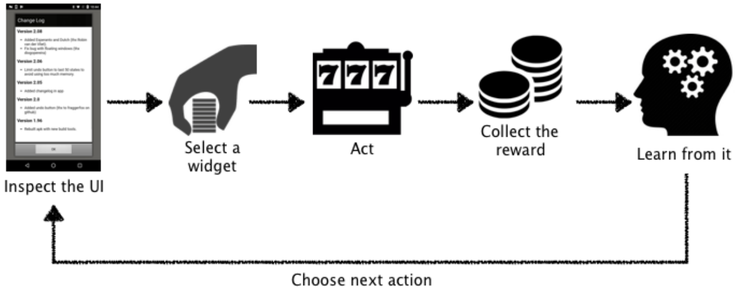

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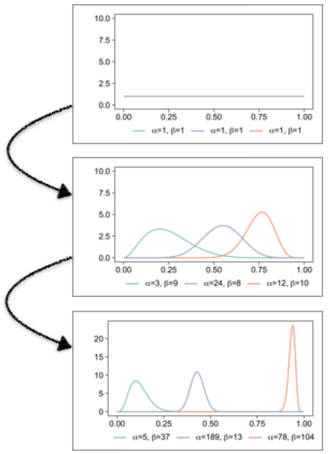

Evaluation — Can RL effectively test apps?

- **Statement coverage**
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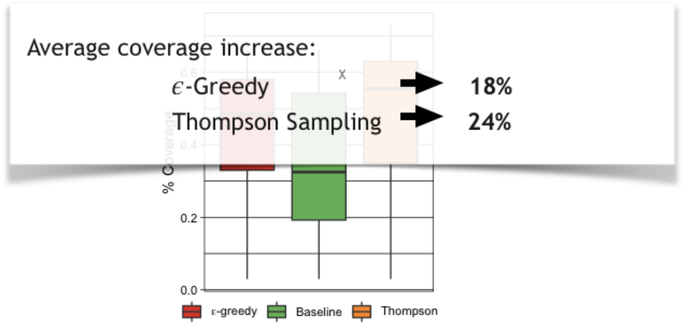
  - 10 runs per app



UNIVERSITÄT DES SAARLANDES

Summary

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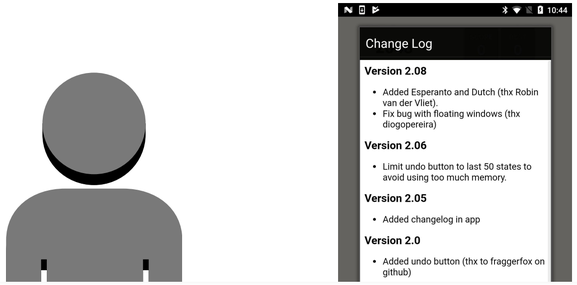
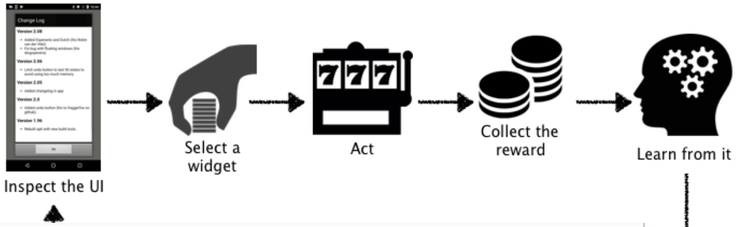


Testing with Reinforcement Learning



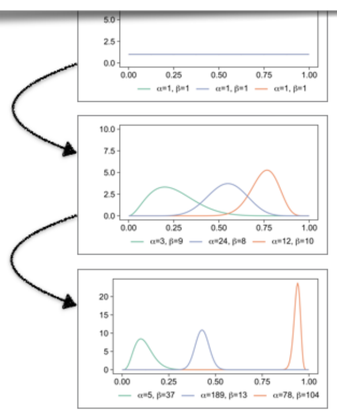
Available on GitHub

https://github.com/uds-se/droidmate-bandits

build passing JitPack 1.0

Reinfo

- Thom
  - Wins and trials
  - β distribution
  - Random sample
  - Select class with best sample
  - Increase trials and wins after each action
- Distributions adjust over time



- Baseline vs ϵ-Greedy vs Thompson Sampling
- 10 runs per app

Average coverage increase:

ϵ-Greedy	18%
Thompson Sampling	24%