JOHNS HOPKINS
BLOOMBERG SCHOOL
of PUBLIC HEALTH

SMART
Johns Hopkins University
STATISTICAL
METHODS AND
APPLICATIONS FOR
RESEARCH IN
TECHNOLOGY

Towards precise walking strides segmentation from accelerometry data in free-living: ADEPT method and further developments

Marta Karas
Advised by Ciprian Crainiceanu, Jacek Urbanek

BIRS: Use of Wearable and Implantable Devices in Health Research
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Wearable and Implantable Technology (WIT) group

Ciprian Crainiceanu,
Jacek Urbanek

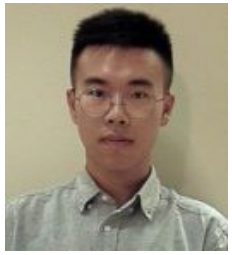
Vadim Zipunnikov

Andrew Leroux

Lacey Etzkorn

Marta Karas

Debangan Dey

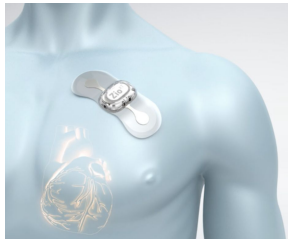


Erjia Cui

Jennifer Xu

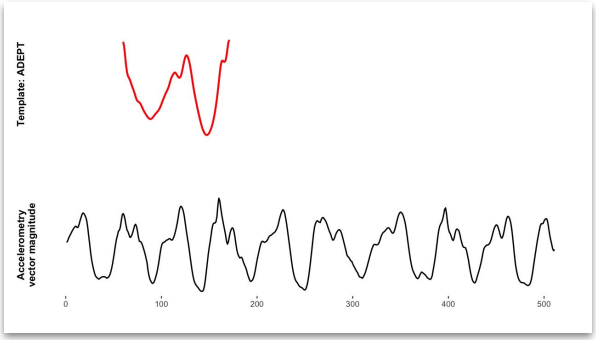
Jawei Bai

John Muschelli

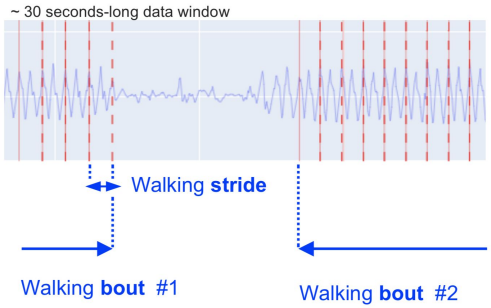


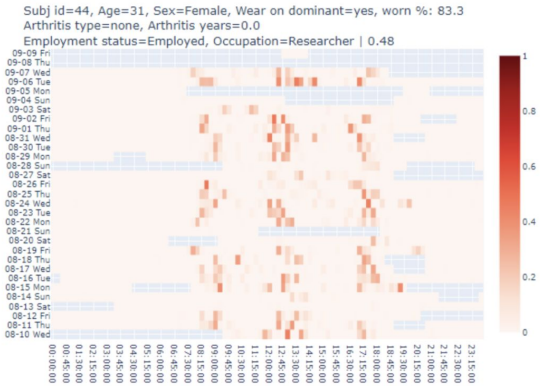
Outline

1. ADEPT method for pattern segmentation, with application to walking strides



2. Towards walking segmentation in free-living: digital biomarkers of pain/stiffness in arthritis patients

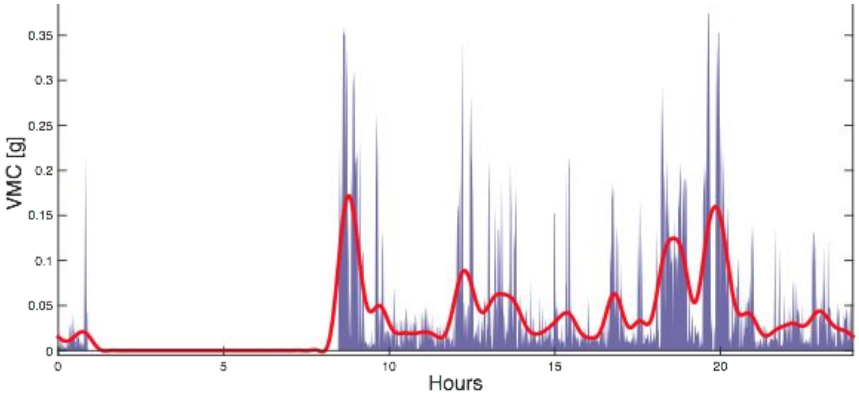




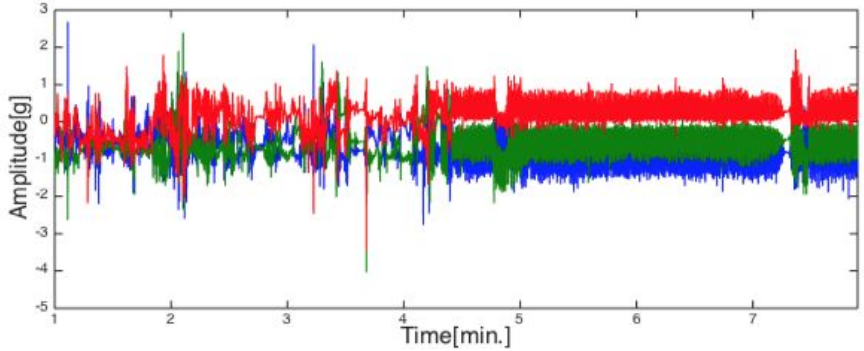
Raw accelerometry data

Macro-scale – summarized data (e.g. 1 min intervals)

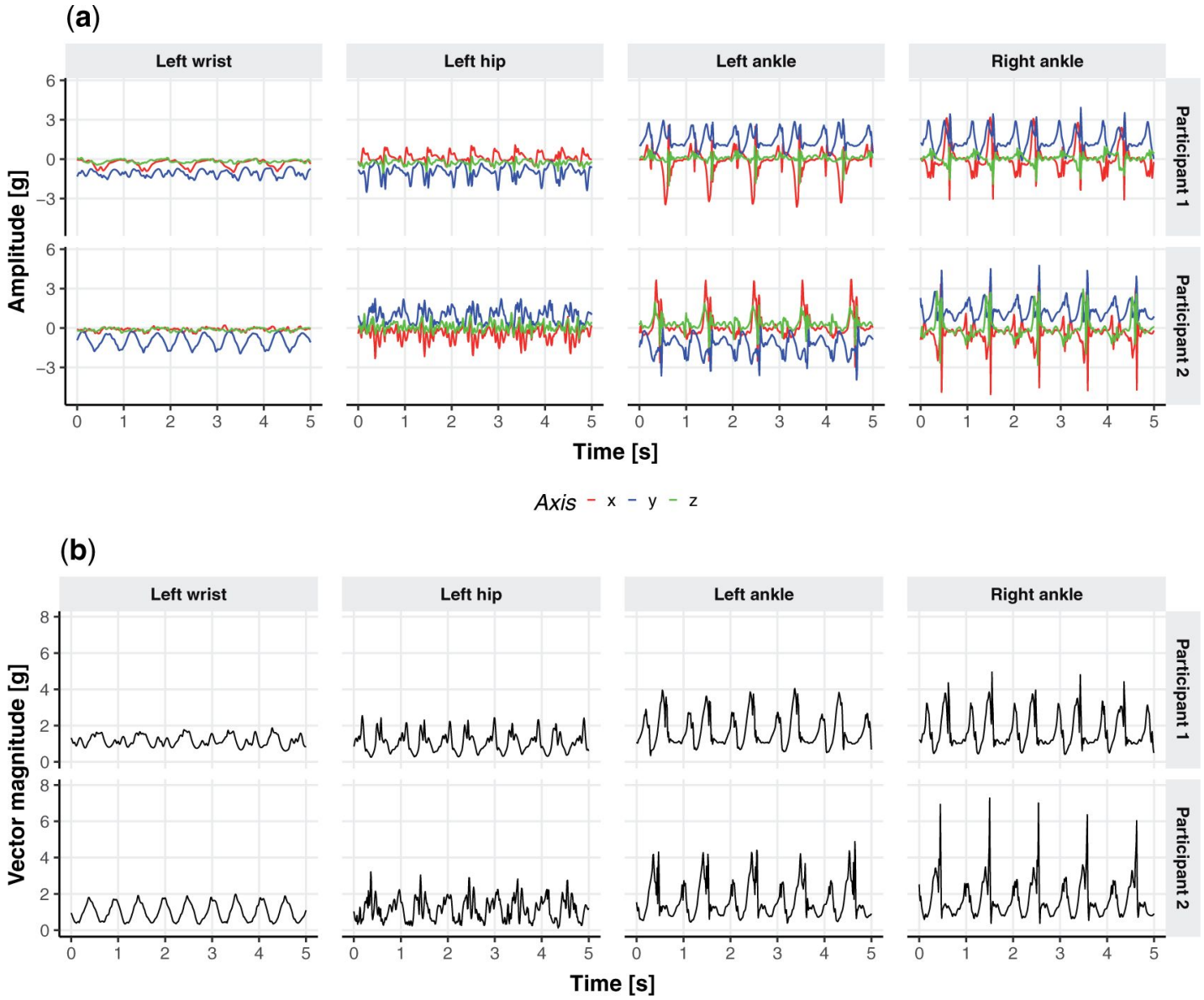
- Activity counts, number of steps etc.



Micro-scale – raw accelerometry data (10Hz+)



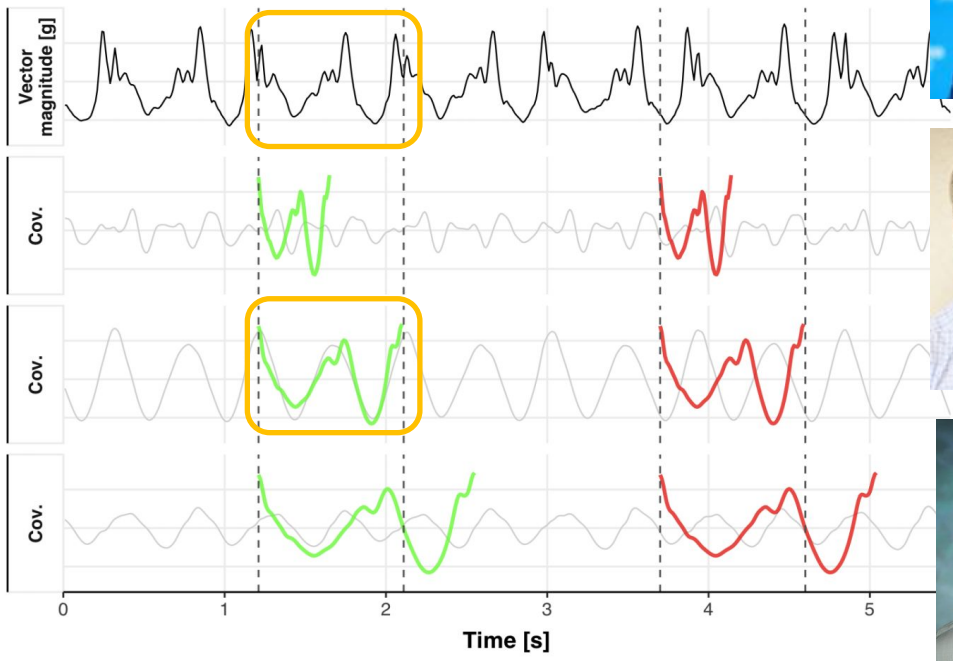
Raw accelerometry data of walking



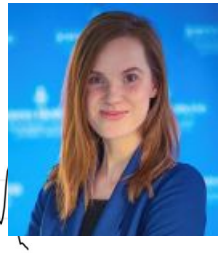
ADEPT method for automatic pattern segmentation from acc. time-series

Adaptive Empirical Pattern Transformation **(ADEPT) method** optimized to segment walking strides from acc vector magnitude time-series:

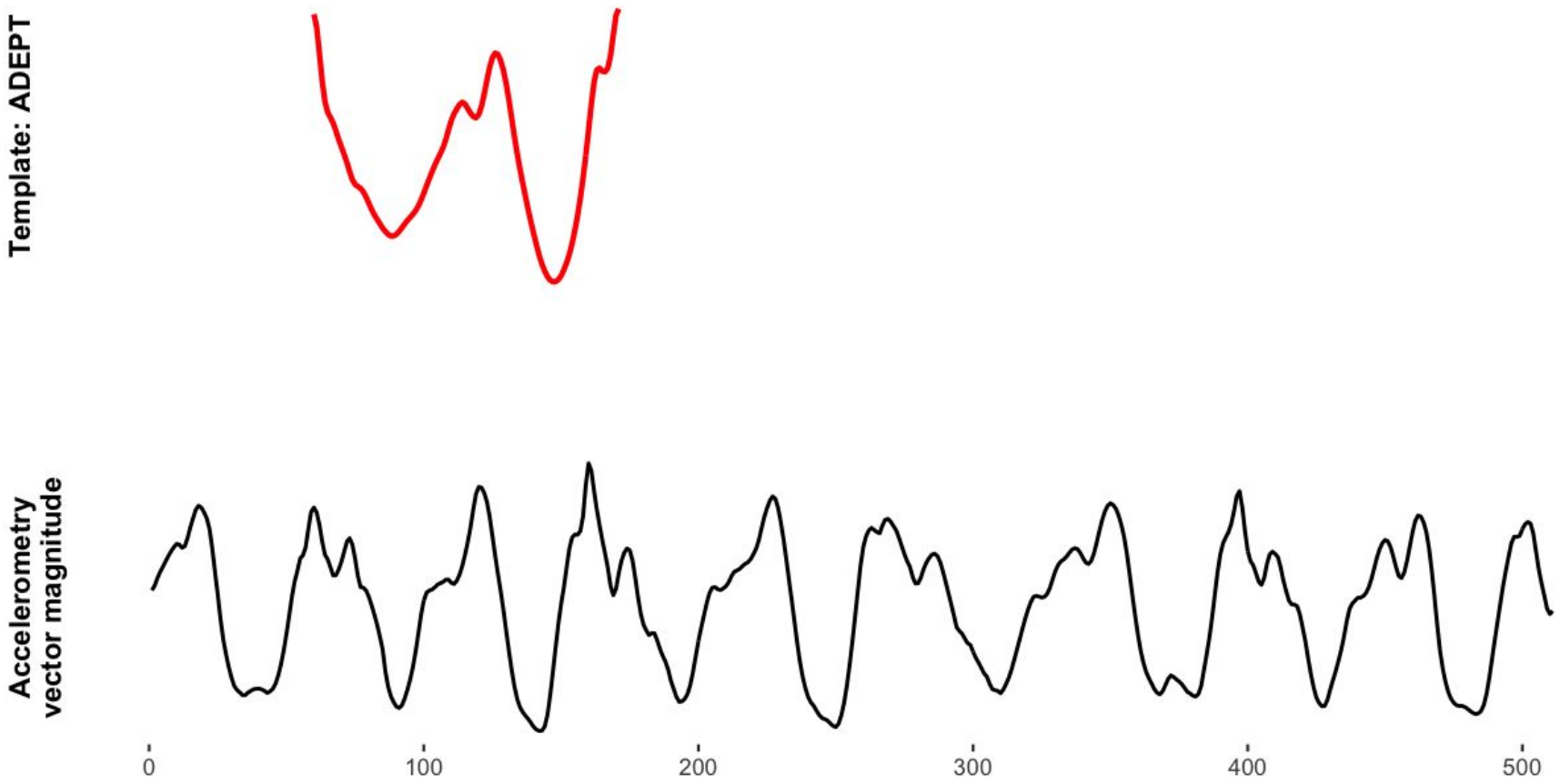
1. Use **stride pattern template**:
   - scale (stretch/shrink),
   - translate (move)
2. Identify scale and time where template has the **highest similarity** (correlation, covariance) to accelerometry time-series



$$W_{\Psi}(s,\tau) = \int_{-\infty}^{\infty} x(t)\frac{1}{\sqrt{s}}\Psi\left(\frac{t-\tau}{s}\right)\mathrm{d}t.$$



* Karas, M., Straczkiewicz, M., Fadel, W., Harezlak, J., Crainiceanu, C., Urbanek, J.K. *Adaptive empirical pattern transformation (ADEPT) with application to walking stride segmentation. Biostatistics*, 2019.


Template: ADEPT
Accelerometry
vector magnitude
0
100
200
300
400
500

ADEPT method for automatic segmentation of walking strides: strengths

- Uses data [r] vector magnitude for pattern-matching

⇨ **Method is invariant to sensor rotation (does not rely on device axes orientation relative to human body)**

- In pattern matching, considers simultaneously: (a) various pattern width values, (b) multiple stride patterns,

⇨ **Accounts for that different people walk differently and with various pace**

- Uses maxima-fine tuning step in the algorithm

⇨ **Algorithm returns precise location of start/end of a walking stride**

ADEPT method: application examples

Context:

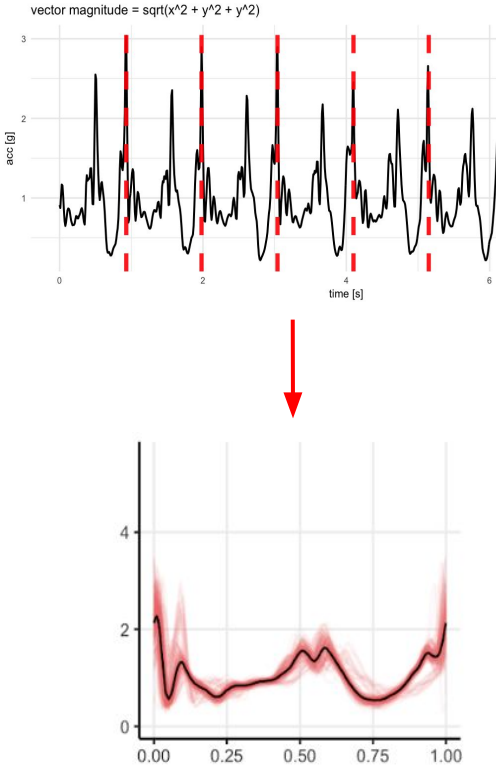
- Supervised walking, semi-supervised walking, free-living walking [*work in progress*]
- Clinical intervention, clinical trial, epidemiological study

Derive measurements of walking/gait:

- **Cadence/walking stride duration**
- Functional data analysis of subject-specific **stride pattern**
- Diurnal patterns of walking
- Variability of those parameters within a trial

Use to:

- Characterize/differentiate individuals in population
- Characterize *changes* within those parameters for individual over time



Adaptive empirical pattern transformation (ADEPT) with application to walking stride segmentation

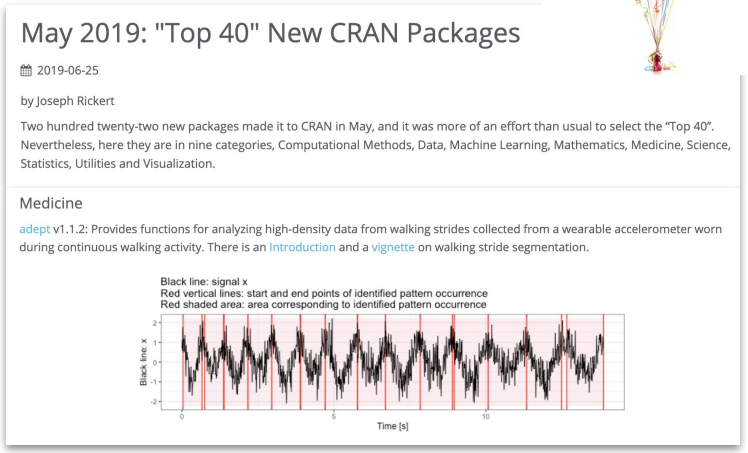
Marta Karas ✉, Marcin Straczkiewicz, William Fadel, Jaroslaw Harezlak, Ciprian M Crainiceanu, Jacek K Urbanek

Biostatistics, kxz033, https://doi.org/10.1093/biostatistics/kxz033

Published: 23 September 2019 **Article history ▾**

- Method application to segment walking strides from continuous walking from **32 healthy adults at 4 locations**: wrist, hip and both ankles
- Highest grade of results reproducibility (R)
    - All data and code available, results 100% reproducible

ADEPT method: software



R package *adept* implements ADEPT method

- CRAN index, GitHub repo
- Vignette 1: Introduction to adept package
- Vignette 2: Walking strides segmentation with adept
- Selected in Top new R packages in May 2019

Also:

- Language-agnostic pseudocode provided [link]
- **Implemented on GPU** for superior speed performance

Digital biomarkers of pain/stiffness in arthritis patients from wrist-collected accelerometry data

- **Arthritis** - swelling and tenderness of one or more of your joints; main symptoms are **joint pain and stiffness**, traditionally measured with questionnaires
- Issue: in drug development, we want to have pain and stiffness being **objectively measured**

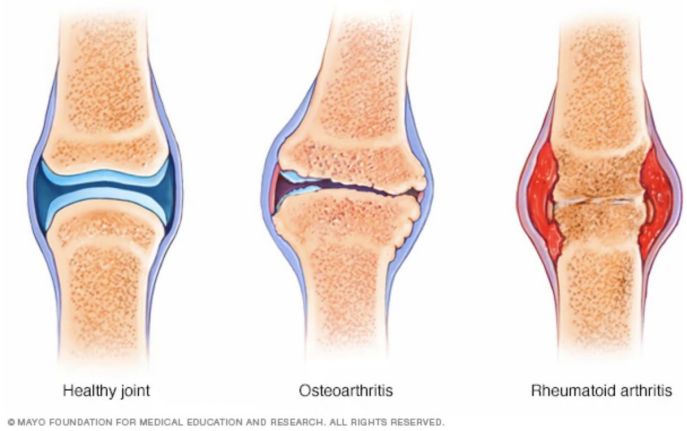


Image source: https://www.mayoclinic.org/diseases-conditions/arthritis/symptoms-causes/

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Previous work (observational study):

- **5x sit-to-stand exercise time is associated with self-reported pain and stiffness** scores
  - Used wrist-worn sensor raw data to measure 5x sit-to-stand time

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We propose:

- **Segment walking strides** from accelerometry data collected **in free-living**
- Use data features of walking strides (stride duration time, others) as pain/stiffness digital biomarker candidates

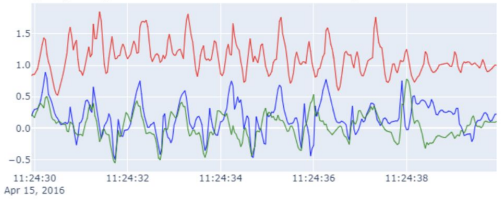
Segment walking in free-living: algorithm

1. Use ADEPT pattern-matching algorithm to **identify individual walking strides** pattern

2. Identify **valid walking bouts** in free-living data

3. Derive data features for each walking stride data segment

[*x*,*y*,*z*] raw accelerometry



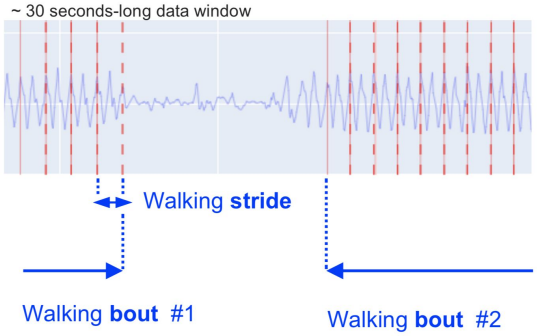
[*r*] = sqrt(x^2 + y^2 + z^2)

ADEPT* pattern-segmentation

Identified **walking stride** (2 subsequent steps)

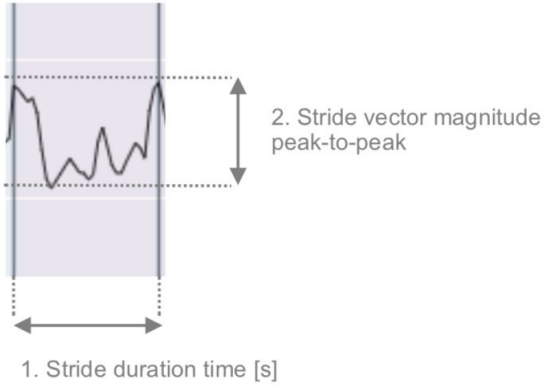
Walking bout:

- sequence of >= 3 walking strides
- subsequent strides must be "valid and similar to each other"



Describe each walking stride:

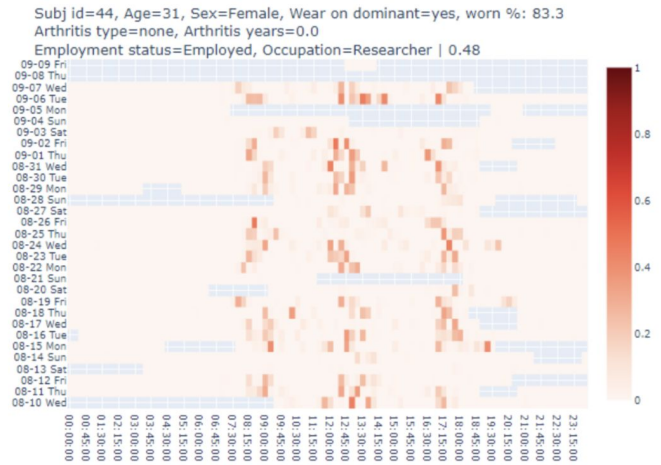
1. Duration time [s]
2. Vector magnitude peak-to-peak
3. Vector magnitude standard deviation
4. Vector magnitude count
5. Azimuth peak-to-peak
6. Azimuth standard deviation



Digital biomarkers of pain/stiffness in arthritis patients from wrist-collected accelerometry data: challenges

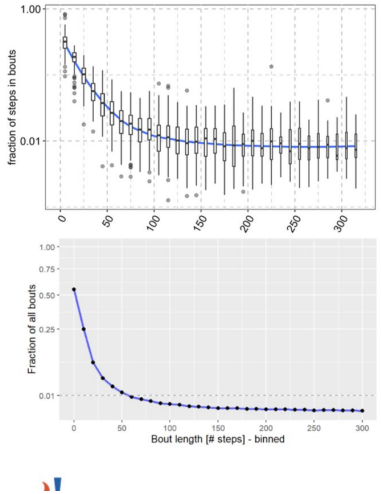
- **Validation of method for walking segmentation** from data collected at wrist in free-living:
  - No gold standard
  - No free-living raw accelerometry data with precise walking labels
- **Statistical modeling** of association between walking data features and self-reported scores of pain and stiffness
  - Account for context of walking?
  - Use walking information from morning only / whole day?
  - Use 1-point summary of per-day per-subject measurements, or use functional predictor?

Idea #1: Example: one study participant.



Idea #2:

- Right upper figure: based on other Novartis study, data collected with accelerometry at **belt buckle-worn sensor**.
- Right lower figure: Presented study, data collected with accelerometry non-dominant **wrist-worn sensor**.



Thank you!