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
Power = 0.5W

OLED Rocks !!!
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)
2 Treat GUI Objects and Images Differently
GUI Objects vs. Images

Adding Injury To Insult

Vikings' Brett Favre Has 2 Fractures In Left Ankle; Status Uncertain For Sunday's Game
Childress critical of Favre as Vikings fall short
Favre admits voicemails, denies photos

Scores & Schedules

NFL Scores
NHL Scores
ALL SCORES TODAY
SCORES BY SPORT
Color Transformation of GUI Objects

Color Counting

Color Mapping

Color Painting
Color Transformation of Images
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)
4 Calculate Color Maps Offline
Color Transformation of GUI Objects

Color Counting

Color Mapping

Color Painting

RGB Pixel

RGB Pixel

Color Counting

Color Mapping

Color Painting

RGB

RGB

RGB

RGB
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
20 Participants
<table>
<thead>
<tr>
<th>Original</th>
<th>Dark</th>
<th>Green</th>
<th>Arbitrary</th>
<th>Inversion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R' = \lambda R$</td>
<td>$G' = \lambda G$</td>
<td>$B' = \lambda B$</td>
<td>$R' = R^*$</td>
</tr>
<tr>
<td></td>
<td>$G' = \lambda R$</td>
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<tr>
<td></td>
<td>$B' = \lambda B$</td>
<td>$B' = \lambda B$</td>
<td>$B' = B^*$</td>
<td>$B' = \lambda (1-B)$</td>
</tr>
<tr>
<td></td>
<td><strong>↓ 25%</strong></td>
<td><strong>↓ 34%</strong></td>
<td><strong>↓ 72%</strong></td>
<td><strong>↓ 66%</strong></td>
</tr>
</tbody>
</table>
**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

Scripting

Parsing

DOM Tree

Style Formatting

Render Tree

Layout Calculation

Render Tree w/ Layout

Painting

Bitmap

Display

Pixel #

RGB
Mapping Optimization

- **Input:**

- **Output:**

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

Internet -> Resource Loading

Scripting -> Parsing

Parsing -> Style Formatting

Style Formatting -> Layout Calculation

Layout Calculation -> Painting

Painting -> Display

DrawPoint \( (x, y, \text{LUT}(\text{RGB})) \)

RGB

\( R'G'B' \)
Implementation

Fennec
Mozilla for Mobile
Display Power Consumption

- Fennec
- Chameleon

70%
A Field Trial
36 Participants; 3 Months
Transformation is **Well Accepted** especially with a **Low** battery level

47%  
**Battery Level High**  

63%  
**Battery Level Low**
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

http://www.ruf.rice.edu/~dongmian/Chameleon.html
Backup
LiveLab: 25 users; 12 months

Software team deals with the logger and data without knowing the participants

Human factor team interacts with the participants

Participants use the instrumented phone in the field

Counting Pixels
\[ I = \frac{V_1 - V_2}{R} \]

\[ P = c + f(1.0) \]

\[ R = 1.0 \]
\[ G = 0.0 \]
\[ B = 0.0 \]

\[
\begin{align*}
R &= 0.2 \\
G &= 0.0 \\
B &= 0.0 \\
R &= 0.4 \\
G &= 0.0 \\
B &= 0.0 \\
R &= 0.6 \\
G &= 0.0 \\
B &= 0.0 \\
R &= 0.8 \\
G &= 0.0 \\
B &= 0.0 \\
R &= 1.0 \\
G &= 0.0 \\
B &= 0.0
\end{align*}
\]
Web Browser is among the most often used applications.
Original

Dark

\[ R' = \lambda R \]
\[ G' = \lambda G \]
\[ B' = \lambda B \]

\[ \downarrow 25\% \]

Green

\[ R' = \lambda R \]
\[ G' = \lambda G \]
\[ B' = \lambda B \]

\[ \downarrow 34\% \]

Arbitrary

\[ R' = R^* \]
\[ G' = G^* \]
\[ B' = B^* \]

\[ \downarrow 72\% \]

Inversion

\[ R' = \lambda(1-R) \]
\[ G' = \lambda(1-G) \]
\[ B' = \lambda(1-B) \]

\[ \downarrow 66\% \]
Delay

![Delay Chart]

- Sampling Window
  - 20x20
  - 10x10
  - 5x5
  - 1x1

- Time (ms)

- Framebuffer reading
- Color contribution vector updating
Transformation is **Well Accepted** especially with a **Low** battery level!
Favorite Color Maps are Decided in Six Weeks
Painting Images

100010
010001
110001
111101

VLD  ZZ  DQ  IDCT

Reordering  Color Conversion

RGB  R’G’B’