# Communication Technologies 2 (CT2)

# Machine Learning: Applications and Algorithms

# [Dead Reckoning]

[M.Sc. Christoph Anderson]

Lecture in WS 2018 / 2019
[06.12.2018]

# Agenda

- Introduction
- Activity Recognition
- Alignment for Context Prediction
- Time-Series II
- WiFi-Fingerprinting
- Dead-Reckoning
- Gaussian Mixture Models
- Sensor Data Fusion

# Outline

- Common Approaches for Positioning
- Motivation
- Introduction to Dead-Reckoning
- Step-Heading-Systems (SHS)
- Inertial-Navigation-Systems (INS)
- Maps
- Pitfalls and Errors

Common Approaches for Positioning

# DEAD-RECKONING

# Common approaches (GPS)

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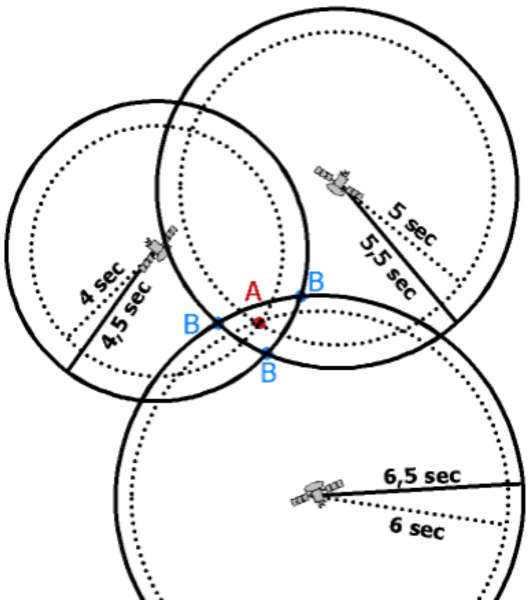
- GPS is widely used for providing positioning services
- Line-of-sight (LoS) transmission with satellites
  - Signal (time sent)
  - Name of the satellite
  - Position
- Poor coverage for indoor environments

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# Common approaches (Trilateration)

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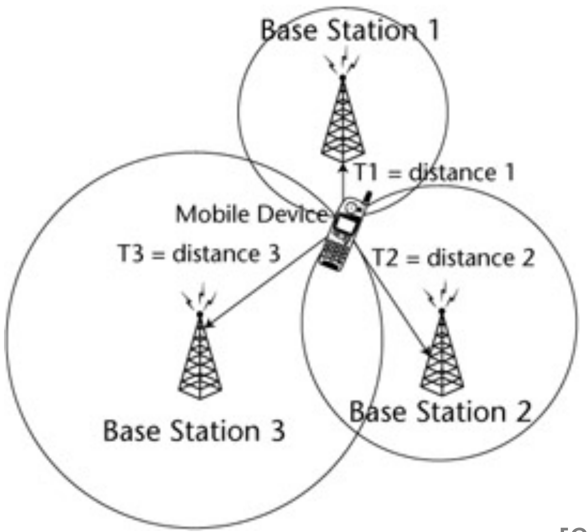
- Time of Arrival (TOA)
  - Measure the propagation time
  - Calculate the distance between the receiver and the transmitter.
  - The clock of transmitters and receivers must be precisely synchronized

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# Common Approaches (WiFi-Fingerprinting)

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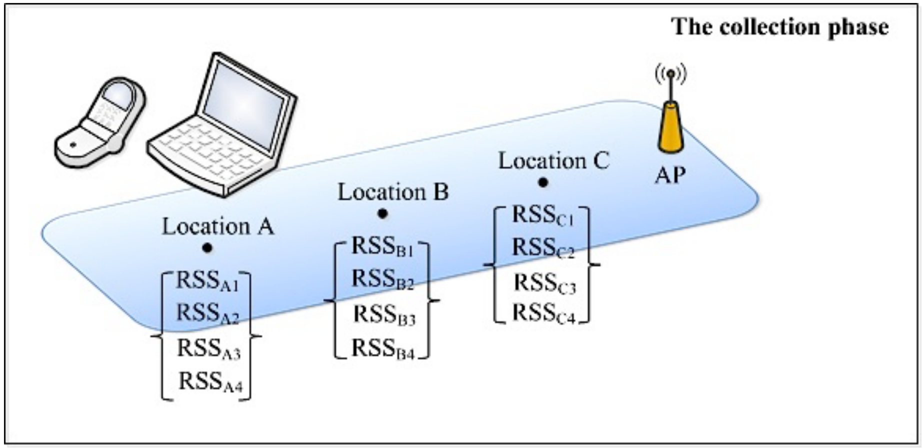
- Information
  - MAC address
  - Receive signal strength indicator (RSSI)
  - SSID
  - Channel (frequency)



# Common Approaches (WiFi-Fingerprinting)

- Information
  - MAC address
  - Receive signal strength indicator (RSSI)
  - SSID
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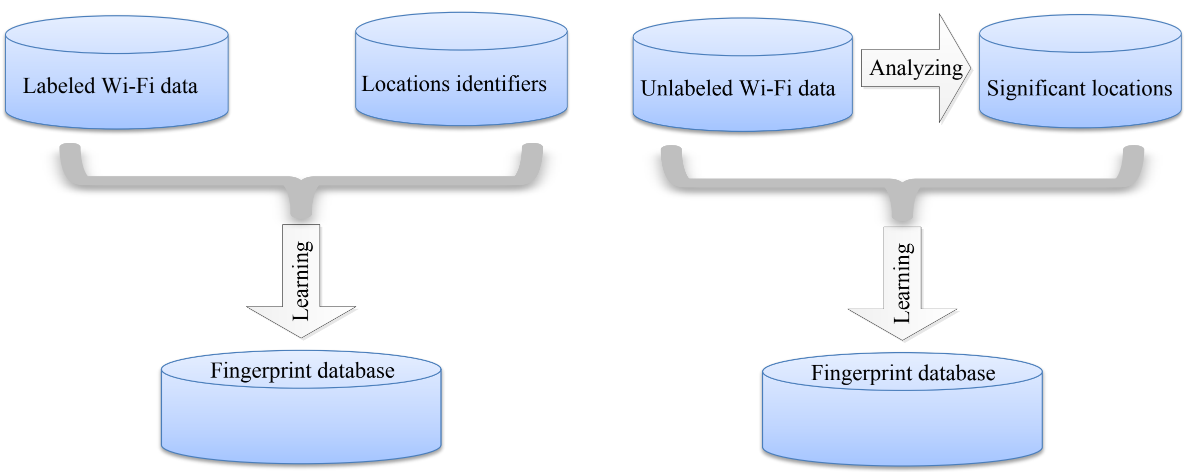

# Common Approaches

- Proximity based approaches
  - RFID-Systems
  - Bluetooth Receivers
- Low administration and calibration
- Need high density of receivers/senders
- Provide only coarse location information

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Motivation

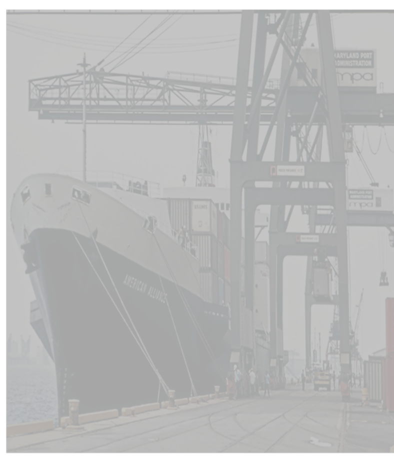
# DEAD-RECKONING

# Motivation

- Why is it useful to know the exact position indoors?
  - Navigation to unknown places/rooms
  - Context-awareness
  - Advertisement
  - Building management

# Motivation

- How to detect ones position?
- Back in history:
  - A captain had to determine the ship‘s position
  - Based on a starting point (harbor, lighthouse etc.)



[1]

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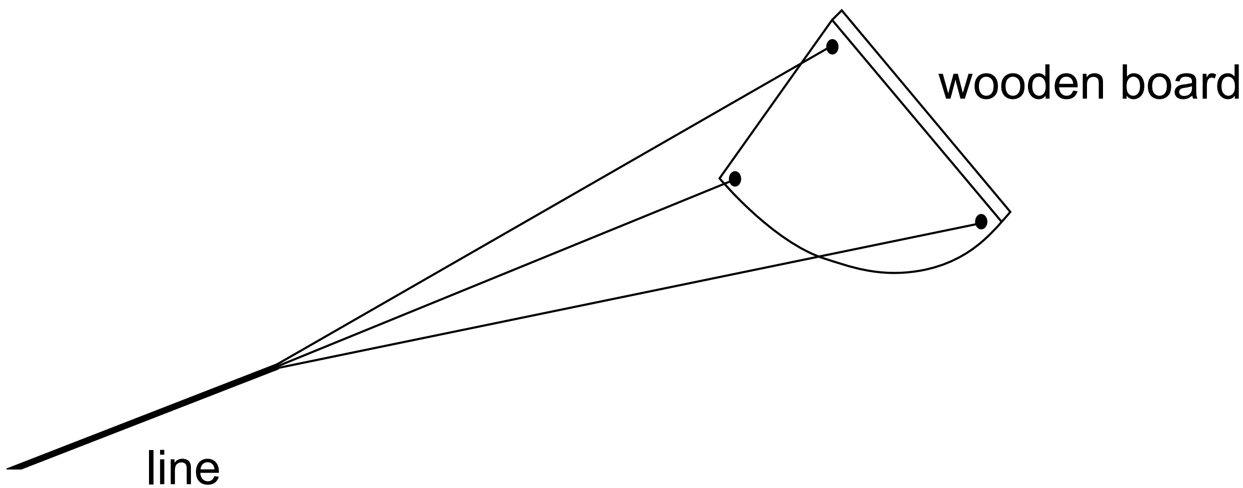
# Motivation

- Determining the position by:
  - Using a log for calculating the speed of the ship
  - Device with a line and a wooden board

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# Motivation

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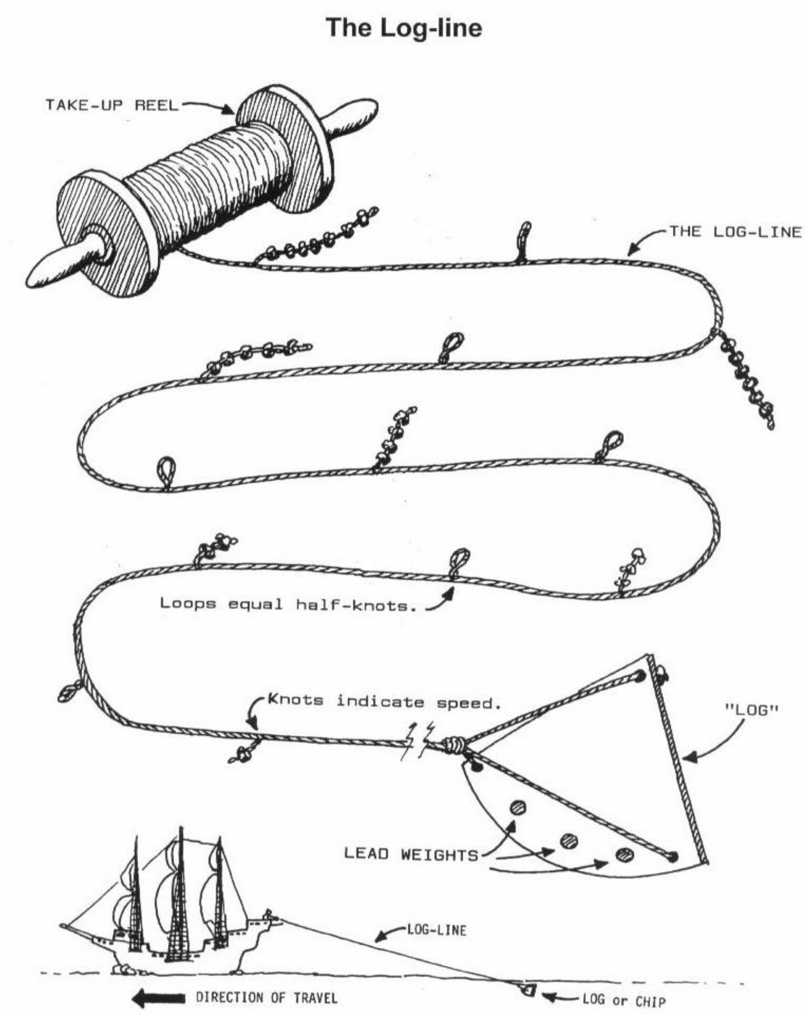
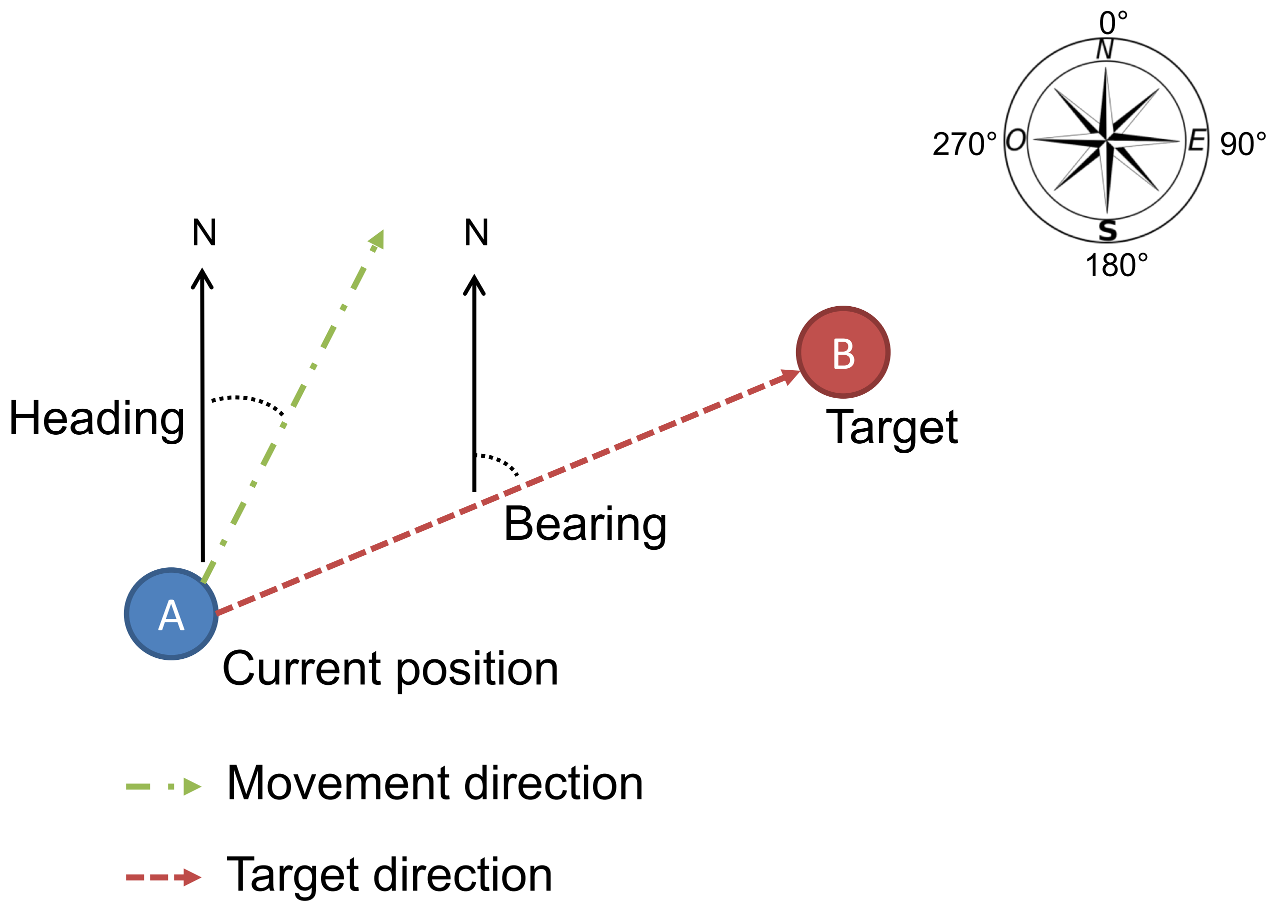



[4]

# Motivation

- Knots were woven into the line at a fixed length
- Estimating the speed of the ship:
  - Using a sand glass for time measuring
  - Knots passed by in that period time
- Calculating the course of the ship:
  - Using a compass for heading, bearing estimation

# Motivation


0°
N
270°
O
E
90°
S
180°
N
N
Heading
B
Target
Bearing
A
Current position
Movement direction
Target direction

Definition

# DEAD-RECKONING

# Definition of Dead-Reckoning

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- What is Dead-Reckoning?

„Dead reckoning is a relative navigation technique. Starting from a known position, successive position displacements are added up…more typically, in heading and speed or distance“ [7]

- Also known as „Deduced Reckoning“
  - D-E-D Reckoning
  - Dead-Reckoning

# Introduction to Dead-Reckoning

- Pedestrian Dead-Reckoning (PDR)
  - Using a smartphone as a navigation tool
  - No log lines or wooden boards
- Built-in sensors
  - Magnetometer
  - Acceleration
  - Gyroscope
  - GPS
  - Wi-Fi
- Low deployment costs

# Introduction to Dead-Reckoning

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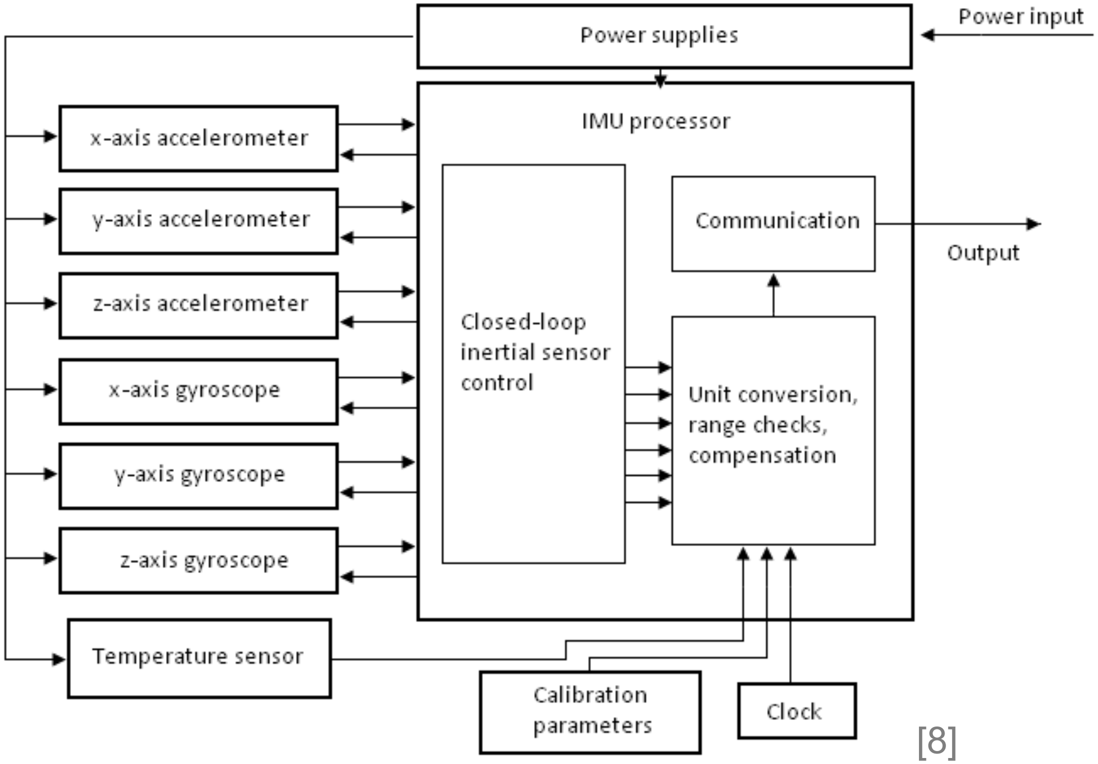
9 Axis IMU Sensor

3-axis gyroscope

3-axis accelerometer

3-axis magnetometer

# Introduction to Dead-Reckoning

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# Introduction to Dead-Reckoning

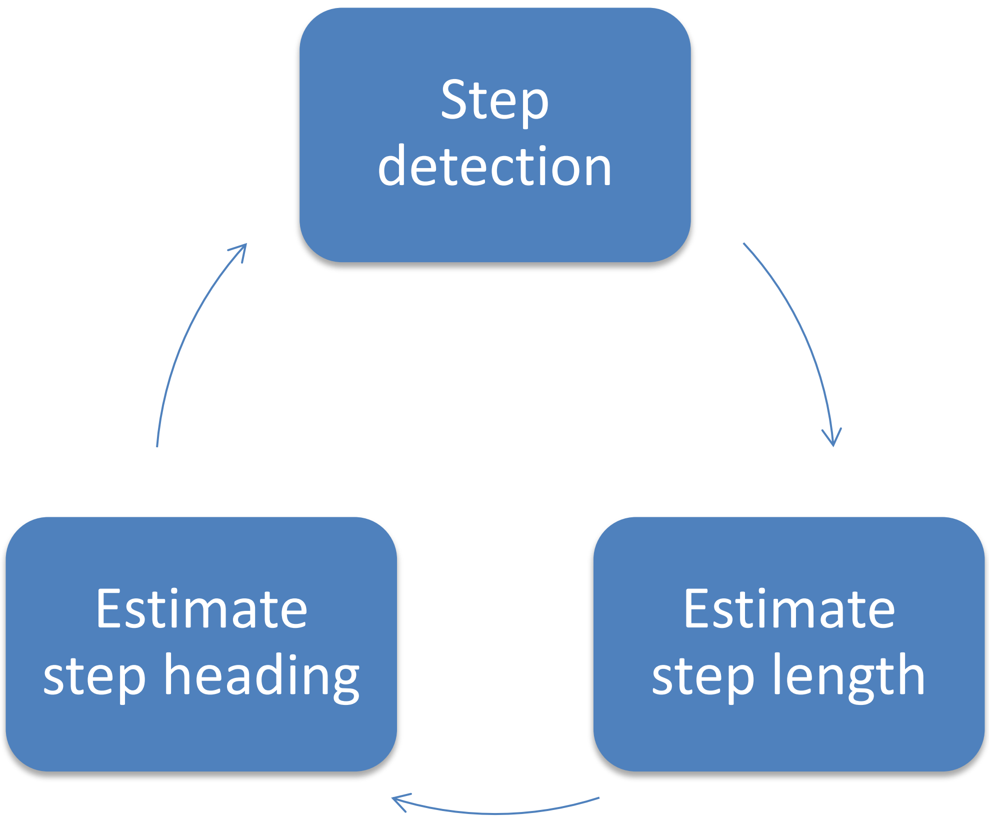
- PDR-Systems can be divided in
  - Step-Heading-Systems (SHS)
  - Inertial-Navigation-Systems (INS)
  - SHS-INS Systems
- Focus lies on SHS-Systems
  - Easier to implement

Step-Heading-Systems / Inertial-Navigation-Systems

# DEAD-RECKONING

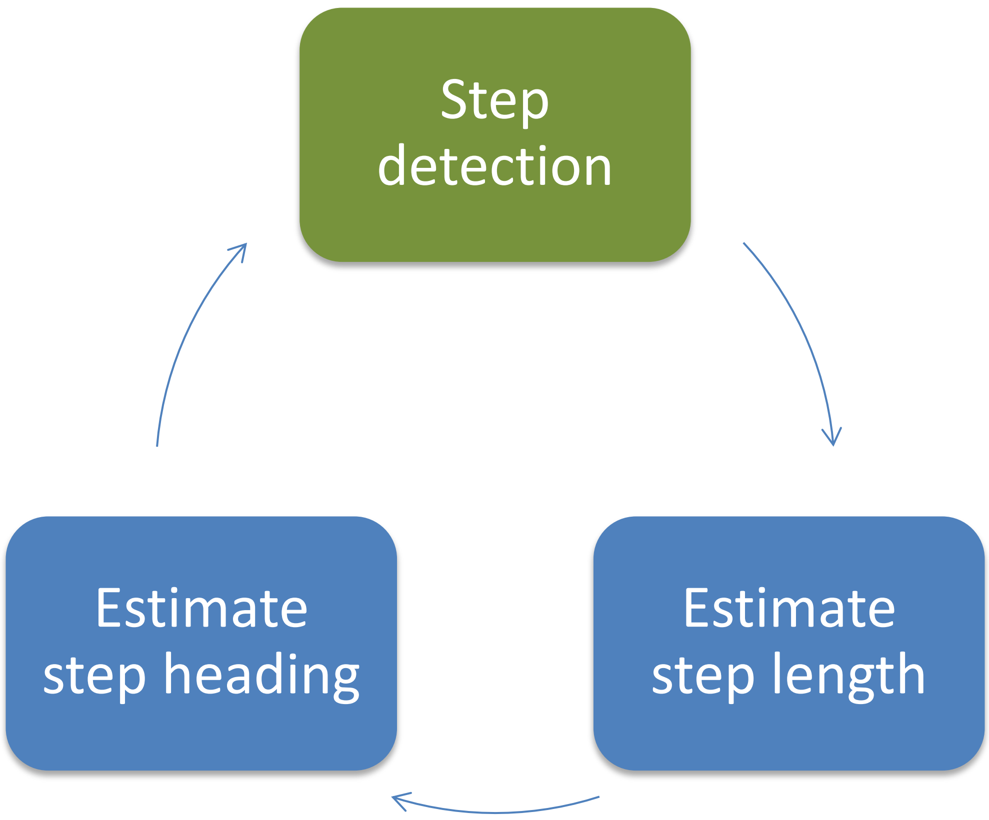
# Step-Heading-Systems (SHS)

- Basic cycle of SHS-Systems



# Step-Heading-Systems (SHS)

- Basic cycle of SHS-Systems

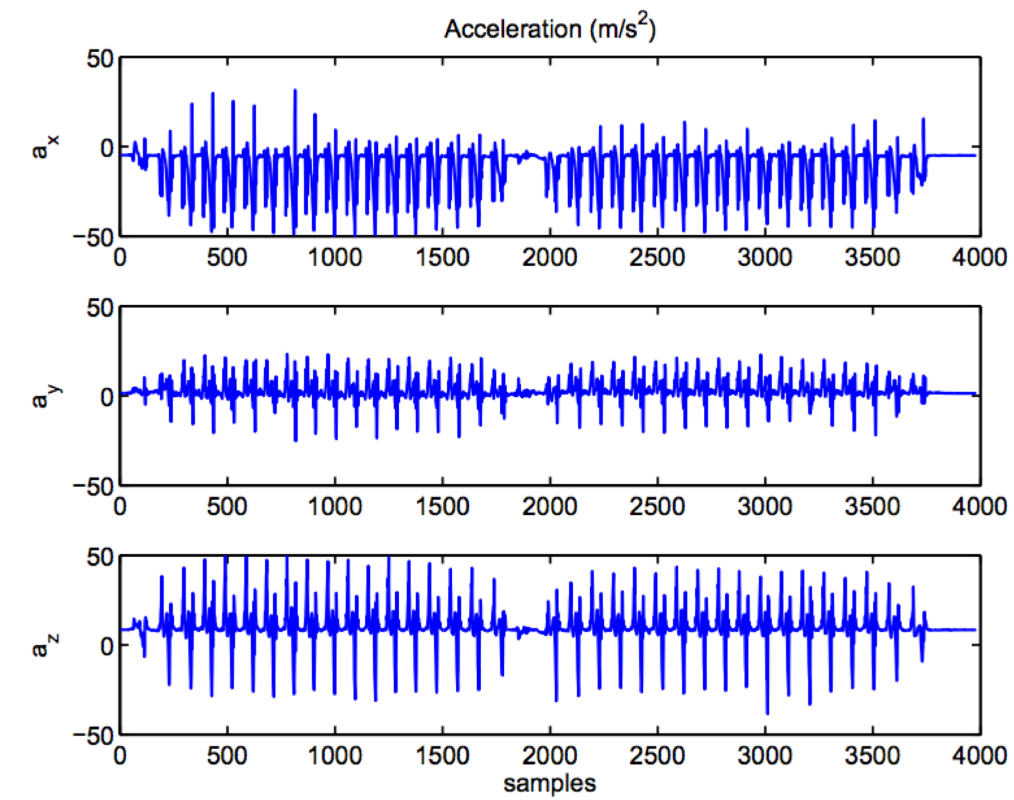


# Step-Heading-Systems (SHS)

- Recognizing steps from sensor data
  - Mostly by using acceleration sensors
  - Other approaches include gyroscopes
- Most of these approaches are threshold based
  - During static phase, sensor will report low values
  - During non-static phase, sensor report activity
- Example: Stance detection
  - Acceleration sensor mounted on the foot
  - Records sensor data and estimate foot stance

# Step-Heading-Systems (SHS)

- Example: Stance detection

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# Step-Heading-Systems (SHS)

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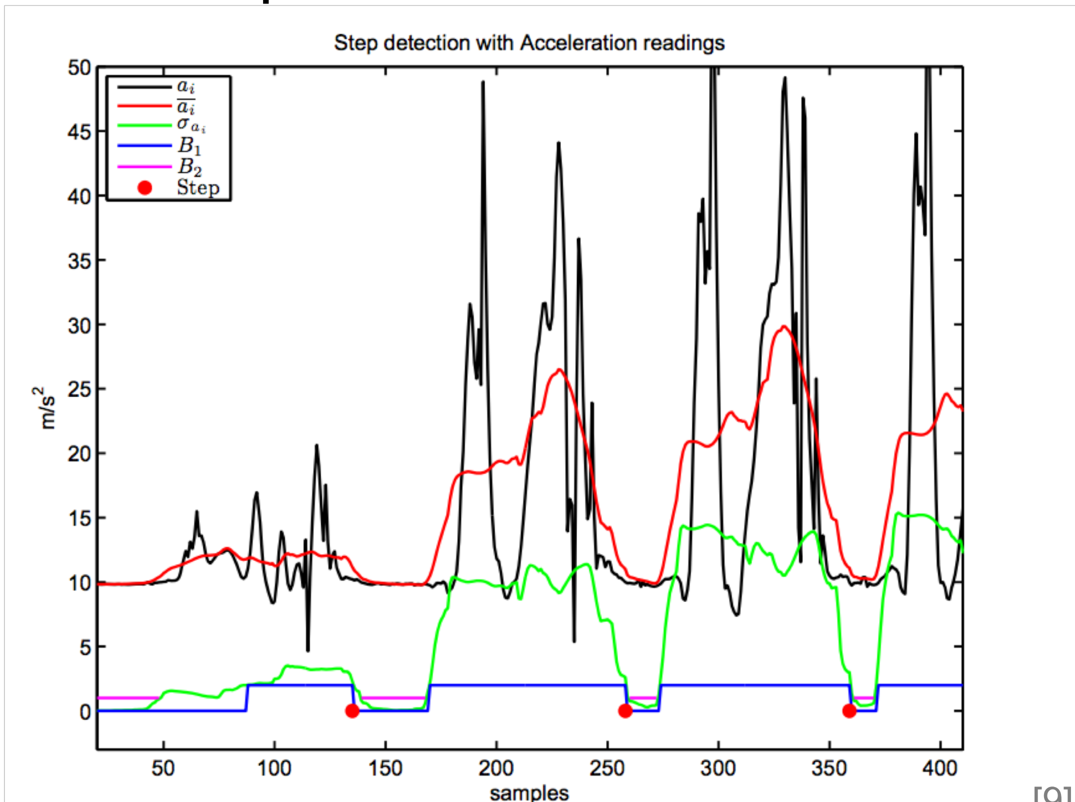
- Example: Stance detection




[9]

$$a_i = \sqrt{a_{x_i}^2 + a_{y_i}^2 + a_{z_i}^2}.$$

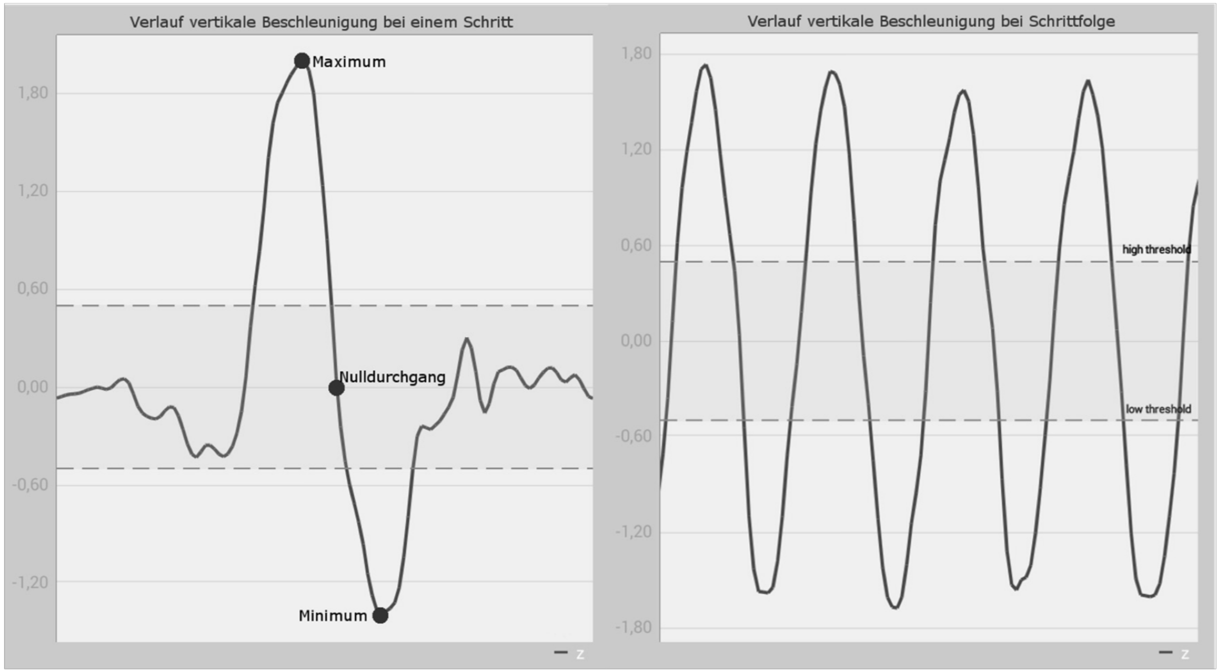
$$\sigma_{a_i}^2 = \frac{1}{2w+1} \sum_{j=i-w}^{i+w} (a_j - \overline{a_j})^2,$$

$$B_{1i} = \begin{cases} \mathrm{T1} & \sigma_{a_i} > \mathrm{T1} \\ 0 & \text{otherwise} \end{cases}.$$

$$\mathrm{B}_{2\mathrm{i}} = \begin{cases} \mathrm{T2} & \sigma_{a_i} < \mathrm{T2} \\ 0 & \text{otherwise} \end{cases}.$$

# Step-Heading-Systems (SHS)

- Example: Step-Cycle detection
  - Acceleration sensor mounted near the waist/leg
  - Same position used for gyroscope based approaches



# Step-Heading-Systems (SHS)

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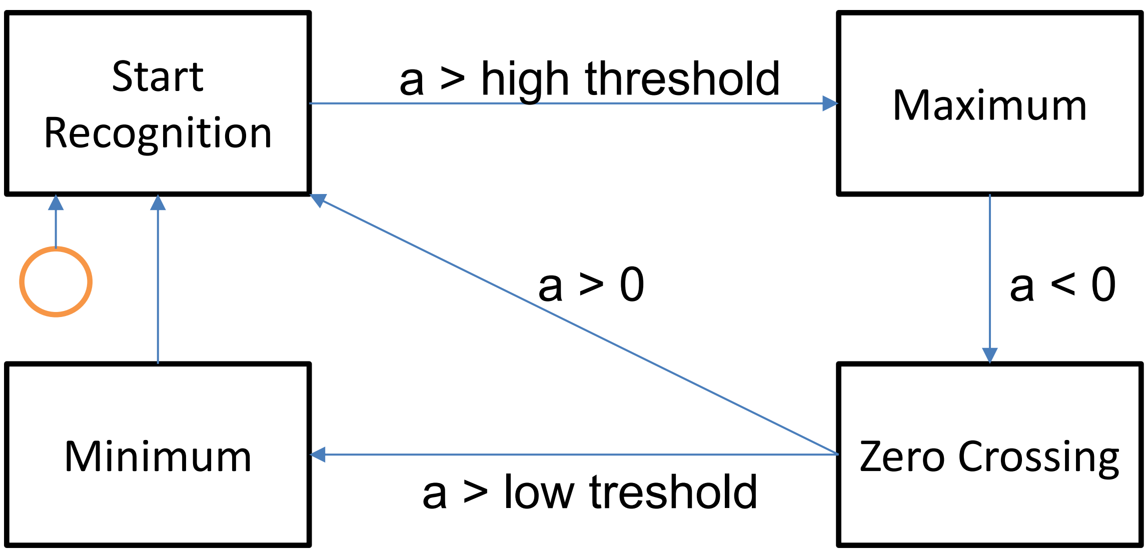
- Example: Step-Cycle detection
  - State-Machine:



# Step-Heading-Systems (SHS)

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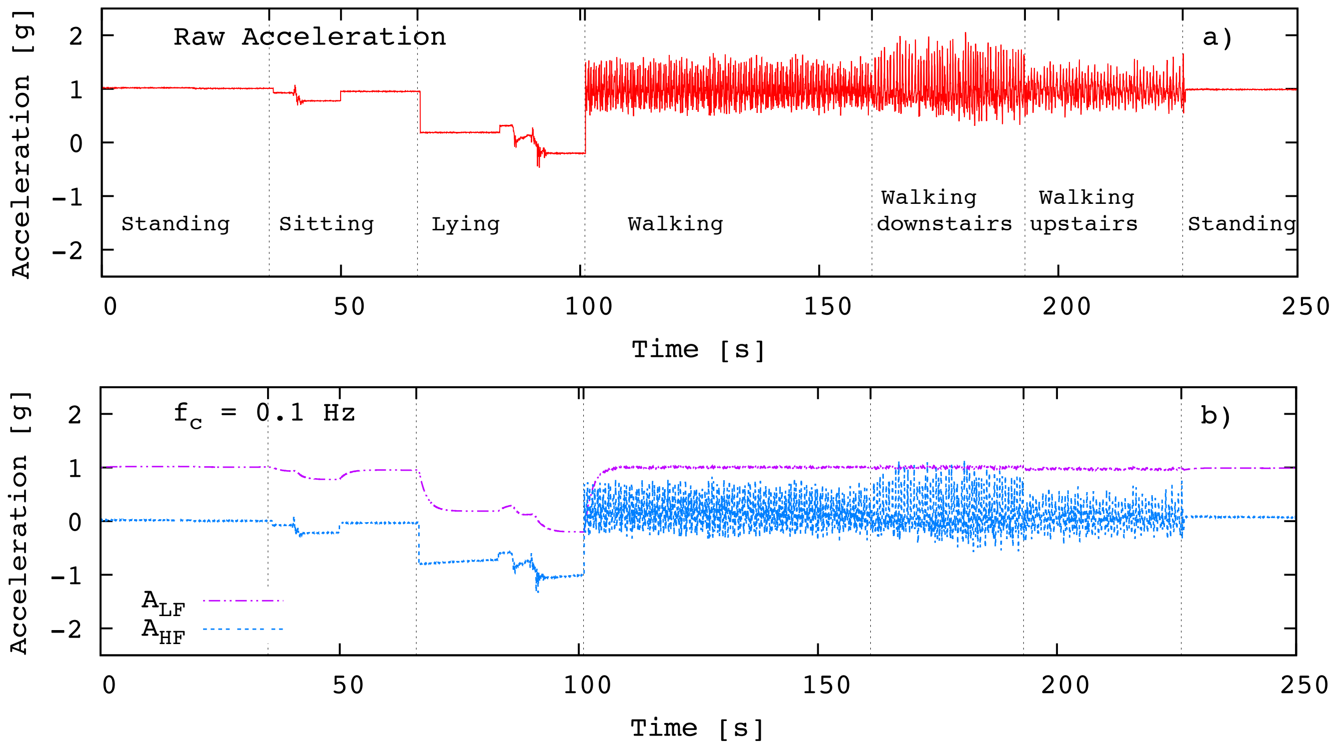
- Example: Step-Cycle detection:
  - Usually common features such as mean, magnitude or variance are used
- Algorithms used for step detection:
  - Peak detection
    - Sharp changes in vertical acceleration
  - Auto correlation
    - Matching periodic patterns in the magnitude signal
  - Zero crossing
    - Detect zero crossings, special form of thresholding

# Step-Heading-Systems (SHS)

- Compensate for:
  - Gravity in acceleration signals
  - Momentary noise and peaks in acceleration
- Signal processing for filtering out noise
  - Average filter
  - Butterworth Low-Pass filter

# Step-Heading-Systems




[10]

# Step-Heading-Systems

- Instead of counting steps:
  - Recognize continuous movements
  - Walking detection
- For example using a decision tree
  - Calculating several features of acceleration signals
  - Variance, Minimum, Maximum…

# Step-Heading-Systems

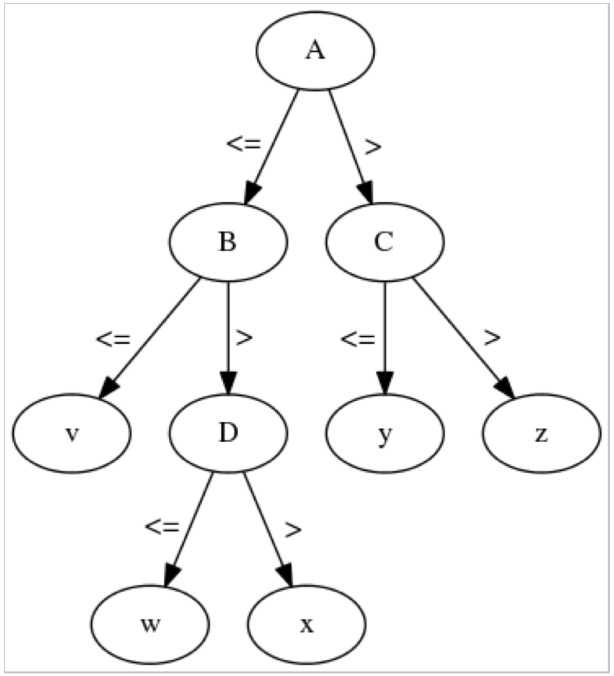
## Information Gain and Entropy

- Information Gain:

$$IG(FS) = H(FS) - H(FS|f)$$

- Entropy:

$$H(FS) = \sum_{i \in FS} -p_i log_2 p_i$$



# Decision Trees

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- Information entropy
  - Comes from information theory
  - The higher the entropy, the higher the information content

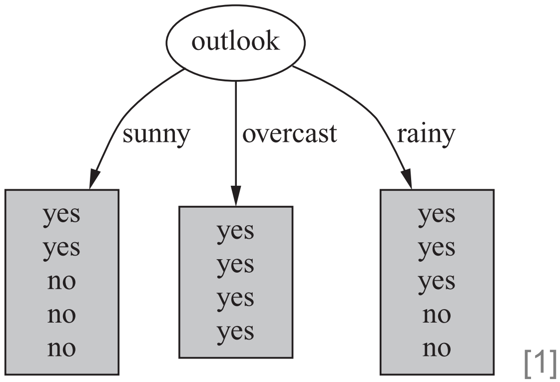
$$\sum_i -p_i \log_2 p_i$$

  - $p_i$ is the probability of class i
  - $\log_2$ is the logarithm to the base 2

# Decision Trees

ComTec

- What is the information entropy?



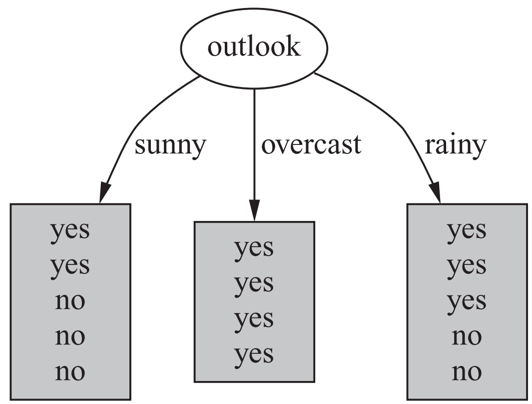

– $info([2,3]) = -\left(\left(-\frac{2}{5} * \log_2\left(\frac{2}{5}\right)\right) + \left(-\frac{3}{5} * \log_2\left(\frac{3}{5}\right)\right)\right) = 0.971 \text{ bits}$

– $info([4,0]) = -\left(-1 * \log_2(1)\right) = 0.0 \text{ bits}$

– $info([3,2]) = -\left(\left(-\frac{3}{5} * \log_2\left(\frac{3}{5}\right)\right) + \left(-\frac{2}{5} * \log_2\left(\frac{2}{5}\right)\right)\right) = 0.971 \text{ bits}$

# Decision Trees

- What is the information entropy?

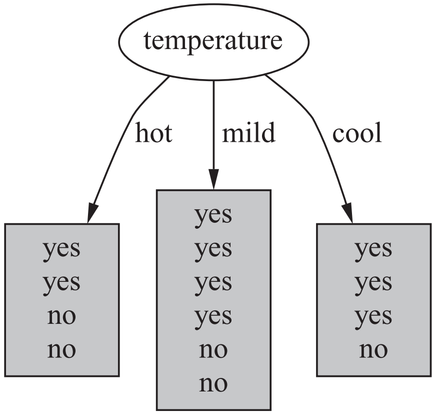



[1]

- $info([2,3],[4,0],[3,2]) = -\left(-\frac{5}{14} * 0.971 + (-\frac{4}{14} * 0) + (-\frac{5}{14} * 0.971)\right) =$ $0.693\ bits$

# Decision Trees

- What is the information entropy?



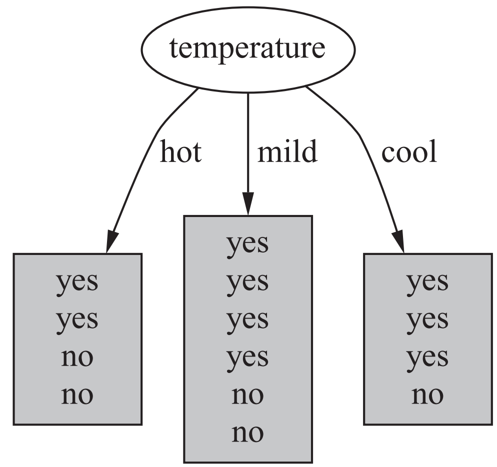

[1]

- $info([2,2]) = -\left(-\frac{2}{4} * \log_2\left(\frac{2}{4}\right) + (-\frac{2}{4} * \log_2\left(\frac{2}{4}\right))\right) = 1 \text{ bit}$
- $info([4,2]) = -\left(-\frac{4}{6} * \log_2\left(\frac{4}{6}\right) + (-\frac{2}{6} * \log_2\left(\frac{2}{6}\right))\right) = 0.918 \text{ bits}$
- $info([3,1]) = -\left(-\frac{3}{4} * \log_2\left(\frac{3}{4}\right) + (-\frac{1}{4} * \log_2\left(\frac{1}{4}\right))\right) = 0.811 \text{ bits}$

# Decision Trees



- What is the information entropy?




[1]

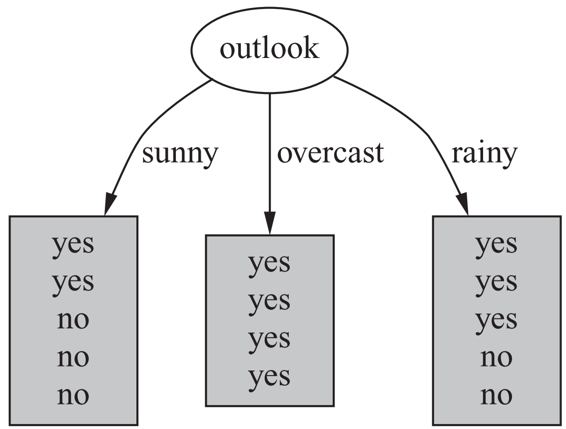
$$- \; info([2,2],[4,2],[3,1]) = \left(-\frac{4}{14} * 1 + (-\frac{6}{14} * 0.918) + (-\frac{4}{14} * 0.811)\right) = 0.911 \; bits$$

# Information Gain

- Information gain
  - Is the amount of information we gain by knowing the value of an attribute
  - (entropy distribution before the split) – (entropy distribution after the split)
- Gives us the attribute which is most useful for descriminating classes
- Describe how important an attribute of the features is

# Information Gain

- What is the information gain?

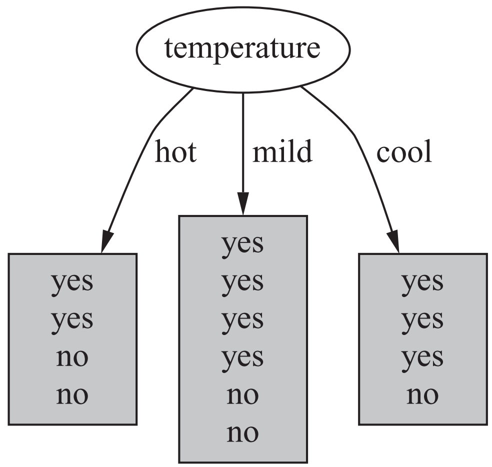



[1]

- $info([9,5]) = -\left(-\frac{9}{14} * \log_2\left(\frac{9}{14}\right) + \left(-\frac{5}{14} * \log_2\left(\frac{5}{14}\right)\right)\right) = 0.940 \text{ bits}$
- $gain(outlook) = info([9,5]) - info([2,3],[4,0],[3,2]) = 0.940 - 0.693 =$ $0.247 \text{ bits}$

# Information Gain

- What is the information gain?




[1]

- $info([9,5]) = -\left(-\frac{9}{14} * \log_2\left(\frac{9}{14}\right) + \left(-\frac{5}{14} * \log_2\left(\frac{5}{14}\right)\right)\right) = 0.940$ bits
- $gain(temperature) = info([9,5]) - info([2,2],[4,2],[3,1]) = 0.940 - 0.911 = 0.029$ bits

# Information Gain

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- What is the information gain?
  - $gain(outlook) = 0.247$ bits
  - $gain(temperature) = 0.029$ bits
  - $gain(humidity) = 0.152$ bits
  - $gain(windy) = 0.048$ bits

- Which attribute should we use for splitting?

# Information Gain

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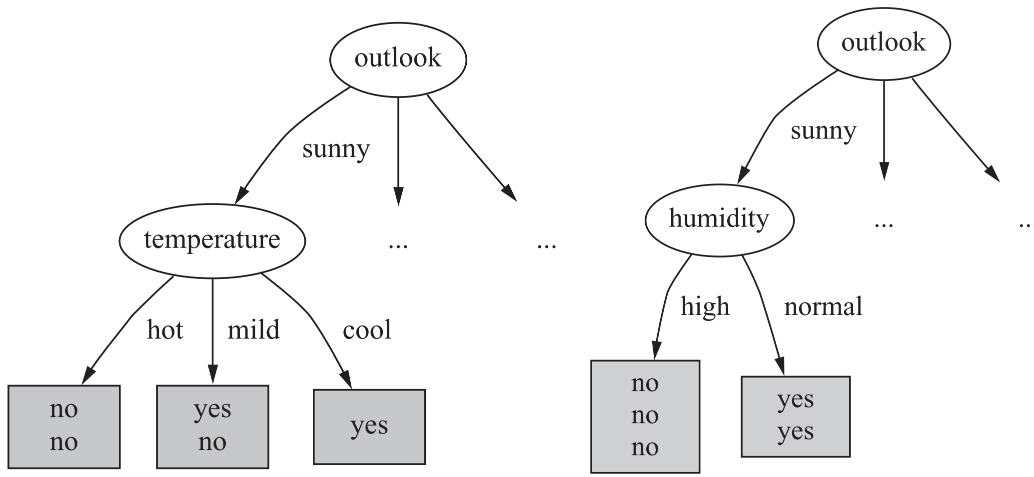


[1]

# Step-Heading-Systems

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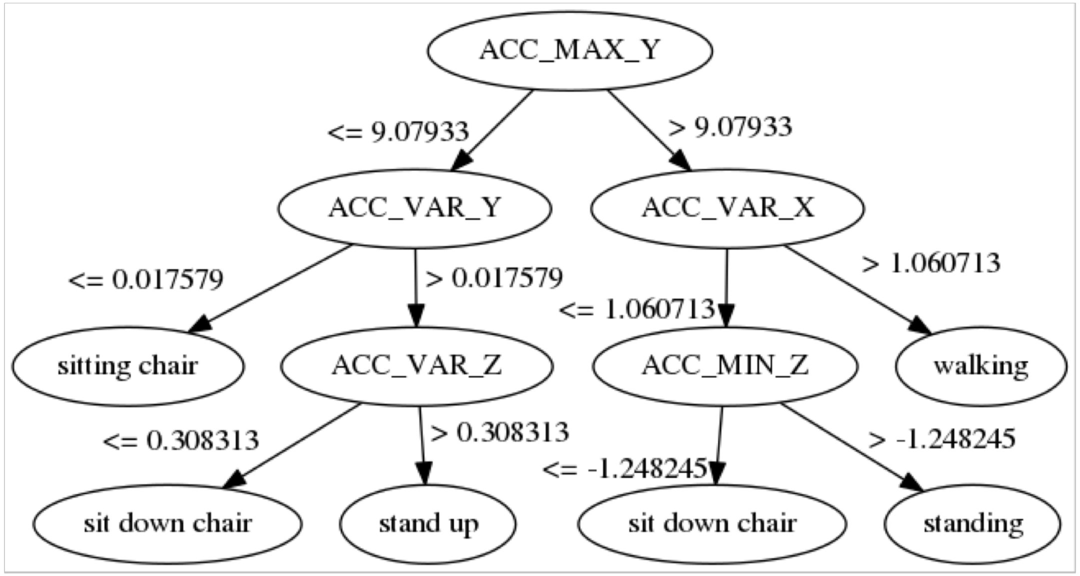
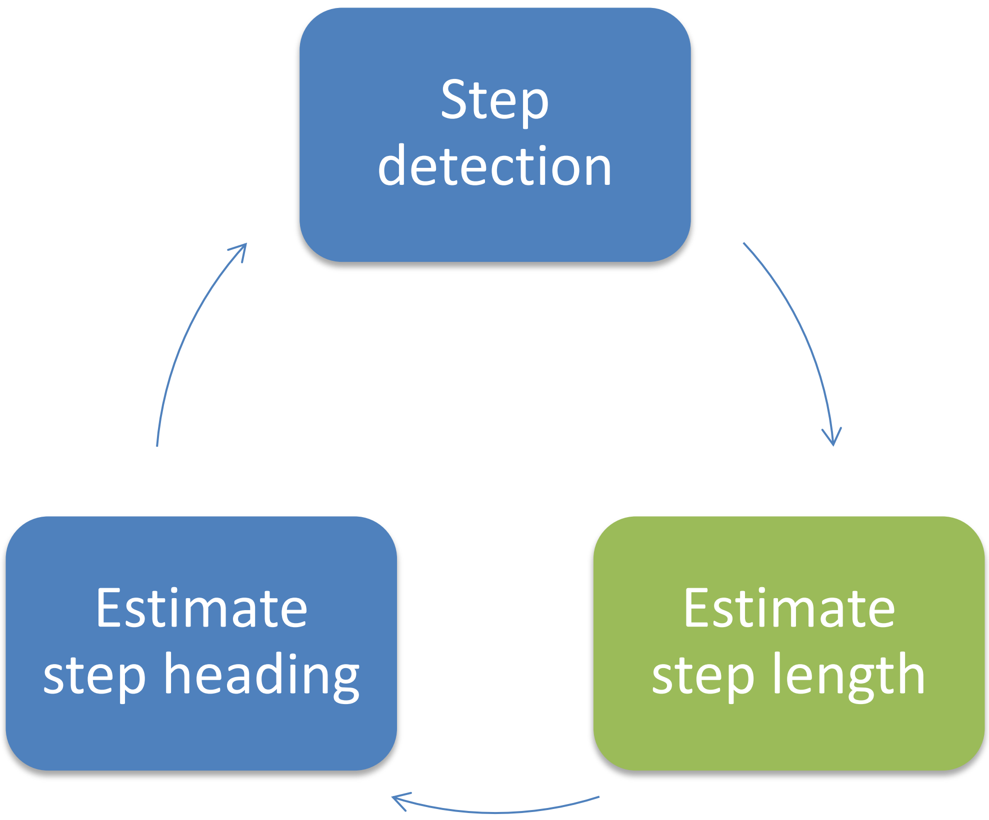
## Decision Tree for estimating walking activities



# Step-Heading-Systems (SHS)

- Basic cycle of SHS-Systems



# Step-Heading-Systems (SHS)

- Step length estimation:
  - Assume that step length is fixed ☺
  - Estimation based on vertical hip displacement
  - Using a function based on step frequency and walking speed
  - Direct measurements using ultra sonic sound

# Step-Heading-Systems (SHS)

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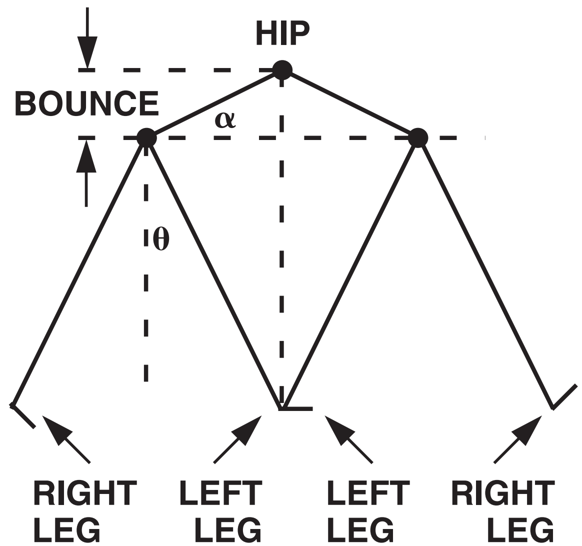
- Assume that step length is fixed:
  - Statistically estimate step length
  - For example: Stride length of runners [11]
    - Roughly 220 cm for men
    - Roughly 210 cm for women
  - However stride length varies as much as +40% to -40% [12]
    - Depends also on leg length

# Step-Heading-Systems (SHS)

- Estimation based on vertical hip displacement

$$Stride \approx \frac{2 \times Bounce}{\alpha}$$




[12]

$$Distance \approx \sqrt[4]{A_{max} - A_{min}} \times n \times K$$

# Step-Heading-Systems (SHS)

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- Function based on step frequency and height
  - Linear relationship between step length and step frequency
  - Step length is proportional to the length of a user’s leg and to the user’s height
  - For example given by:

$$s = h \cdot (a \cdot f_{step} + b) + c$$

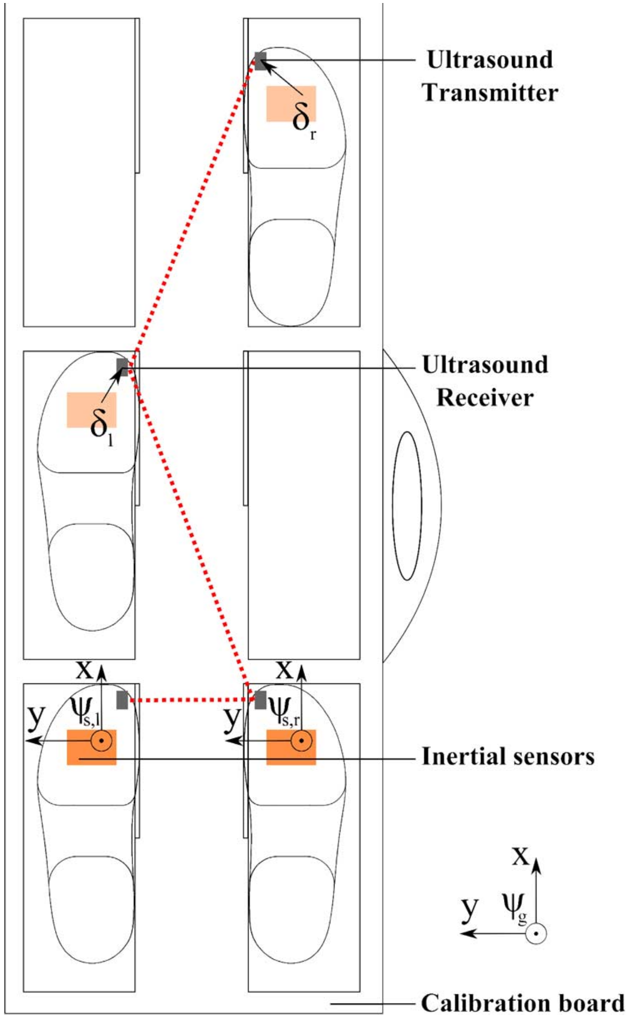
$$K = \{a, b, c\} \in \mathbb{R} \quad [13]$$

# Step-Heading-Systems (SHS)

- Direct measurements using ultra sonic sound
  - For example: Fusing ultrasound estimates and inertial sensors
  - Estimates errors range between 1.7cm (+- 1.8cm) for step length and 1.2cm (+-1.2cm) for stride length

# Step-Heading-Systems





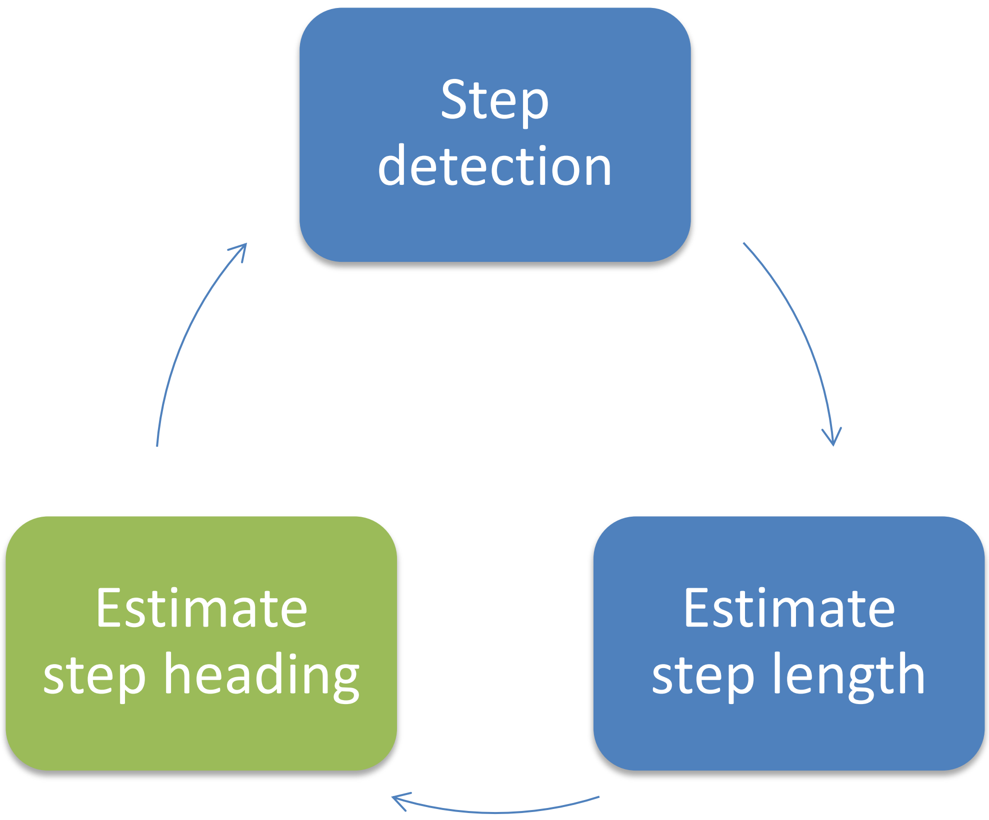

$$d_U = v_s \cdot t_{ToF}.$$

$$v_s = 331.4 \cdot (1 + 1.83 \cdot 10^{-3} \cdot T_C)$$

[14]

# Step-Heading-Systems (SHS)

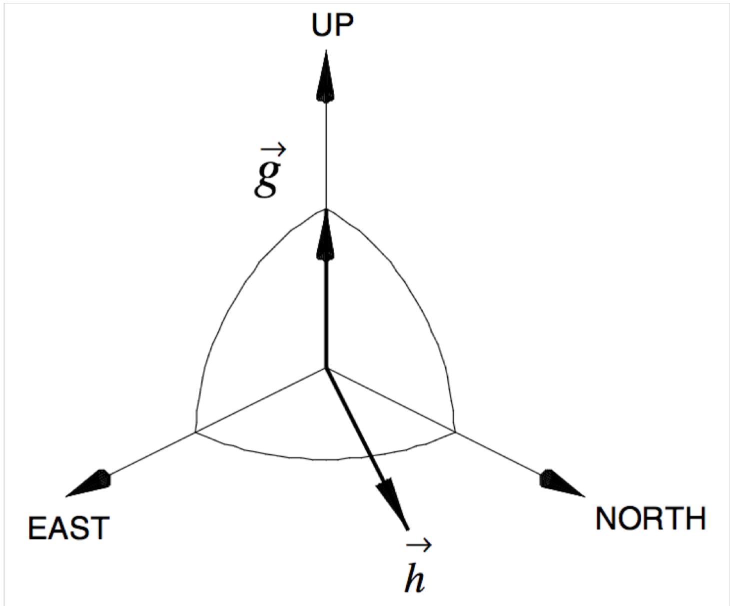
- Basic cycle of SHS-Systems



# Step-Heading-Systems (SHS)

- Estimate step heading:
  - Using gyroscopes and/or magnetometers
- Using magnetometers work when:
  - There is no or little magnetic interferences
  - Which is not often the case in buildings
- Integrating over gyroscope values
  - Gives the angular position
  - Drifts over time
- Combination of both to reduce drift

# Estimate Step-Heading




[17]

# Estimate Step-Heading

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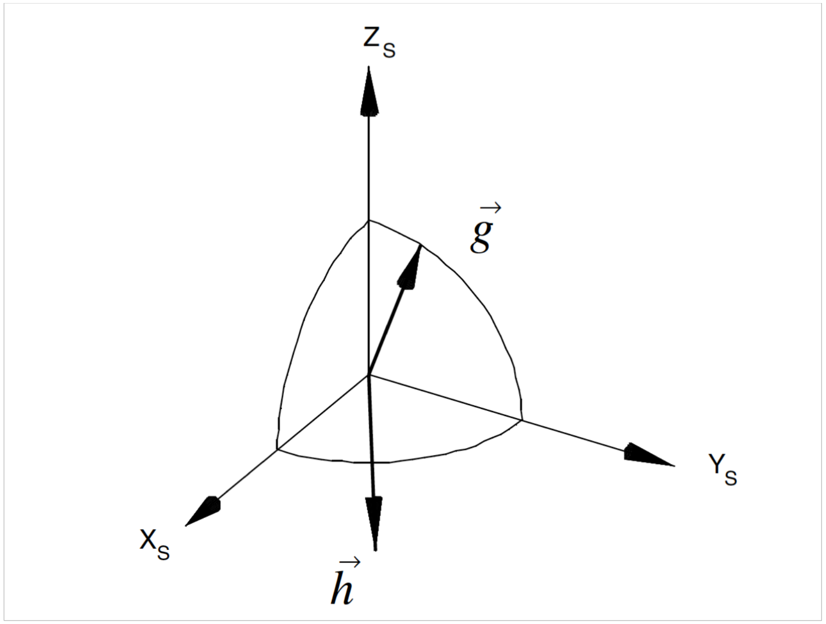
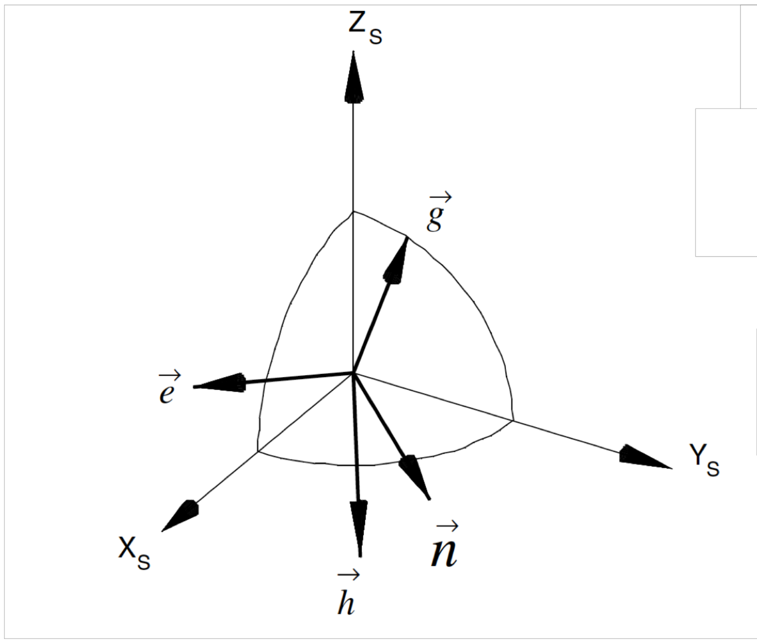



[17]

# Estimate Step-Heading

ComTec




$$d_G = A^{S-G} d_S$$

$$\mathrm{E_S} = \frac{\mathrm{h_S} \times \mathrm{g_S}}{\|\mathrm{h_S} \times \mathrm{g_S}\|}$$

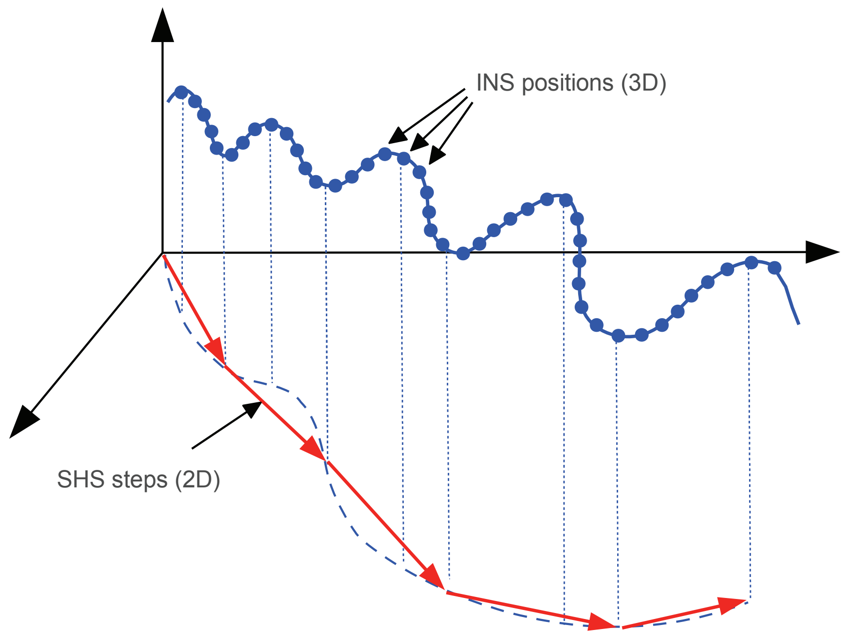
$$\vec{h}_{\mathrm{perp}} = (\vec{h} - \vec{h} \cdot \vec{g})\vec{g}$$

$$N_S = \frac{(h_S - h_S \cdot g_S)g_S}{\|(h_S - h_S \cdot g_S)g_S\|}$$

[17]

# Inertial-Navigation-Systems (INS)

- INS-Systems using 3D-Vectors for navigation
  - Systems that need information on height




[15]

Maps

# DEAD-RECKONING

# Maps

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- What about navigation?
  - Using maps for navigation purposes
  - Geo-referenced maps
- Using different vector layers for objects
  - Doors
  - Walls

# Maps

ComTec

Attributtabelle - comtec_doors :: Objekte gesamt: 27, gefiltert: 27, gewählt: 0
id
room_id_0
room_id_1
blank
Alle Objekte anzeigen
Attributtabelle - comtec_rooms :: Objekte gesamt: 20, gefiltert: 20, gewählt: 0
id
desc
room_nr
blank
Alle Objekte anzeigen

# Maps

- Attributes

```
WKT;id;room_id_0;room_id_1;blank
"LINESTRING (9.47288763796637 51.311221854868627,9.472886471859514 51.31121347227073)";-21;0;1;
"LINESTRING (9.472885305752657 51.311204542979972,9.472884139645801 51.311195249226529)";-22;0;3;
"LINESTRING (9.472861692088829 51.31118449762706,9.472874519264241 51.311183950935487)";-23;0;13;
"LINESTRING (9.472853529340839 51.311179212941639,9.47285148865384 51.311162812189934)";-25;19;13;
"LINESTRING (9.47291795674462 51.311181764169163,9.472931366973462 51.311181217477561)";-26;3;13;
```

ComTec

Errors and Pitfalls

# DEAD-RECKONING

# Errors and Pitfalls

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- What about noise and inaccuracies?
  - Inaccurate step detection, length and heading estimation will cause the PDR-System to fail
  - Basically only one „subsystem“ needs to fail

# Errors and Pitfalls

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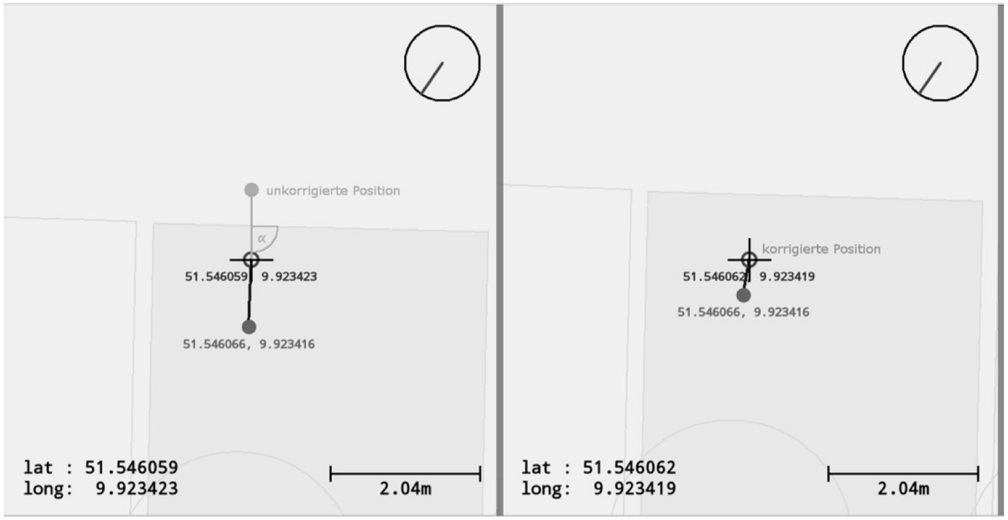
- Inaccurate step detection
  - User is moving but the system is not recognizing it
  - System will count more/less steps than actually done
- Step detection and length estimation errors:



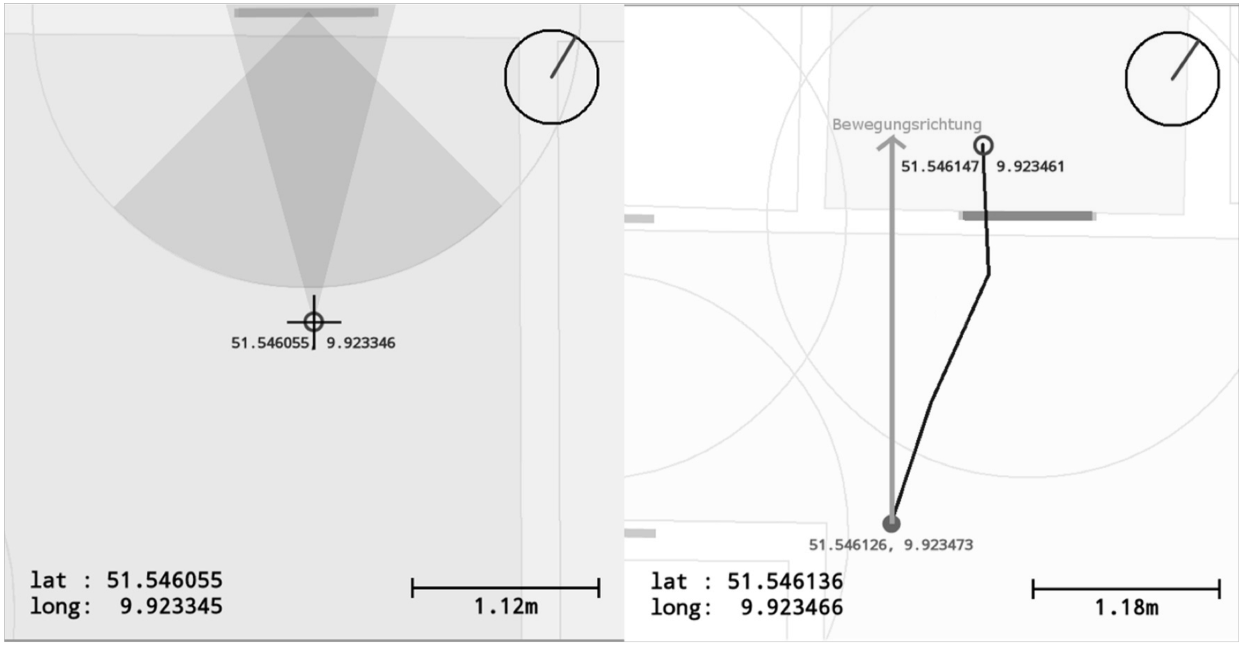
# Errors and Pitfalls

- Step heading estimation errors

# Errors and Pitfalls

ComTec

- Adjacent rooms and doors



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