Chameleon: A Color-Adaptive Web Browser for Mobile OLED Displays

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Display is a major power consumer in a smartphone.

A. Carroll, "A analysis of power consumption in a smartphone," 2010
Organic Light-Emitting Diode
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
Power = 2.0W
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!
OLED Rocks !!!

Power = 0.5W
An OLED-friendly theme works for GUIs
but not for Contents
65% of the contents in the web are White
Web Design solves the problem?

Non-Mobile

Mobile

OLED-Friendly
50% of the webpages visited by iPhone users are Non-Mobile

Max: 70%  
Min: 20%  
Median: 50% 

LiveLab: A field study  
(25 users; 12 months)
Generate Device Specific OLED Power Model
Single pixel $i$ 

$$P_i = a \cdot R_i + b \cdot G_i + c \cdot B_i$$

A display with $N$ pixels 

$$P = \sum_{i=1}^{N} P_i = \sum_{i=1}^{N} (a \cdot R_i + b \cdot G_i + c \cdot B_i)$$
Linear RGB Values

Power (μW)

Nokia N85

Google Nexus One

Samsung Galaxy S

Red (R)

Green (G)

Blue (B)
Treat GUI Objects and Images Differently
GUI Objects vs. Images
Color Transformation of GUI Objects

- **Color Counting**
- **Color Mapping**
- **Color Painting**

![Graphs and pixel count comparison](image)
Color Transformation of Images
3. Keep Color Consistency for Each Website
Color Consistency per Website
Top 20 websites contribute 90% of the webpages visited by each user.

Average % of usage (with Max and Min) of all users

LiveLab: A field study (25 iPhone users; 12 months)
Calculate Color Maps Offline
Color Transformation of GUI Objects

- Color Counting
- Color Mapping
- Color Painting
2 Weeks of training work for 3 Months
Websites remain Color Consistent over many years.

http://confabulator.blogspot.com/2007/01/how-little-web-sites-have-changed-over.html
5 Give User Options
Original

\[ R' = \lambda R \]
\[ G' = \lambda G \]
\[ B' = \lambda B \]
\[ \downarrow 25\% \]

Dark

\[ R' = \lambda R \]
\[ G' = \lambda G \]
\[ B' = \lambda B \]
\[ \downarrow 25\% \]

Green

\[ R' = \lambda_R R \]
\[ G' = \lambda_G G \]
\[ B' = \lambda_B B \]
\[ \downarrow 34\% \]

Arbitrary

\[ R' = R^* \]
\[ G' = G^* \]
\[ B' = B^* \]
\[ \downarrow 72\% \]

Inversion

\[ R' = \lambda(1-R) \]
\[ G' = \lambda(1-G) \]
\[ B' = \lambda(1-B) \]
\[ \downarrow 66\% \]
Different users prefer different transformations for a website.
Even the **same** user may favor **different** color transformations for **different** websites.
1. Generate Device Specific OLED Power Model
2. Treat GUI Objects and Images Differently
3. Keep Color Consistency for Each Website
4. Calculate Color Maps Offline
5. Give User Options
Color Counting

Internet

Resource Loading

Parsing

Style Formatting

Layout Calculation

Painting

Display

DOM Tree

Render Tree

Render Tree w/ Layout

Bitmap

Pixel #

RGB

Scripting

Parsing

Internet

Painting

Display

Resource Loading

Style Formatting

Layout Calculation
Mapping Optimization

- **Input:**
  - RGB

- **Output:**
  - RGB
  - R'G'B'

- **Algorithm**
  - Arbitrary
    - $\text{min Power}$
    - s.t. for any $i, j$
    - $\Delta E ((L'_i, a'_i, b'_i), (L'_j, a'_j, b'_j)) = \lambda \Delta E ((L_i, a_i, b_i), (L_j, a_j, b_j))$
Painting GUI Objects

Internet

Resource Loading

Parsing

Style Formatting

Layout Calculation

Painting

Display

DrawPoint \((x, y, LUT(RGB))\)

RGB

R’G’B’
Implementation

Fennec
Mozilla for Mobile
Display Power Consumption

- Fennec
- Chameleon

70%
A Field Trial
36 Participants; 3 Months

- Female: 18 participants
- Male: 18 participants

Age groups:
- Age <20: 4 participants
- Age 21-25: 10 participants
- Age 26-30: 8 participants
- Age >30: 14 participants

Educational backgrounds:
- High School Students: 12 participants
- Business: 10 participants
- Computer Science: 6 participants
- Engineering: 8 participants
- Education: 4 participants
- Science: 2 participants
- Law: 2 participants
- Art & Literature: 2 participants

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Transformation is **Well Accepted** especially with a **Low** battery level.

- **Battery Level High**
  - Transformed: 47%
  - Original: 53%

- **Battery Level Low**
  - Transformed: 63%
  - Original: 37%
Summary

• Color transformation is beneficial: 40% system power reduction for web browsing
• Color transformation is well accepted by users if performed properly
• Chameleon tremendously benefited from studying users