Genetic Improvement of Mobile Apps to Reduce Energy Consumption: Achievements and Challenges

Massimiliano Di Penta
University of Sannio, Italy
dipenta@unisannio.it
http://www.ing.unisannio.it/mdipenta

Joint work with

Gabriele Bavota (Free University of Bozen, Italy)

Carlos Bernal-Cárdenas (College of William & Mary, VA, USA)

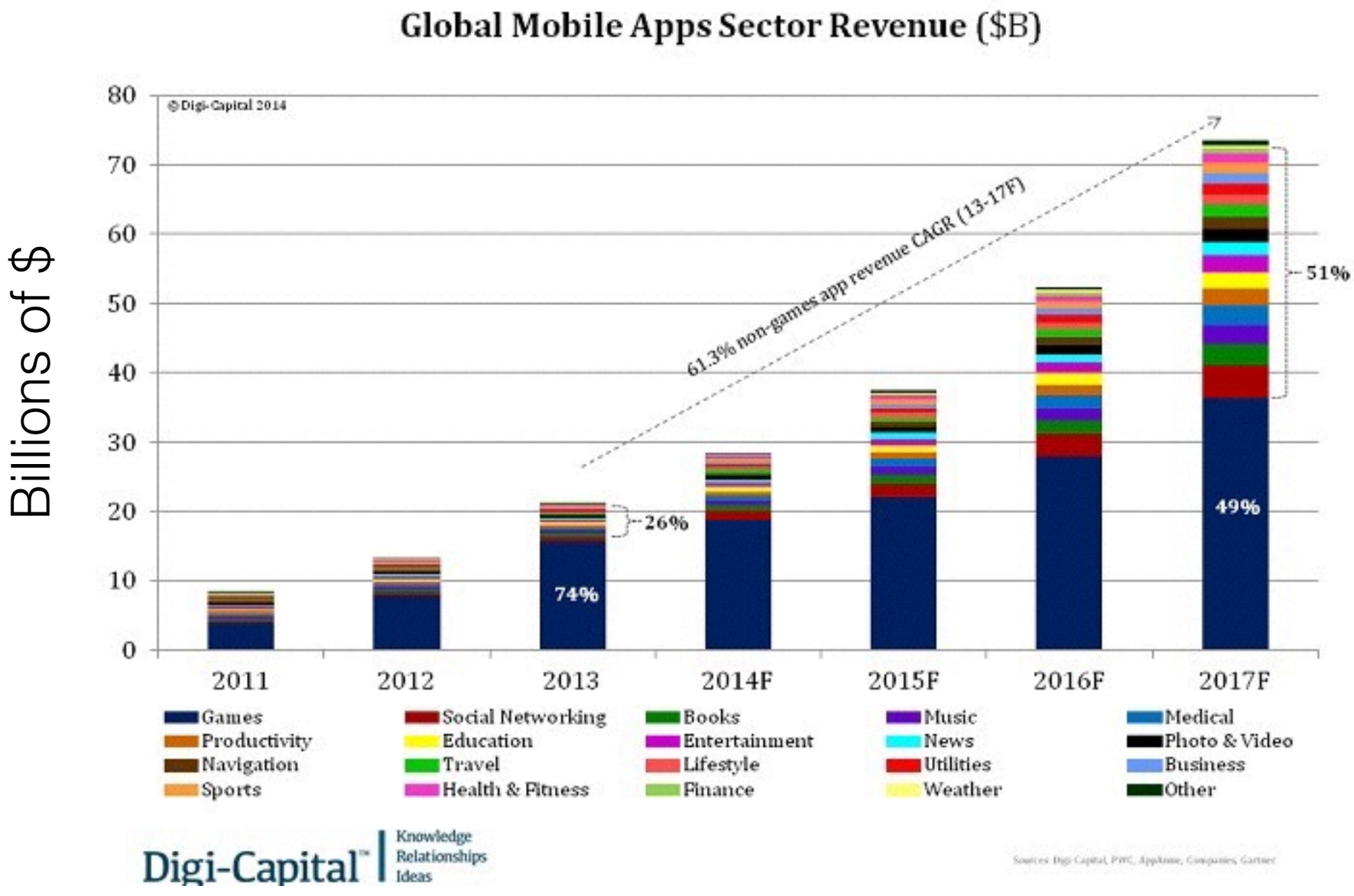
Mario Linares-Vásquez (College of William & Mary, VA, USA)

Rocco Oliveto (Univ. of Molise, Italy)

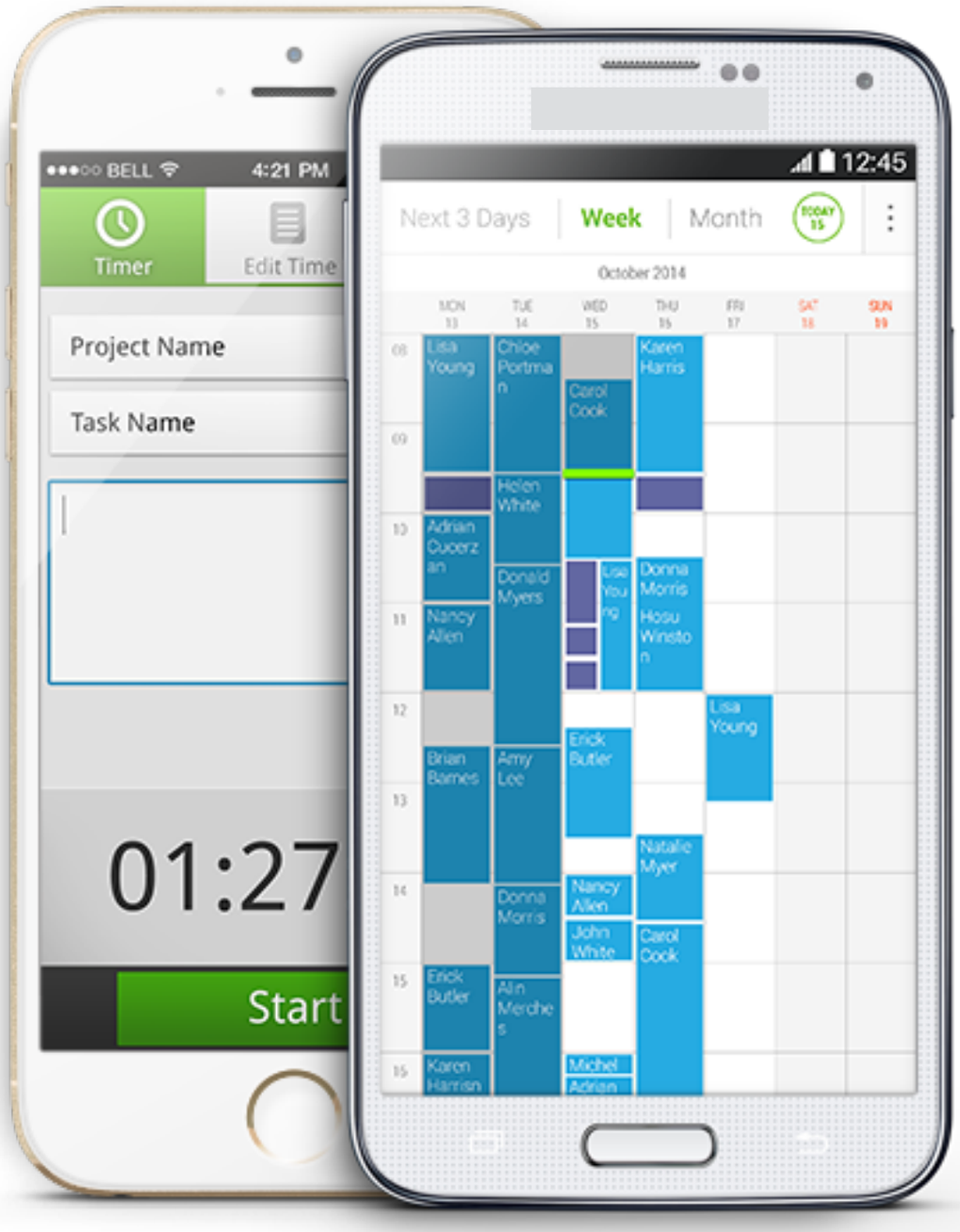
Denys Poshyvanyk (College of William & Mary, VA, USA)

Mobile App Economy

Mobile App Market Revenue

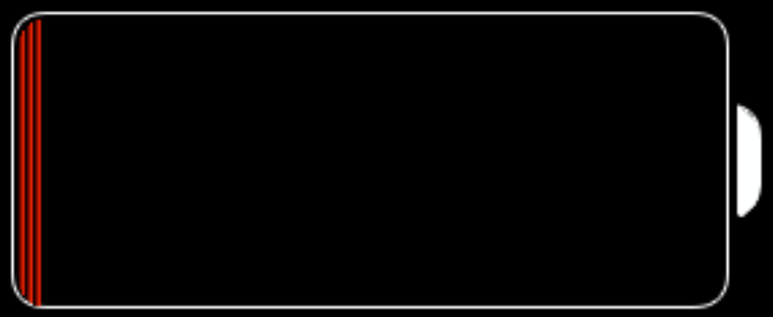


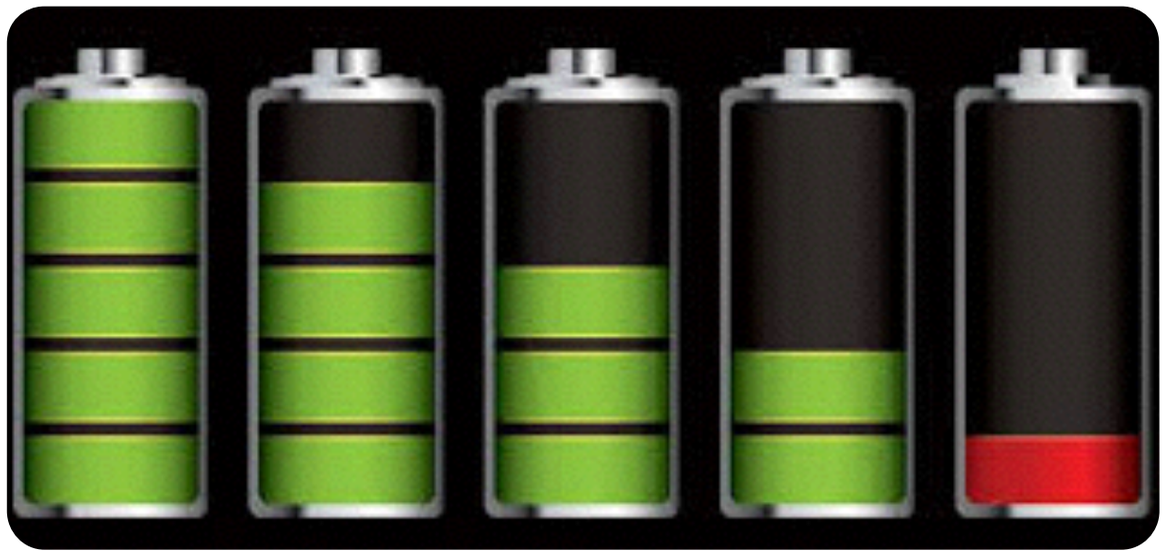
http://venturebeat.com/2014/04/29/mobile-apps-could-hit-70b-in-revenues-by-2017-as-non-game-categories-take-off/


BELL
4:21 PM
Timer
Edit Time
Project Name
Task Name
01:27
Start
12:45
Next 3 Days
Week
Month
October 2014
MON 13
TUE 14
WED 15
THU 16
FRI 17
SAT 18
SUN 19
Lisa Young
Chloe Portman
Carol Cook
Karen Harris
Helen White
Adrian Cuoerzan
Donald Myers
Nancy Allen
Lisa Young
Donna Morris
Hosu Winston
Lisa Young
Brian Barnes
Amy Lee
Erick Butler
Natalie Myer
Donna Morris
Nancy Allen
John White
Carol Cook
Erick Butler
Alin Merches
Michel
Adrian
Karen Harris


ANGRY BIRDS
PLAY


3:04
2
Beacon St
400ft
9:08AM
¾mi
4:00min
Marlborough St
Beacon St
Byron St
Beaver Pl
S
Chestnut St
6mph
Brimmer St
290ft



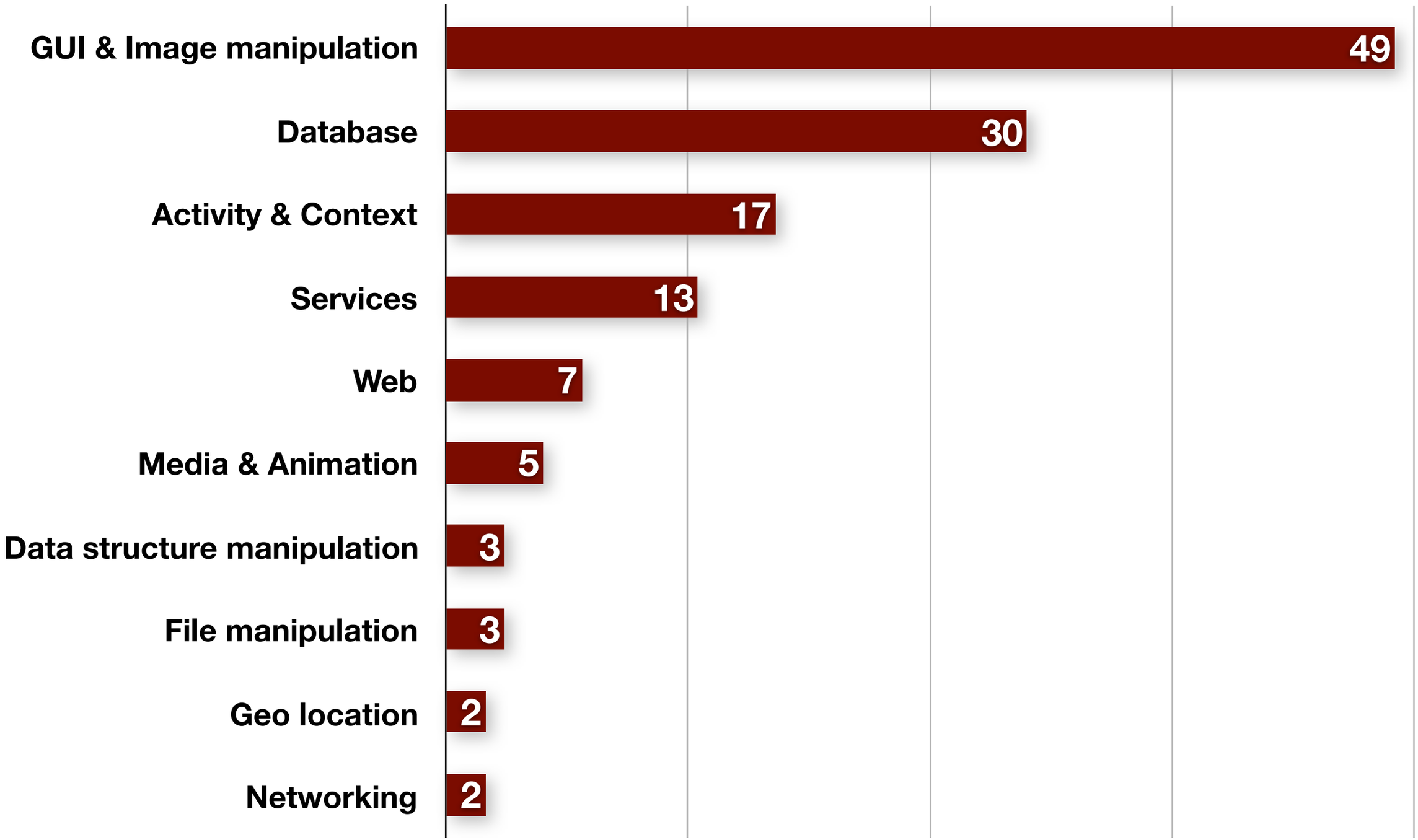


Energy Matters!


18V XR LI-ION
5
AH

Ok these are the obvious things…

Android Energy-Greedy APIs



Mario Linares Vásquez, Gabriele Bavota, Carlos Bernal-Cárdenas, Rocco Oliveto, Massimiliano Di Penta, Denys Poshyvanyk: Mining energy-greedy API usage patterns in Android apps: an empirical study. MSR 2014: 2-11

How Can Search-Based Approaches Help In Optimizing Software Energy Consumption?

Alter the program to reduce energy consumption

At the same time, preserve other characteristics

Energy consumption on (AM)OLED Displays

Related work

IEEE TRANSACTIONS ON MOBILE COMPUTING, VOL. 11, NO. 9, SEPTEMBER 2012 1587

Power Modeling and Optimization for OLED Displays

Mian Dong, *Student Member*, *IEEE*, and Lin Zhong, *Member*, *IEEE*

Making Web Applications More Energy Efficient for OLED Smartphones

Ding Li, Angelica Huyen Tran, William G. J. Halfond
Department of Computer Science
University of Southern California
Los Angeles, California, USA
{dingli, tranac, halfond}@usc.edu

Detecting Display Energy Hotspots in Android Apps

Mian Wan, Yuchen Jin, Ding Li and William G. J. Halfond
University of Southern California
Los Angeles, California, USA
Email: {mianwan, yuchenji, dingli, halfond}@usc.edu

Limitations of existing approaches

Optimization: Single objective
(with some constraints on contrast)

Color scheme: Random or original palette

Design Improvement: Individual screen

Optimizing Energy Consumption of GUIs in Android Apps: A Multi-objective Approach

Mario Linares-Vásquez[1], Gabriele Bavota[2], Carlos Bernal-Cárdenas[1]
Rocco Oliveto[3], Massimiliano Di Penta[4], Denys Poshyvanyk[1]
[1]The College of William and Mary, Williamsburg, VA, USA — [2]Free University of Bozen, Bolzano, Italy
[3]University of Molise, Pesche (IS), Italy — [4]University of Sannio, Benevento, Italy

ABSTRACT

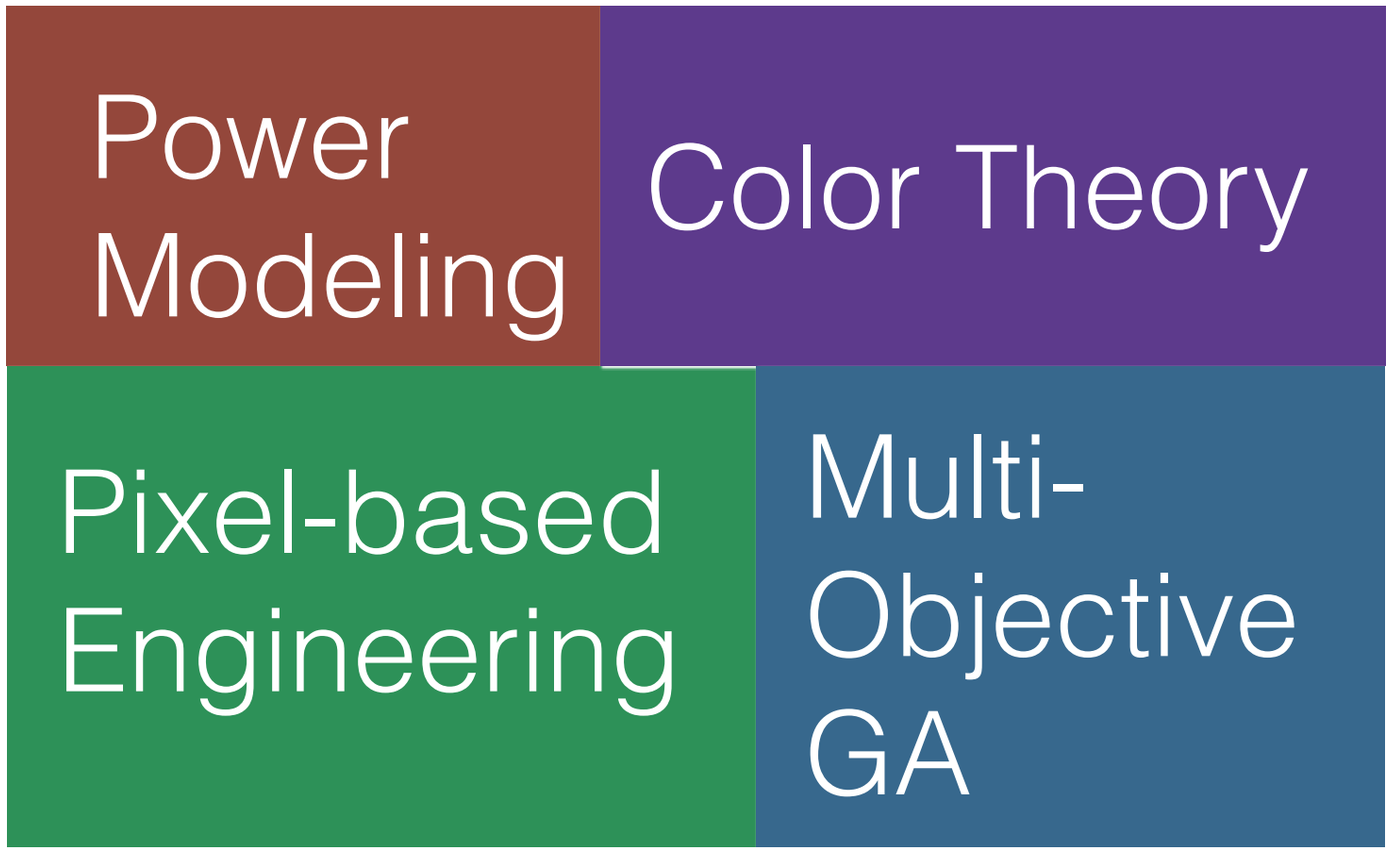
The wide diffusion of mobile devices has motivated research towards optimizing energy consumption of software systems—including apps—targeting such devices. Besides efforts aimed at dealing with various kinds of energy bugs, the adoption of Organic Light-Emitting Diode (OLED) screens has motivated research towards reducing energy consumption by choosing an appropriate color palette. Whilst past research in this area aimed at optimizing energy while keeping an acceptable level of contrast, this paper proposes an approach, named GEMMA (Gui Energy Multi-objective optiMization for Android apps), for generating color palettes using a multi-objective optimization technique, which produces color solutions optimizing energy consumption and contrast while using consistent colors with respect to the original color palette. An empirical evaluation that we performed on 25 Android apps demonstrates not only significant improvements in terms of the three different objectives, but also confirmed that in most cases users still perceived the choices of colors as attractive. Finally, for several apps we interviewed the original developers, who in some cases expressed the intent to adopt the proposed choice of color palette, whereas in other cases pointed out directions for future improvements.

have been aimed at engineering energy-friendly hardware components in mobile devices, some recent research has also focused on energy-aware development practices for reducing the energy consumption in mobile apps. For instance, common energy bugs in mobile apps have been identified and catalogued [27, 28, 32, 34, 42], as well as typical hot spots [39] together with energy greedy APIs [26,33]. In addition, several infrastructures and methods have been proposed to measure and estimate the energy consumption of mobile devices and apps [16, 18, 23, 29].

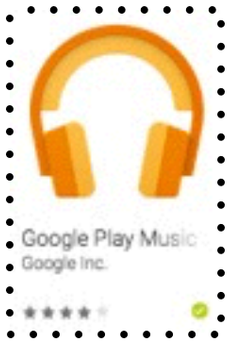
Some practices for avoiding and fixing energy hotspots (bugs) in mobile apps focus on how the apps should use energy-greedy hardware components in the device, such as GPS, Wi-Fi, or the screen. In the case of LCD displays, the energy drawn from the battery is constant regardless of the colors displayed on the screen. However, this is not the case for OLED displays, for which the energy consumption depends on the combinations of colors at the sub-pixel level. This property of OLED displays motivated the adoption of power models for estimating the energy drawn by the graphical user interfaces (GUI) displayed on the screen. In fact, previous work have used power models to estimate and improve the energy consumption of web browsers [11], mobile web apps [24], and mobile apps in general [12, 39]. All these prior techniques on improving energy consumption

Mario Linares Vásquez, Gabriele Bavota, Carlos Eduardo Bernal-Cárdenas, Rocco Oliveto, Massimiliano Di Penta, Denys Poshyvanyk: Optimizing energy consumption of GUIs in Android apps: a multi-objective approach. ESEC/SIGSOFT FSE 2015: 143-154

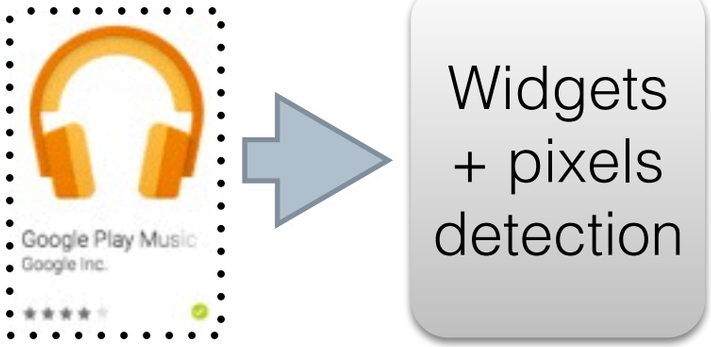
GEMMA : **G**ui **E**nergy **M**ulti-objective opti**M**ization for **A**ndroid apps



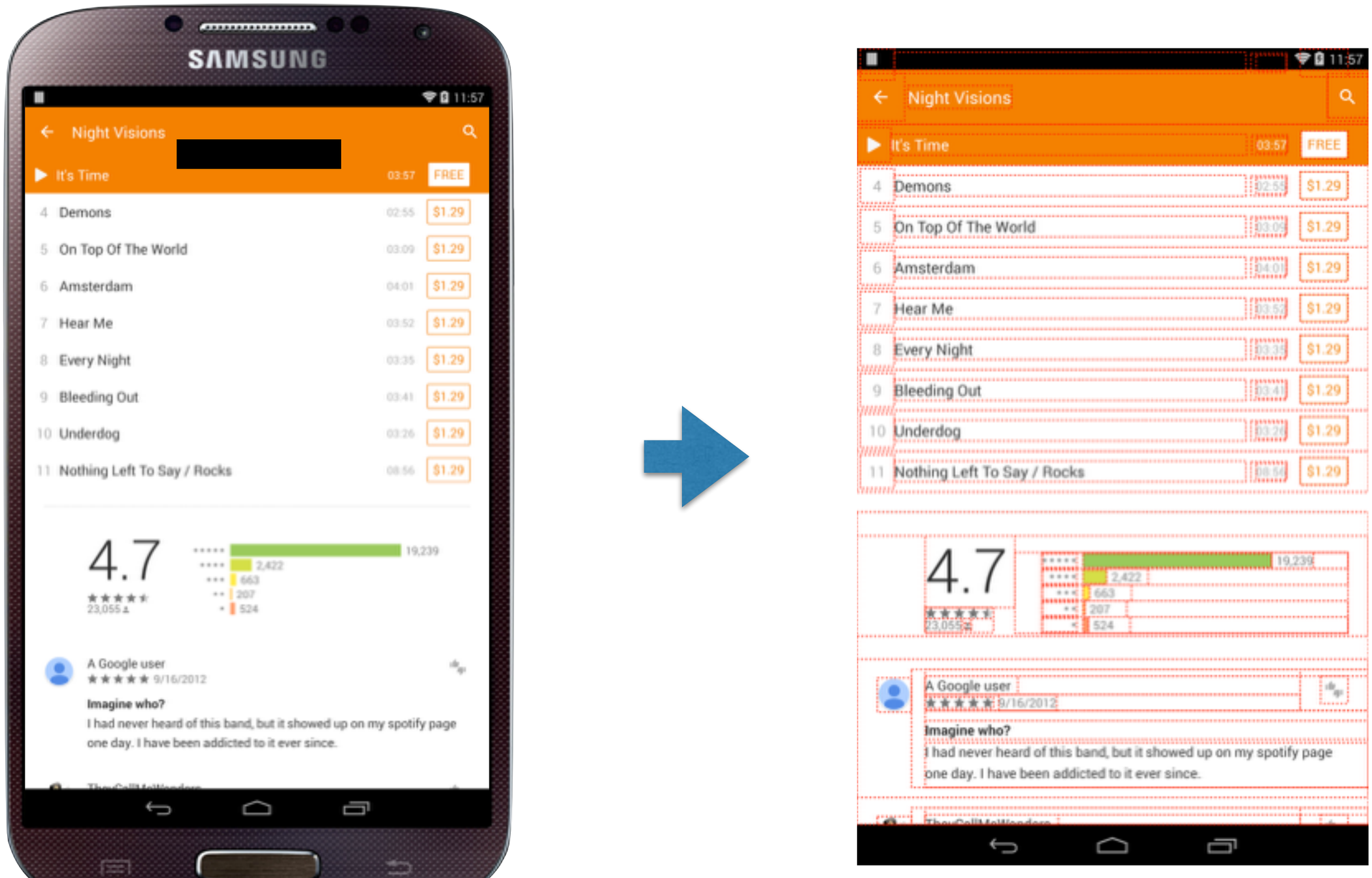
GEMMA Overview



GEMMA Overview

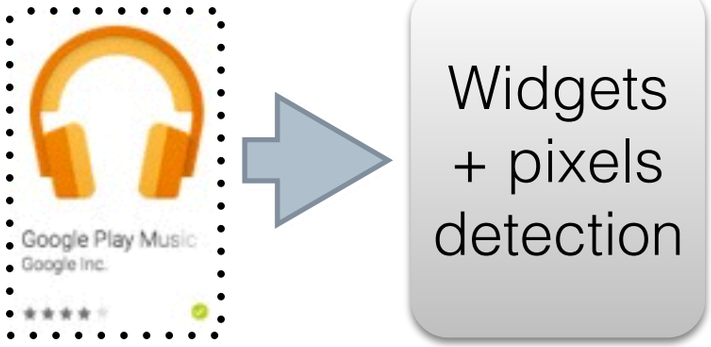


Widget Detection

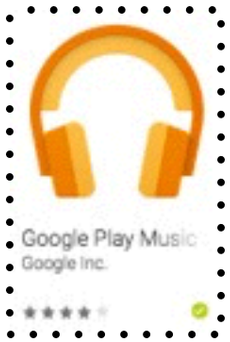


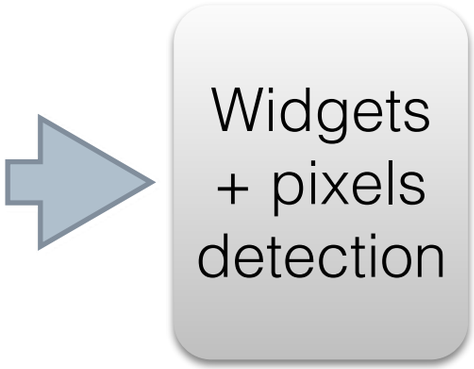
Using Android Hierarchy Viewer

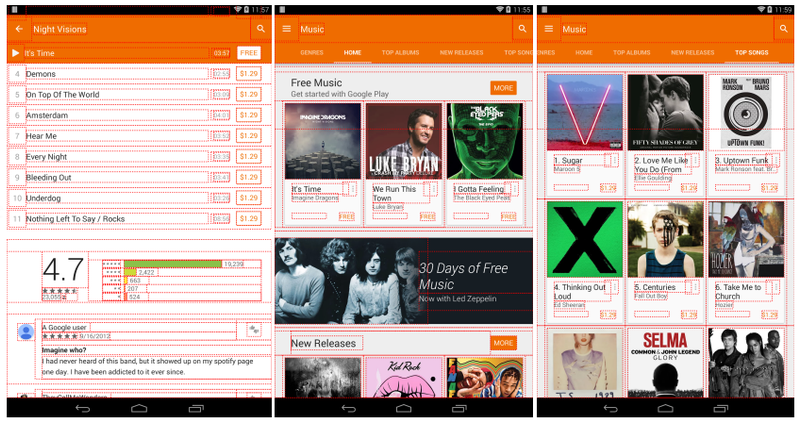
GEMMA Overview



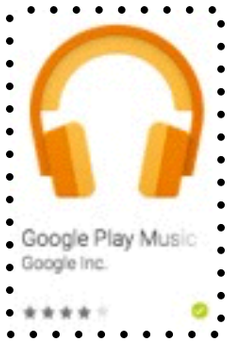
GEMMA Overview



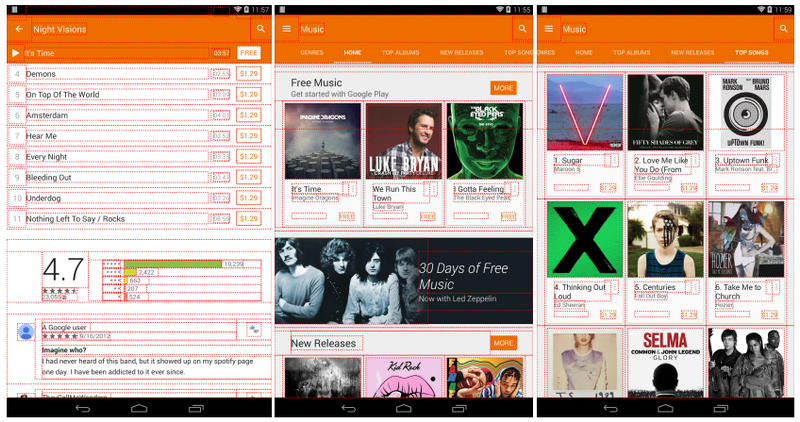




GEMMA Overview



Widgets + pixels detection



Color quantization

Color Quantization

Fix

TOP 3 contrast-based color-medoids

Border, background, text color

Color Quantization

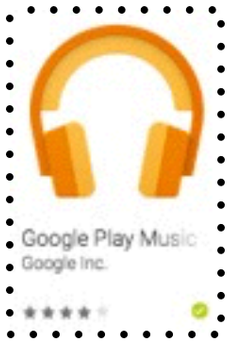
Fix

TOP 3 contrast-based color-medoids

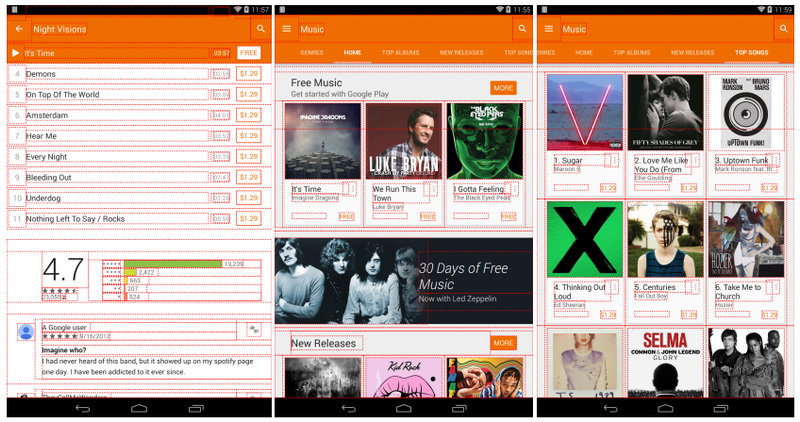
Border, background, text color

Fix

GEMMA Overview

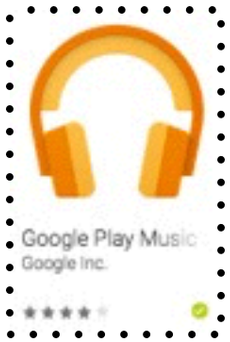


Widgets + pixels detection

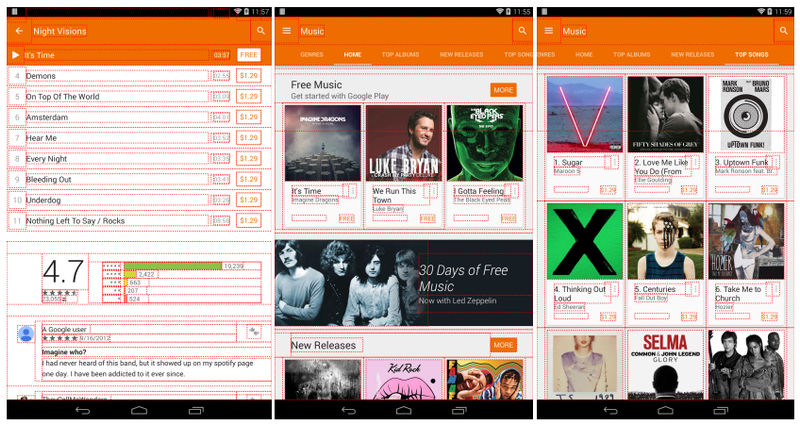


Color quantization

GEMMA Overview



Widgets + pixels detection



Color quantization

Bag-of-color-pixels

Bag-of-color-components

Bags Of Color Pixels (BOCPs)

> (45,20) , (90,10)....

> (10,20) , (30,30)....

> (90,120) , (300,80)....

> (20,900) , (20,910)....

> (5,100) , (5,110)....

> (10,10) , (20,10)....

Bags Of Color Components (BOCCs)

> TextView1, ...

> FrameLayout2, ...

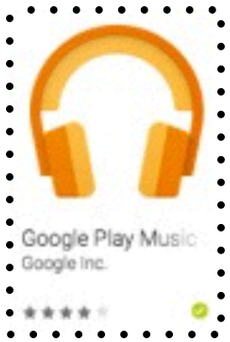
> View3, ...

> Button1, ...

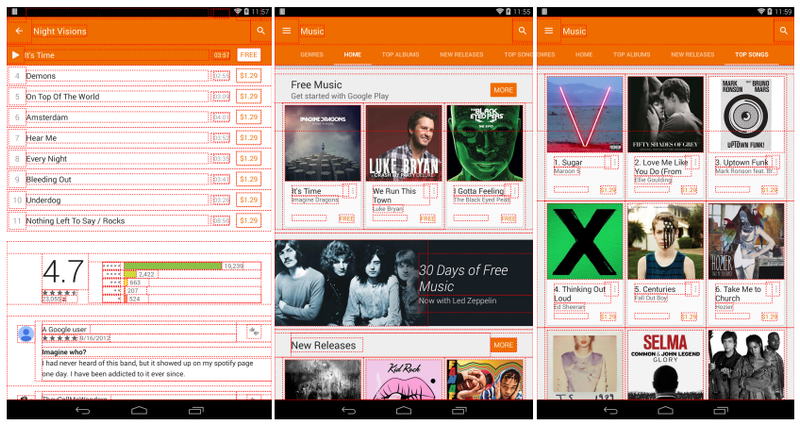
> Button1, ...

> TextView1

GEMMA Overview



Widgets + pixels detection

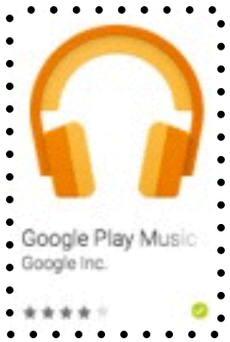


Color quantization

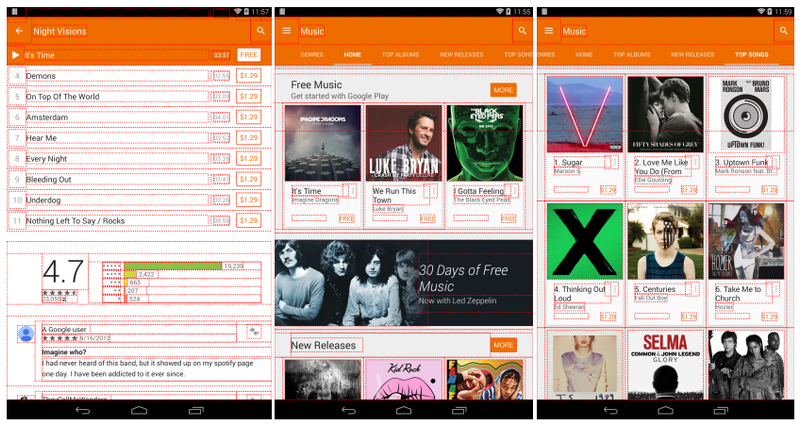
Bag-of-color-pixels

Bag-of-color-components

GEMMA Overview



Widgets + pixels detection



Color quantization

Bag-of-color-pixels

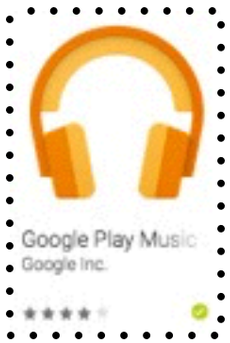
Bag-of-color-components

Multi objective GA

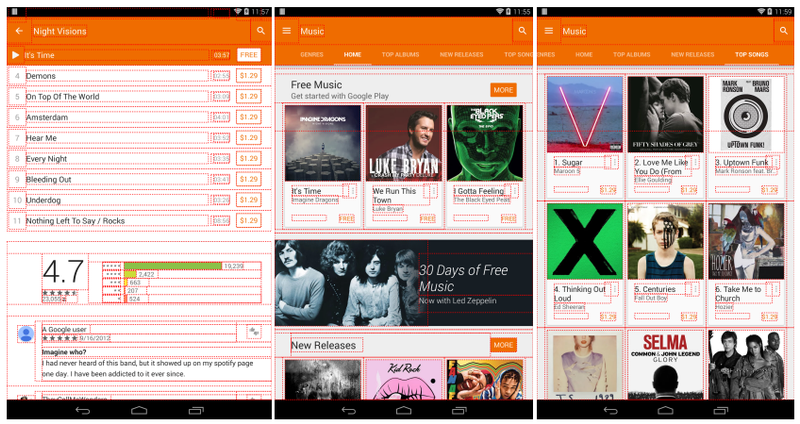
GA objectives: (i) min energy, (ii) max contrast, (iii) min distance to original design

Constraint: contrast > threshold

GEMMA Overview



Widgets + pixels detection



Color quantization

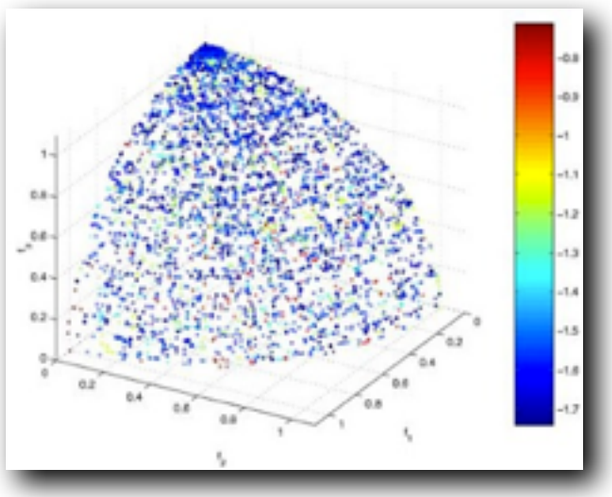
Bag-of-color-pixels

Bag-of-color-components

Multi objective GA

GA objectives: (i) min energy, (ii) max contrast, (iii) min distance to original design

Constraint: contrast > threshold



GA Representation and Operators

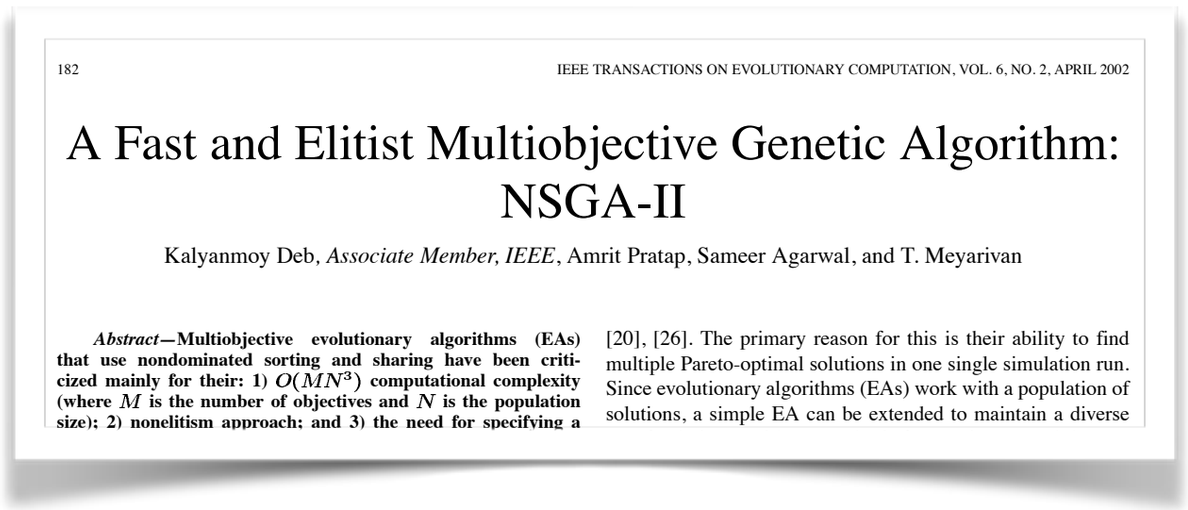
i-th gene := “i-th BOCP”

S = 

One-point crossover

Bit-flip mutation

Binary tournament selection



182 IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION, VOL. 6, NO. 2, APRIL 2002

A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II

Kalyanmoy Deb, *Associate Member, IEEE*, Amrit Pratap, Sameer Agarwal, and T. Meyarivan

***Abstract*—Multiobjective evolutionary algorithms (EAs) that use nondominated sorting and sharing have been criticized mainly for their: 1) $O(MN^3)$ computational complexity (where M is the number of objectives and N is the population size); 2) nonelitism approach; and 3) the need for specifying a**

[20], [26]. The primary reason for this is their ability to find multiple Pareto-optimal solutions in one single simulation run. Since evolutionary algorithms (EAs) work with a population of solutions, a simple EA can be extended to maintain a diverse

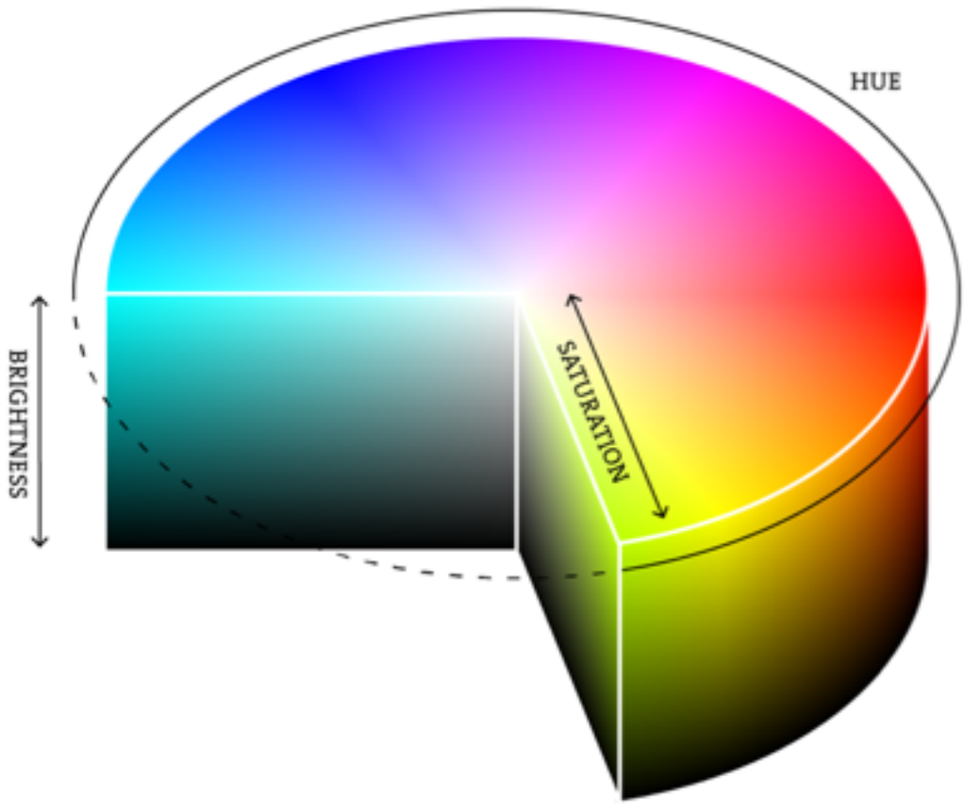
Color palettes - I

Original colors

Black

White

Color palettes - II



2 colors

3 colors

4 colors

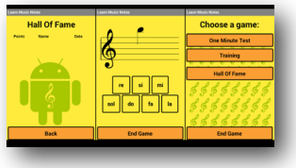
Equidistant harmony (EH)

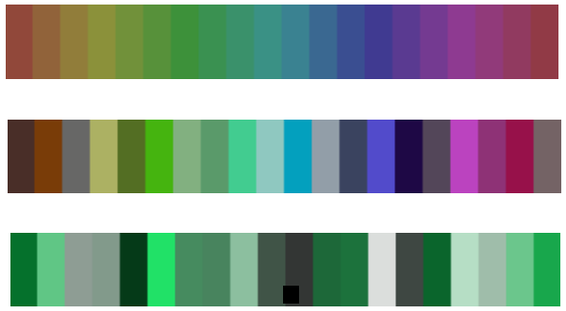
EH with Random Saturation and Brightness

Monochromatic

Initial Population

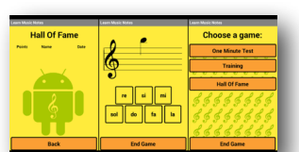
Palette 1

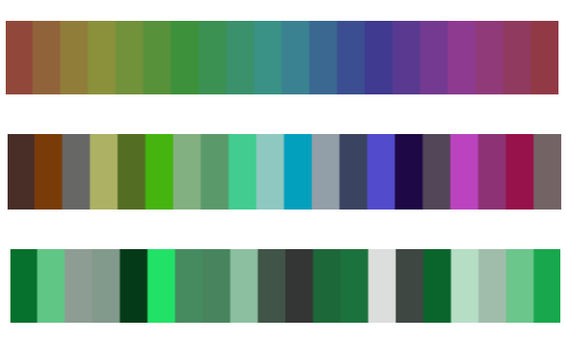




BOCP 1

Palette 50





BOCP 50

Initial Population

512 colors

Palette 1

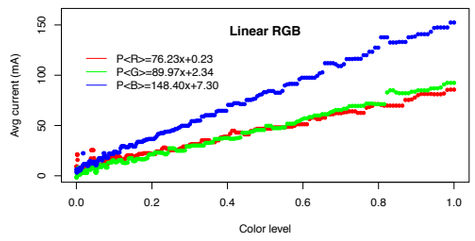
BOCP 1

Palette 50

BOCP 50

Fitness Functions

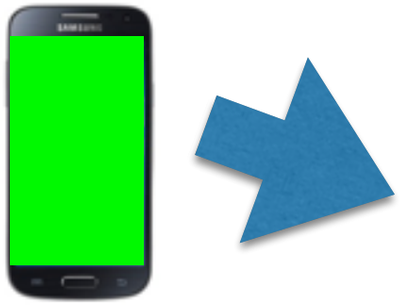
1 - Minimize Energy

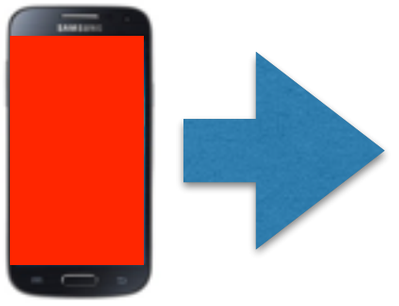


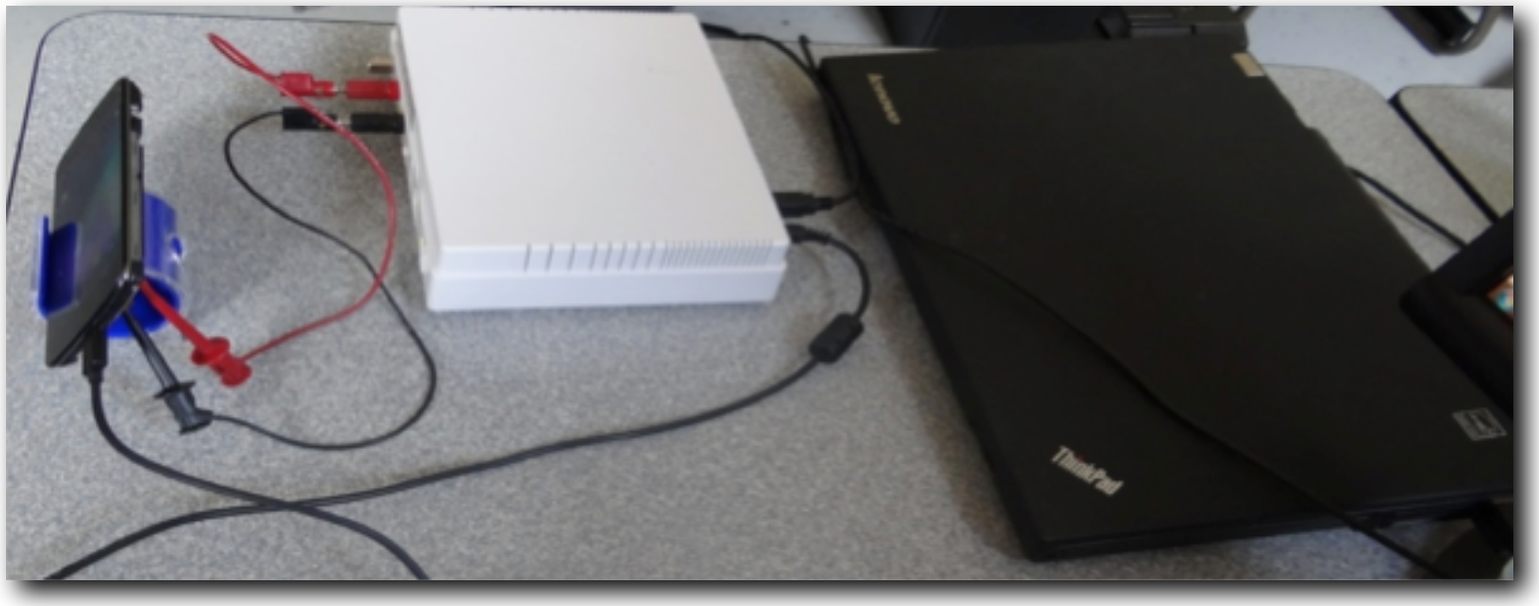
Energy Consumption Fitness

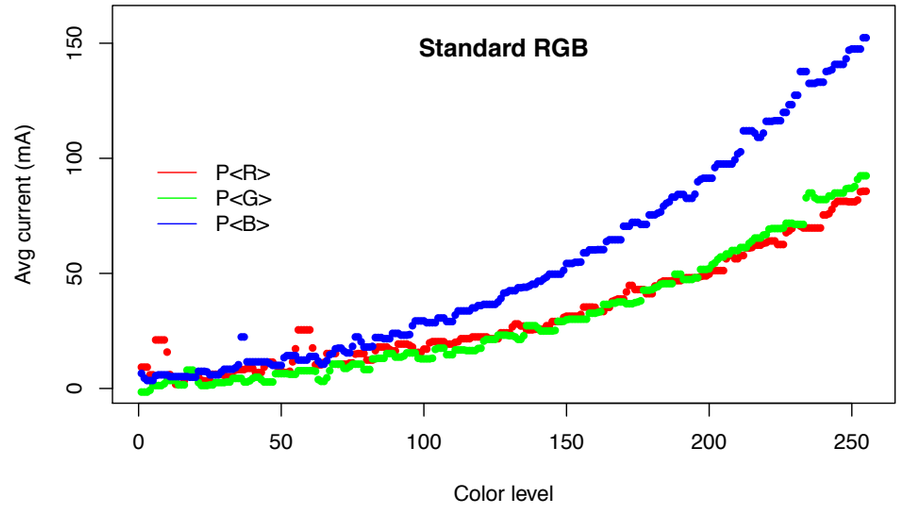
Screens being shown for a different (average) time are weighted differently

Getting Consumption Profiles…







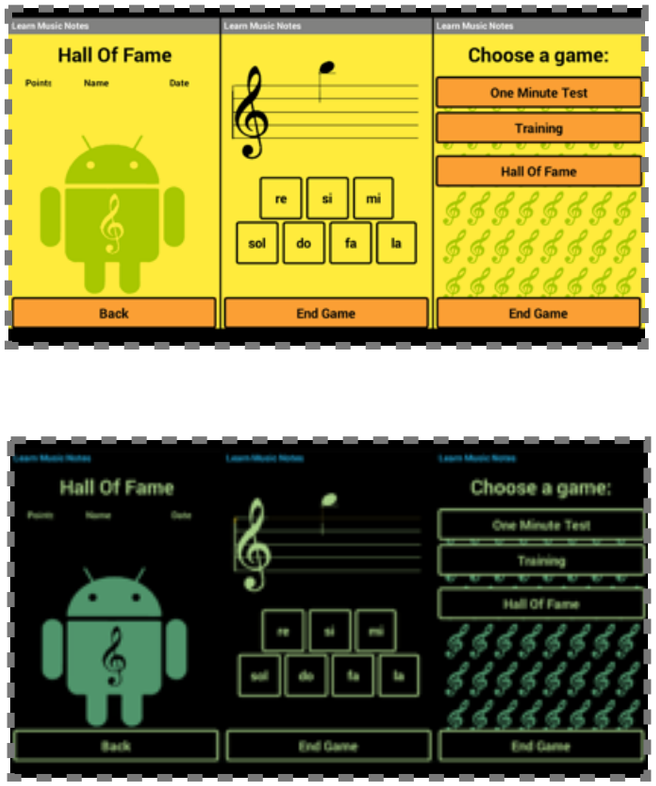


2 - Maximize Contrast

Contrast calculator

Contrast Fitness

3 - Minimize distance from original design



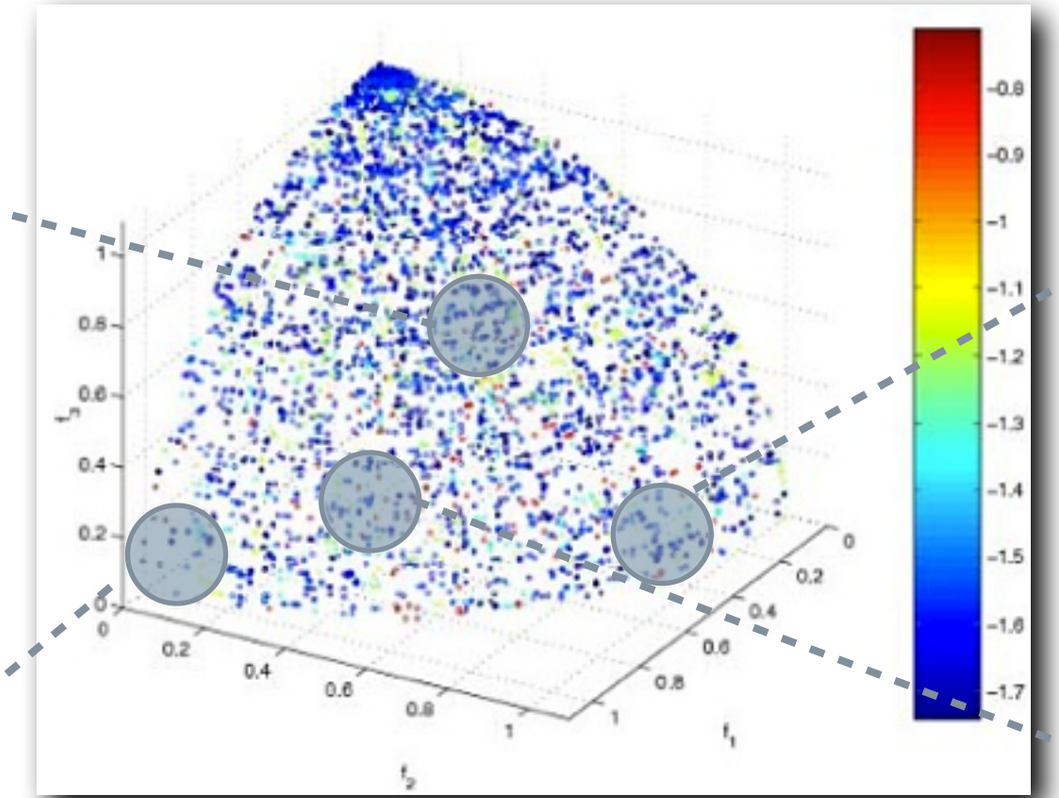
Distance calculator

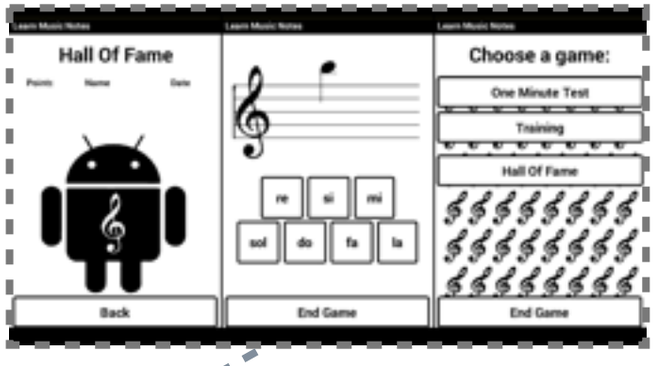
Design fitness

Distance between each color
and the closest color in the original palette

Solutions (Pareto Front)

Median distance

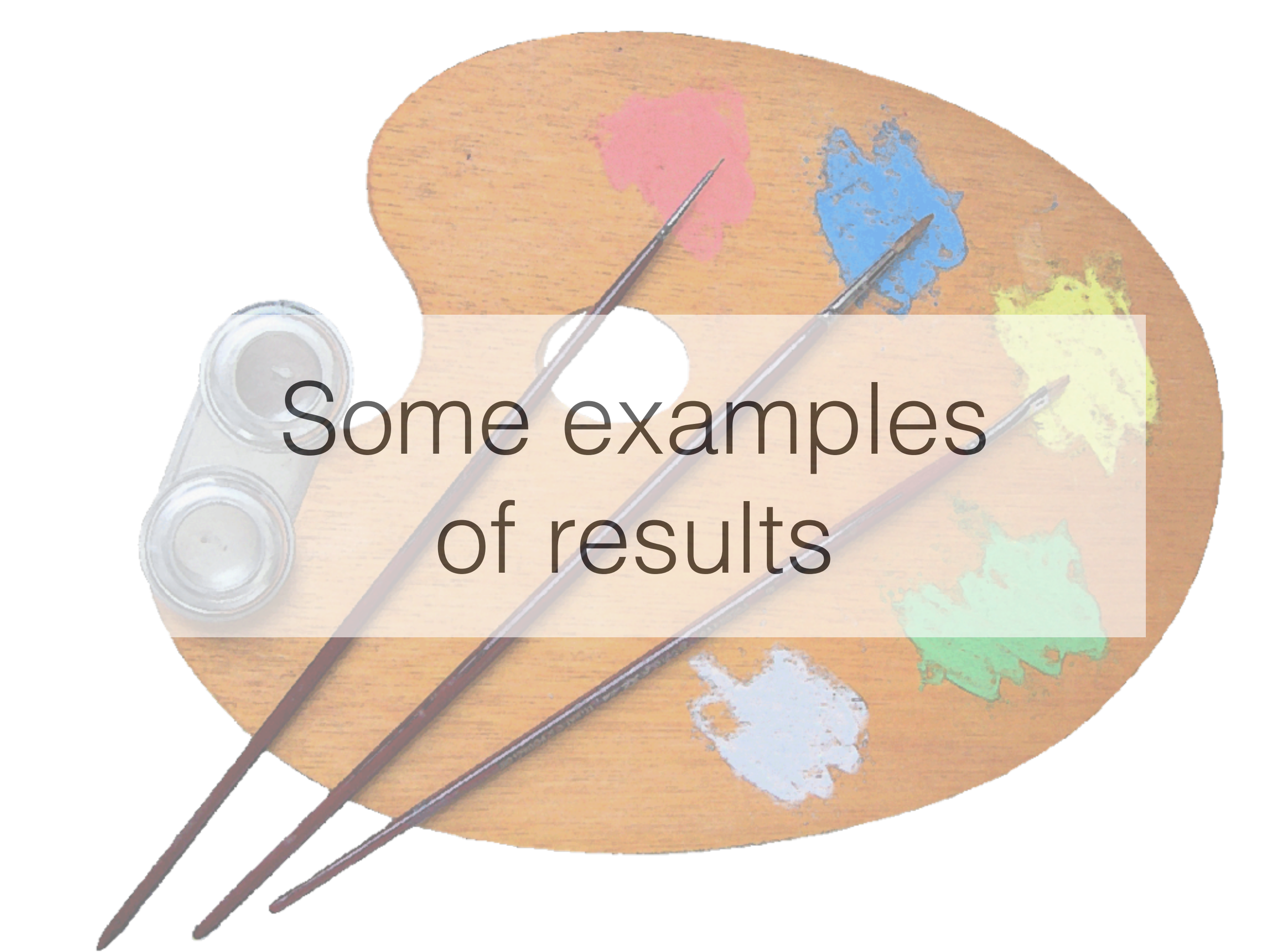




Median contrast

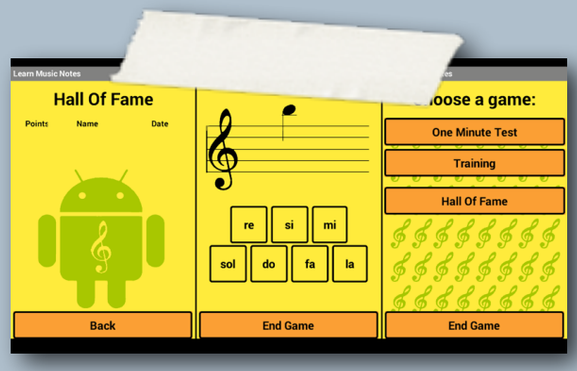
Lowest energy

Median energy



Some examples of results

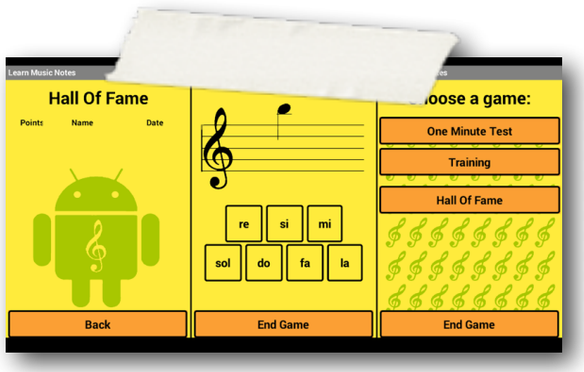
Option 1



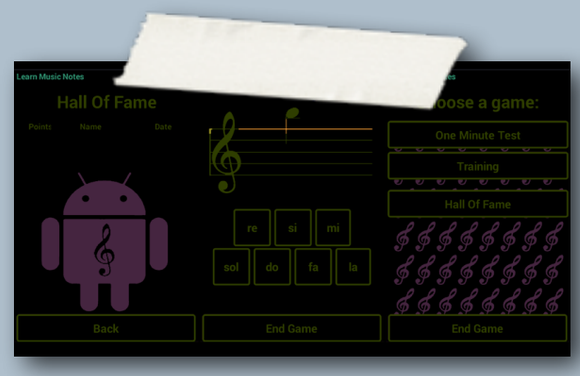
Option 2

Option 3

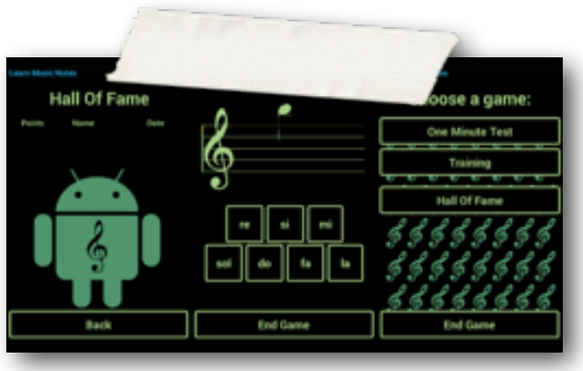
Option 1

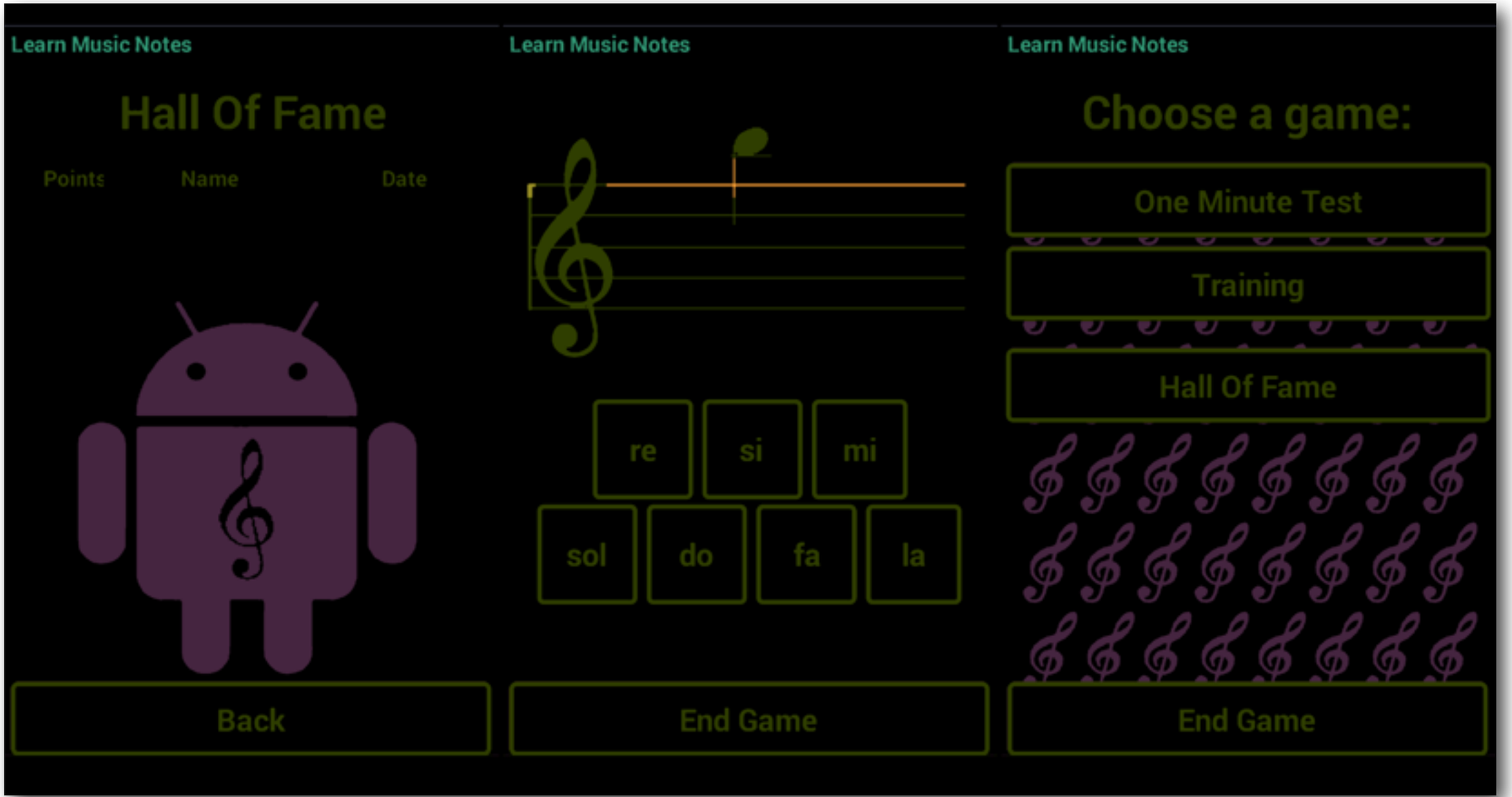


Option 2

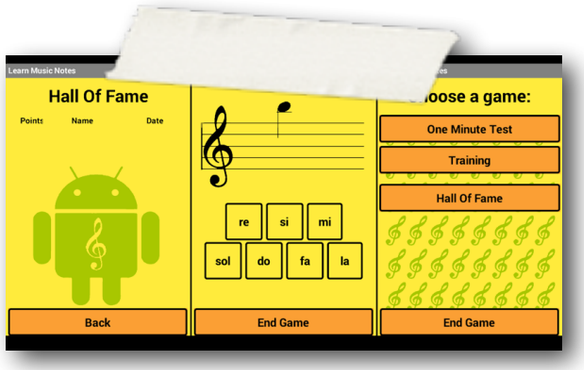


Option 3

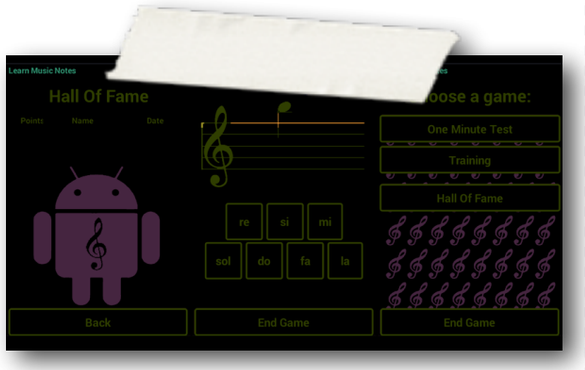




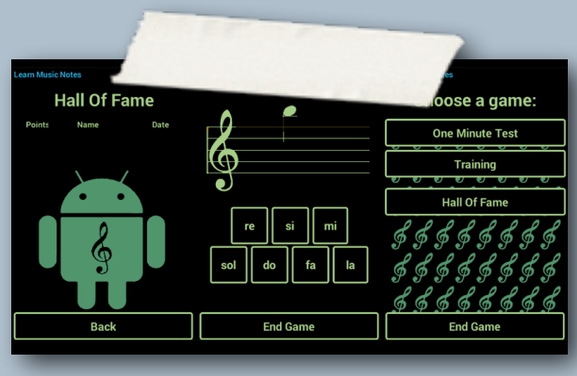
Option 1

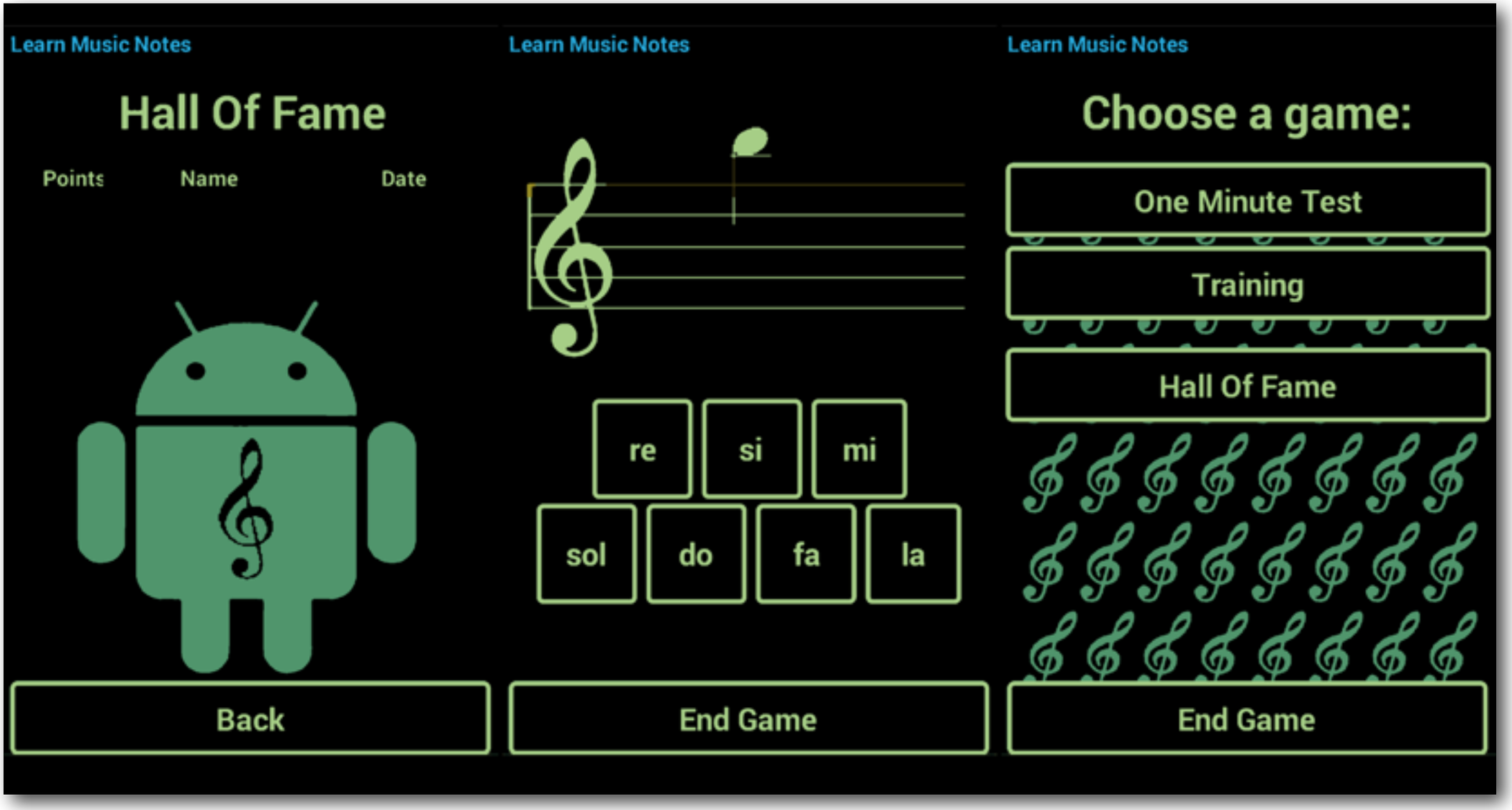


Option 2

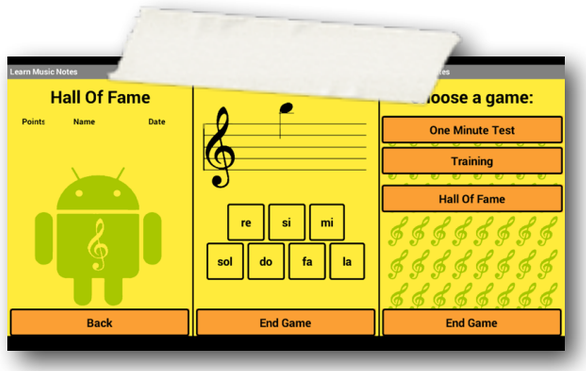


Option 3

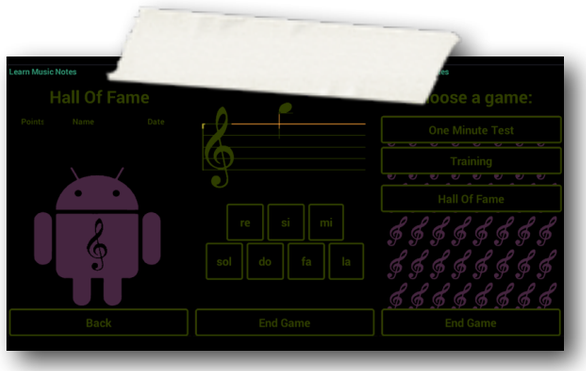




Option 1

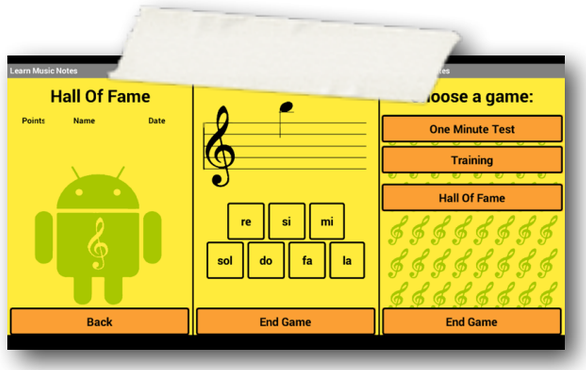


Option 2

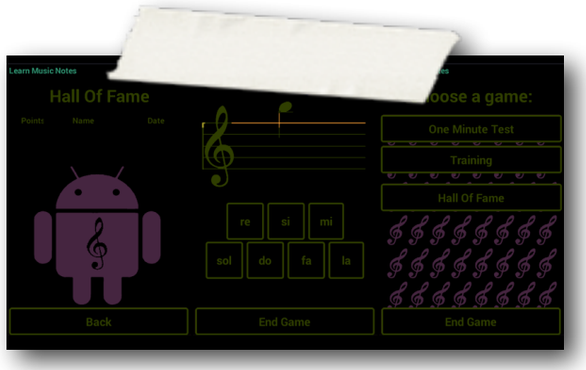


Option 3

Option 1



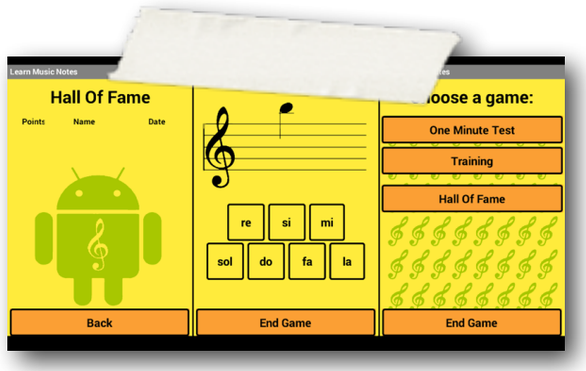
Option 2



Option 3

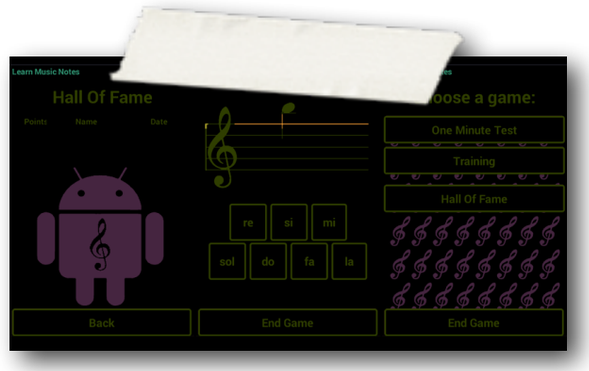
ORIGINAL DESIGN

Option 1



ORIGINAL DESIGN

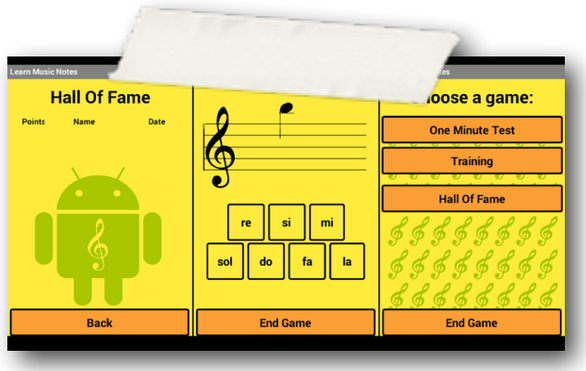
Option 2



LOWEST ENERGY

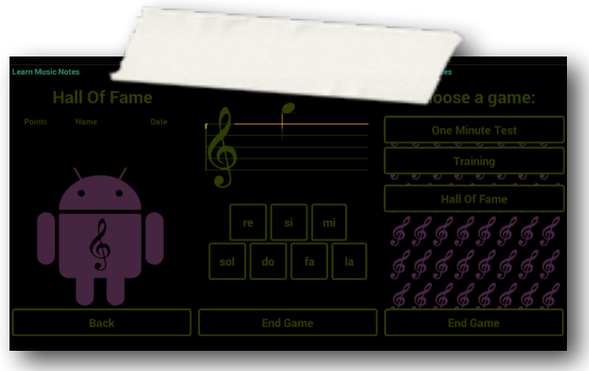
Option 3

Option 1



ORIGINAL DESIGN

Option 2



LOWEST ENERGY

Option 3

MEDIAN ENERGY

Empirical Evaluation

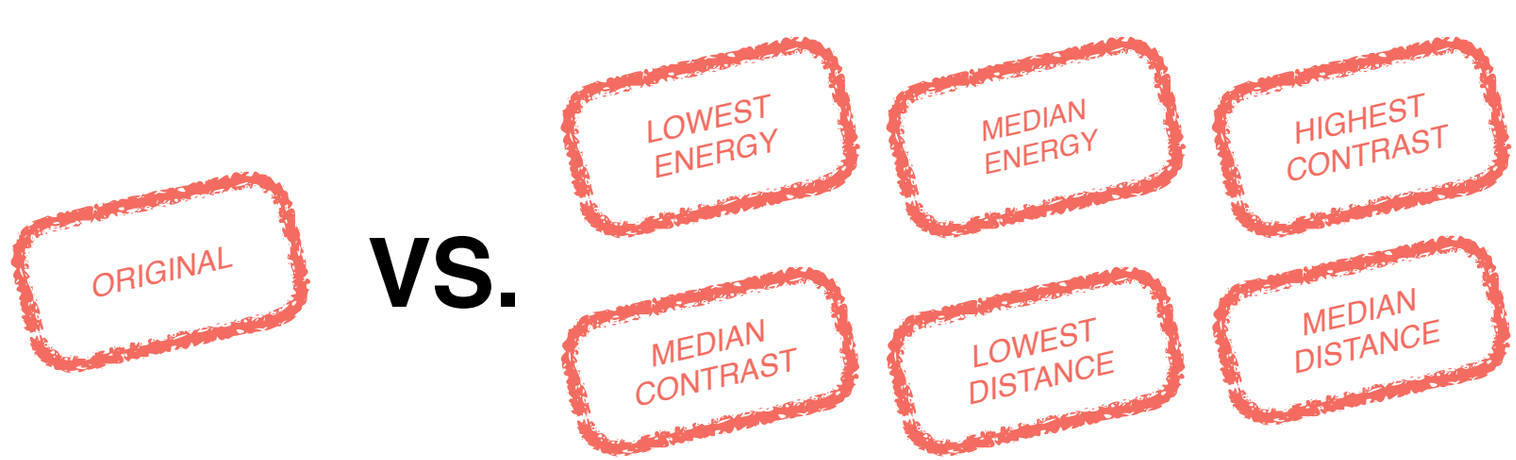
Empirical Evaluation

25
Apps

84
Participants

3 + 4
Project Managers
Apps

1. Improving original design:
Energy, contrast, design

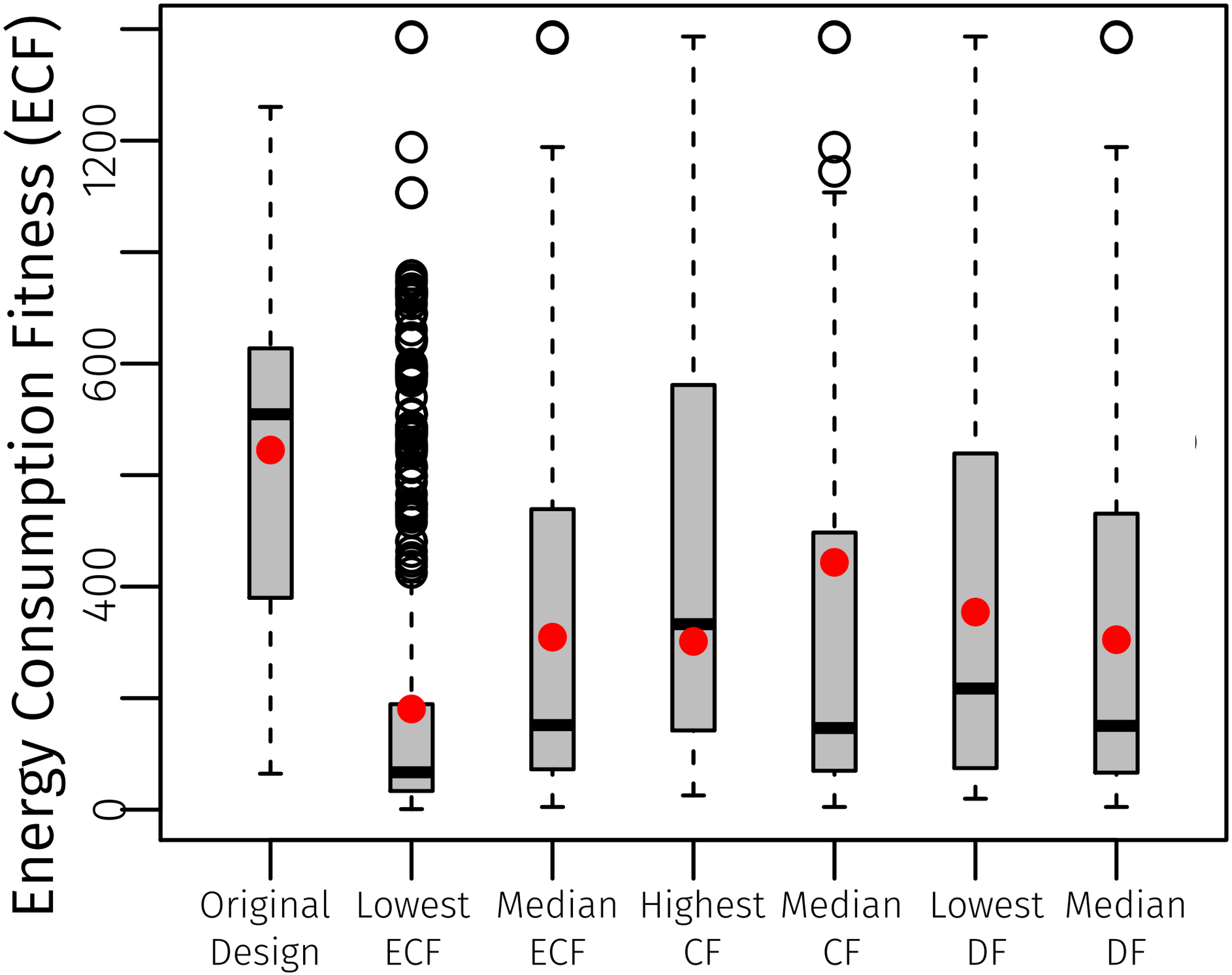


Energy Fitness

Contrast Fitness

Design Fitness

Reducing Energy Consumption



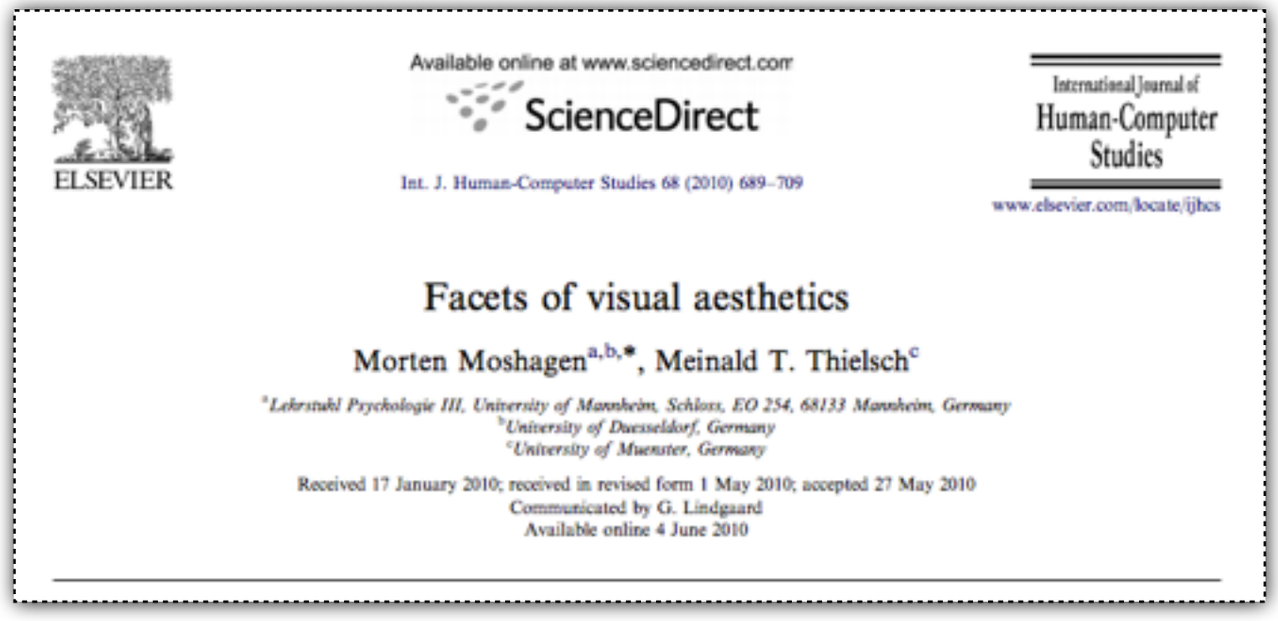
Empirical Evaluation

25
Apps

84
Participants

3 + 4
Project Managers Apps

2. Visual aesthetics: colorfulness



Available online at www.sciencedirect.com
ScienceDirect
Int. J. Human-Computer Studies 68 (2010) 689–709
International Journal of Human-Computer Studies
www.elsevier.com/locate/ijhcs
ELSEVIER

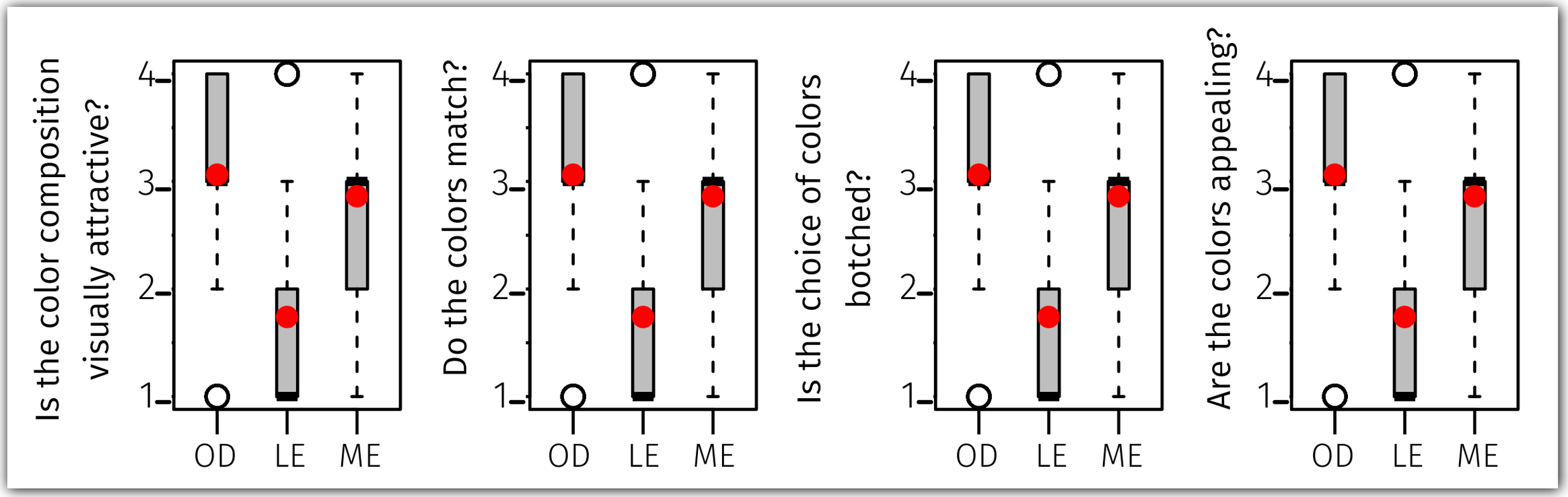
Facets of visual aesthetics

Morten Moshagen[a,b,*], Meinald T. Thielsch[c]

[a]Lehrstuhl Psychologie III, University of Mannheim, Schloss, EO 254, 68133 Mannheim, Germany
[b]University of Duesseldorf, Germany
[c]University of Muenster, Germany

Received 17 January 2010; received in revised form 1 May 2010; accepted 27 May 2010
Communicated by G. Lindgaard
Available online 4 June 2010

Visual appealing color schemes



OD = original Design
LE = Lowest Energy
ME = Median Energy

Empirical Evaluation

25
Apps

84
Participants

3 + 4
Project Managers + Apps

3. Industrial applicability

Project managers

Applicability of GEMMA

“I would definitively use this combination of colors in my app. The final result is excellent and I really like the effect of the GUI with a black background. This helps in saving battery and makes the app more elegant. I will propose the new combination of colors for the next release of the app”

Luciano Cotone - IdeaSoftware

Limitations

The overall improvement may vary for different kinds of apps/scenarios

…and on different hardware

Not suitable for image-intensive apps (e.g. games)

We’re currently measuring the overall gain for some scenarios

Challenges and Open Research Directions

Energy-Aware Testing

Goal: Generate test data that reveal energy hotspots

Challenge: try to identify cases different from obvious (CPU intensive and long tasks)

Energy-Aware Refactoring

Goal: perform a sequence of refactoring action to minimize energy consumption

Challenge: preserve other characteristics of the software (e.g., maintainability)

Is it the improvement really worthwhile?

Replacing Data Structures

Previous work has shown that

- Some data structures are more expensive than others [Manotas et al., 2014]
- Some persistence layers cost more than others [Linares et al., 2014]

Goal: automated transformations taking into account:

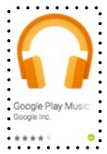
- Energy consumption
- Maintainability
- Performance

Irene Lizeth Manotas Gutiérrez, Lori L. Pollock, James Clause: SEEDS: a software engineer's energy-optimization decision support framework. ICSE 2014: 503-514

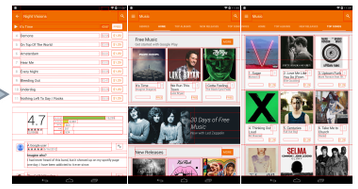
Conclusions

GEMMA Overview

Dynamic analysis



Widgets + pixels detection



Color quantization

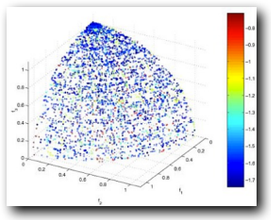
Bag-of-color-pixels

Bag-of-color-components

Multi objective GA

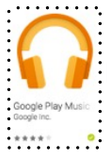
GA objectives: (i) min energy, (ii) max contrast, (iii) min distance to original design

Constraint: contrast > threshold

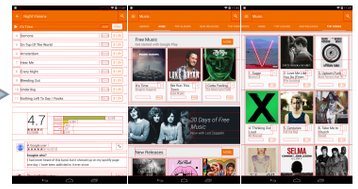


GEMMA Overview

Dynamic analysis



Widgets + pixels detection



Color quantization

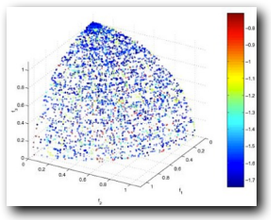
Bag-of-color-pixels

Bag-of-color-components

Multi objective GA

GA objectives: (i) min energy, (ii) max contrast, (iii) min distance to original design

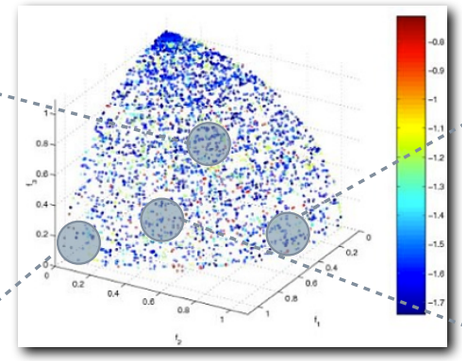
Constraint: contrast > threshold



Solutions (Pareto Front)

Median distance

Median contrast

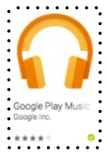


Lowest energy

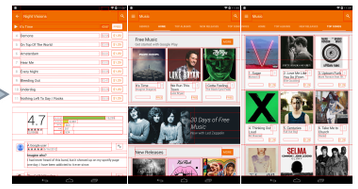
Median energy

GEMMA Overview

Dynamic analysis



Widgets + pixels detection



Color quantization

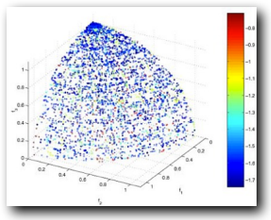
Bag-of-color-pixels

Bag-of-color-components

Multi objective GA

GA objectives: (i) min energy, (ii) max contrast, (iii) min distance to original design

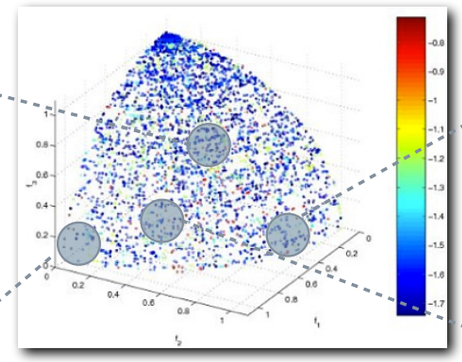
Constraint: contrast > threshold



Solutions (Pareto Front)

Median distance

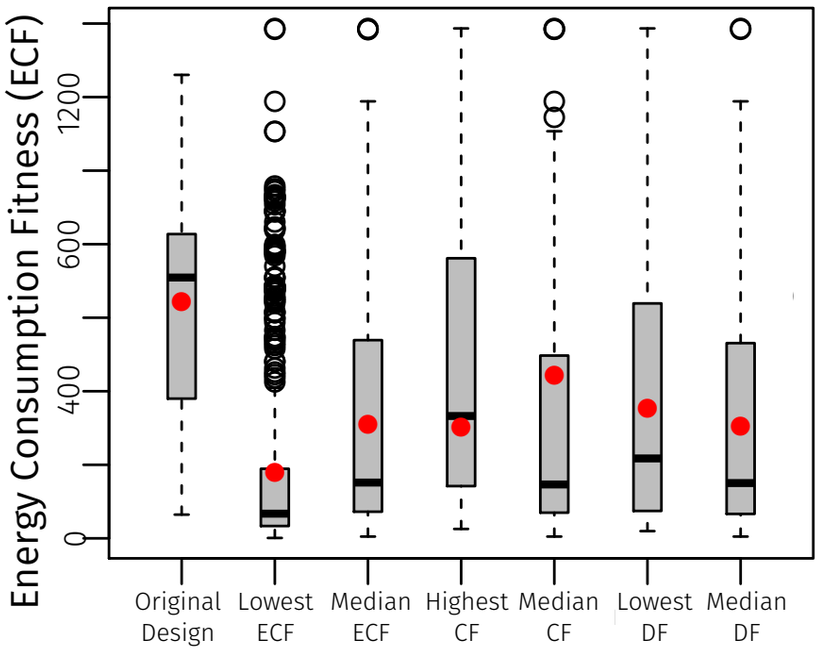
Median contrast



Lowest energy

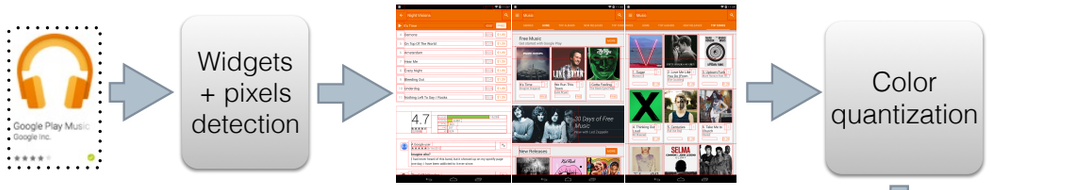
Median energy

Reducing Energy Consumption

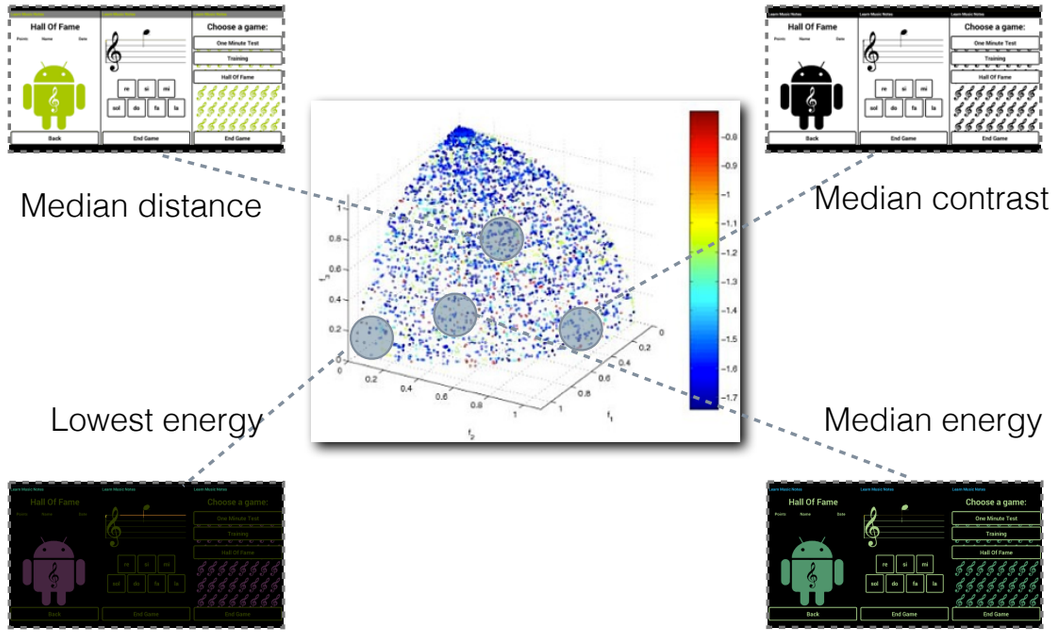


GEMMA Overview

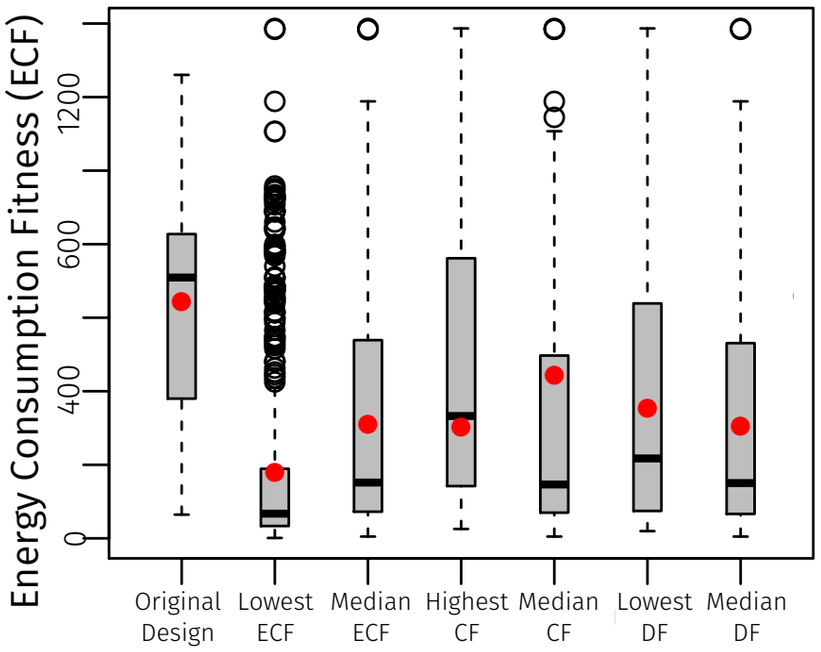
Dynamic analysis



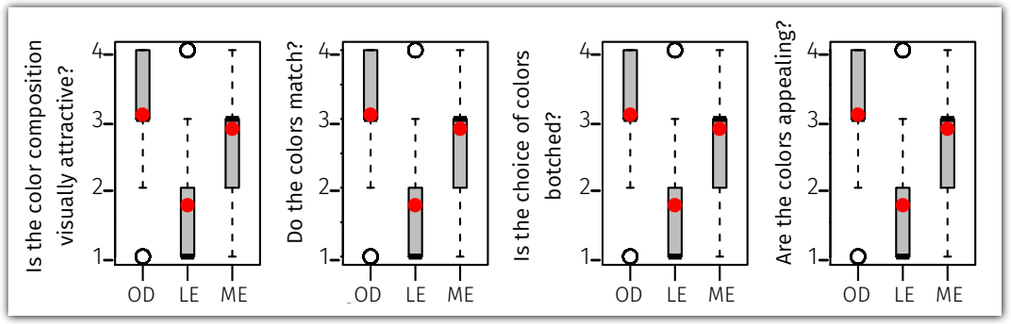
Solutions (Pareto Front)



Reducing Energy Consumption



Visual appealing color schemes



OD = original Design
LE = Lowest Energy
ME = Median Energy