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Master's degree ICT Internet Multimedia Engineering

CNN AS FEATURE EXTRACTORS: THE CASE OF INERTIAL SIGNALS

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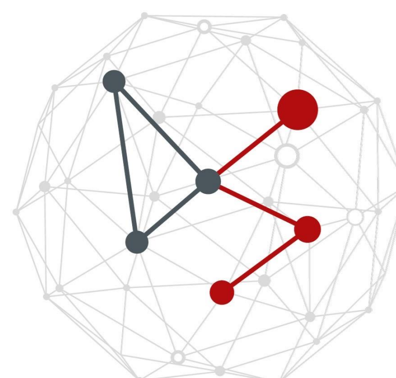

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Outline

- Analysis of inertial signals
  - System model
  - Data acquisition & preprocessing
  - Coordinate transformation
  - Template based segmentation
  - CNN architecture
  - One-class SVM
  - Sequential decision making
  - Numerical results

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ANALYSIS OF INERTIAL SIGNALS

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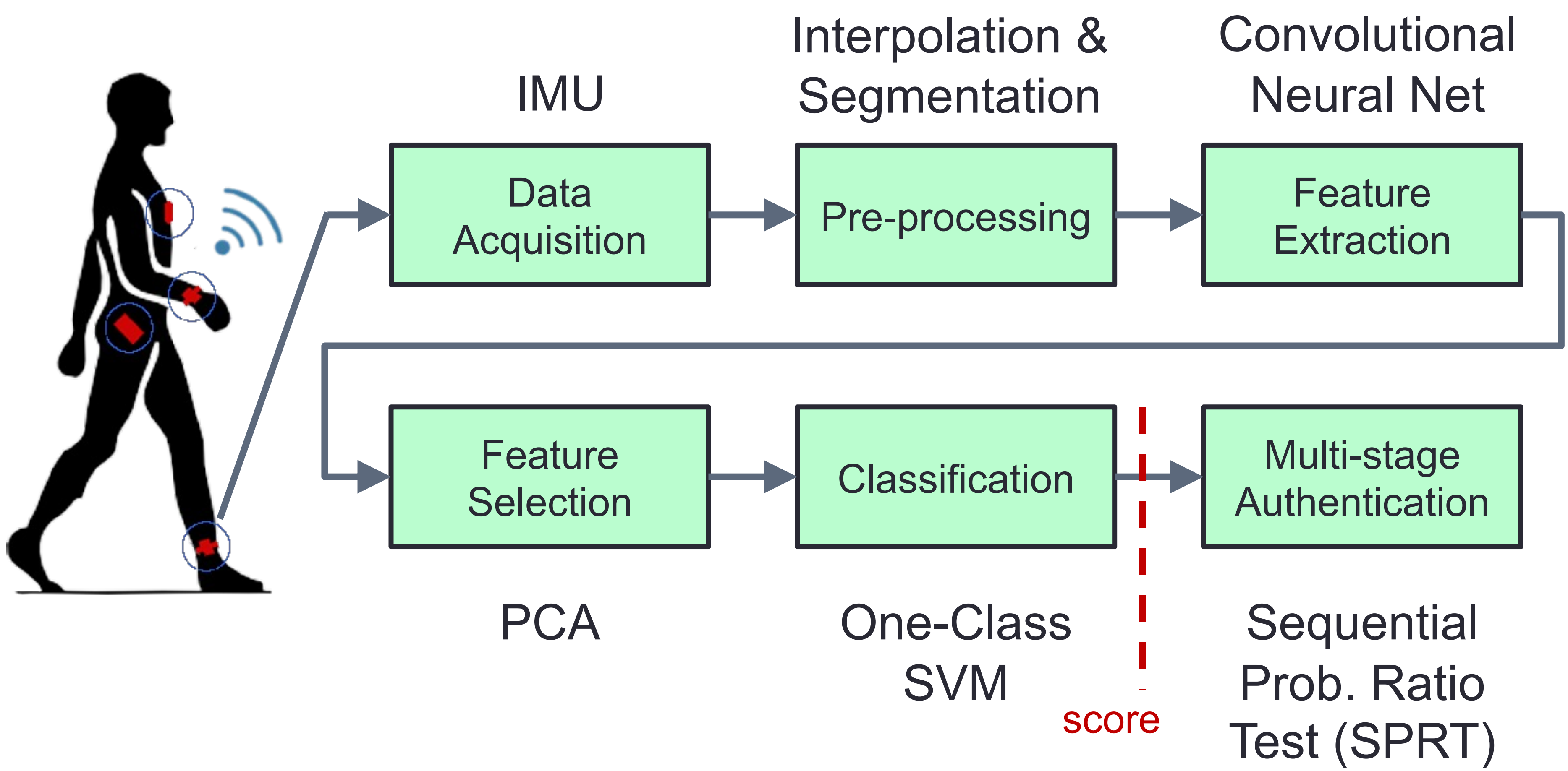
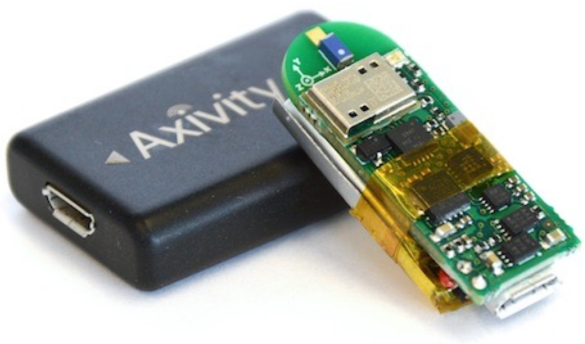
System Model



Data Acquisition (1/2)

Inertial Measurement Unit (IMU)

- **Axivity WAX9**
  - **Accelerometer** ±2 / 4 / **8 g** (14 bit resolution)
  - **Gyroscope** ±250 / 500 / **2000 dps** (16 bit resolution)
  - Temperature 0 - 65 °C (0.1˚C resolution)
  - Pressure 30-110 kPA (1Pa resolution)
  - Max. sampling frequency: **400 Hz**
  - Bluetooth LE radio
  - https://axivity.com/downloads/wax9
- Worn on the ankle of the user



Data Acquisition (2/2)

Smartphone

- Measures the 9 axes
- Sampling frequency
  - Fluctuates (non-realtime OS)
  - Some samples may be lost
  - Re-interpolation needed
- Carried in the front pocket

Pre-processing

Interpolation & resampling

- Cope with missing points & variable sample rate

Coordinate system transformation

- Onto rotation invariant system

Template extraction

- Manually done from acc & gyro magnitudes

Segment extraction

- Correlation measure between signal & template

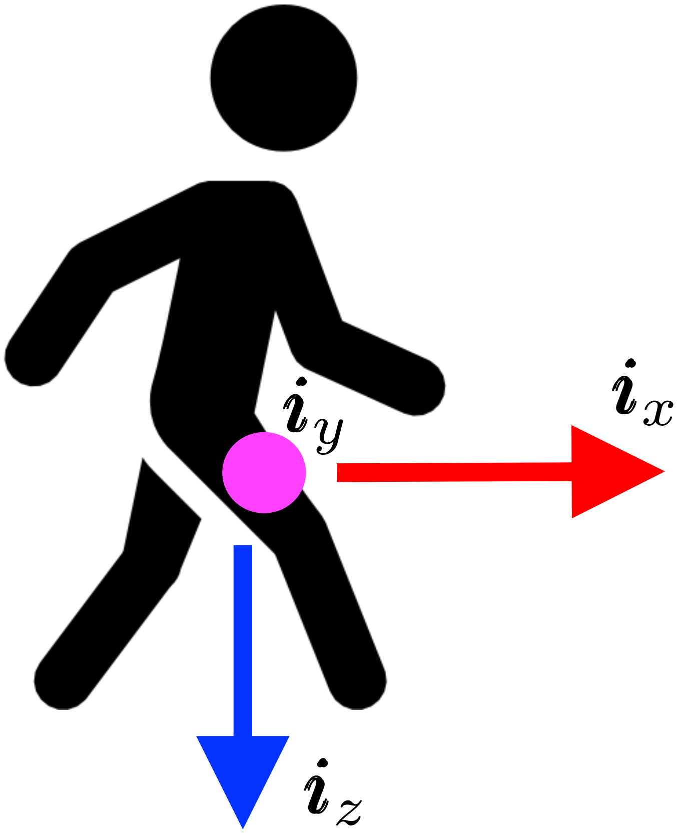
$$\mathrm{corr\_dist} = 2 - \mathrm{corr}(\mathrm{acc}) - \mathrm{corr}(\mathrm{gyro})$$

Transformation of coordinate system

- Only needed for smartphone system
- Accelerometer and gyroscope
  - Measured in the coordinate system of the smartphone
  - This depends on phone orientation in the pocket
  - Not good
- What we need
  - To measure a trajectory that is independent of the phone orientation
  - Orientation invariant coordinate system
- Solution
  - Move the x, y, z measurements (9 axes)
    - from phone system to orientation invariant coordinate system

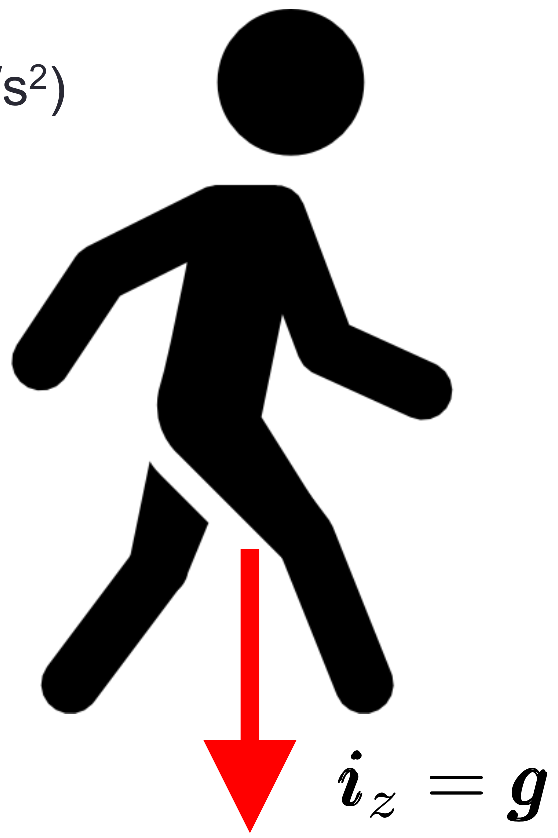
Orientation invariant coordinate system

- 3 orthogonal versors are to be found
- One pointing forward
  - Aligned with direction of motion
- One pointing down
  - Aligned with gravity (and user's torso)
- One tracking lateral movement
  - Orthogonal to the other two versors



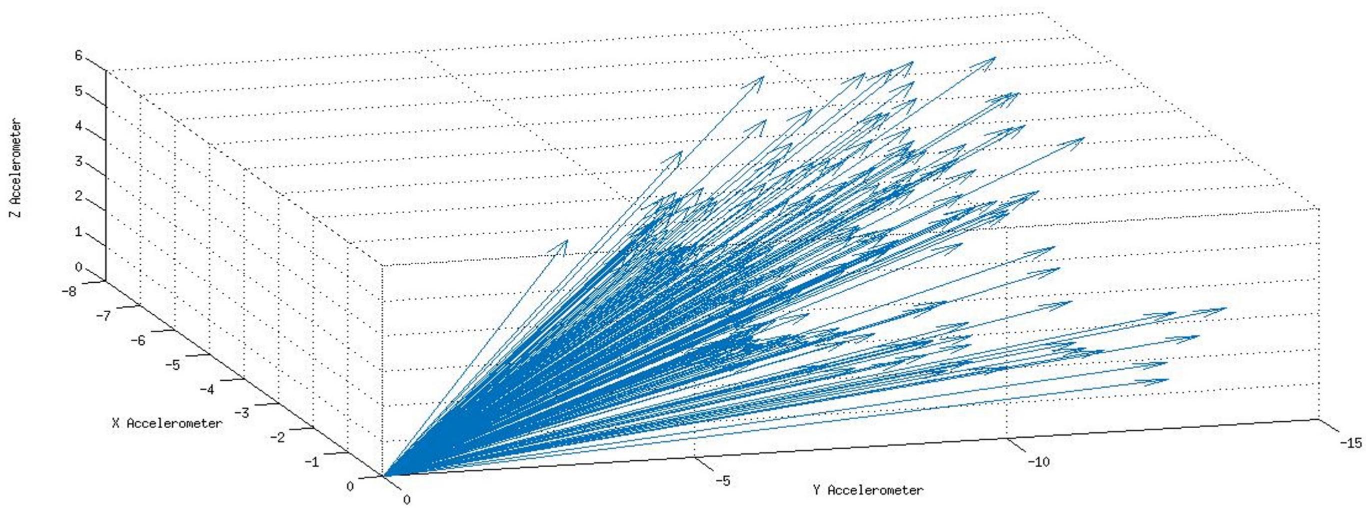
Orientation invariant coordinate system

- Solution
  - Gravity! **g** = (g_x, g_y, g_z)
  - Is a constant acceleration vector
  - We even know its average value (9.81 m/s^2)



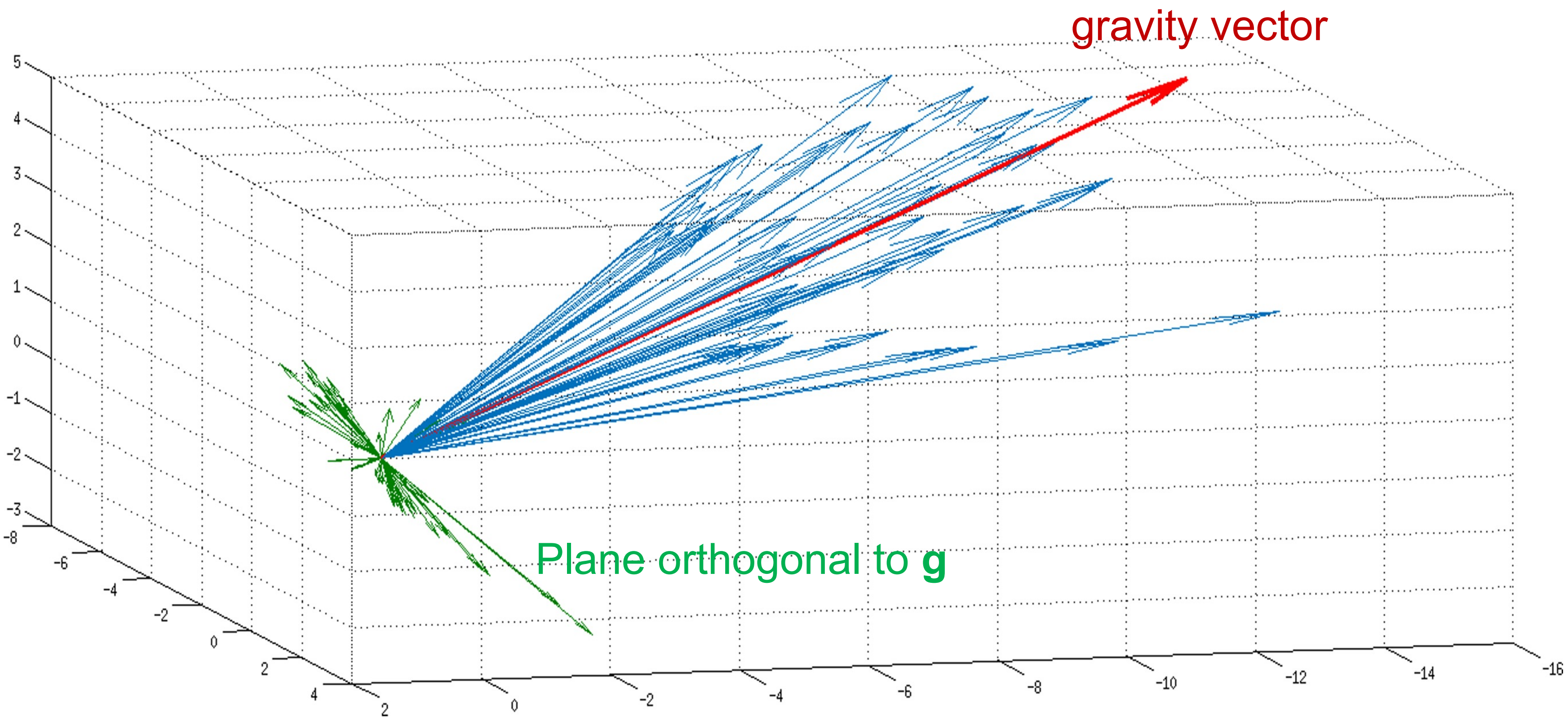
Orientation invariant coordinate system

- Obtaining the new coordinate system
  - Measure accelerometer signal (a_x, a_y, a_z), in the native system
  - Low pass filter to extract constant gravity vector (0 Hz component)
  - This will be aligned with the first versor (pointing down)
  - Below graph
    - 3D acceleration signal
    - There is a main component (gravity)



Low pass filtering and projection

- Low pass filtering to find **g**
- Projection onto orthogonal plane to **g**

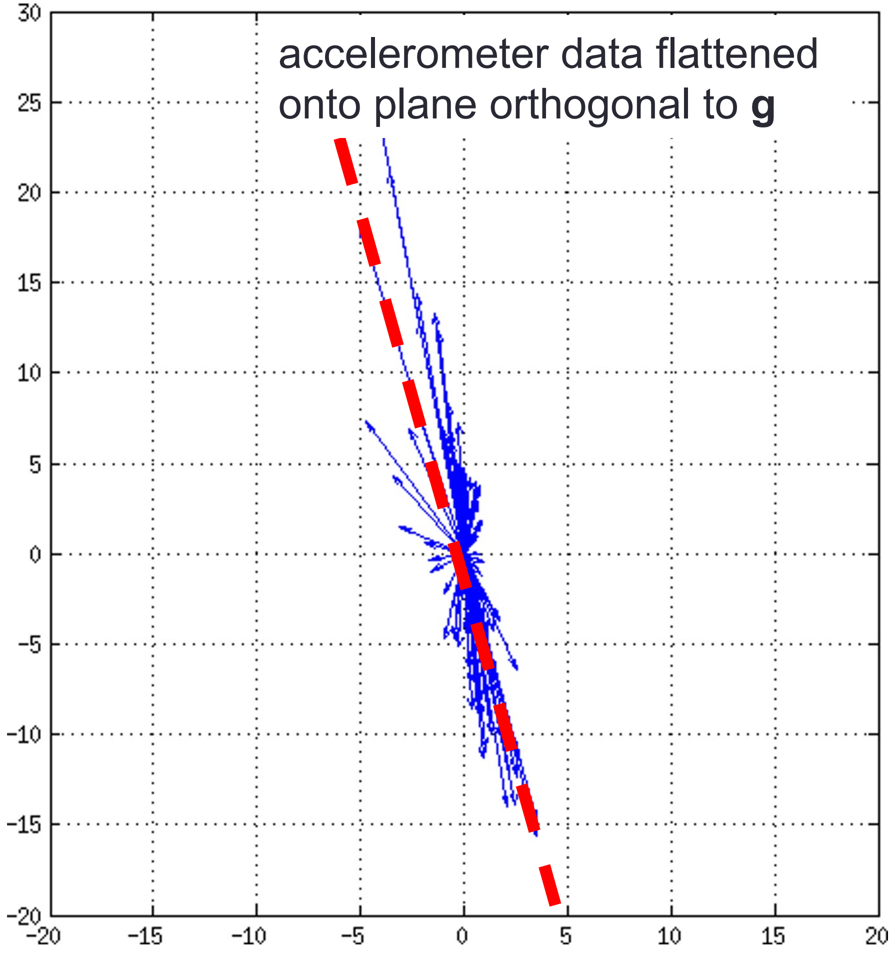


Plane orthogonal to **g**

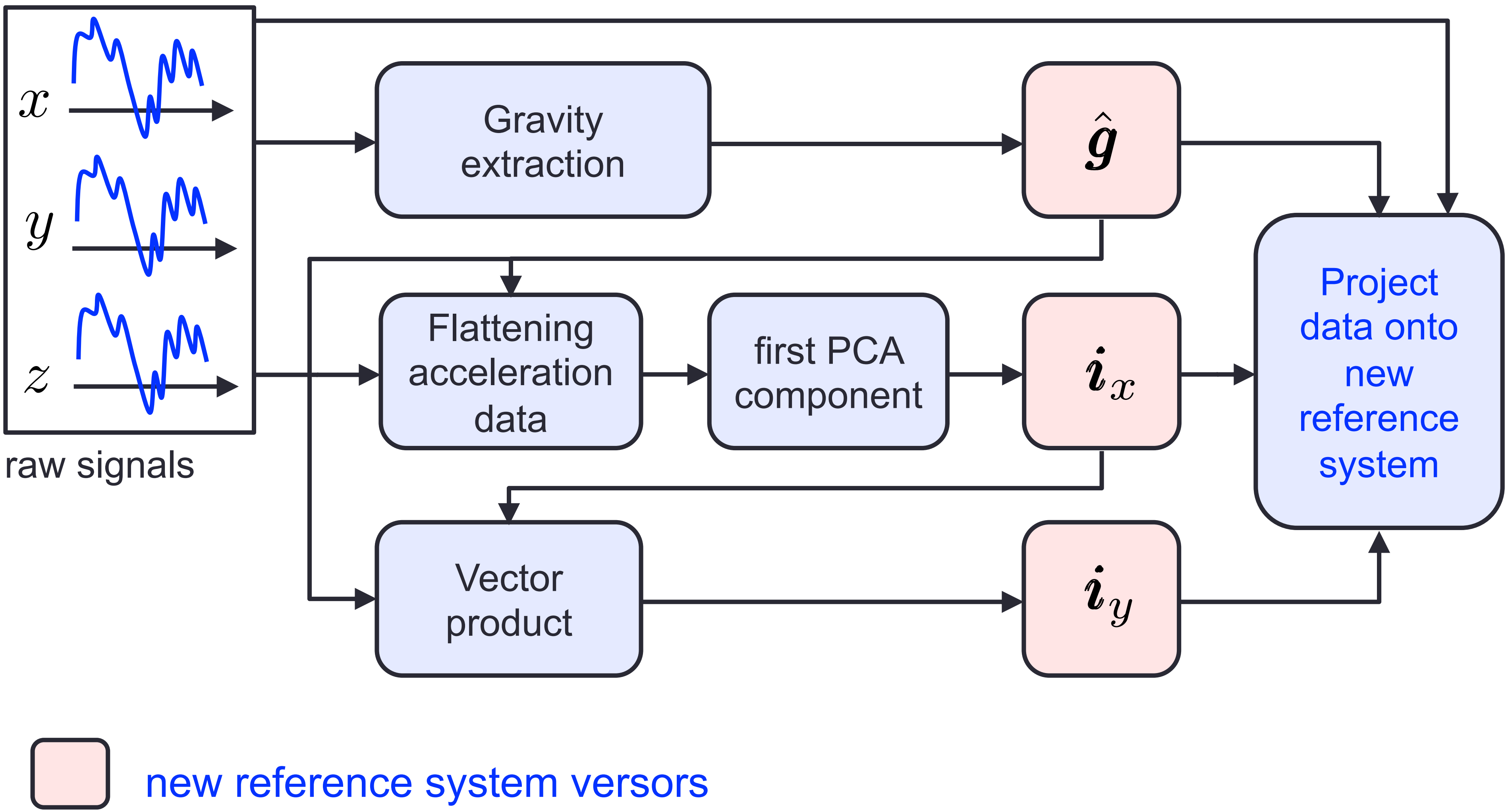
- How to identify the forward direction of motion?
  - Corresponds to dashed line
- Variance of data cloud
  - Is max along direction of motion

maximum variance → PCA!!!

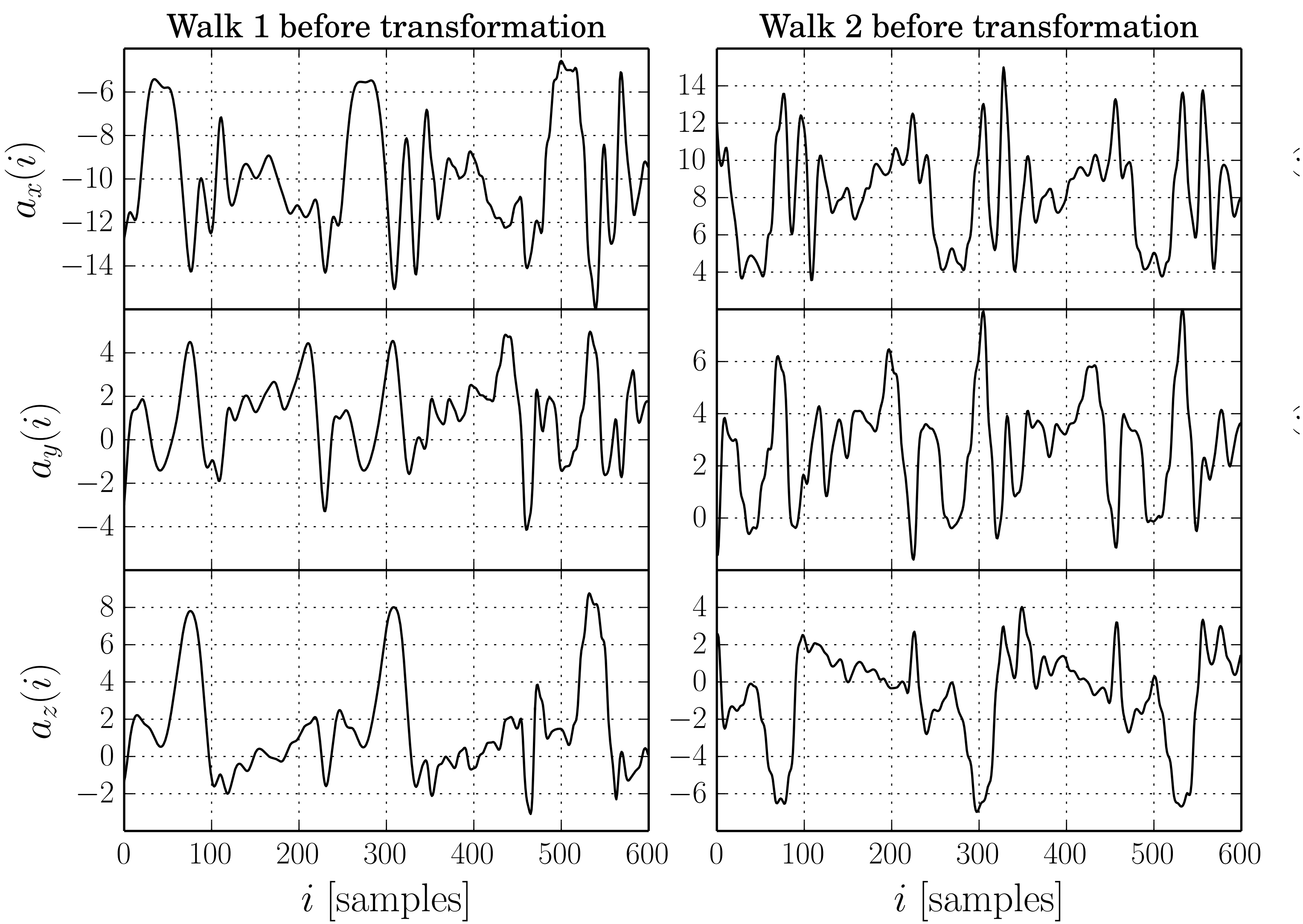
- First PCA component
- Has strongest variance



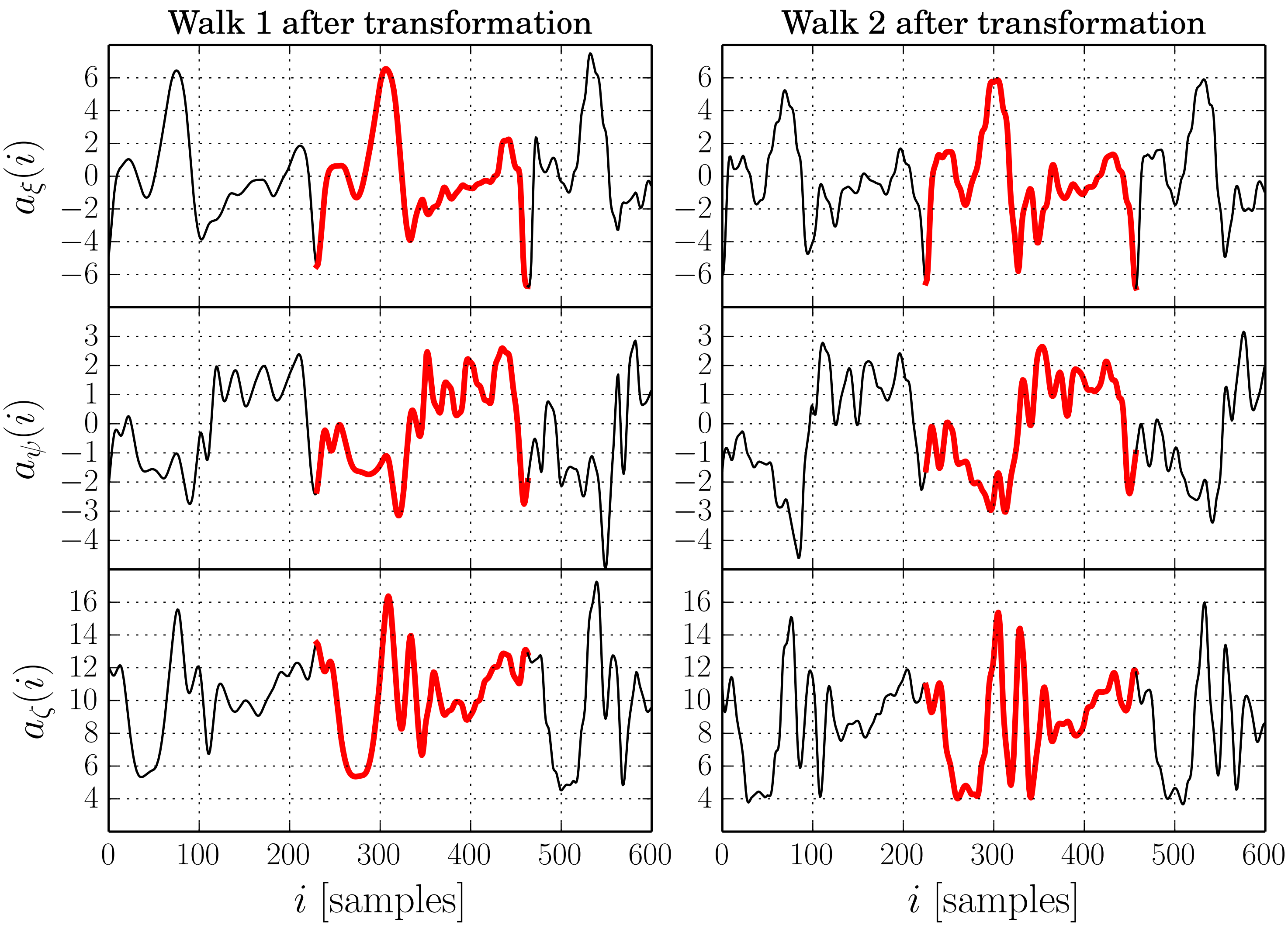
Reference system transform



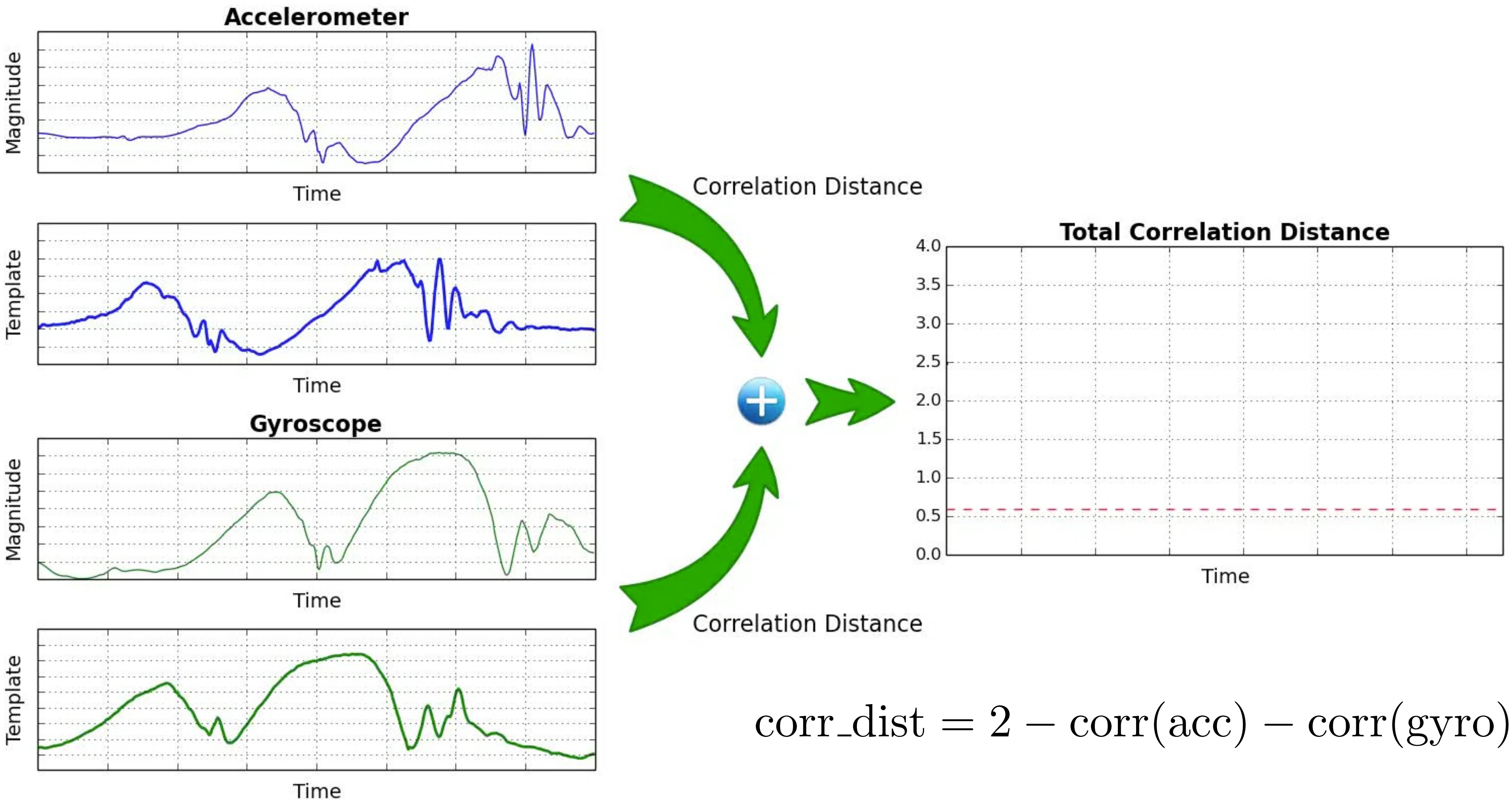
Walking pattern before tranform



Walking pattern after tranform

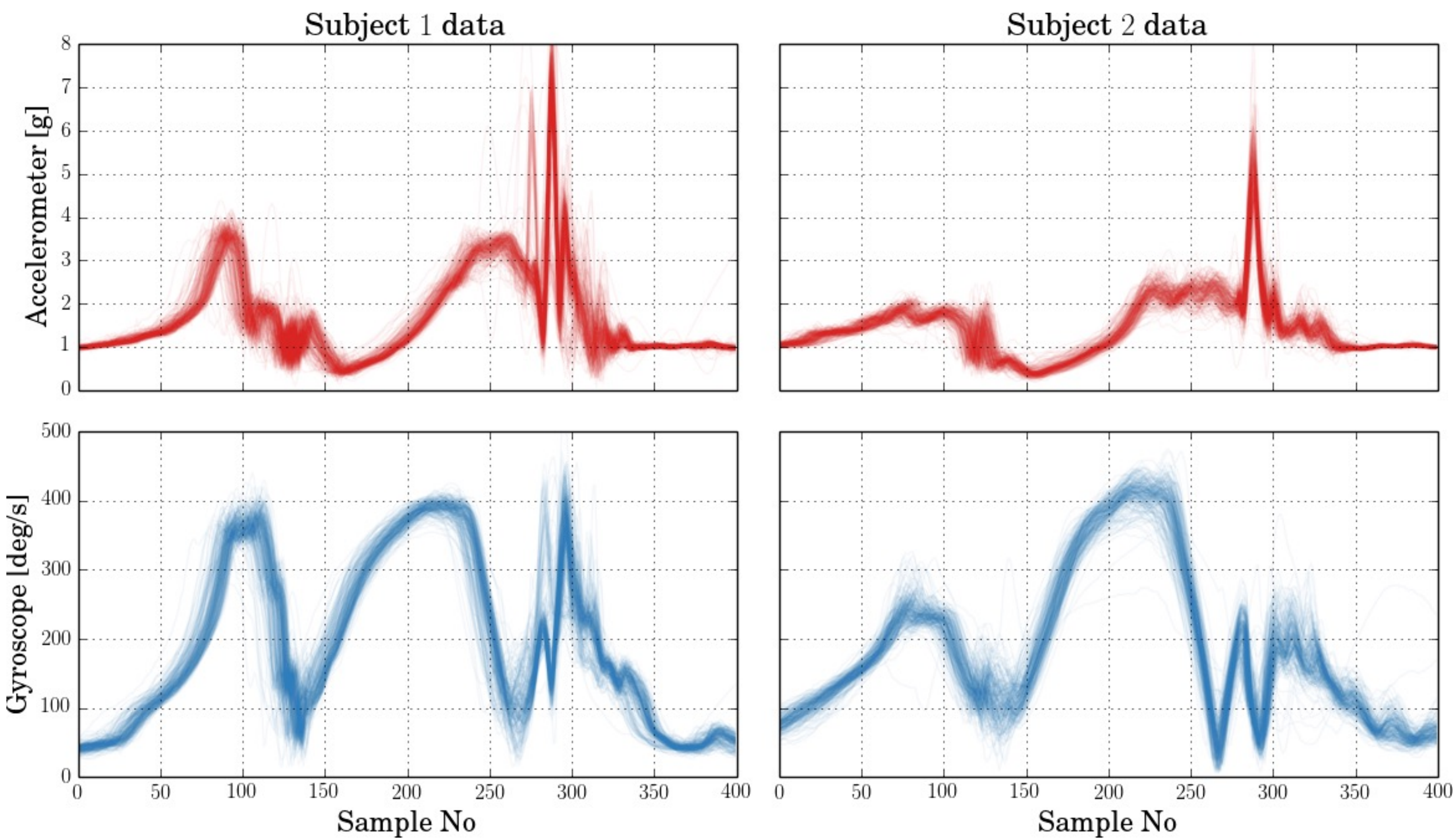


Template-based segmentation

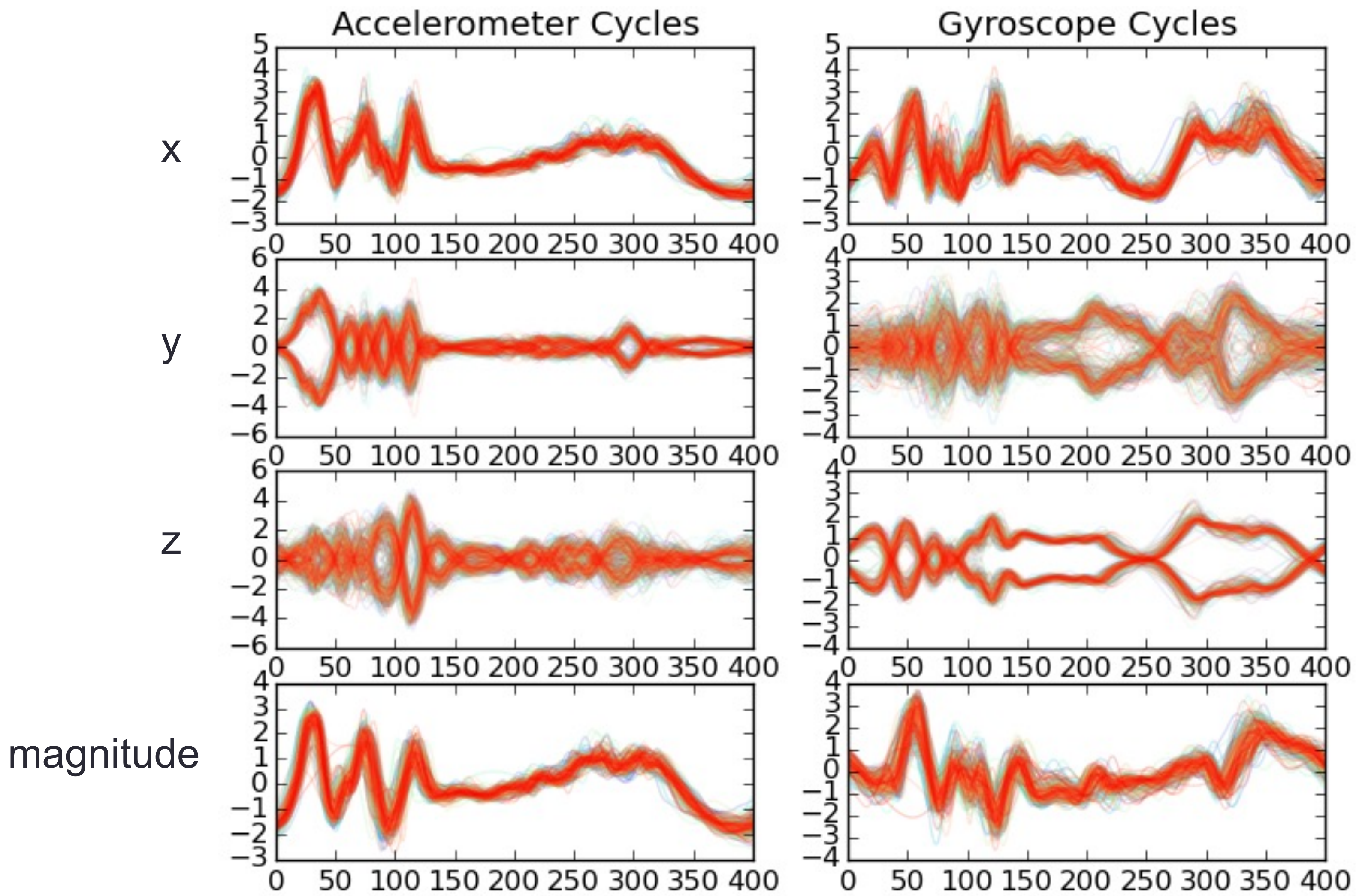


$$\mathrm{corr\_dist} = 2 - \mathrm{corr}(\mathrm{acc}) - \mathrm{corr}(\mathrm{gyro})$$

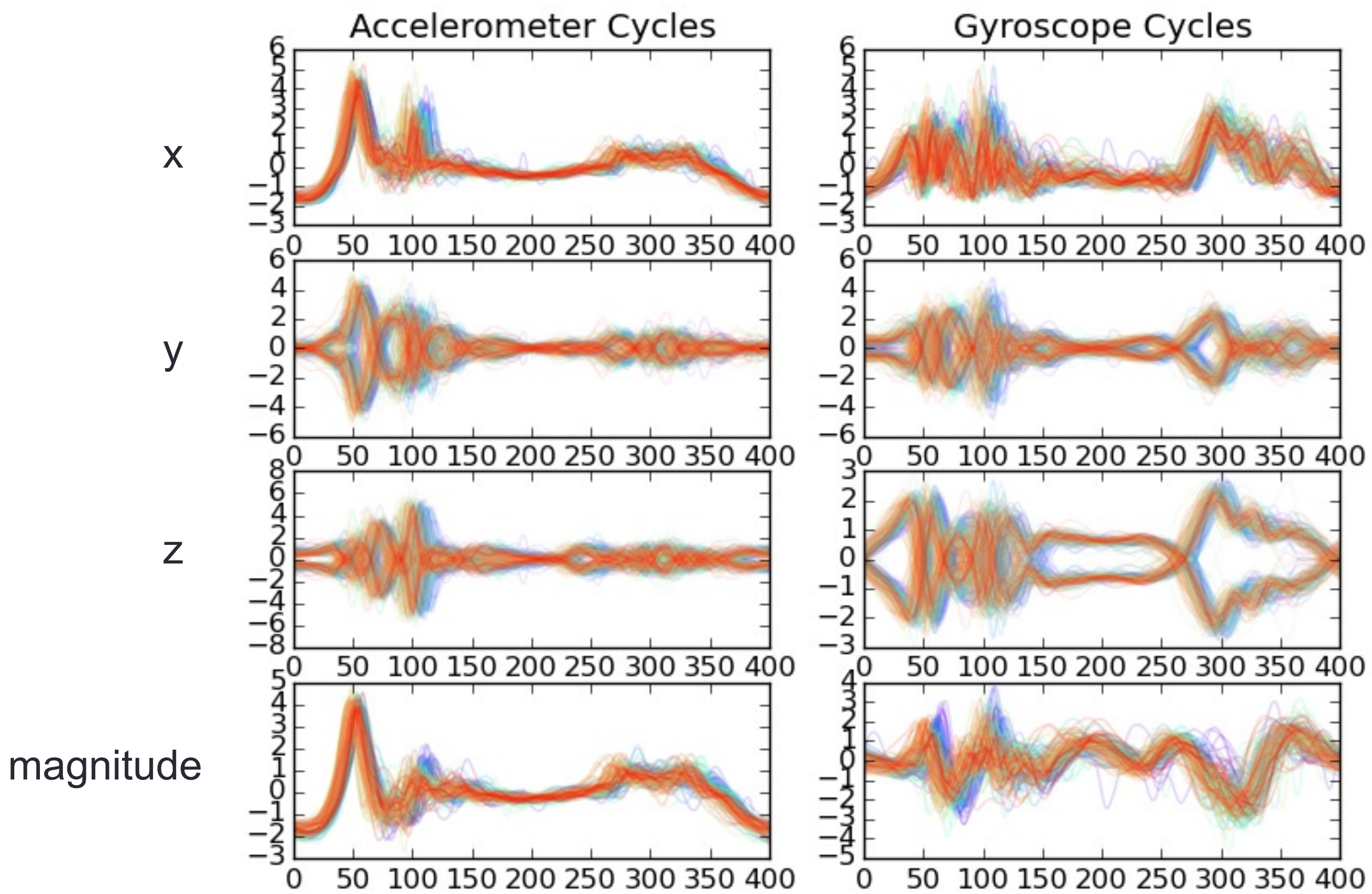
Walking pattern examples: two subjects



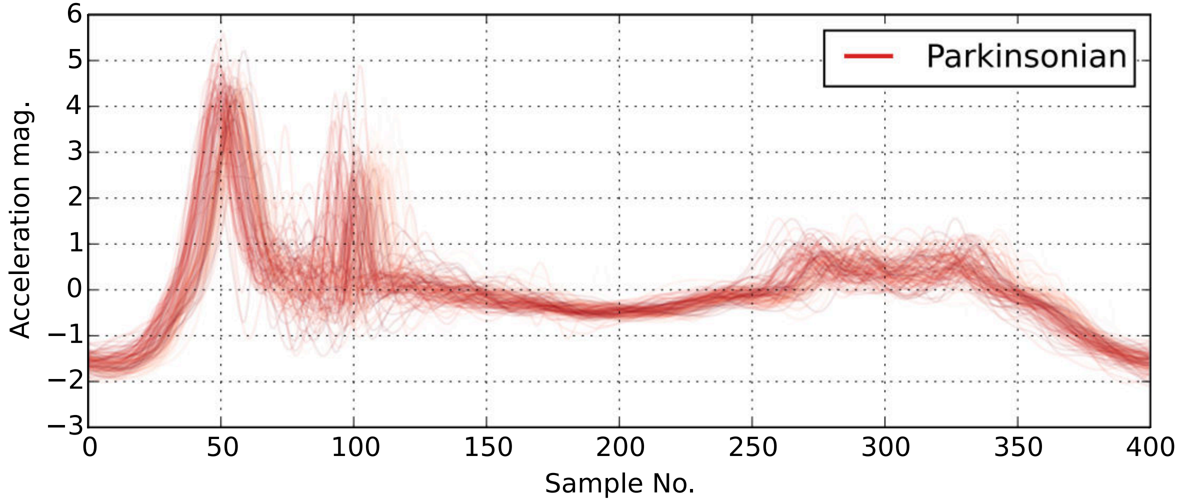
Healthy young male

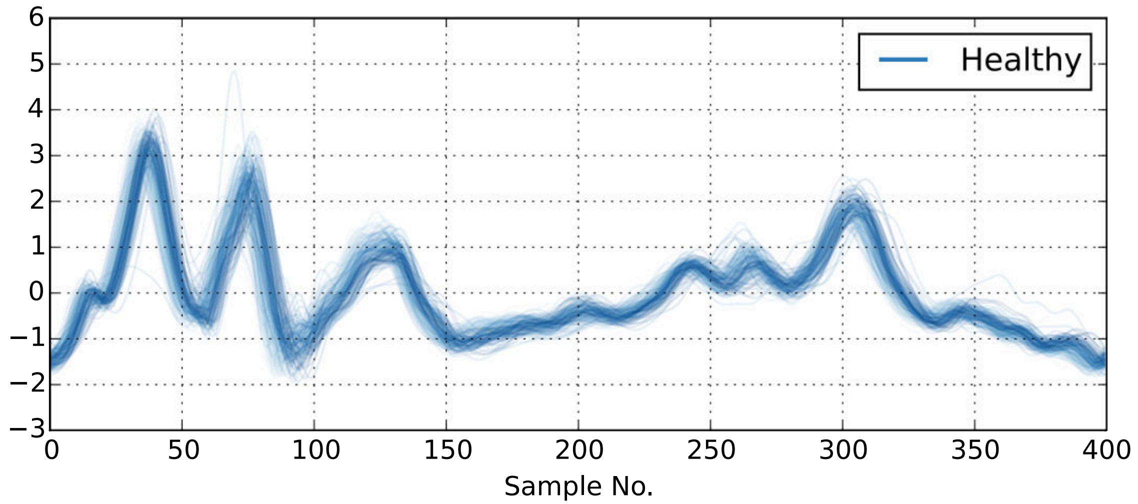


Parkinsonian



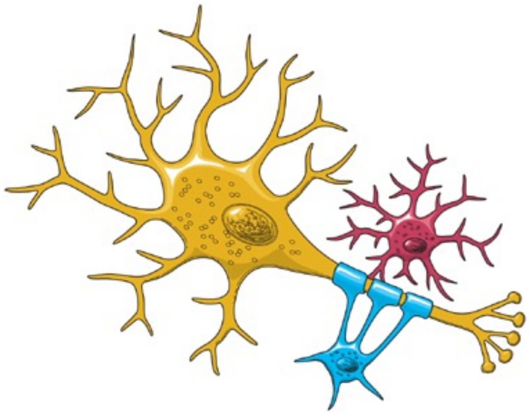
Healthy *vs* Parkinsonian





Convolutional Neural Network (CNN)

- Supervised training (50 subjects)
  - 10 minutes of walk, at least 2 sessions each
  - Smartphones
    - Asus Zenfone 2,
    - Samsung S3 Neo,
    - Samsung S4,
    - LG G2, LG G4,
    - Google Nexus 5



- CNN to extract of relevant features
  - Automatic feature engineering

CNN – conv layer 1

- **CL1** We do not capture any correlation among different accelerometer and gyroscope axes
- 20, 1D kernels of size 1 x 10: processing each input vector separately. For each walking cycle, input vectors are (normalized to a fixed lenght):

$$\boldsymbol{a}_x, \boldsymbol{a}_y, \boldsymbol{a}_z, |\boldsymbol{a}|, \mathbf{gyr}_x, \mathbf{gyro}_y, \mathbf{gyro}_z, |\mathbf{gyro}|$$

- Activation functions are linear

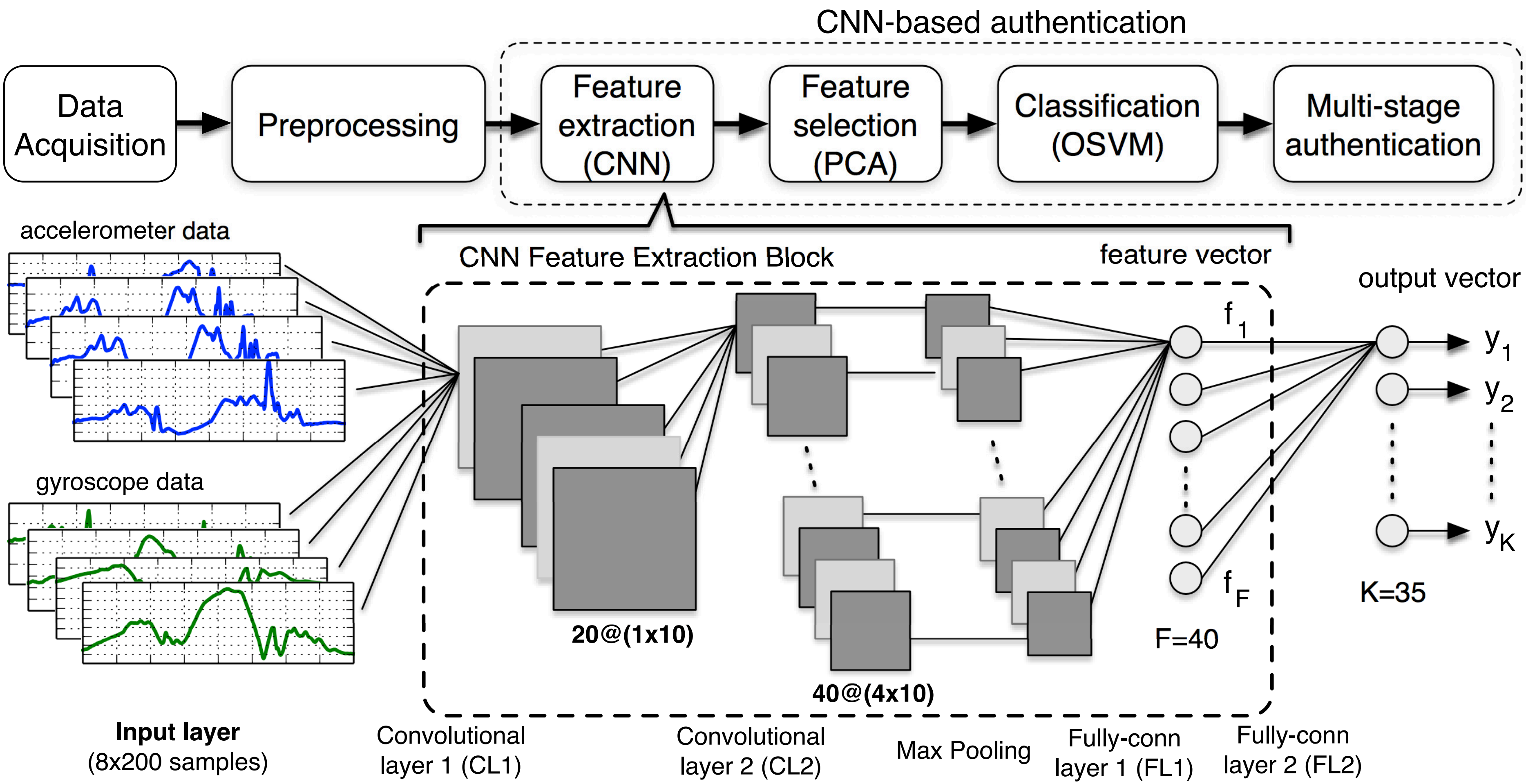
CNN – conv layer 2

- **CL2** With the second convolutional layer we seek discriminant and class-invariant features.
- 40, 2D kernels of size 4 x 10: the cross-correlation among input vectors is considered
- tanh: non-linear activation functions
- Max pooling: applied to
  - reduce the dimensionality and
  - increase spatial invariance

Fully connected layers 2 and 3

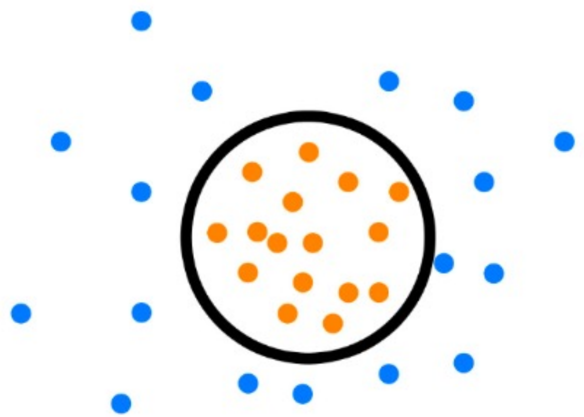
- **FL2** fully connected layer with tanh activations
  - Has F output neurons
  - These are the features extracted by the network
- **FL3** fully connected layer with softmax activations
  - Has K output neurons
  - One for each user in the training dataset

CNN architecture



One-Class SVM [S+00]

- Only target class (orange) data is available
- Training finds the *boundary* (tick circle)
- Classification output: score
  - Distance from the boundary



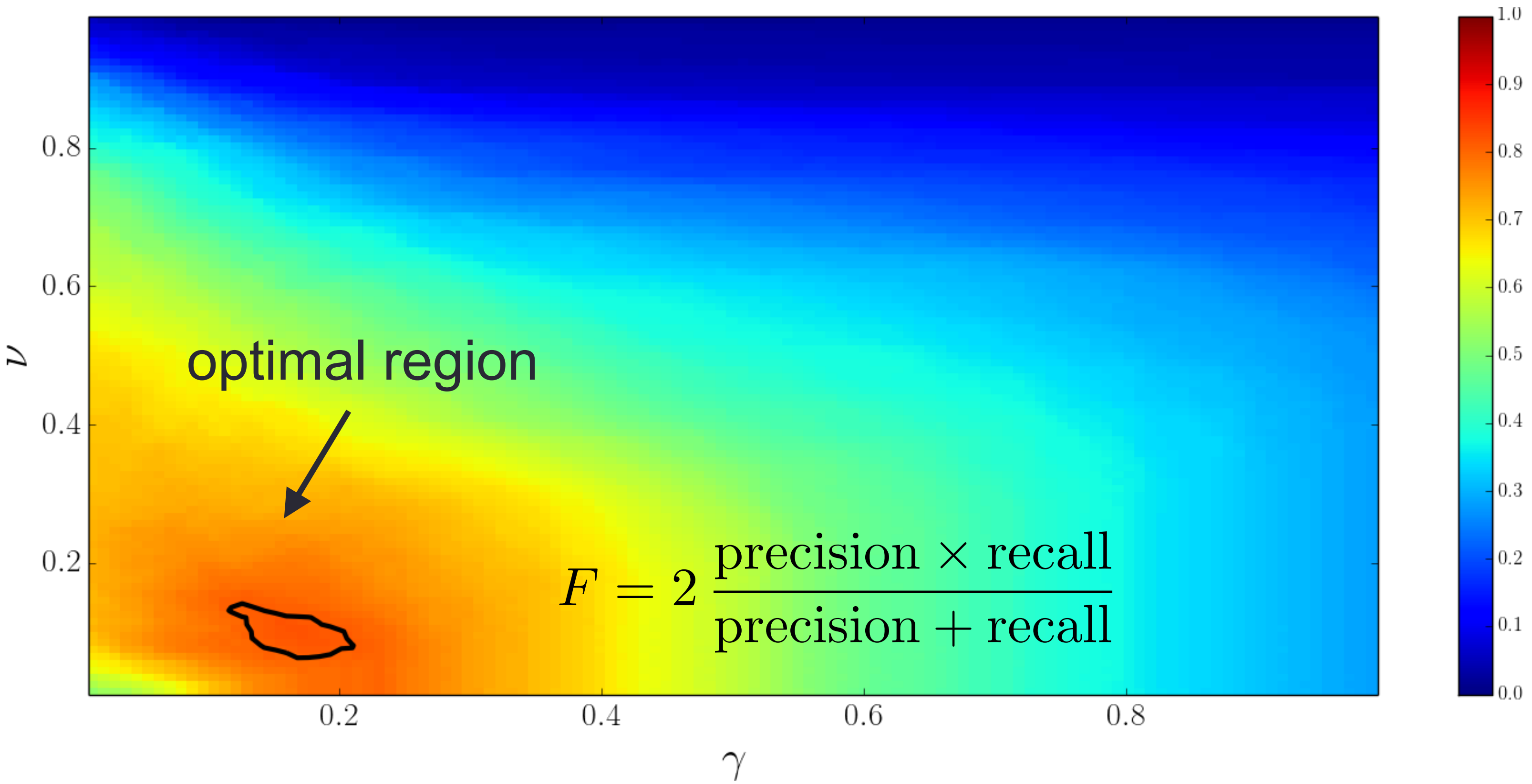
- Training
  - We only used data from target user
- Test
  - Data from the negative class are also used
  - Performance assessment

[S++00] B. Schölkopf, J.C. Plattz, J. Shawe-Taylory, A.J. Smolax, Robert C. Williamson, "Estimating the Support of a High-Dimensional Distribution," *Neural Computation Journal*, Vol. 13, No. 7, Pages 1443-1471, July 2001.

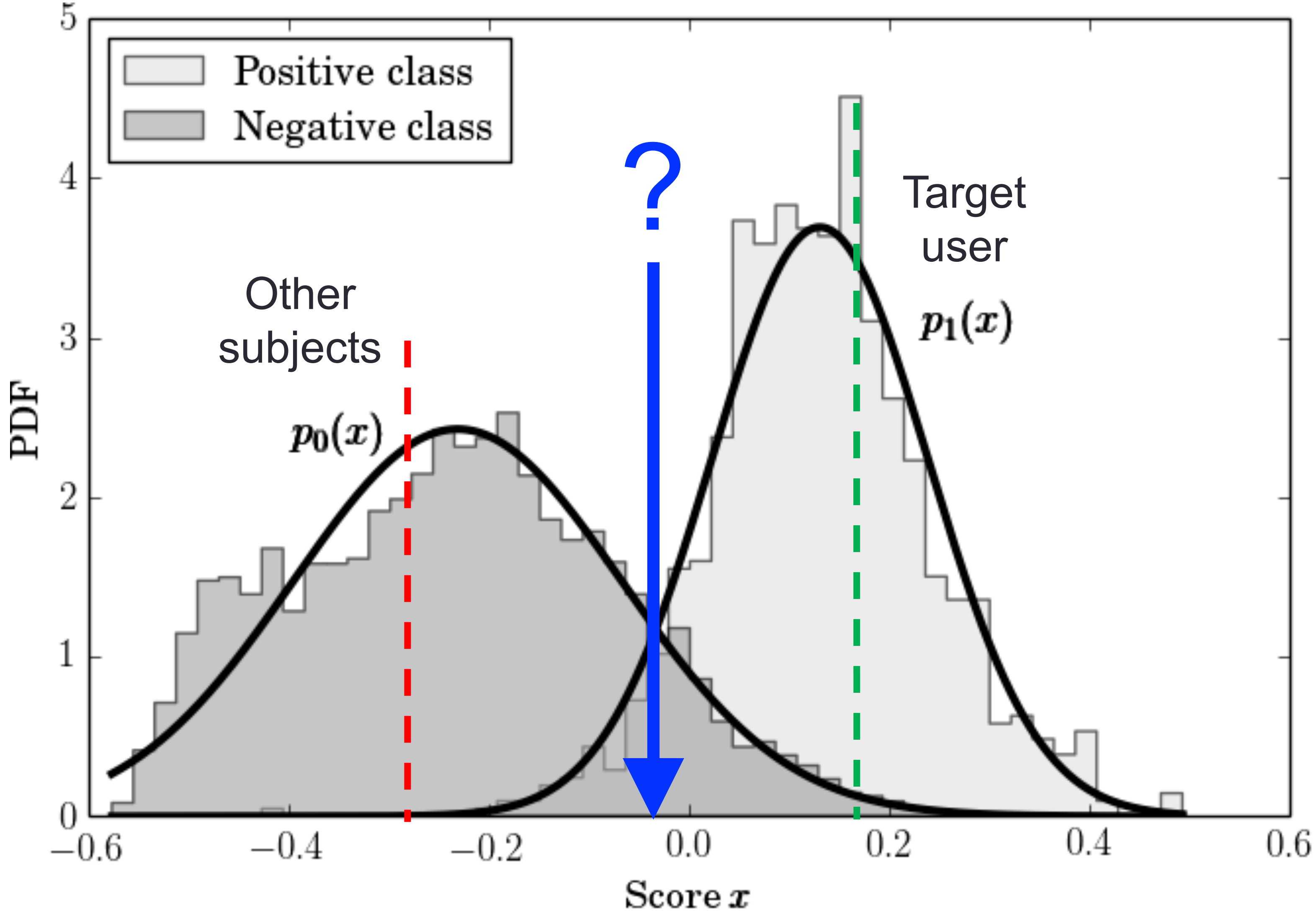
OSVM –parameters setting

Precision: no. of true positives classified as positives / tot. classified as positives
Recall: no. of true positives classified as positives / tot. no. of true positives

F-measure



One-Class SVM (test output)



“I got the light bulb”

- A single walking cycle
  - Single pass through the network
  - Single SVM score
  - Unclear answer if happens to be in between the two pdfs
- What about observing multiple subsequent scores
  - Will they all fall in the problematic region (where the pdfs intersect)?
  - Probably not ☺
- Accumulating scores from multiple cycles
  - Should increase our likelihood of detecting the user

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- Accumulating scores from multiple cycles
  - Should increase our likelihood of detecting the user
  - But, how can we do this?

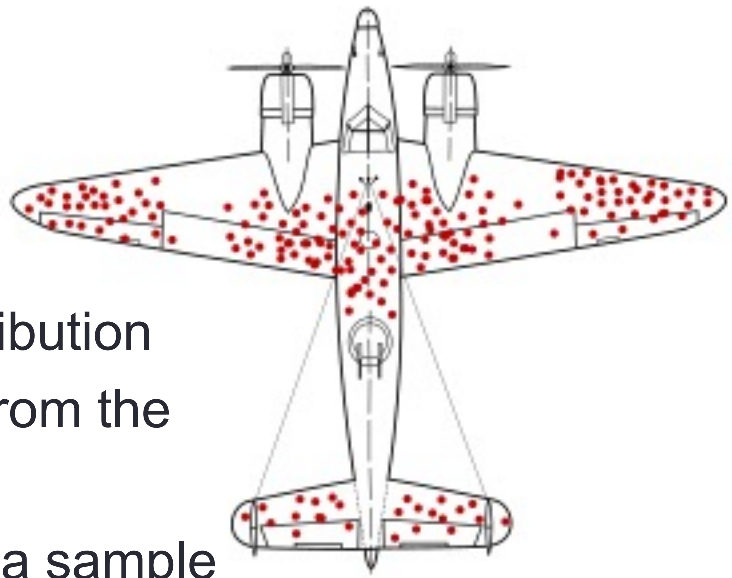
Abraham Wald

- American mathematician
- Born in Cluj, Romania
- Contributed in
  - decision theory,
  - geometry,
  - econometrics
- Worked @ Columbia University
- Founded the field of statistical sequential analysis

October 31, 1902 –
December 13, 1950

[W47] Abraham Wald, “Sequential analysis,” Dover, New York, NY, US, 1947.

Abraham Wald



- During **world war II**
  - Wald lead a group to study the distribution of damages from planes returning from the battlefield
  - He realized that such distribution is a sample conditioned on the survival of the airplanes (Bayes again…)
  - Taking care of this **bias** revealed that
    - The airplanes that were lost in battle were mainly hit in the undamaged spots/areas of those that returned
    - So the recommendation was to add special protection to the undamaged areas of the returning planes
  - This is an example of survivorship bias
    - As crucial data from fatally hit planes is ignored

Sequential decision making (1/2)

Sequential Probability Ratio Test (SPRT) [W47]

$$p_0(x) = p(x|H_0) \qquad H_0 \longrightarrow \text{OTHER USERS' CLASS}$$
$$p_1(x) = p(x|H_1) \qquad H_1 \longrightarrow \text{TARGET CLASS}$$

- Samples acquired sequentially, one at a time
  - are of either class H_0 (pdf p_0) or H_1 (pdf p_1)
  - are i.i.d.
- Extension to correlated samples is in [TNB15]

[W47] A. Wald, "Sequential analysis," Dover, New York, NY, US, 1947.
[TNB15] A. Tartakovsky, I. Nikiforov, M. Basseville, "Sequential Analysis Hypothesis Testing and Changepoint Detection," CRC Press, 2015.

Sequential decision making (2/2)

Sequential Probability Ratio Test (SPRT) [W47]

$$H_1 \rightarrow p_1(x) = p(x|H_1)$$

TARGET CLASS

$$H_0 \rightarrow p_0(x) = p(x|H_0)$$

LOG-LIKELIHOOD ratio:

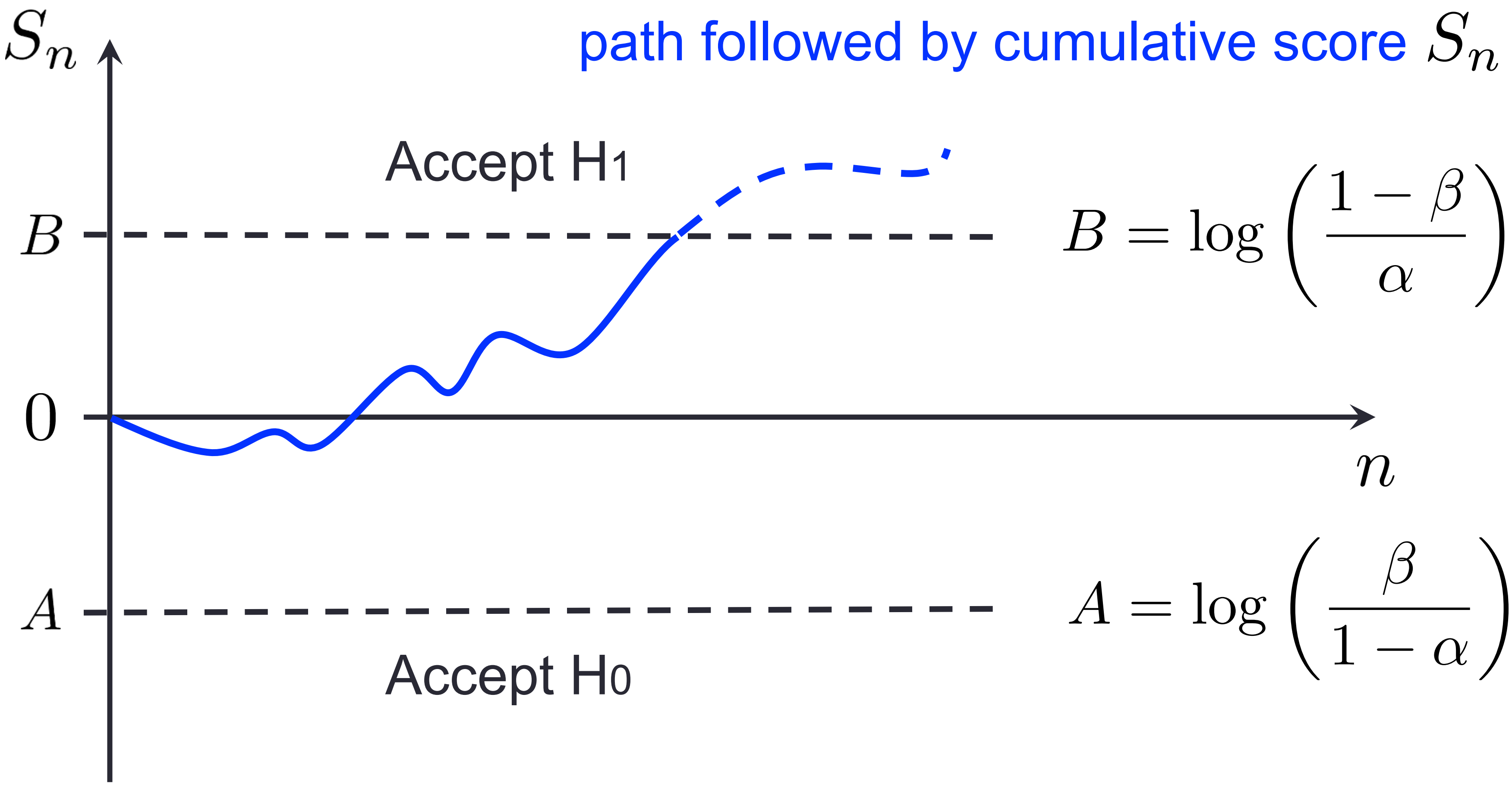
$$S_n = \log\left(\frac{p(x_1,\ldots,x_n|H_1)}{p(x_1,\ldots,x_n|H_0)}\right) = \sum_{i=1}^{n} \log\left(\frac{p_1(x_i)}{p_0(x_i)}\right)$$

$\beta =$ probability of accepting H0 when H1 is true

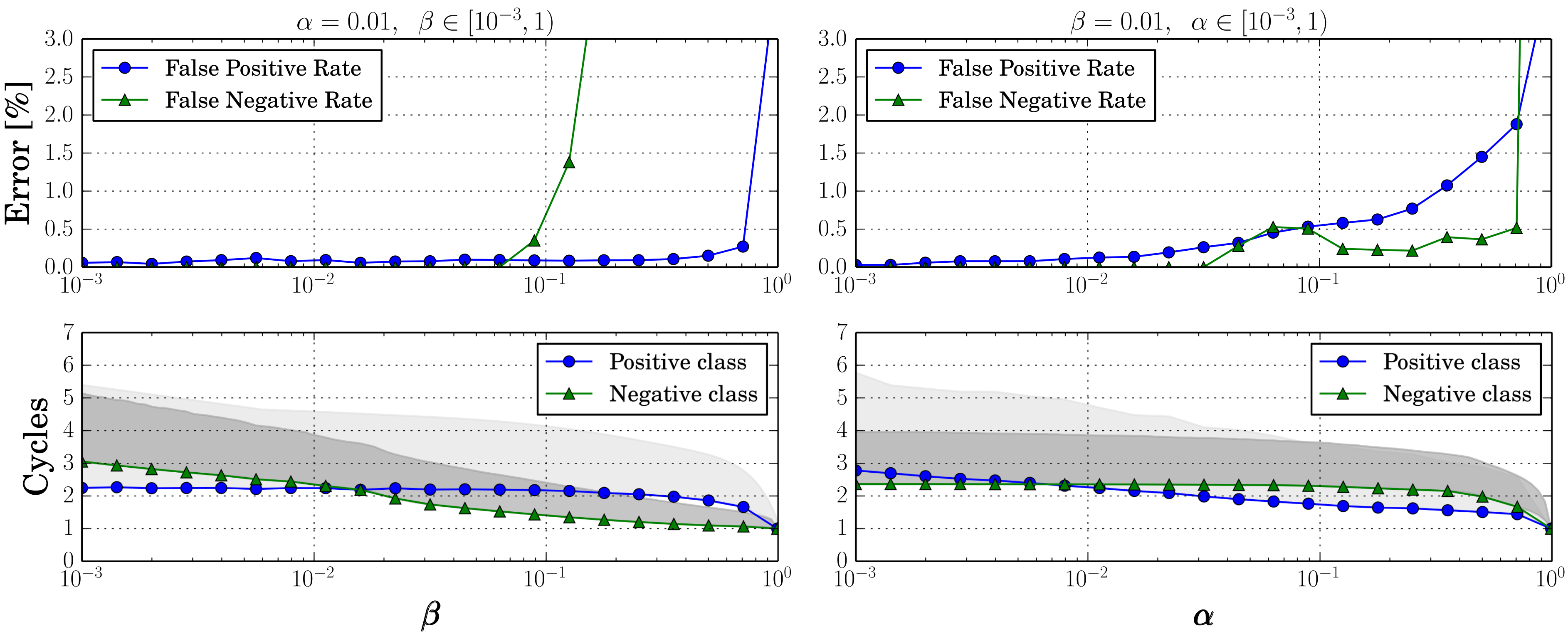
$\alpha =$ probability of accepting H1 when H0 is true

[W47] A. Wald, “Sequential analysis,” Dover, New York, NY, US, 1947.
[TNB15] A. Tartakovsky, I. Nikiforov, M. Basseville, “Sequential Analysis Hypothesis Testing and Changepoint Detection,” CRC Press, 2015.

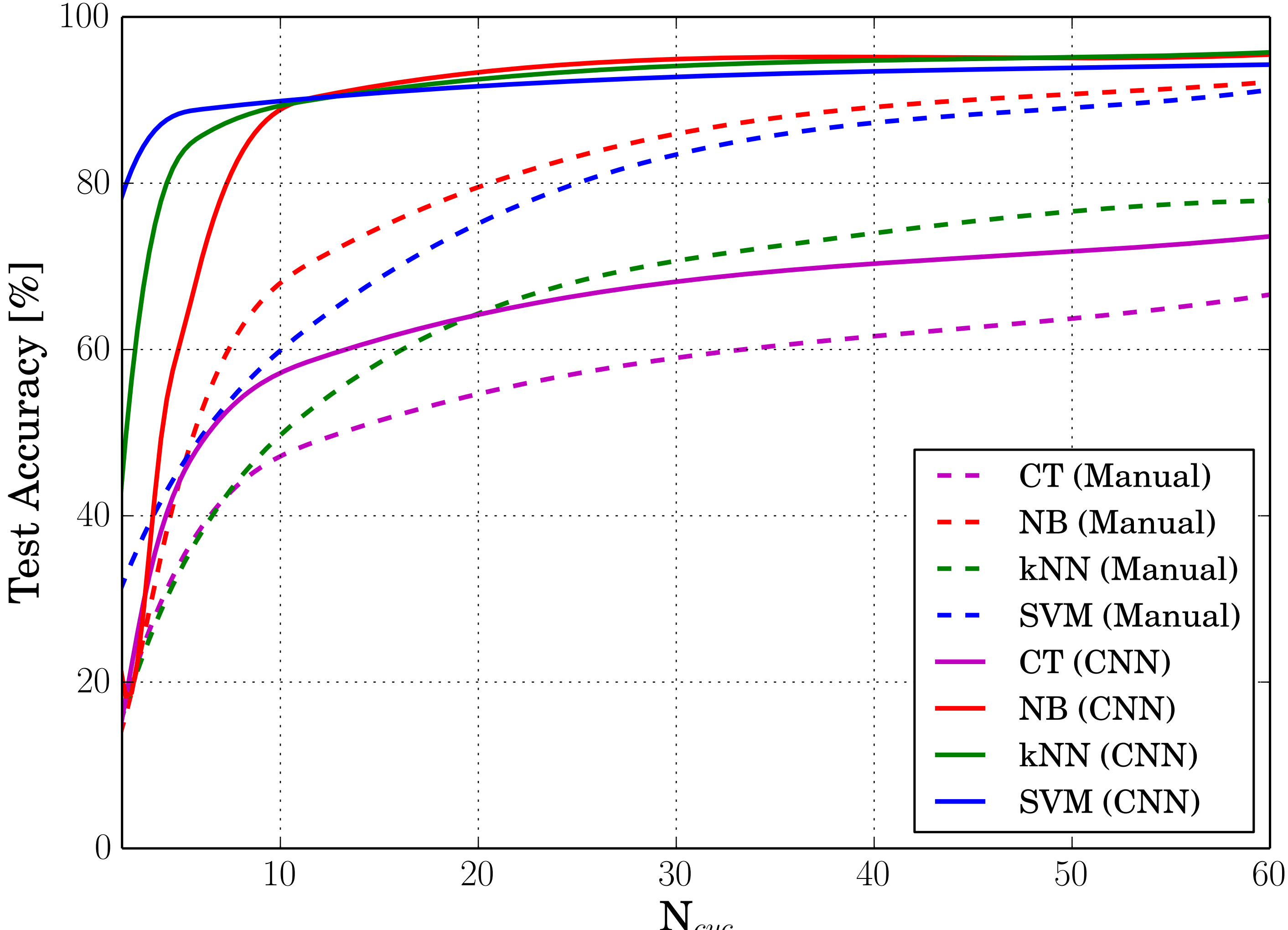
Sequential analysis



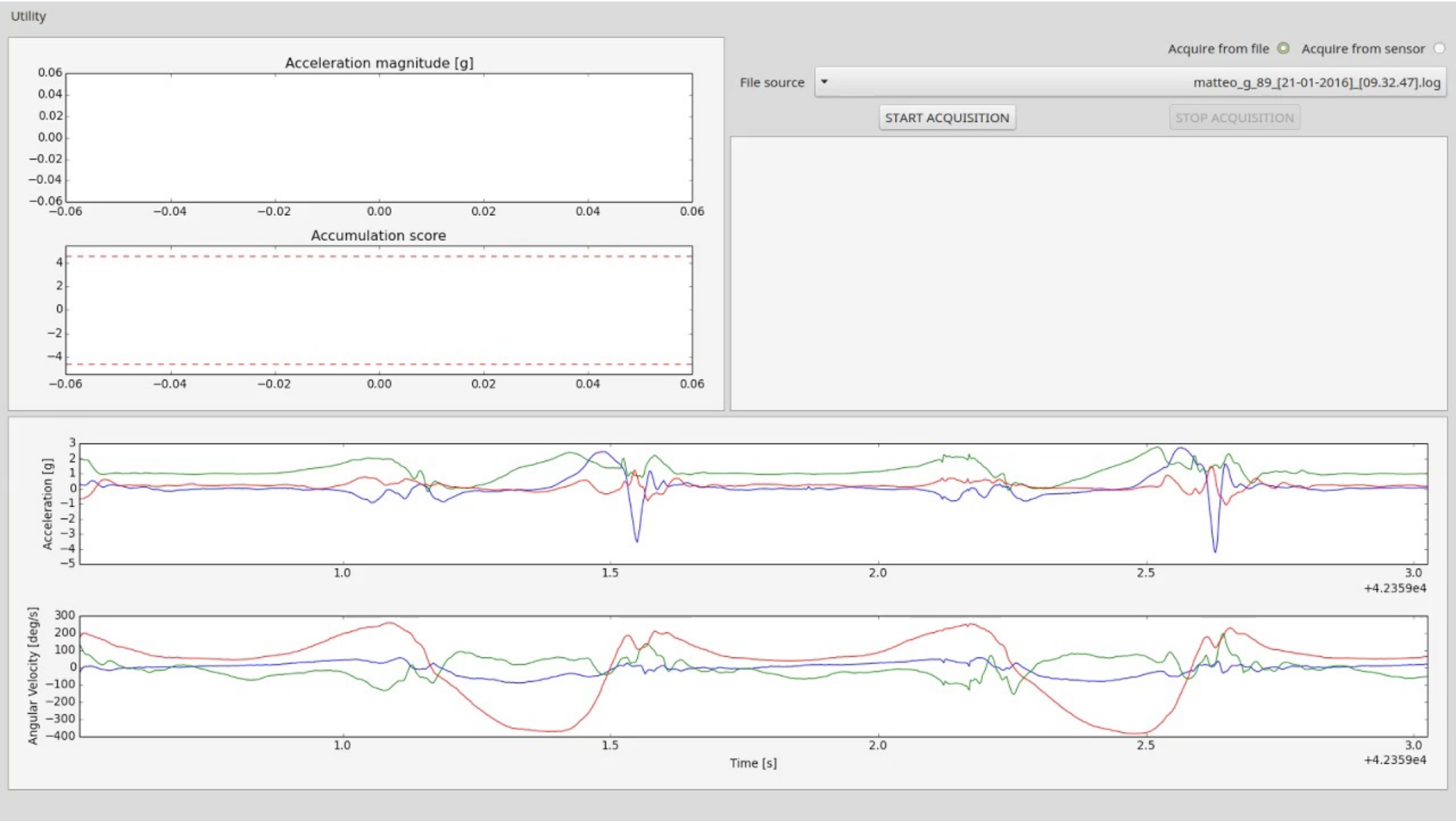
Final results



Feature extraction CNN *vs* SOTA



Demo


Utility
Acquire from file
Acquire from sensor
File source
matteo_g_89_[21-01-2016]_[09.32.47].log
START ACQUISITION
STOP ACQUISITION
Acceleration magnitude [g]
Accumulation score
Acceleration [g]
Angular Velocity [deg/s]
Time [s]
+4.2359e4

Bibliography

- [S++00] B. Schölkopf, J.C. Plattz, J. Shawe-Taylory, A.J. Smolax, Robert C. Williamson, “Estimating the Support of a High-Dimensional Distribution,” *Neural Computation Journal*, Vol. 13, No. 7, Pages 1443-1471, July 2001.
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- [GR18] M. Gadaleta, M. Rossi, ”IDNet: Smartphone-based Gait Recognition with Convolutional Neural Networks,” *Pattern Recognition*, Vol. 74, Pages 25–37, February 2018.

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