

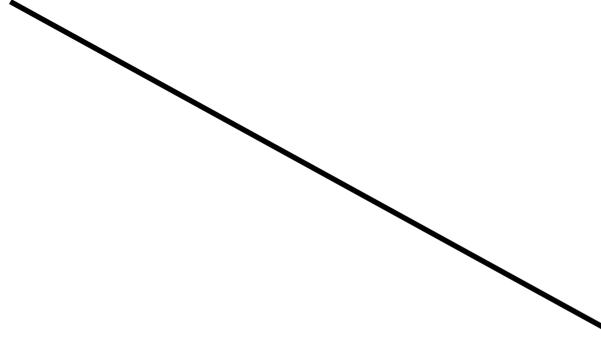
# Mosaic: Cross-platform User-interaction Record and Replay for the Fragmented Android Ecosystem

**Matthew Halpern**, Yuhao Zhu, Ramesh Peri\*, Vijay Janapa Reddi  
Department of Electrical and Computer Engineering, UT Austin  
\*Intel Corporation

ISPASS - March 31st, 2015

# Building **Better** Computer Systems

Run **faster**



Building **Better** Computer Systems

Last longer

Run **faster**

Building **Better** Computer Systems

Last longer

Run **faster**

Building **Better** Computer Systems

Be **reliable**

More **secure**

Last **longer**

Run **faster**

More **fair**

Building **Better** Computer Systems

Be **cooler**

Be **reliable**

Less **buggy**

More **debuggable**

# Building “**Better**” Computer Systems

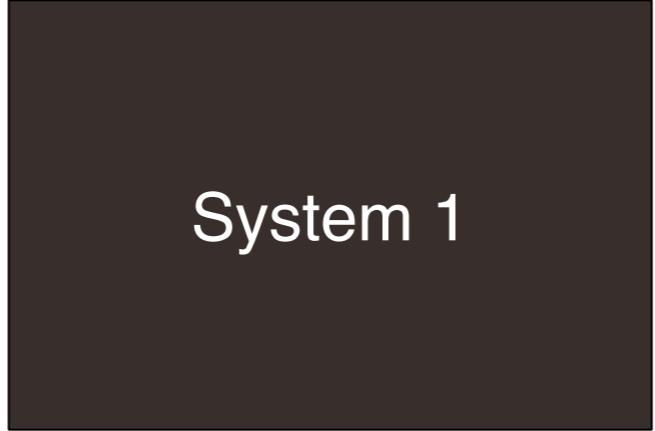
How Do We Know We Are  
Building “**Better**” Computer Systems?

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Building “**Better**” Computer Systems?

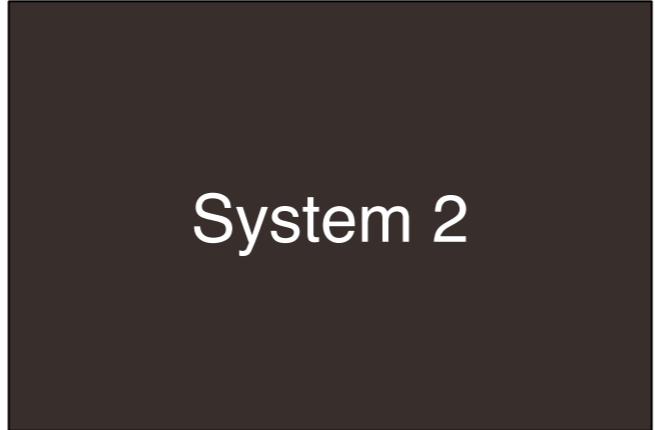
We compare them.

# Quantitative Performance Comparisons

# Quantitative Performance Comparisons

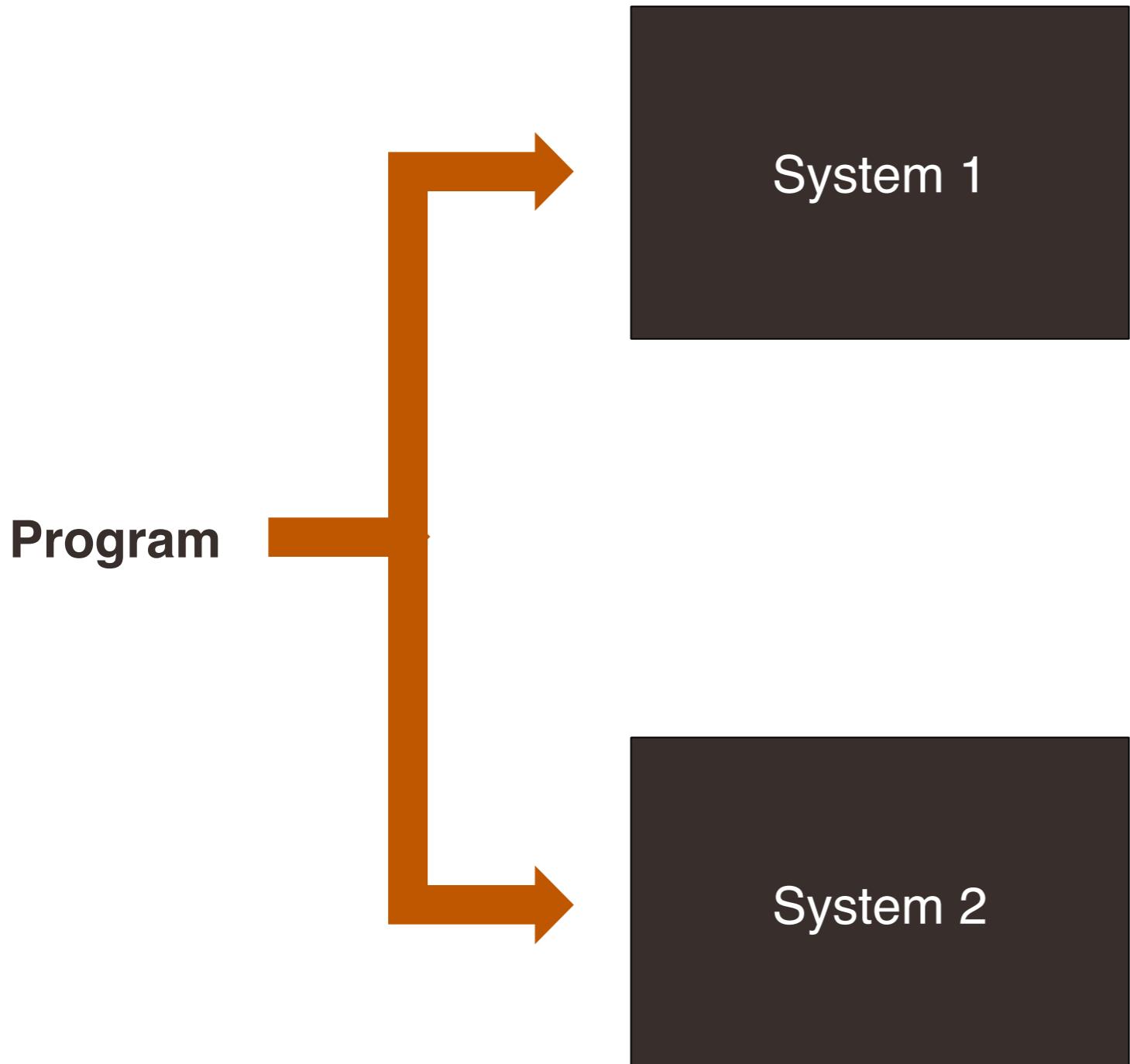


System 1

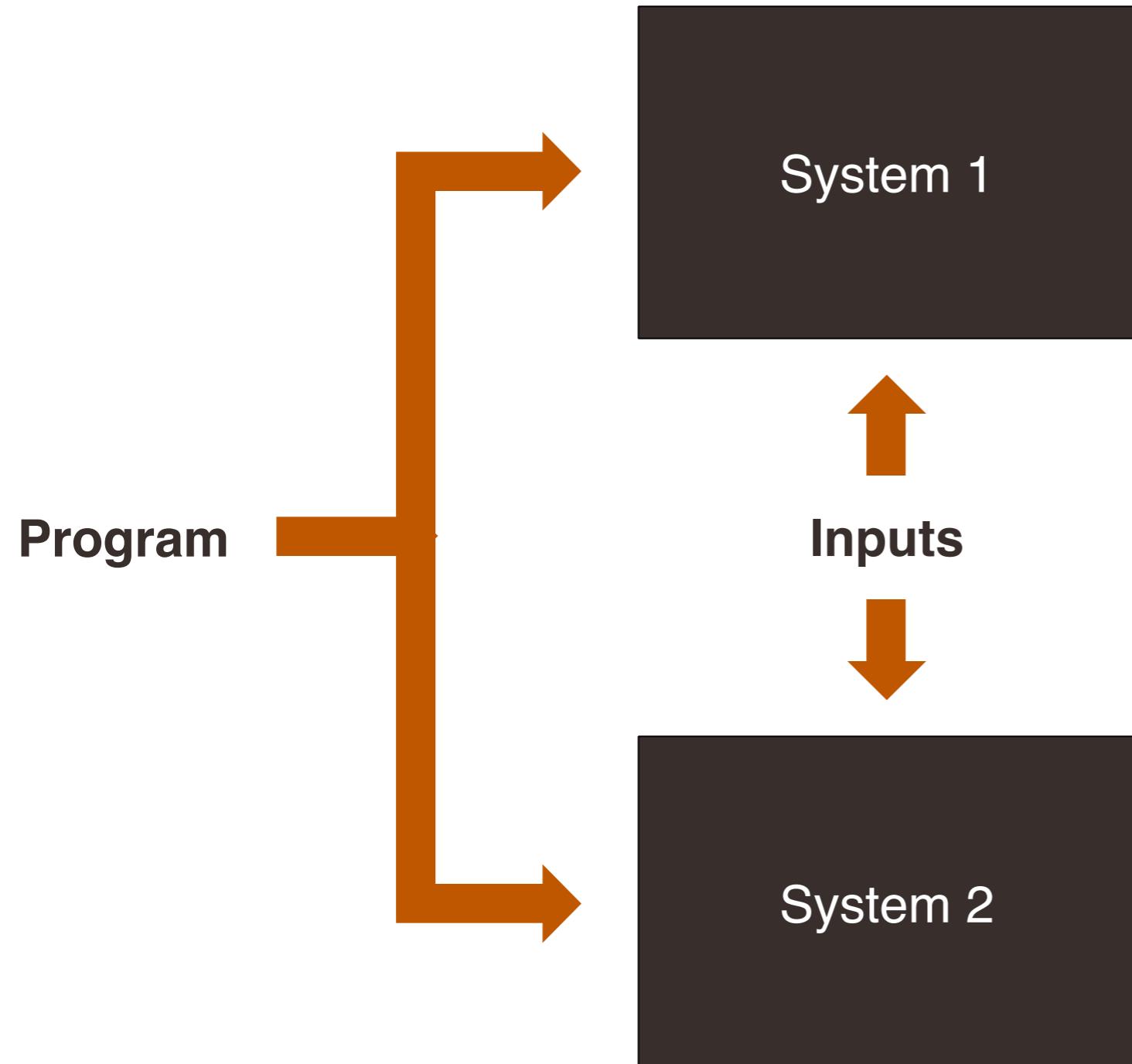


System 2

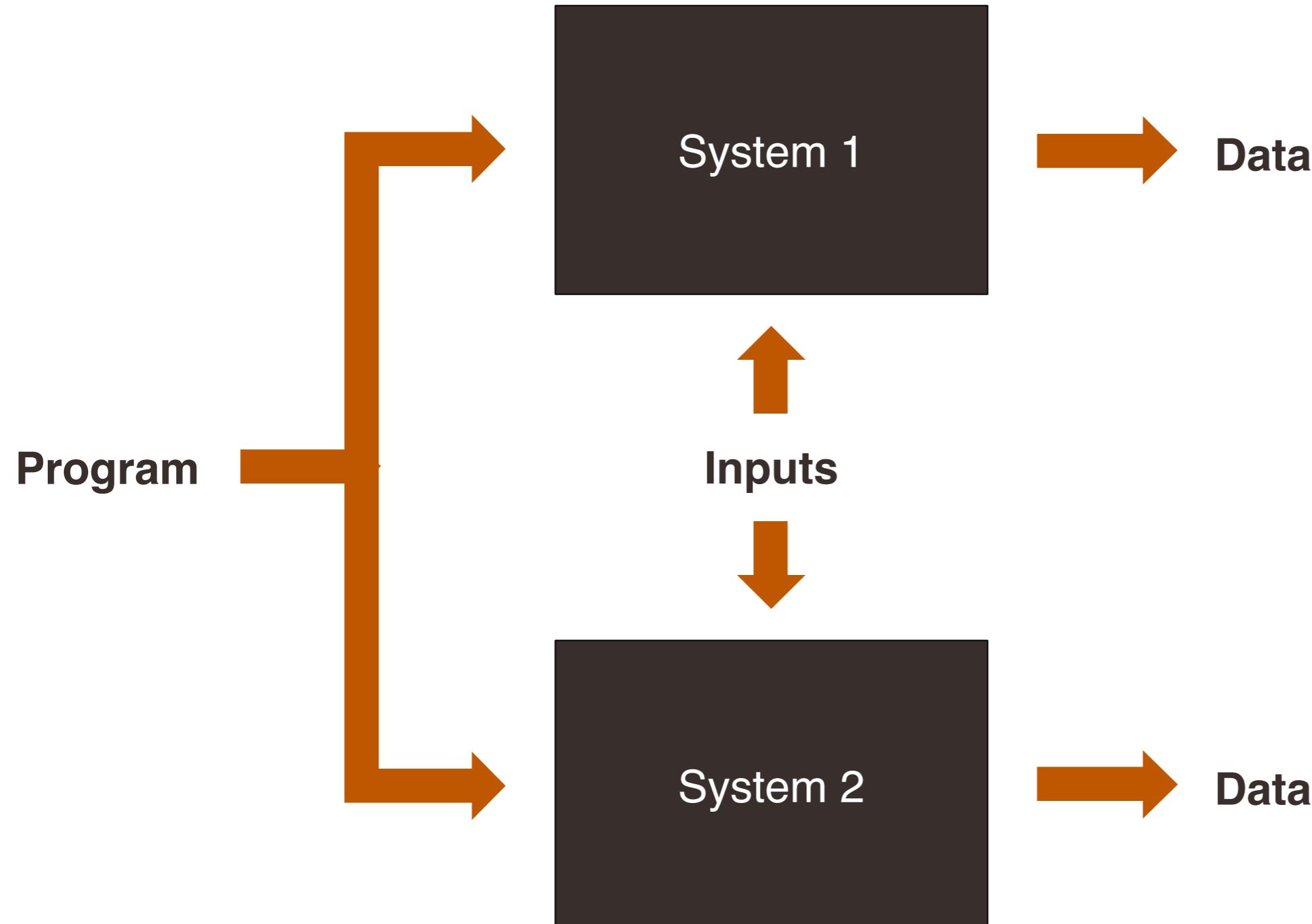
# Quantitative Performance Comparisons



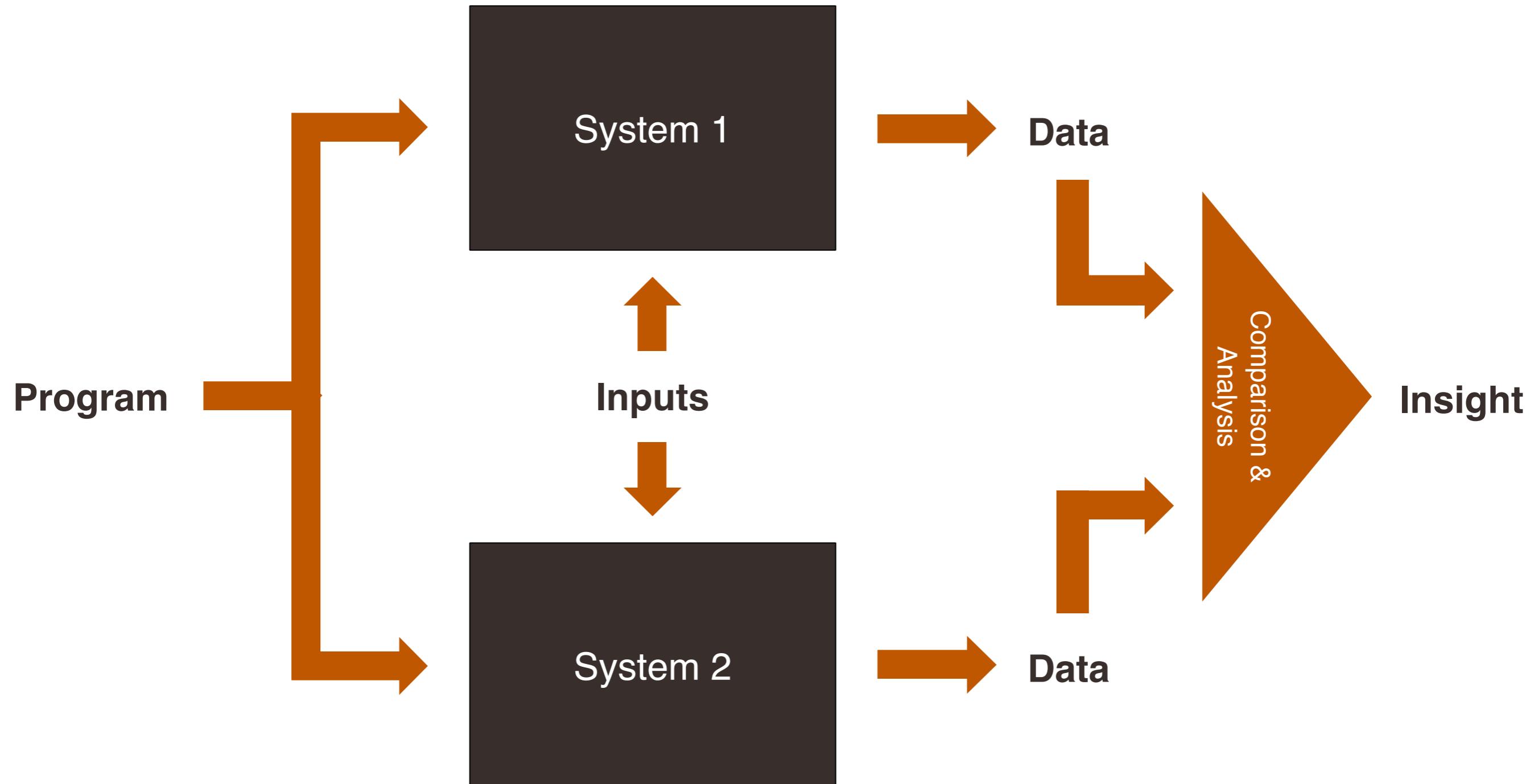
# Quantitative Performance Comparisons



# Quantitative Performance Comparisons



# Quantitative Performance Comparisons

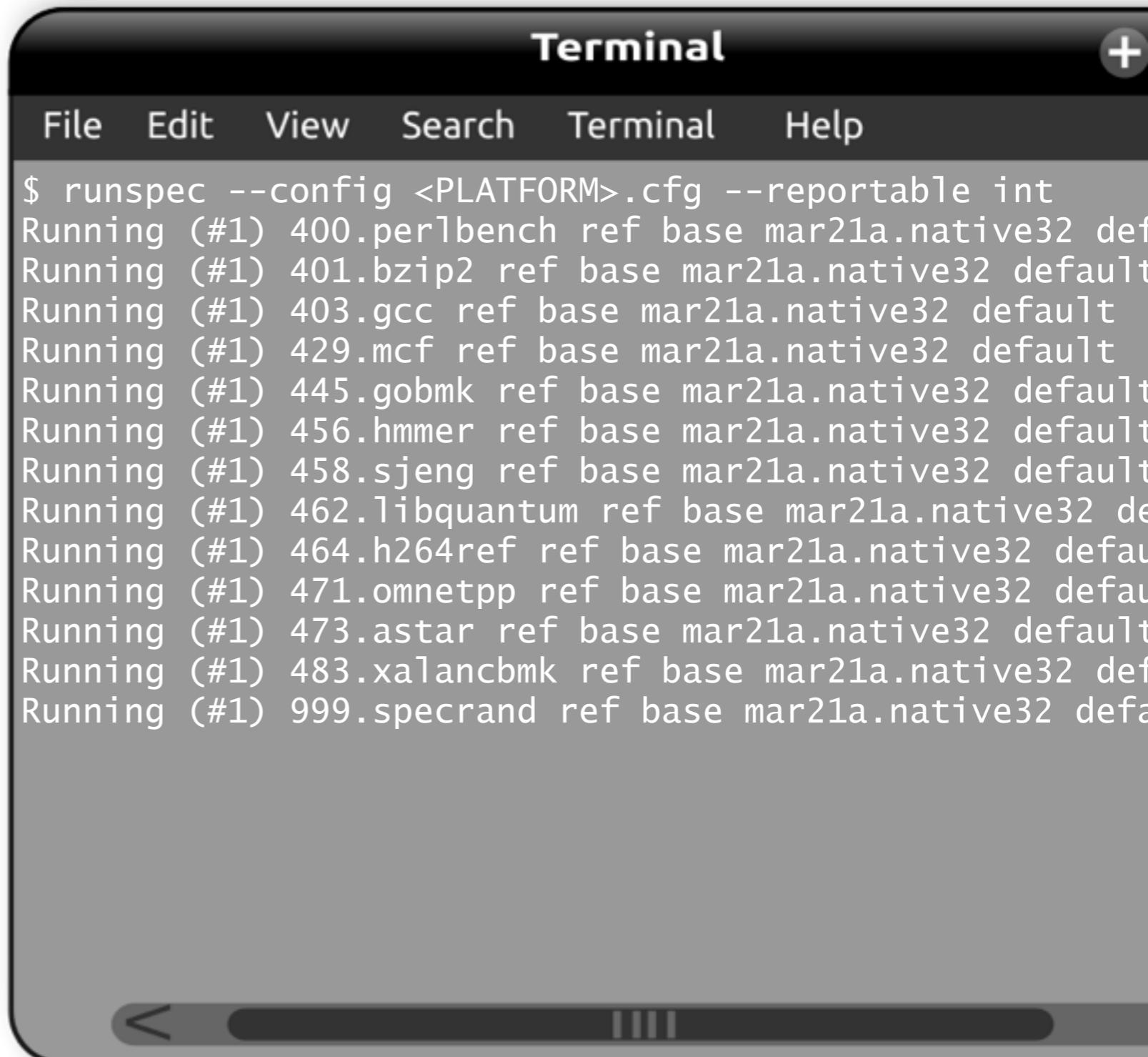


# SPEC CPU 2006

```
$ runspec --config <PLATFORM>.cfg --reportable int
Running (#1) 400.perlbench ref base mar21a.native32 default
Running (#1) 401.bzip2 ref base mar21a.native32 default
Running (#1) 403.gcc ref base mar21a.native32 default
Running (#1) 429.mcf ref base mar21a.native32 default
Running (#1) 445.gobmk ref base mar21a.native32 default
Running (#1) 456.hmmer ref base mar21a.native32 default
Running (#1) 458.sjeng ref base mar21a.native32 default
Running (#1) 462.libquantum ref base mar21a.native32 default
Running (#1) 464.h264ref ref base mar21a.native32 default
Running (#1) 471.omnetpp ref base mar21a.native32 default
Running (#1) 473.astar ref base mar21a.native32 default
Running (#1) 483.xalancbmk ref base mar21a.native32 default
Running (#1) 999.specrand ref base mar21a.native32 default
```

# SPEC CPU 2006

- Representative
- Repeatable
- Cross-Platform



The image shows a terminal window with a dark theme. The title bar says "Terminal". The menu bar includes "File", "Edit", "View", "Search", "Terminal", and "Help". A "+" icon is in the top right corner. The main area displays the following text:

```
$ runspec --config <PLATFORM>.cfg --reportable int
Running (#1) 400.perlbench ref base mar21a.native32 default
Running (#1) 401.bzip2 ref base mar21a.native32 default
Running (#1) 403.gcc ref base mar21a.native32 default
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Running (#1) 999.specrand ref base mar21a.native32 default
```

# SPEC CPU 2006

- Representative
- Repeatable
- Cross-Platform



The image shows a terminal window titled "Terminal" with a menu bar containing File, Edit, View, Search, Terminal, and Help. The main area of the terminal displays the following command and its execution:

```
$ runspec --config <PLATFORM>.cfg --reportable int
Running (#1) 400.perlbench ref base mar21a.native32 default
Running (#1) 401.bzip2 ref base mar21a.native32 default
Running (#1) 403.gcc ref base mar21a.native32 default
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```

# SPEC CPU 2006

## ✓ Representative

- Repeatable

- Cross-Platform



Terminal

```
Edit View Search Terminal Help
```

```
runspec --config <PLATFORM>.cfg
Running (#1) 400.perlbench ref base
Running (#1) 401.bzip2 ref base mar21a.native32 default
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# SPEC CPU 2006

- ✓ Representative
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- Cross-Platform



```
Terminal
Edit View Search Terminal Help
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Running (#1) 400.perlbench ref base mar21a.native32 default
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Running (#1) 999.specrand ref base mar21a.native32 default
```

# SPEC CPU 2006

- ✓ Representative
- ✓ Repeatable
- ✓ Cross-Platform

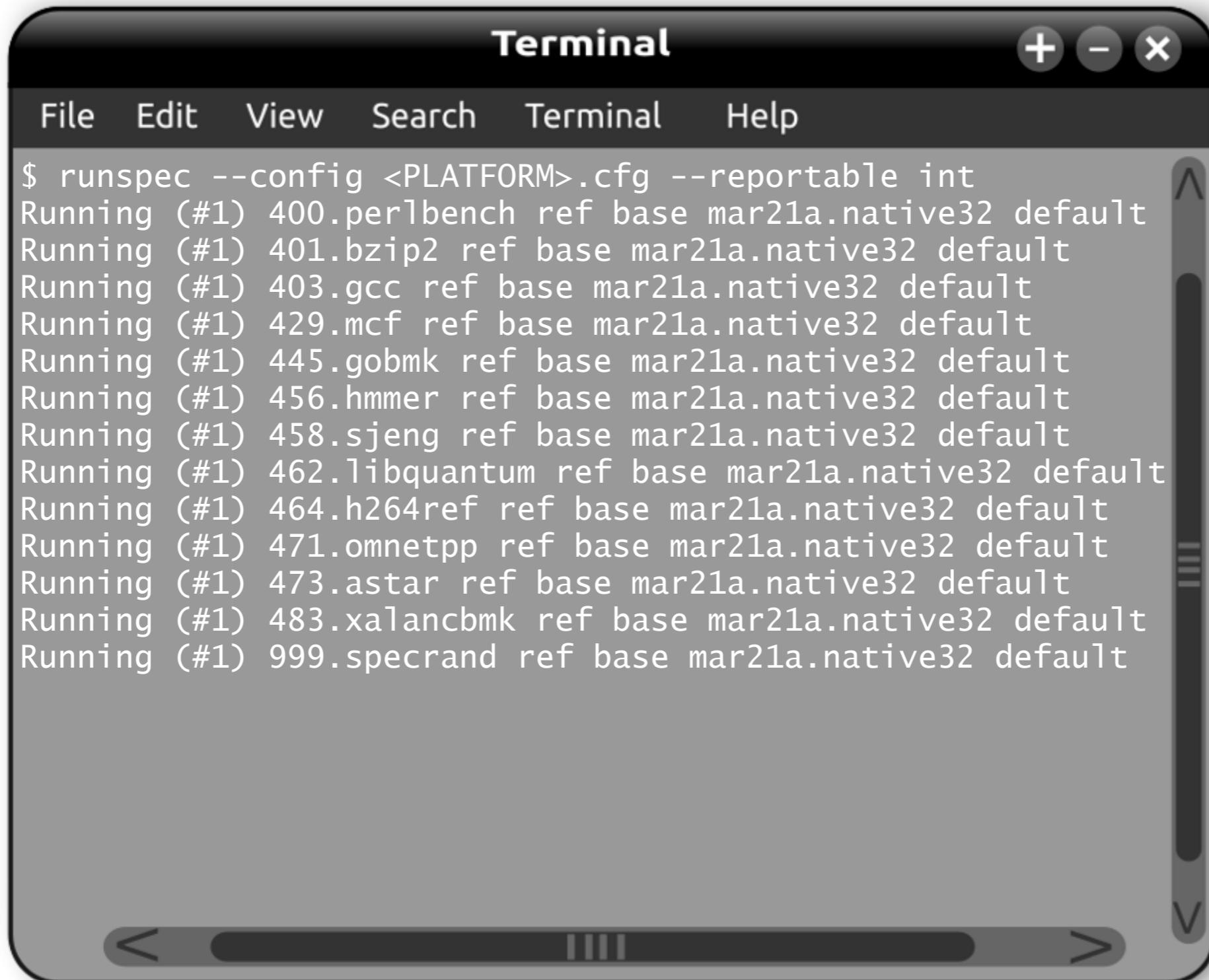


Terminal

Edit View Search Terminal Help

```
runspec --config <PLATFORM>.cfg
Running (#1) 400.perlbench ref base mar21a.native32 default
Running (#1) 401.bzip2 ref base mar21a.native32 default
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Running (#1) 483.xalancbmk ref base mar21a.native32 default
Running (#1) 999.specrand ref base mar21a.native32 default
```

# SPEC CPU 2006

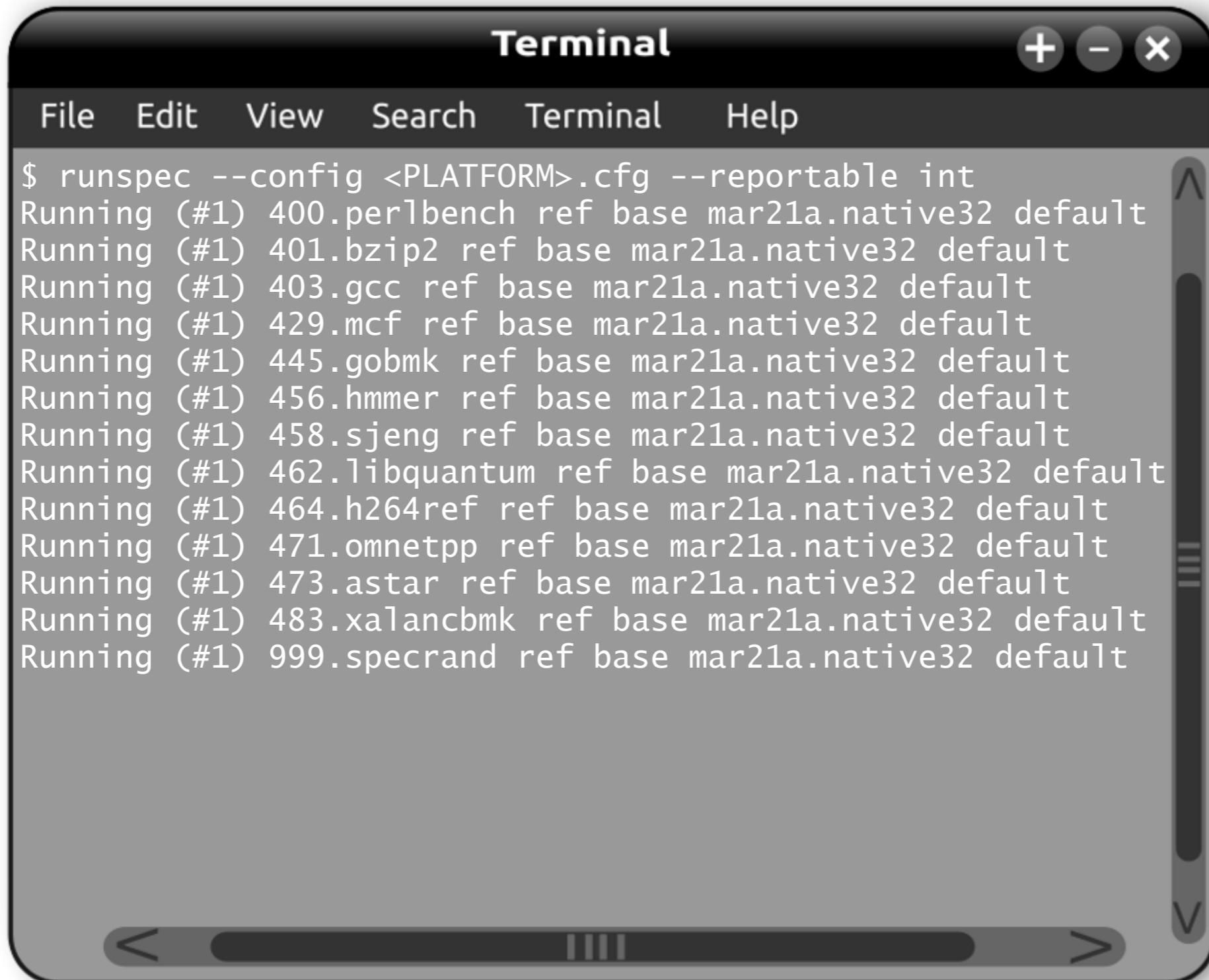


The image shows a Mac OS X-style Terminal window titled "Terminal". The window has standard OS X window controls at the top right. The menu bar includes "File", "Edit", "View", "Search", "Terminal", and "Help". The main pane displays the output of the "runspec" command:

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Running (#1) 483.xalancbmk ref base mar21a.native32 default
Running (#1) 999.specrand ref base mar21a.native32 default
```

The terminal window features scroll bars on the right side and a scroll bar at the bottom.

# SPEC CPU 2006



The image shows a Mac OS X-style Terminal window titled "Terminal". The window has standard OS X window controls (minimize, maximize, close) at the top right. The menu bar includes "File", "Edit", "View", "Search", "Terminal", and "Help". The main pane displays the output of the "runspec" command:

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$ runspec --config <PLATFORM>.cfg --reportable int
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```

The terminal window features scroll bars on the right side and a scroll bar at the bottom.

# Mobile Applications Require Interactivity



# Mobile Applications Require Interactivity



# Mobile Applications

- Representative
- Repeatable
- Cross-Platform



# Mobile Applications

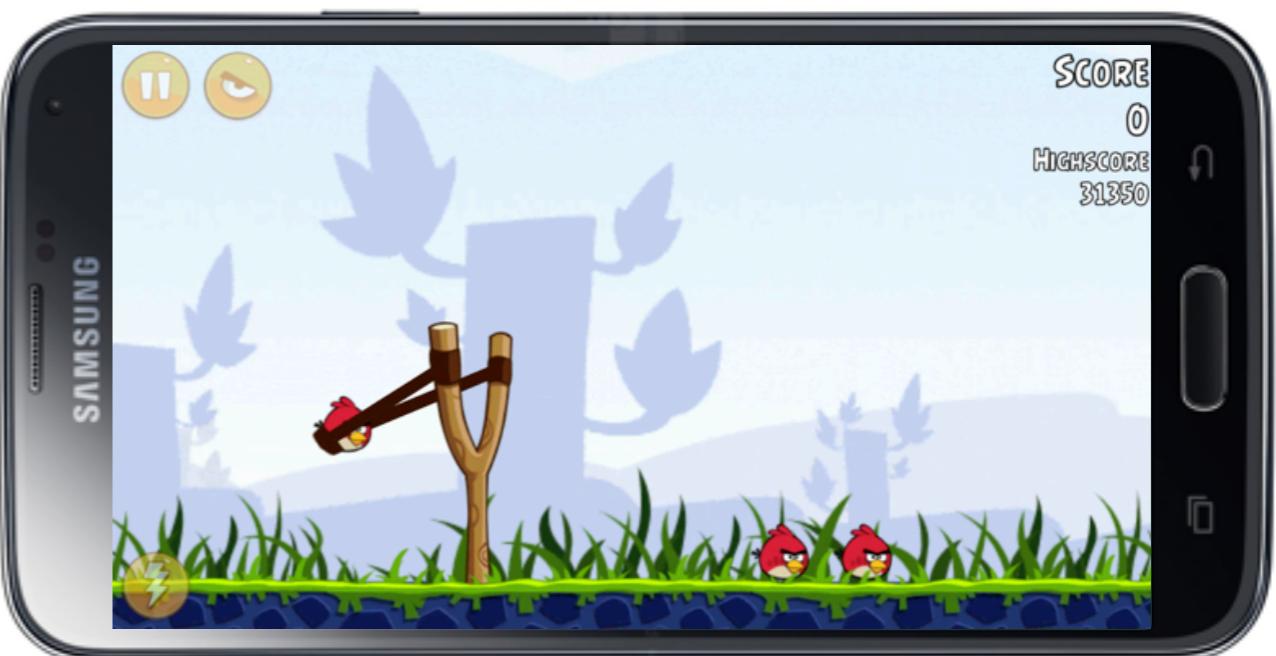
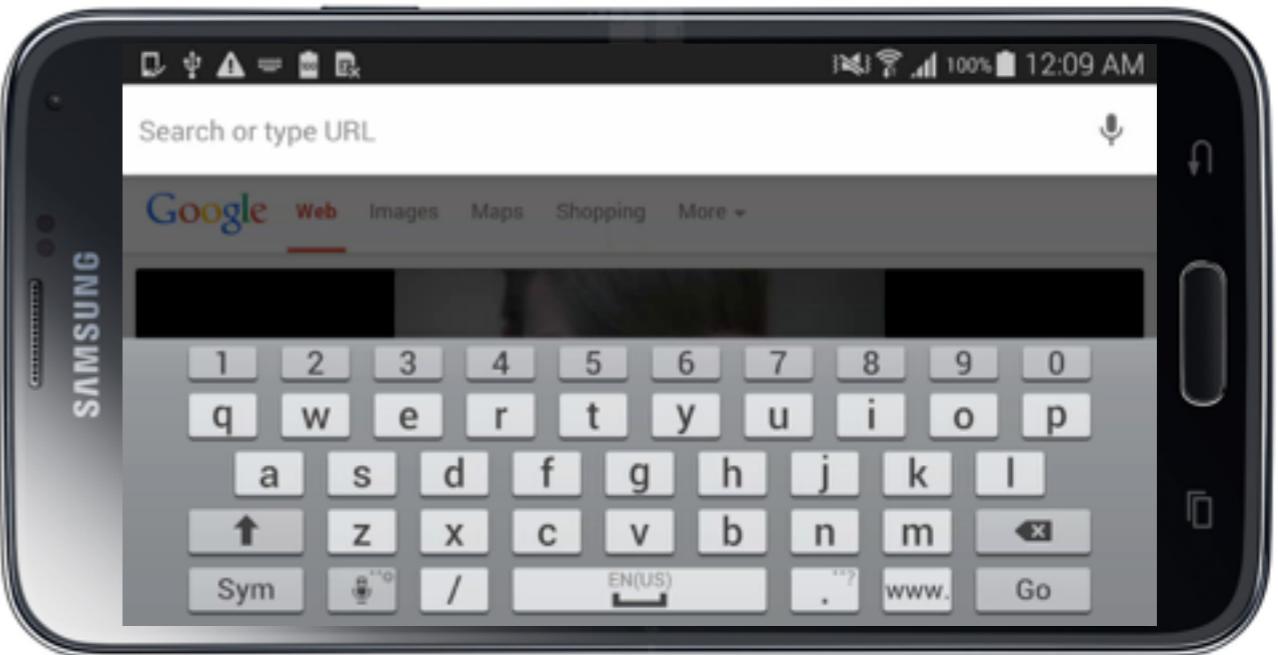
- Representative
- Repeatable
- Cross-Platform



# Mobile Applications

## X Representative

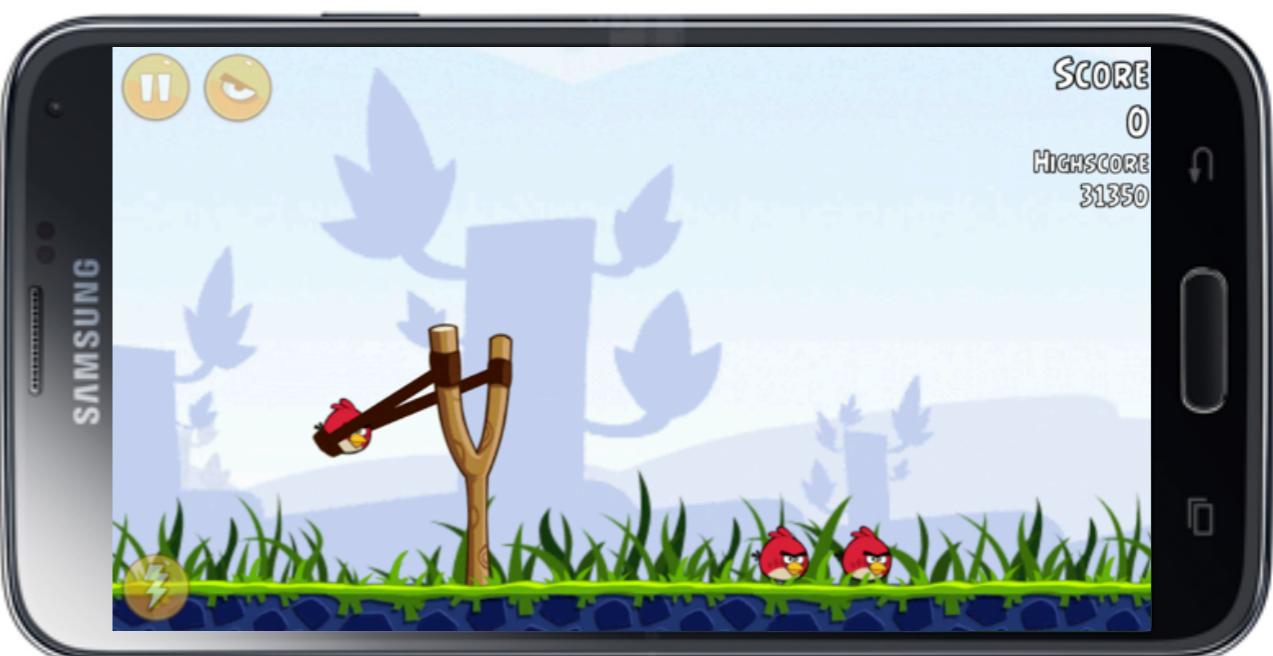
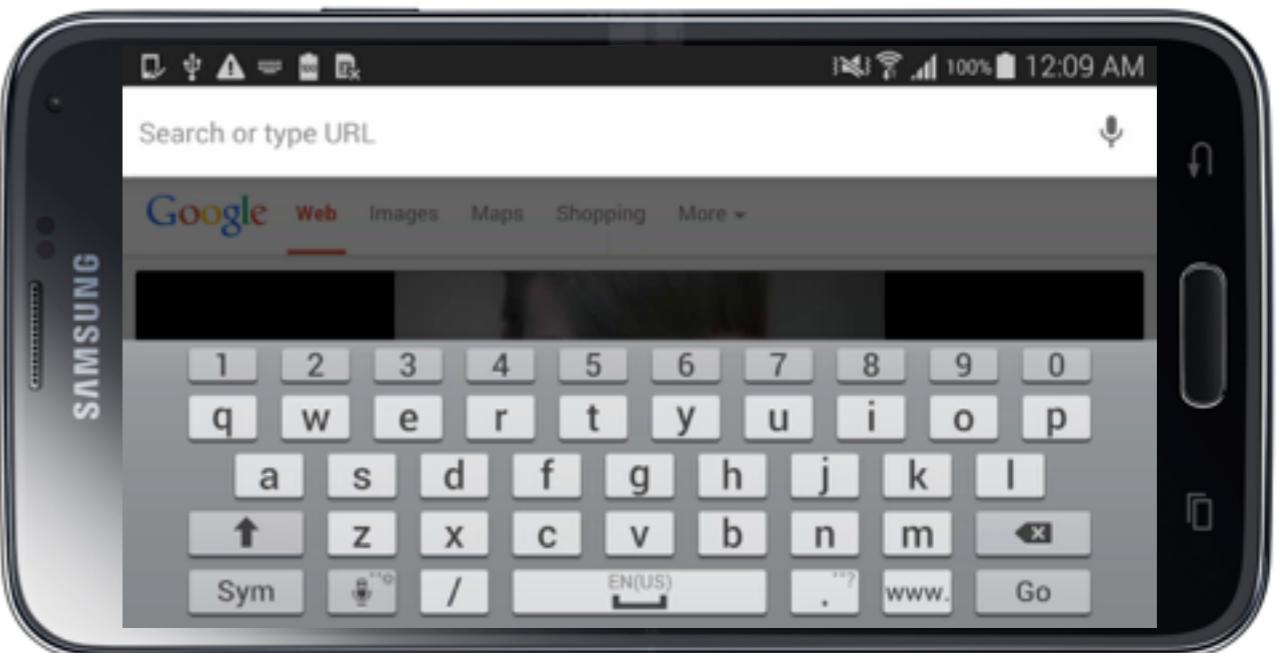
- Repeatable
- Cross-Platform



# Mobile Applications

## X Representative

- Repeatable
- Cross-Platform



# Mobile Applications

X Representative

X Repeatable

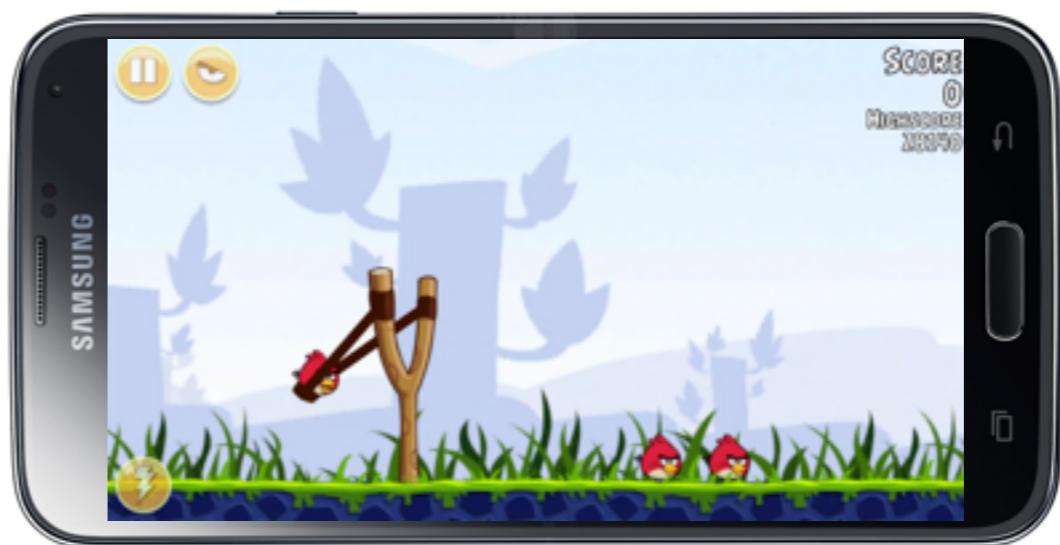
- Cross-Platform



Yuhao



Ramesh



Vijay

# Mobile Applications

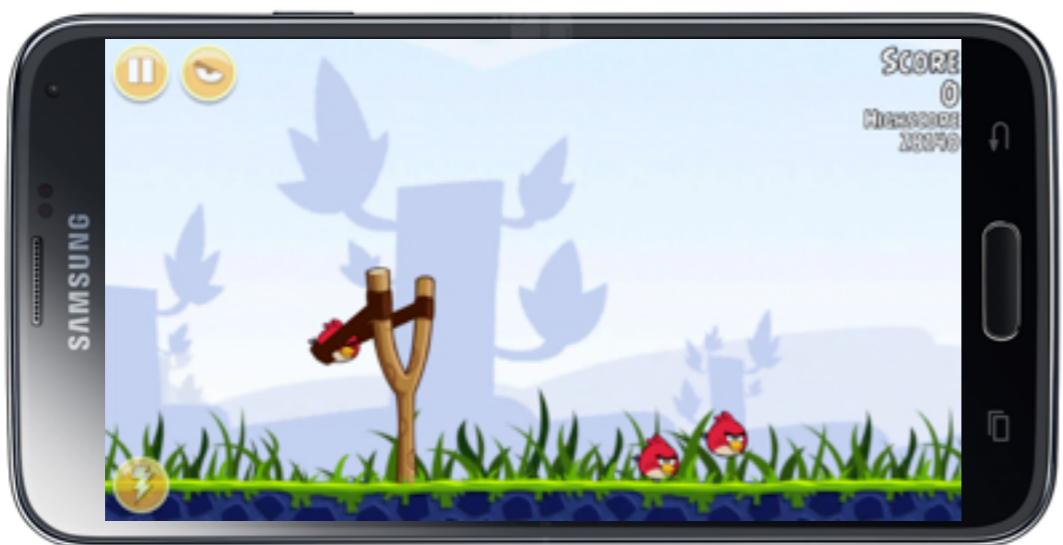
X Representative

X Repeatable

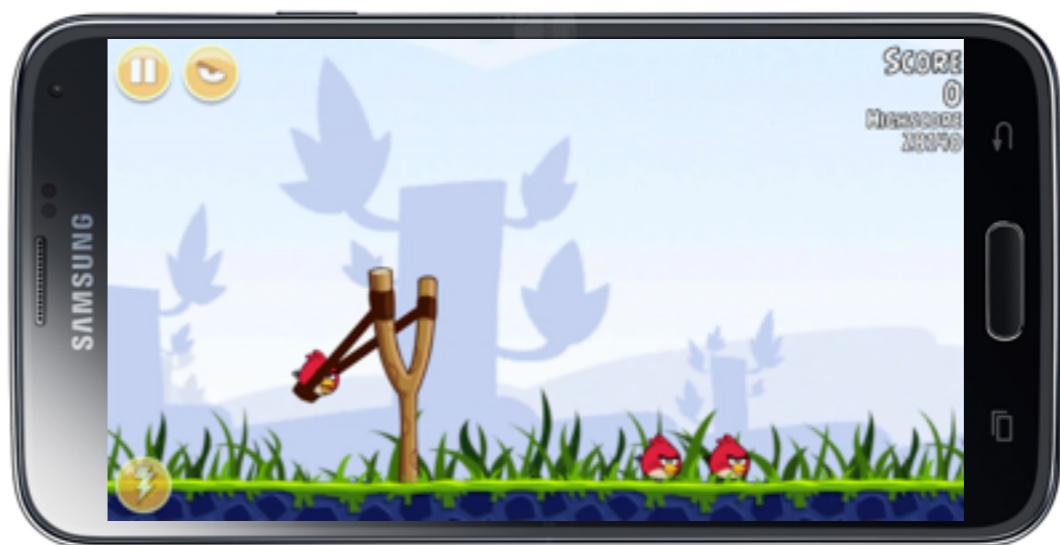
- Cross-Platform



Yuhao



Ramesh



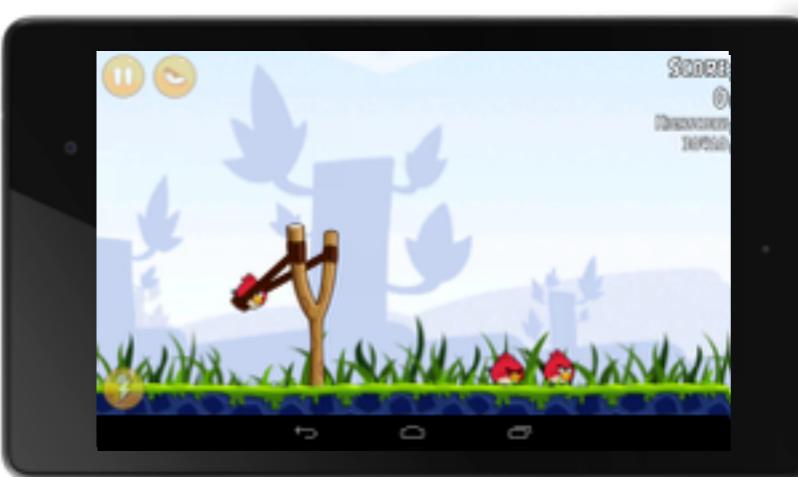
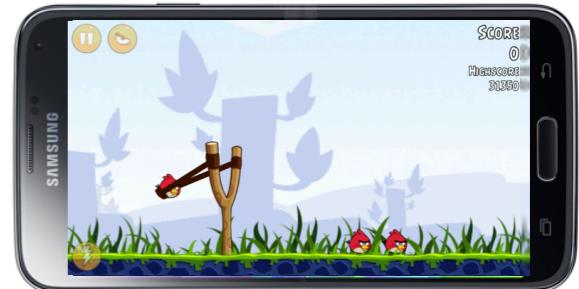
Vijay

# Mobile Applications

X Representative

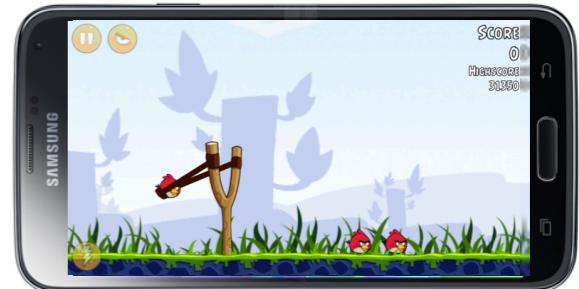
X Repeatable

X Cross-Platform



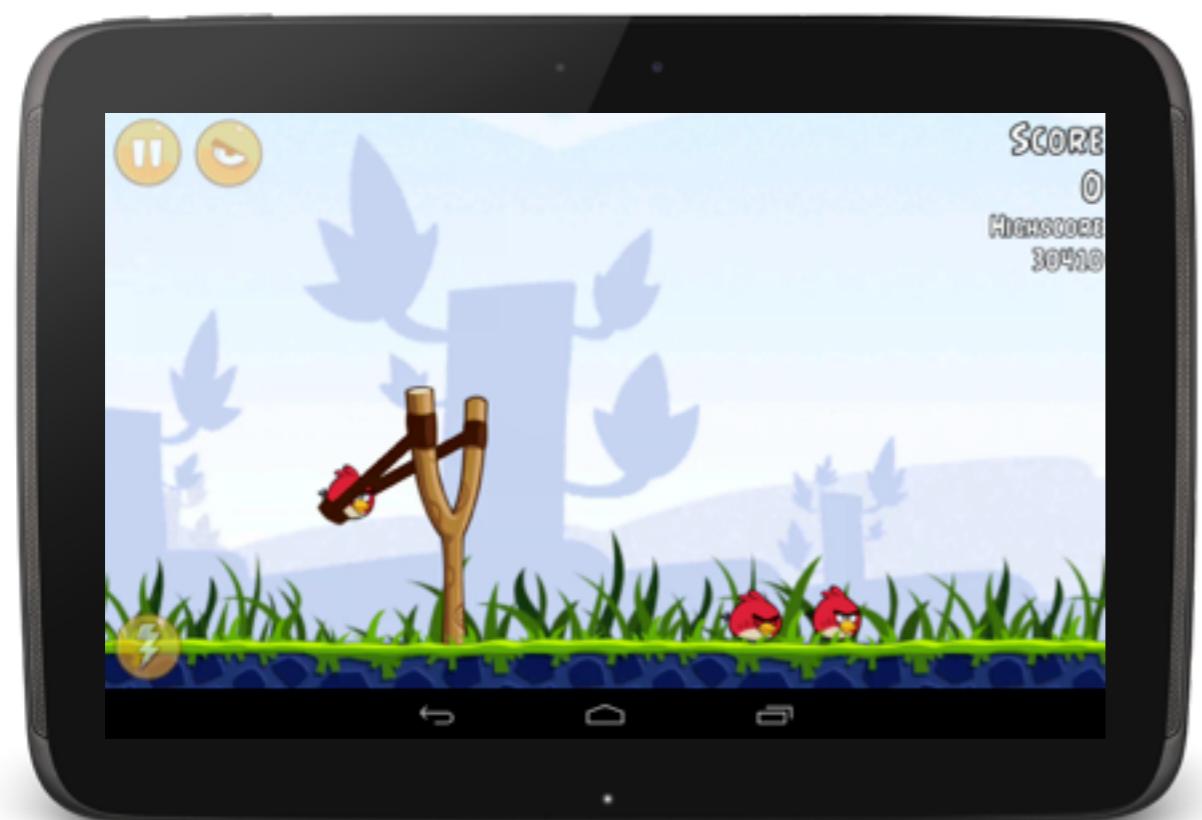
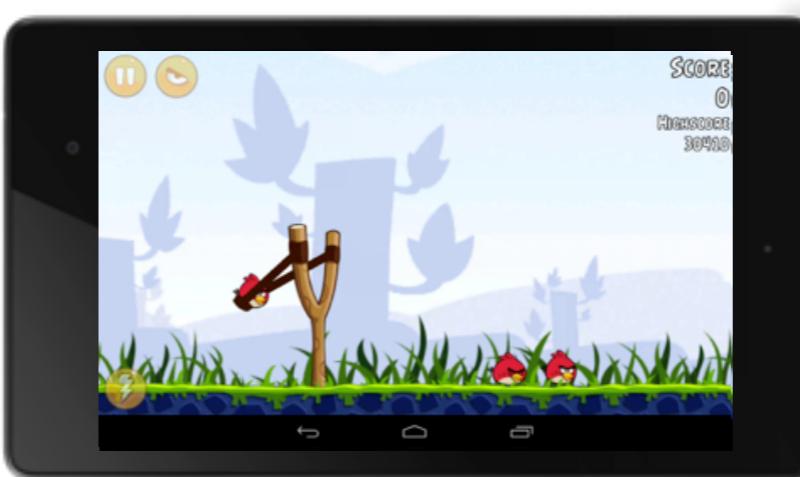
# Mobile Applications

X Representative



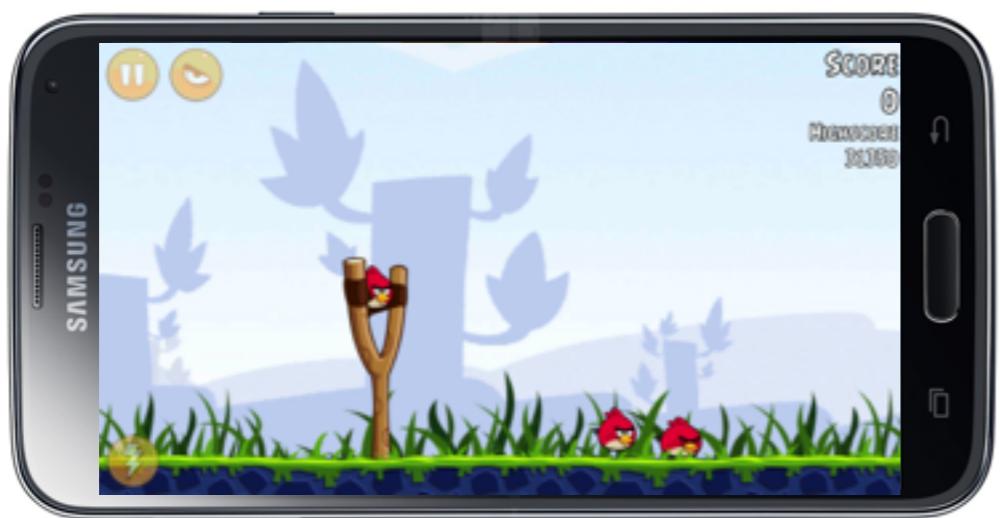
X Repeatable

X Cross-Platform



# The Cross-Platform Requirement

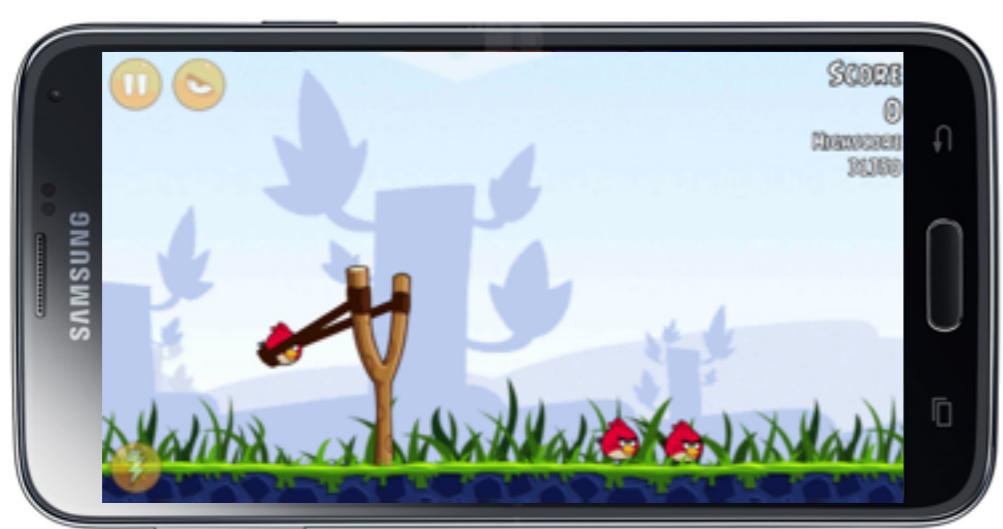
Samsung Galaxy S5



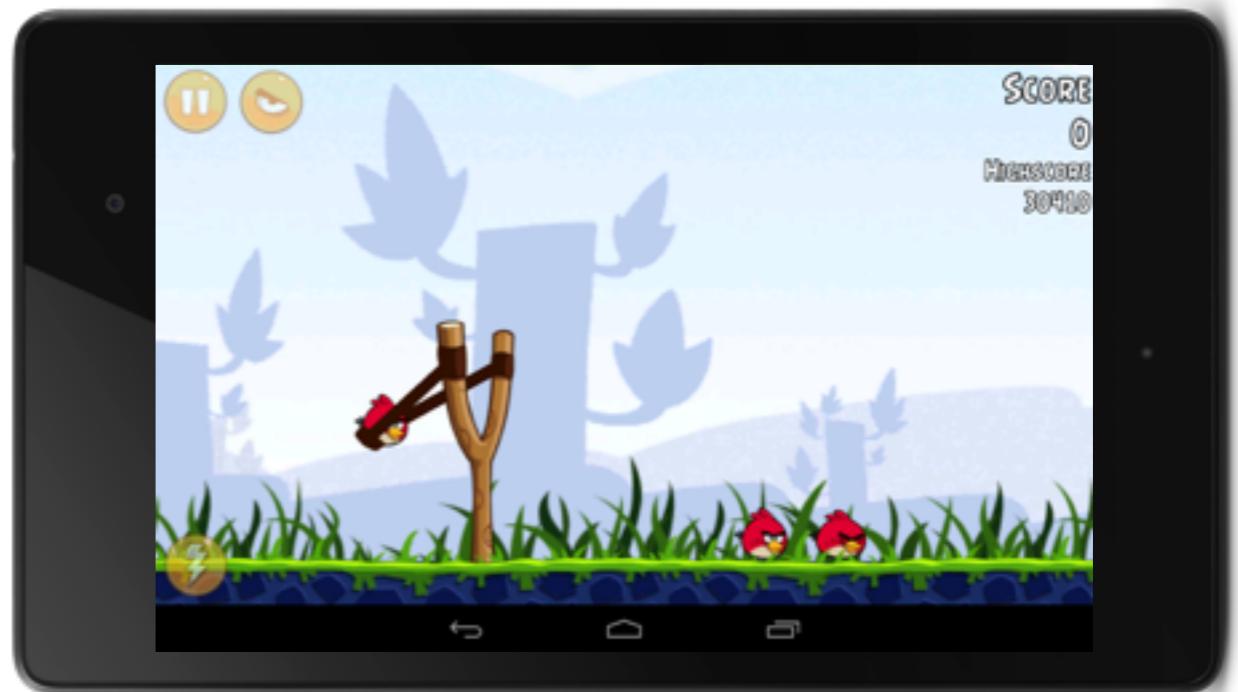
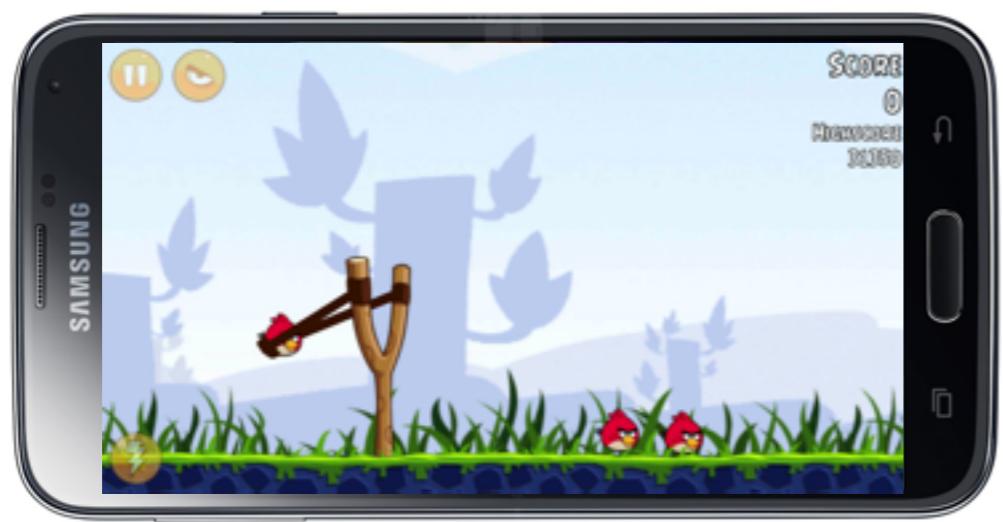
Asus Nexus 7



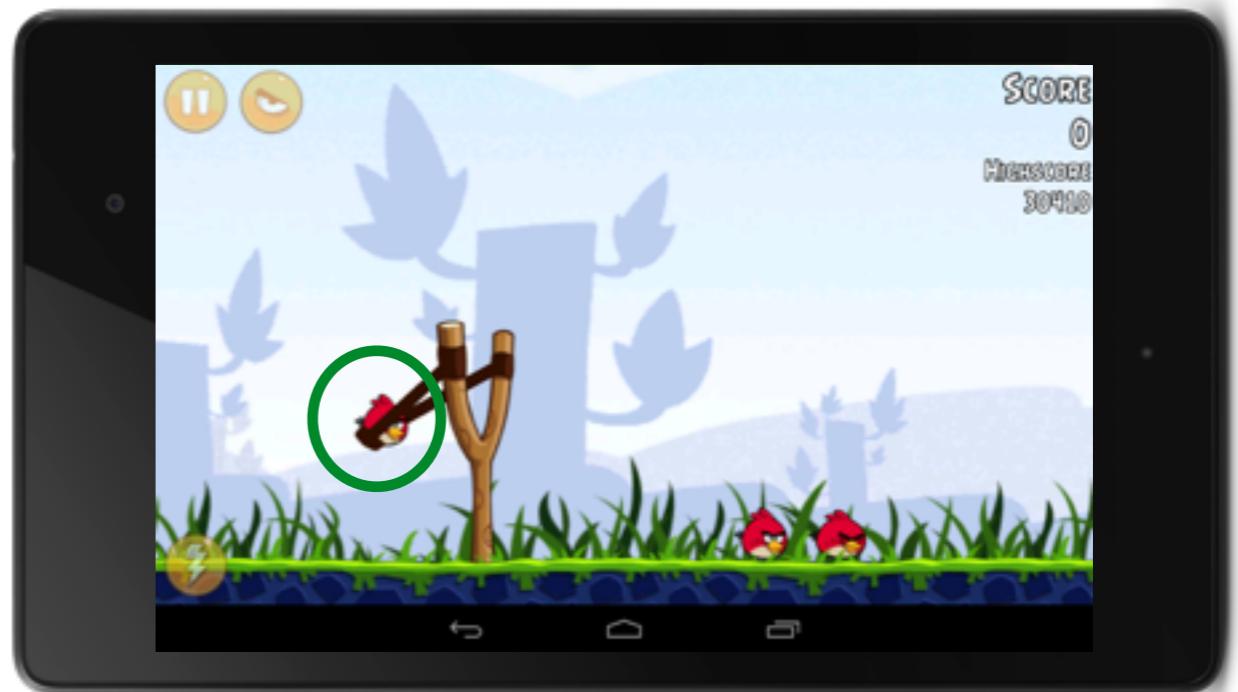
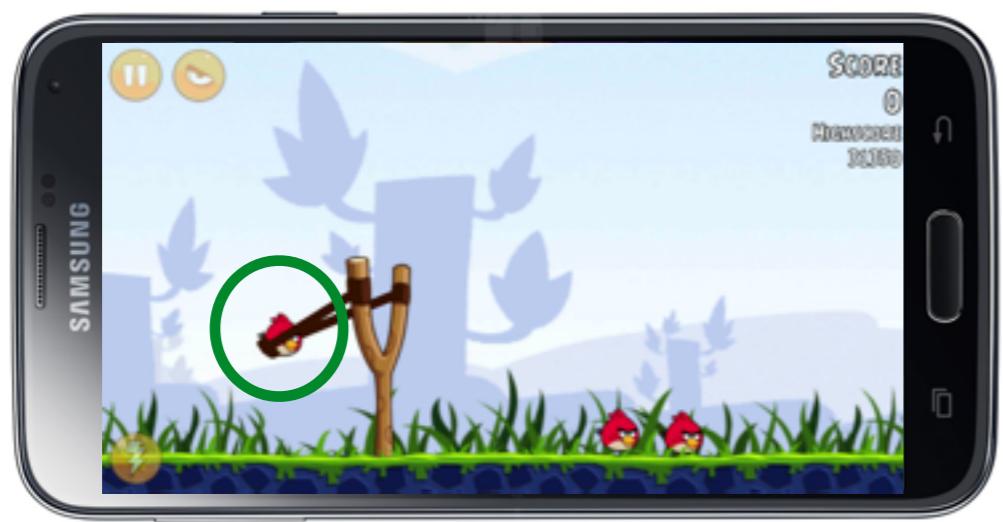
# The Cross-Platform Requirement



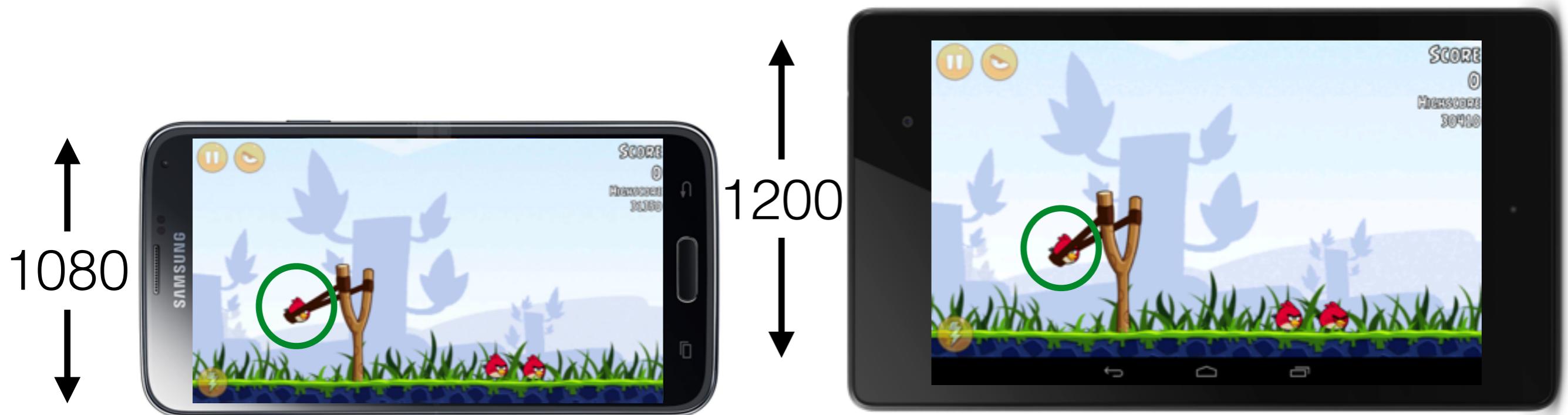
# The Cross-Platform Requirement



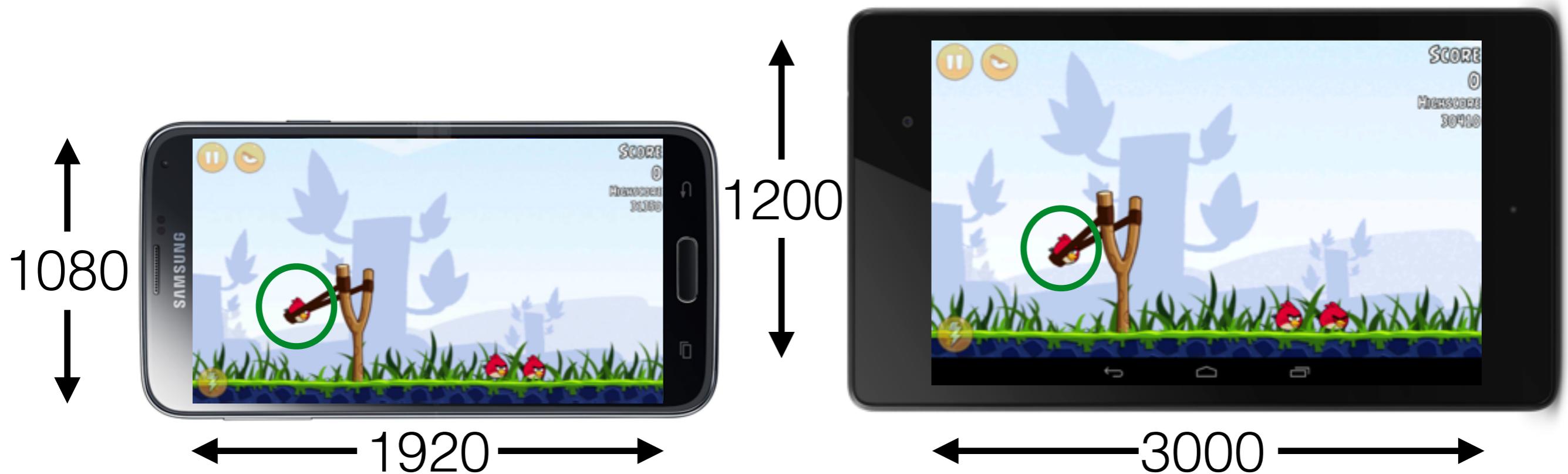
# The Cross-Platform Requirement



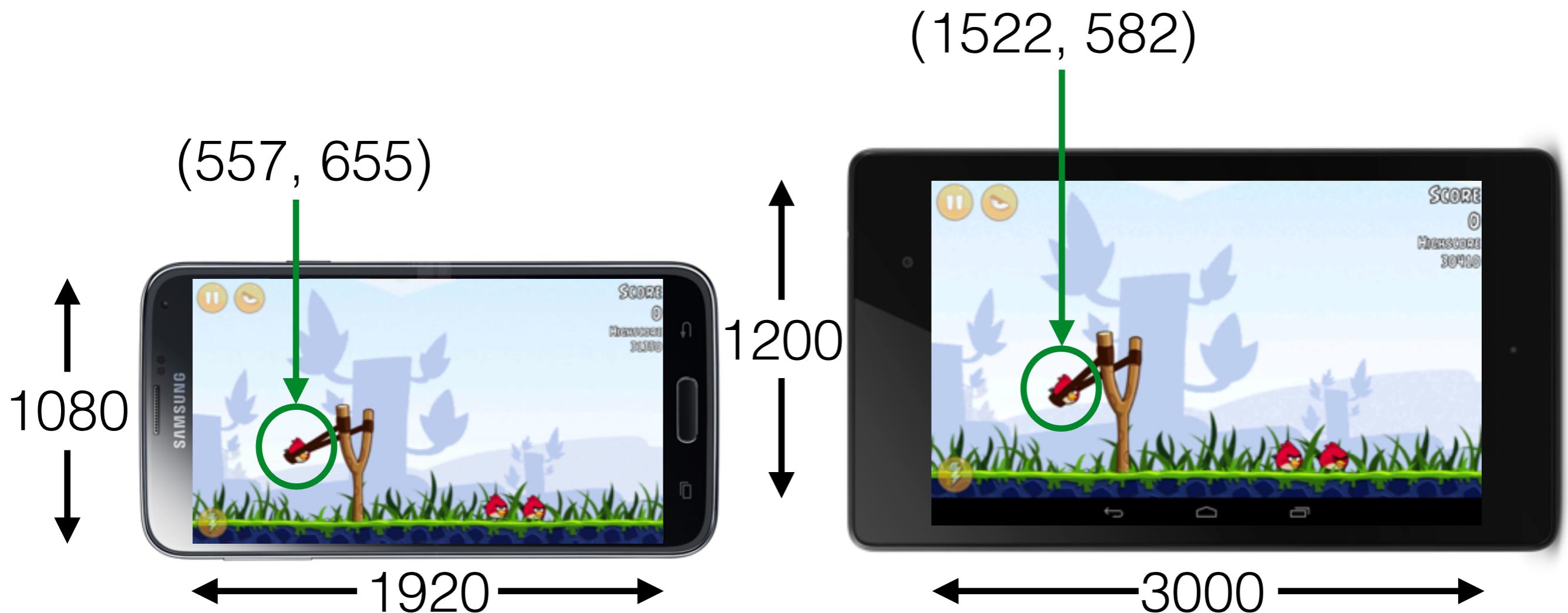
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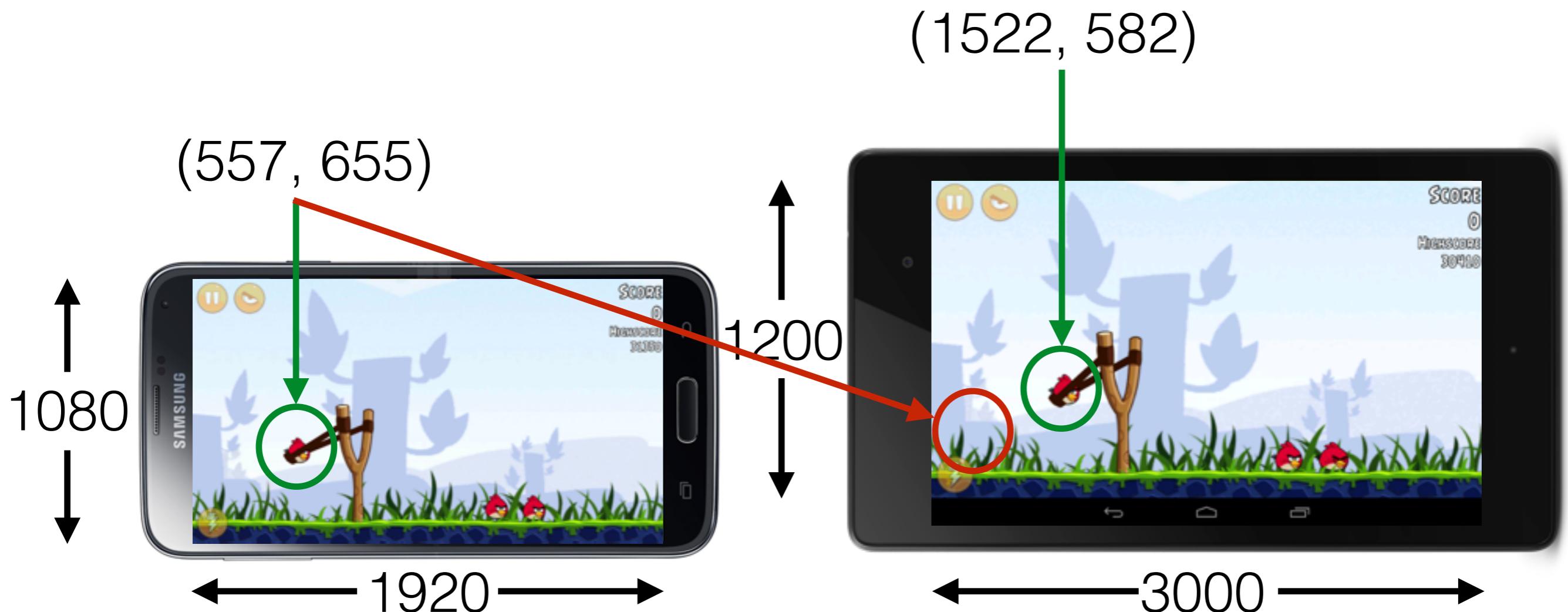
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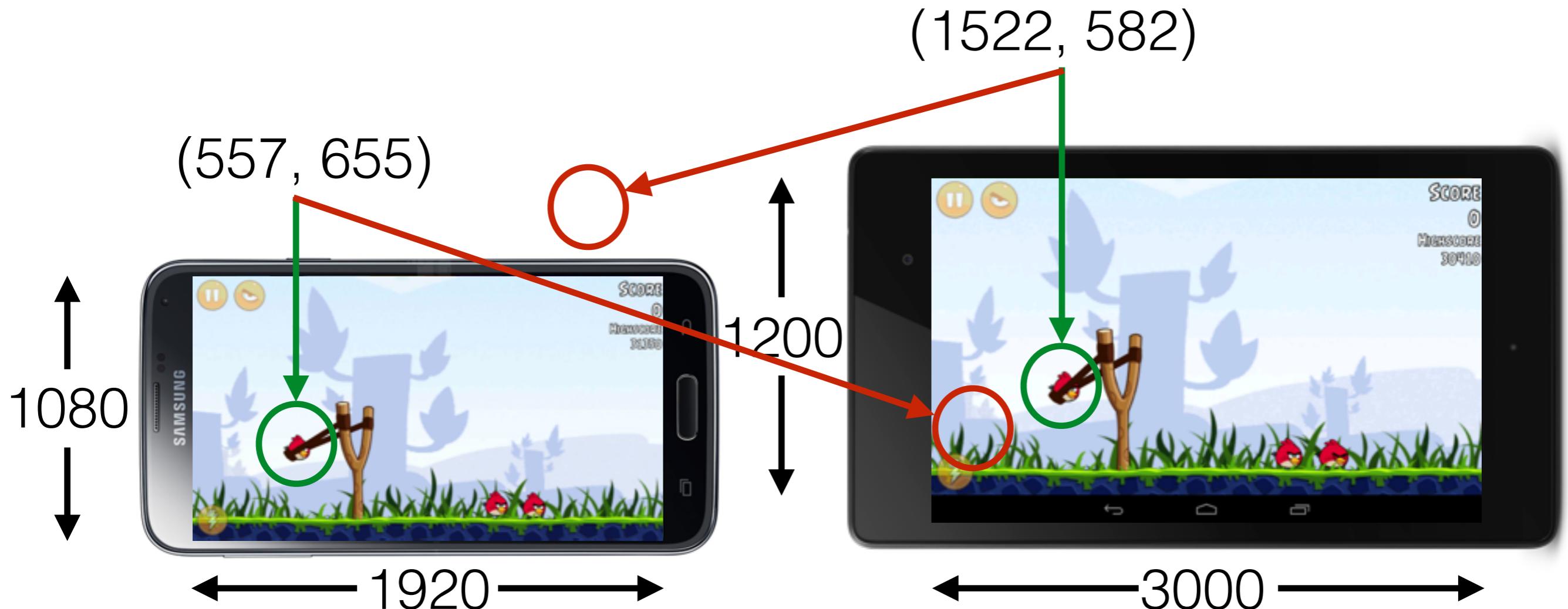
# The Cross-Platform Requirement



# The Cross-Platform Requirement

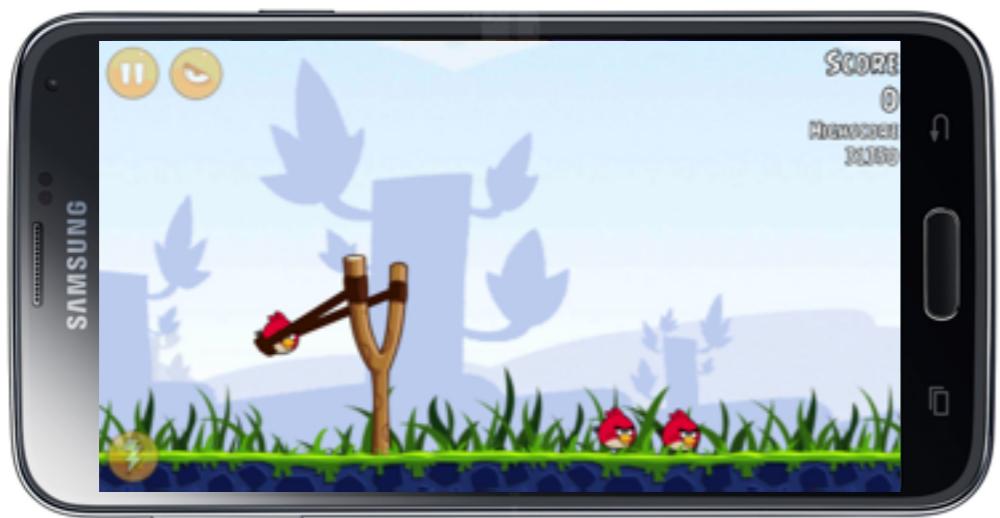


# The Cross-Platform Requirement



# The Cross-Platform Requirement

Samsung Galaxy S5

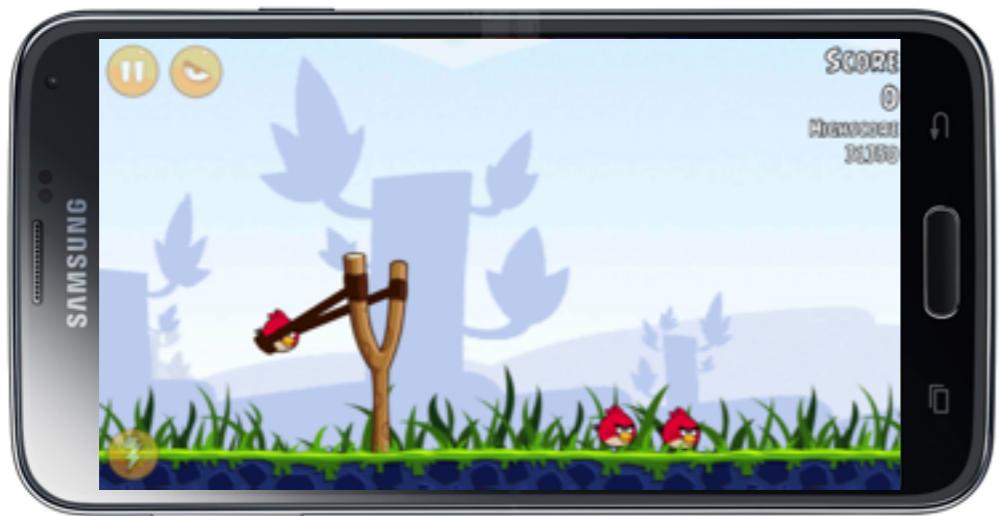


Asus Nexus 7



# The Cross-Platform Requirement

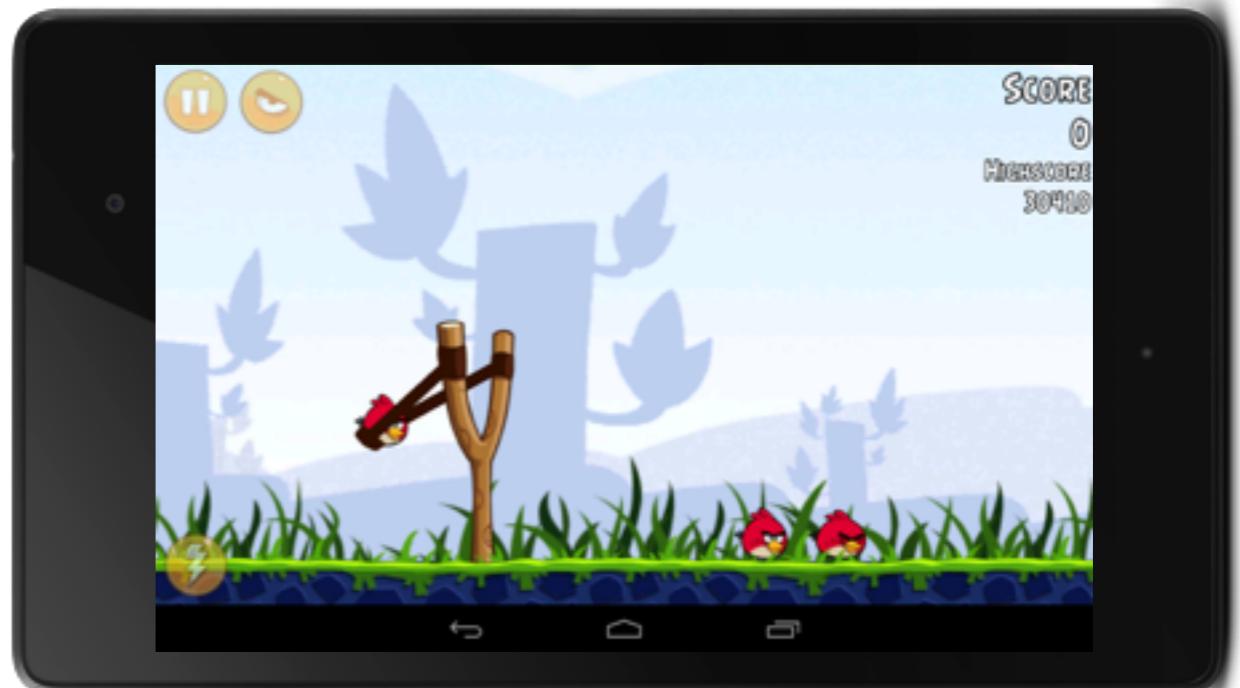
Samsung Galaxy S5



1080 x 1920

Touchscreen

Asus Nexus 7



3000 x 1200

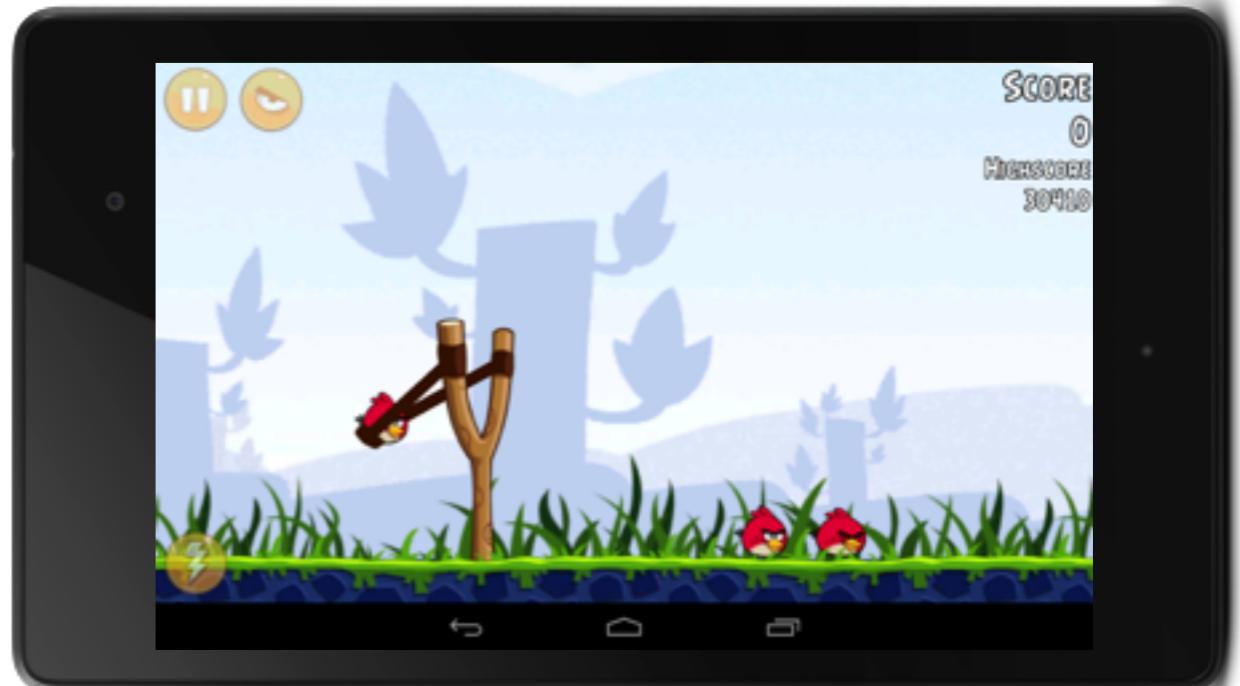
# The Cross-Platform Requirement

Samsung Galaxy S5



1080 x 1920  
Smartphone

Asus Nexus 7

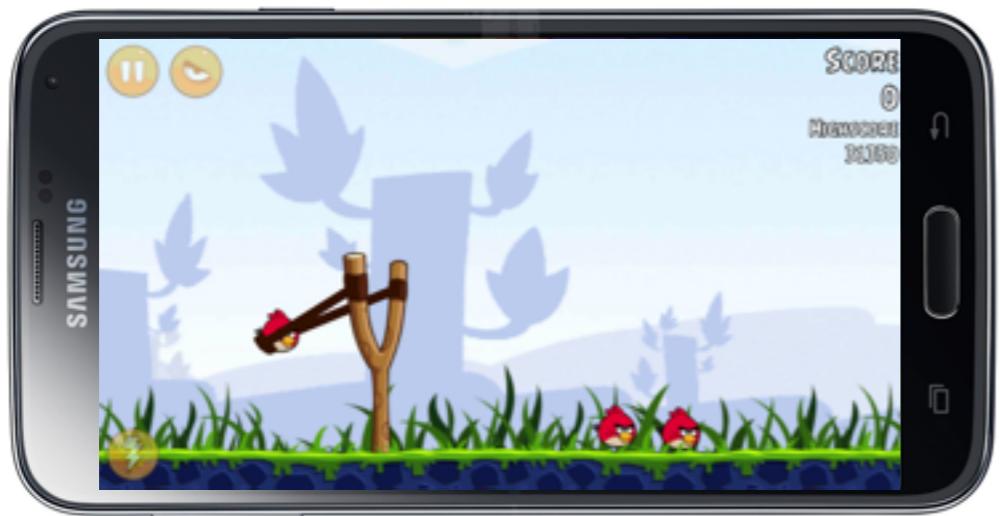


**Touchscreen  
Form Factor**

3000 x 1200  
Tablet

# The Cross-Platform Requirement

Samsung Galaxy S5

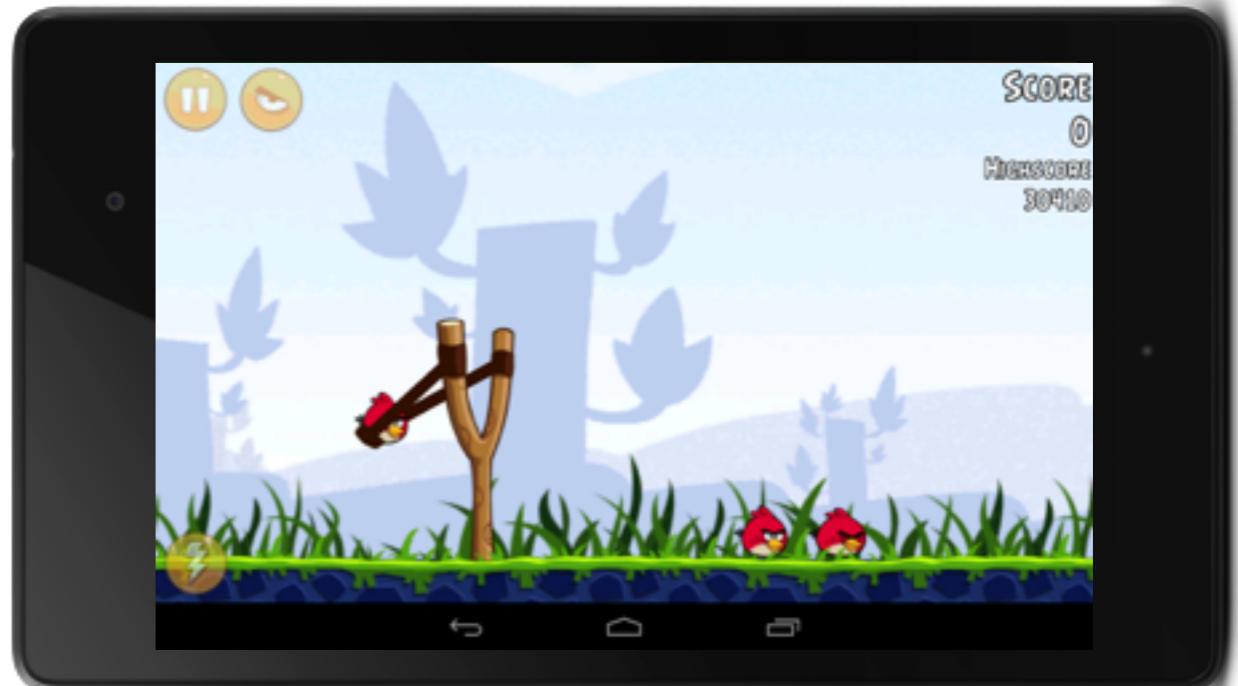


1080 x 1920

Smartphone

Android 4.4.2

Asus Nexus 7



**Touchscreen**  
**Form Factor**  
**OS Version**

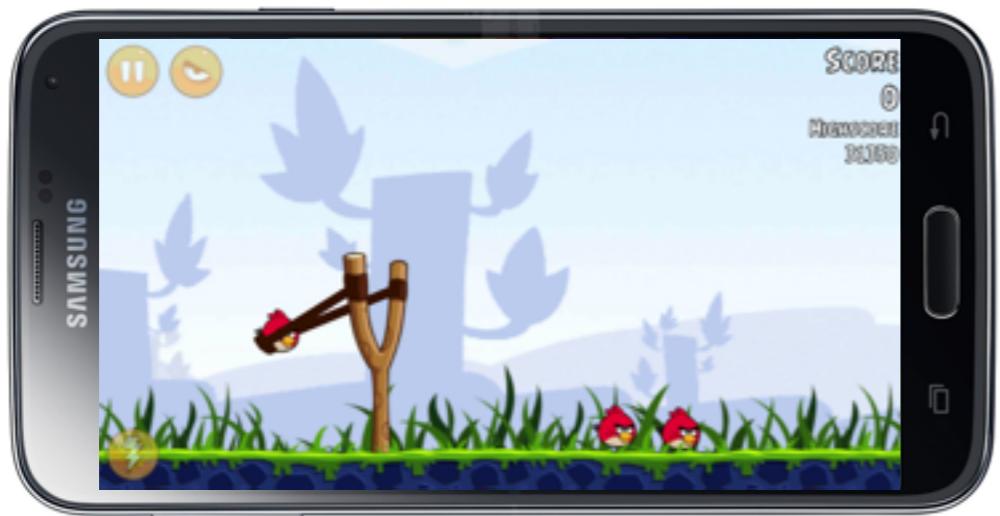
3000 x 1200

Tablet

Android 4.1

# The Cross-Platform Requirement

Samsung Galaxy S5



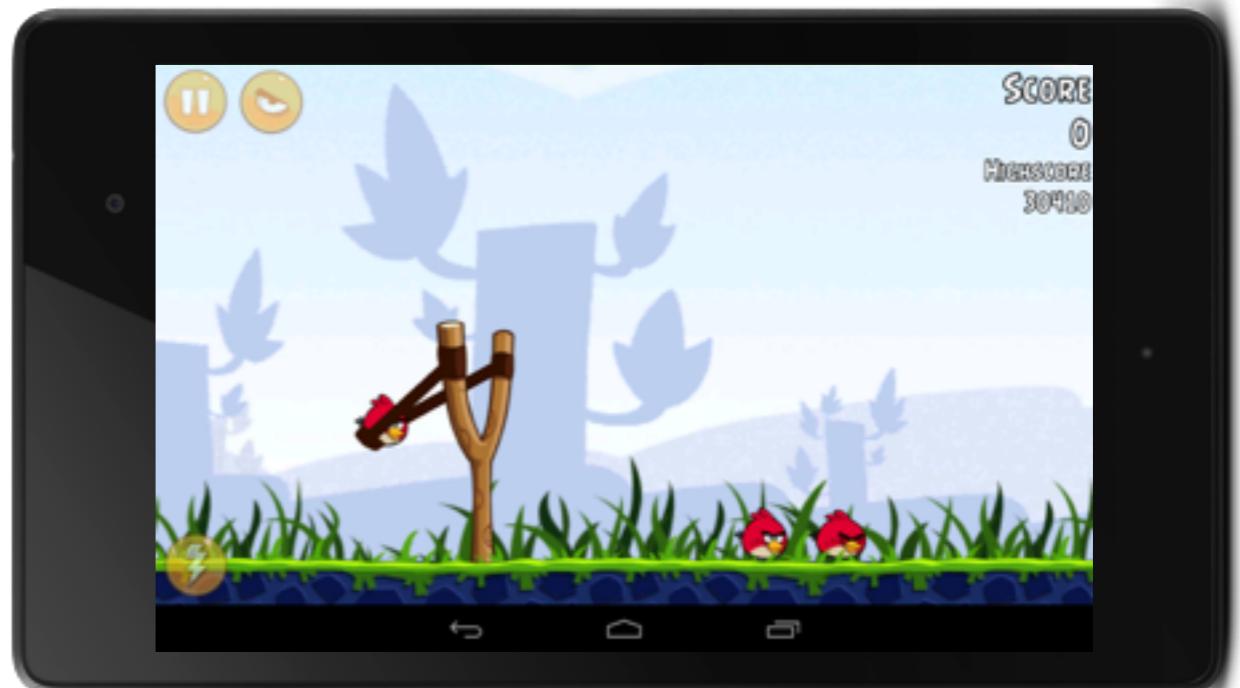
1080 x 1920

Smartphone

Android 4.4.2

...

Asus Nexus 7



3000 x 1200

Tablet

Android 4.1

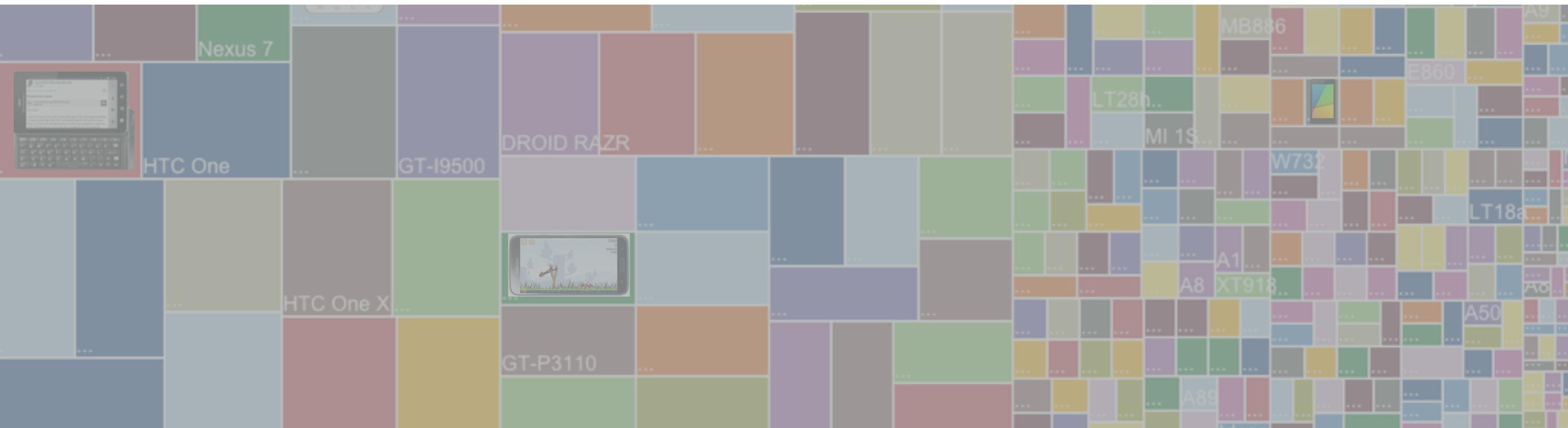
...

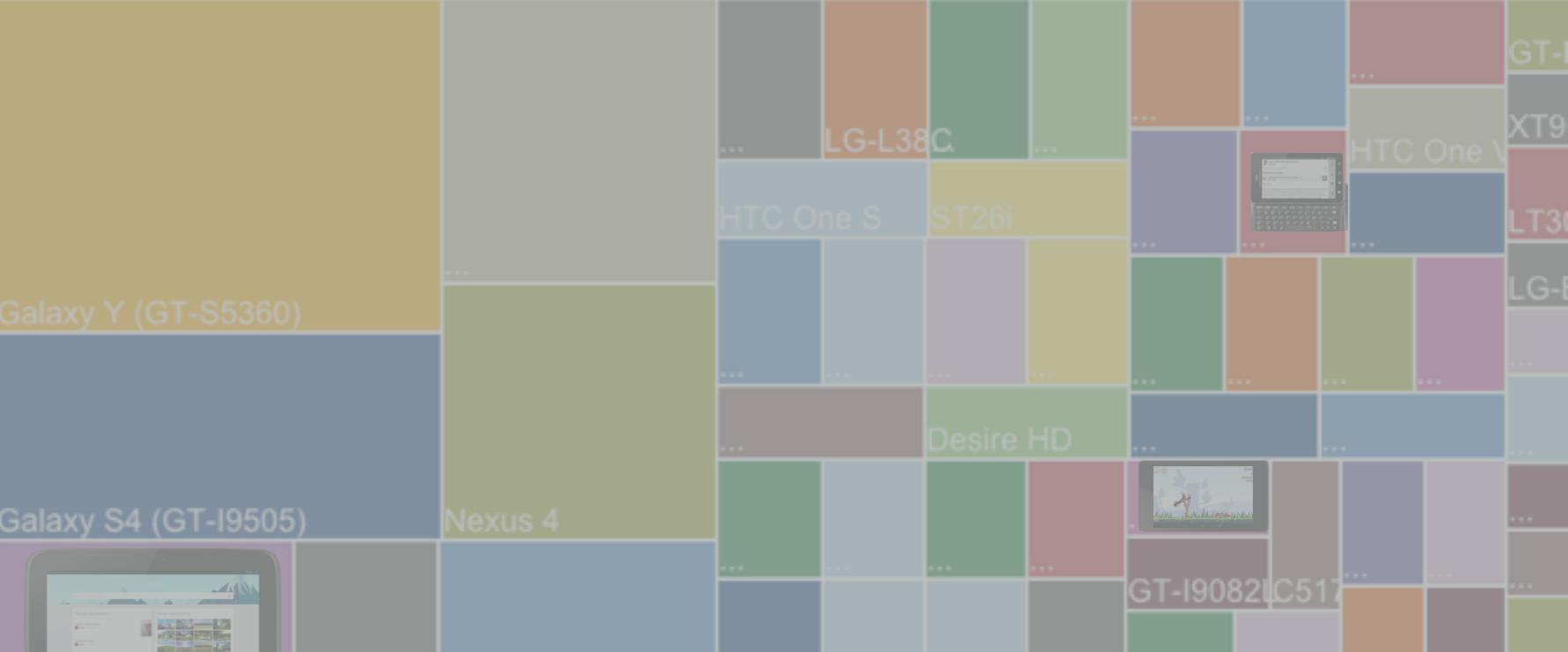
**Touchscreen**  
**Form Factor**  
**OS Version**





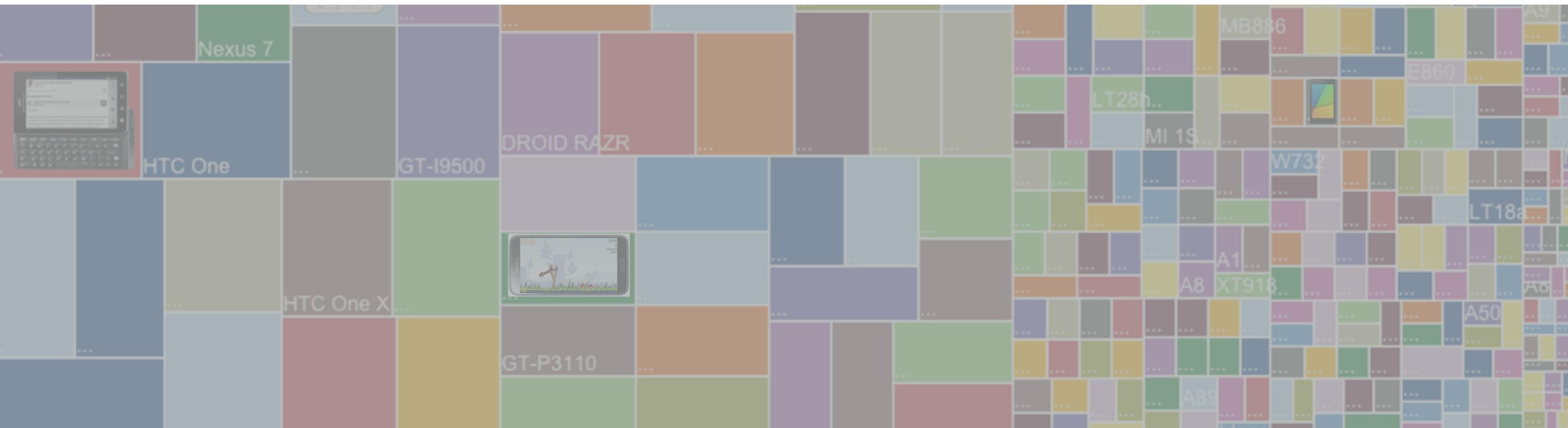
# “The Fragmentation Problem”

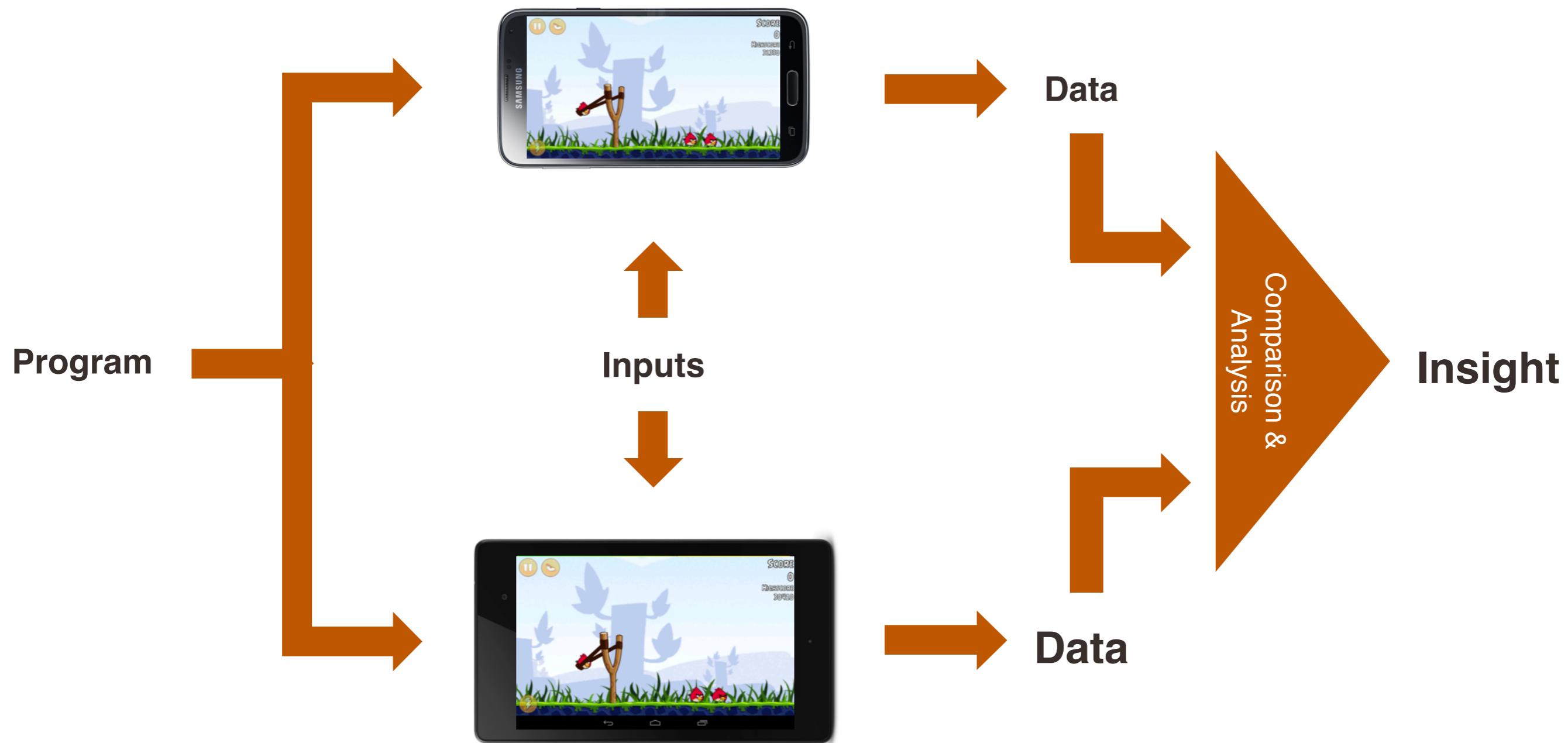


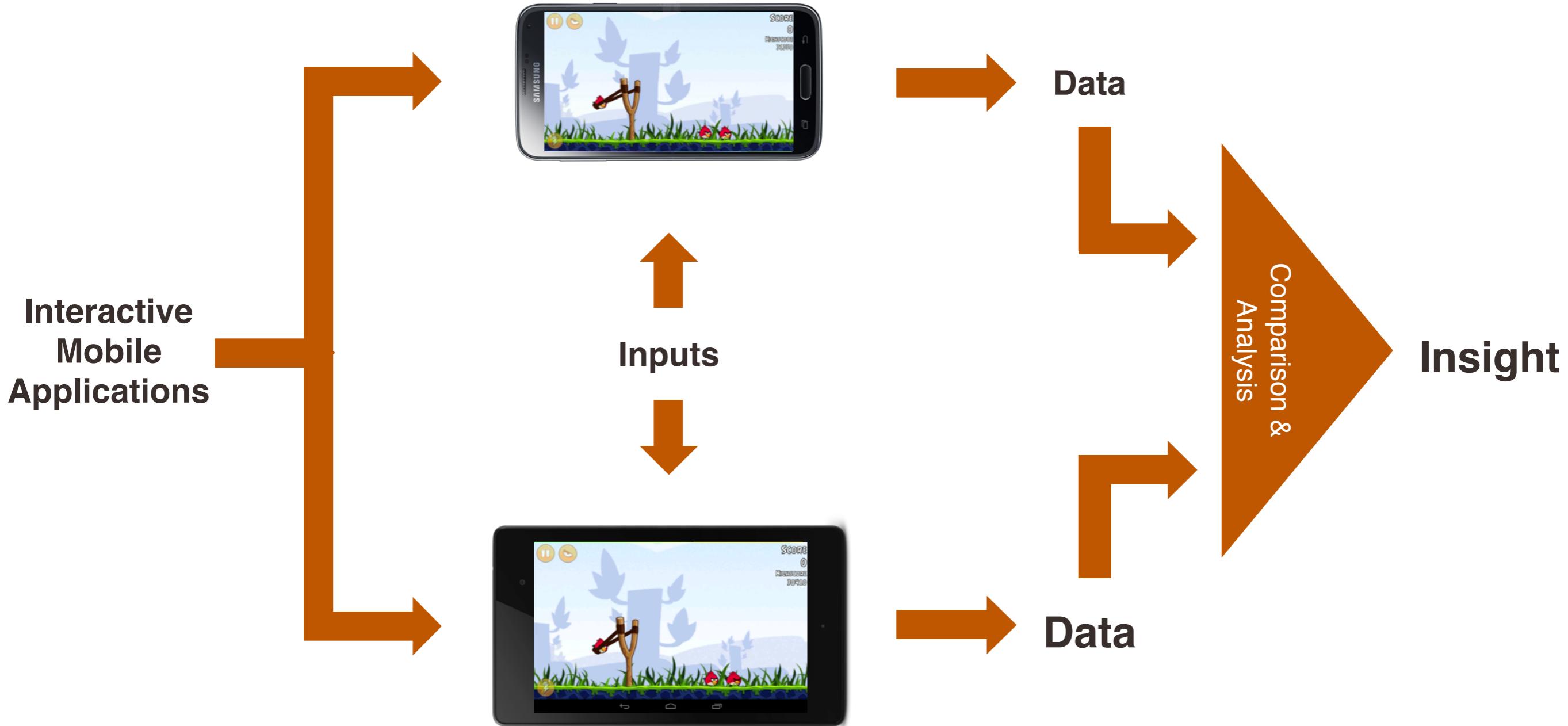


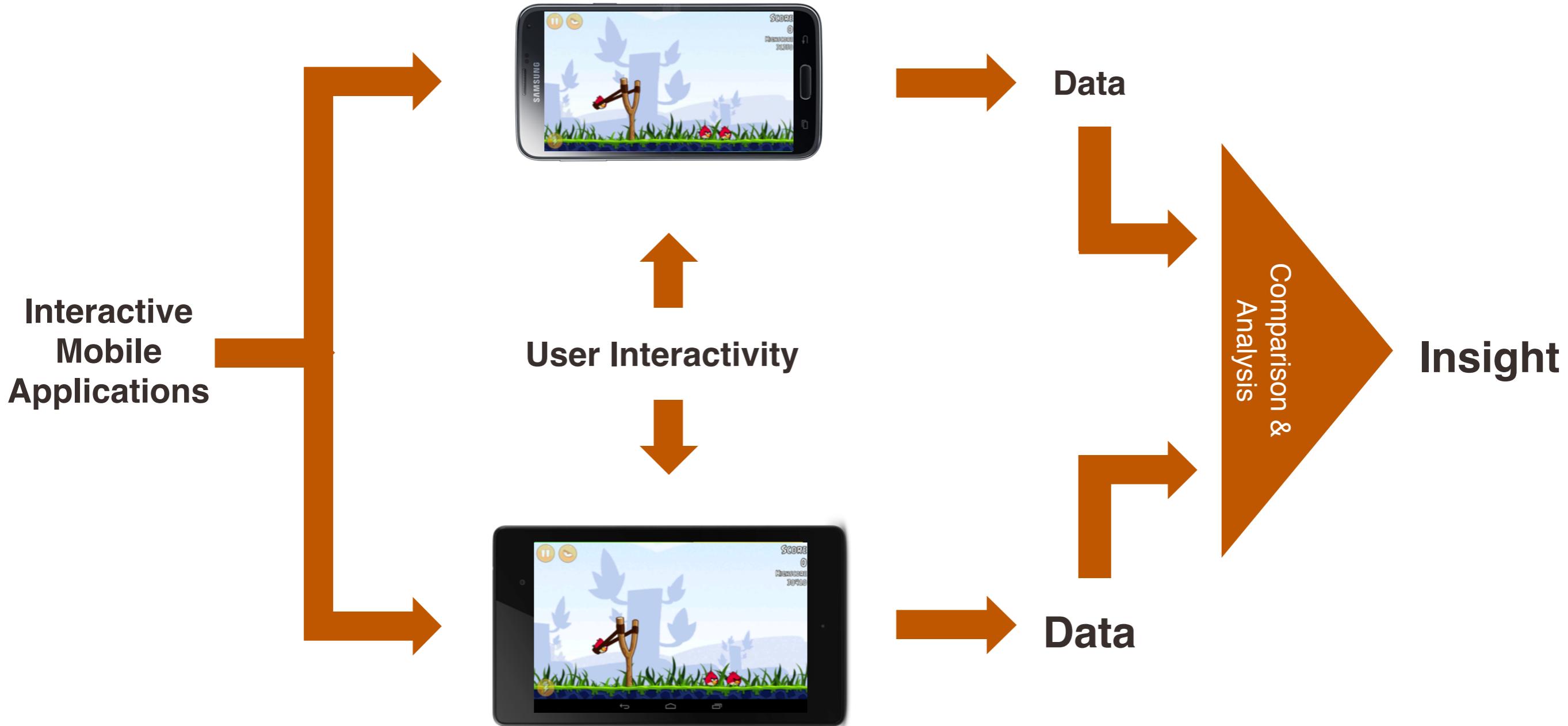
# “The Fragmentation Problem”

Form Factors x Displays x Processors x OS's x UI's x Drivers

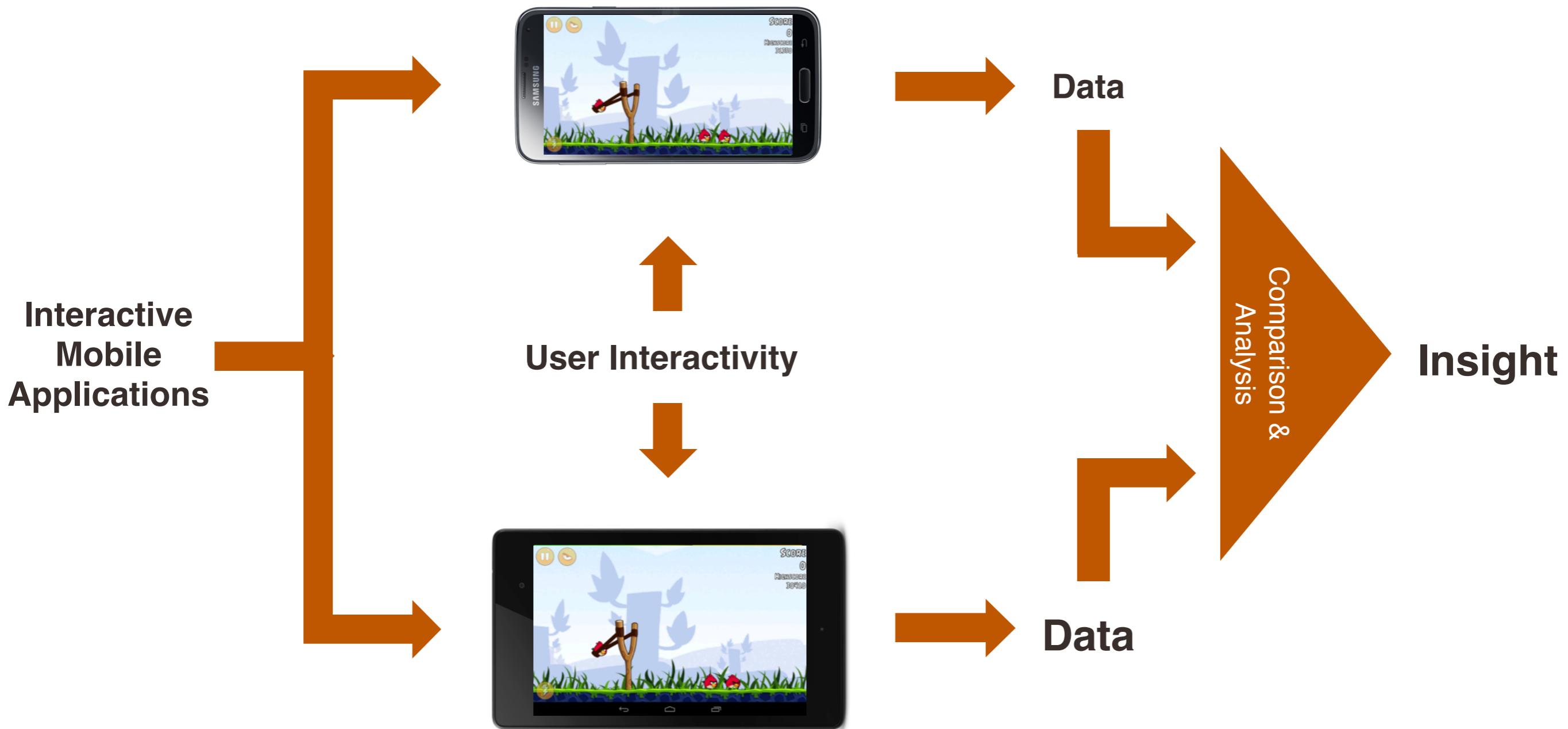




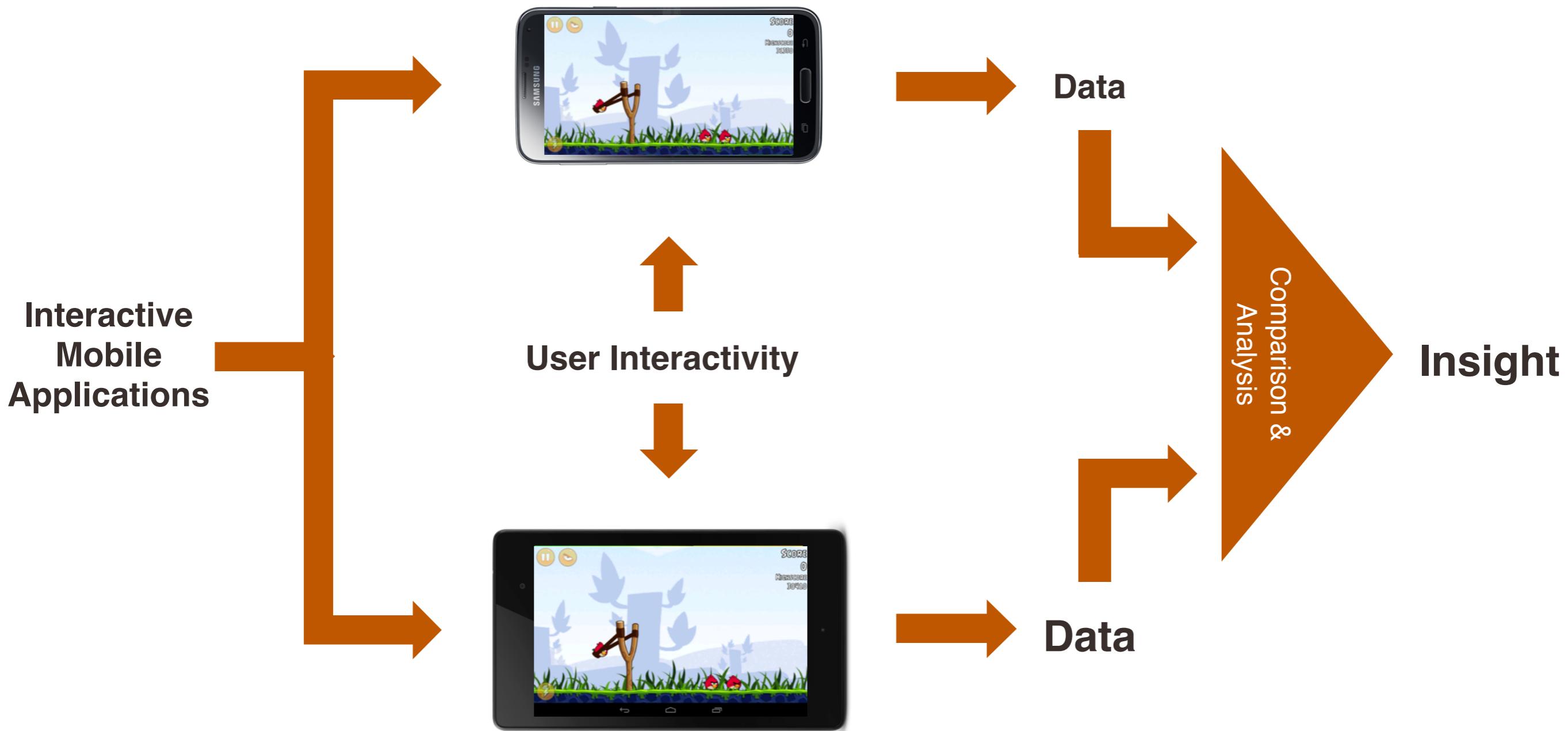




# Portable user interactivity that is device agnostic.

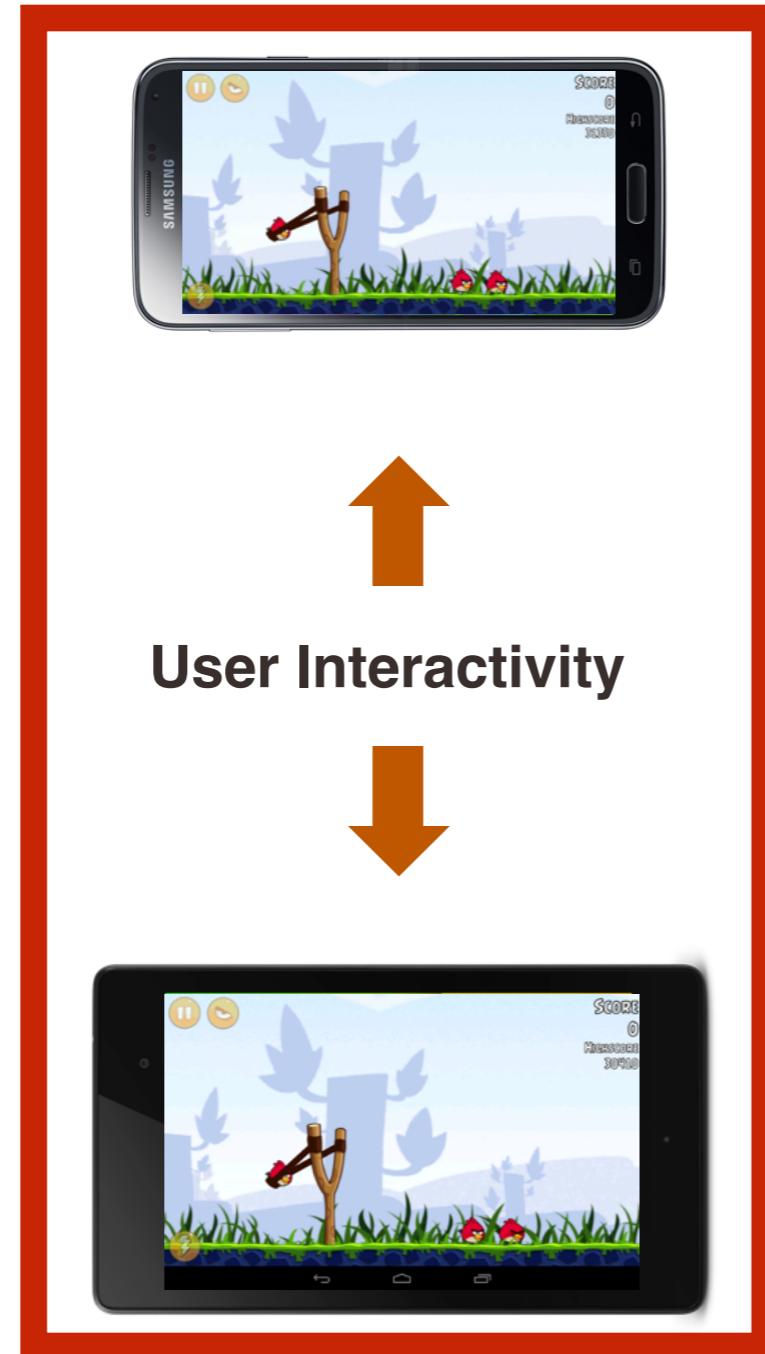


# **Portable** user interactivity that is **device agnostic**.



# **Representative** user interactivity is **device specific**.

# **Portable** user interactivity that is **device agnostic**.



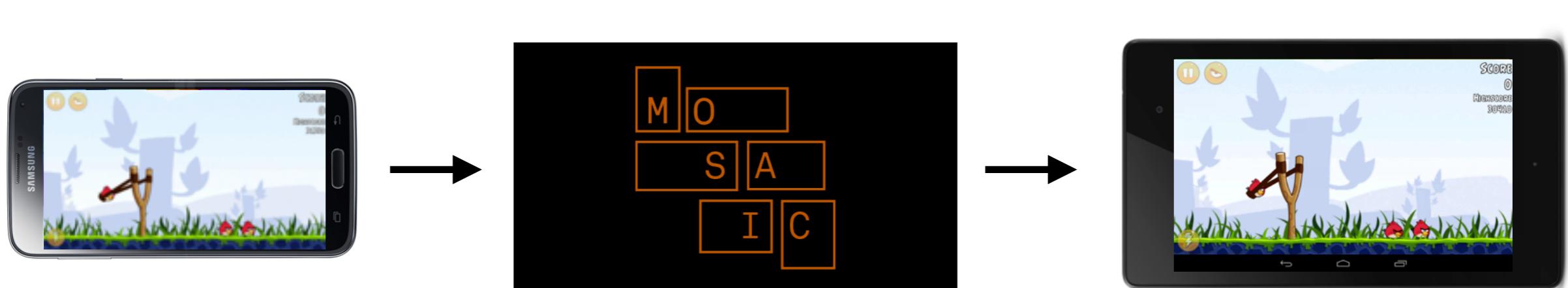
# **Representative** user interactivity is **device specific**.

# **Portable** user interactivity that is **device agnostic**.



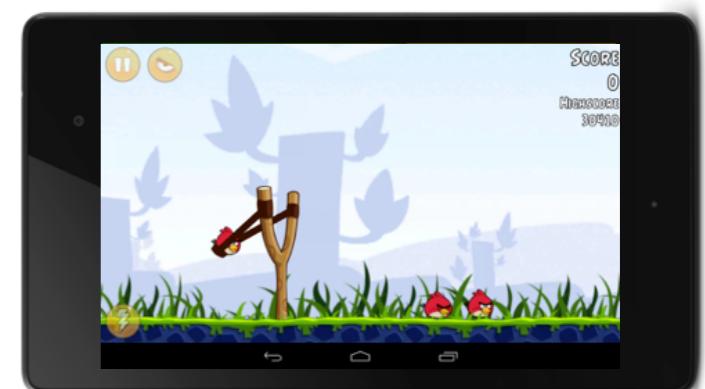
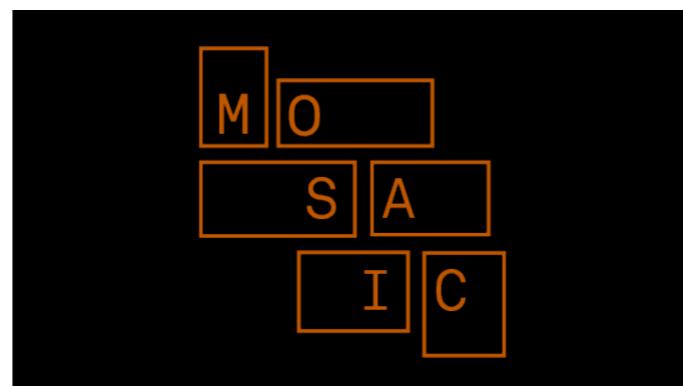
# **Representative** user interactivity is **device specific**.

# Mosaic Makes Interactivity Portable

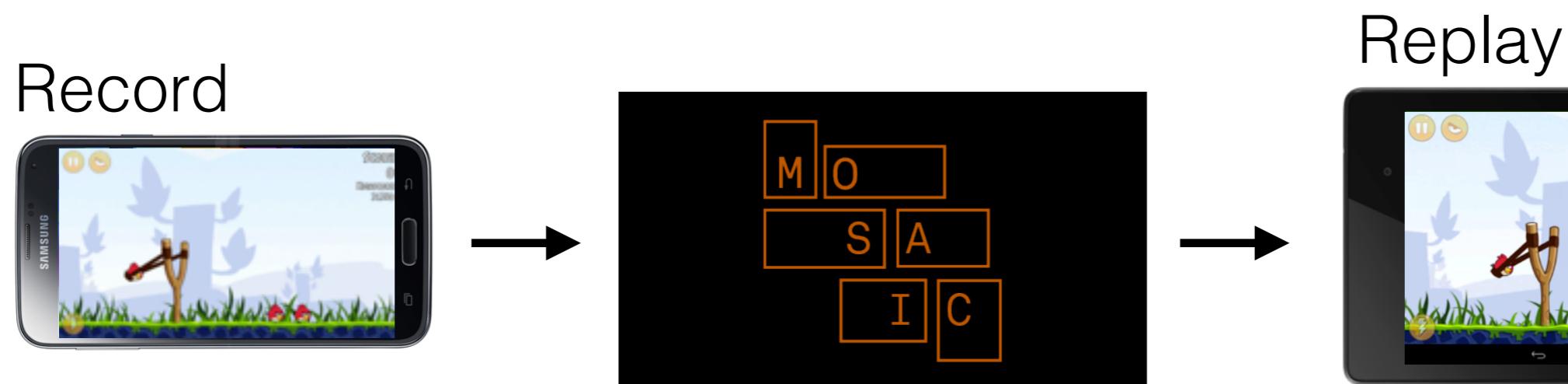


# Mosaic Makes Interactivity Portable

Record

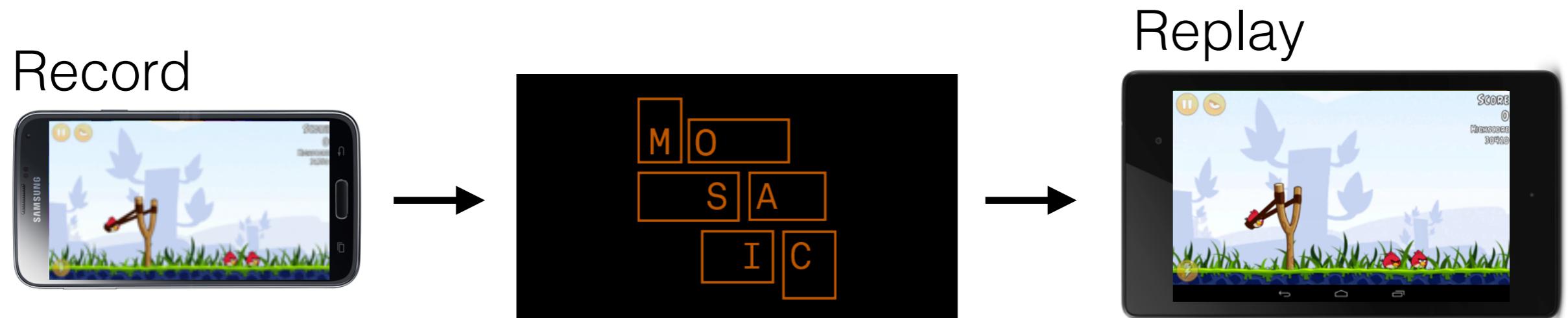


# Mosaic Makes Interactivity Portable



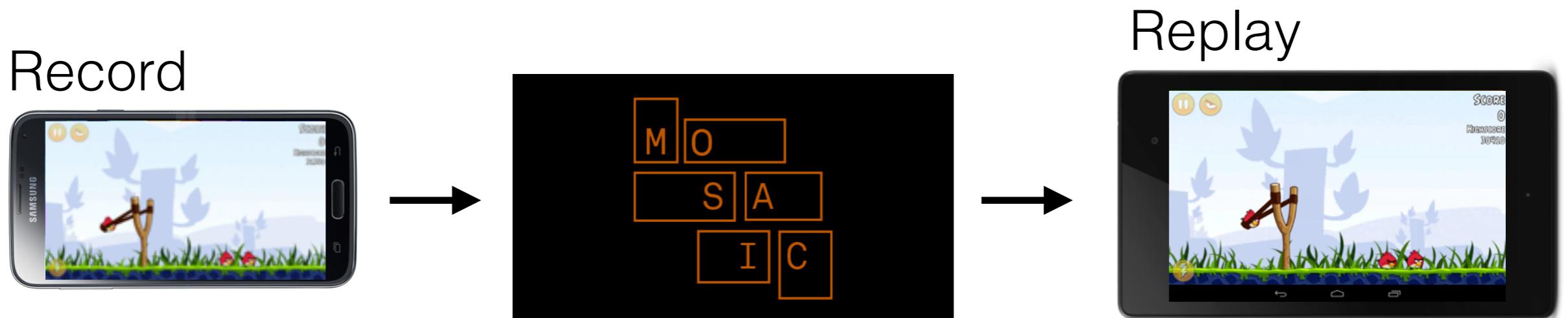
# Mosaic Makes Interactivity Portable

✓ Off-the-shelf Mobile Devices



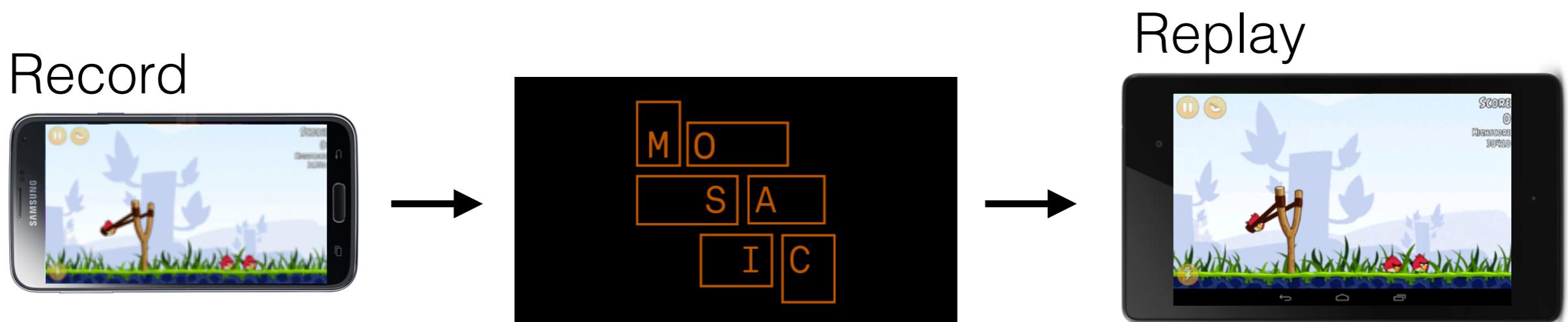
# Mosaic Makes Interactivity Portable

- ✓ Off-the-shelf Mobile Devices
- ✓ Mainstream Mobile Applications



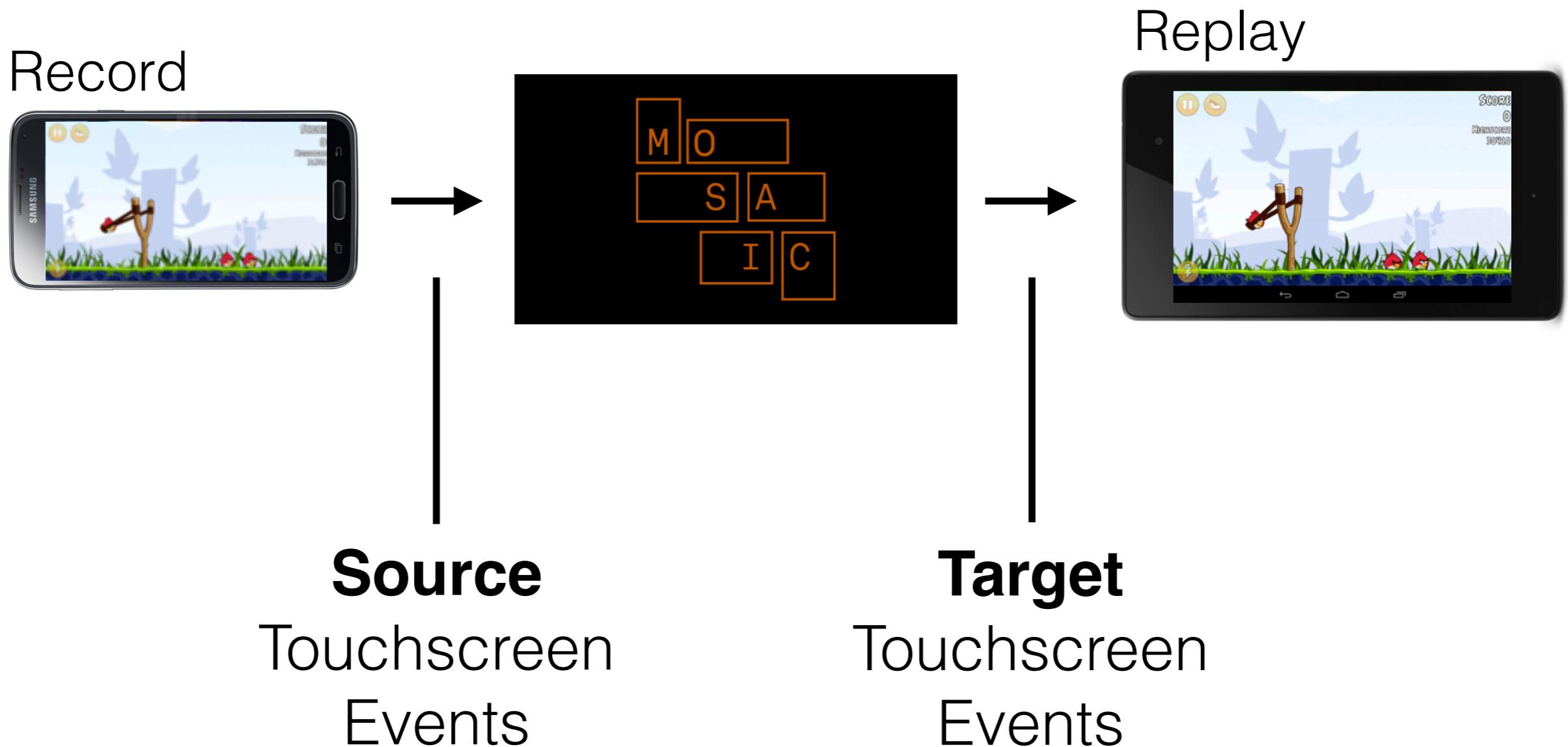
# Mosaic Makes Interactivity Portable

- ✓ Off-the-shelf Mobile Devices
- ✓ Mainstream Mobile Applications
- ✓ Low Overhead



# Mosaic Makes Interactivity Portable

- ✓ Off-the-shelf Mobile Devices
- ✓ Mainstream Mobile Applications
- ✓ Low Overhead



# Touchscreen Events



# Touchscreen Events



# Touchscreen Events



Contact point 1 found

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1  
Interaction has ended

# Touchscreen Events



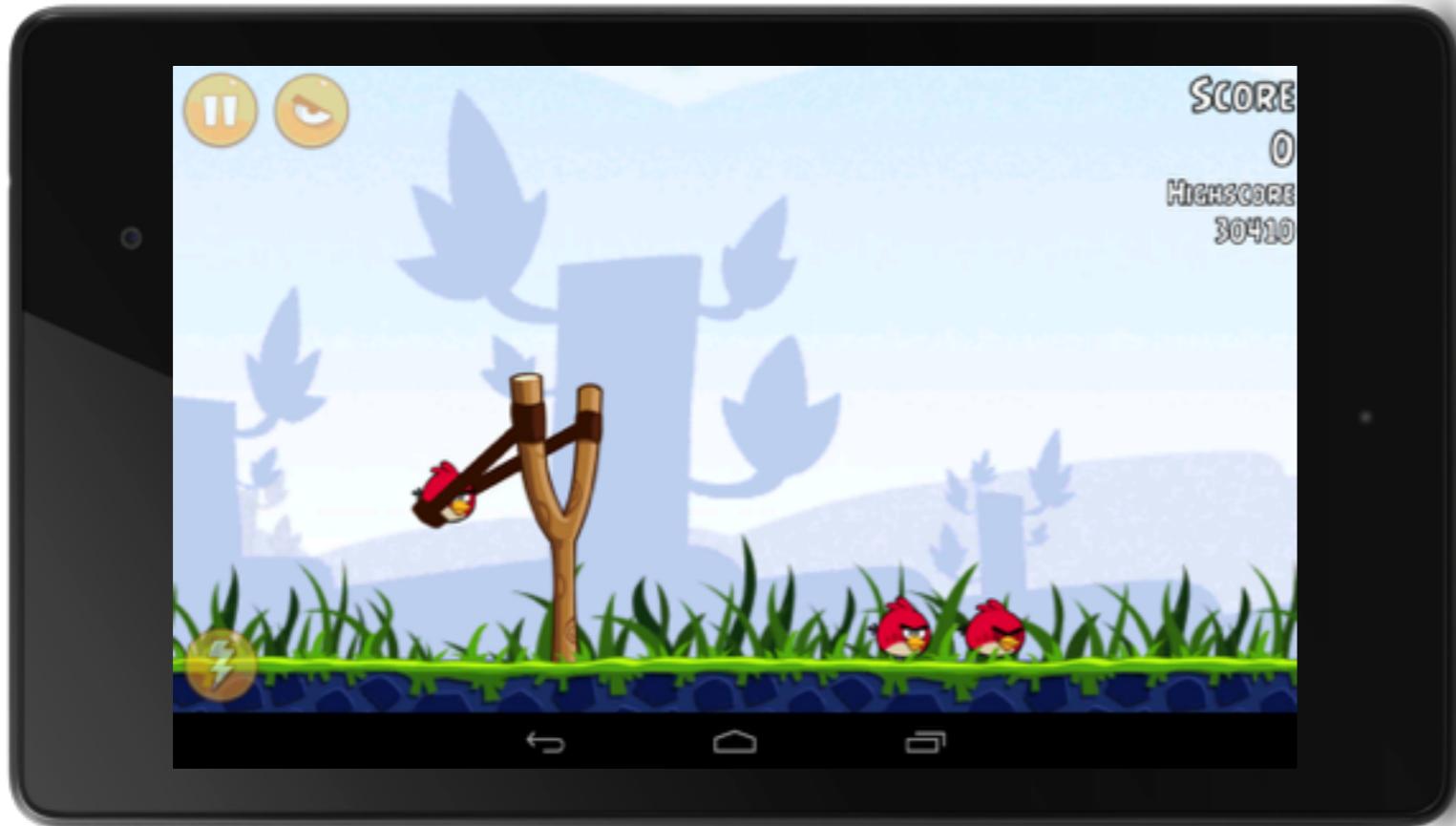
Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1  
Interaction has ended

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1  
Interaction has ended

# Touchscreen Events



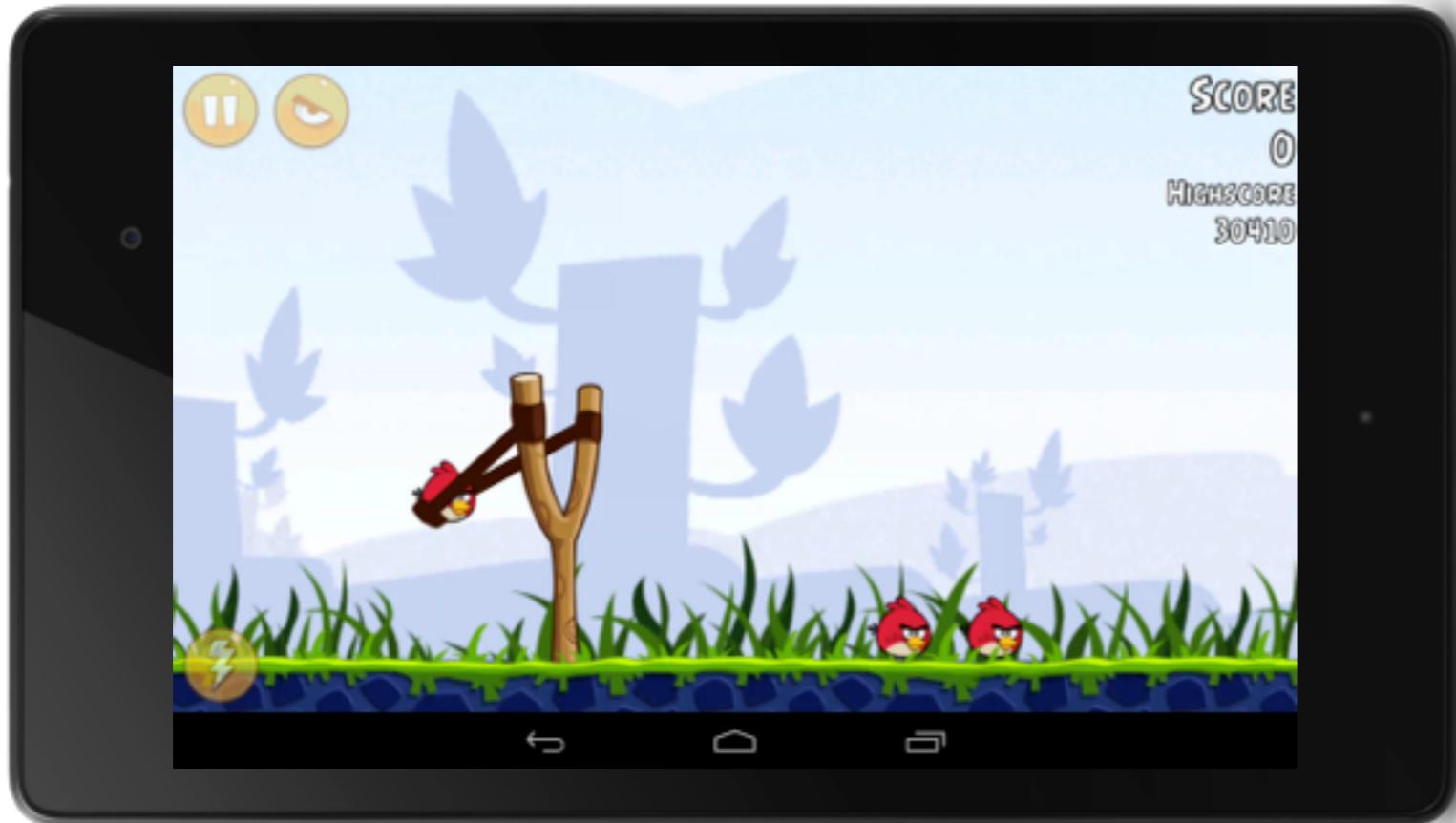
Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1  
Interaction has ended  
Contact point 1 is gone

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1  
Interaction has ended  
Contact point 1 is gone  
Interaction has ended

# Touchscreen Events



Contact point 1 found  
X-position is at X0  
Y-position is at Y0  
Pressure is N  
Interaction has ended  
X-position is at X1  
Y-position is at Y1  
Interaction has ended  
Contact point 1 is gone  
Interaction has ended

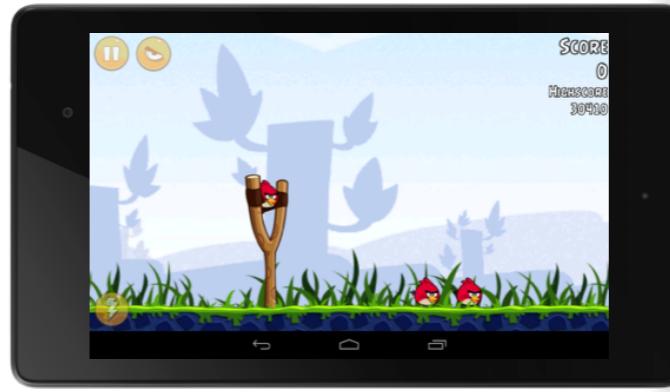
# Touchscreen Events

<u>Event Code</u>	<u>Event Value</u>	<u>Event Description</u>
ABS_MT_TRACKING_ID	1	Contact point 1 found
ABS_MT_POSITION_X	X0	X-position is at X0
ABS_MT_POSITION_Y	Y0	Y-position is at Y0
ABS_MT_PRESSURE	N	Pressure is N
SYN_REPORT	NULL	Interaction has ended
ABS_MT_POSITION_X	X1	X-position is at X1
ABS_MT_POSITION_Y	Y1	Y-position is at Y1
SYN_REPORT	NULL	Interaction has ended
ABS_MT_TRACKING_ID	-1	Contact point 1 is gone
SYN_REPORT	NULL	Interaction has ended

# Touchscreen Events

<u>Event Code</u>	<u>Event Value</u>	<u>Event Description</u>
ABS_MT_TRACKING_ID	1	Contact point 1 found
ABS_MT_POSITION_X	X0	X-position is at X0
ABS_MT_POSITION_Y	Y0	Y-position is at Y0
ABS_MT_PRESSURE	N	Pressure is N
SYN_REPORT	NULL	Interaction has ended
ABS_MT_POSITION_X	X1	X-position is at X1
ABS_MT_POSITION_Y	Y1	Y-position is at Y1
SYN_REPORT	NULL	Interaction has ended
ABS_MT_TRACKING_ID	-1	Contact point 1 is gone
SYN_REPORT	NULL	Interaction has ended

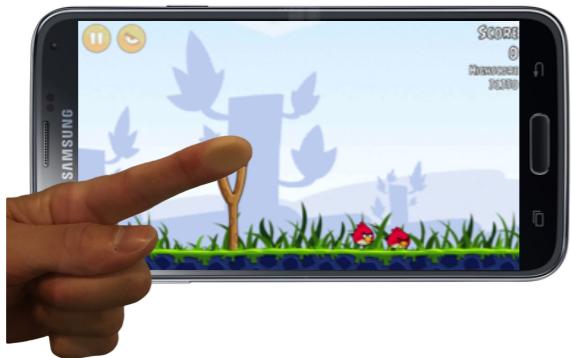
# Touchscreen Event Differences



# Touchscreen Event Differences



# Touchscreen Event Differences



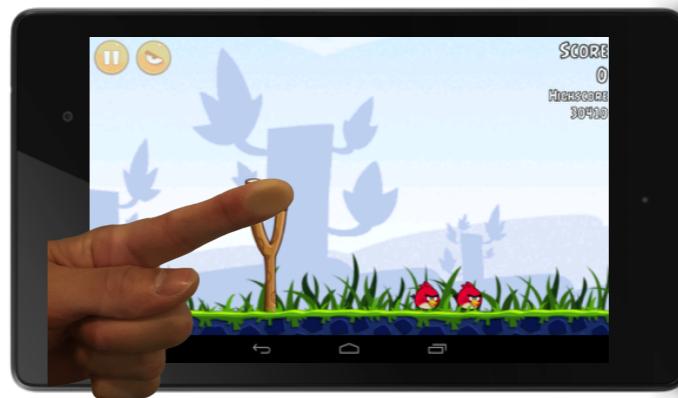
`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`



`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Event Differences



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`SYN_REPORT`



`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

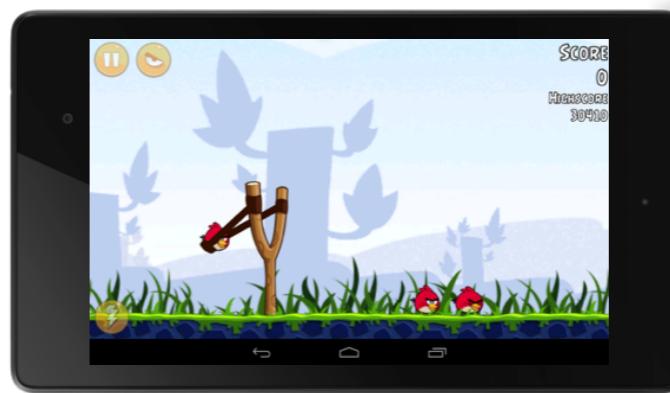
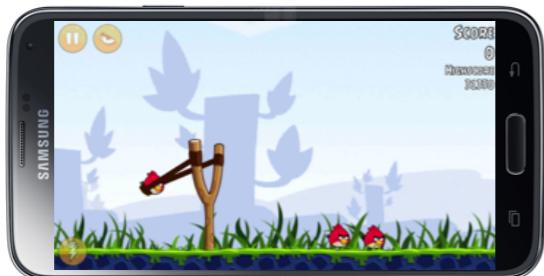
`SYN_REPORT`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`SYN_REPORT`

# Touchscreen Event Differences



ABS\_MT\_TRACKING\_ID

ABS\_MT\_POSITION\_X

ABS\_MT\_POSITION\_Y

ABS\_MT\_PRESSURE

SYN\_REPORT

ABS\_MT\_POSITION\_X

ABS\_MT\_POSITION\_Y

SYN\_REPORT

ABS\_MT\_TRACKING\_ID

SYN\_REPORT

ABS\_MT\_TRACKING\_ID  
BTN\_TOUCH

ABS\_MT\_POSITION\_X

ABS\_MT\_POSITION\_Y

ABS\_MT\_TOUCH\_MAJOR

ABS\_MT\_TOUCH\_MINOR

SYN\_REPORT

ABS\_MT\_POSITION\_X

ABS\_MT\_POSITION\_Y

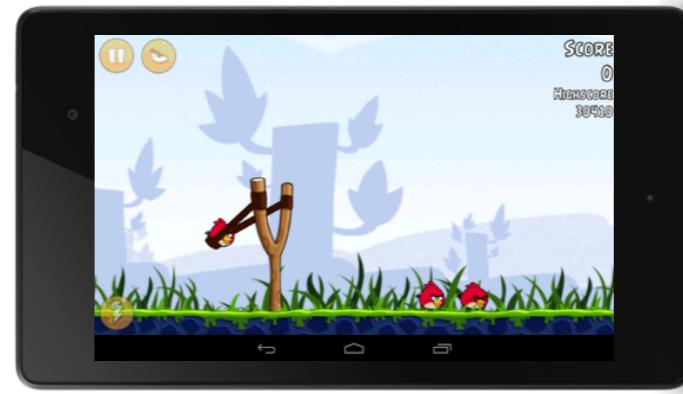
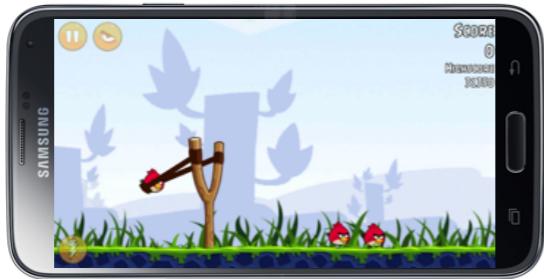
SYN\_REPORT

ABS\_MT\_TRACKING\_ID

BTN\_TOUCH

SYN\_REPORT

# Touchscreen Event Differences



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`  
`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`  
`SYN_REPORT`  
`ABS_MT_TRACKING_ID`

`SYN_REPORT`

`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`  
`ABS_MT_TOUCH_MAJOR`  
`ABS_MT_TOUCH_MINOR`

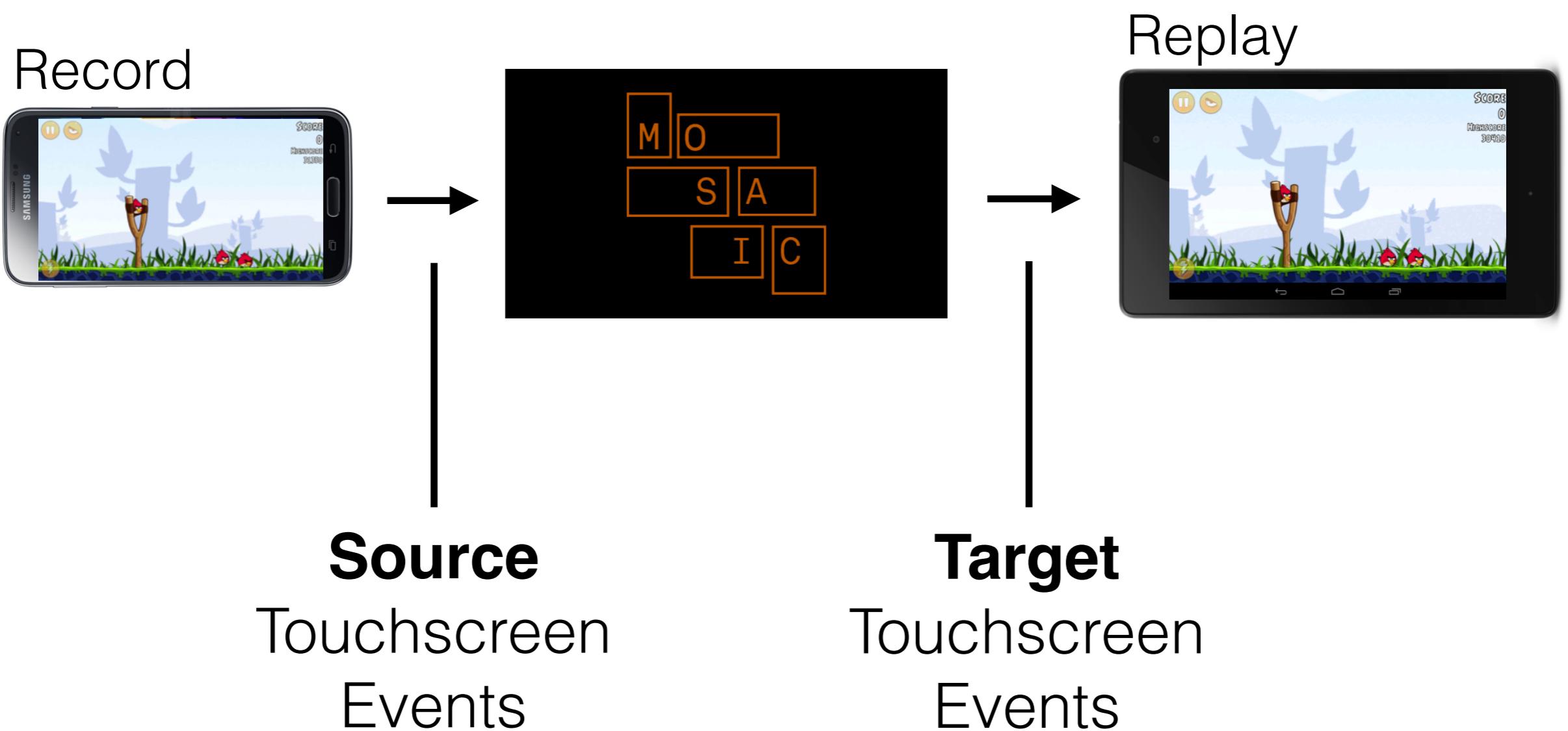
`SYN_REPORT`

`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`  
`SYN_REPORT`

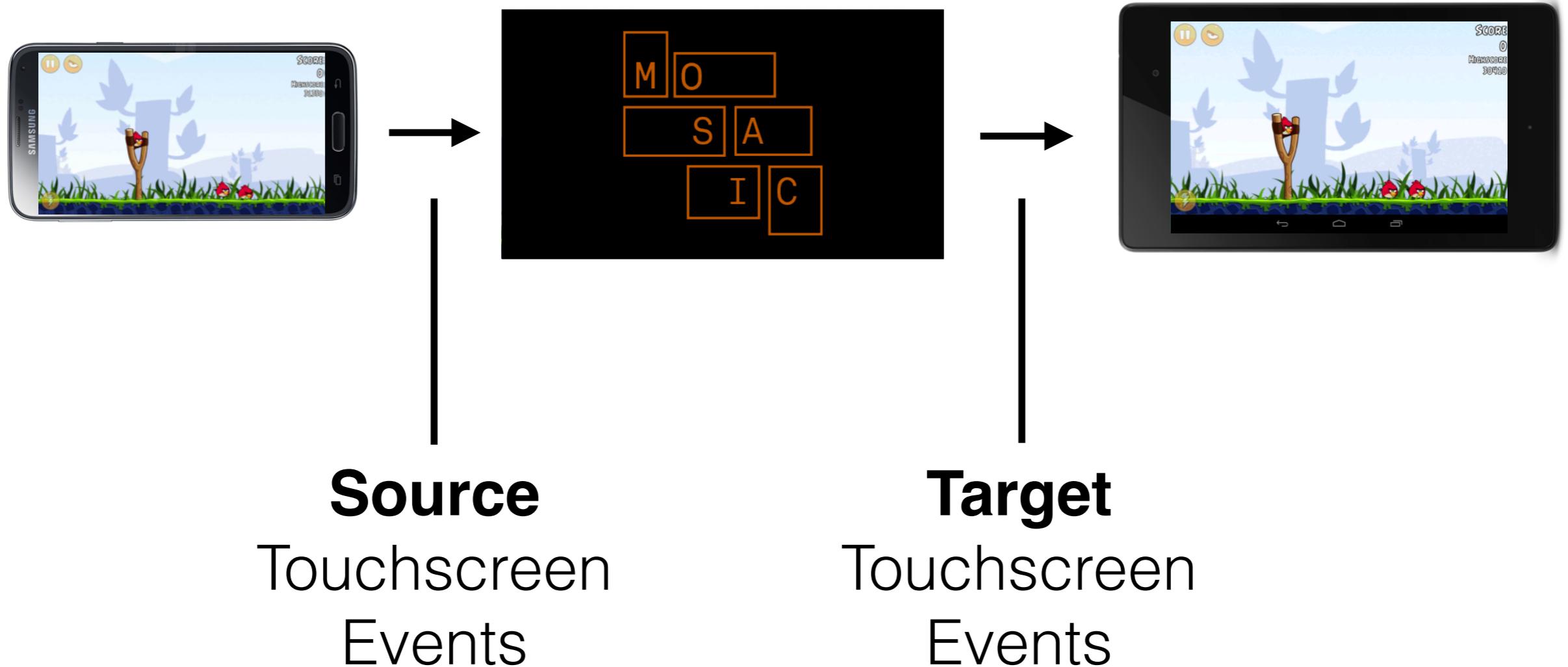
`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`SYN_REPORT`

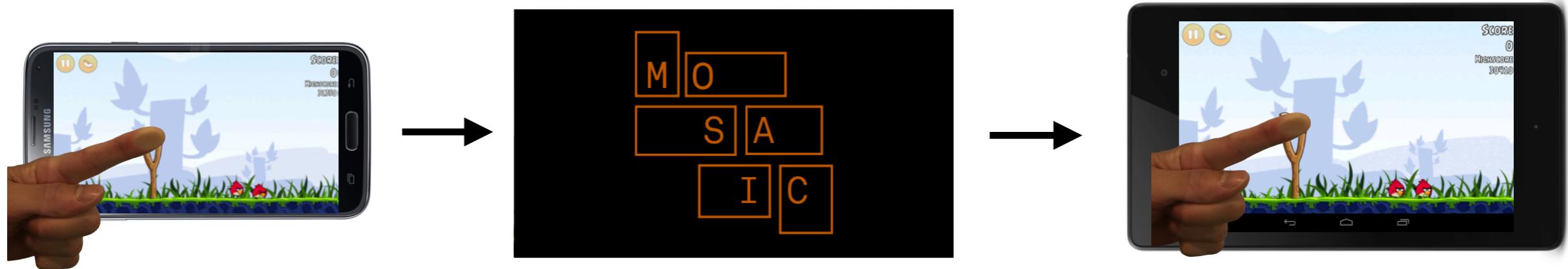
# How Mosaic Makes Interactivity Portable



# Touchscreen Driver



# Touchscreen Driver



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

`ABS_MT_TRACKING_ID`

`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

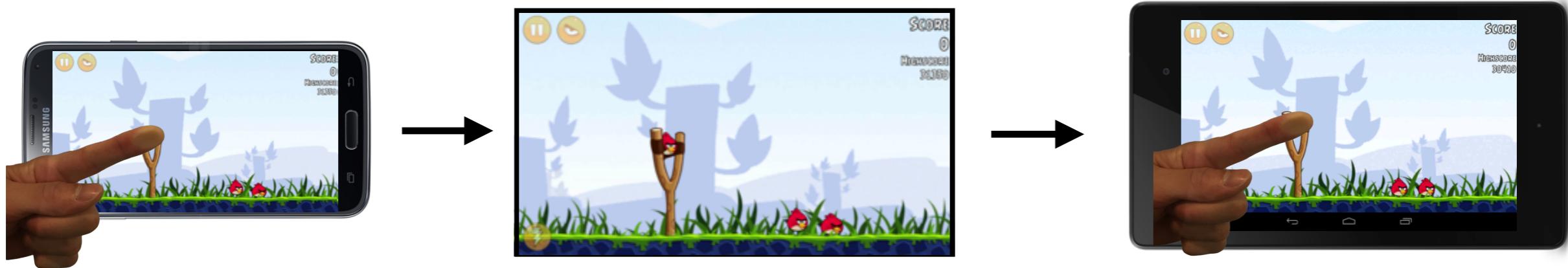
`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Driver

Virtualized Interactivity



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

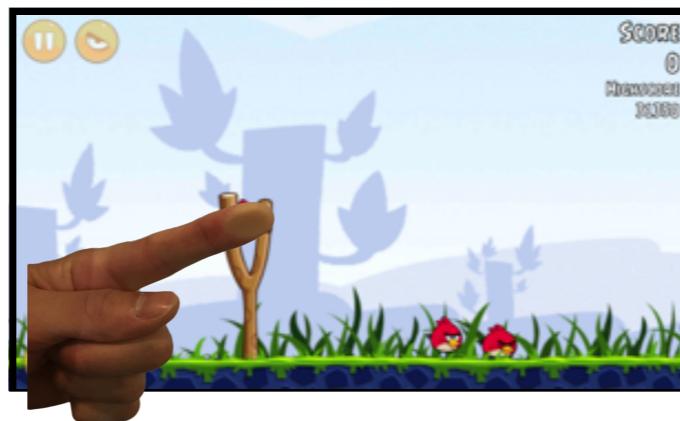
`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Driver

## Virtualized Interactivity



`ABS_MT_TRACKING_ID`

Press XYY YXY

`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`

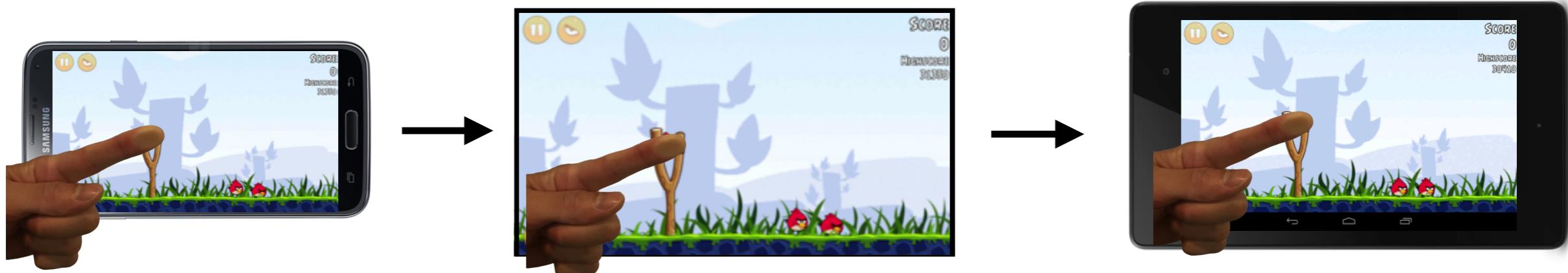
`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`  
`ABS_MT_TOUCH_MAJOR`  
`ABS_MT_TOUCH_MINOR`

`ABS_MT_PRESSURE`  
`SYN_REPORT`

`SYN_REPORT`

# Touchscreen Driver

Virtualized Interactivity



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

Press XYX YXY

`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

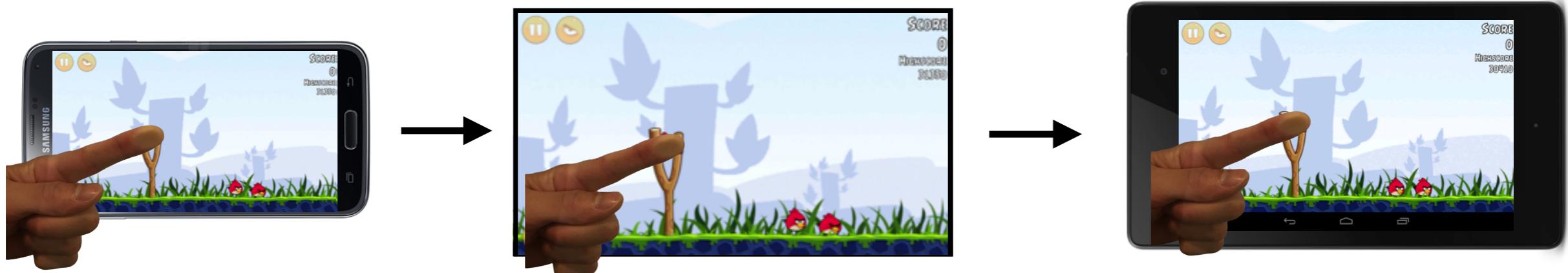
`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Driver

Virtualized Interactivity



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

Press XYY YXY

`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

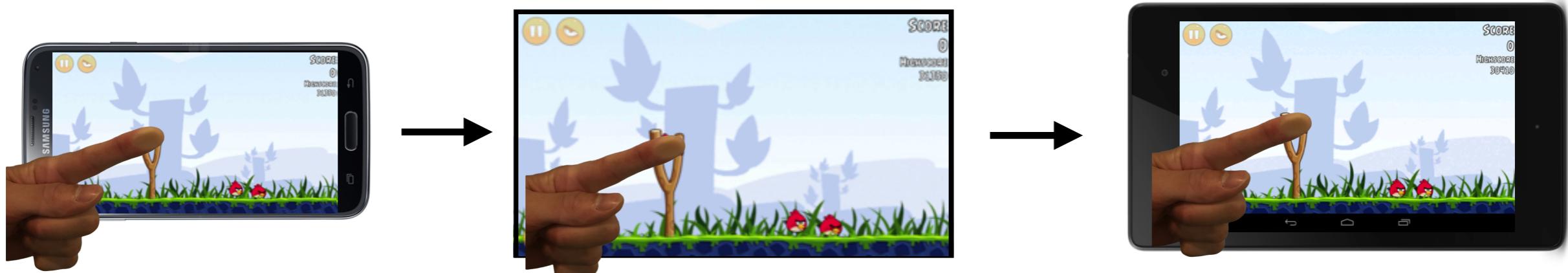
`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Driver

Virtualized Interactivity



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

Press XYY YXY



`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

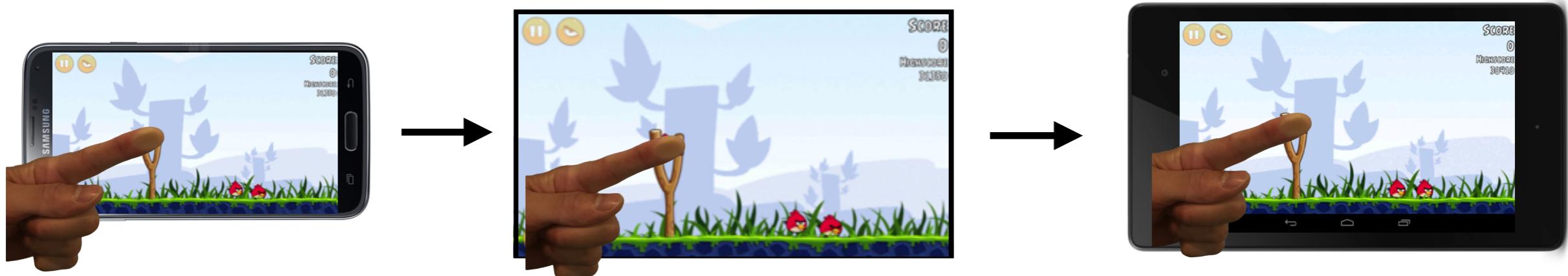
`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Driver

Virtualized Interactivity



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

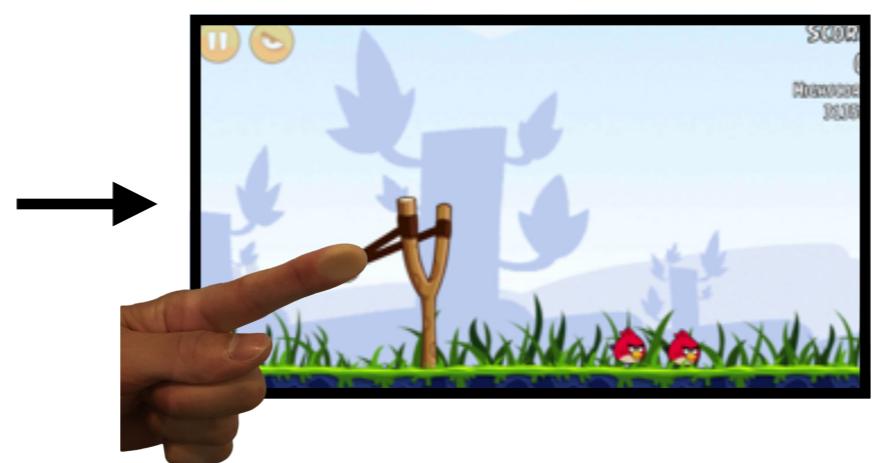
Press X Y X Y X Y

`ABS_MT_TRACKING_ID`  
`BTN_TOUCH`  
`ABS_MT_POSITION_X`  
`ABS_MT_POSITION_Y`  
`ABS_MT_TOUCH_MAJOR`  
`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

# Touchscreen Driver

## Virtualized Interactivity



`ABS_MT_TRACKING_ID`

Press `XYY YXY`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`SYN_REPORT`

Move `XYX YXY`

`ABS_MT_TRACKING_ID`

`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

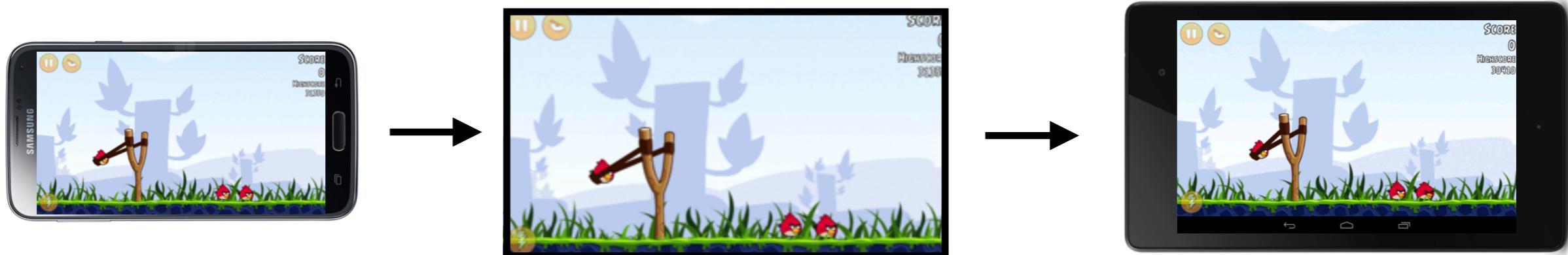
`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`SYN_REPORT`

# Touchscreen Driver

## Virtualized Interactivity



`ABS_MT_TRACKING_ID`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_PRESSURE`

`SYN_REPORT`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`SYN_REPORT`

`ABS_MT_TRACKING_ID`

`SYN_REPORT`

Press `XYY YXY`

Move `XYX YXY`

Release

`ABS_MT_TRACKING_ID`

`BTN_TOUCH`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

`ABS_MT_TOUCH_MAJOR`

`ABS_MT_TOUCH_MINOR`

`SYN_REPORT`

`ABS_MT_POSITION_X`

`ABS_MT_POSITION_Y`

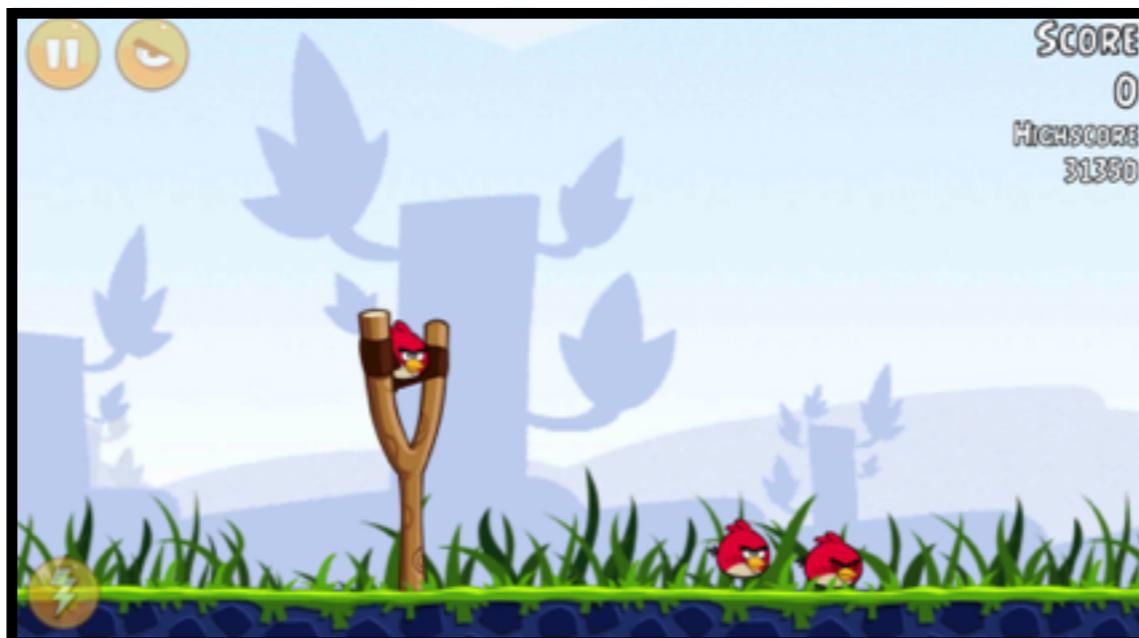
`SYN_REPORT`

`ABS_MT_TRACKING_ID`

`BTN_TOUCH`

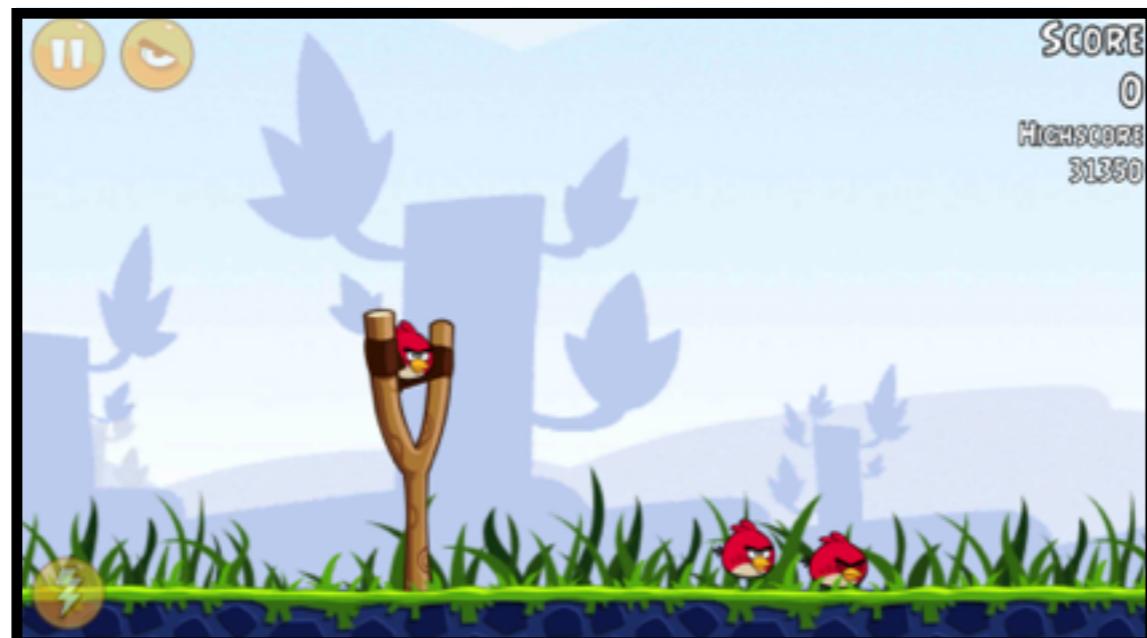
`SYN_REPORT`

# Virtualizing Interactions



# Virtualizing Interactions

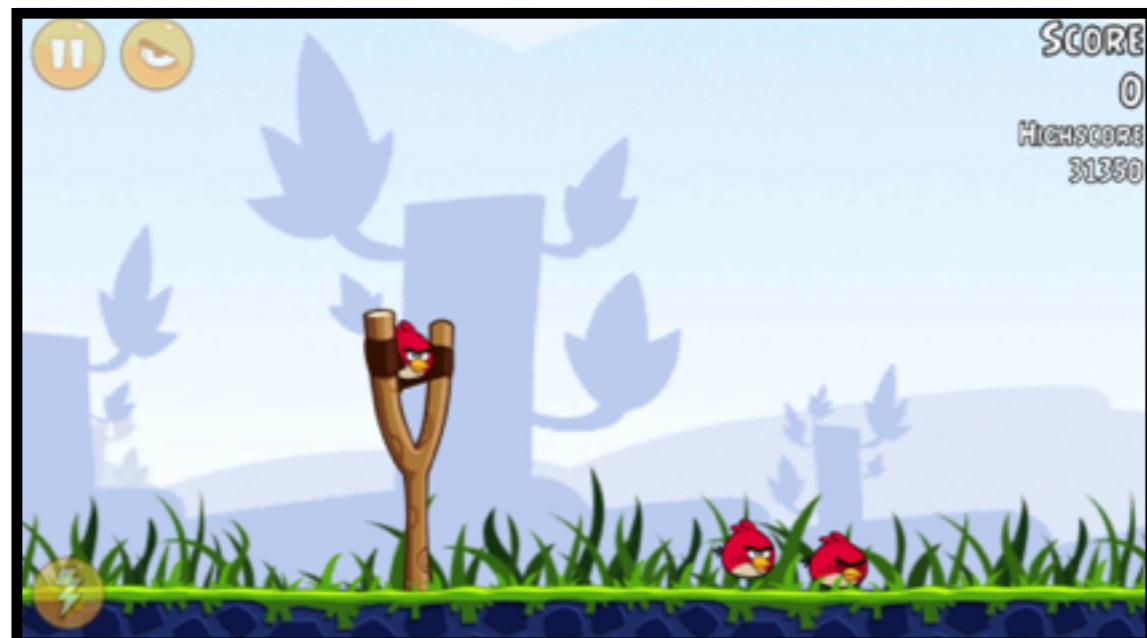
- Timing
- Type
- Location



# Virtualizing Interactions

- Timing
- Type
- Location

```
time finger <N> <interaction> [ [x] [y] ]
```



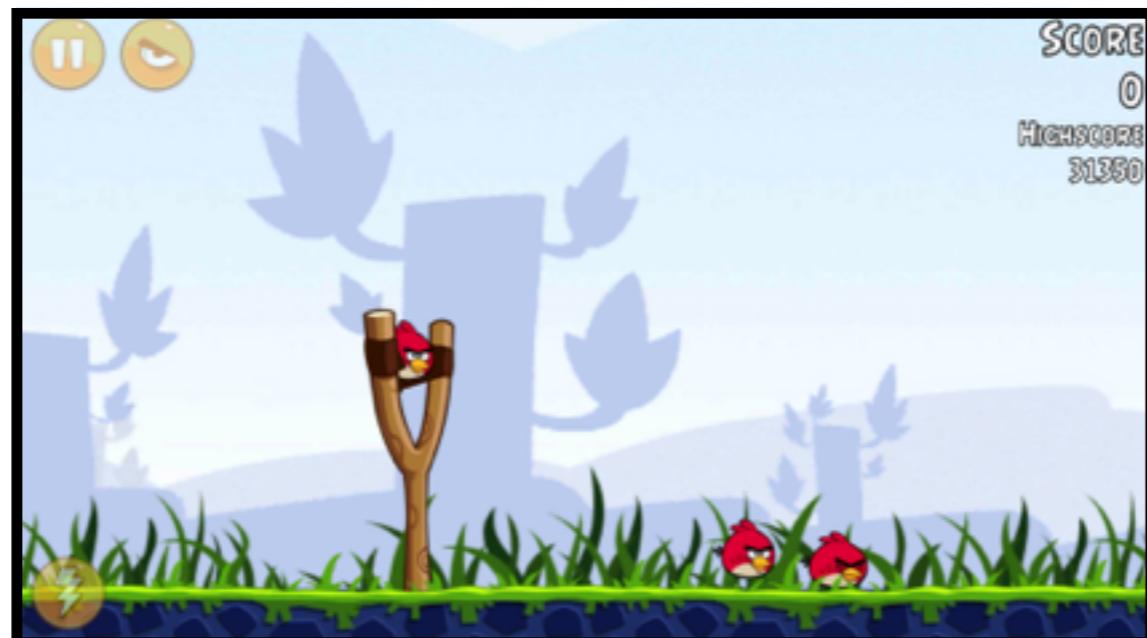
# Virtualizing Interactions

✓ Timing

- Type

- Location

```
time finger <N> <interaction> [ [x] [y] ]
```



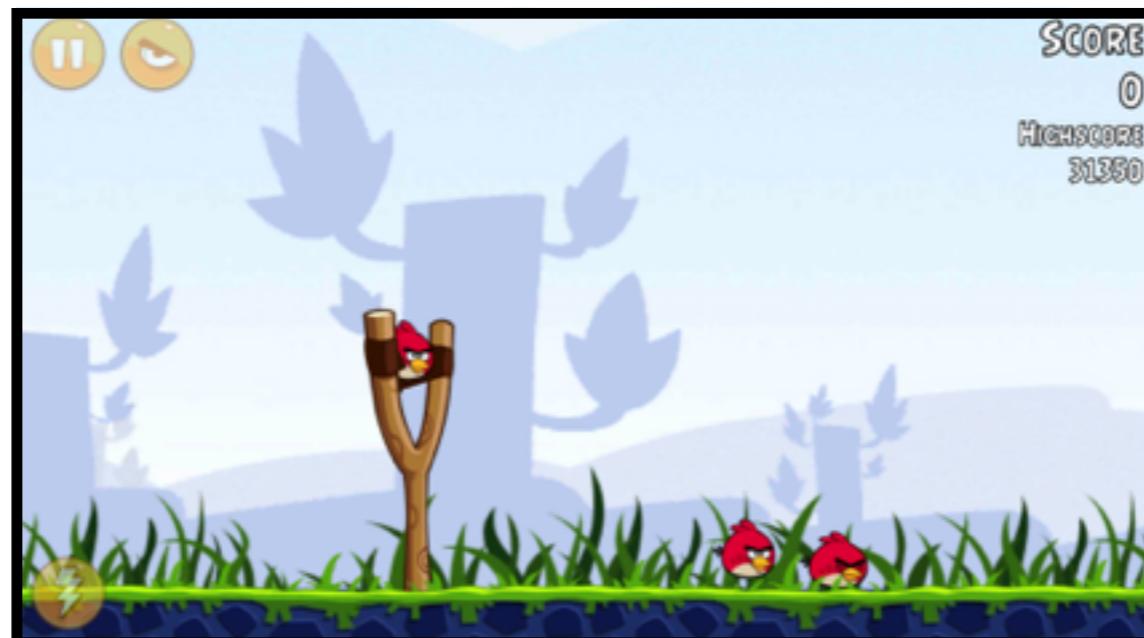
# Virtualizing Interactions

✓ Timing

- Type

- Location

```
time finger <N> <interaction> [ [x] [y] ]
```



# Virtualizing Interactions

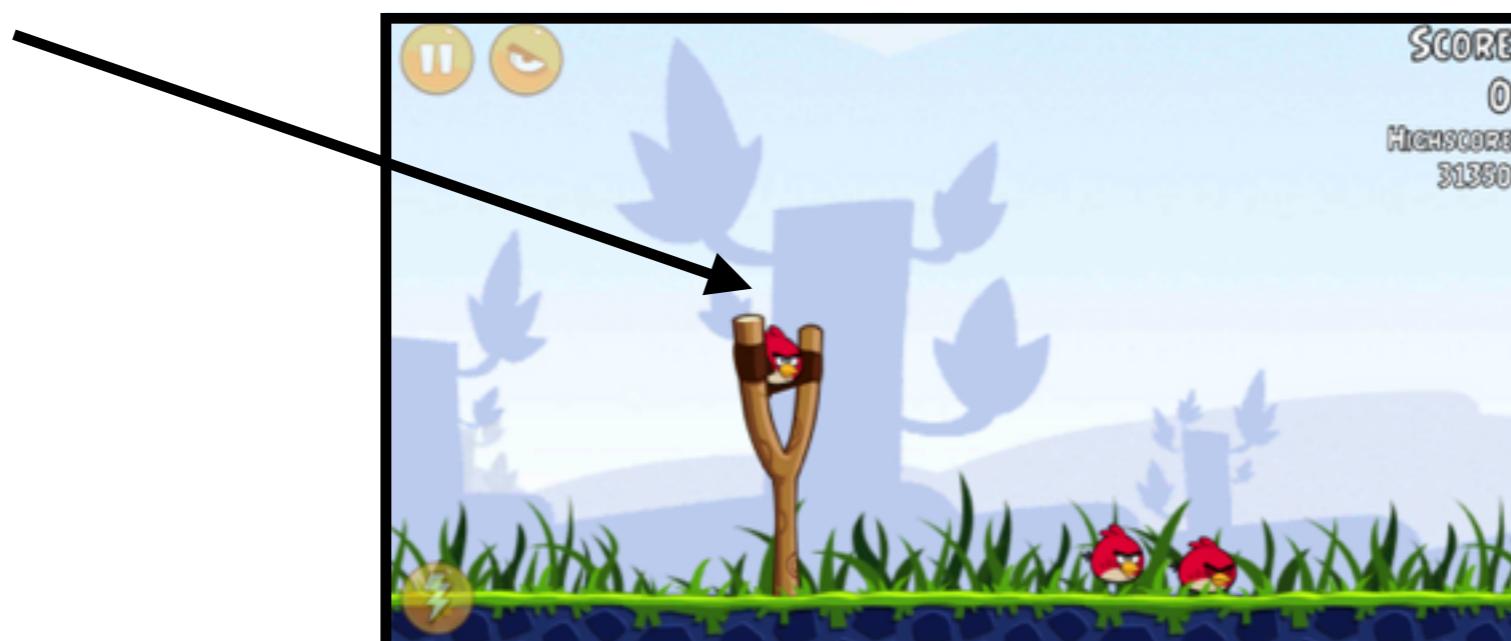
✓ Timing

• Type

• Location

```
time finger <N> <interaction> [ [x] [y] ]
```

Press



# Virtualizing Interactions

✓ Timing

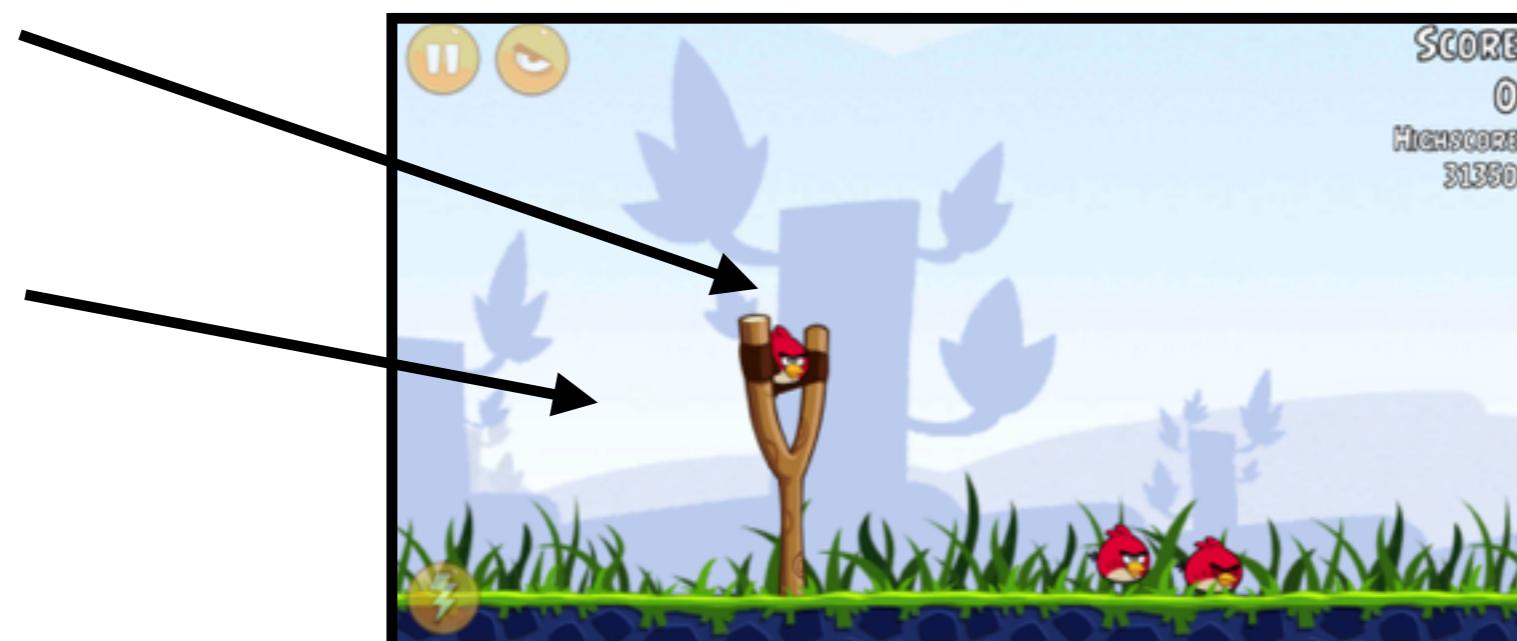
- Type

- Location

```
time finger <N> <interaction> [ [x] [y] ]
```

Press

Move



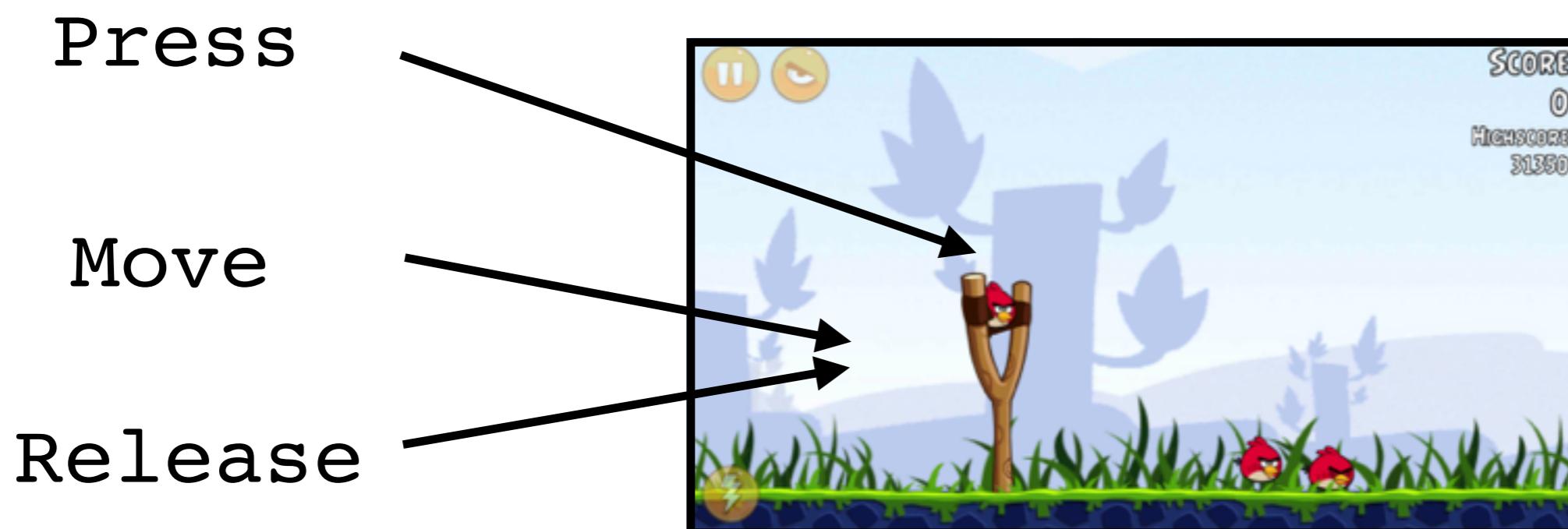
# Virtualizing Interactions

✓ Timing

• Type

• Location

```
time finger <N> <interaction> [ [x] [y] ]
```



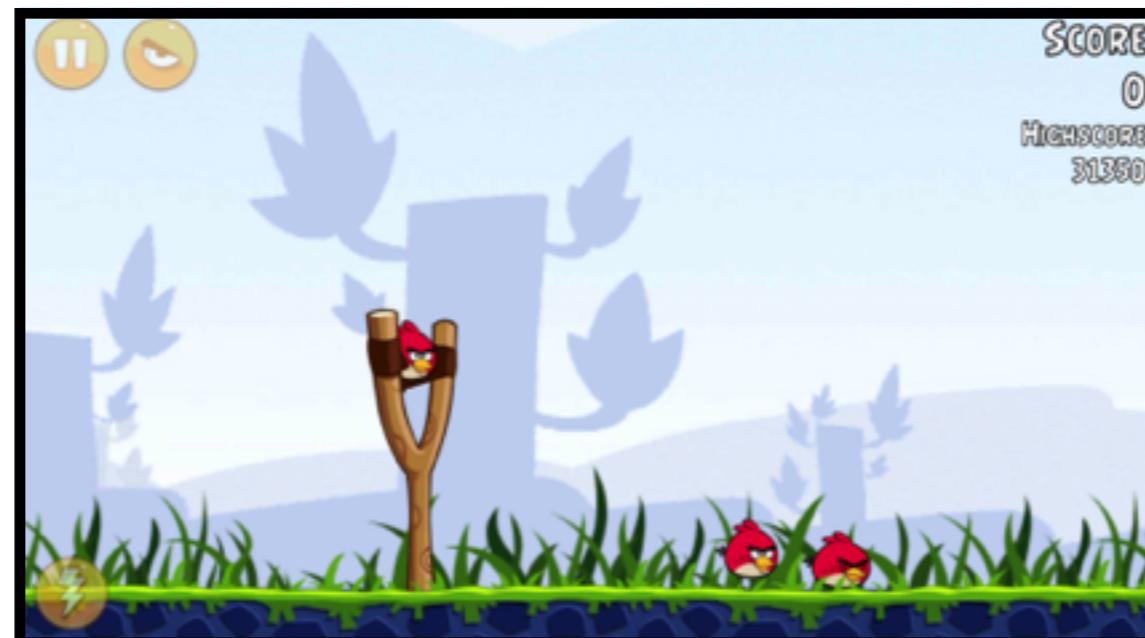
# Virtualizing Interactions

✓ Timing

- Type

- Location

```
time finger <N> <interaction> [ [x] [y] ]
```



# Virtualizing Interactions

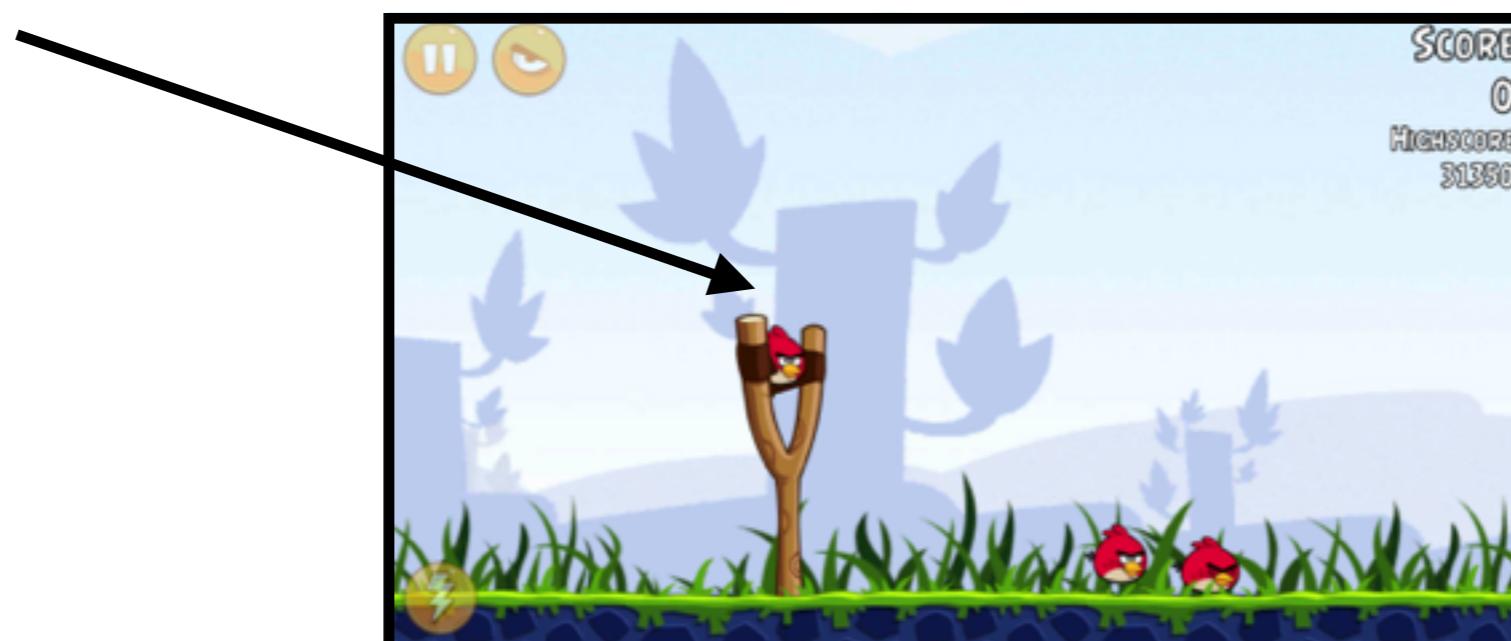
✓ Timing

• Type

• Location

```
time finger <N> <interaction> [ [x] [y] ]
```

Press



# Virtualizing Interactions

✓ Timing

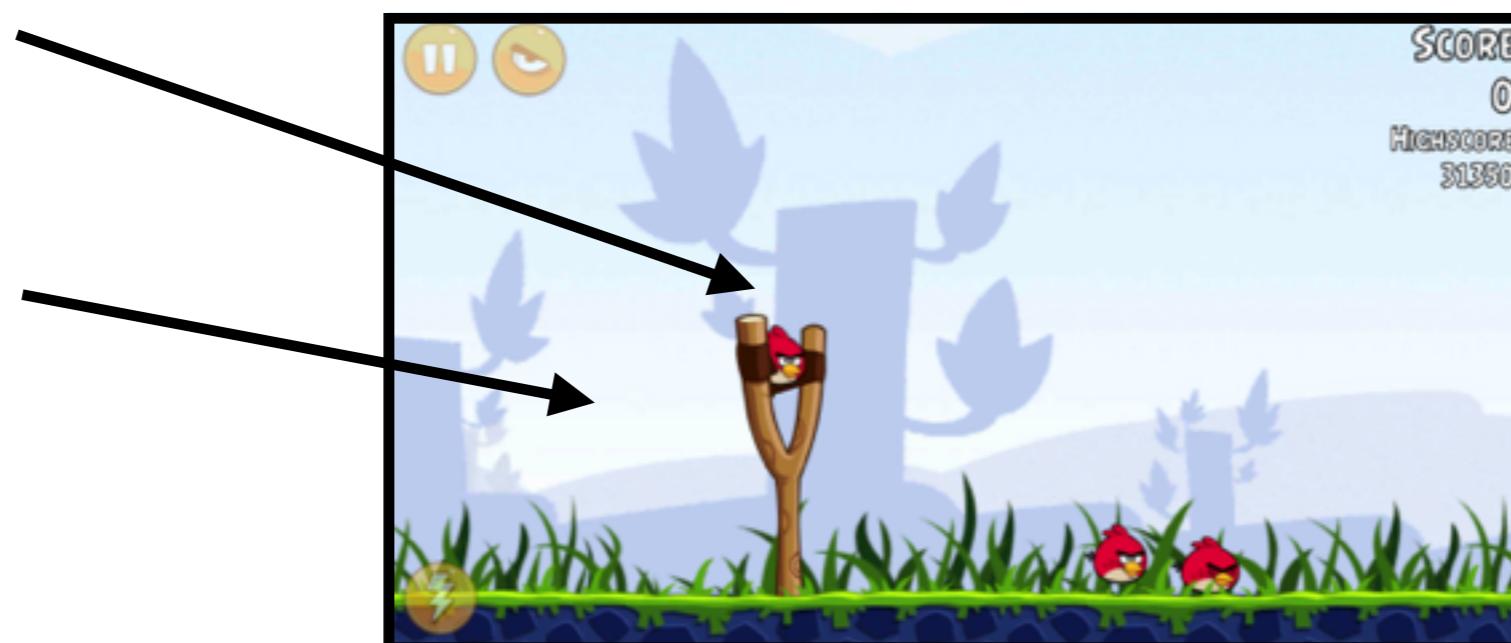
• Type

• Location

```
time finger <N> <interaction> [ [ x ] [ y ] ]
```

Press

Move



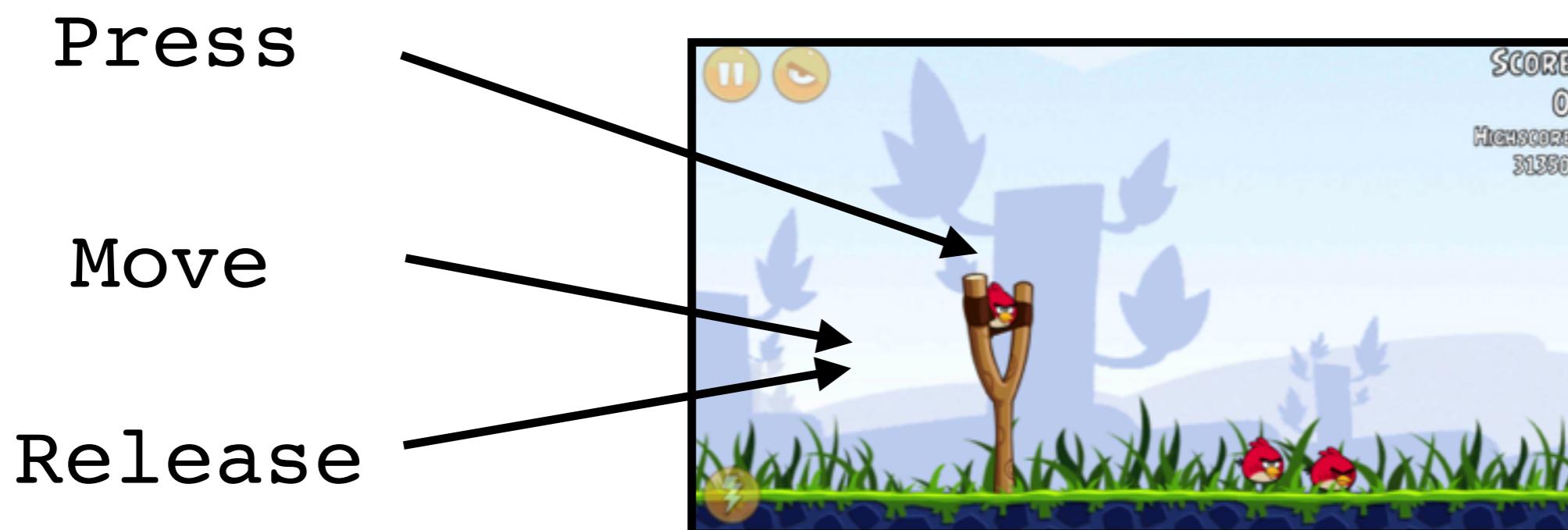
# Virtualizing Interactions

✓ Timing

• Type

• Location

```
time finger <N> <interaction> [ [ x ] [ y ] ]
```



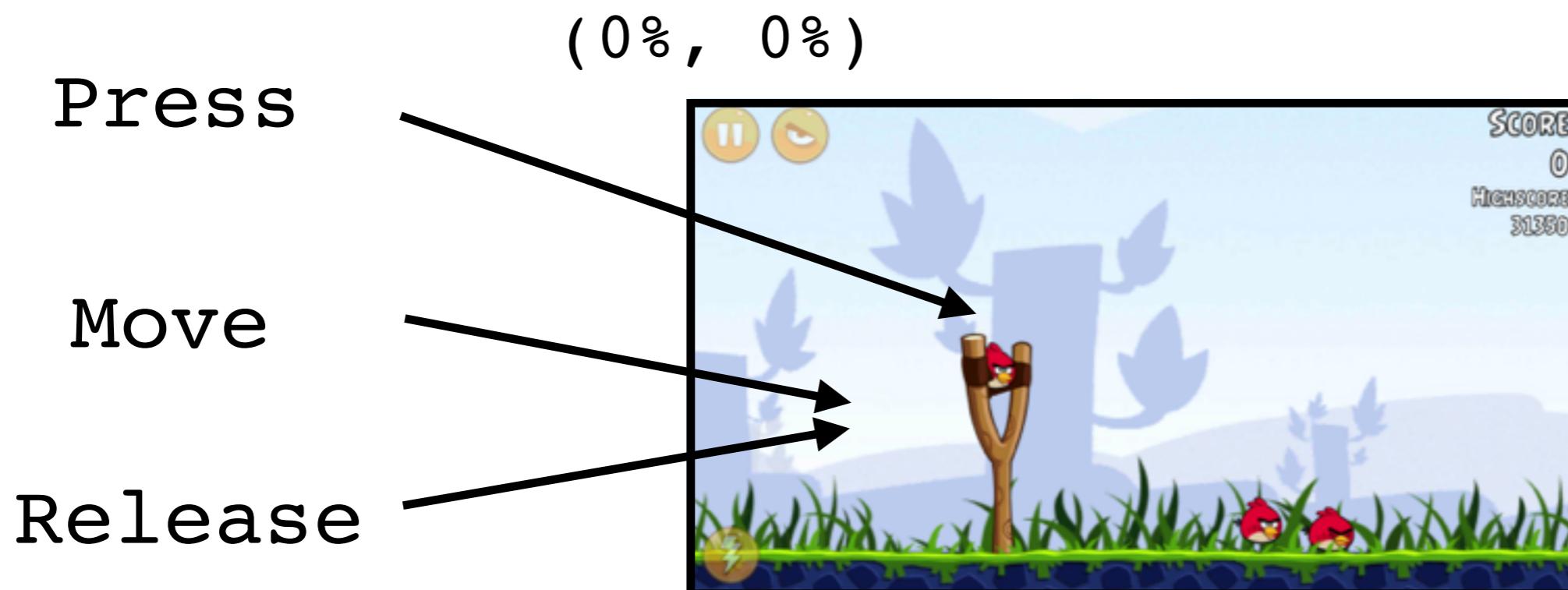
# Virtualizing Interactions

✓ Timing

- Type

- Location

```
time finger <N> <interaction> [ [ x ] [ y ] ]
```



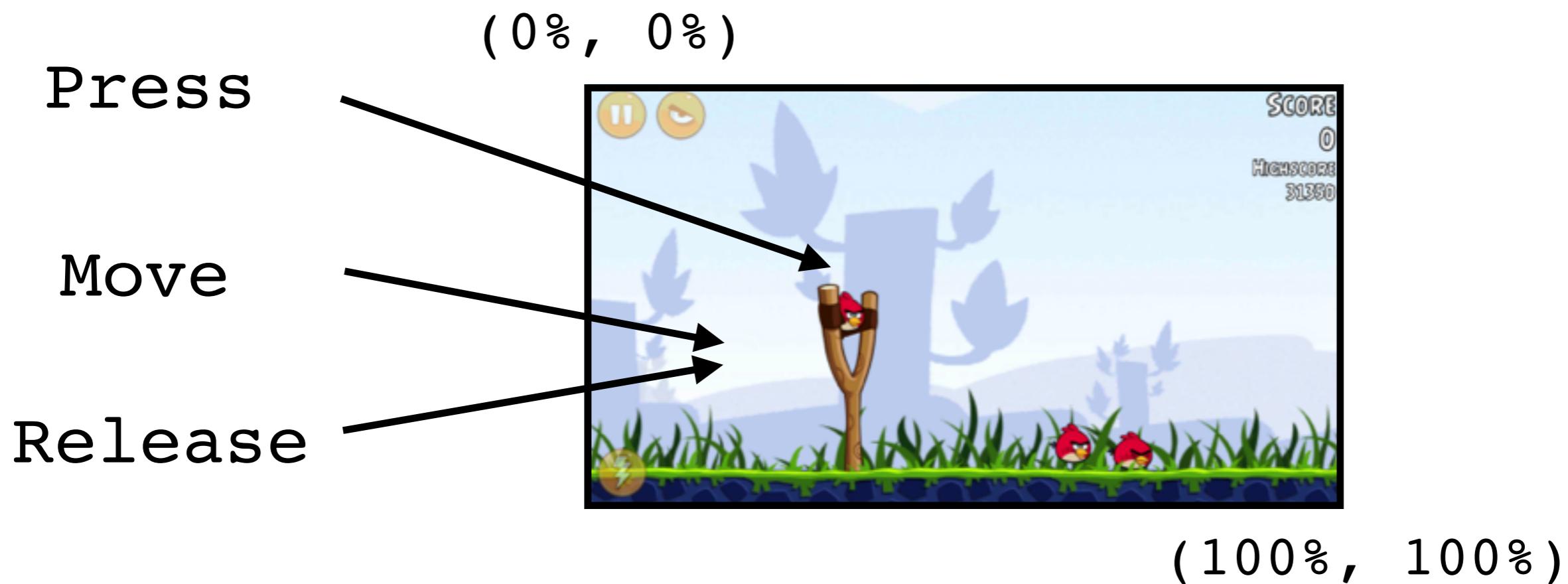
# Virtualizing Interactions

✓ Timing

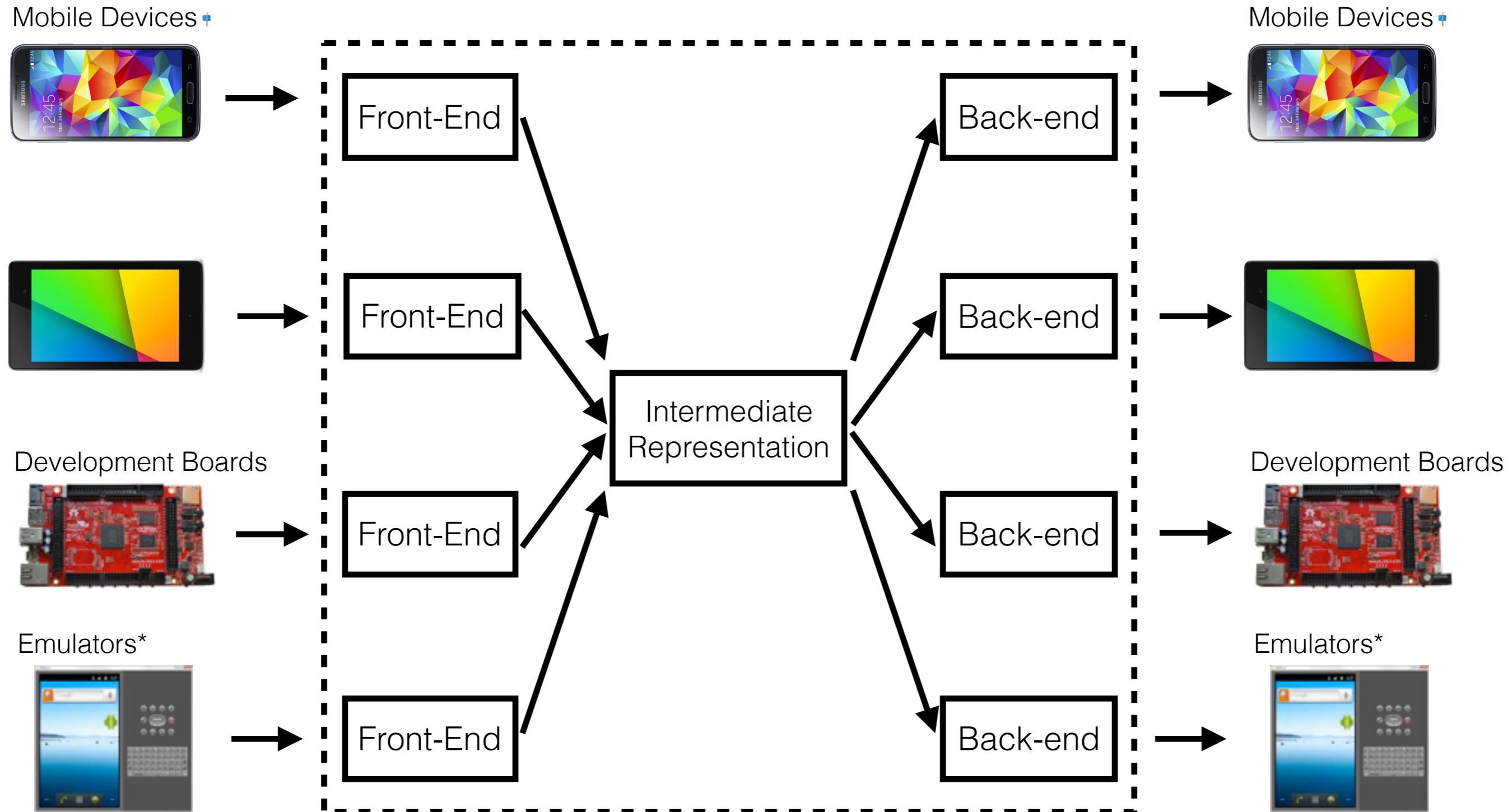
• Type

• Location

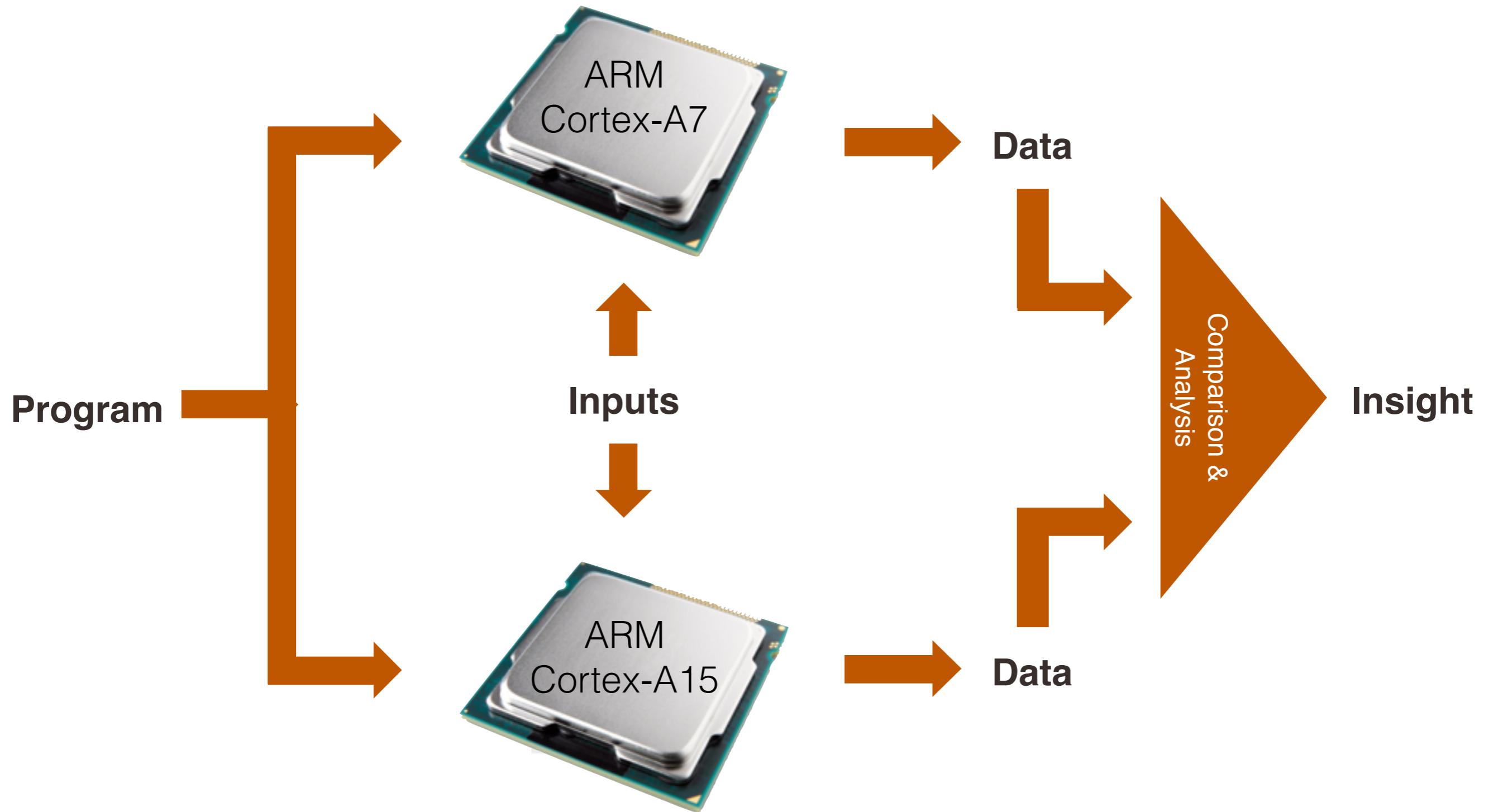
```
time finger <N> <interaction> [ [ x ] [ y ] ]
```

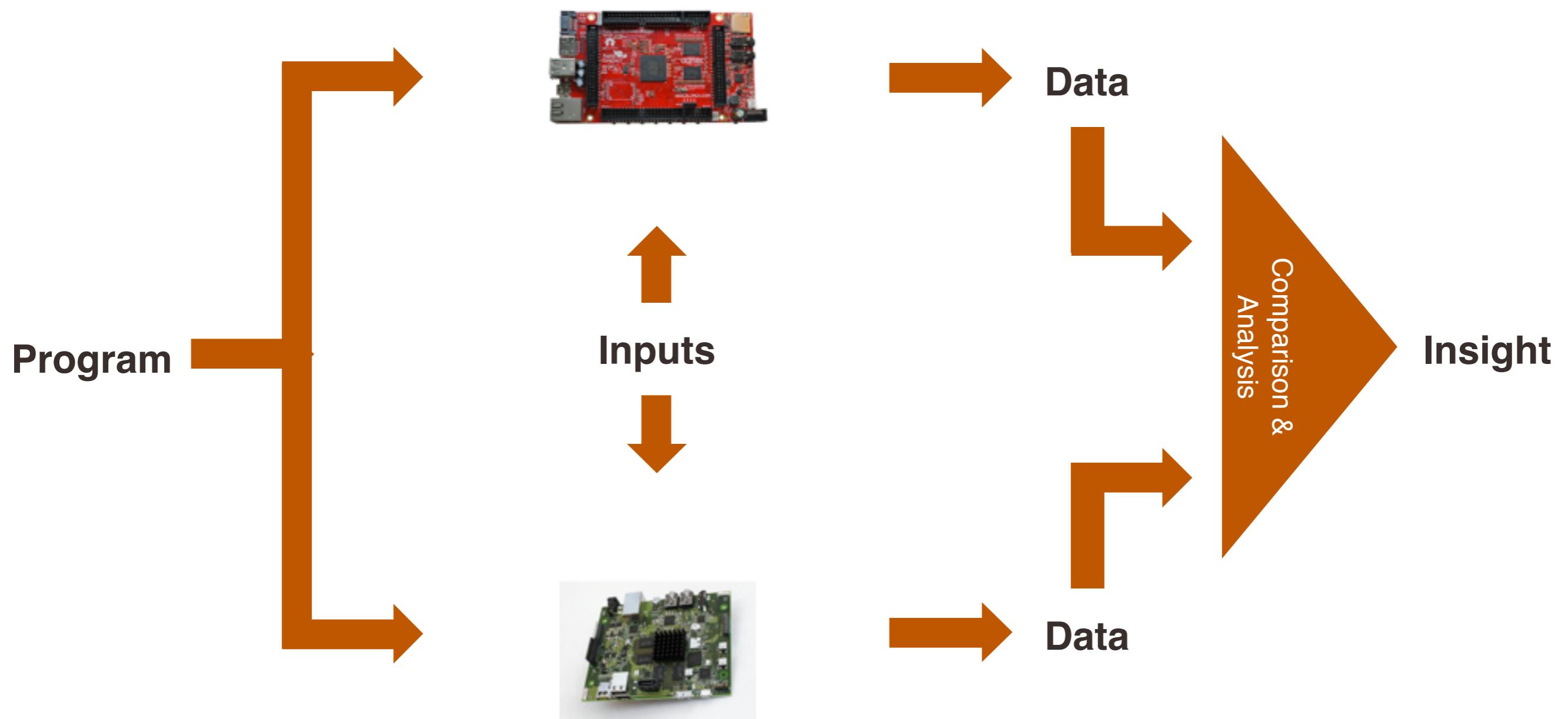


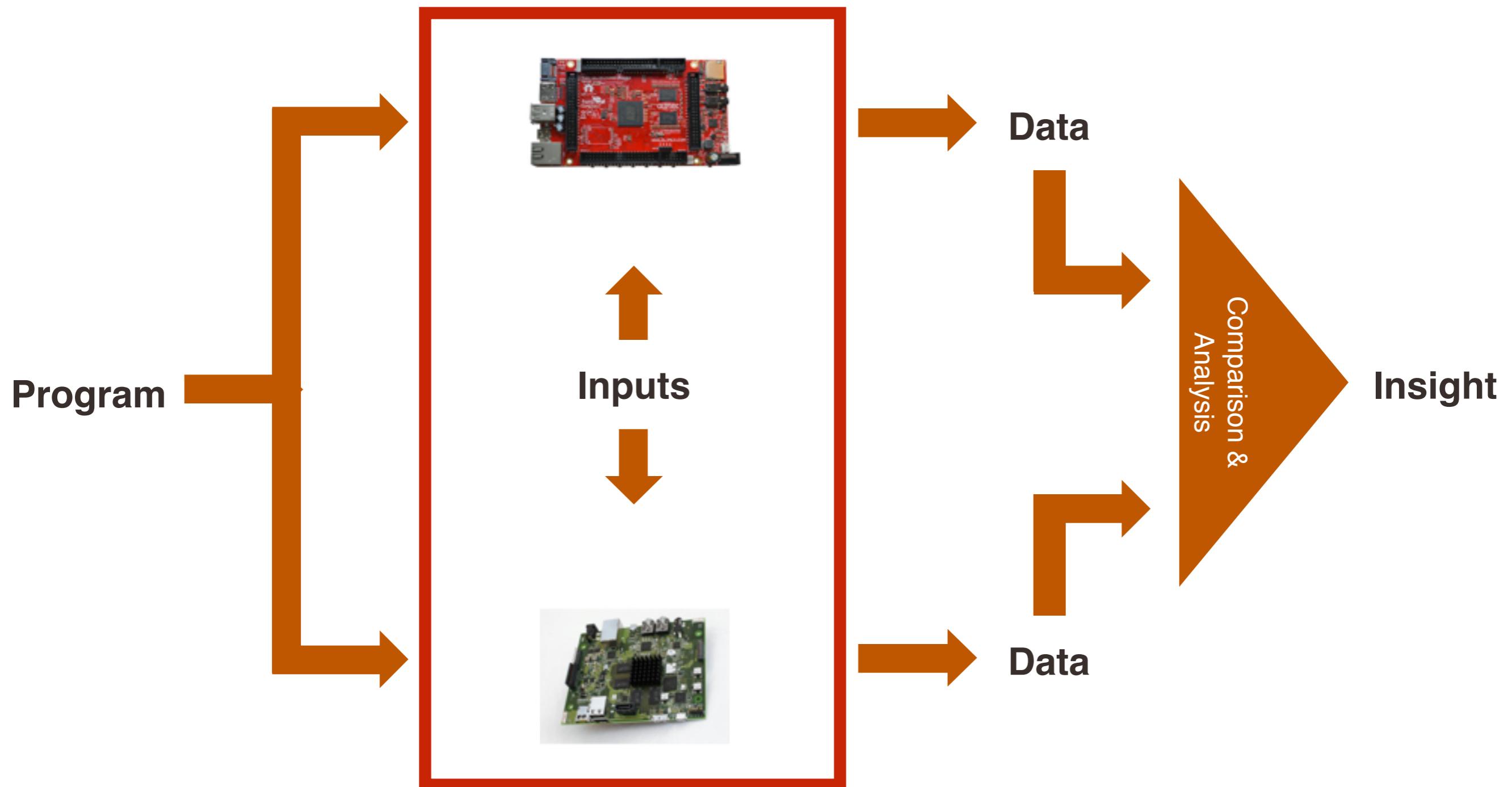
# How Mosaic Solves The Portability Paradox

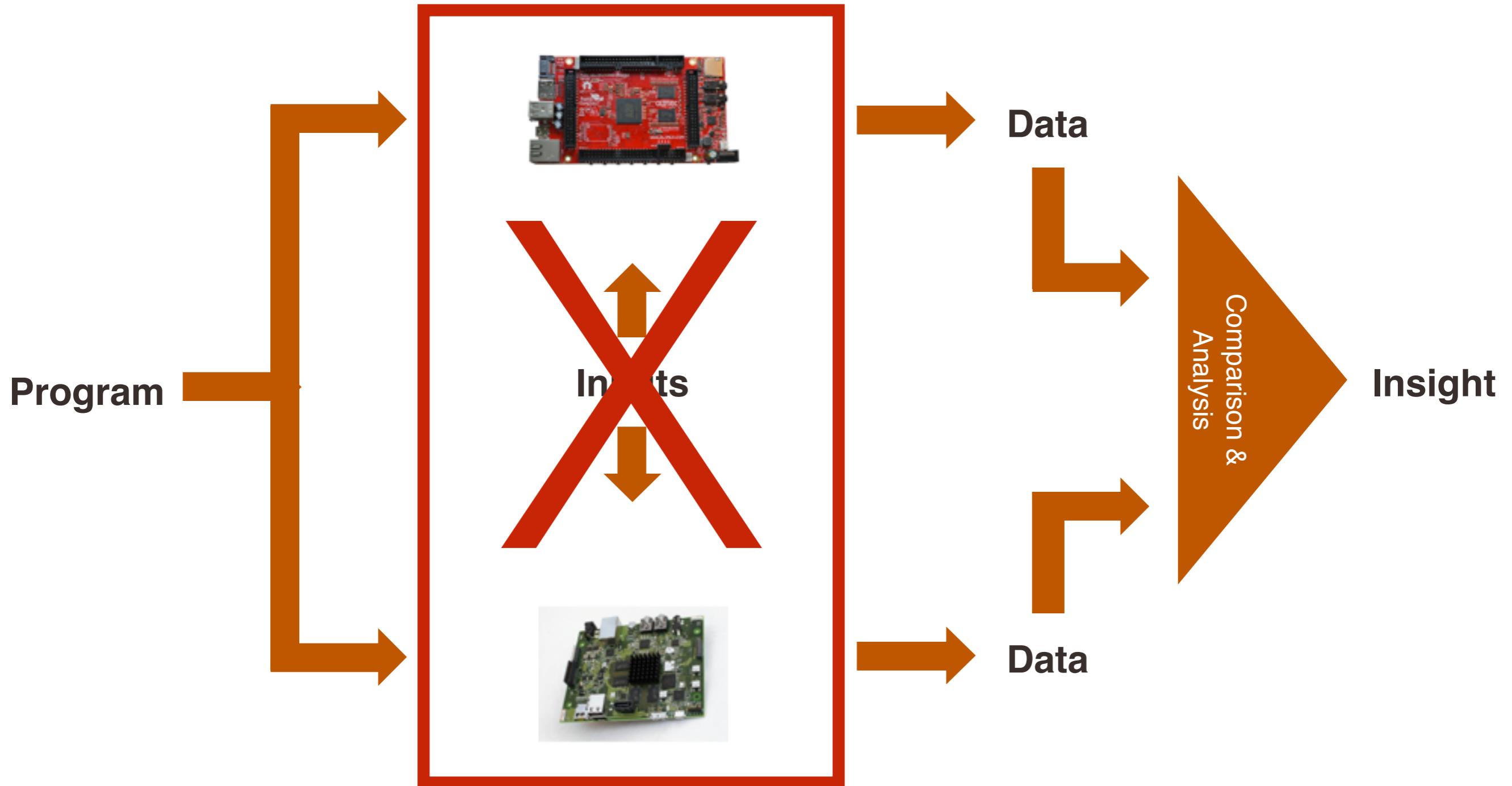


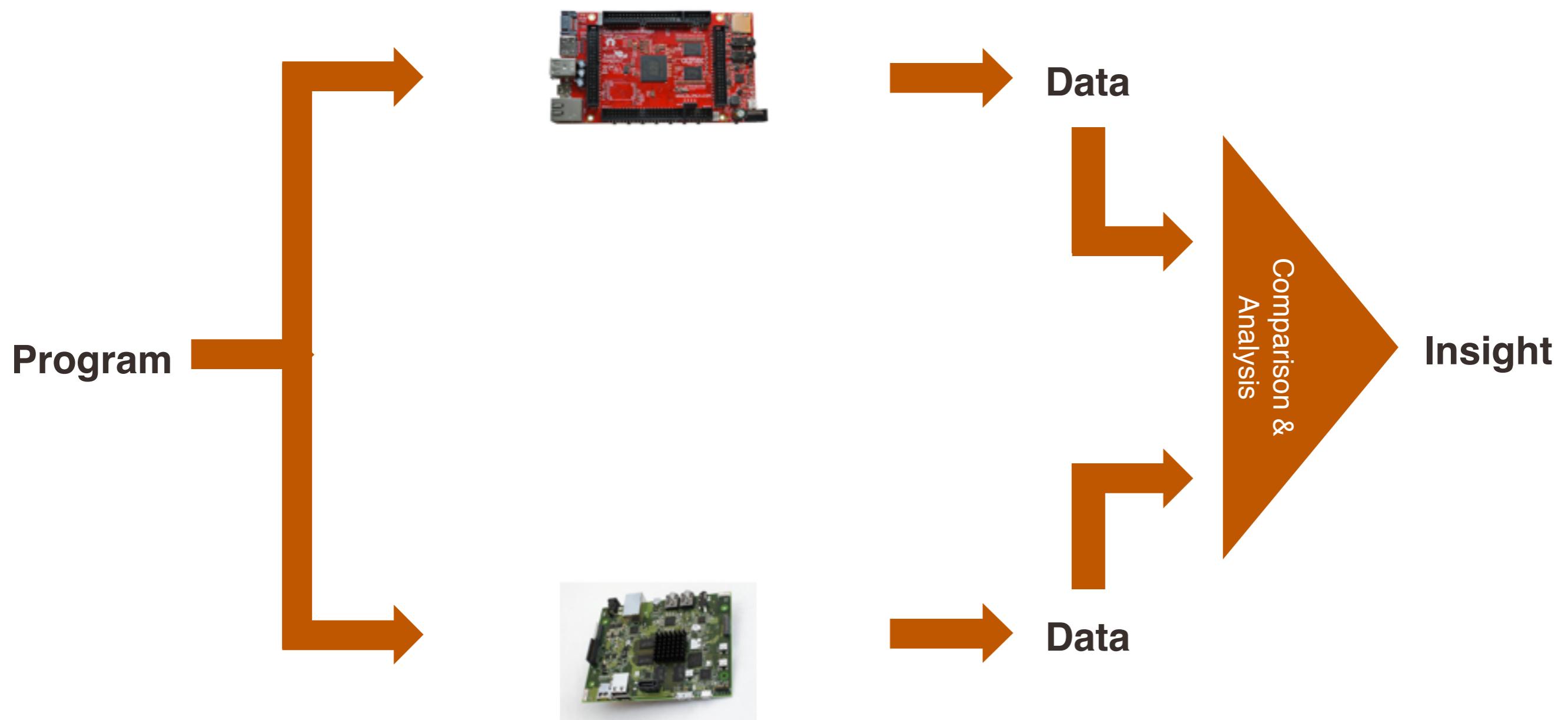
\* Modifications to emulator needed - see paper for details

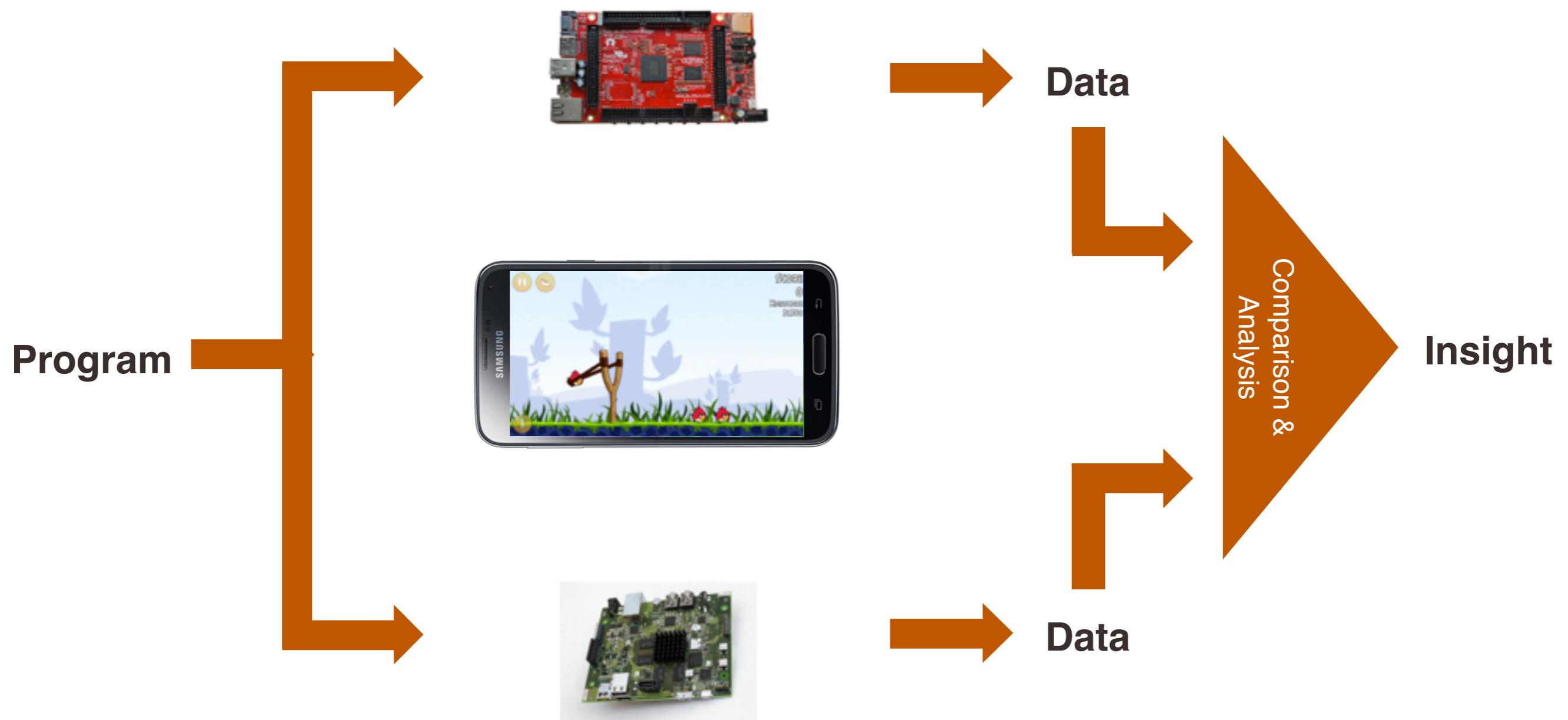


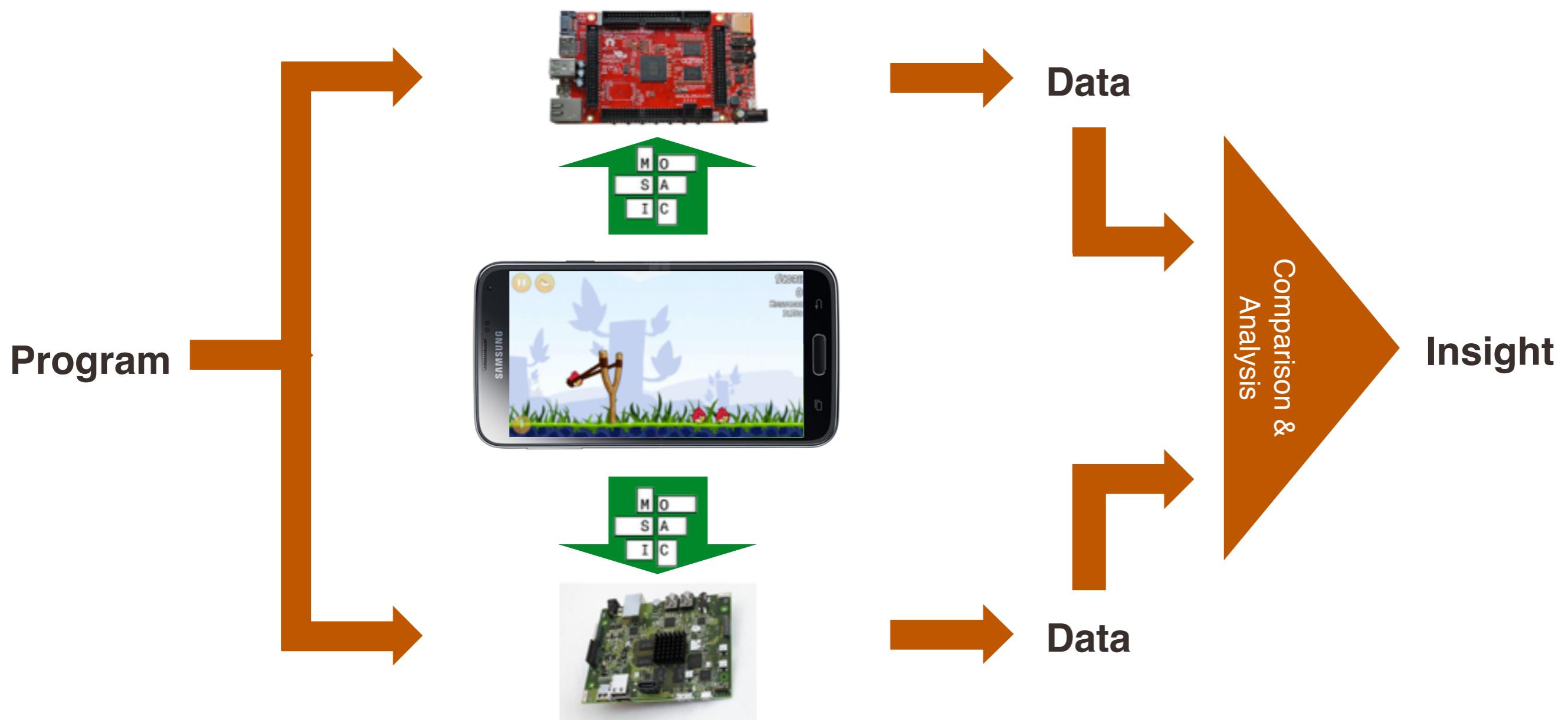


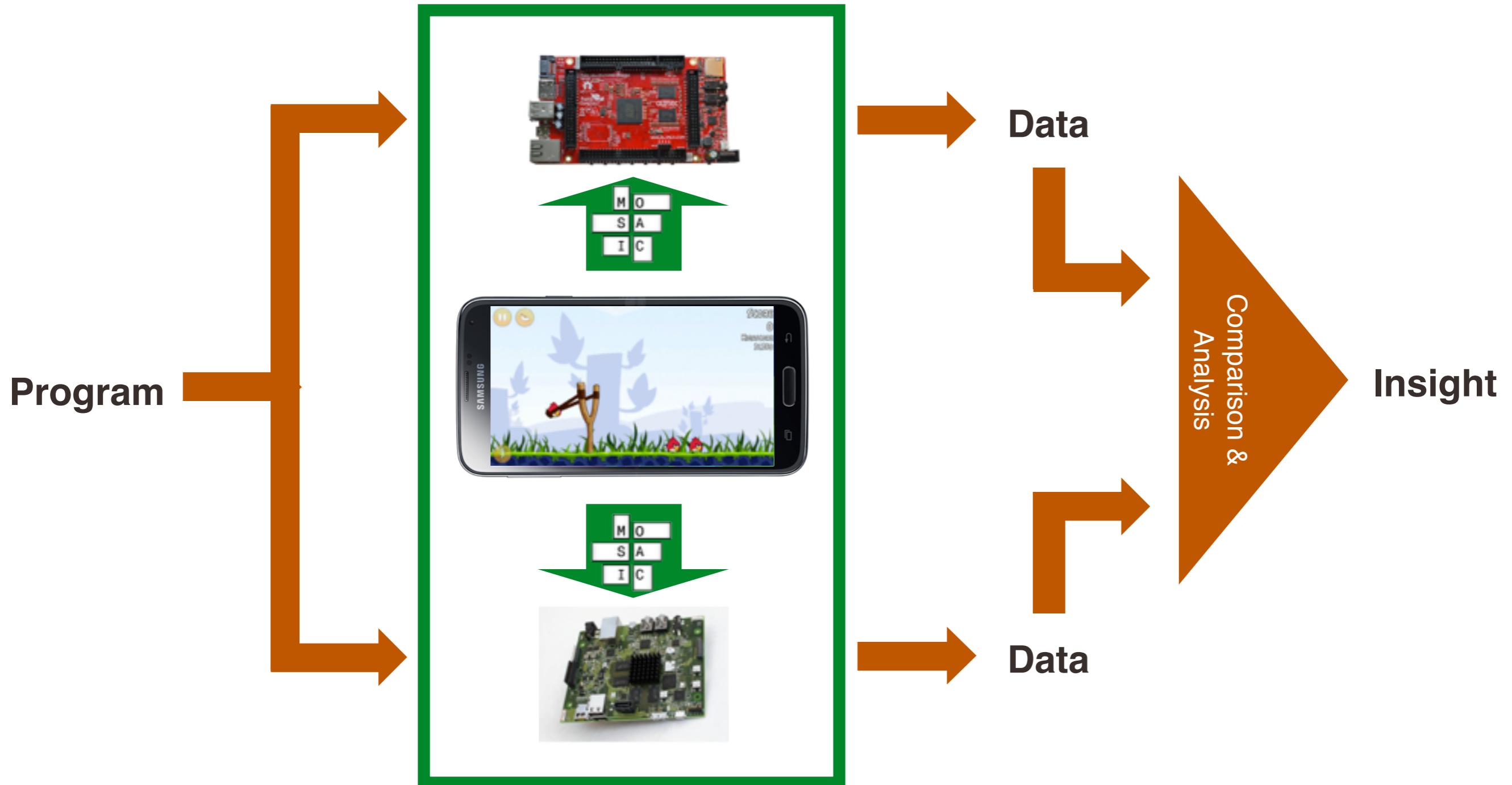






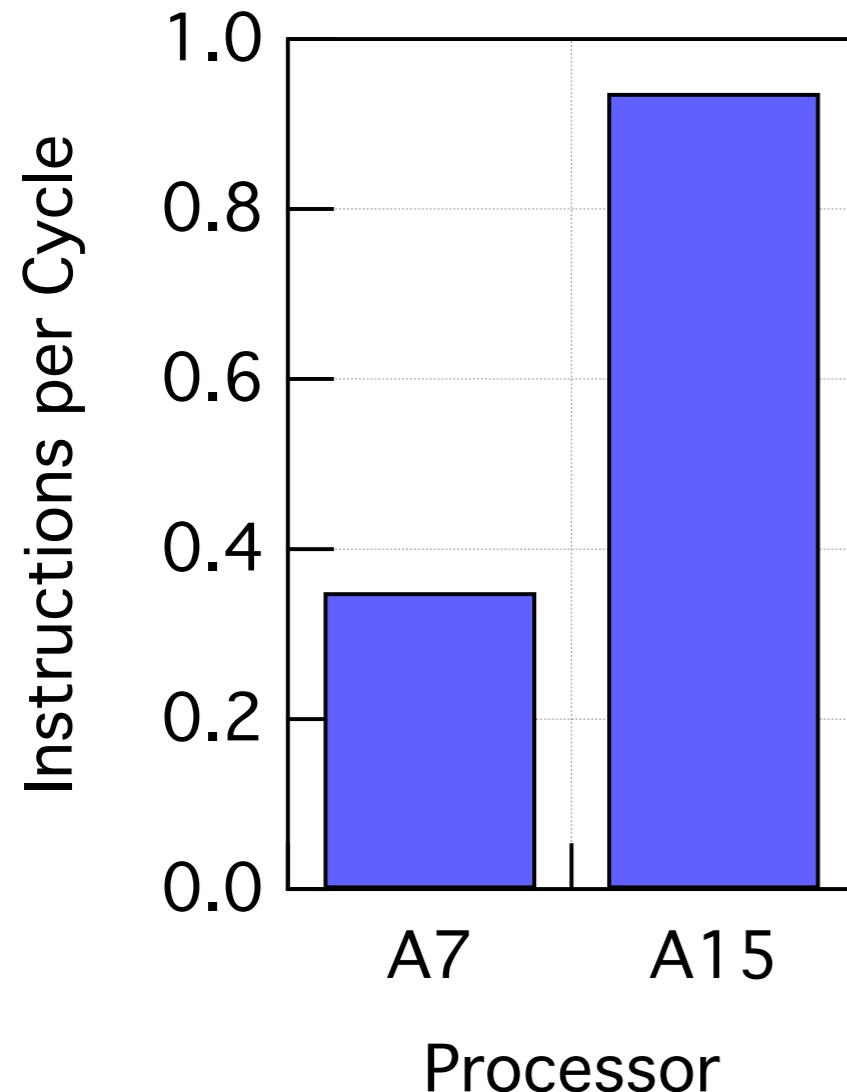




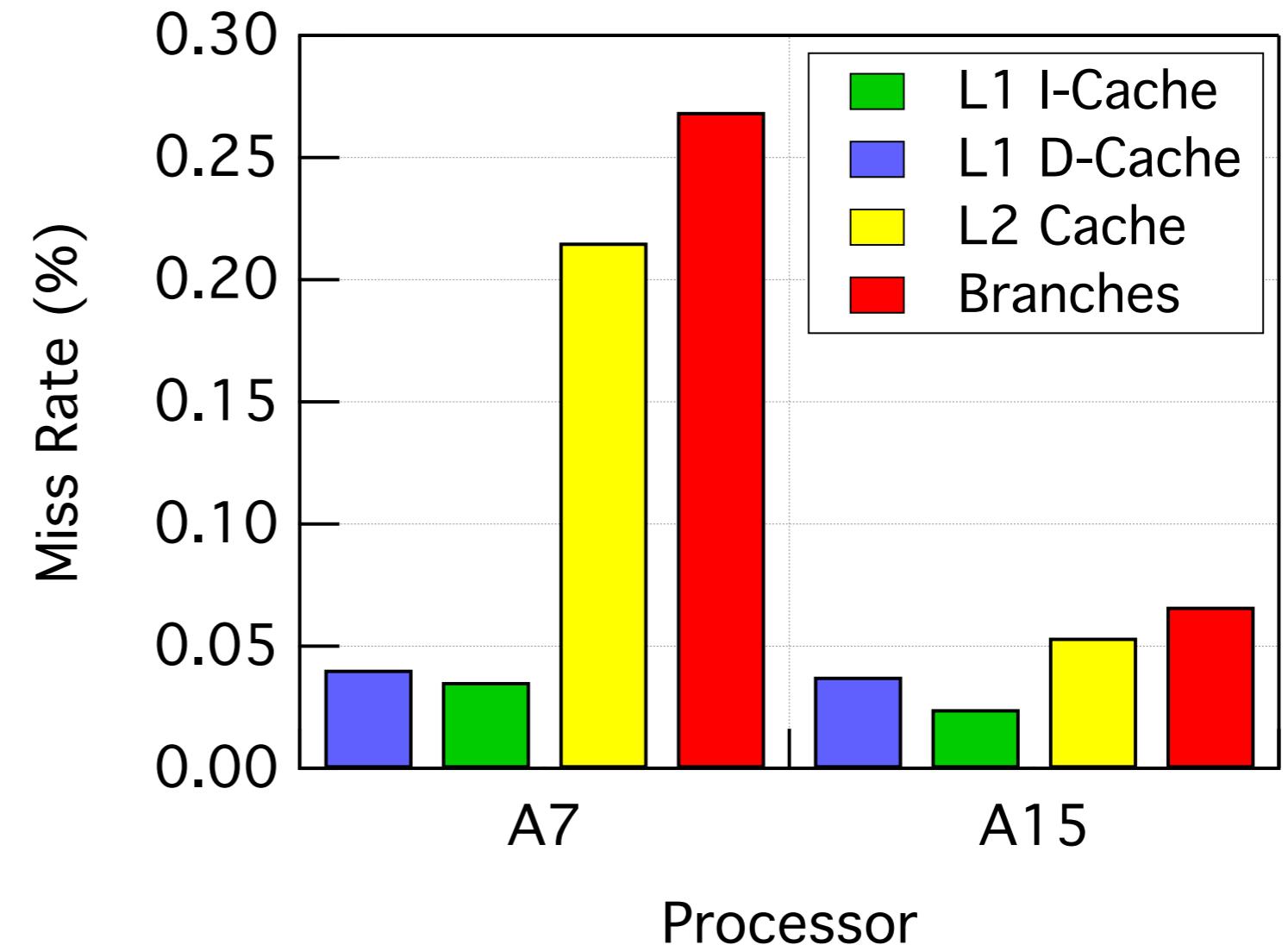
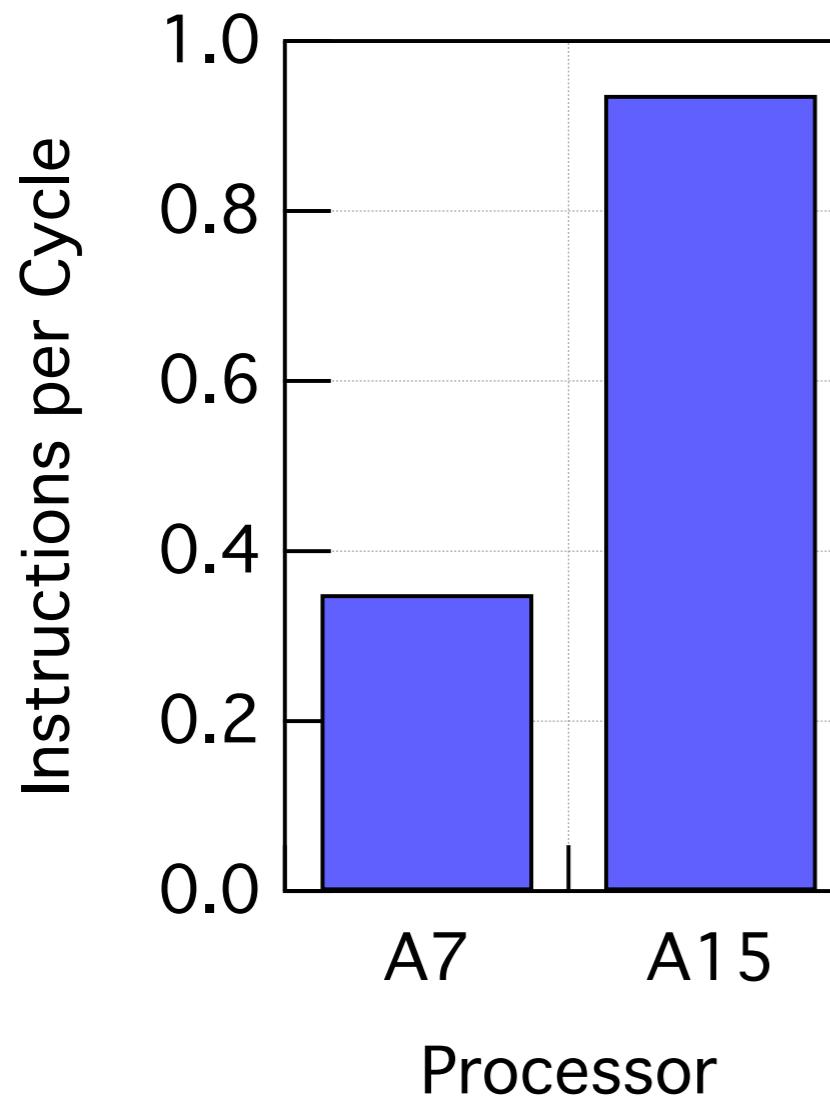


# Identifying Microarchitectural Bottlenecks

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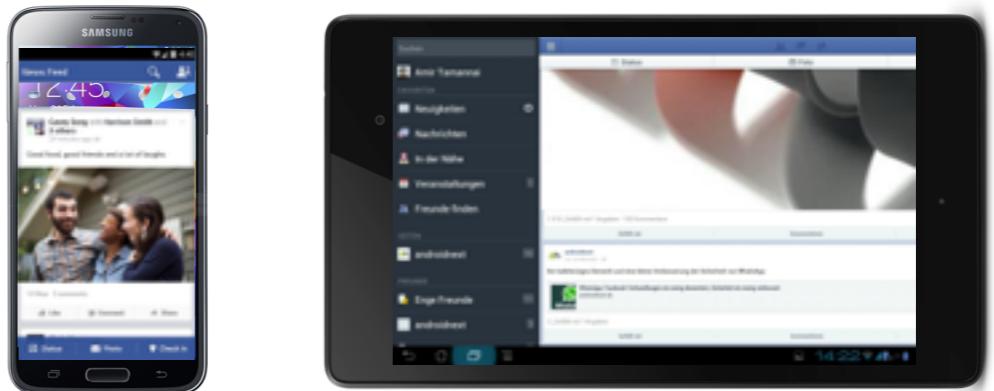
# Mosaic Assumptions and Requirements

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- **Linear UI Scaling**

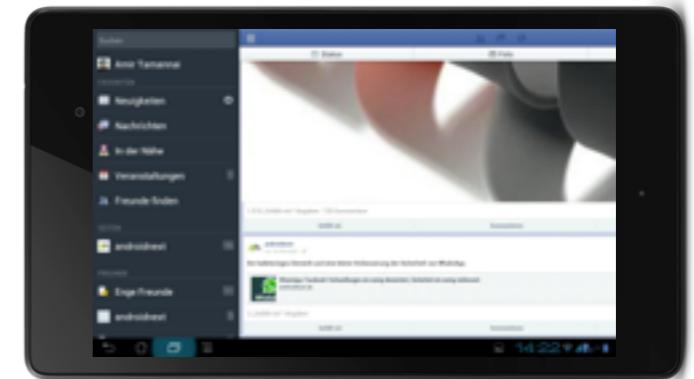
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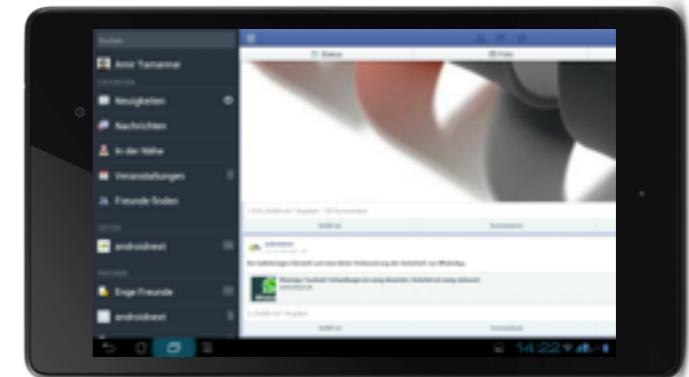
- **Linear UI Scaling**



- **Repeatable Application Behavior**

# Mosaic Assumptions and Requirements

- Linear UI Scaling

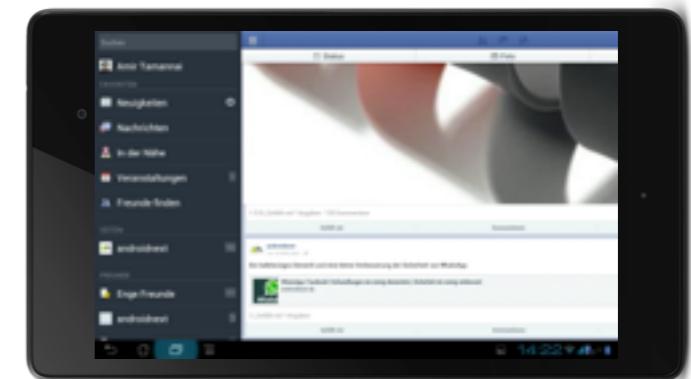


- Repeatable Application Behavior

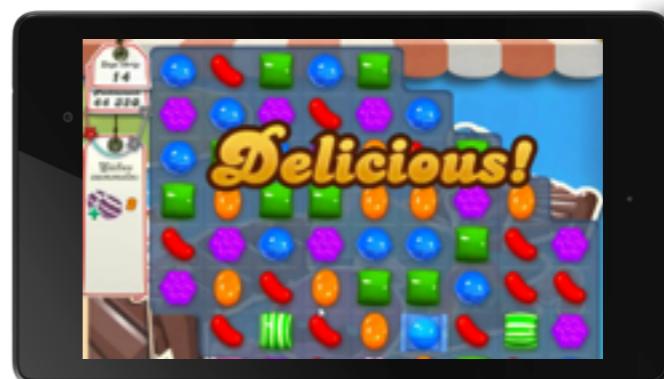


# Mosaic Assumptions and Requirements

- **Linear UI Scaling**



- **Repeatable Application Behavior**



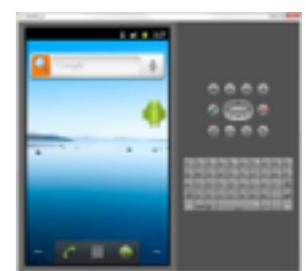
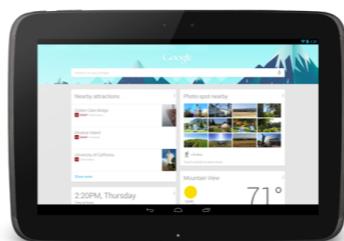
- **“Imperceptible” Performance**

# Mosaic Assumptions and Requirements

## Many Applications Meet These Requirements

Adobe Reader*	Angry Birds*	Big Fish Casino	Bingo Fever - World Trip	Bingo - Secret Cities
Bubble Bee	Bubble Blaze	Bubble Witch Saga 2	Chase	Chrome*
Clash of Lords 2	Clean Master	Coin Dozer	Destiny	DH 2014
Diamond Digger Saga	Dolphin Browser	Five Nights at Freddys	Flashlight*	Flipagram
Google Play Newsstand	Hill Climb Racing*	iHeartRadio	Instagram	Jump Ninja
Legend of Master Online	Messenger	Minion Rush	MonsterWarlord	News & Weather
Firefox	Photo Grid	Piano Tiles	Slotomania	Slots Fever
Slots - House Of Fun	Solitaire	Spider-Man	Steel Avengers	Temple Run 2*
Tycoon Mania	Video Poker	Walmart	WatchESPN	YouTube*

Evaluated across several different Android-based platforms



Mobile Devices

Dev Boards Emulators\*

with less than 1% performance and 6 kB memory overheads

# Conclusion

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- ▶ **Mobile device fragmentation** is not only a developer issue, but also complicates mobile systems research



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# Conclusion

- ▶ **Mobile device fragmentation** is not only a developer issue, but also complicates mobile systems research
- ▶ We developed a **novel user-interaction virtualization technique** to overcome device fragmentation
- ▶ **Mosaic enables cross-platform performance comparisons** that incorporate representative and repeatable user interactivity



# You can checkout Mosaic soon

 Watch ▾

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@ <https://github.com/matthalp/mosaic>