# Optimizing Display Energy Consumption for Hybrid Android Apps (Invited Talk)

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## ABSTRACT

Energy has emerged as an important quality metric for apps that run on mobile platforms. This talk describes our approach for reducing display energy by automatically changing the color schemes used by a web app so that the pages consume less energy when displayed on an OLED based smartphone.

## Categories and Subject Descriptors

D.2.5 [**Testing and Debugging**]: Diagnostics

## General Terms

Performance

## Keywords

Energy optimization, display energy, mobile systems, web applications

## 1. INTRODUCTION AND MOTIVATION

Energy has become an important quality metric for mobile apps. Recent studies have shown that energy related complaints can represent a significant source of user unhappiness with an app [2]. However, developers have traditionally not had extensive guidance for how to reduce the energy consumption of their apps. New techniques (e.g., [3, 4, 8]) have started to address this problem by providing developers with tools to understand, at a source line level, what is consuming energy in their apps.

These techniques have enabled us to gain new insights into how energy is consumed by apps and identify areas for improvement [7]. In particular, these results show that almost 62% of an app's energy is consumed when it is either sleeping or waiting for input. The primary cause of that non-execution time energy consumption is display energy, which can consume 40–60% of an app's total energy [9]. These results motivate attention to reducing display energy.

Many popular modern smartphones use OLED based displays. An interesting characteristic of these displays is that they consume less energy when displaying dark (e.g., black) colors than light colors (e.g., white). Intuitively, a way to take advantage of this is to modify an app's colors to use a color layout with black as the dominant color instead of the ever popular light or white backgrounds. However, this is challenging because the UIs of an app can be dynamically generated and colors must be adjusted in a way that balances energy efficiency and aesthetics. Prior work has either required developers to manually generate these new color schemes, which is labor intensive, or simply used color inversion, which reduces aesthetics since color differences are not maintained in the transformed app [1].

In this talk, we present our prior work in developing an approach that can help developers in making their web apps more energy efficient when displayed on an OLED based smartphone [9]. The way this is done is that the approach analyzes the implementation of the target web application to identify its UI layout and colors. Then the approach uses this information to find a new energy efficient color scheme that tries, as much as possible, to maintain color differences between neighboring elements. An example before and after image of a transformed web app is shown in Figure 1.
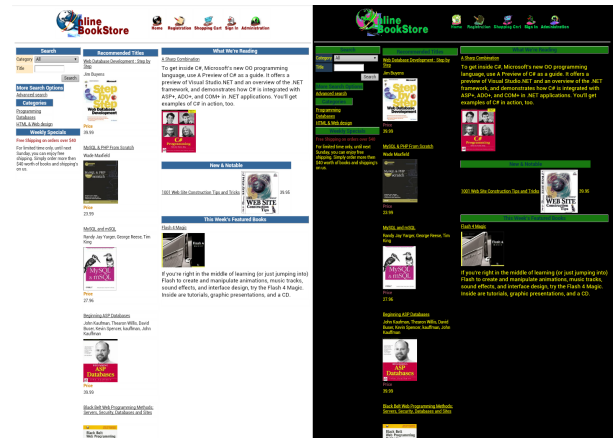


Figure 1: Example output of the Nyx approach

## 2. APPROACH

Our approach can be roughly described as having five steps. The first step is a static analysis that examines the server-side code of the web app and builds a model representing the potential HTML content that it could generate. In

the second step, the approach parses this model to identify the visual relationships between tags, such as "contained by" and "next to." After identifying these relationships, the third step of the approach is to determine the colors of the text and background of the different HTML elements and abstract this information into a Color Conflict Graph (CCG) that only shows colors and their visual relationships with each other. Each edge of the CCG is weighted to signify a priority in maintaining the corresponding relationship. Once the CCG is complete, the approach solves for a recoloring that is more energy efficient but maintains, as closely as possible, the color differences between edges in the CCG. Since solving for the best recoloring is an NP problem, in the fourth step, the approach uses a search-based approximation to find an optimal solution. Finally, in the fifth step, the approach uses bytecode rewriting and parsing-based transformations to insert the new color scheme into the application.

## 3. EVALUATION

To evaluate the effectiveness of our approach, we implemented it in a prototype tool, Nyx [10]. Our implementation is for Java-based web applications and we evaluated it on a set of seven web applications that ranged in size from 5K to 154K SLOC and used a variety of frameworks, such as JSP, Velocity, and Turbine. For all of the apps it was possible to analyze and transform them in under three minutes.

In terms of energy savings, we found that energy consumption of the display, once it had loaded and rendered the page, decreased by 40%. We also saw a power decrease of 25% while the page was loading and rendering. This occurred because modern mobile browsers start to render a page before it has finished loading. Overall, these are significant results and show the potential of our technique to reduce energy consumption.

We also performed a study to assess the aesthetics of the transformed web pages. To do this, we gave a group of 20 grad students the original and optimized versions of the subject apps and asked them to rate their attractiveness, readability, and acceptability. Overall, the students rated the transformed web pages as 17% less attractive and 14% less readable (using a 10 point scale). However, when given a summary of the energy savings that could be achieved for each page, 67% of the students indicated it would be acceptable for normal usage, and 97% indicated it would be acceptable when the battery level was critical.

## 4. SUMMARY

The energy consumed by the display component of a smartphone device represents a significant portion of the overall energy expended by the device. This talk focused on recent work ([9]), Nyx, that optimizes energy consumption by automatically transforming the colors used by an app's UI so that the UI consumes less energy when displayed on an OLED based smartphone. The evaluation results of Nyx were very positive and show that it was able to reduce display energy by an average of 40%. Nyx was able to generate these results in an average time of under three minutes and the aesthetics of its color schemes were acceptable to users when they were made aware of the power savings.

In future work, we are investigating the use of Nyx to detect display energy hotspots (e.g., [?]) and refine the Nyx mechanisms to improve on the aesthetics for parts of the transformation that were considered less attractive by end users. We will also investigate other areas for energy improvement in mobile apps, such as network communication [5, 6].

## 5. ACKNOWLEDGMENTS

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