MINING SMARTPHONE MOBILITY DATA

Mobile technology overview

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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 )

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<th>Sensor</th>
<th>Type</th>
<th>Avail. since</th>
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<td>1.5</td>
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<tr>
<td>Light</td>
<td>HW</td>
<td>1.5</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>HW</td>
<td>1.5</td>
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<tr>
<td>Proximity</td>
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<tr>
<td>Temperature</td>
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<td>Orientation</td>
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<td>Gyroscope</td>
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<td>Pressure</td>
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<tr>
<td>Relative humidity</td>
<td>HW</td>
<td>4.0</td>
</tr>
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- 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 \( \rightarrow \) Free fall
- Stationary device, after 45° rotation:
  - Same magnitude, but rotated

Accelerometer 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);
    }
}
```

Accelerometer 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];
    ...
    @Override
    public final void onAccuracyChanged(Sensor sensor, int accuracy) {
        ...
    }
} // SensorActivity
```

Accelerometer 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 \( \rightarrow \) gyroscope

Gyroscope Basics

- Measures angular speed
  - Degrees per second (dps)
- Example: L3G4200D (iPhone)
  - \$6.5 (DiCiKey, bulk)
  - 18mW on / 4.5mW sleep (0.02mW off):
  - 12.5 days / 50 days
  - \( \pm 250\text{dps} \), \( \pm 500\text{dps} \), \( \pm 2000\text{dps} \) range
  - 16-bit dynamic range
  - 100 / 200 / 400 / 800Hz sample rate
  - Temperature sensor (8-bit range)
  - Simple interrupt generator & FIFO

Gyroscope Baseline

- 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**
- Summarizing: 9 DoF (degrees of freedom) available
  - 3-axis accelerometer Linear acceleration (translation)
  - 3-axis gyro Angular velocity (rotation)
  - 3-axis magnetometer Global reference (Earth)
- 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:
  \[ g_t = \lambda_0 (a_t + a_{t-2}) + \lambda_1 a_{t-1} + \kappa_1 g_{t-1} + \kappa_2 g_{t-2} \]

Basic operation, also used for:
- Linear acceleration estimate \( a_t \approx g_t \)
- 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 (\( \sim t^3 \))
- 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
- Thermometer
  - But: gyroscope & compass often output temperature as well
- Light intensity
- Pressure (barometric) \( \rightarrow \) altitude

Future trend:
- Independent motion / sensor processors
  - Already on iPhones for a couple of years

**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

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 lowest power

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 OS level APIs (?)
- Google Maps offers indoors navigation
- Custom solutions also exist (e.g., ultrasound-based)
- More on this later...

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

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**Cellular**

- Historical technologies:
  - 2G: GPRS (GSM)
  - 2.5G: EDGE
- Current technologies:
  - "3G": UMTS (HSDPA, HSPA, HS(D)PA+)
  - "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

**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

**Bluetooth Low Energy (BLE)**

- Entirely separate stack (Zigbee derivative)
- Goals: low power, low latency, low(er) cost
- Initially developed by Nokia, became standard in 2010
- Standard on both iPhone and 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

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Power overview

- 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

Cellular and WiFi power

- 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

- 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!

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Device / installation identifiers

- Often, a unique identifier for a specific app installation is what’s really required
- Simple; e.g., generate new random UUID on first run
- Safer, less intrusive
- Hardware identifier
- On phones: IMEI or ESN/MEID (may be illegal to modify) usually works; also ICCID (SIM card)
- Non-phones: ANDROID_ID (UUID on first boot; versions > 2.2)
- Caveat: persists when device changes owner
- Requires READ_PHONE_STATE permission

Account authentication

- Web: OAuth has become dominant standard
- Mobile: APIs serving similar purpose, OS-specific
- E.g., Android account manager APIs:
  - Based on pluggable authenticator modules
  - Can generate service auth tokens for apps that request them
  - May allow reuse of token by different apps (e.g., auto-login)
  - Good support for background processes (e.g., sync adapters)
  - Multiple token types (e.g., read-only vs. full-access), similar to OAuth
  - Use of token is service-dependent (protocol, data format, etc)
Sync adapters & content providers

- **Sync adapter (Android):**
  - 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 (Android):**
  - APIs to expose (synced) data to other applications
  - Well-defined query endpoints and schemas
  - Cursor-like API

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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)

A note on “deep linking”

- **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

Tutorial plan

11:55 – 13:00 Katharina
- Resource-constrained graphical models
- App usage mining and traffic prediction

Lunch break (13:30-14:30)

14:30 – 15:15 Tina
- Local-based social networks
- Mobile advertising and search

15:15 – 16:10 Dimitrios
- Learning from trajectory data
- Crowdsourcing and applications

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