Dartmouth

CLEMSON UNIVERSITY

Amulet: An Energy-Efficient, Multi-Application Wearable Platform

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amulet

amulet-project.org

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Wearables

Wristbands

Long lived wearables usually for fitness sensing, with longer lifetimes, but closed source and hardware.

Smartwatches

Very flexible development platforms, with short lifetime, often closed operating systems and hardware.

Tradeoffs

Wristbands

Pros:

- Long lifetime

Cons:

- Closed platform
- Not flexible

Smartwatches

Pros:

- Flexibility

Cons:

- Closed hardware or software
- Short lifetimes

Shortcomings

Flexibility

- Not open

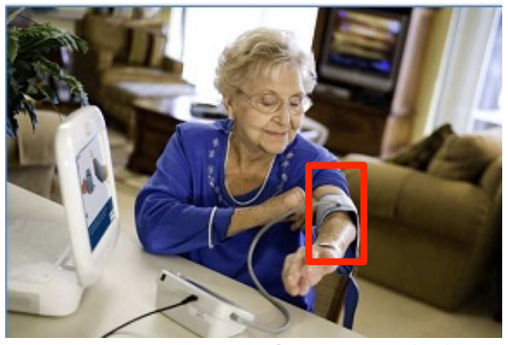
Lifetime

- Does not enable mHealth

mHealth

mobile systems in healthcare

Courtesy: http://sarahcait.blogspot.com/



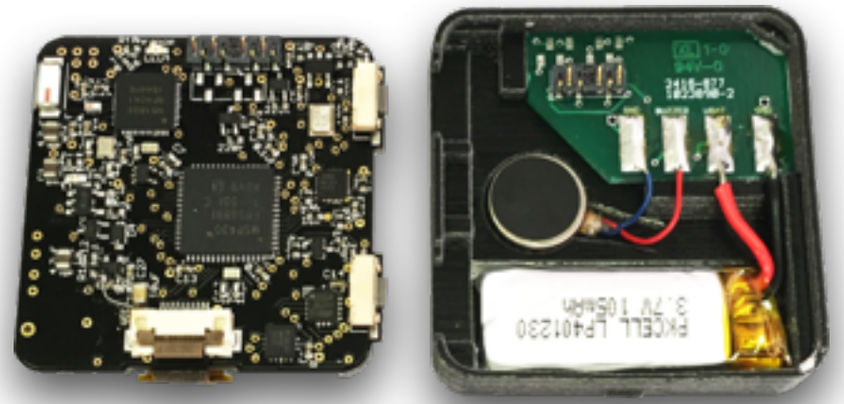
Courtesy: experientia.com

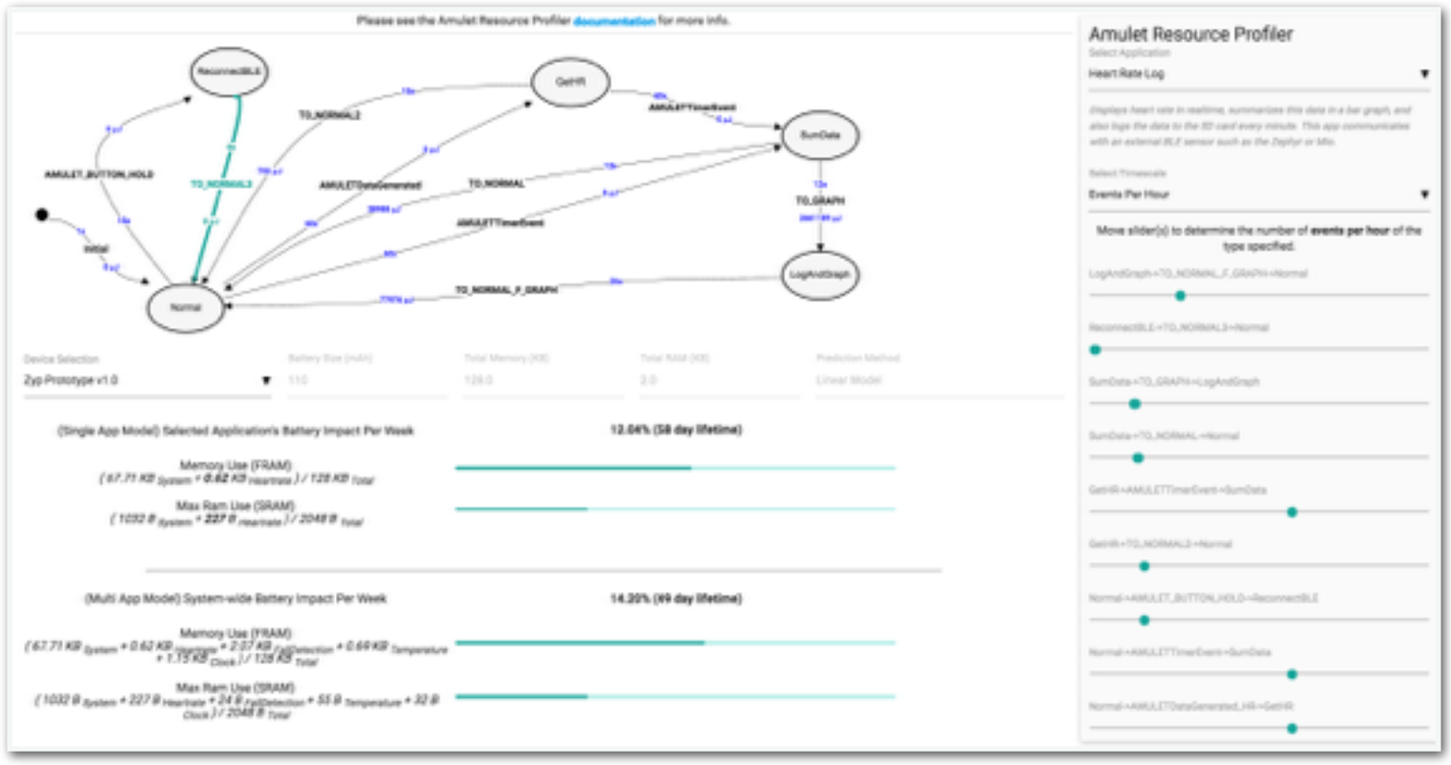
Courtesy: good.is

Courtesy: seniorcarecenter.com

Courtesy: sana.mit.edu

Amulet Platform





This Talk

1. Design

2. Implementation

3. Evaluation

Design

Multiple applications

- Need app isolation

Long battery lifetime

- Designed for low power operation

Developer tools

- Focused on energy

Usable

Open Source and Hardware

Multi Application

Flexibility

- Multiple developers, multiple apps
- Users have different needs

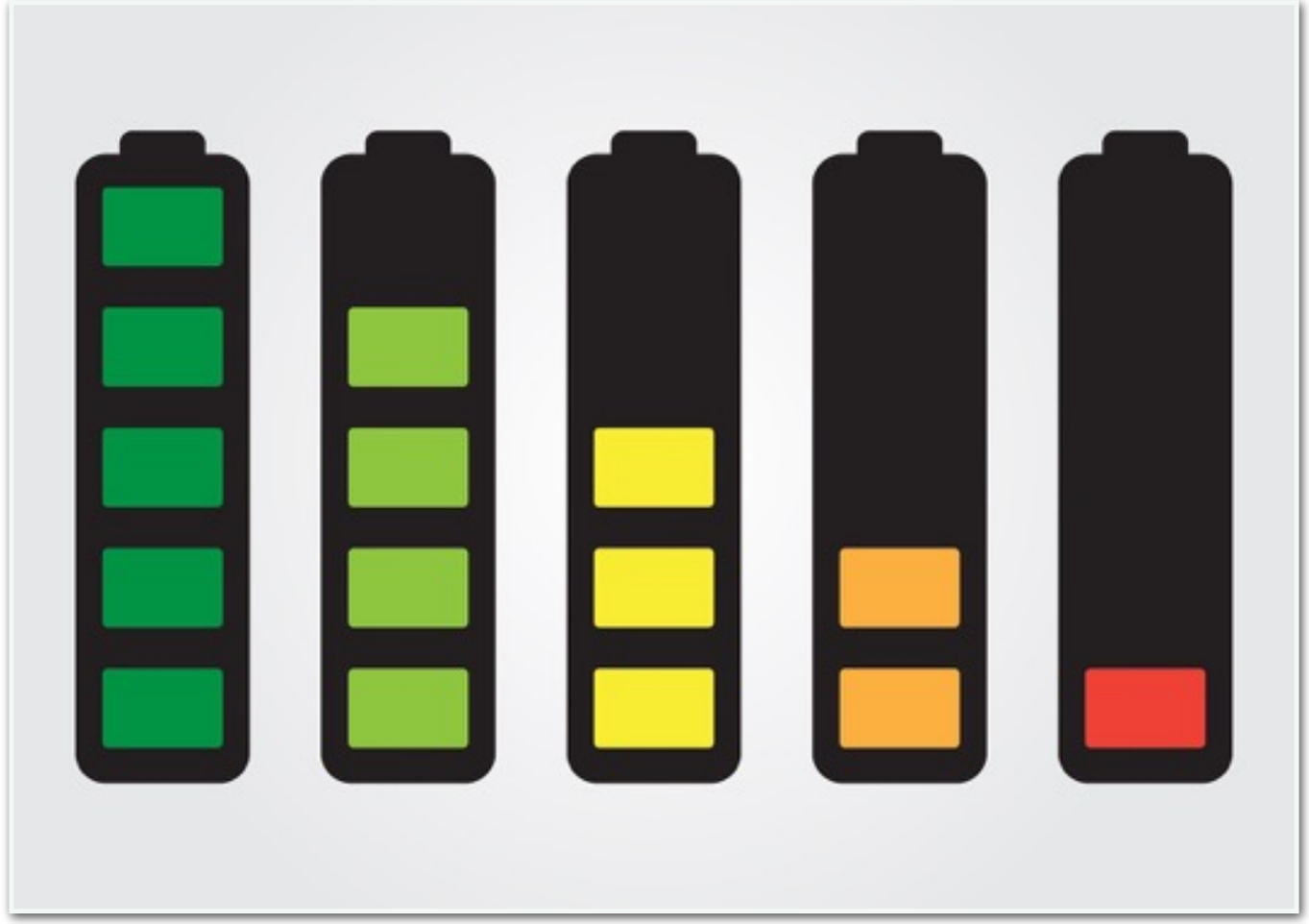
Security

- Sandboxing for isolation among apps
- Access control for sensors, peripherals

Lifetime

Need weeks and months

- Not hours and days!
- Support long term studies, deployments



Developer Tools

1. Where is my energy going?

2. How does the environment, and the user behavior change energy?

3. What can I change in my code to increase the lifetime?

Open

Open Source

- Use, adapt, change

Open Hardware

- Remix, redo, enhance

Amulet

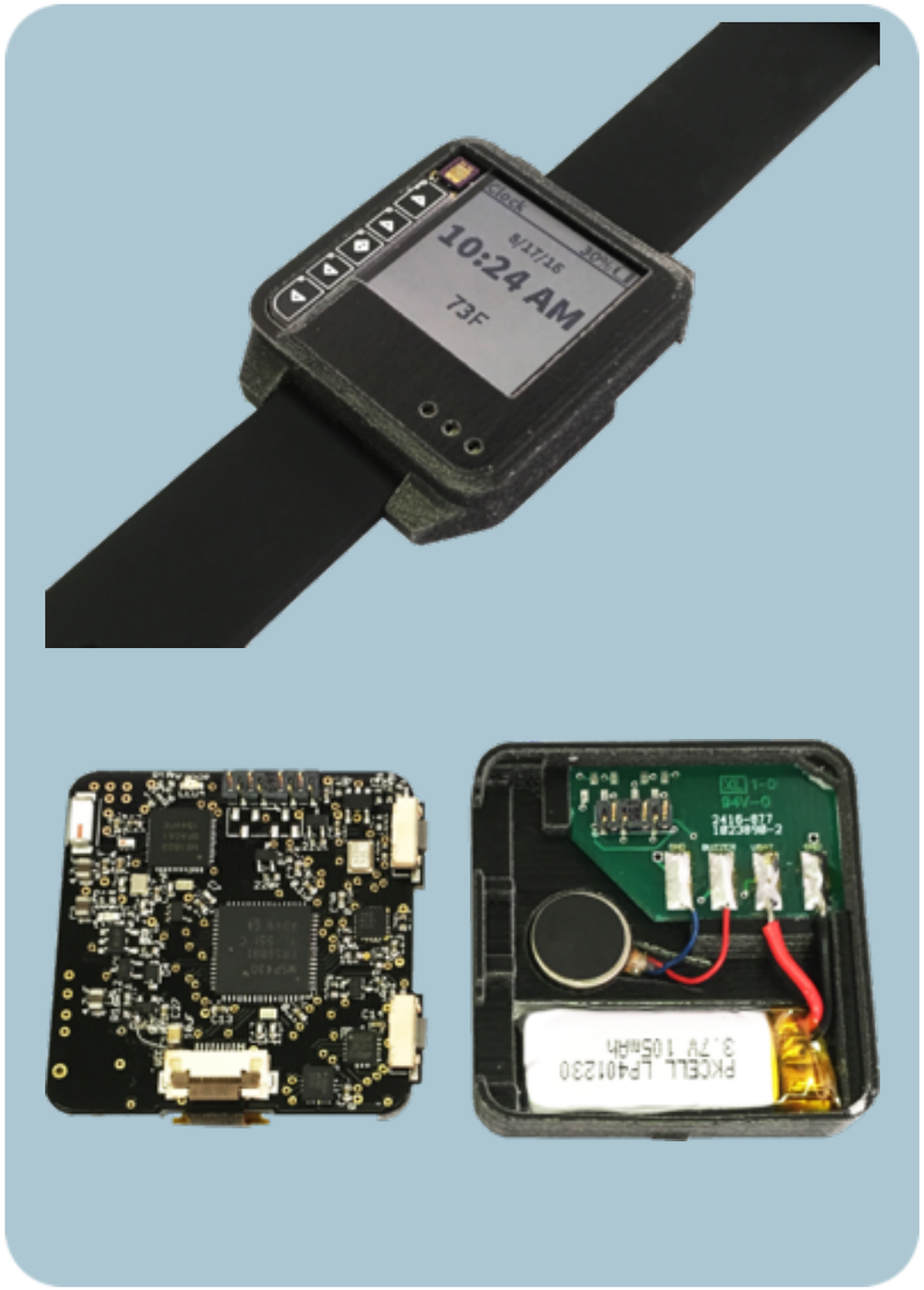
1. Open Hardware Wearable

2. Amulet-OS and API

3. Amulet Firmware Toolchain

4. Amulet Resource Profiler and UI

Device



Sensors

- 3-axis gyroscope, ST Electronics L3GD20H
- 3-axis nano-power accelerometer, Analog ADXL362
- Ambient light, UVA/B, temp, sound, battery

Computing

- Nordic nRF51822, ARM Cortex M0, 32K RAM, 256K FLASH
- TI MSP430FR5989, 2KB SRAM, 128KB FRAM
- microSD card slot

Network

- BLE radio (Central & Peripheral)
- Supported protocols: heartrate, battery, running services

Output

- Monochrome 128x128 Sharp Memory LCD
- or two single color LEDs
- haptic feedback via vibrator motor

Input

- two buttons
- capacitive touch slider
- accelerometer

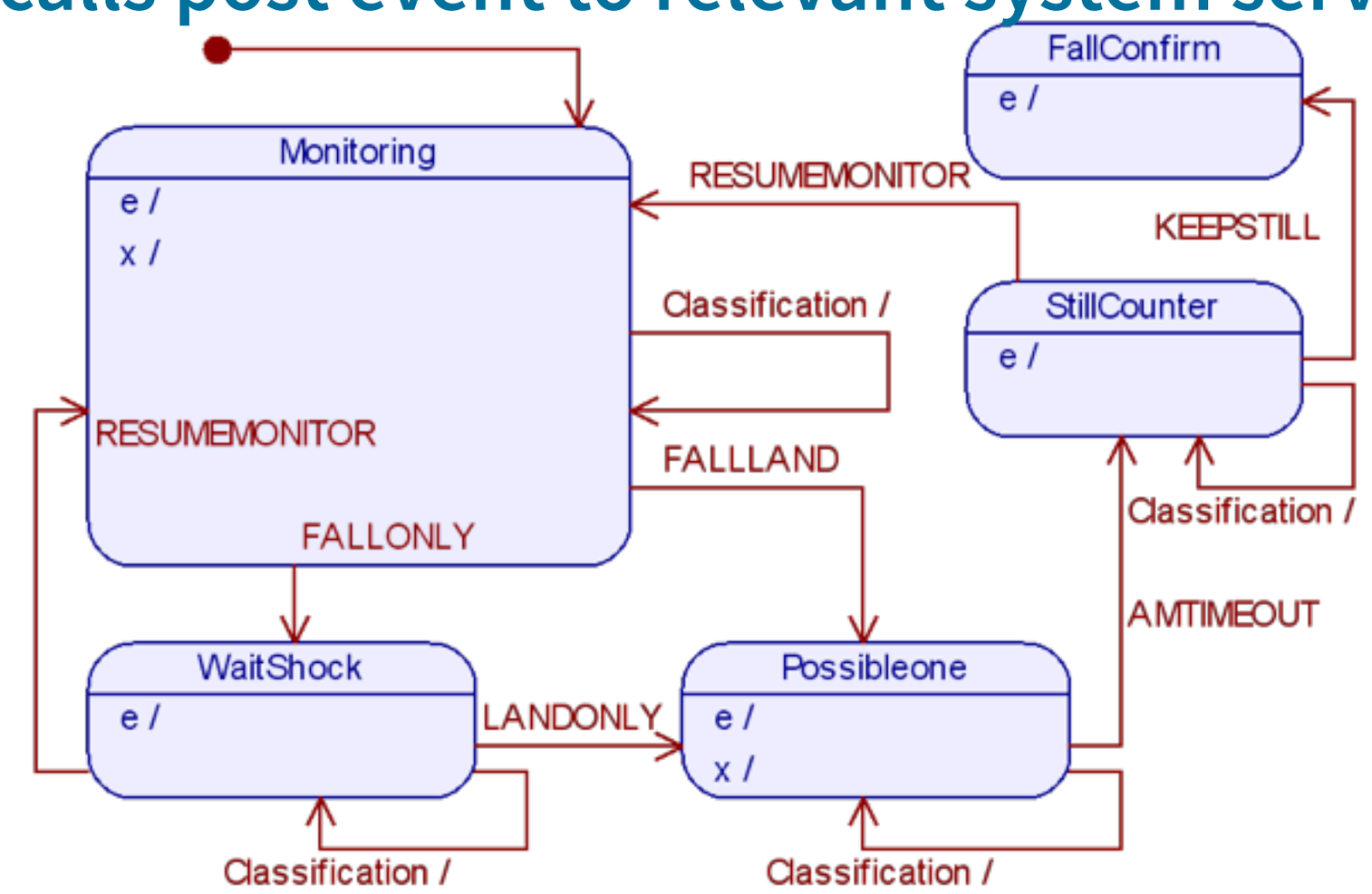
Battery

- Polymer Li-Ion,110 mAh, 3.7V,MCP73831 recharge

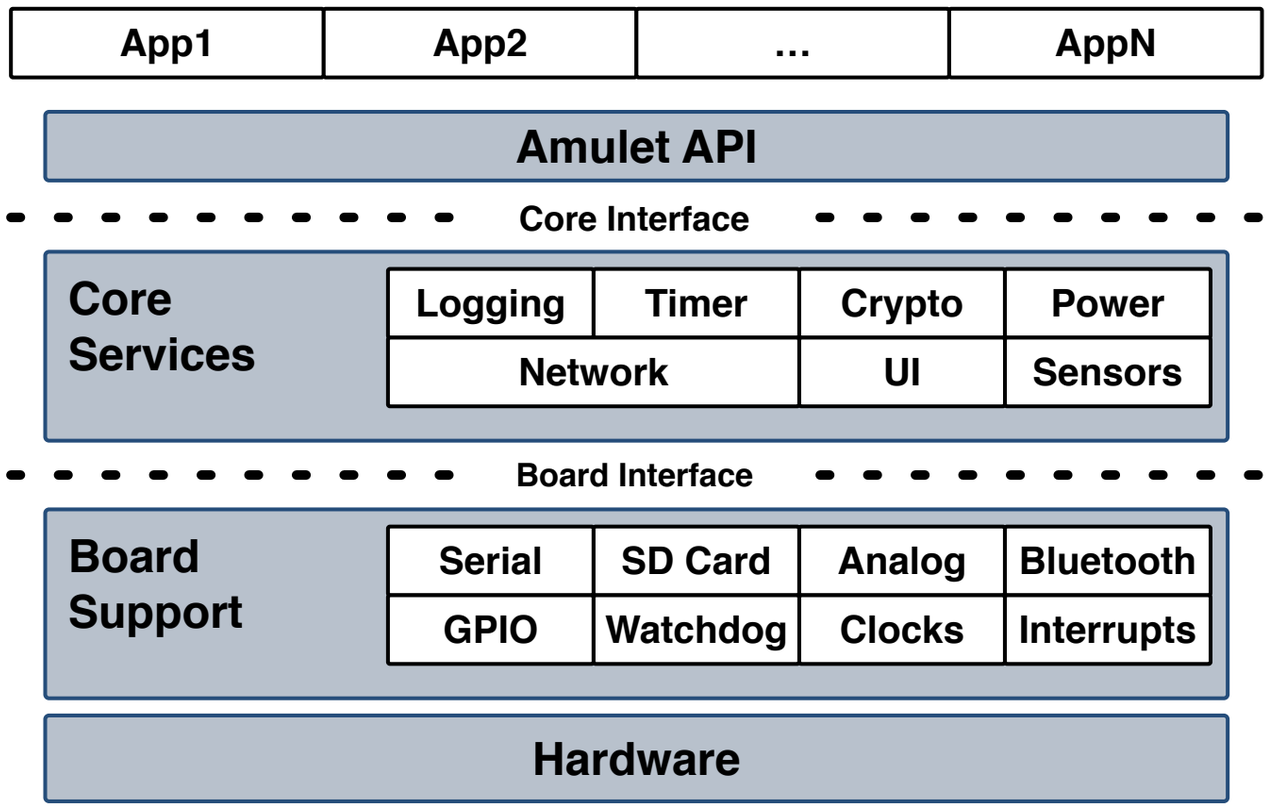
Amulet-OS

Apps: finite-state machines w/memory

- set of *states*, *variables*, and *event handlers*
- all state is explicit, in non-volatile storage
- no threads: handlers run to completion
- API calls post event to relevant system service



Amulet-OS




```
...
void AmuletSubscribeInternalSensor(
    uint8_t sensor_id);
uint16_t AmuletGetHR();
uint8_t AmuletGetBatteryLevel();
uint16_t AmuletGetLightLevel();
uint16_t AmuletGetTemperature();
uint16_t AmuletGetAudio();
int16_t AmuletGetAccelX(uint8_t idx);
void AmuletBoldText(uint8_t x, uint8_t y,
     __char_array message);
void AmuletClearRect(int16_t x, int16_t y,
     uint8_t w, uint8_t h);
void AmuletHapticSingleBuzz();
uint8_t AmuletLogAppend(uint8_t log_name,
    __char_array line_contents);
...
```

Subscribe to sensors, log data, communicate, interact.

Amulet Firmware Toolchain

Firmware analysis, translation, compile

- Manage multiple applications
- Analyze for isolation
- Profile for energy and memory usage

App Isolation and Resource Profiling

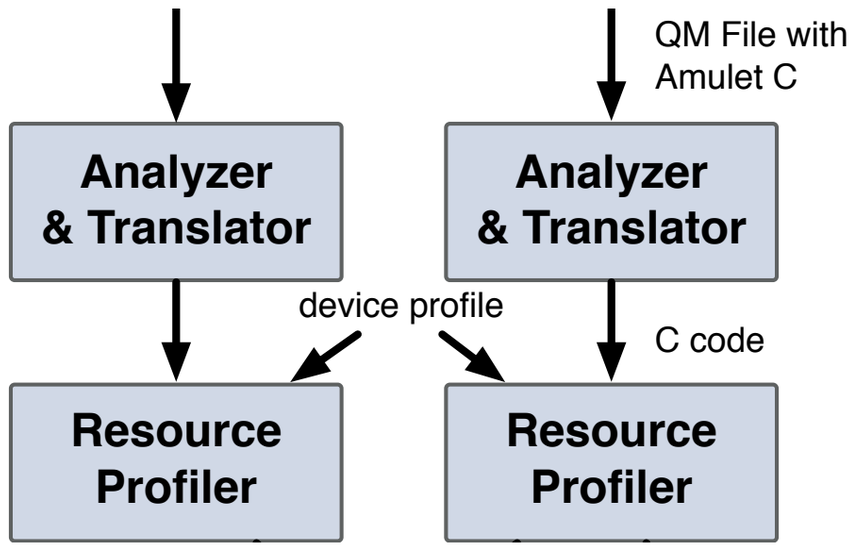
AFT Workflow

Some restrictions on C:

1. no dynamic memory
2. no pointers
3. no recursion

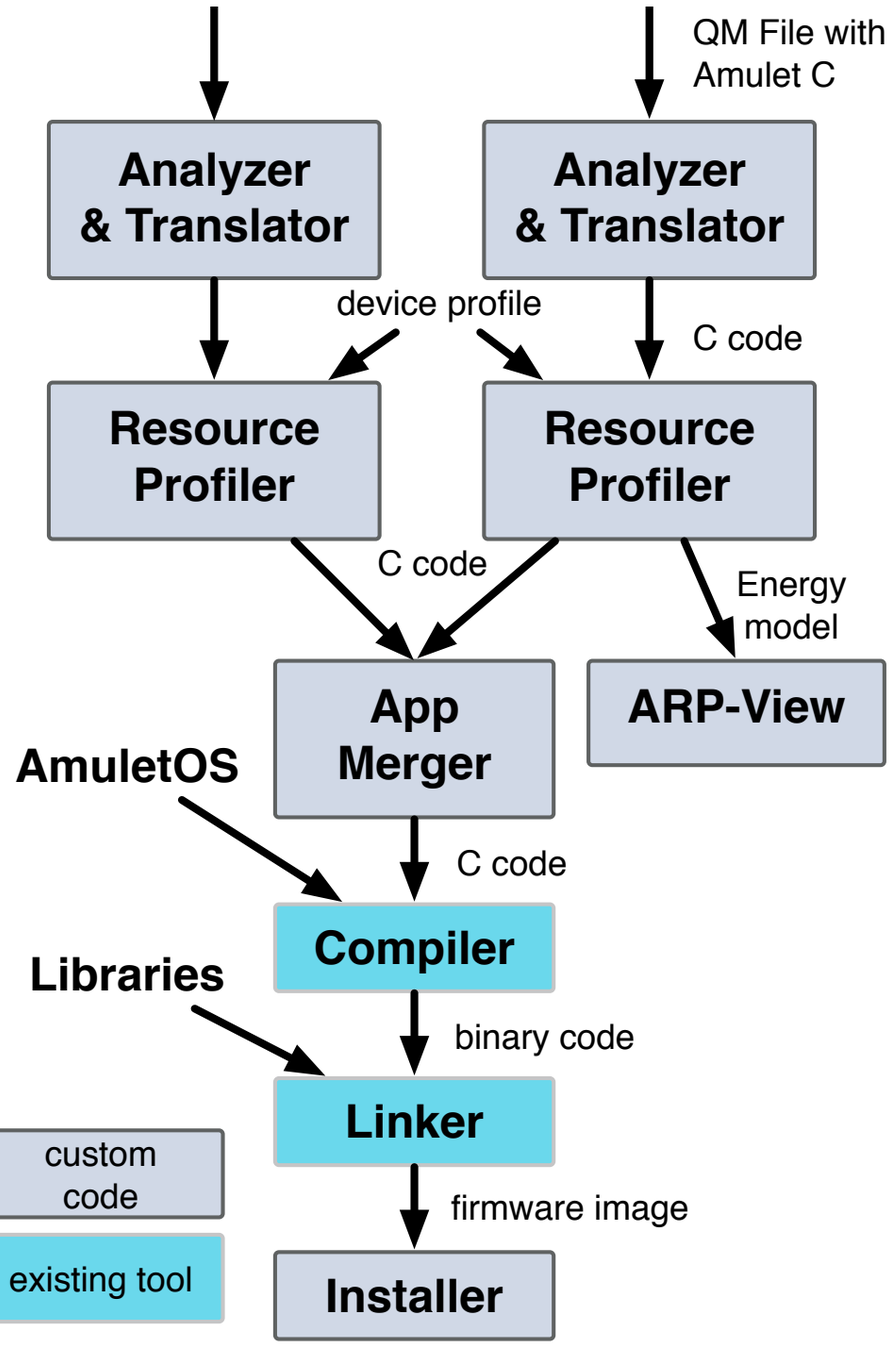
Check app access control and language violations.

AFT Workflow

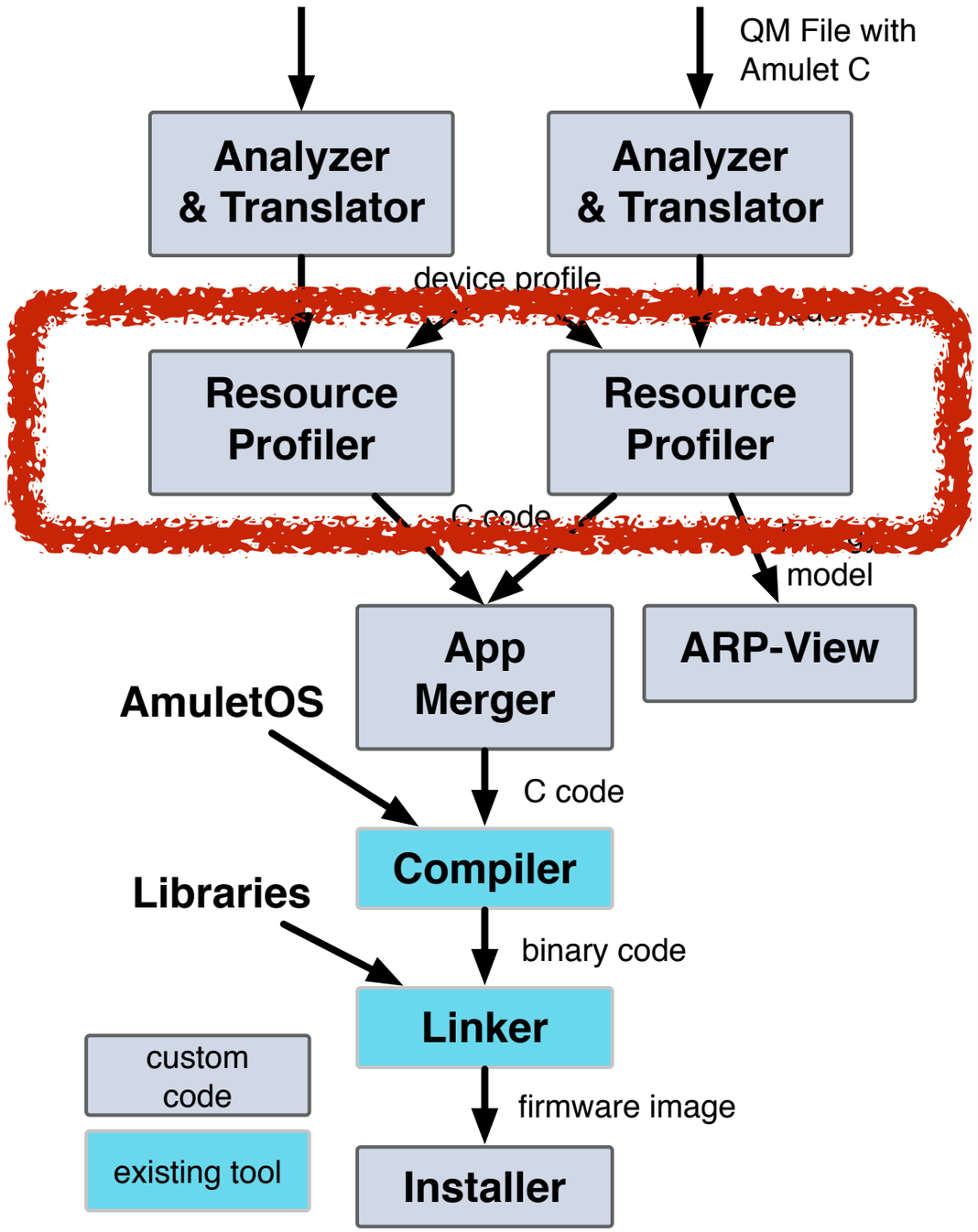


Profile energy and memory resource usage.

AFT Workflow



Amulet Resource Profiler (ARP)



Amulet Resource Profiler

Designing for low power is not enough

- Developers can always write bad apps
- This can be because of ignorance
- Or because tools don't exist!

Must support developers!

Amulet Resource Profiler

89% of users consider battery lifetime the most important feature[1].

Energy is a first class concern for users.

Why not for developers?

[1] “Your smartphone’s best app? battery life, say 89% of Britons.” The Guardian, May 2014

Resource Model

Concerned with energy

- Secondary concern: memory

Model the device itself

- One time, at device manufacture

Model the application(s)

- Compile time

Device Energy Model

Device Profile

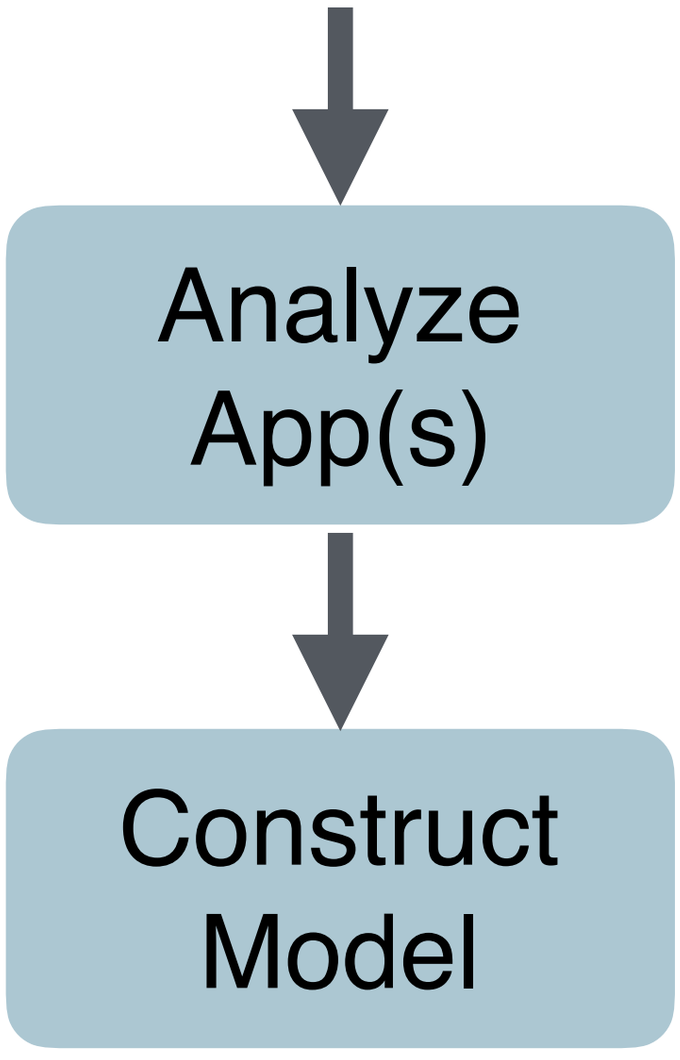
Hardware Info

- Steady state draw
- Sleep currents
- Sensor power costs
- Device memory
- API Calls

Generated once per device type.

App Energy Model

Device Profile




```
// Update temperature if changed:
uint8_t new_temp = AmuletGetTemperature();

if (new_temp != temp) {
    temp = new_temp;
    char temp_disp[5];
    AmuletITOA(temp, temp_disp);
    char F[2] = &amp;quot;F&amp;quot;;;
    AmuletConcat(temp_disp, F);
    AmuletClearRect(0,75,
      LCD_HORIZONTAL_MAX, MEDIUM_FONT_SIZE);
    AmuletMediumCenteredText(75, temp_disp);
    refresh_display = 1;
}
```

ARP-View

Interface for energy insights

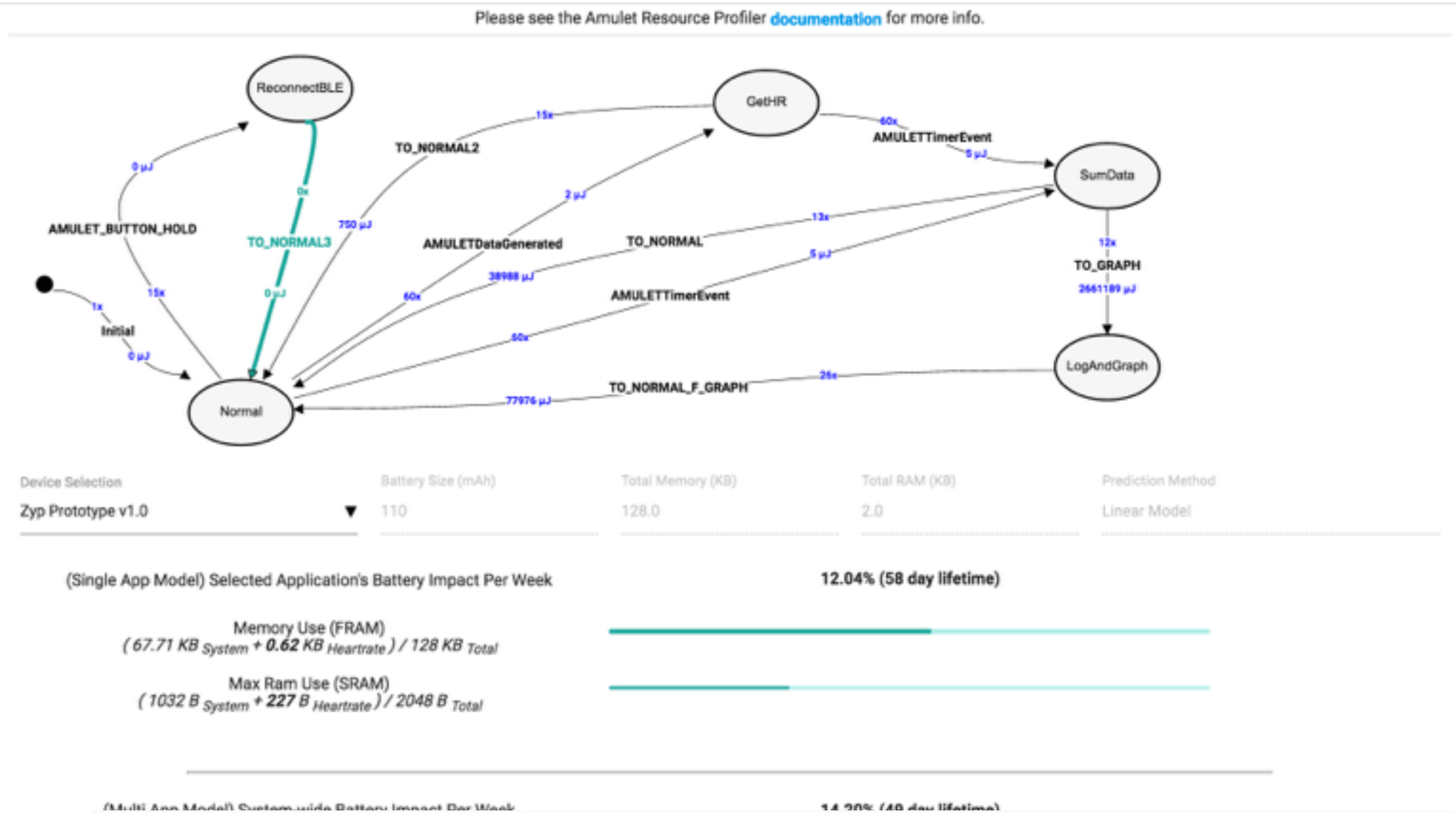
- Generated at compile time

Can model user behavior

- Model environment triggers as well

Explore design tradeoffs

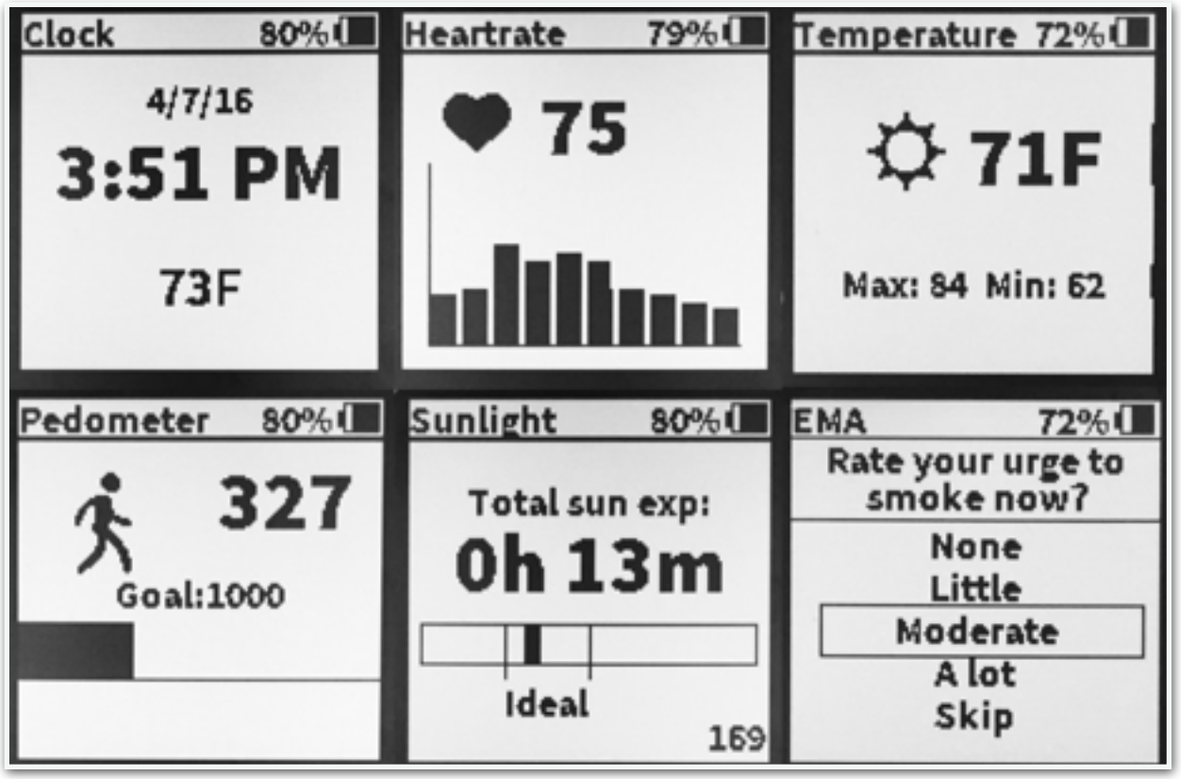
ARP-View

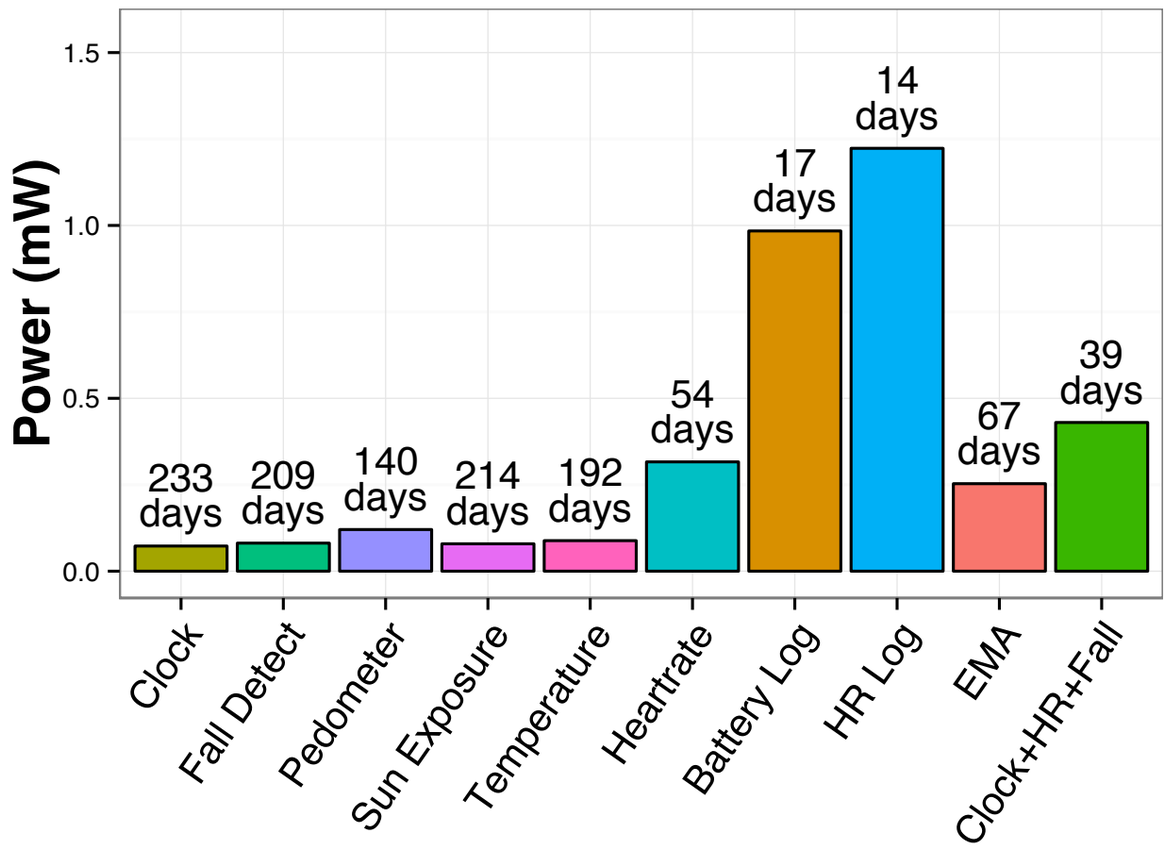


Energy focused development.

Evaluation

1. Battery Lifetime

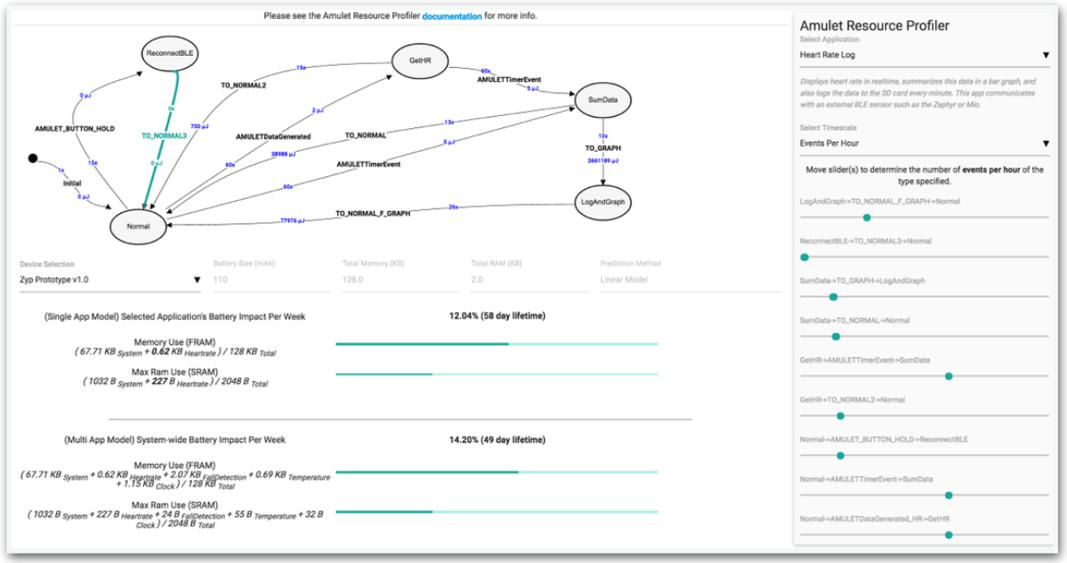


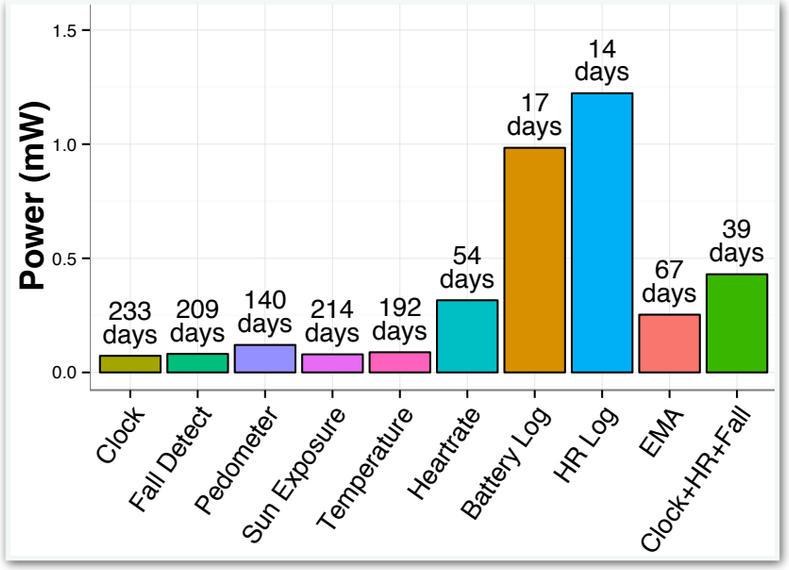


Battery lifetimes ranging from 2 weeks, to 8 months.

Evaluation

ARP Prediction Accuracy





Predictions

Actual

Prediction accuracy of 90-98% for our apps.

User Study

ARP-View: usability and energy

- what is the developer energy mental model?
- does ARP-view force devs to think about energy?
- 10 programmers, 30 minute task and survey
- 9/10 subject reported positive outcomes

ARP-view assists developers.

Pilot Study

mHealth: smoking cessation surveys

- monitored heart rate using BLE
- presented surveys at intervals during the day
- recorded survey responses and heart rate
- 6 participants, 1 week, 48 hours of deployment
- usability survey that informed hardware rev(s)

Demonstrates mHealth feasibility.

Evaluation

Great battery lifetimes

- 2 weeks to 8 months

Accurate prediction results

- 90-98% accuracy

Usable by users, researchers, and developers.

Future

Secure firmware toolchain

- OTA firmware updates and security

Body are health network (BAHN)

- Extending the reach of Amulet

Energy Harvesting Wearables

- Solar, or vibration powered, no charging!

Priority: Enabling your applications!

Summary

Amulet is…

1. Open source, open hardware, multi app wearable device

2. Firmware toolchain isolating applications and resource profiling.

3. Energy focused application development with ARP-View

amulet-project.org

https://github.com/AmuletGroup/amulet-project