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V-EDGE: FAST SELF-CONSTRUCTIVE POWER MODELING OF SMARTPHONES BASED ON BATTERY VOLTAGE DYNAMICS

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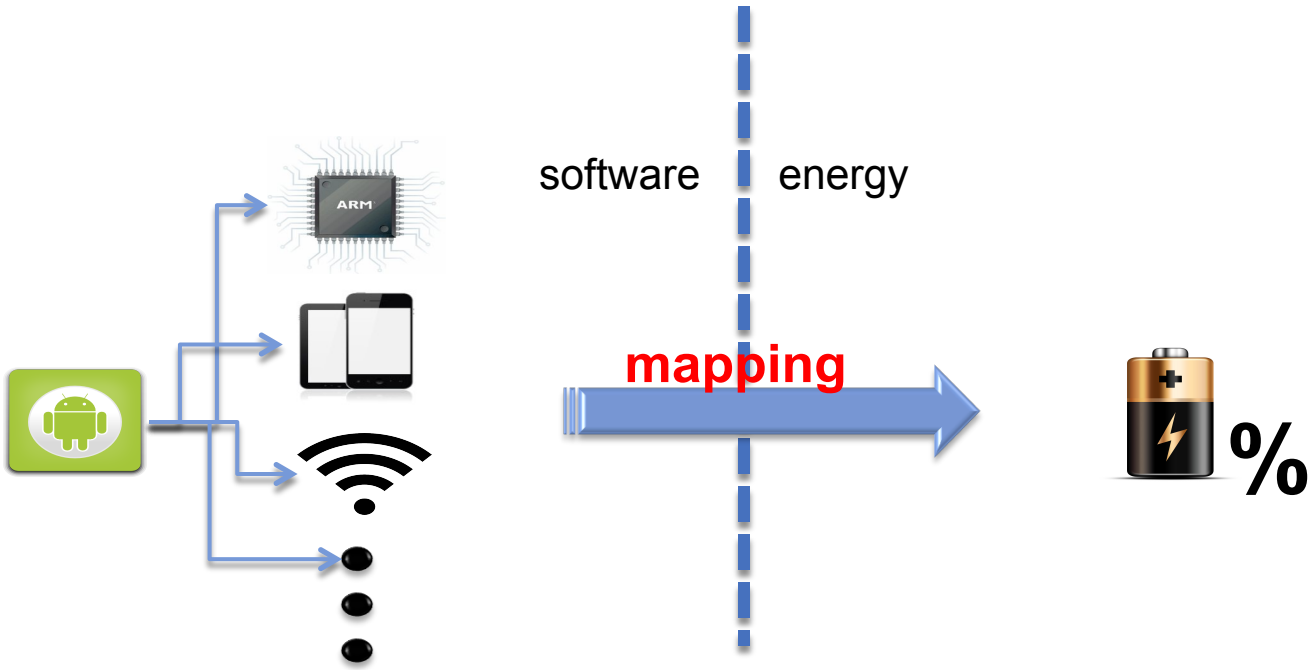
Introducing Power Model

- Power model - relationship between power draw & system activities
- It is foundation to power management & optimization



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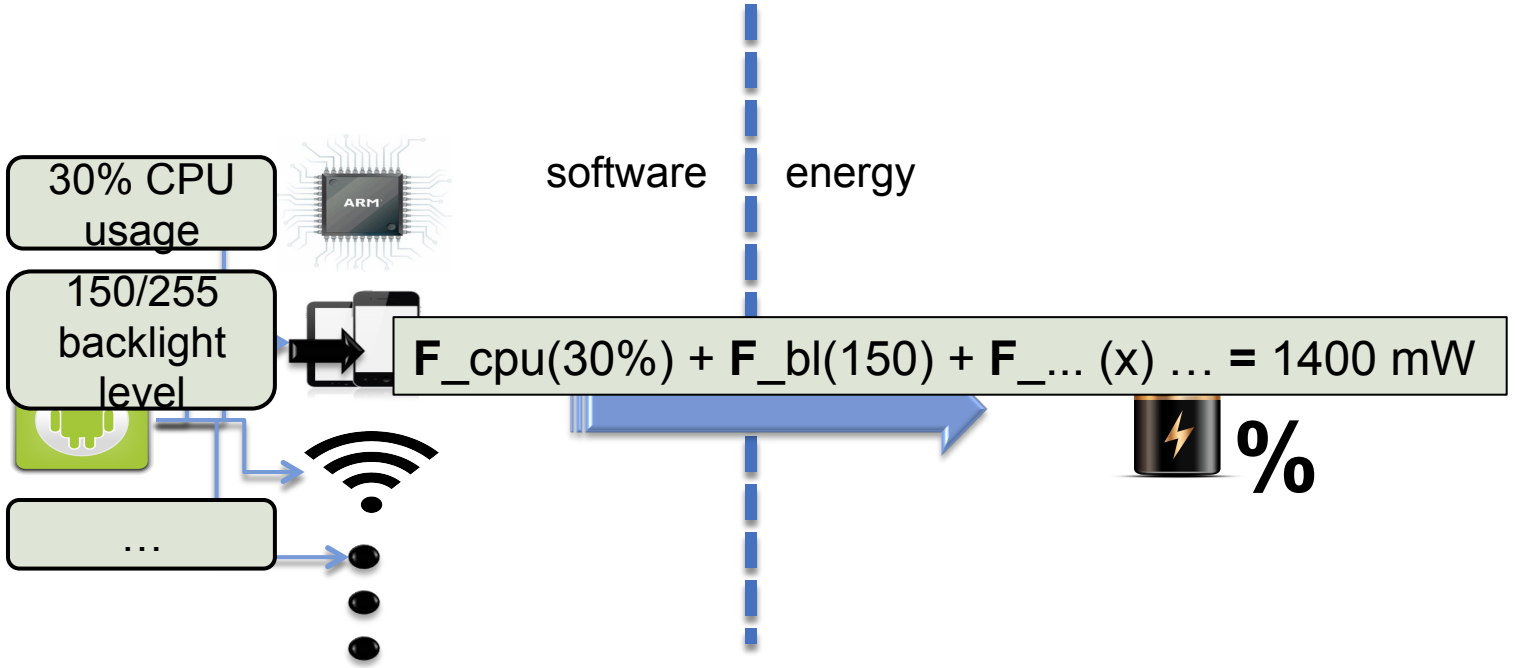

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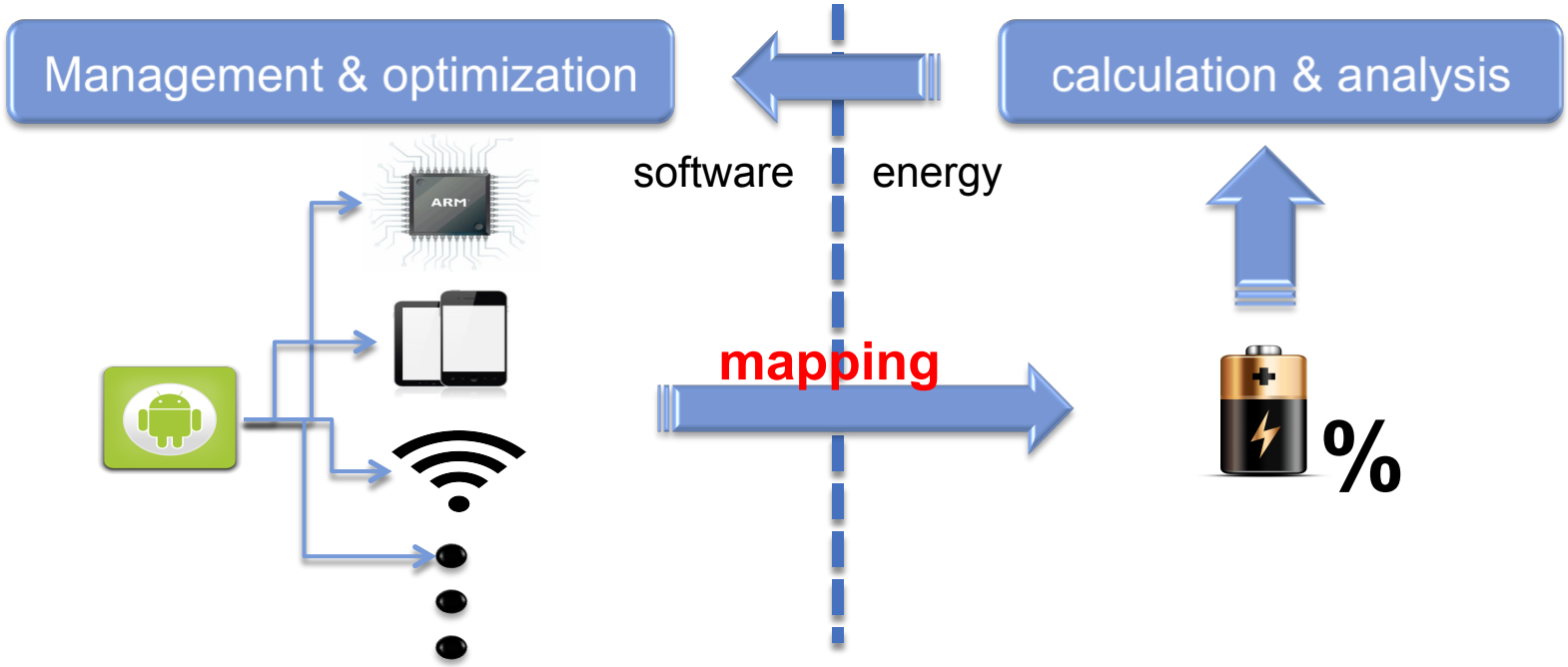
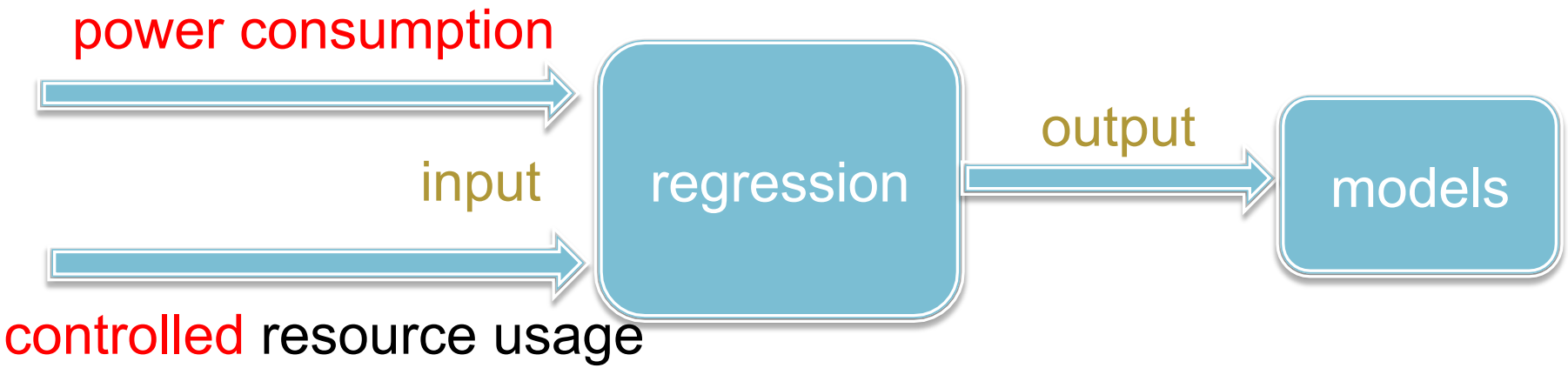


How to Build Power Models?



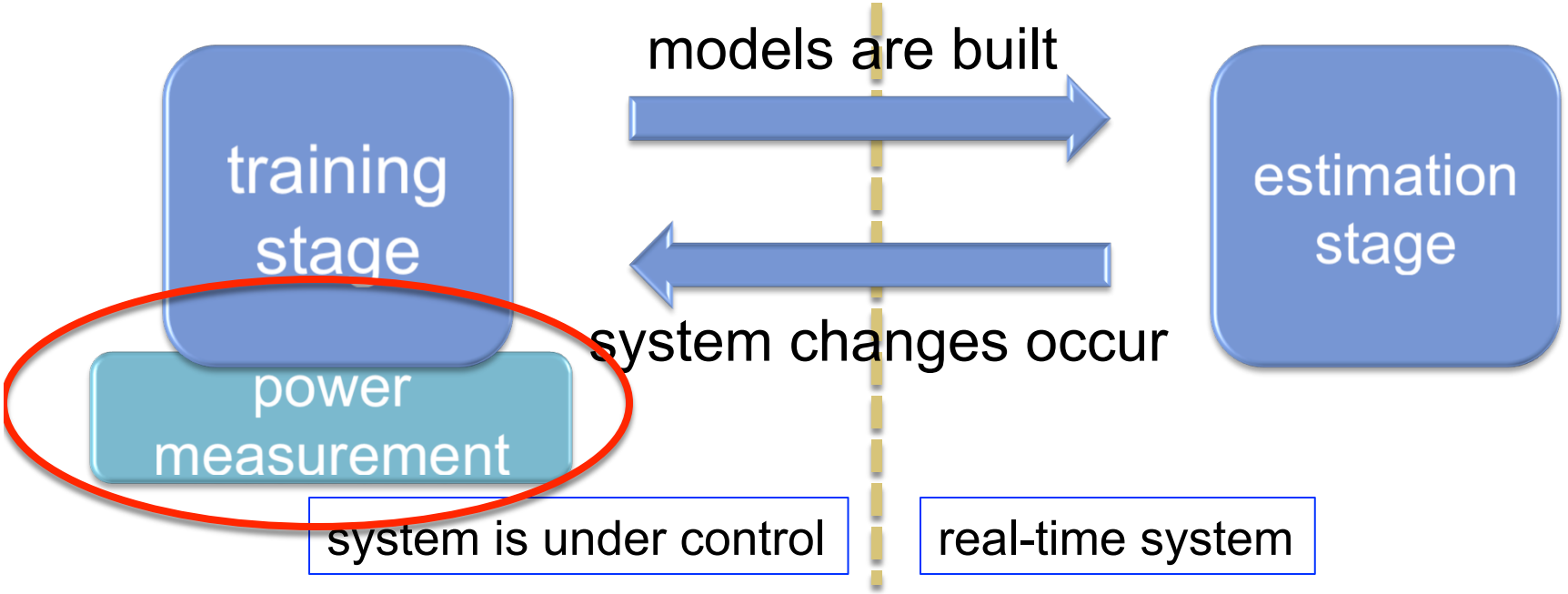
Resource usage
Sampled CPU utilizations
Sampled Screen backlight levels
…

Power consumption
Voltage
Discharging current

P = V * I

models
Linear
Nonlinear
…

Requirements of Power modeling

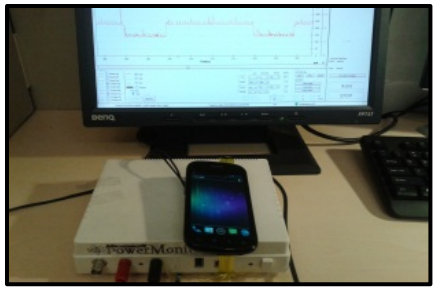


Every phone is unique → Personalized models

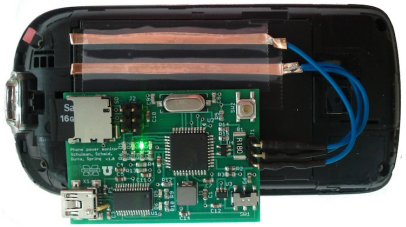
1 User activities are not expected
In training stage
2 Model adaption is needed
→ Fast training

External Metering

- Measure **V** and ***I*** from external hardware
  - Calculate power from ***V * I***



Monsoon power monitor



BattOr power monitor

  - Drawbacks
    - Labor-intensive
    - Inflexible/inaccurate
    - Expert knowledge required

Self Metering

- Measure ***V*** and ***I*** from interior battery interfaces
  - Battery interfaces are registers exposed by battery fuel gauge IC

  - Disadvantage
    - A large number of existing phones cannot support, e.g., Galaxy Nexus

SOD Approach

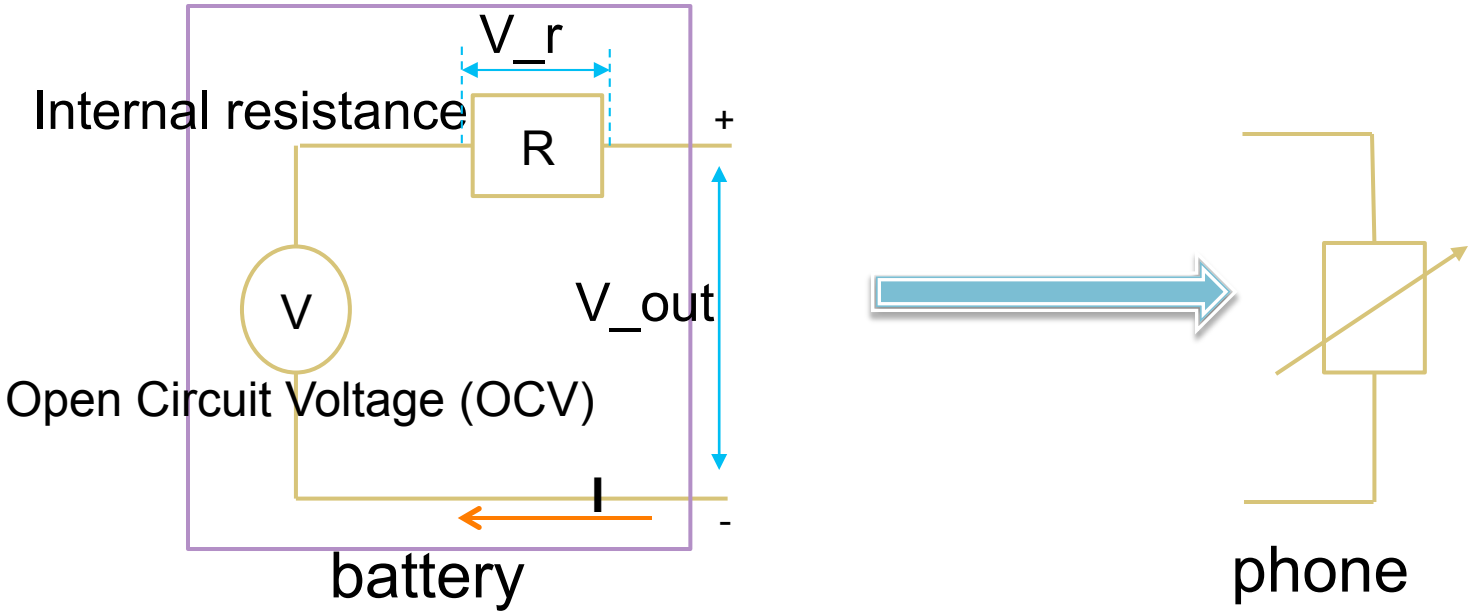
- Self metering with SOD (State of Discharge)
  - SOD: percentage of energy left in battery

 SOD 70%  SOD 100%

  - Calculate power from the SOD changes
  - Limitations
    - Slow
      - There are only 100 discrete SOD values
      - Wait a long time period to observe value changes
    - Inaccurate

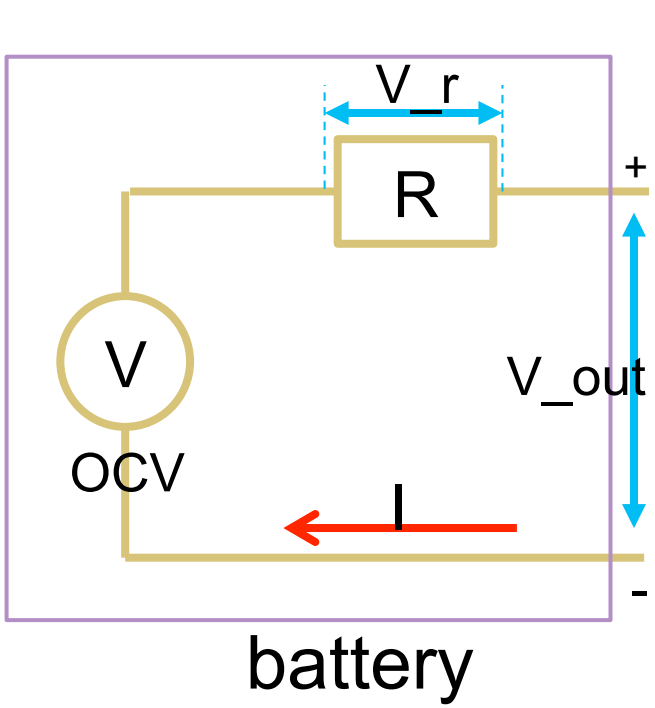
V-edge Metering

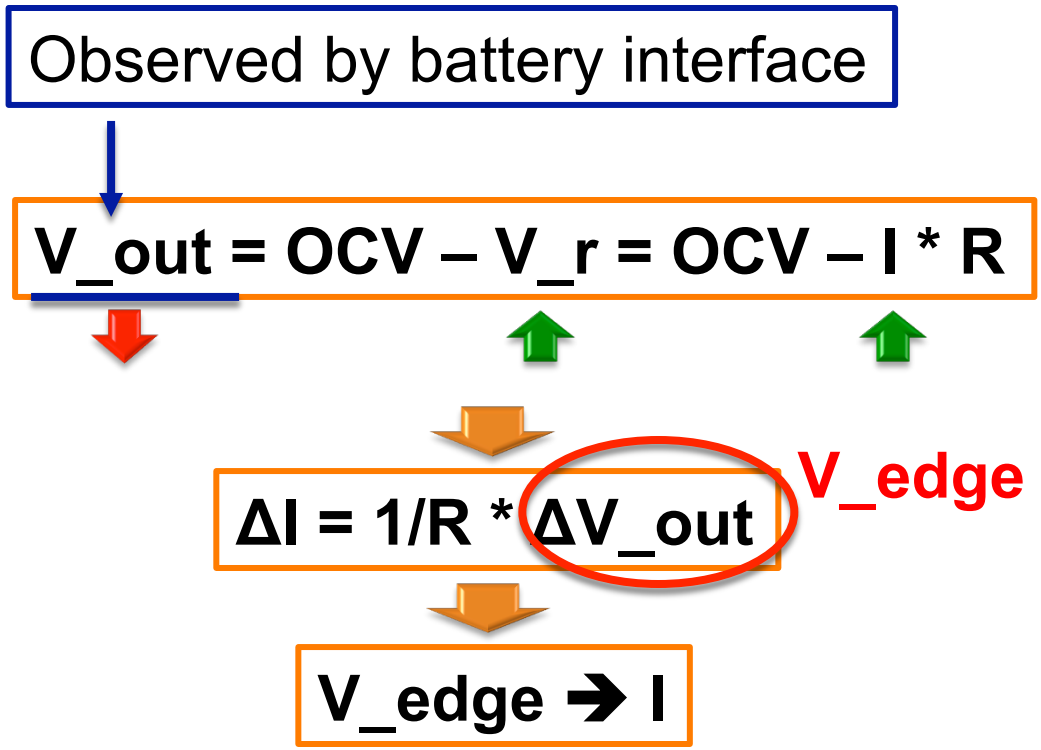
- Leverage battery characteristics
  - Instantaneous current changes lead to instantaneous output voltage dynamics



Battery Dynamics

- Discharging current changes lead to output voltage dynamics



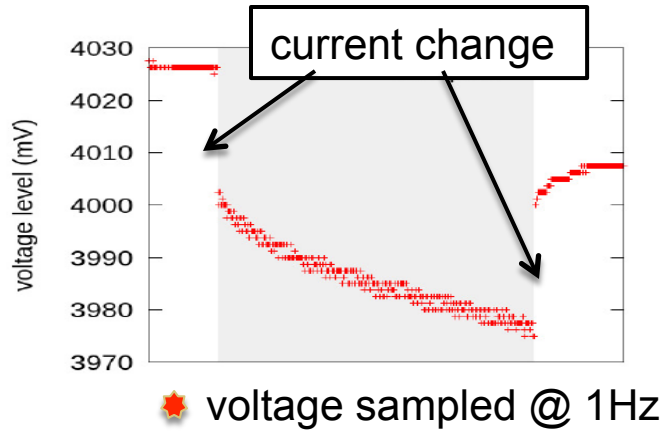


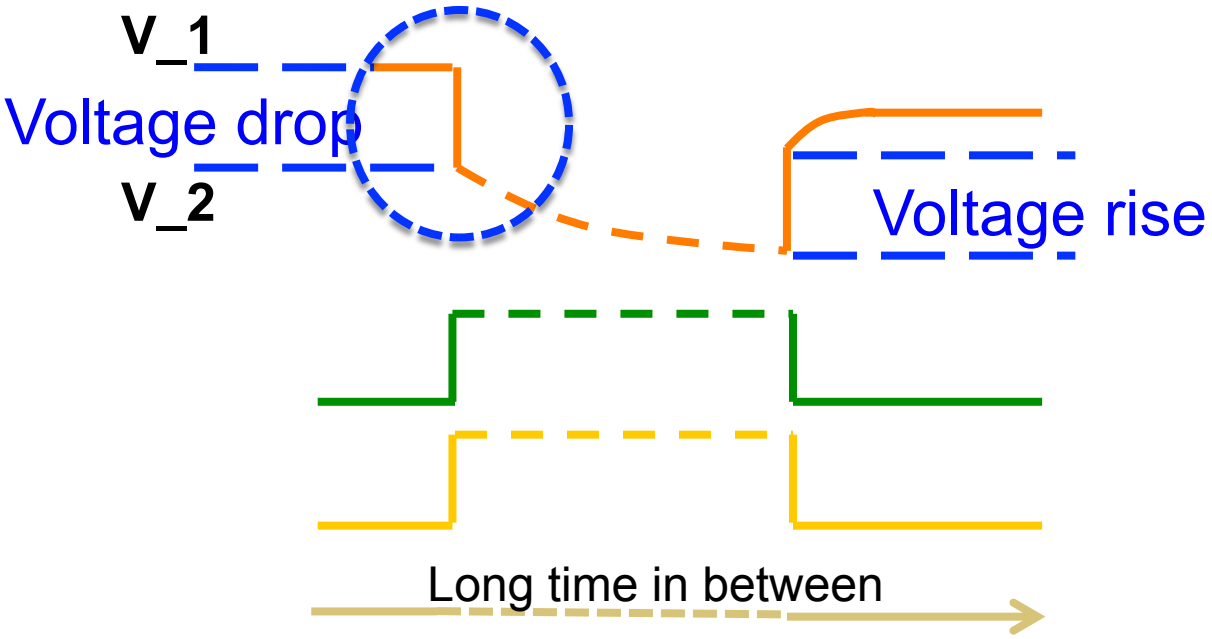
we can infer current from voltage dynamics

Theory vs. Experiment

- V-edge: voltage difference before and after an operation

V_edge = V_1 – V_2

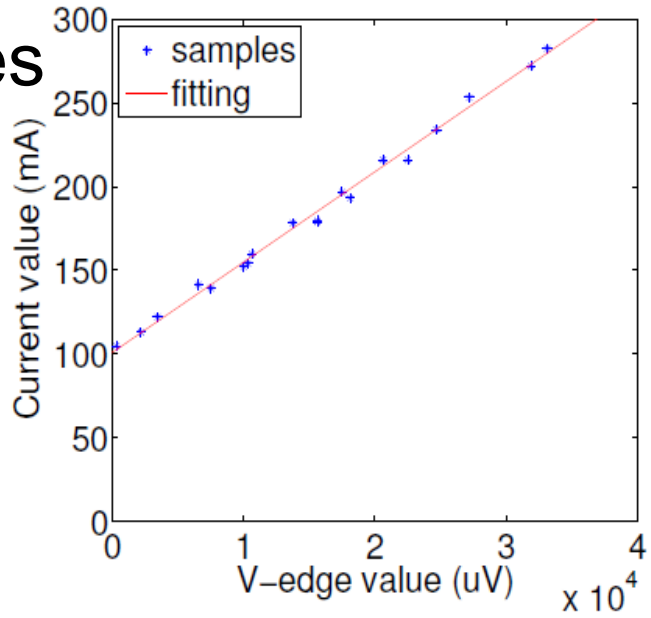




V-edge is Accurate

- Stable linear relationship between V-edge and current change
  - Test on 8 batteries of two phones
  - Various current change cases
  - Coefficient of Determination

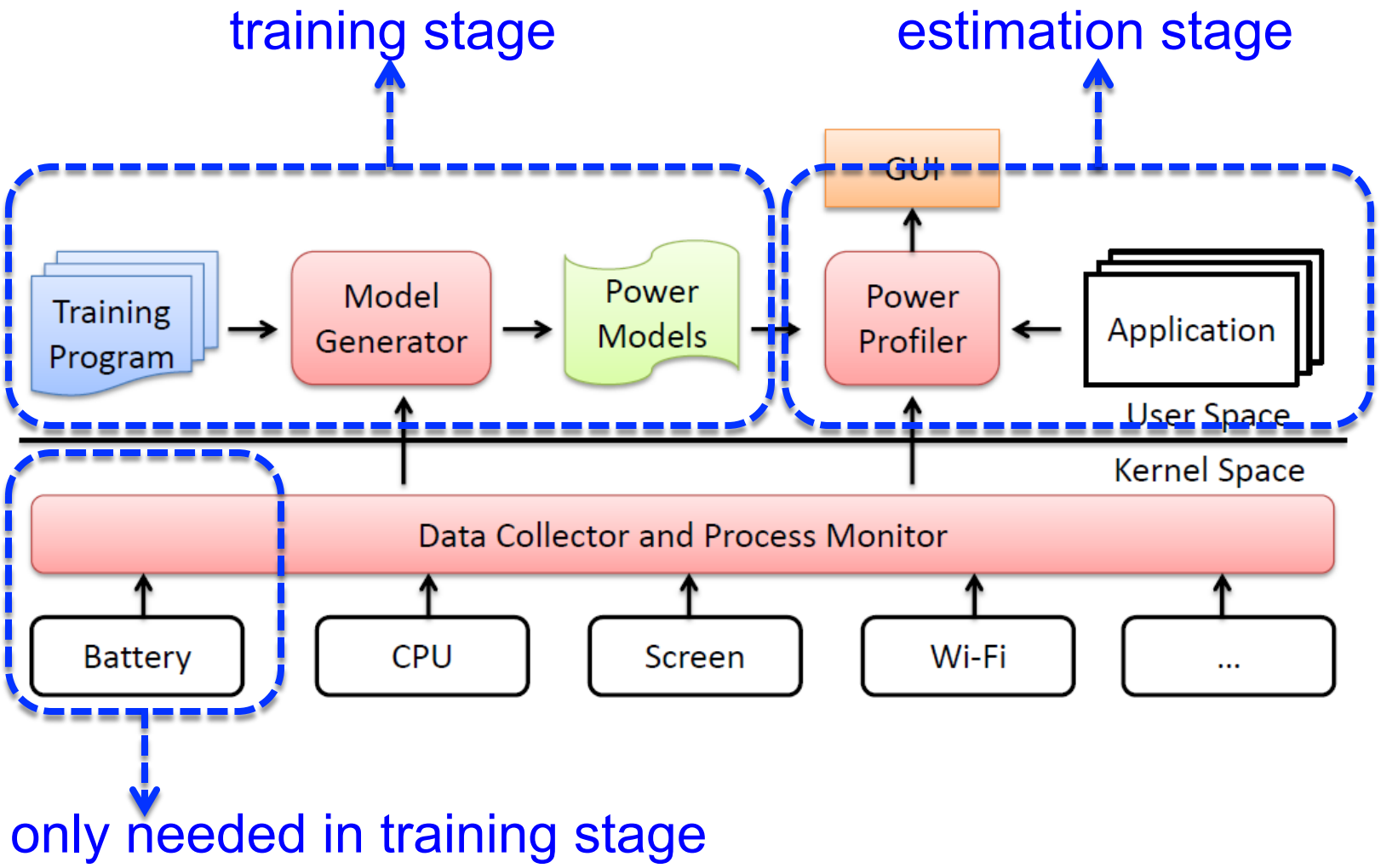
    R^2 > 0.995



V-edge is Fast and Sensitive

- Fast
  - As fast as battery interface update rate
    - E.g., on Nexus S, ¾ sec (V-edge) V.S. 15 min (SOD)
- Sensitive
  - Detect 4% CPU usage change with 100% success ratio
- Fine-grained V-edge resolution

V-edge Implementation



Model Considered

- CPU
  - Frequency ***f*** and utilization ***U***
    - $P = a\_f * U + b\_f$
- Screen
  - Backlight level ***L*** and average pixel color ***RGB***
    - $P = F(L) * (c\_r * R + c\_g * G + c\_b * B)$
- Wi-Fi
  - Throughput ***D***
    - $P = d * D + e$
- GPS
  - Service status ***S***
    - $P = f * S$

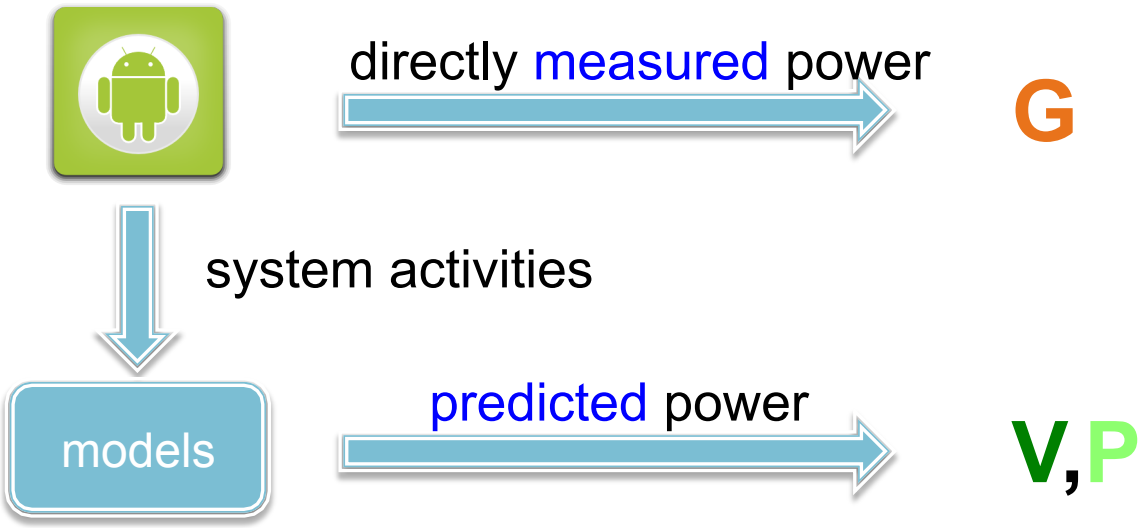
Evaluation

- Training overhead
  - 400+ training programs → 1.2 h building time
  - 100X faster than SOD
- Accuracy
  - Real energy consumption error
    - Stricter than model parameter comparison
  - Component model
    - Random benchmarks on CPU, screen, …
  - Real applications
    - Include video playback, VoIP call, web browsing …

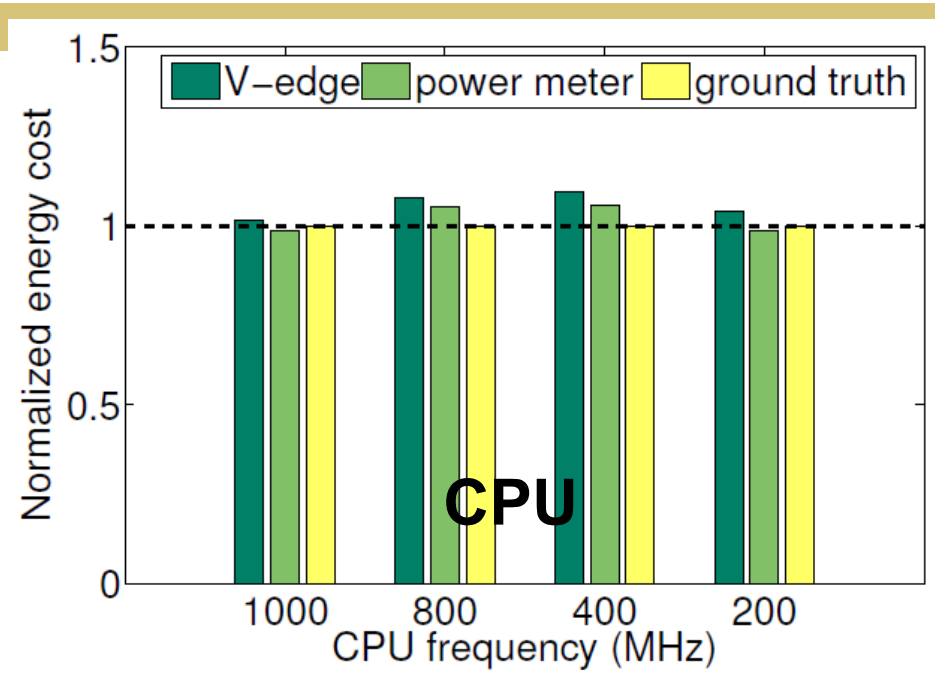
Accuracy

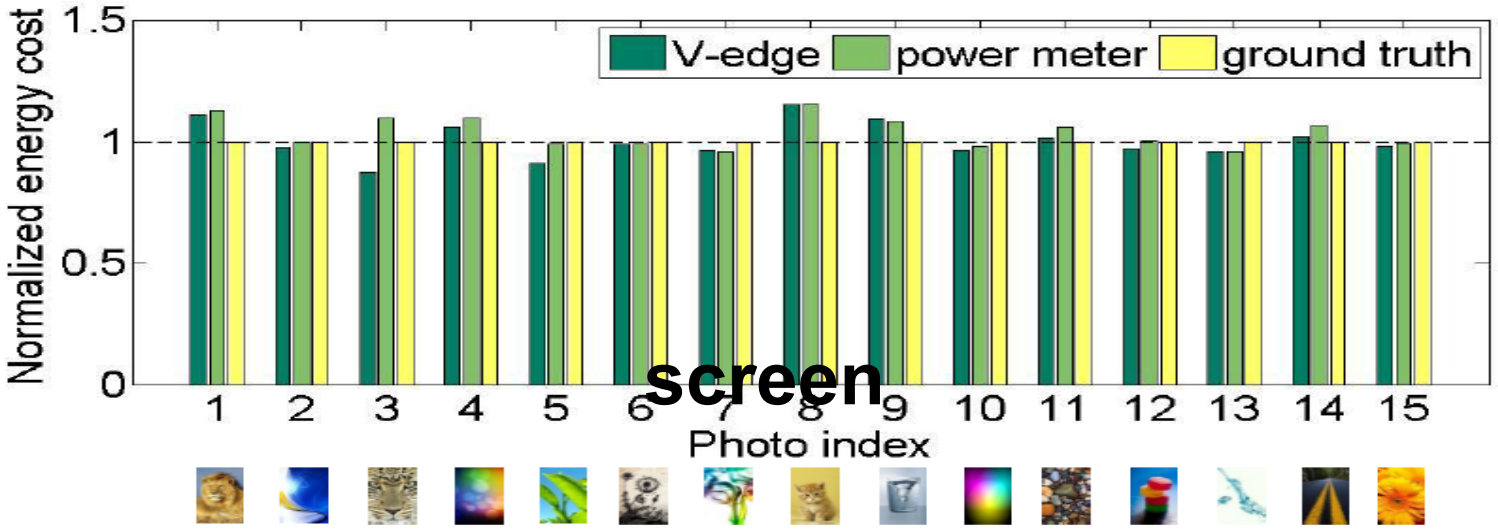
Comparison:

- G: ground truth measurement
- V,P: estimations using models
  - V: V-edge
  - P: external-metering-based



Accuracy – CPU and Screen





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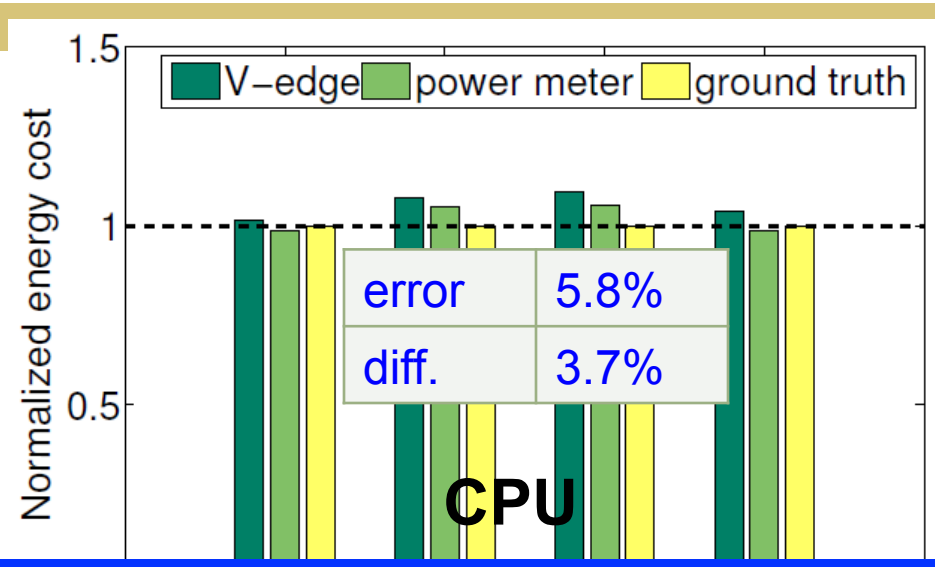
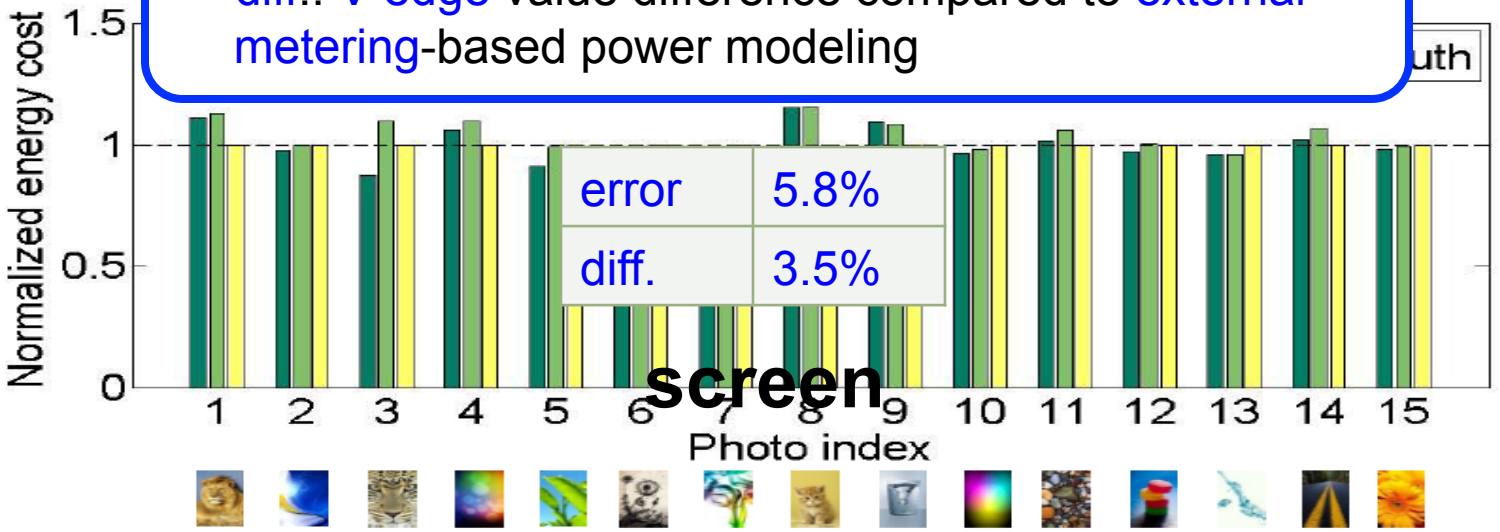
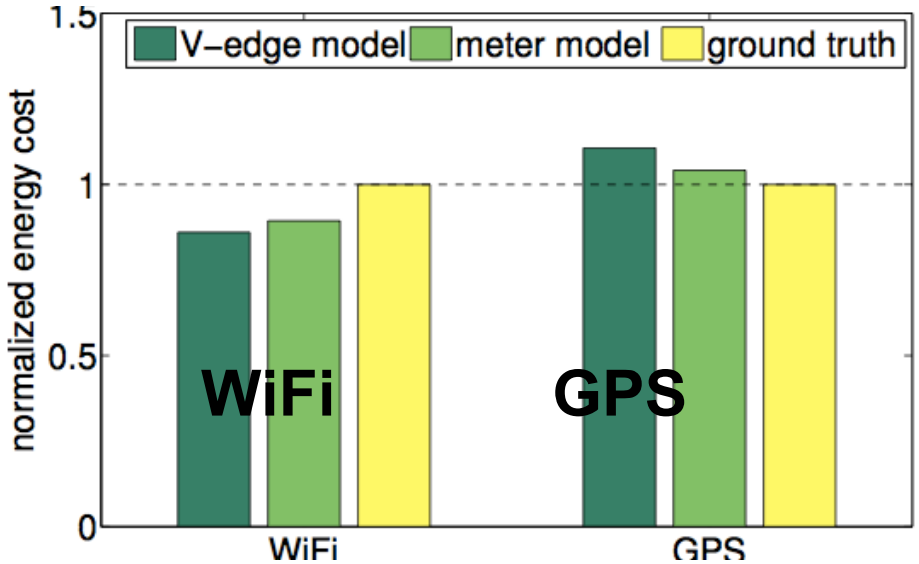
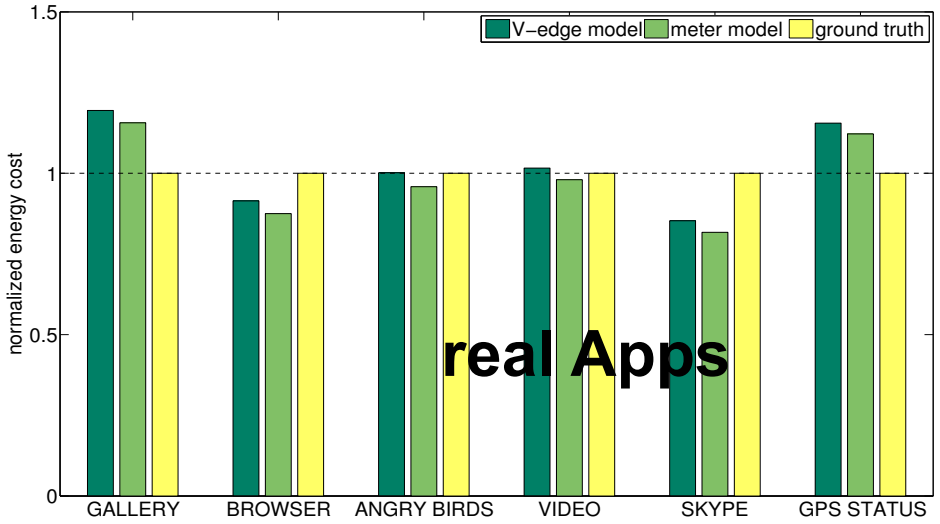


- error: V-edge error compared to ground-truth
- diff.: V-edge value difference compared to external-metering-based power modeling



Accuracy – WiFi, GPS, and Apps





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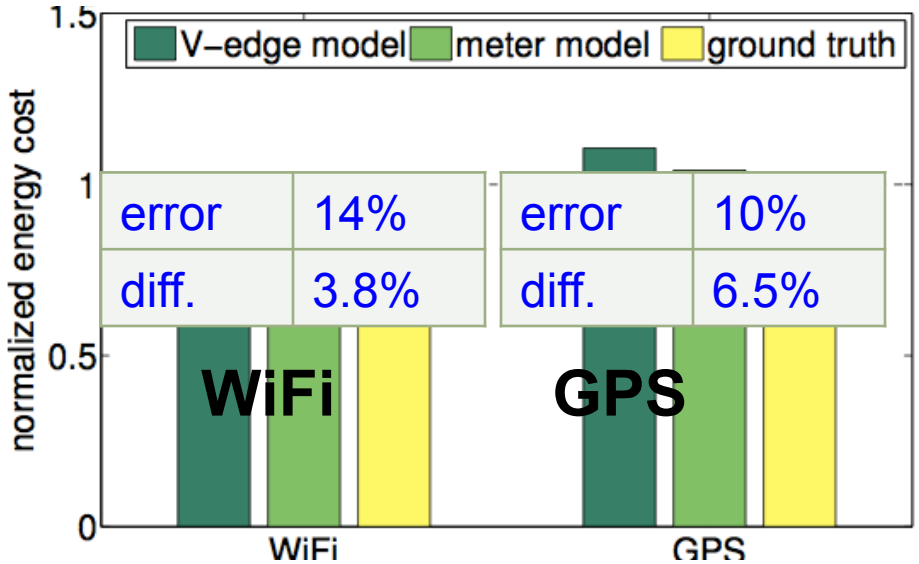

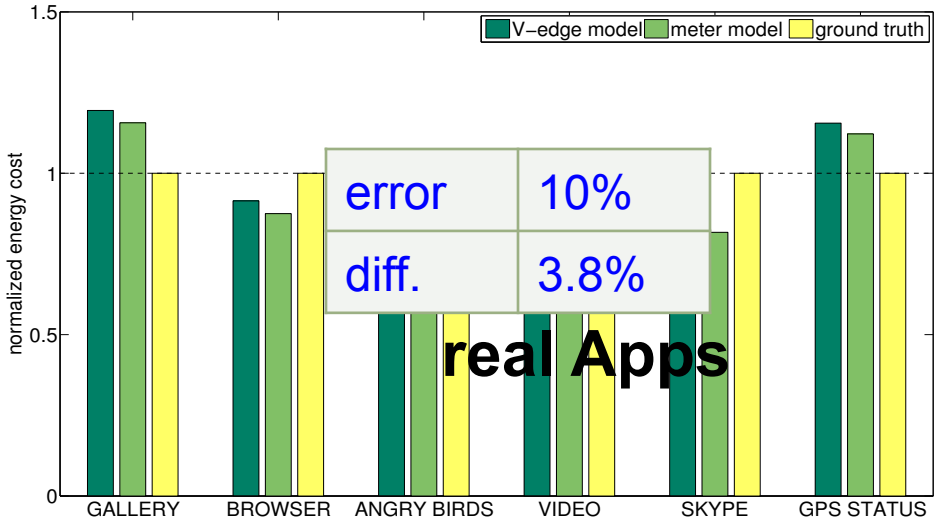

Conclusions

- Key finding on battery powered devices
  - current change can be determined from instantaneous voltage change
- A new self-constructive power model building with only ***V*** readings
  - Works for most phones
  - 100X faster than SOD method
  - Within 4% difference to models using external metering
- Evaluations demonstrated the effectiveness in power modeling

Thank you

- Any questions?