CS 403X Mobile and Ubiquitous Computing

Lecture 10: Sensors

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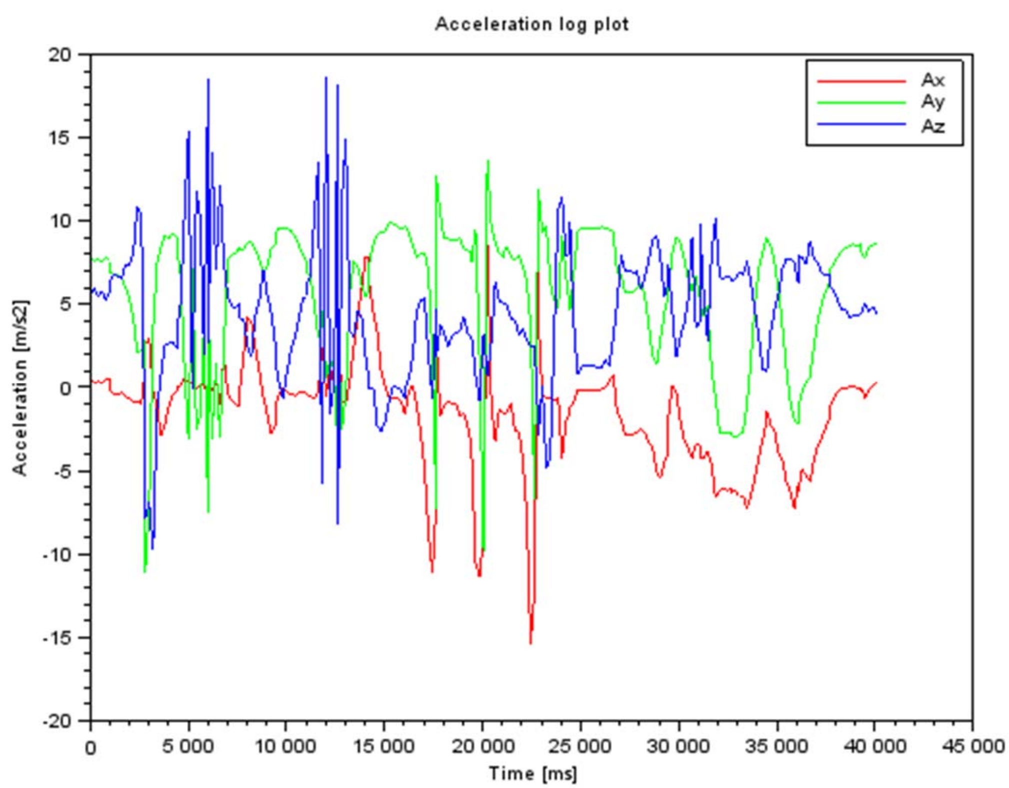
Android Sensors

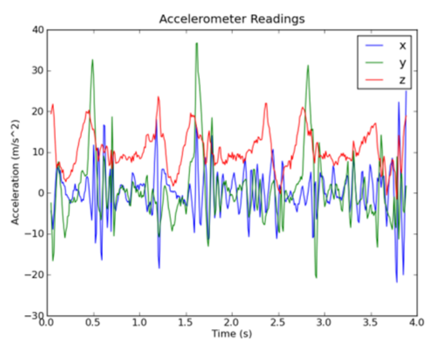
What is a Sensor?

- Converts physical quantity (e.g. light, acceleration, magnetic field) into a signal
- **Example:** accelerometer converts acceleration along X,Y,Z axes into signal

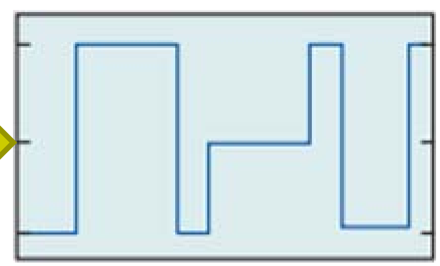


So What?

- Raw sensor data can be processed into meaningful info
- **Example:** Raw accelerometer data can be processed/classified to infer user's activity (e.g. walking running, etc)
- Audio samples can be processed/classified to infer stress level in speaker's voice



Raw accelerometer readings



Machine learning Feature extraction and classification

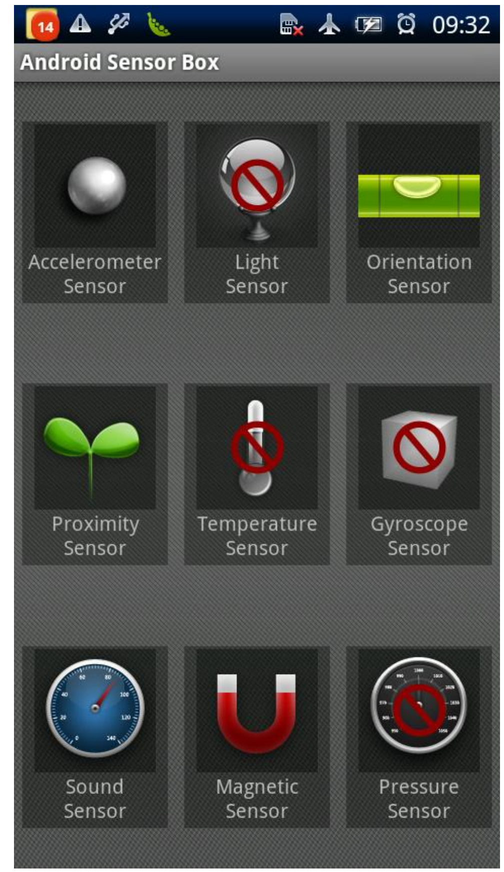
Walking
Running
Jumping
Step count
Calories burned
Falling

Android Sensors

- Microphone (sound)
- Camera
- Temperature
- Location (GPS, A-GPS)
- Accelerometer
- Gyroscope (orientation)
- Proximity
- Pressure
- Light

- **Different phones do not have all sensor types!!**

AndroSensor



Android Sensor Box

Android Sensor Framework

- Enables apps to:
  - Access sensors available on device and
  - Acquire raw sensor data
- Specifically, using the Android Sensor Framework, you can:
  - Determine which sensors are available
  - Determine capabilities of individual sensors (e.g. max. range, manufacturer, power requirements, resolution)
  - Register and unregister sensor event listeners
  - Acquire raw sensor data and define data rate

http://developer.android.com/guide/topics/sensors/sensors_overview.html

Android Sensor Framework

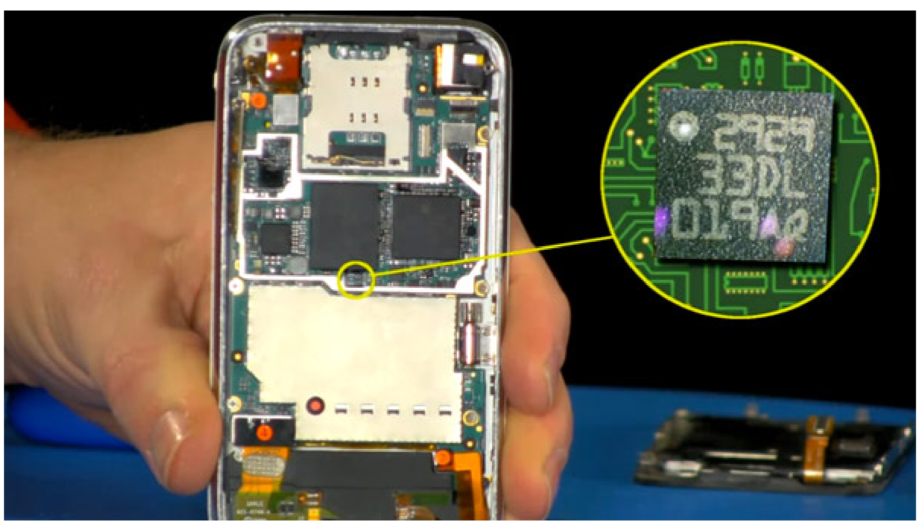
- Android sensors can be either hardware or software

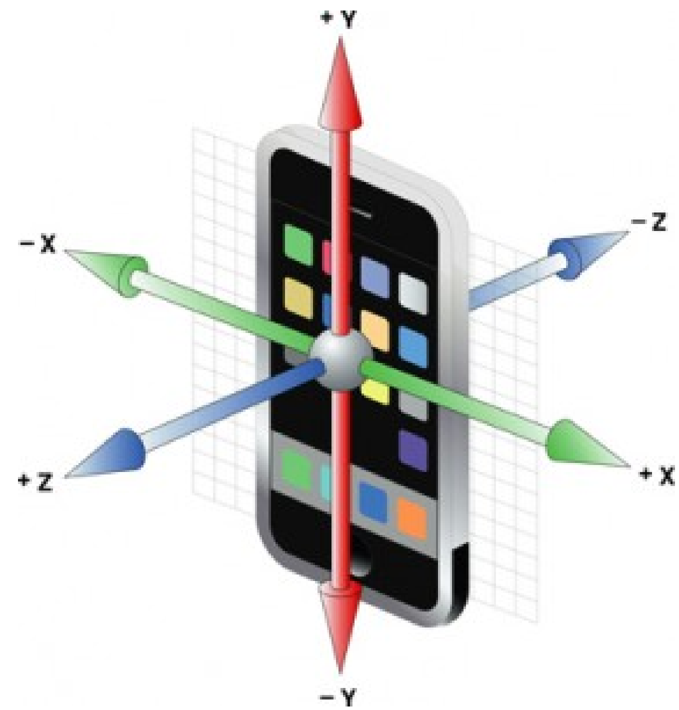
- **Hardware sensor:**
  - physical components built into phone,
  - Measure specific environmental property. E.g. temperature

- **Software sensor (or virtual sensor):**
  - Not physical device
  - Derives their data from one or more hardware sensors
  - **Example:** gravity sensor

Accelerometer Sensor

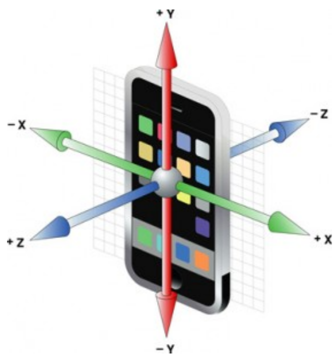
- Acceleration is **rate of change of velocity**
- Accelerometers
  - Measure **change** of speed in a direction
  - Do not measure velocity
- Phone's accelerometer measures acceleration along its X,Y,Z axes





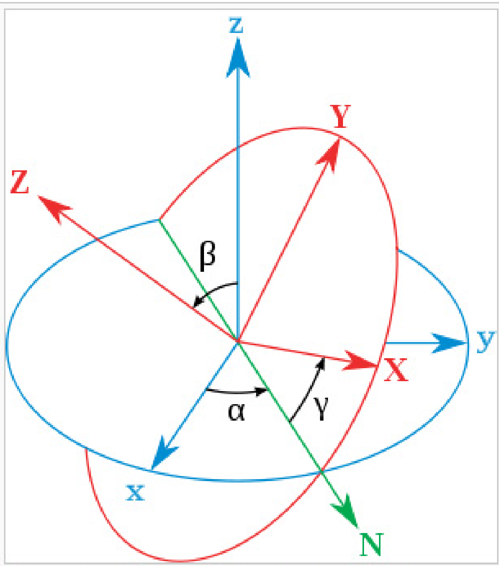
Sensor Types Supported by Android

- TYPE_ACCELEROMETER
  - Measures device acceleration along X,Y,Z axes **including gravity** in m/s^2
  - **Common uses:** motion detection (shake, tilt, etc)
- TYPE_LINEAR_ACCELEROMETER
  - Measures device acceleration along X,Y,Z axes **excluding gravity** in m/s^2
  - **Common uses:** monitoring acceleration along single axis
- TYPE_GRAVITY
  - Measures **gravity along X,Y,Z axes** in m/s^2
  - **Common uses:** motion detection (shake, tilt, etc)



Sensor Types Supported by Android

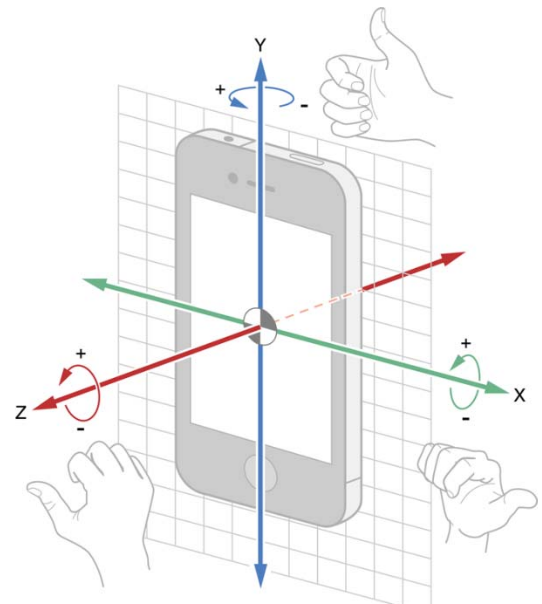
- TYPE_ROTATION_VECTOR
  - Measures **device's orientation** expressed as 3 rotation vectors
  - **Common uses:** motion detection and rotation



Euler angles – The xyz (fixed) system is shown in blue, the XYZ (rotated) system is shown in red. The line of nodes, labeled N, is shown in green.

Blue: Fixed reference axes
Red: Rotated axes

- TYPE_GYROSCOPE
  - Measures device's **rate of rotation** around X,Y,Z axes in rad/s
  - **Common uses:** rotation detection (spin, turn, etc)

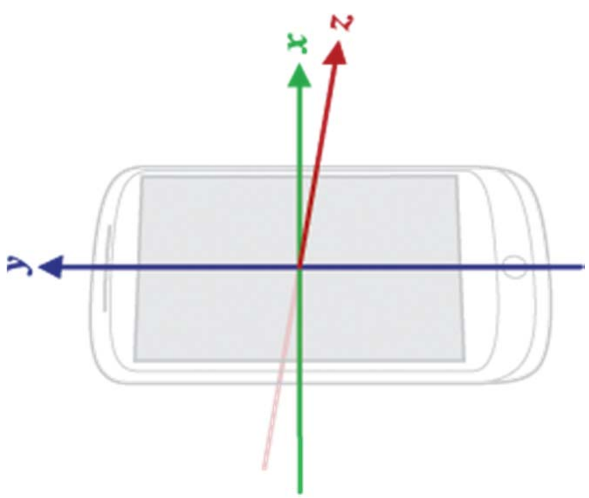


Sensor Types Supported by Android

- TYPE_AMBIENT_TEMPERATURE
  - Measures ambient **room temperature** in degrees Celcius
  - **Common uses:** monitoring room air temperatures
- TYPE_LIGHT
  - Measures ambient **light level (illumination)** in lux
  - Lux is SI measure of illuminance, measures luminous flux per unit area
  - **Common uses:** controlling screen brightness
- TYPE_MAGNETIC_FIELD
  - Measures **magnetic field** for X,Y,Z axes in μT
  - **Common uses:** Creating a compass

Sensor Types Supported by Android

- TYPE_PRESSURE
  - Measures ambient **air pressure** in hPa or mbar
  - Force per unit area
  - **Common uses:** monitoring air pressure changes
- TYPE_ORIENTATION
  - Measures degrees of **rotation about X,Y,Z axes**
  - **Common uses:** Determining device position



Sensor Types Supported by Android

- TYPE_PROXIMITY
  - Measures an **object's proximity to device's screen**
  - **Common uses:** determine whether handset is held to a person's ear

- TYPE_RELATIVE HUMIDITY
  - Measures relative ambient humidity in percent (%)
  - Expresses **% of max possible humidity currently present in air**
  - **Common uses:** monitoring dewpoint, absolute, and relative humidity

- TYPE_TEMPERATURE
  - Measures **temperature of phone (or device)** in degrees Celsius.
  - Replaced by TYPE_AMBIENT_TEMPERATURE in API 14
  - **Common uses:** monitoring temperatures

2 New Hardware Sensor in Android 4.4

- TYPE_STEP_DETECTOR
  - Triggers sensor event each time user takes a step
  - Delivered event has value of 1.0 + timestamp of step

- TYPE_STEP_COUNTER
  - Also triggers a sensor event each time user takes a step
  - Delivers total ***accumulated number of steps since this sensor was first registered by an app***,
  - Tries to eliminate false positives
- **Common uses:** Both used in step counting, pedometer apps
- Requires hardware support, available in Nexus 5
- Alternatively available through Google Fit (more later)

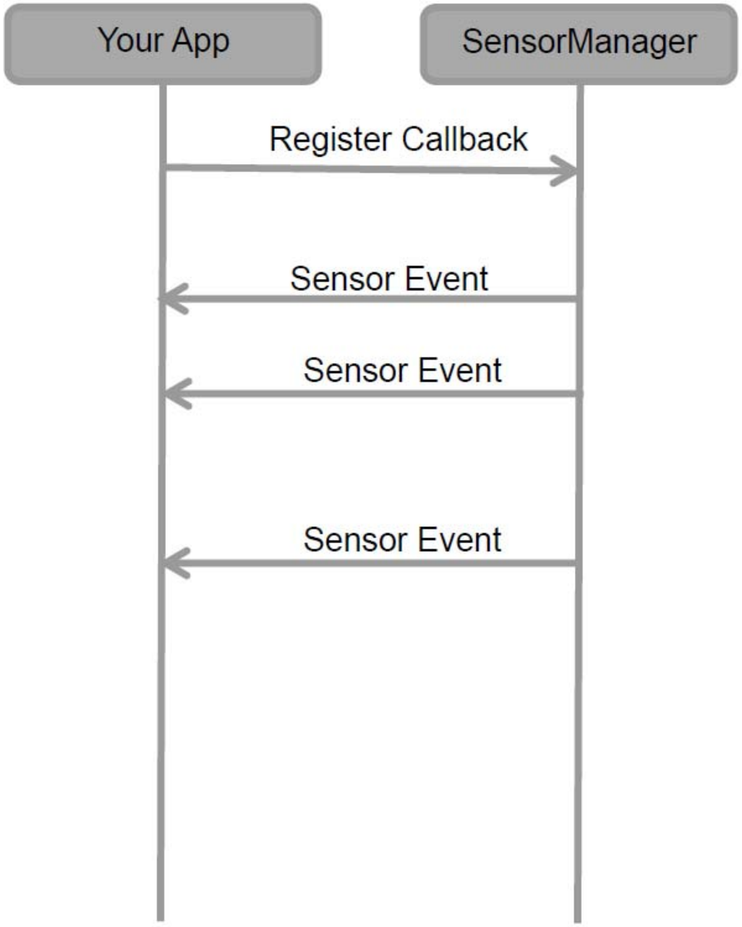
Sensor Programming

- Sensor framework is part of **android.hardware**
- Classes and interfaces include:
  - **SensorManager**
  - **Sensor**
  - **SensorEvent**
  - **SensorEventListener**
- These sensor-APIs used for 2 main tasks:
  - Identifying sensors and sensor capabilities
  - Monitoring sensor events

Sensor Events and Callbacks

- App sensors send events asynchronously, when new data arrives

- General approach:
  - App registers callbacks
  - **SensorManager** notifies app of sensor event whenever new data arrives (or accuracy changes)



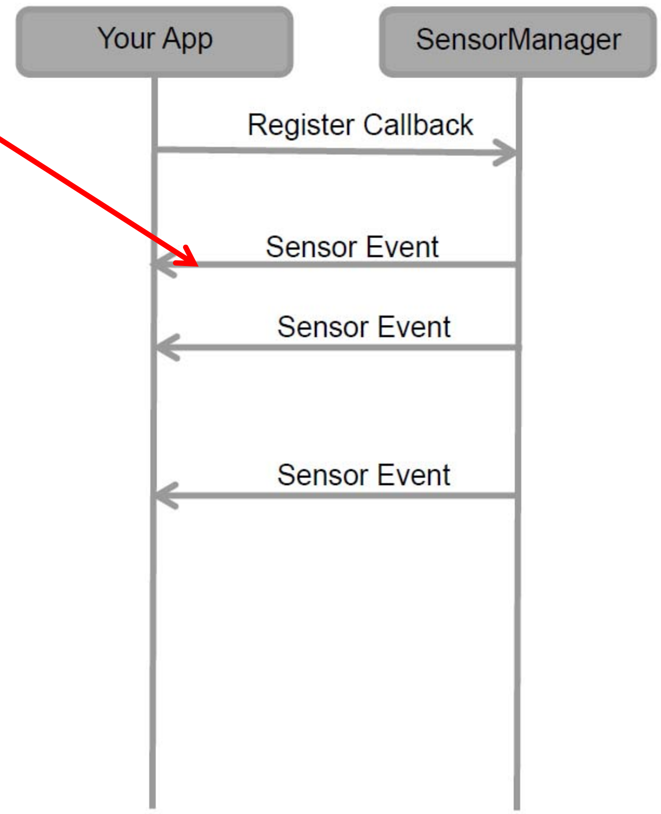
Sensor

- A class that can be used to create instance of a specific sensor

- Has methods used to determine a sensor's capabilities

SensorEvent

- Android system provides information about a sensor event as a **sensor event object**
- **Sensor event object** includes:
  - ***Sensor:*** Type of sensor that generated the event
  - ***Values:*** Raw sensor data
  - ***Accuracy:*** Accuracy of the data
  - ***Timestamp:*** Event timestamp



Sensor Values Depend on Sensor Type

Sensor	Sensor event data	Description	Units of measure
TYPE_ACCELEROMETER	SensorEvent.values[0]	Acceleration force along the x axis (including gravity).	m/s^2
	SensorEvent.values[1]	Acceleration force along the y axis (including gravity).	
	SensorEvent.values[2]	Acceleration force along the z axis (including gravity).	
TYPE_GRAVITY	SensorEvent.values[0]	Force of gravity along the x axis.	m/s^2
	SensorEvent.values[1]	Force of gravity along the y axis.	
	SensorEvent.values[2]	Force of gravity along the z axis.	
TYPE_GYROSCOPE	SensorEvent.values[0]	Rate of rotation around the x axis.	rad/s
	SensorEvent.values[1]	Rate of rotation around the y axis.	
	SensorEvent.values[2]	Rate of rotation around the z axis.	
TYPE_GYROSCOPE_UNCALIBRATED	SensorEvent.values[0]	Rate of rotation (without drift compensation) around the x axis.	rad/s
	SensorEvent.values[1]	Rate of rotation (without drift compensation) around the y axis.	
	SensorEvent.values[2]	Rate of rotation (without drift compensation) around the z axis.	
	SensorEvent.values[3]	Estimated drift around the x axis.	
	SensorEvent.values[4]	Estimated drift around the y axis.	
	SensorEvent.values[5]	Estimated drift around the z axis.	

Sensor Values Depend on Sensor Type

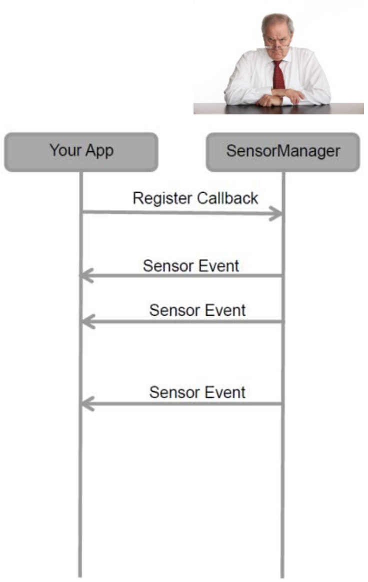
Sensor	Sensor event data	Description	Units of measure
TYPE_LINEAR_ACCELERATION	SensorEvent.values[0]	Acceleration force along the x axis (excluding gravity).	m/s^2
	SensorEvent.values[1]	Acceleration force along the y axis (excluding gravity).	
	SensorEvent.values[2]	Acceleration force along the z axis (excluding gravity).	
TYPE_ROTATION_VECTOR	SensorEvent.values[0]	Rotation vector component along the x axis ($x * \sin(\theta/2)$).	Unitless
	SensorEvent.values[1]	Rotation vector component along the y axis ($y * \sin(\theta/2)$).	
	SensorEvent.values[2]	Rotation vector component along the z axis ($z * \sin(\theta/2)$).	
	SensorEvent.values[3]	Scalar component of the rotation vector (($\cos(\theta/2)$)).[1]	
TYPE_SIGNIFICANT_MOTION	N/A	N/A	N/A
TYPE_STEP_COUNTER	SensorEvent.values[0]	Number of steps taken by the user since the last reboot while the sensor was activated.	Steps
TYPE_STEP_DETECTOR	N/A	N/A	N/A

SensorEventListener

- Interface used to create 2 callbacks that receive notifications (sensor events) when:
  - Sensor values change **(onSensorChange( ))** or
  - When sensor accuracy changes **(onAccuracyChanged( ))**

SensorManager

- A class that provides methods for:
  - Accessing and listing sensors
  - Registering and unregistering sensor event listeners
- Can be used to create instance of sensor service
- Also provides sensor **constants** used to:
  - Report sensor accuracy
  - Set data acquisition rates
  - Calibrate sensors



Sensor API Tasks

- **Sensor API Task 1: Identifying sensors and their capabilities**
- Why identify sensor and their capabilities at runtime?
  - Disable app features using sensors not present, or
  - Choose sensor implementation with best performance

- **Sensor API Task 2: Monitor sensor events**
- Why monitor sensor events?
  - To acquire raw sensor data
  - Sensor event occurs every time sensor detects change in parameters it is measuring

Sensor Availability

- Different sensors are available on different **Android versions**

Sensor	Android 4.0 (API Level 14)	Android 2.3 (API Level 9)	Android 2.2 (API Level 8)	Android 1.5 (API Level 3)
TYPE_ACCELEROMETER	**Yes**	**Yes**	**Yes**	**Yes**
TYPE_AMBIENT_TEMPERATURE	**Yes**	n/a	n/a	n/a
TYPE_GRAVITY	**Yes**	**Yes**	n/a	n/a
TYPE_GYROSCOPE	**Yes**	**Yes**	n/a[1]	n/a[1]
TYPE_LIGHT	**Yes**	**Yes**	**Yes**	**Yes**
TYPE_LINEAR_ACCELERATION	**Yes**	**Yes**	n/a	n/a
TYPE_MAGNETIC_FIELD	**Yes**	**Yes**	**Yes**	**Yes**
TYPE_ORIENTATION	**Yes**[2]	**Yes**[2]	**Yes**[2]	**Yes**
TYPE_PRESSURE	**Yes**	**Yes**	n/a[1]	n/a[1]
TYPE_PROXIMITY	**Yes**	**Yes**	**Yes**	**Yes**
TYPE_RELATIVE_HUMIDITY	**Yes**	n/a	n/a	n/a
TYPE_ROTATION_VECTOR	**Yes**	**Yes**	n/a	n/a
TYPE_TEMPERATURE	**Yes**[2]	**Yes**	**Yes**	**Yes**

Identifying Sensors and Sensor Capabilities

- First create instance of **SensorManager** by calling **getSystemService( )** and passing in SENSOR_SERVICE argument

```
private SensorManager mSensorManager;
...
mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
```

- Then list sensors available on device by calling **getSensorList( )**

```
List<Sensor> deviceSensors = mSensorManager.getSensorList(Sensor.TYPE_ALL);
```

- To list particular type, use **TYPE_GYROSCOPE, TYPE_GRAVITY**, etc

http://developer.android.com/guide/topics/sensors/sensors_overview.html

Determing if Device has at least one of particular Sensor Type

- Device may have multiple sensors of a particular type.
  - E.g. multiple magnetometers
- If multiple sensors of a given type exist, one of them must be designated “the default sensor” of that type
- To determine if specific sensor type exists use **getDefaultSensor( )**
- **Example:** To check whether device has a magnetometer

```
private SensorManager mSensorManager;
...
mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
if (mSensorManager.getDefaultSensor(Sensor.TYPE_MAGNETIC_FIELD) != null){
  // Success! There's a magnetometer.
  }
else {
  // Failure! No magnetometer.
  }
```

Determining Capabilities of Sensors

- Some useful methods of **Sensor** class methods:
  - **getResolution( ):** get sensor's resolution
  - **getMaximumRange( ):** get maximum measurement range
  - **getPower( ):** get sensor's power requirements
  - **getMinDelay( ):** min time interval (in microseconds) sensor can use to sense data. Return values:
    - **0 value:** Non-streaming sensor, reports data only if sensed parameters change
    - **Non-zero value:** streaming sensor

Monitoring Sensor Events

- To monitor raw sensor data, 2 callback methods exposed through **SensorEventListener** interface need to be implemented:
- **onSensorChanged:**
  - Invoked by Android system to report new sensor value
  - Provides **SensorEvent** object containing information about new sensor data
  - New sensor data includes:
    - **Accuracy:** Accuracy of data
    - **Sensor:** Sensor that generated the data
    - **Timestamp:** Times when data was generated
    - **Data:** New data that sensor recorded

Monitoring Sensor Events

- **onAccuracyChanged:**
  - invoked when accuracy of sensor being monitored changes
  - Provides reference to **sensor object** that changed and the new accuracy of the sensor
  - Accuracy represented as status constants SENSOR_STATUS_ACCURACY_LOW, SENSOR_STATUS_ACCURACY_MEDIUM,
  - SENSOR_STATUS_ACCURACY_HIGH,
  - SENSOR_STATUS_UNRELIABLE

Example: Monitoring Light Sensor Data

- **Goal:** Monitor light sensor data using **onSensorChanged( )**, display it in a **TextView** defined in main.xml

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

  @Override
  public final void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    setContentView(R.layout.main);

    mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
    mLight = mSensorManager.getDefaultSensor(Sensor.TYPE_LIGHT);
  }

  @Override
  public final void onAccuracyChanged(Sensor sensor, int accuracy) {
    // Do something here if sensor accuracy changes.
  }
```

Create instance of Sensor manager

Get default Light sensor

Example: Monitoring Light Sensor Data (Contd)

```
  @Override
  public final void onSensorChanged(SensorEvent event) {
    // The light sensor returns a single value.
    // Many sensors return 3 values, one for each axis.
    float lux = event.values[0];
    // Do something with this sensor value.
  }

  @Override
  protected void onResume() {
    super.onResume();
    mSensorManager.registerListener(this, mLight, SensorManager.SENSOR_DELAY_NORMAL);
  }

  @Override
  protected void onPause() {
    super.onPause();
    mSensorManager.unregisterListener(this);
  }
}
```

Get new light sensor value

Register sensor when app becomes visible

Unregister sensor if app is no longer visible to reduce battery drain

Handling Different Sensor Configurations

- Different phones have different sensors built in
- **E.g.** Motorola Xoom has pressure sensor, Samsung Nexus S doesn't
- If app uses a specific sensor, how to ensure this sensor exists on target device? Two options
  - **Option 1:** Detect device sensors at runtime, enable/disable app features as appropriate
  - **Option 2:** Use Google Play filters so only devices possessing required sensor can download app

Option 1: Detecting Sensors at Runtime

- Following code checks if device has a pressure sensor

```
private SensorManager mSensorManager;
...
mSensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
if (mSensorManager.getDefaultSensor(Sensor.TYPE_PRESSURE) != null){
// Success! There's a pressure sensor.
}
else {
// Failure! No pressure sensor.
}
```

Option 2: Use Google Play Filters to Target Specific Sensor Configurations

- Can use **<uses-feature>** element in AndroidManifest.xml to filter your app from devices without required sensors

- **Example:** following manifest entry ensures that only devices with accelerometers will see this app on Google Play

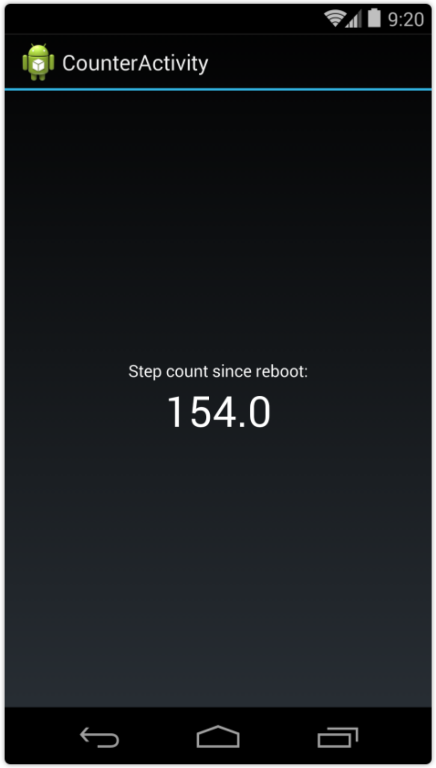
```
<uses-feature android:name="android.hardware.sensor.accelerometer"
              android:required="true" />
```

- **Can list** accelerometers, barometers, compass (geomagnetic field), gyroscope, light and proximity using this approach

Example Step Counter App

- **Goal:** Track user's steps, display it in TextView
- **Note:** Phone hardware must support step counting

```java
package com.starboardland.pedometer;

import android.app.Activity;
import android.content.Context;
import android.hardware.*;
import android.os.Bundle;
import android.widget.TextView;
import android.widget.Toast;

public class CounterActivity extends Activity implements SensorEventListener {

    private SensorManager sensorManager;
    private TextView count;
    boolean activityRunning;

    @Override
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.main);
        count = (TextView) findViewById(R.id.count);

        sensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
    }
```



https://theelfismike.wordpress.com/2013/11/10/android-4-4-kitkat-step-detector-code/

Example Step Counter App (Contd)

```
    @Override
    protected void onResume() {
        super.onResume();
        activityRunning = true;
        Sensor countSensor = sensorManager.getDefaultSensor(Sensor.TYPE_STEP_COUNTER);
        if (countSensor != null) {
            sensorManager.registerListener(this, countSensor, SensorManager.SENSOR_DELAY_UI);
        } else {
            Toast.makeText(this, "Count sensor not available!", Toast.LENGTH_LONG).show();
        }

    }

    @Override
    protected void onPause() {
        super.onPause();
        activityRunning = false;
        // if you unregister the last listener, the hardware will stop detecting step events
//        sensorManager.unregisterListener(this);
    }
```

https://theelfismike.wordpress.com/2013/11/10/android-4-4-kitkat-step-detector-code/

Example Step Counter App (Contd)

```java
    @Override
    public void onSensorChanged(SensorEvent event) {
        if (activityRunning) {
            count.setText(String.valueOf(event.values[0]));
        }

    }

    @Override
    public void onAccuracyChanged(Sensor sensor, int accuracy) {
    }
}
```

https://theelfismike.wordpress.com/2013/11/10/android-4-4-kitkat-step-detector-code/

Best Practices for Sensor Usage

1. **Unregister sensor listeners:** when done using sensor or when app is paused
   - Otherwise sensor continues to acquire data, draining battery

2. **Don’t test sensor code on emulator**
   - Must test sensor code on physical device, emulator doesn’t support sensors

Best Practices for Sensor Usage (Contd)

3. **Don’t block onSensorChange( ) method:**
   - Android system may call onsensorChanged( ) often
   - So… don’t block it
   - Perform any heavy processing (filtering, reduction of sensor data) outside **onSensorChanged( )** method

4. **Avoid using deprecated methods or sensor types:**
   - TYPE_TEMPERATURE sensor type deprecated, use TYPE_AMBIENT_TEMPERATURE sensor type instead

Best Practices for Sensor Usage (Contd)

5. **Verify sensors before you use them:**
   - Don't assume sensor exists on device, check first before trying to acquire data from it

6. **Choose sensor delays carefully:**
   - Sensor data rates can be very high
   - Choose delivery rate that is suitable for your app or use case
   - Choosing a rate that is too high sends extra data, wastes system resources and battery power

References

- Android Sensors Overview, http://developer.android.com/guide/topics/sensors/sensors_overview.html
- Busy Coder's guide to Android version 6.3
- CS 65/165 slides, Dartmouth College, Spring 2014
- CS 371M slides, U of Texas Austin, Spring 2014