**Mining Data from Mobile Devices**

**Mobile technology overview**

*Spiros Papadimitriou, Tina Eliassi-Rad*

---

**Mobile OSes**

- iOS
- Android
- Windows Phone
- Blackberry
- Symbian
- (Ubuntu, Mozilla, OpenMoko, …)

---

**Why do you care?**

- What is possible?
- What might be possible?
- What is not possible?

A basic understanding of the realities helps make realistic assumptions about

- Collection
- Transmission
- Processing

---

**Overview**

- Sensors & location API
- Network connectivity
- Power
- Accounts (“identity”)
- Mobile app basics

---

**Smartphone sensors**

*(Android)*

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Type</th>
<th>Avail. since</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Light</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Proximity</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Temperature</td>
<td>HW</td>
<td>1.5 (4.0)</td>
</tr>
<tr>
<td>Orientation</td>
<td>SW</td>
<td>1.5</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Pressure</td>
<td>HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Gravity</td>
<td>SW/HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Linear acceleration</td>
<td>SW/HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Rotation vector</td>
<td>SW/HW</td>
<td>2.3</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>HW</td>
<td>4.0</td>
</tr>
</tbody>
</table>

- Hardware or software ("virtual")
- iPhone: more standardized
- Android: greater variety, no minimum required, varied APIs across versions

---

**Accelerometer**

**Introduction**

- Measures acceleration
  - Static (gravity) → orientation
  - Dynamic (linear motion)

- Example: LIS33DLH (iPhone)
  - ~$1.5 (DigiKey, bulk)
  - 0.7mW on / 0.03mW low power:
    - 325 days / 20 years (1440mAh @ 3.8V)
  - ±2g / ±4g / ±8g selectable range
  - 16-bit dynamic range
  - 0.5Hz – 1KHz sample rate
  - Simple interrupt generators (free fall, motion)
**Accelerometer**

**Basics**

- Measures force exerted on device (vector)
- Stationary device, lying flat:
  - Force preventing it from falling (opposite to gravity)
  - Zero force ➔ Free fall
- Stationary device, after 45° rotation:
  - Same magnitude, but rotated

**Example code (1/3)**

```java
public class SensorActivity extends Activity implements SensorEventListener {
  private SensorManager mSensorManager;
  private Sensor mAccelerometer;

  @Override
  public final void onCreate(Bundle savedInstanceState) {
    mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
    mAccelerometer = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
    mSensorManager.registerListener(this, mAccelerometer, SensorManager.SENSOR_DELAY_NORMAL);
  }

  Android (1/2) [continued]
```

**Example code (2/3)**

```java
@Override
public final void onSensorChanged(SensorEvent event) {
  float ax = event.values[0],
  ay = event.values[1],
  az = event.values[2];

  ... // SensorActivity
```

**Example code (3/3)**

```java
@Override
public final void onAccuracyChanged(Sensor sensor, int accuracy) {
  ... // SensorActivity
```

**Shortcomings**

- Cannot distinguish between gravity and acceleration
- Impossible: "equivalence principle"
- Solution: use low-pass filter to estimate gravity
- What if device simultaneously rotates & linearly accelerates?
  - Confused; need more data ➔ gyroscope

**Gyroscope**

**Introduction**

- Measures angular speed
  - Degrees per second (dps)

  - Example: L3G4200D (iPhone)
    - ±6.5 (DigiKey, bulk)
    - 18mW on / 4.5mW sleep (0.02mW off):
      - 12.5 days / 50 days
    - ±250dps / ±500dps / ±2000dps range
    - 16-bit dynamic range
    - 100 / 200 / 400 / 600Hz sample rate
    - Temperature sensor (8-bit range)
    - Simple interrupt generator & FIFO
Gyroscope
Basics
• Measures angular speed of rotation
  - Represented by numbers for each axis (but: rotation axis is different)
  - Right-hand rule
• Integrate to obtain orientation
  - …with care, since non-collinear rotations are not commutative

Magnetometer (compass)
Introduction
• Measures direction and magnitude of (Earth’s) magnetic field
  - Example: AK8973/5 (iPhone)
    - <$1 (Wikipedia), ~$2 (AliExpress; non-bulk)
    - 20mW sensor on / 3mW @10Hz:
      11 days / 76 days

Inertial measurement & navigation
• 9 DoF (degrees of freedom) available
  - 3-axis accelerometer
  - 3-axis gyro
  - 3-axis magnetometer
• Combine in software for accurate:
  - Position, velocity, and acceleration (linear and angular)
  - Dead reckoning

Inertial measurement
Gravity estimation
Low-pass filter on acceleration data;
  e.g., on Android Gingerbread:
  \[ g_i = \lambda_0 (a_t + a_{t-2}) + \lambda_1 a_{t-1} - \kappa_1 g_{t-1} - \kappa_2 g_{t-2} \]
Basic operation, also used for:
  - Linear acceleration estimate \( a_i \)
  - Rotation vector (orientation wrt. magnetic north)

Inertial navigation
Dead reckoning
1. Integrate gyro to obtain orientation
2. Use accelerometer and gyro (orientation) data to estimate linear acceleration
3. Doubly integrate acceleration to obtain position change
   - Errors accumulate over time (\( t^3 \))
   - Error depends on sampling rate
   - How accurate is it?
   - “Pro” (air navigation) answer:
     - GPS: better than 9m
     - Inertial: ~650m after one hour

Other sensors
• Proximity
Less common:
  - Thermometer
    - But: gyroscope & compass often has temperature output as well
  - Light
  - Pressure (barometric) \( \rightarrow \) altitude
Location APIs

- Low-level location providers:
  - GPS
  - WiFi
  - Cell tower
  - ...

- Mid-level:
  - Fused location providers

- Higher-level:
  - Geo-fencing
  - Activity recognition

Location APIs

Location providers (low-level)
- GPS, WiFi, cell tower, ...
- Differ in:
  - Accuracy
  - Availability / freshness
  - Power consumption

- Listen for location updates
- Choose how to update location estimate

Location APIs

Fused location services
- Combine different location providers
- User specifies:
  - Min and max update period
  - Accuracy preferences
- Location service takes care of managing different low-level providers, to obtain best accuracy at low(est) power

Location APIs

Geo-fences and activities
- Geo-fencing:
  - User specifies a POI or map area
  - Requests to receive alerts when user is near / inside fence

Activity recognition (Android APIs):
- Use sensor and location data to detect what user is doing
  - Walking vs cycling vs driving
- Provides probability for each activity

Indoor localization

- No O/S level APIs (?)
- Google Maps offers indoors navigation
  - Mix of WiFi-based localization and (very rough) dead reckoning
- May be possible to obtain WiFi RSS data
  - Android offers APIs, iOS is restricted
  - Also: iBeacon (BLE-based, proximity)
- Other applications have used other signals (like audio)
  - Custom solutions also exist (e.g., ultrasound-based)
- More on this later …

Overview

- Sensors
- Network connectivity
- Power
- Accounts ("identity")
- Mobile app basics
Cellular

• Various standards have evolved over the years
• Hard to track (too much marketing hype…)
• But: rapidly increasing bandwidth and decreasing cost

<table>
<thead>
<tr>
<th>Standard</th>
<th>Year</th>
<th>D/L (max)</th>
<th>U/L (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPRS</td>
<td>1997</td>
<td>60-80kb/s</td>
<td>20-40kb/s</td>
</tr>
<tr>
<td>EDGE</td>
<td>2003</td>
<td>177-237kb/s</td>
<td>60-119kb/s</td>
</tr>
<tr>
<td>HSPA</td>
<td>2006</td>
<td>14-42mb/s</td>
<td>11-22mb/s</td>
</tr>
<tr>
<td>HSPA+</td>
<td>2008</td>
<td>28-166mb/s</td>
<td>1-6mb/s</td>
</tr>
<tr>
<td>LTE</td>
<td>2010</td>
<td>12-300mb/s</td>
<td>5-75mb/s</td>
</tr>
</tbody>
</table>

*Numbers based on marketing claims, please take with grain of salt
**Approx. year (first major deployment)

Historical technologies:
• 2G: GPRS (GSM)
• 2.5G: EDGE

Current technologies:
• “3G”: UMTS (HSDPA, HSUPA, HS[DP]A+)
• “4G”: LTE

Other technologies (failed adoption):
• WiBro, WiMax, …

802.11b/g/n (WiFi)

• Introduced around the same time as GPRS
• Evolved over time: bandwidth and ubiquity

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Year</th>
<th>B/W (Mbit/s max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>1997</td>
<td>2</td>
</tr>
<tr>
<td>b</td>
<td>1999</td>
<td>11</td>
</tr>
<tr>
<td>g</td>
<td>2003</td>
<td>54</td>
</tr>
<tr>
<td>n</td>
<td>2009</td>
<td>72.2</td>
</tr>
<tr>
<td>ac (draft)</td>
<td>2012</td>
<td>88-867</td>
</tr>
</tbody>
</table>

Bluetooth

• Developed by Ericsson in 1994
• Standardized in 1998
• Developed over years

• Designed almost concurrently with WiFi: designed for short-range communications with peripherals (not Ethernet/IP packets only)
  • Fairly complex
  • Fairly ubiquitous

<table>
<thead>
<tr>
<th>Class</th>
<th>mW (max)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Version</th>
<th>Data rate (Mbit/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>2.0 + EDR</td>
<td>3</td>
</tr>
<tr>
<td>3.0 + HS</td>
<td>24</td>
</tr>
</tbody>
</table>

Bluetooth Low Energy (BLE)

<table>
<thead>
<tr>
<th>Spec</th>
<th>BLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (max)</td>
<td>100m</td>
</tr>
<tr>
<td>Data rate</td>
<td>1-3Mbit/s</td>
</tr>
<tr>
<td>App. throughput</td>
<td>0.7-2.1Mbit/s</td>
</tr>
<tr>
<td>Latency</td>
<td>100ms (typ.)</td>
</tr>
<tr>
<td>Time to send data</td>
<td>6ms</td>
</tr>
<tr>
<td>Peak current</td>
<td>&lt;30 mA</td>
</tr>
<tr>
<td>Power consumption</td>
<td>10-50% (use case dep.)</td>
</tr>
</tbody>
</table>

• Entirely separate stack (Zigbee derivative)
• Goals: low power, low latency, low(er) cost
• Initially developed by Nokia, became standard in 2010
• Standard on iPhone, not yet on Android

Other

• Zigbee / XBee
• Cheap transceivers (e.g., Nordic chipsets)

• Non-standard (on phones), require ugly dongles, etc.
• But, might be worth it for prototyping
Overview

- Sensors
- Network connectivity
- Power
  - Accounts ("identity")
  - Mobile app basics

Power overview

- Cellular and WiFi power
  - Overall comparable power draw
  - WiFi can consume substantially less (esp. if kept connected)
  - But cellular is always available/on
  - One larger transfer is much better than many small ones

- Bluetooth power
  - Comparable to WiFi
  - Bluetooth 4.0 (BLE):
    - Up to 10x lower power draw
    - Lower latency & cost
    - Designed for peripherals / sensors
    - iPhone: standard
    - Android: not yet

Sensor power

- Not substantial, per se
  - 3-20 mW → several days of power from iPhone 5 battery
  - What’s the big deal?
  - CPU power consumption!
    - For reasonable accuracy: 200Hz sample rate prevents CPU from entering sleep mode (more soon…)
  - Solution: dedicated processor; either
    - Separate app.-specific processor chip
    - All-in-one IMU chip (e.g., MPU6050)
### Advanced sleep modes

**CPU power**
- If doing no work, it’s much better to turn off CPU completely
- Even for a few milliseconds (better than nothing)
- Around 30x less power draw
- All modern phones will do this automatically
  - Additionally, facilities to reduce number of wakeups: e.g., batching timer events, background messaging (aka. push notifications), etc.

### Display power
- Substantial power draw, esp. at high brightness
- Not really relevant for sensing applications (unless user interaction is required?)

### Power consumption summary
- Primary power consumers:
  - CPU
  - Radios
  - Display

### Power overview
**Nexus S (Dec 2010) vs Nexus 4 (Nov 2012)**
- Phones released two years apart: mostly similar
  - (Except WiFi, not sure what’s going on there…)
  - Battery capacity up.. a bit
- Don’t assume power draw will magically go down; need to actively manage it in your design and code!

### Overview
- Sensors
- Network connectivity
- Power
- Accounts (“identity”)
- Mobile app basics

### Account manager APIs
- Centralized facility for
  - Managing accounts
  - Managing authentication tokens
- Works in conjunction with other APIs to provide access to content
Sync adapters & content providers

- **Sync adapter:**
  - Centralized facility for background syncing of on-device and remote data (e.g., contacts, posts, etc).
  - Allows optimizations (e.g., to conserve power).

- **Content provider:**
  - APIs to expose (synced) data to other applications.
  - Well-defined query endpoints and schemas.
  - Cursor-like API.

Overview

- Sensors
- Network connectivity
- Power
- Mobile app basics

Programming paradigm

Heavily event-oriented!

- Application must respond to its environment; e.g.,
  - Network connectivity changes
  - Incoming calls / messages / events
  - Sensor / location data
- ... Application must use resources efficiently; e.g.,
  - May be pre-empted and/or killed at any time
  - May choose to respond to status information (e.g., battery level)
- ... Cannot:
  - Assume a single main() thread with sequential flow
  - Control lifetime of thread(s)

Activity lifecycle (Android)

- Android: an app can declare which activities handle a particular URL pattern
  - E.g., YouTube app could declare that URLs with http:// protocol and youtube.com domain can be handled by it’s video player activity
  - If multiple apps can handle the same URL type, the user will be prompted to choose
- iOS: similar, but not as general/broad (?)
Background tasks

Short lived (e.g., fetch a URL):
- Can be started in separate threads
- But: need to be prepared for activity termination/restart

Long lived:
- Need to use system APIs to register themselves and allow system to manage them
- Timers, background services, RPC interfaces

Avoid whenever possible!!
- Use system services instead, e.g., geo-fences, push notifications, etc