$E^3$: Energy-Efficient Engine for Frame Rate Adaptation on Smartphones

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Enjoy Our Smartphone Everyday

- Angry Birds
- Youtube
- Adobe Reader
- Pandora Radio
- Skype
- The Weather Channel
- Amazon
- Facebook
- TV.com
- Handango Store

Browse the webpage; News & Magazines; IM & Social, Travel & Local; Maps; Media; Reading; Game ......
Powerful Smartphone Drains Battery Quickly

When using Apps such as web-browser, the battery drains quickly.
Inspiration from High Power Consumption during Human-Screen Interaction

Human-Screen Interaction applications:
- *more than 20* input-events per second
- *more than 30% time* for touch-screen operations
Scrolling - Finger Operations on Touch-screens

Scrolling Time Ratio = \frac{\text{Scrolling Operation Time}}{\text{Application Usage Time}} > 30\%
Scrolling Operations vs Power Consumption

Power Consumption during a Web Surfing

- Unlocking & Loading: 6%
- Scrolling: 53%
Is It a General Problem? Yes!

Scrolling Energy Consumption Ratio (%)

- YouTube: 60%
- Gas Buddy: 52%
- Twitter: 37%
- Browser
- Reader
- Facebook
- Google Map
- Flickr
- ESPN
- Craigslist
- Pandora
Insight of a Scrolling Operation

- Catching a touch event
- Processing a touch event
- Feeding back to screen display

Before

After
The Secret of Frame Rate

Frame Rate (FPS) = \frac{The \ number \ of \ screen \ update \ operations}{Time}

- The higher frame rate, the more smooth the image display
- Frame Rate = 60fps

Root Cause: The Frame Rate Strategy

For frame rate, smooth the play

te = 60fps
The Secret of Frame Rate

- Is it necessary to use a fixed 60 frames per second?
  - No, not really

- Can we just cut it to 30 frames per second in order to save energy?
  - Yes, but at the cost of user experience
    - lower frame rate
    - bigger image difference between two frames
    - less smooth display

- What is the frame rate that people really need?
Frame Rate that People Really Need

- Image difference between two frames:

  \[ \text{Diff} \propto \frac{\text{Scroll Speed}}{\text{Frame Rate}} \]

- To guarantee the user experience:

  \[ r > r_{\text{min}}(s) \]

  \( r_{\text{min}}(s) \): the minimum frame rate that guarantees the user experience at scrolling speed \( s \).

The satisfied frame rate:

- Minimize the power consumption

- Guarantee the user experience
Satisfied Frame Rate Model

Log Model

$$\text{Frame Rate}_{\text{min}}(\text{speed}) = a \cdot \log(\text{speed} + b) + c$$
$E^3$: System Design & Work Flow
Work Flow – *Initiating Stage*

Learning the preference of a user: energy saving without affecting user experience

User Specific Preference Model:

\[ \text{Frame Rate}_{\text{user}}(\text{speed}) = a \times \log(\text{speed} + b) + c \]
Work Flow – Reacting Stage

Initiating Stage → Reacting Stage → Evolving Stage

- Real-time Scrolling Speed
- Distance of finger positions
- Time interval

User Experience & Energy Efficient

Satisfied Frame Rate

Frame Rate Controlling

Calculation

Frame Rate min (Speed)
Work Flow – Evolving Stage

- Dynamically update the preference model based on the feedback from the user.
Prototype and Experimental Evaluation

- Implement our system on five kinds of devices.
- Over 300 volunteers participate in the trace collecting.
- Not aware of which smartphone is embedded with $E^3$.
Measurement Tools and Testbeds

The source code of E3 and tools are available at:
Impact on User Experience

Grading System:
How experience difference between smartphones with and without $E^3$
Impact on Energy Saving

CPU Consumption

Saved By E3

Overall Consumption

Saved By E3
Existing Work on Smartphone Energy Consumption

- Smartphone Power Model
  - Bellosa et. al[COLP’03], Fan et. al[ISCA’12],
    Dong et.al [Mobisys’11], Pathak et.al [EuroSys’11]

- CPU Power Consumption
  - Choi et.al[DATE’04], Rajan et.al [Mobisys’11],

- Radio Power Consumption
  - Balasubramanian et. al[Sigcom’09], Qian et. al
    [WWW’12], Schulman et.al [Mobicom’10]

- Screen Power Consumption
  - Anand et.al[Mobisys’11], Chameleon [Mobisys’11],

- Application Energy Consumption
  - Pathak et.al[HotNetsX’11], Pathak et.al
    [Mobisys’12]
Conclusion

- Investigate the impact of human-screen reactions to the power consumption on mobile devices
  - Scrolling operation causes large energy consumption
- Propose an innovative frame rate adaptation system $E^3$
  - Realize energy saving without affecting user experience
- Implement our system successfully on different mobile devices
  - Verify the feasibility of $E^3$
Thanks & Questions?