The marauder's map or the use of non-intrusive range laser scanners in the context of smart rooms

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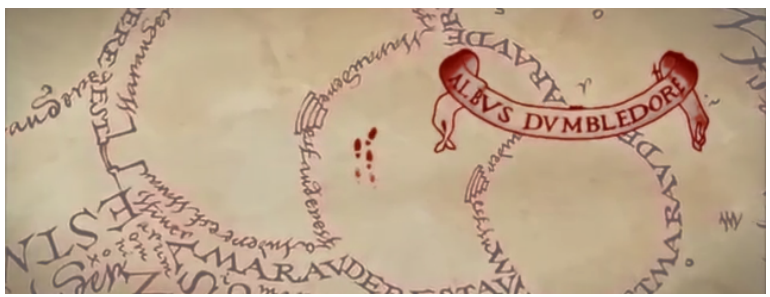
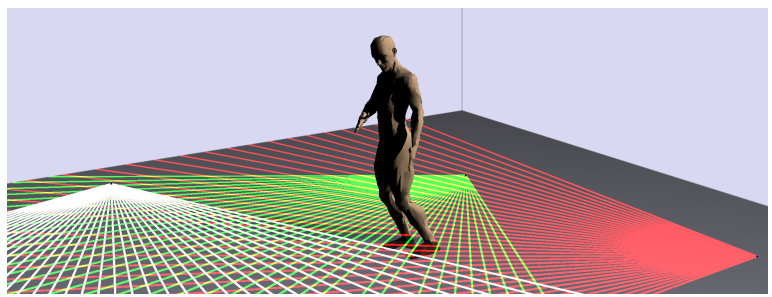




University of Sherbrooke — October, 24th 2014

Outline

This presentation is for the general public and doesn't aim to go into scientific details.

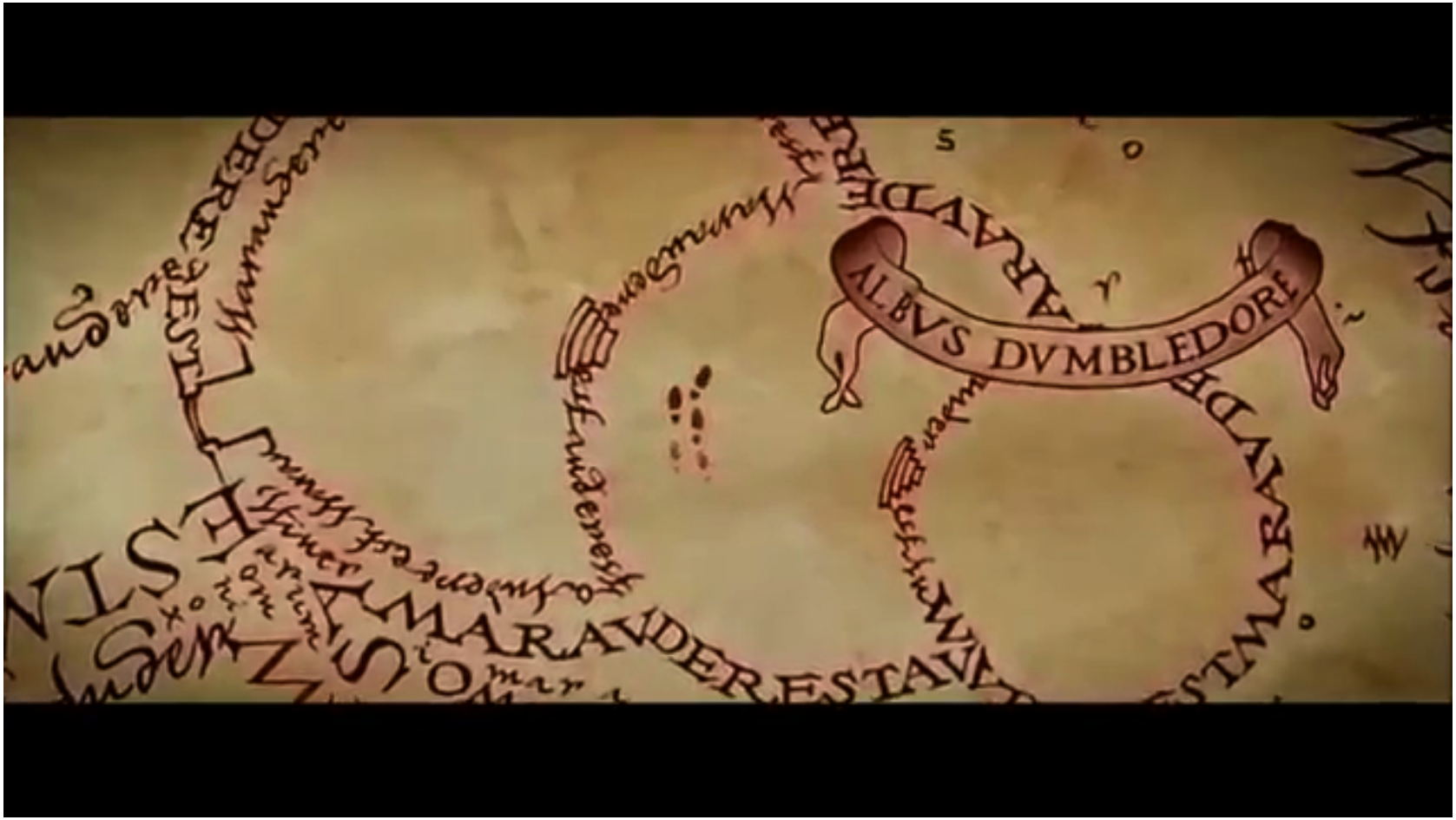
Outline

The marauder's map in Harry Potter: a dream?

https://www.youtube.com/watch?v=o3-KM-_fni0

ACKNOWLEDGMENT: I thank Sophie Lejeune for this very nice idea of comparing the capabilities of *GAIMS* with the marauder's map in Harry Potter.

The marauder's map in Harry Potter: a dream?



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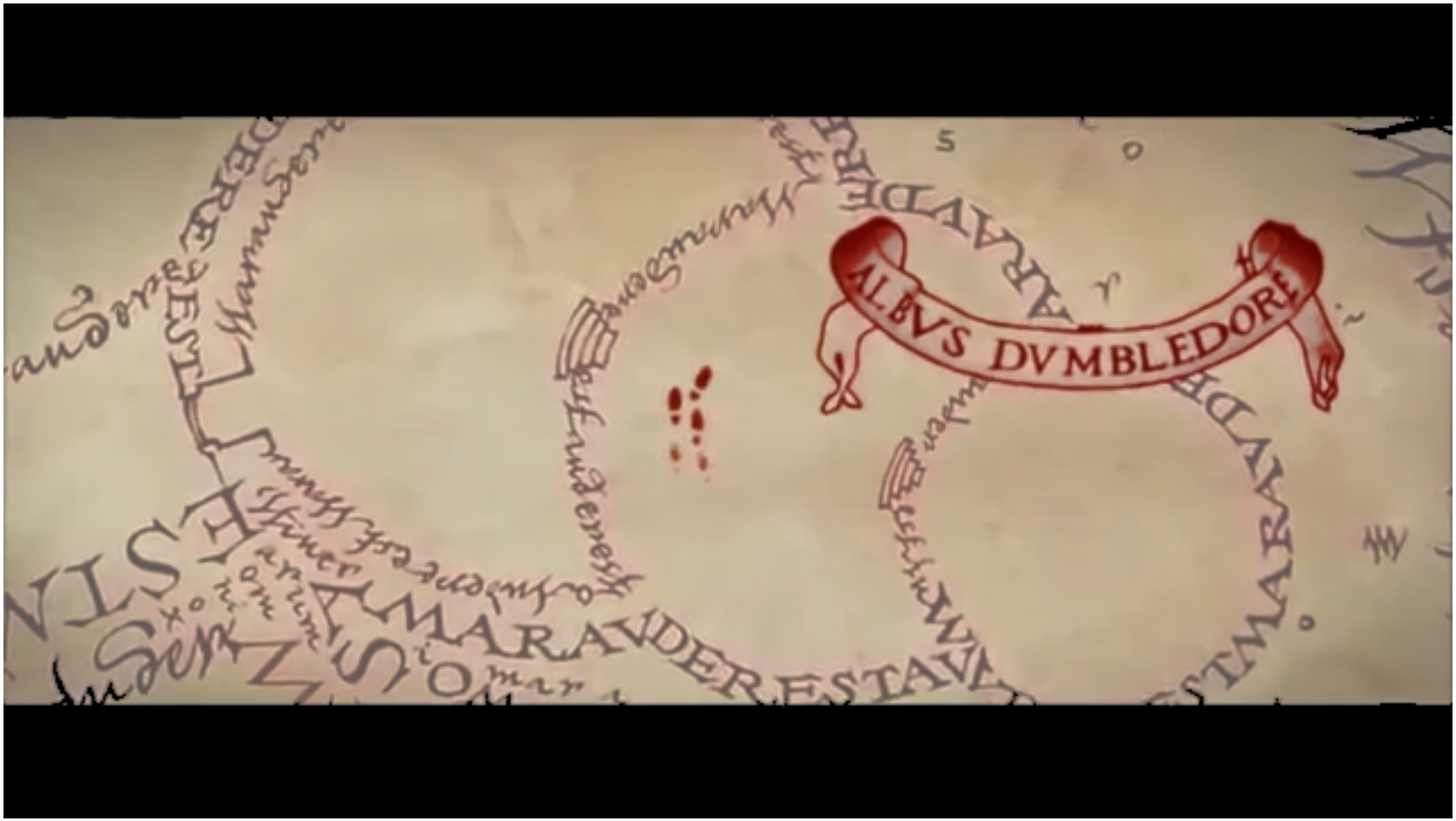
The marauder's map in Harry Potter: a dream?



https://www.youtube.com/watch?v=o3-KM-_fni0

The features of the marauder's map

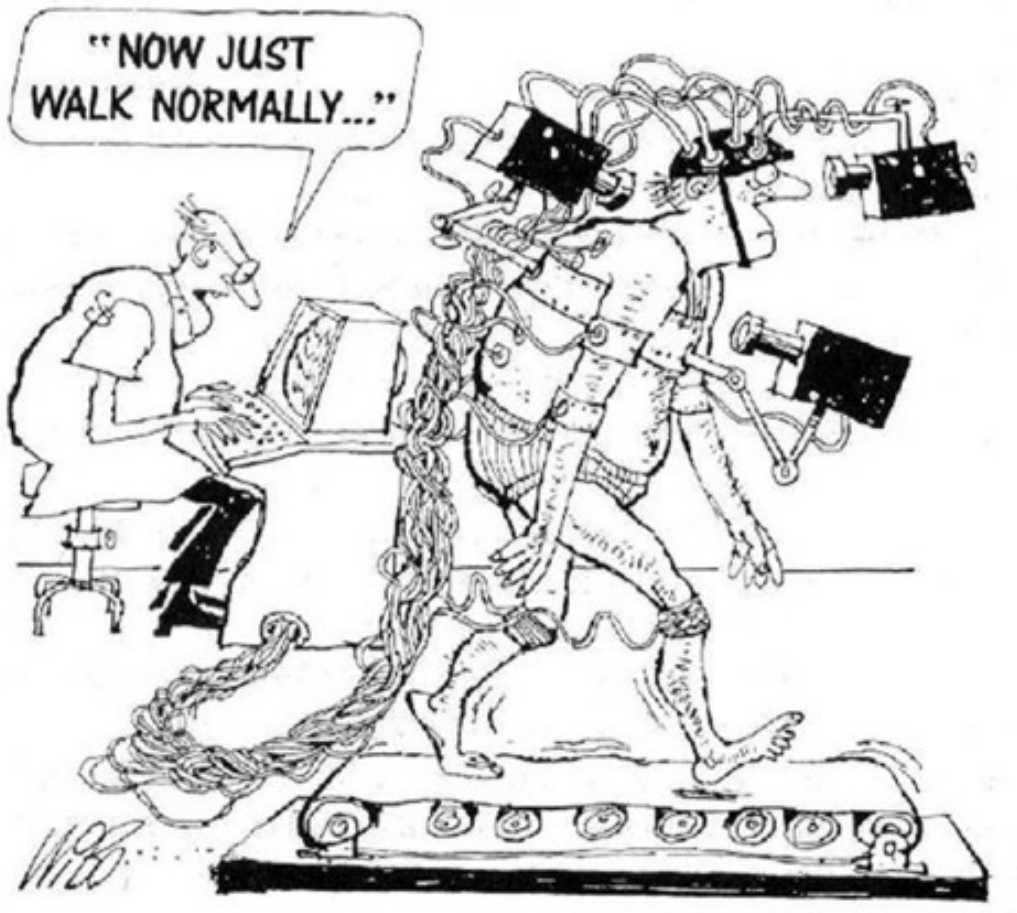
- a precise map of the environment
- showing in realtime the footsteps
- accurately identifying each person
- unfoolable by artifices
- without placing any sensor on the persons

In the project *GAIMS*:

- we use range laser scanners ($\Rightarrow$ non-intrusive)
- we estimate the feet trajectories ($\Rightarrow$ we show footsteps) and derive gait descriptors
- we use machine learning techniques to infer some information about the observed person (gender, height, weight, identity, and we can detect and characterize alcohol intake as well as some neurological diseases)

Why are we interested by non-intrusive measurements?

Mainly for medical application, but a lot of other applications can benefit from it.

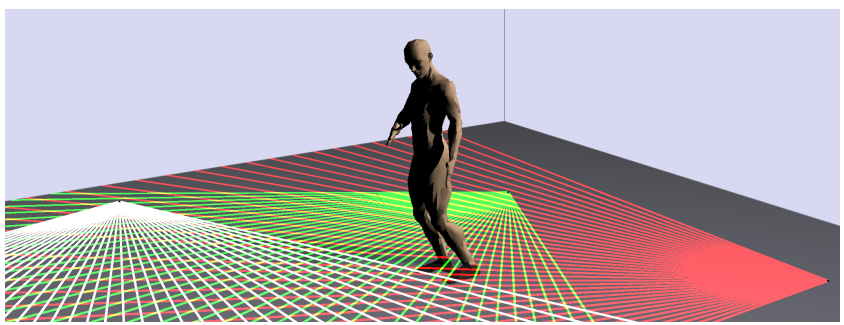


http://www.er.uqam.ca/nobel/r33400/kelvin.gif

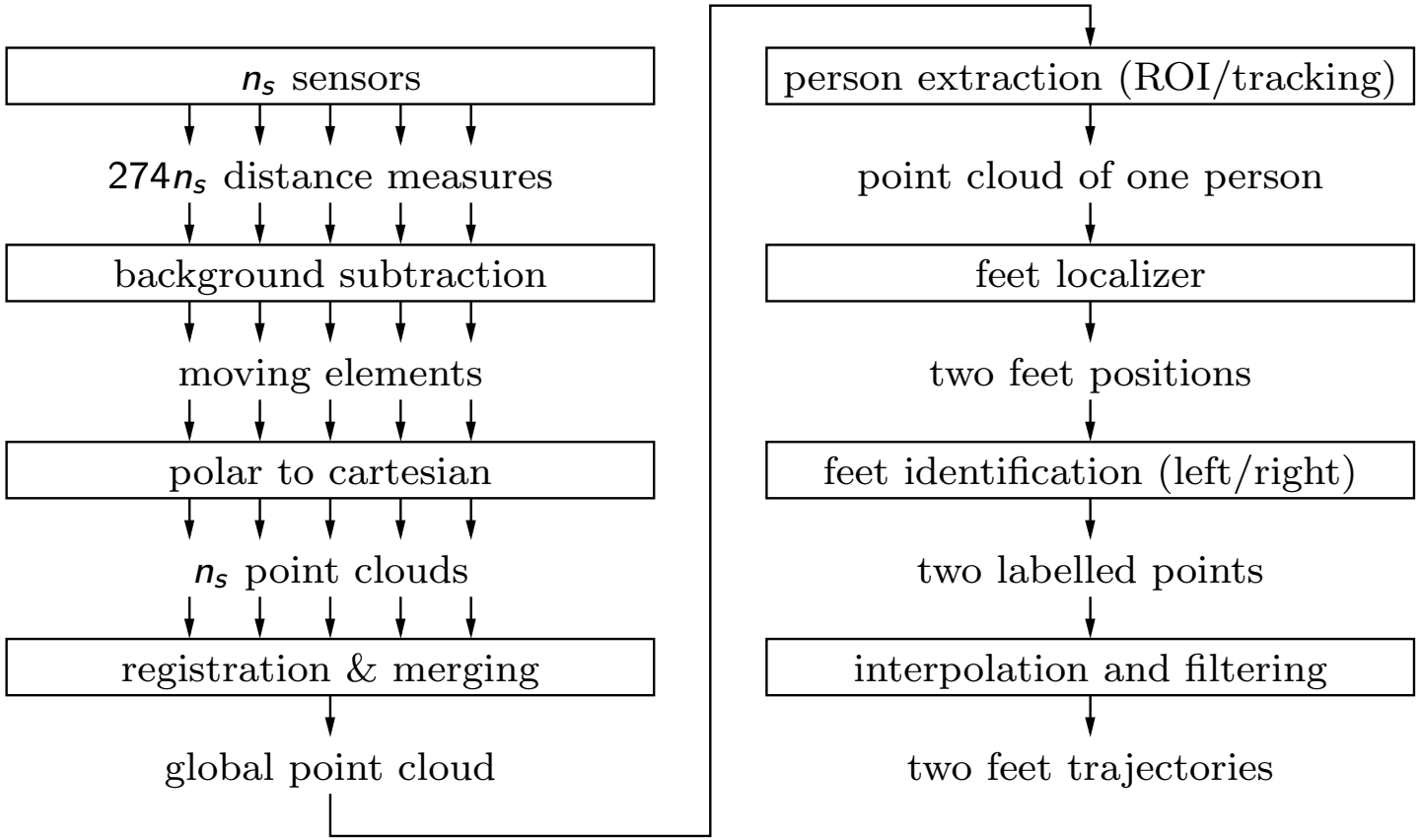
Outline

GAIMS (*GAIt Measuring System*)

- We track the feet with a high accuracy and precision, without equipping the person with markers or sensors.
- A set of unsynchronized range laser scanners are scanning a common horizontal plane (15 *cm* above the floor).
- Insensitive to lighting conditions and to the colors of clothes.
- We use sensors working at 15Hz, taking 274 distance measures in a plane and in a field of view of about 96°.



The signal processing pipeline



REFERENCE: S. Piérard, S. Azrour, and M. Van Droogenbroeck. Design of a reliable processing pipeline for the non-intrusive measurement of feet trajectories with lasers. In IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), pages 4432-4436, Florence, Italy, May 2014.

Realtime visualization of the measured trajectories

This is "easy" to do by using *GAIMS* and *I-see-3D* together.

REFERENCE: S. Piérard, V. Pierlot, A. Lejeune, and M. Van Droogenbroeck. I-see-3D! An interactive and immersive system that dynamically adapts 2D projections to the location of a user's eyes. In International Conference on 3D Imaging (IC3D), Liège, Belgium, December 2012.

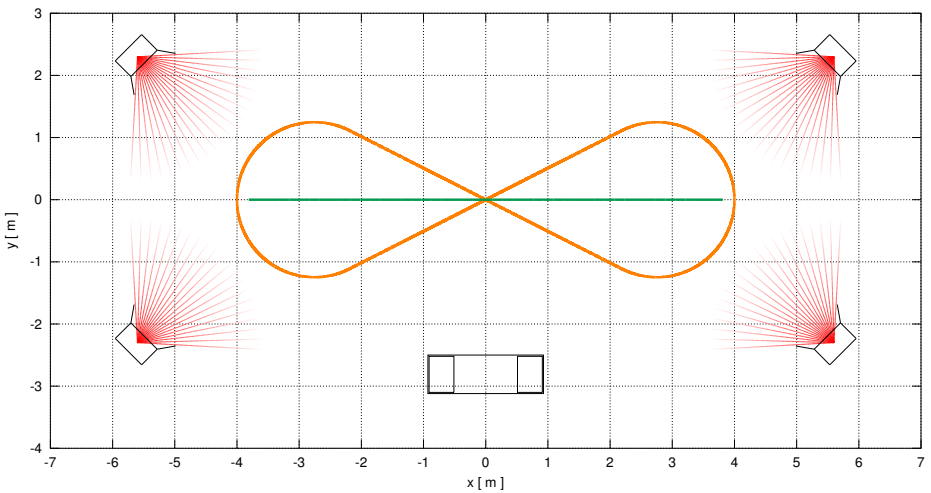
The gait descriptors provided by GAIMS

GAIMS derives many gait characteristics (currently 26) from the feet trajectories. They are related to:

- the speed;
- the inter-feet distance;
- the deviation from the followed path;
- the cadence;
- the stride length;
- the gait asymmetry;
- the temporal variability;
- the proportion of double limb support time;
- *etc.*

Example of application: gait analysis by neurologists

In our target application, 4 sensors (in red) scan a common horizontal plane at 15 Hz. The patients are asked to walk in 3 different modes (comfortable, as fast as possible, tandem) along a straight path (in green) or a ∞-shaped path (in orange).



We aim at estimating reliably the feet trajectories in the gray area. The maximal walking speed is 3.6 m/s ($\simeq$ 13 km/h).

Example of input : walk at preferred pace

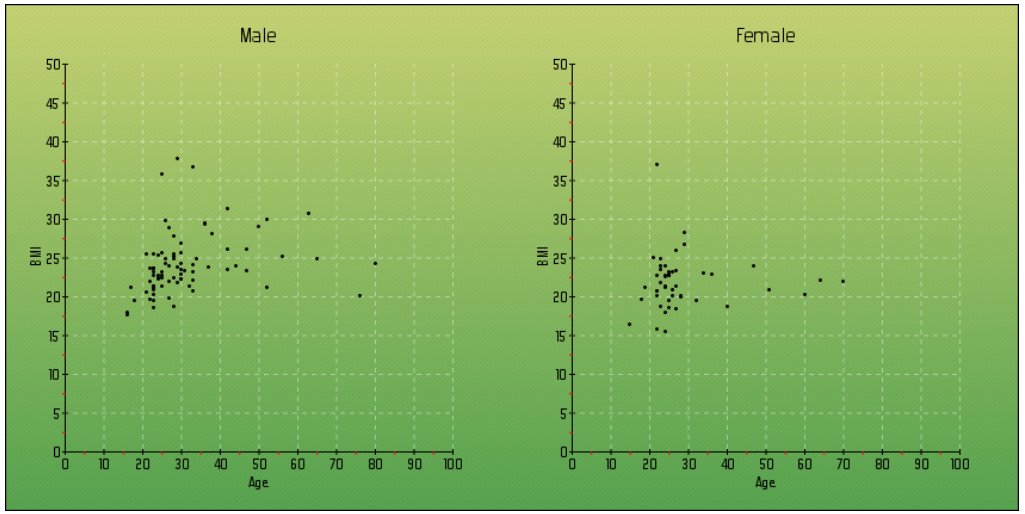
(click here to play video)

Example of input : walk in tandem mode

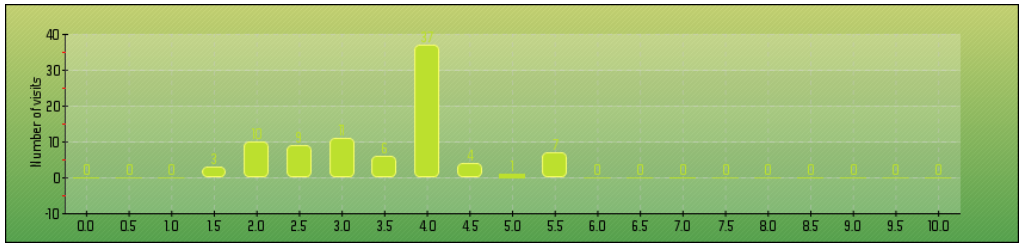
(click here to play video)

Our database

- more than 6500 tests recorded, and still growing!
- 129 healthy persons (41 recorded at least 5 times)



- 71 patients with multiple sclerosis



- 24 volunteers for drinking alcohol

The acquisition protocol

	test	1	2	3	4	5	6	7	8	9	10	11	12
distance	25 *ft*	●	●	●	●	●	●						
	20 *m*							●	●	●			
	100 *m*										●	●	
	500 *m*												●
mode	comfortable	●	●					●			●		
	fast			●	●				●			●	●
	tandem					●	●			●			

Outline

Preliminary remark

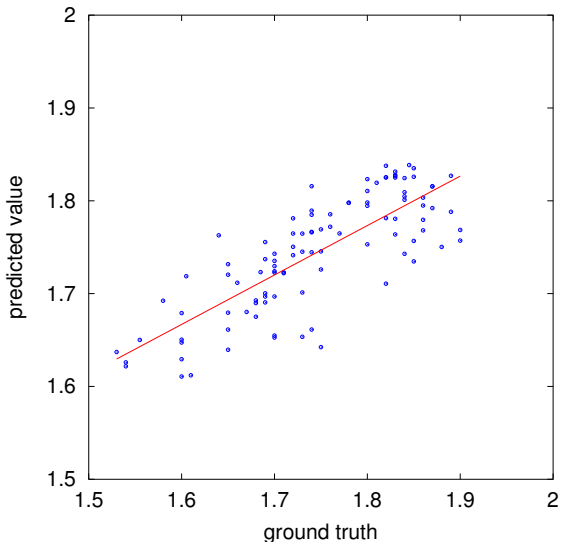
The results presented in this section have been obtained with the database of *GAIMS*. The acquisition conditions were standardized.

We expect a larger variability of the gait in free living conditions. Future work could assess our methods in less constrained environments.

Estimation of morphological characteristics

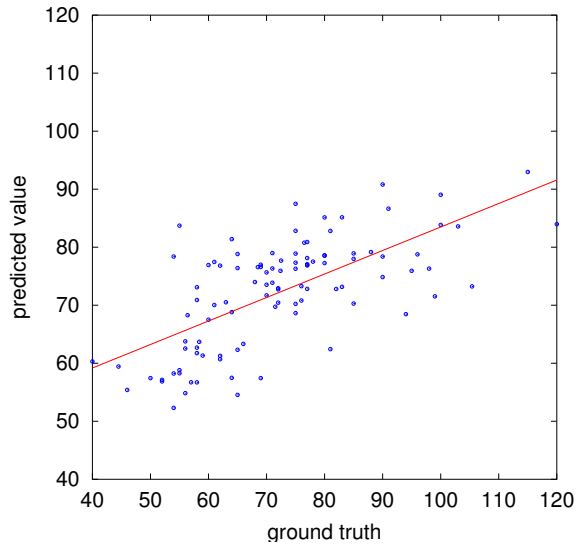
Machine learning algorithm: the *ExtRaTrees* (regression).
Input: the gait descriptors provided by *GAIMS*.

height



correlation coefficient = 0.79
mean absolute error = 4.0 *cm*

weight



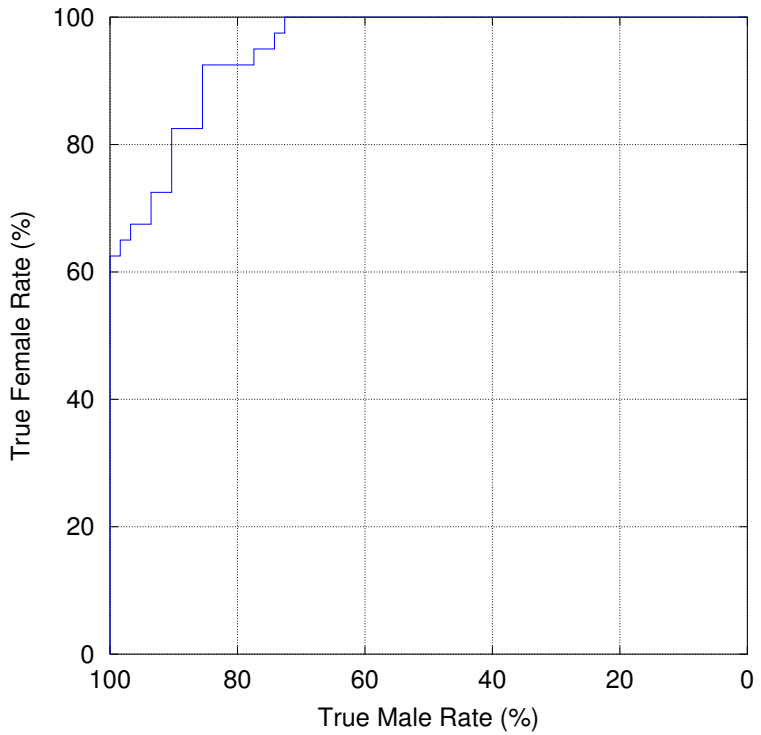
correlation coefficient = 0.67
mean absolute error = 8.4 *Kg*

REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

Estimation of morphological characteristics

Machine learning algorithm: the *ExtRaTrees* (classification).
Input: the gait descriptors provided by *GAIMS*.

gender



REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

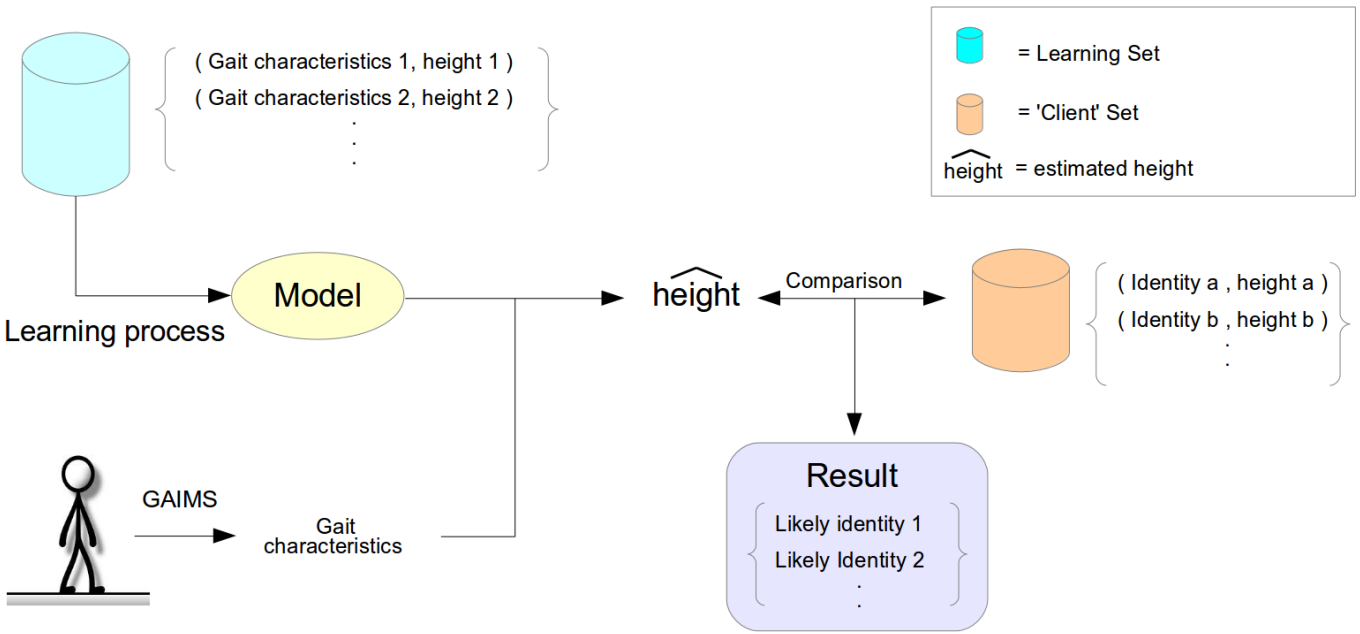
Biometric identification with GAIMS

- This is the first work, to our knowledge, about gait recognition based on range laser scanners.
- The database gathers the gait characteristics of 114 people, acquired with *GAIMS*.
- Among these, 41 people were recorded at least five times to take the intra-subject variability into account.
- "Gait also has the advantage of being difficult to hide, steal, or fake."

REFERENCE: N. Boulgouris, D. Hatzinakos, and K. Plataniotis. Gait recognition: a challenging signal processing technology for biometric identification. IEEE Signal Processing Magazine, 22(6):78-90, November 2005.

Biometric identification with GAIMS

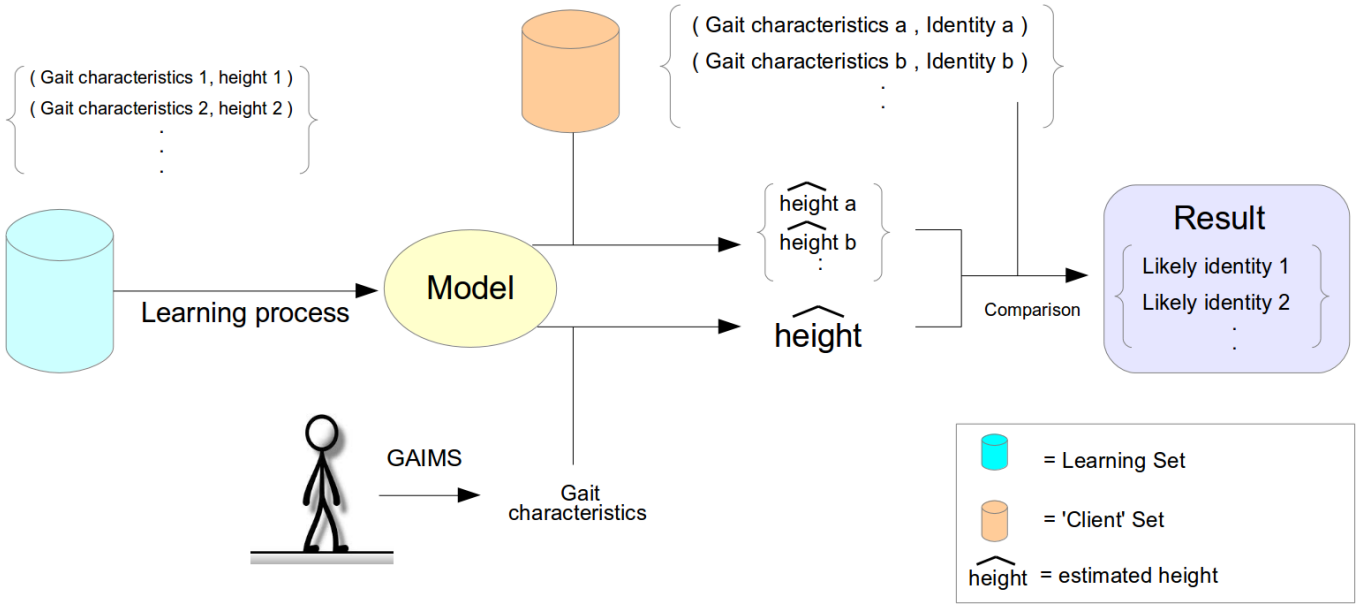
A first system:



REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

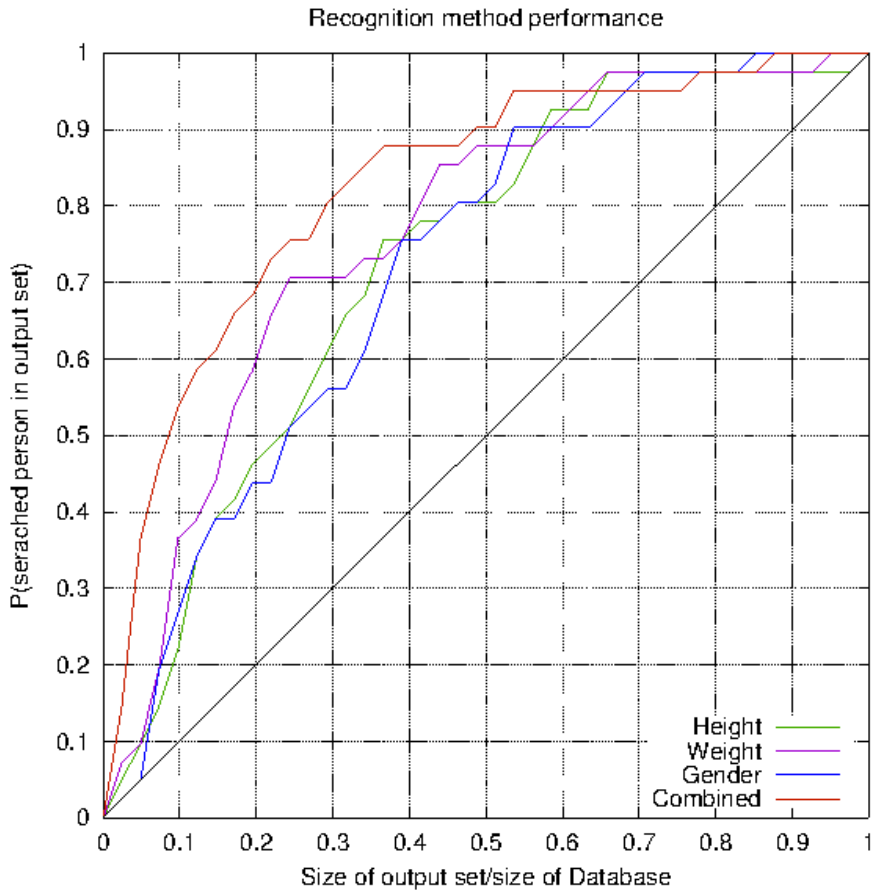
Biometric identification with GAIMS

Let's improve it by taking into the biases of the estimators



REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

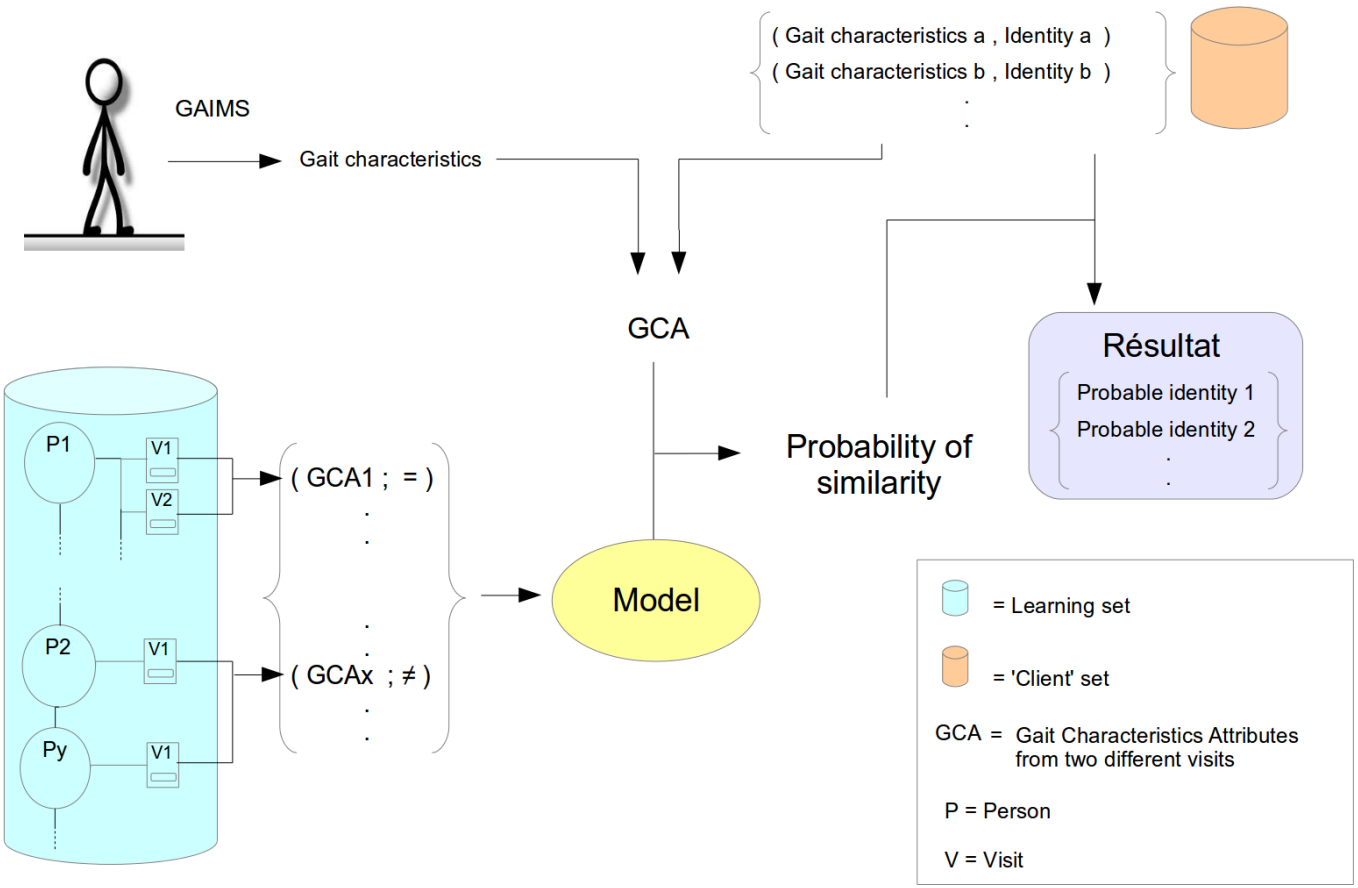
Biometric identification with GAIMS



REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

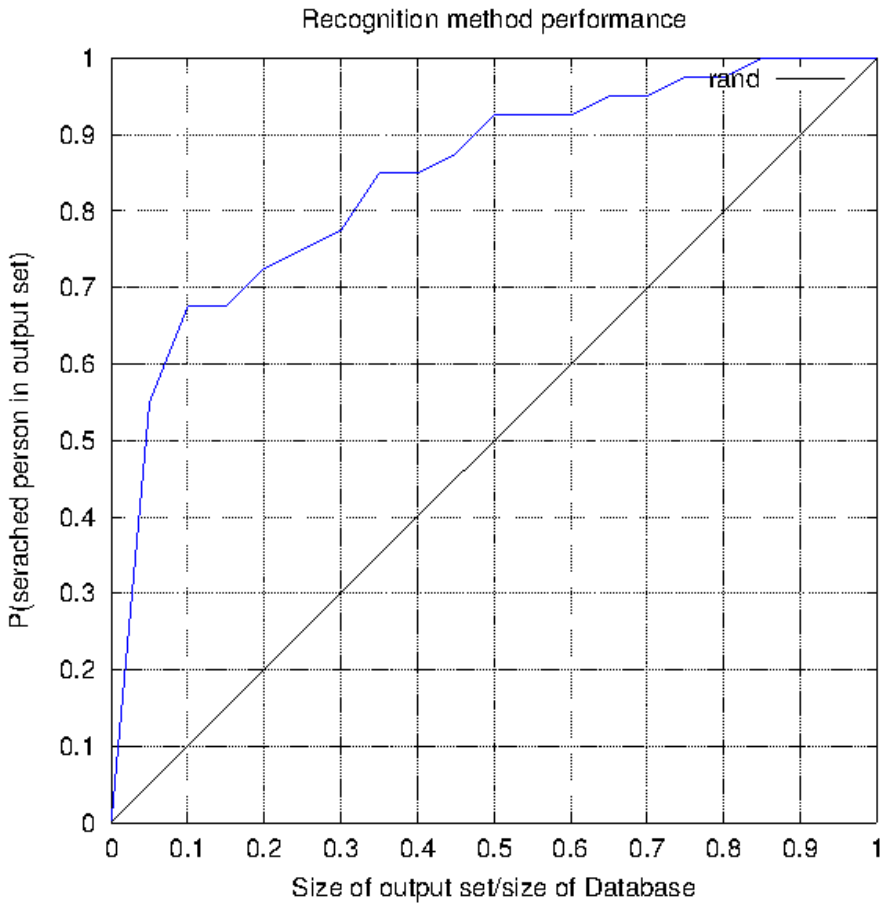
Biometric identification with GAIMS

A second system:



REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

Biometric identification with GAIMS



REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

Biometric identification with GAIMS

We can still improve the previous results by introducing the concept of "client".

- A gait recognition system can be replicated in many different places: the "clients".
- Each client has a different set of users, so there are two cases:
  1. The client must only establish his database and uses a generic gait recognition model.
  2. The client has to execute a machine learning algorithm to create a model optimized for him, in addition to the creation of his database.

By particularizing the similarity model for the client, our results suggest that it is possible to achieve a correct recognition rate of **100%**, for clients needing to recognize 1 person among 41.

REFERENCE: S. Lejeune. Reconnaissance de personnes sur base des caractéristiques de la marche observées avec des capteurs laser. Master's thesis, University of Liège, Belgium, 2014.

Is (s)he drunk?

As everybody walk in a different way, it is difficult to tell whether a person has taken alcohol or not, based on the observation of the feet trajectories. However, if you know the person, then you can guess his state from the gait descriptors provided by *GAIMS*.

- we assume we have two recordings of the same person
- we assume that the person is clean in at least one recording
- we want to know if the person consumed alcohol in the first, in the second, or in none of the recordings

Is (s)he drunk?

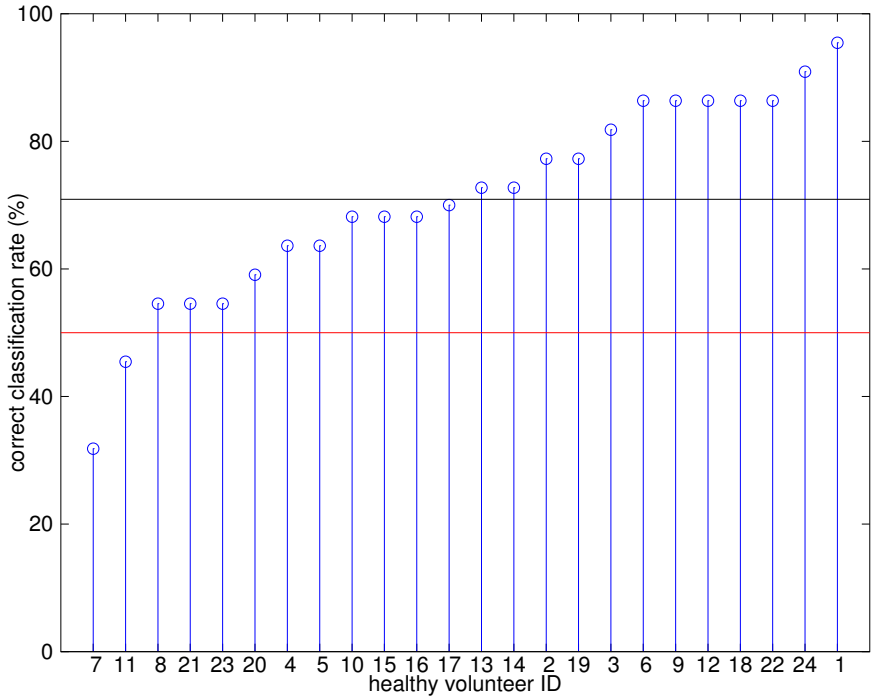
Our study:

- 24 healthy volunteers, aged between 22 and 57 years.
- Approved by the ethics committee (because of the medical reason for this study, as it will be explained in a few slides).
- We measured the BAC: $\mu = 67mg/l$, $\sigma = 22mg/l$.
- The most important modifications are behavioral, and the gait disorder specialists had difficulties to see any difference on feet movements induced by ethanol.
- We use the *ExtRaTrees* (classification) for each pair of tests. The attributes are

$$\omega(T_a), \pi(T_a), \left\{ \frac{f_i(T_a) + f_i(T_b)}{2}, f_i(T_b) - f_i(T_a), \frac{f_i(T_b) - f_i(T_a)}{f_i(T_a) + f_i(T_b)} \right\}_{i=1}^{26}$$

Is (s)he drunk?

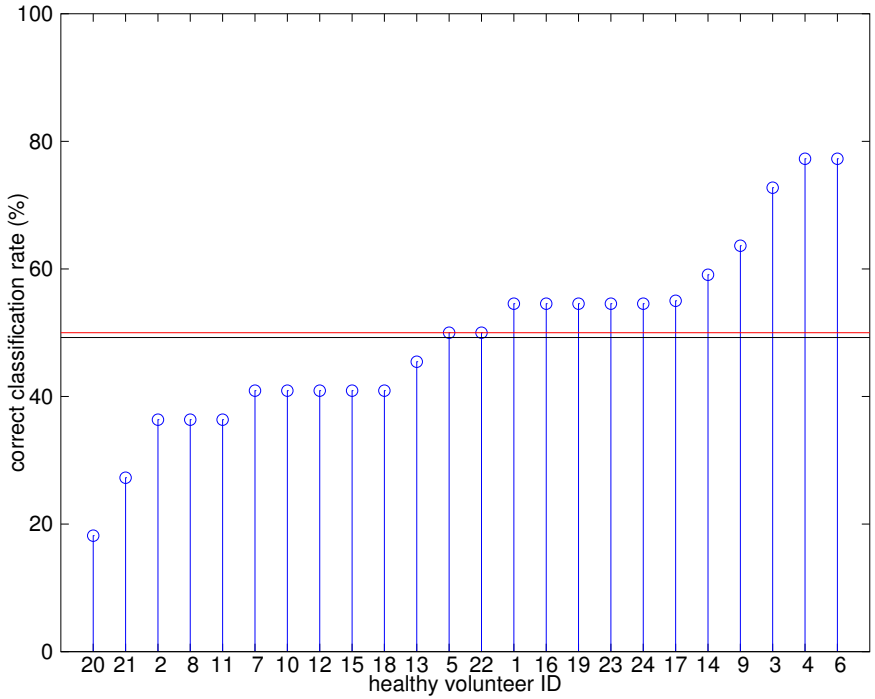
Results obtained with all gait descriptors provided by *GAIMS*:



REFERENCE: S. Piérard, R. Phan-Ba, and M. Van Droogenbroeck. Machine learning techniques to assess the performance of a gait analysis system. In European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning (ESANN), pages 419-424, Bruges, Belgium, April 2014.

Is (s)he drunk?

Results obtained with the gait descriptors related to a stopwatch:



REFERENCE: S. Piérard, R. Phan-Ba, and M. Van Droogenbroeck. Machine learning techniques to assess the performance of a gait analysis system. In European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning (ESANN), pages 419-424, Bruges, Belgium, April 2014.

Is (s)he drunk?

Can a human expert do better ? No !

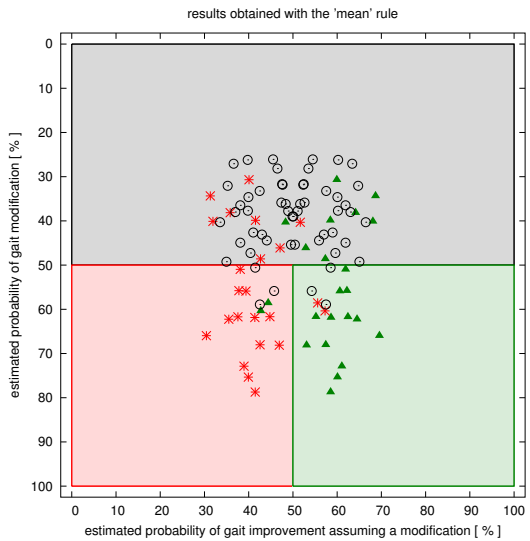
We have shown 228 randomly ordered pairs of video sequences (recorded during the acquisitions) to 14 other gait disorder specialists (neurologists of the university hospital of Liège).

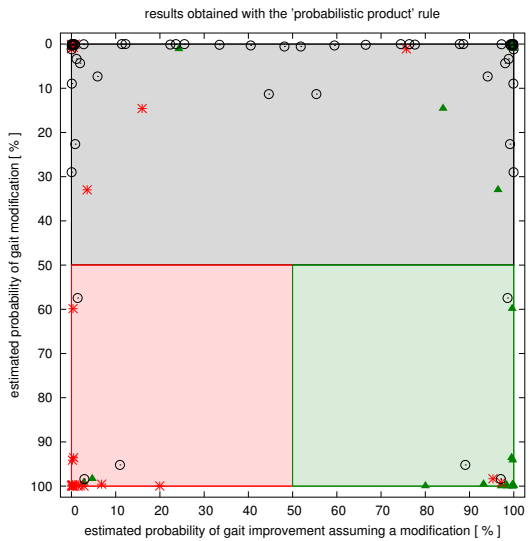
Their correct decision rate (62.28%, with a high inter-expert variability) is clearly lower than the one of our automatic classification system based on GAIMS (70.9%).

REFERENCE: S. Piérard, R. Phan-Ba, and M. Van Droogenbroeck. Machine learning techniques to assess the performance of a gait analysis system. In European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning (ESANN), pages 419-424, Bruges, Belgium, April 2014.

Is (s)he drunk?

- We asked 27 other healthy persons to perform twice the tests (during two consecutive visits), without any alcohol intake.
- These are the results we obtain when a third class is added for the pairs of visits (without alcohol, without alcohol):





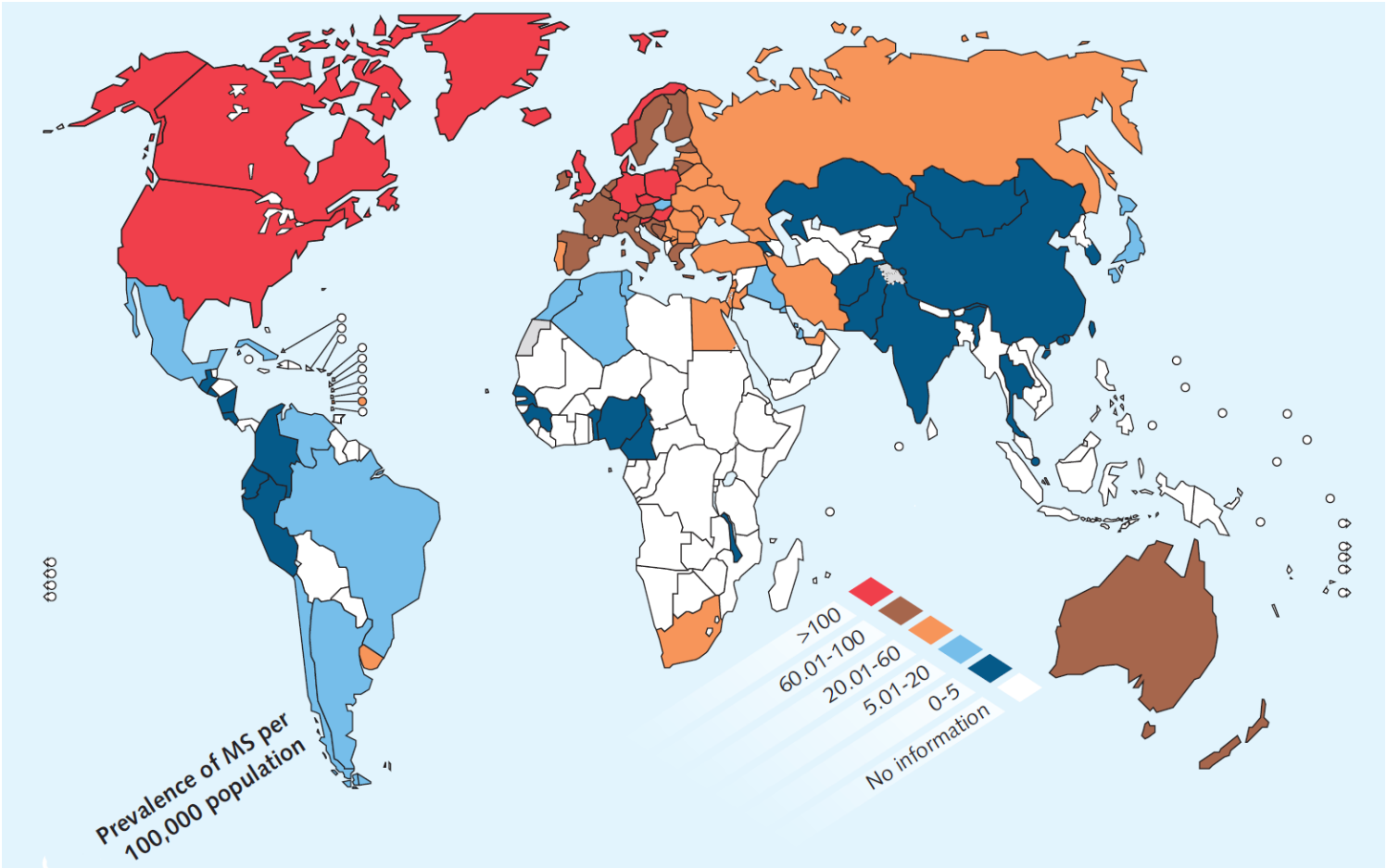
REFERENCE: S. Piérard, S. Azrour, R. Phan-Ba, and M. Van Droogenbroeck. Detection and characterization of gait modifications, for the longitudinal follow-up of patients with neurological diseases, based on the gait analyzing system GAIMS. In BIOMEDICA (the European Life Sciences Summit), Maastricht, The Netherlands, June 2014.

Outline

The prevalence of multiple sclerosis in the world

USA: 400,000 Canada: 65,000 France: 57,000 Belgium: 12,000

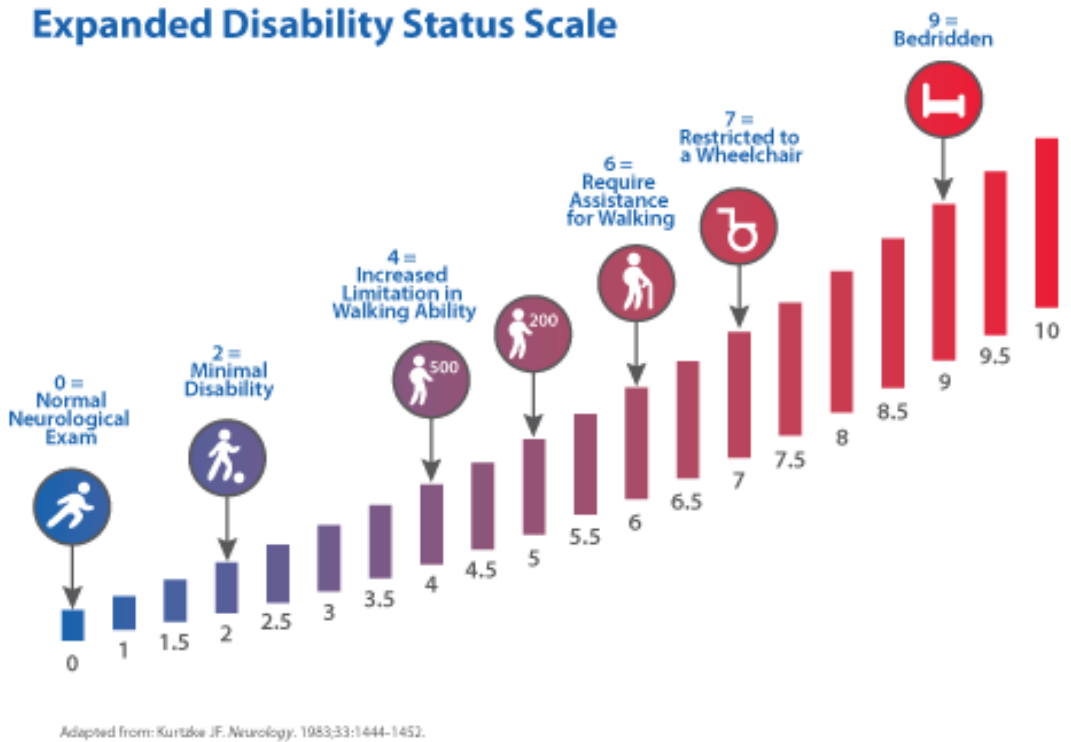
World: 2,500,000 persons have MS



World Health Organization and Multiple Sclerosis International Federation, Atlas Multiple Sclerosis Resources in the World. WHO, 2008.

The *Expanded Disability Status Scale* (EDSS)

- The EDSS score quantifies the disability in multiple sclerosis.
- The EDSS is based on 8 functional systems, and is only partly based on the gait disability.
- The EDSS is correlated with the motor impairments.



http://www.mobilitymattersinms. com/uk/assessment-tests.aspx

Why analyzing the gait of MS patients ?

- Most of the patients with MS have walking difficulties and they often perceive these difficulties as the most important source of disability.

REFERENCE: C. Heesen, J. Böhm, C. Reich, J. Kasper, M. Goebel, and S. Gold. Patient perception of bodily functions in multiple sclerosis: gait and visual function are the most valuable. Multiple Sclerosis, 14:988–991, 2008.

- Ambulation impairments appear during the early stages of the disease and the magnitude of the gait modification is a good indicator of the disease activity.

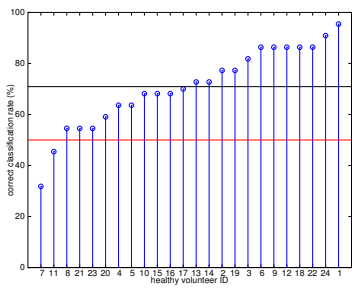
REFERENCE: R. Phan-Ba, P. Calay, P. Grodent, G. Delrue, E. Lommers, V. Delvaux, G. Moonen, and S. Belachew. Motor fatigue measurement by distance-induced slow down of walking speed in multiple sclerosis. PLoS ONE, 7(4):8 pages, April 2012.

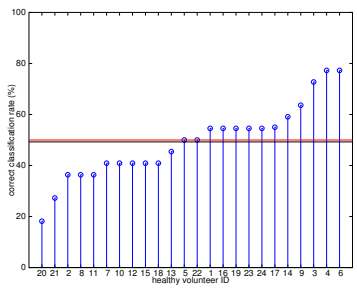
- The clinical evaluation of the gait could help in proposing appropriate drugs and physical therapy to counter the effects of the disease.

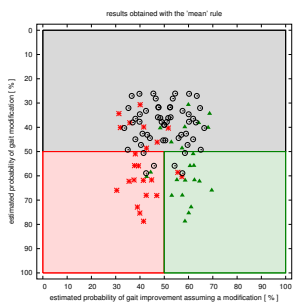
Ataxia (MS $\simeq$ alcohol)

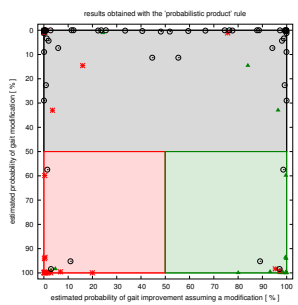
The ambulation impairments have often a component related to ataxia. Alcohol induces ataxia. So, alcohol intake is a good proxy to learn and test models for MS.

- $\hookrightarrow$ The results presented in the previous section hold also for MS.
- $\hookrightarrow$ *GAIMS* can be useful to the contrary of a stopwatch.
- $\hookrightarrow$ It is possible to discriminate between "gait deterioration", "no modification", and "gait improvement".



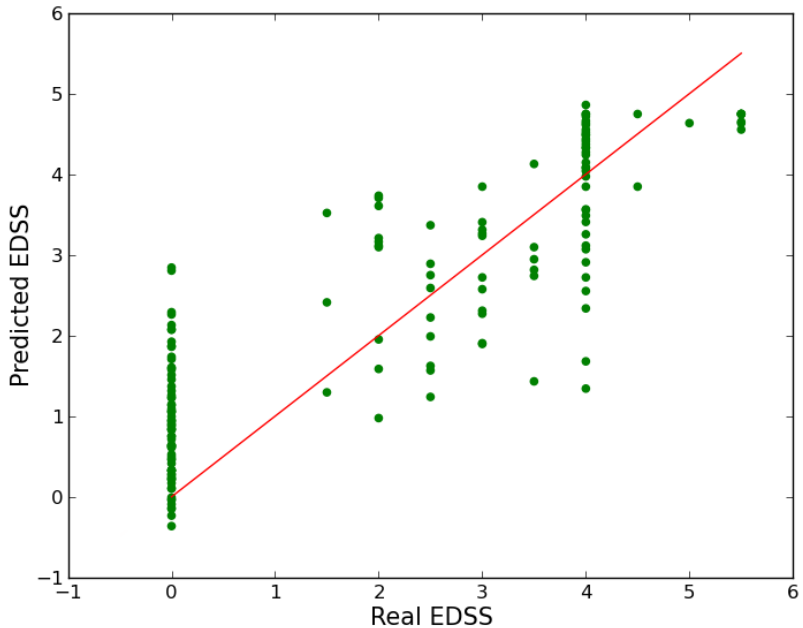






Estimating the EDSS

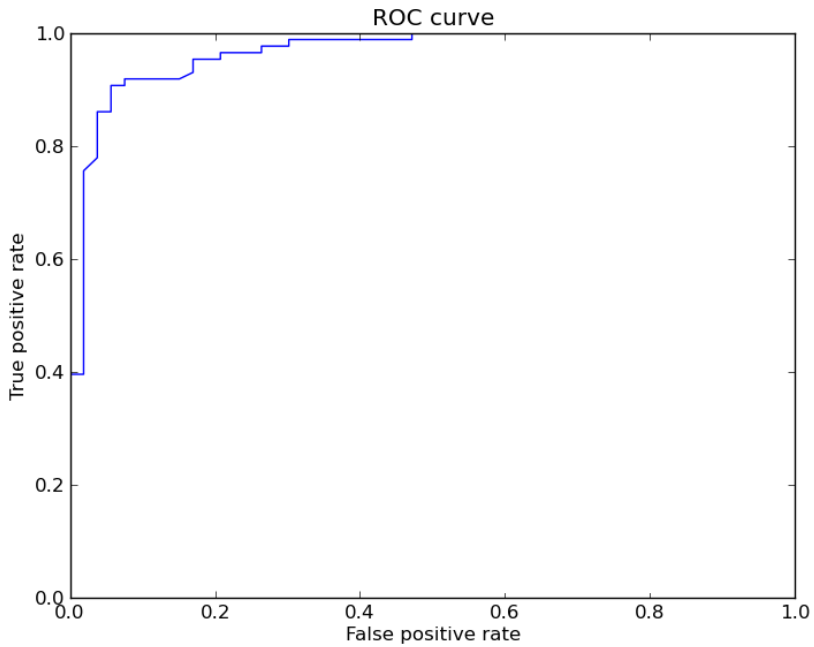
- The gait descriptors are normalized with respect to the morphological characteristics.
- One prediction per test, averaged for each visit.



REFERENCE: S. Azrour, S. Piérard, P. Geurts, and M. Van Droogenbroeck. Data normalization and supervised learning to assess the condition of patients with multiple sclerosis based on gait analysis. In European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning (ESANN), pages 649-654, Bruges, Belgium, April 2014.

Diagnosing multiple sclerosis

- The gait descriptors are normalized with respect to the morphological characteristics.
- One prediction per test, averaged for each visit.



REFERENCE: S. Azrour, S. Piérard, and M. Van Droogenbroeck. Using gait measuring system (GAIMS) to discriminate patients with multiple sclerosis from healthy persons. In BEMEKO Workshop on measurement: Challenges and Opportunities, Liège, Belgium, November 2013.

The motor fatigue plays an important role

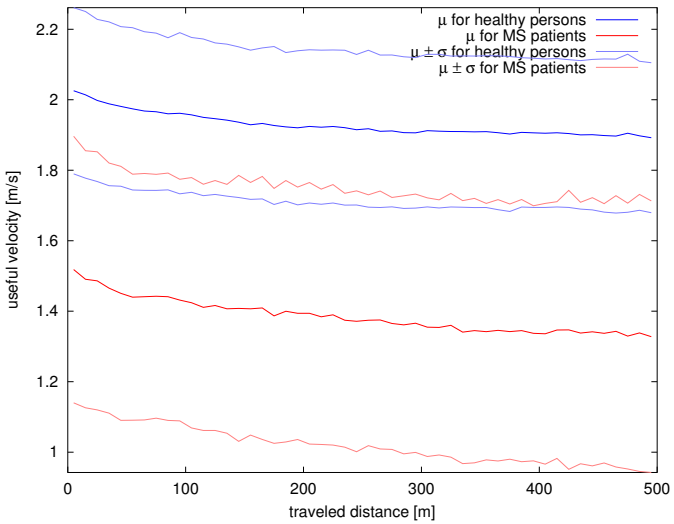
In this study:

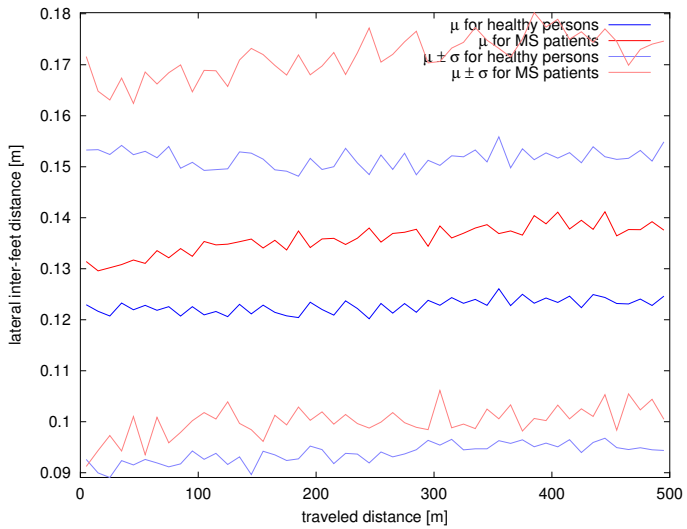
- The *ExtRaTrees* are used to predict if the observed person is healthy (HP) or has multiple sclerosis (MSP) based on a the temporal evolution of the gait descriptors provided by *GAIMS*.
- 115 HP and 59 MSP (median EDSS 3.26) walked a 500 m distance (25 laps of an 8-shaped path) as fast as possible, and their gait was recorded with *GAIMS*.
- The measures taken over the total path, and 50 consecutive windows of 10 m, have been analyzed. This led to 26 GDs for the total path, and for each window.

REFERENCE: S. Piérard, S. Azrour, R. Phan-Ba, V. Delvaux, P. Maquet, and M. Van Droogenbroeck. Diagnosing multiple sclerosis with a gait measuring system, an analysis of the motor fatigue, and machine learning. Multiple Sclerosis Journal, 20(S1):171, September 2014. Proceedings of ACTRIMS/ECTRIMS 2014 (Boston, USA), P232.

REFERENCE: R. Phan-Ba, P. Calay, P. Grodent, G. Delrue, E. Lommers, V. Delvaux, G. Moonen, and S. Belachew. Motor fatigue measurement by distance-induced slow down of walking speed in multiple sclerosis. PLoS ONE, 7(4):8 pages, April 2012.

The motor fatigue plays an important role





REFERENCE: S. Piérard, S. Azrour, R. Phan-Ba, V. Delvaux, P. Maquet, and M. Van Droogenbroeck. Diagnosing multiple sclerosis with a gait measuring system, an analysis of the motor fatigue, and machine learning. Multiple Sclerosis Journal, 20(S1):171, September 2014. Proceedings of ACTRIMS/ECTRIMS 2014 (Boston, USA), P232.

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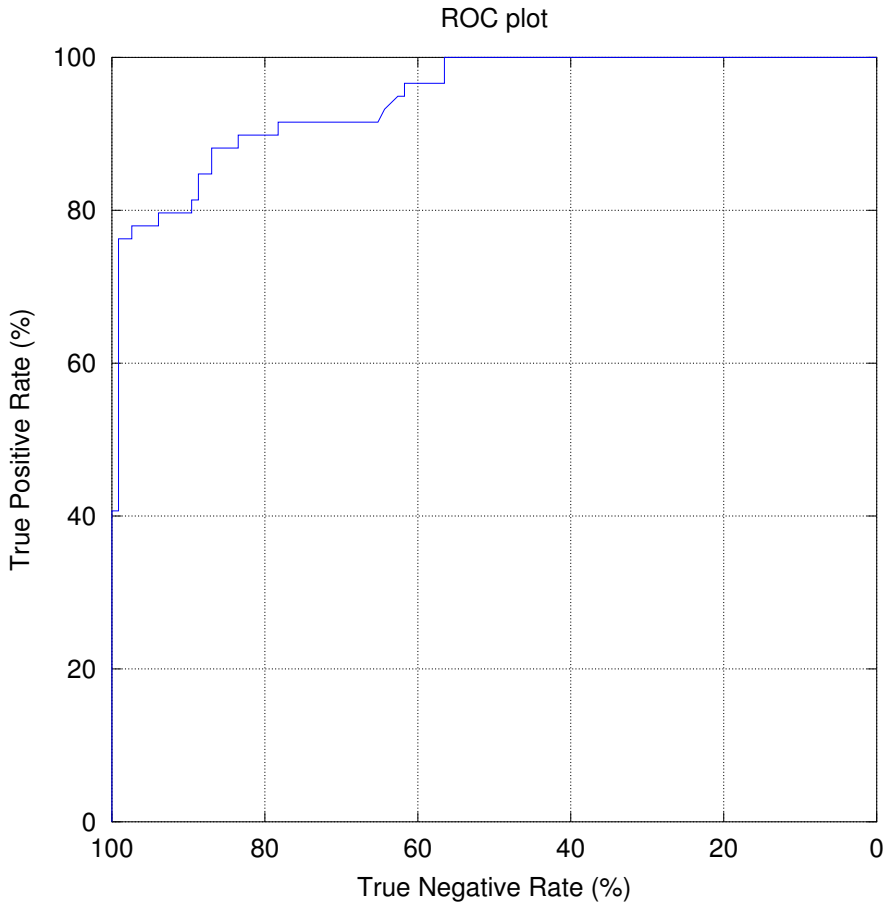

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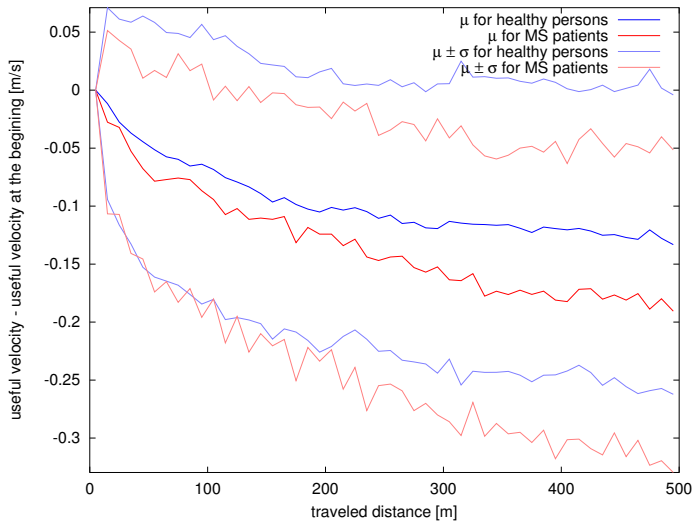

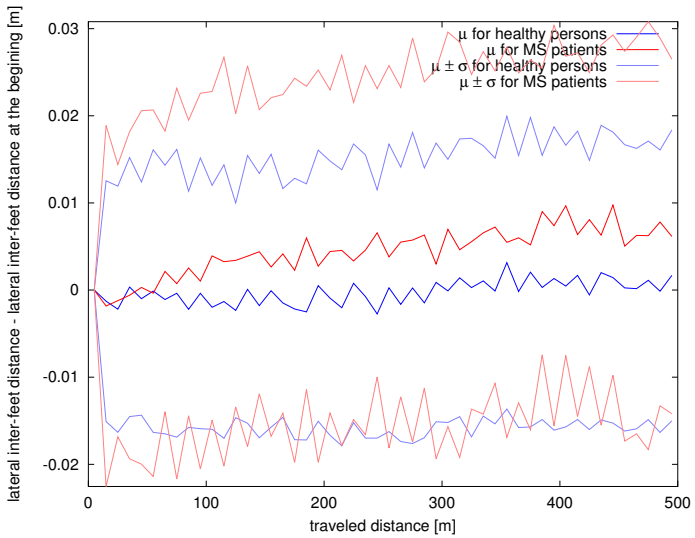

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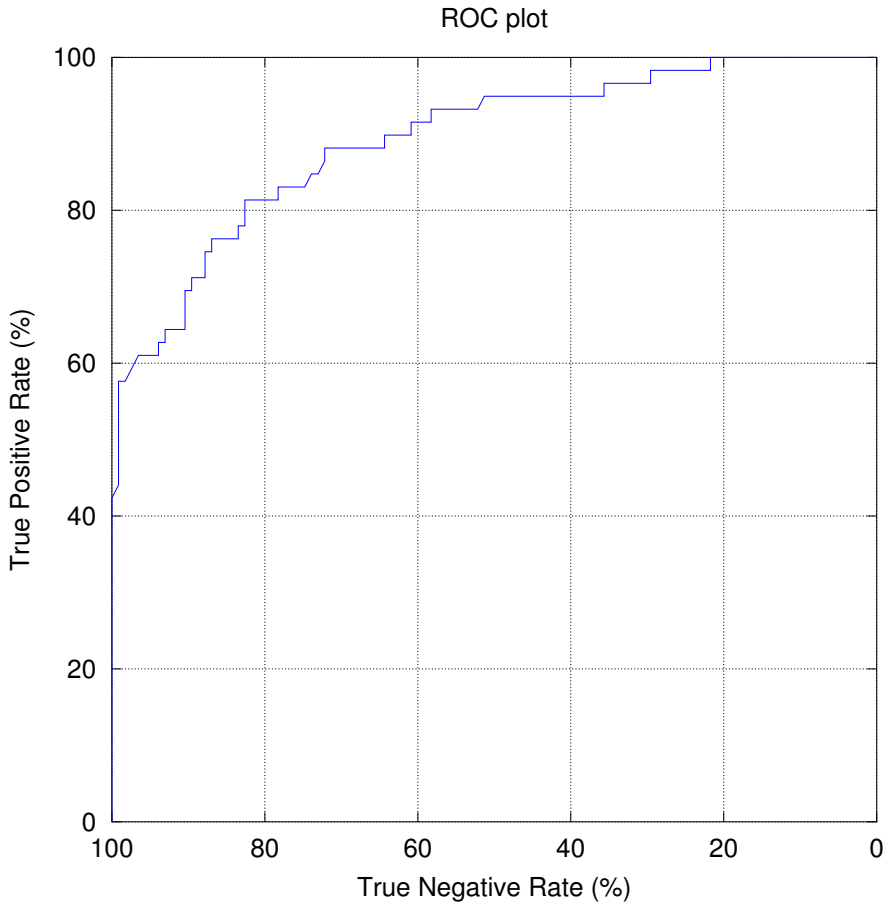


REFERENCE: S. Piérard, S. Azrour, R. Phan-Ba, V. Delvaux, P. Maquet, and M. Van Droogenbroeck. Diagnosing multiple sclerosis with a gait measuring system, an analysis of the motor fatigue, and machine learning. Multiple Sclerosis Journal, 20(S1):171, September 2014. Proceedings of ACTRIMS/ECTRIMS 2014 (Boston, USA), P232.

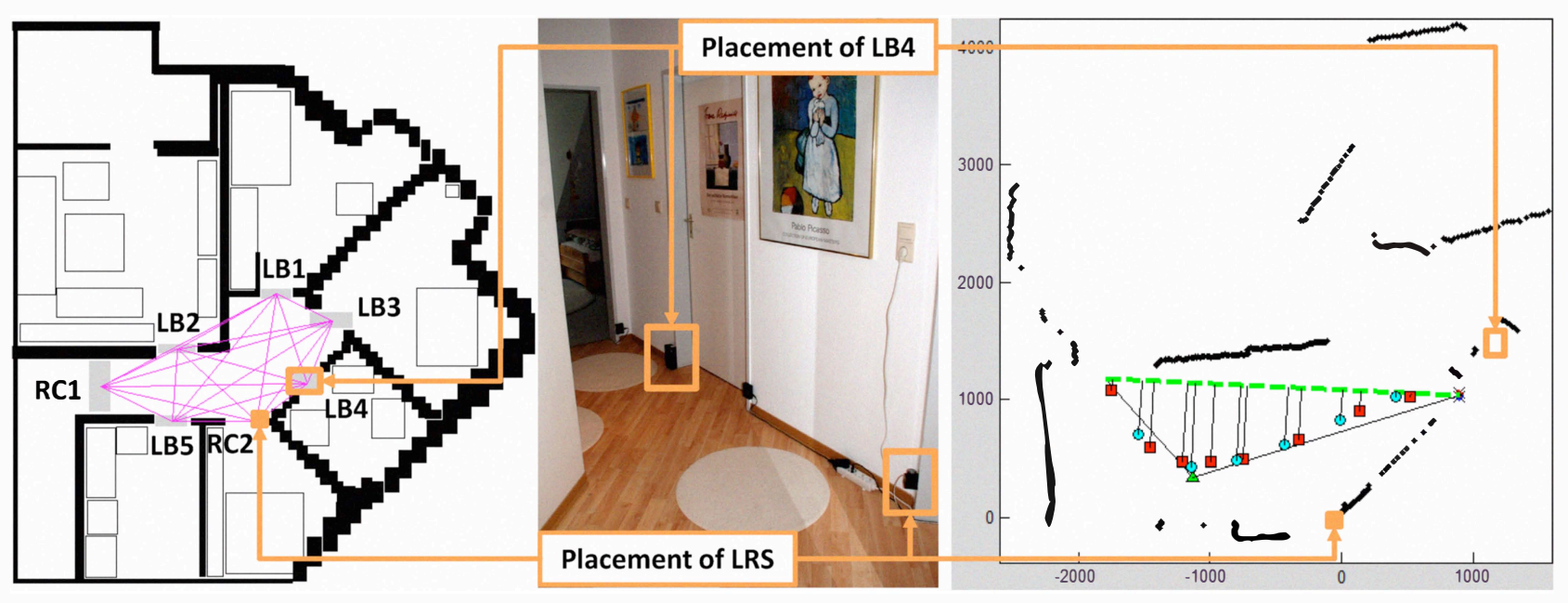
Quantity and quality of the physical therapy

- There exist correlations between some gait characteristics measured with *GAIMS* and the quantity and quality of the physical therapy and physical activity followed by MSP: the speed, the double support time, the deviation from the followed path (during tandem walk), and the lateral distance between feet, as well as the speed decrease during a long walk.
- The positive correlation between the lateral inter-feet distance and the quantity of physical therapy and physical activity was unexpected and is still unexplained.
- Remarkably, correlations between some gait characteristics provided by *GAIMS* and the emotional state of the patients have also been observed: the more the PMS feel coached by their physical therapist, the more the double support time is reduced when walking a small distance as fast as possible.

REFERENCE: A. Giet. Création et validation multimodale d'une échelle mesurant la qualité de la kinésithérapie et de l'activité physique chez les personnes souffrant de sclérose en plaques. Master's thesis, University of Liège, Belgium, 2013.

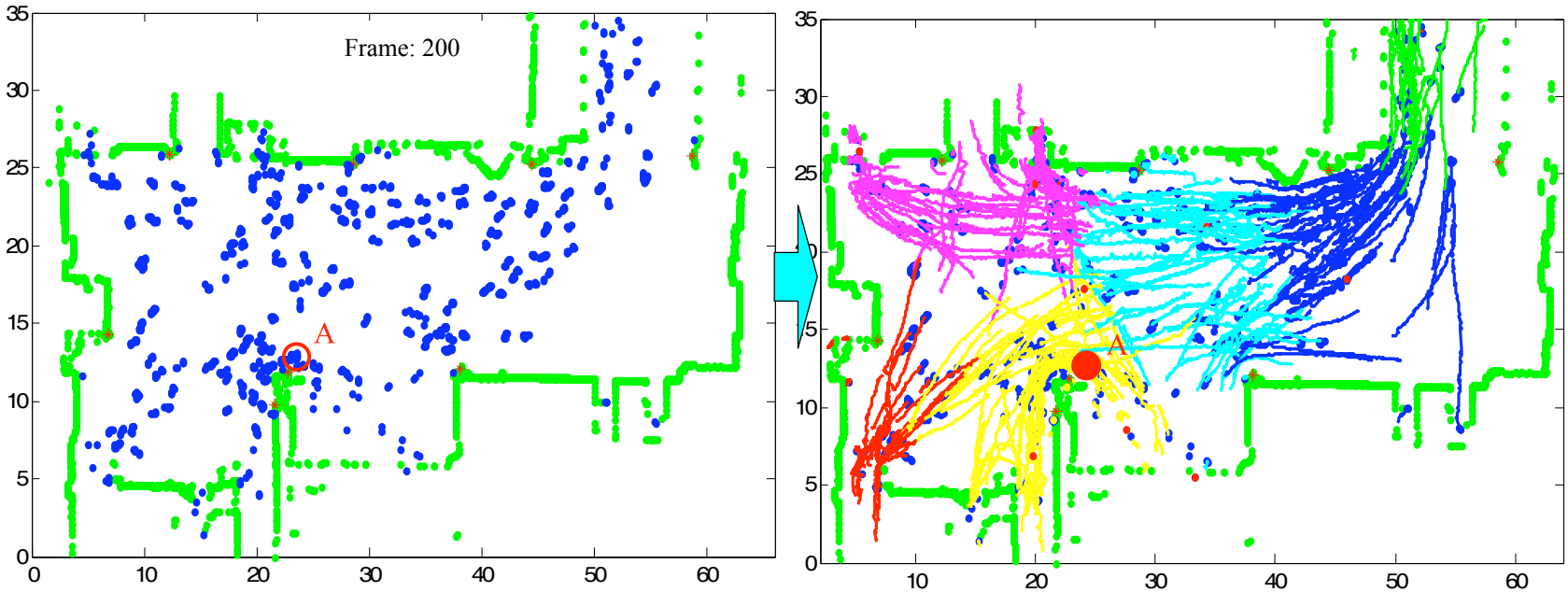
Outline

Mobility assessment tests in domestic environments



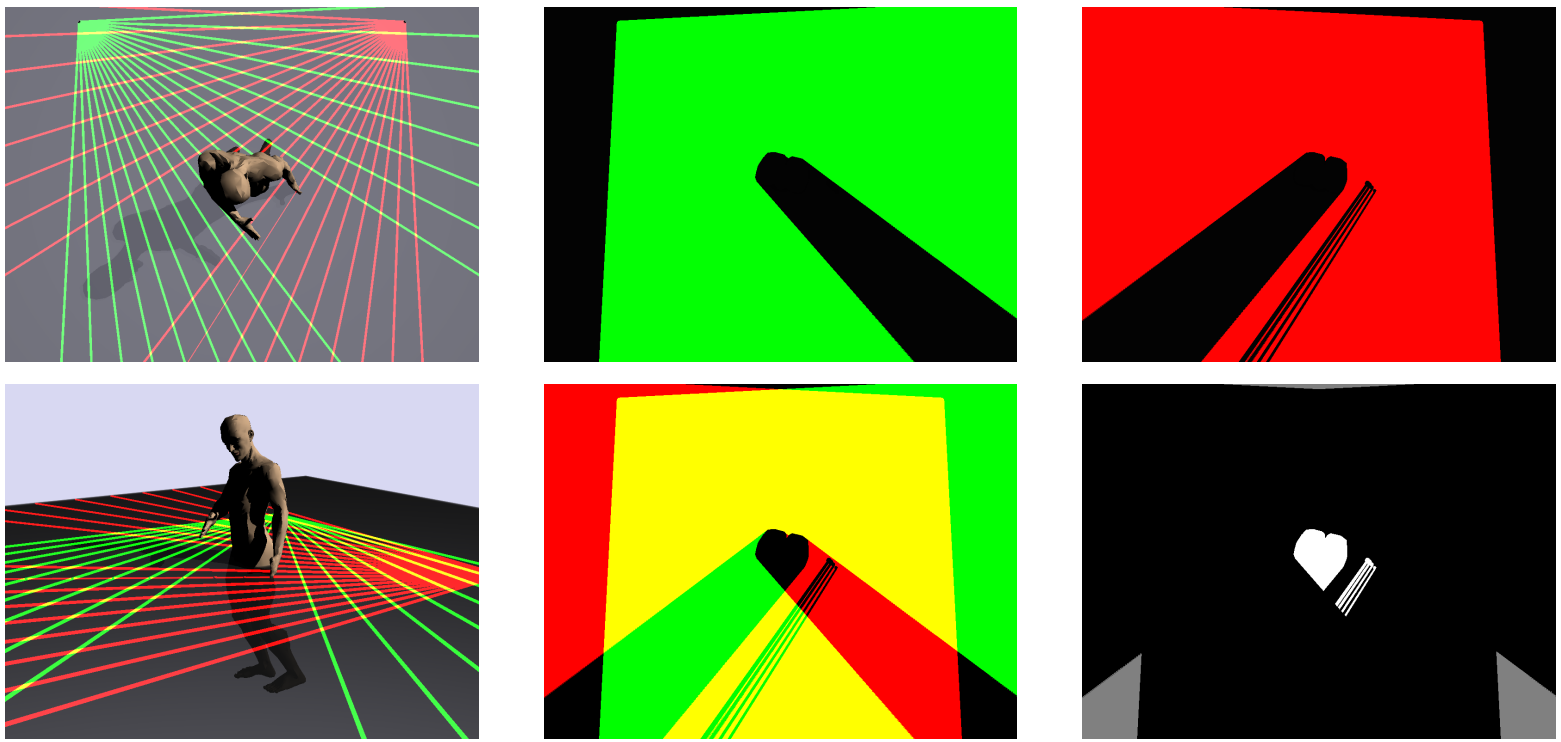
REFERENCE: T. Frenken, M. Lipprandt, M. Brell, M. Gövercin, S. Wegel, E. Steinhagen-Thiessen, and A. Hein. Novel approach to unsupervised mobility assessment tests: Field trial for aTUG. In 6th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth), pages 131 –138, San Diego, USA, May 2012.

Tracking people



REFERENCE: X. Song, X. Shao, H. Zhao, J. Cui, R. Shibasaki, and H. Zha. An online approach: Learning- semantic-scene-by-tracking and tracking-by-learning-semantic-scene. In IEEE International Conference on Computer Vision and Pattern Recognition (CVPR), pages 739–746, San Francisco, USA, June 2010.

Working with silhouettes instead of point clouds



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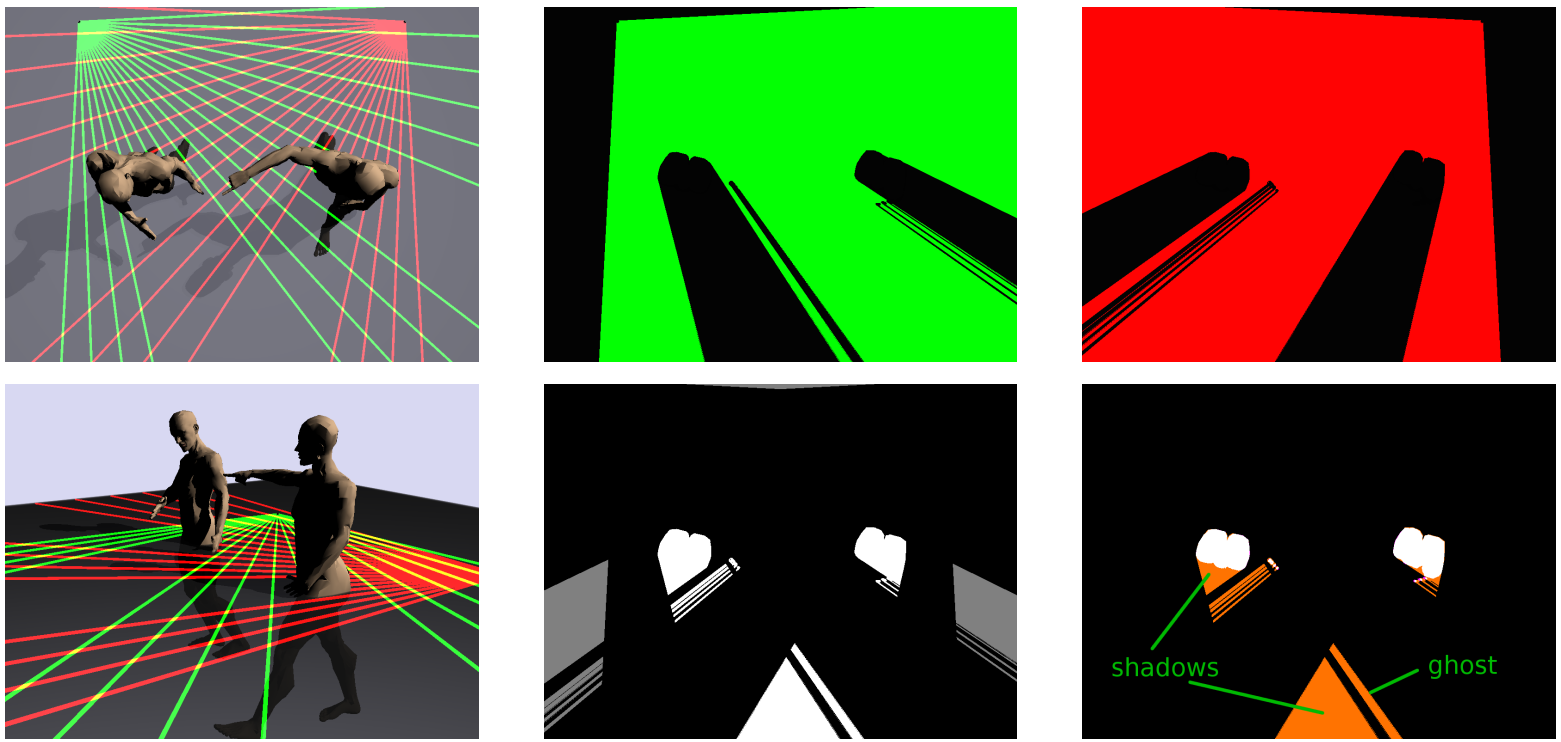

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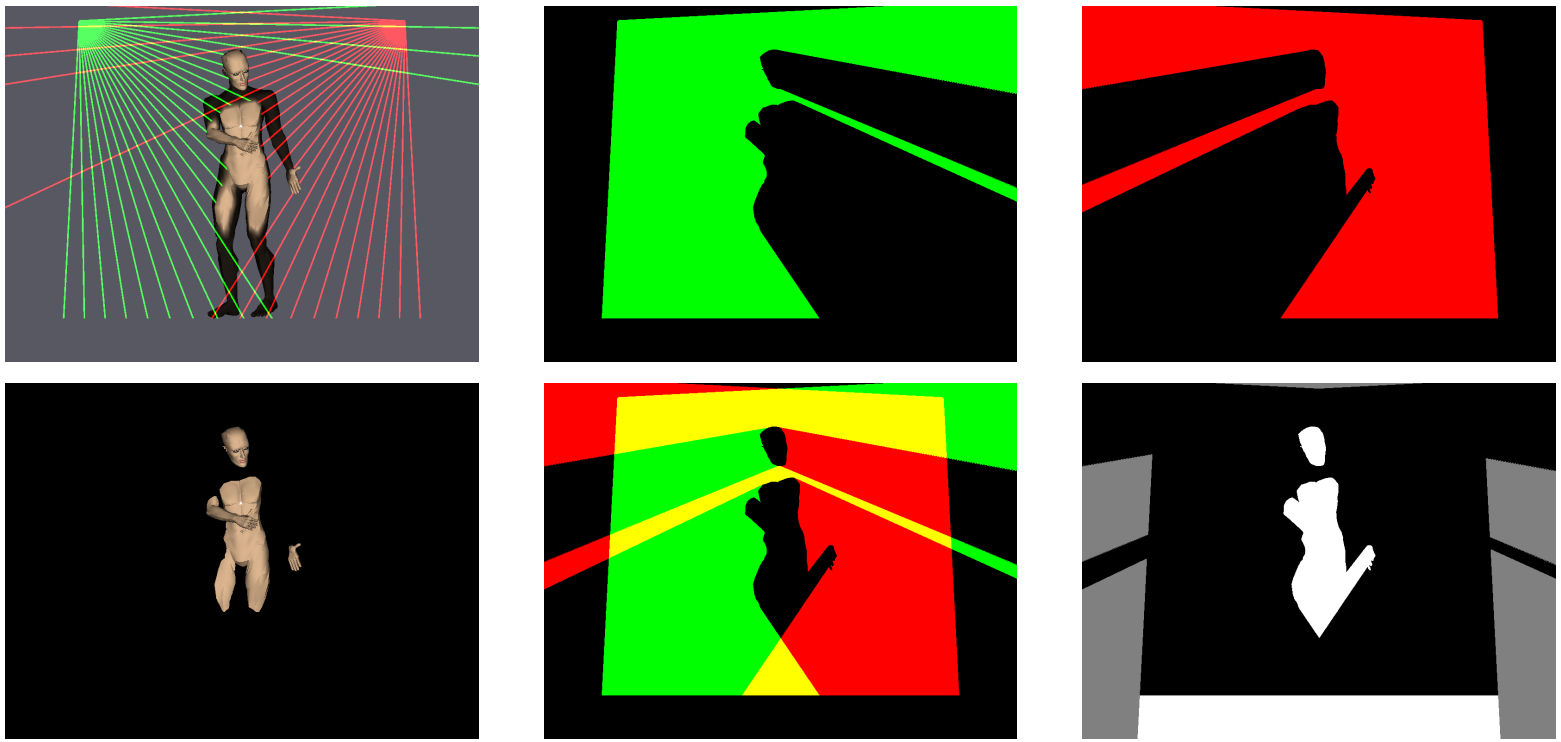
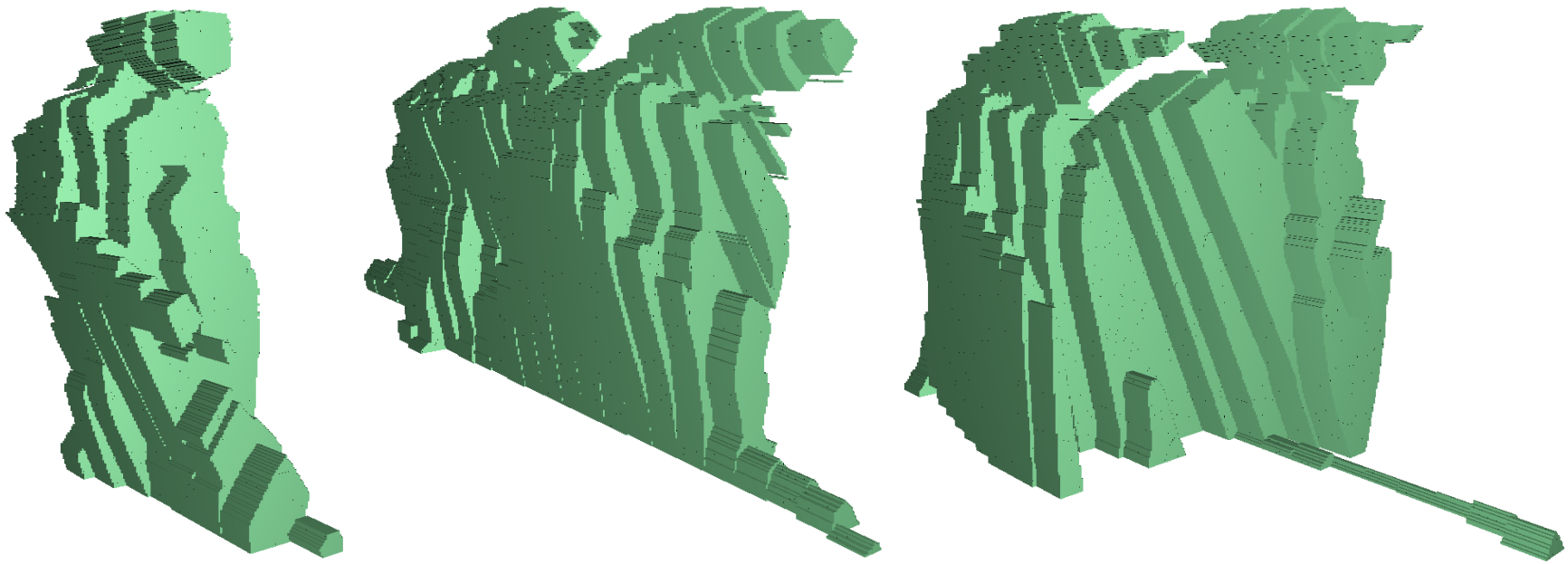


REFERENCE: O. Barnich, S. Piérard, and M. Van Droogenbroeck. A virtual curtain for the detection of humans and access control. In Advanced Concepts for Intelligent Vision Systems (ACIVS), Part II, pages 98–109, Sydney, Australia, December 2010.

Working with silhouettes instead of point clouds

If we add a third dimension corresponding to the time, we obtain volumes describing the movements and the interactions:

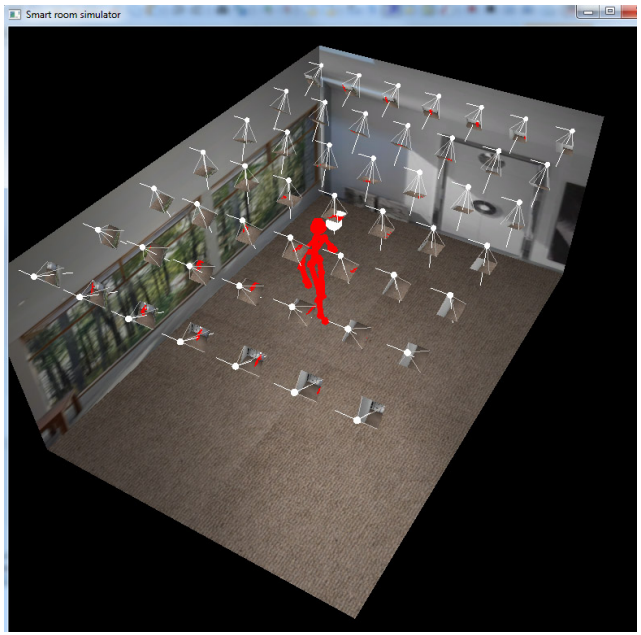


This can be used to detect piggybacking and tailgating . . .

REFERENCE: O. Barnich, S. Piérard, and M. Van Droogenbroeck. A virtual curtain for the detection of humans and access control. In Advanced Concepts for Intelligent Vision Systems (ACIVS), Part II, pages 98–109, Sydney, Australia, December 2010.

Where is it preferable to place the sensors?

@ *CREI*, we try to answer this question, by simulation.

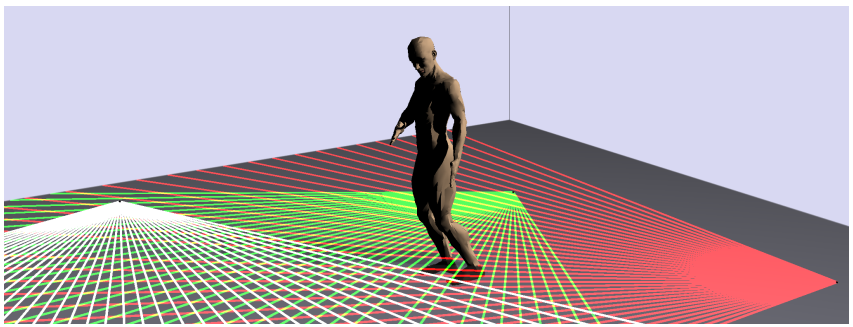


REFERENCE: http://www.makehuman.org

Outline

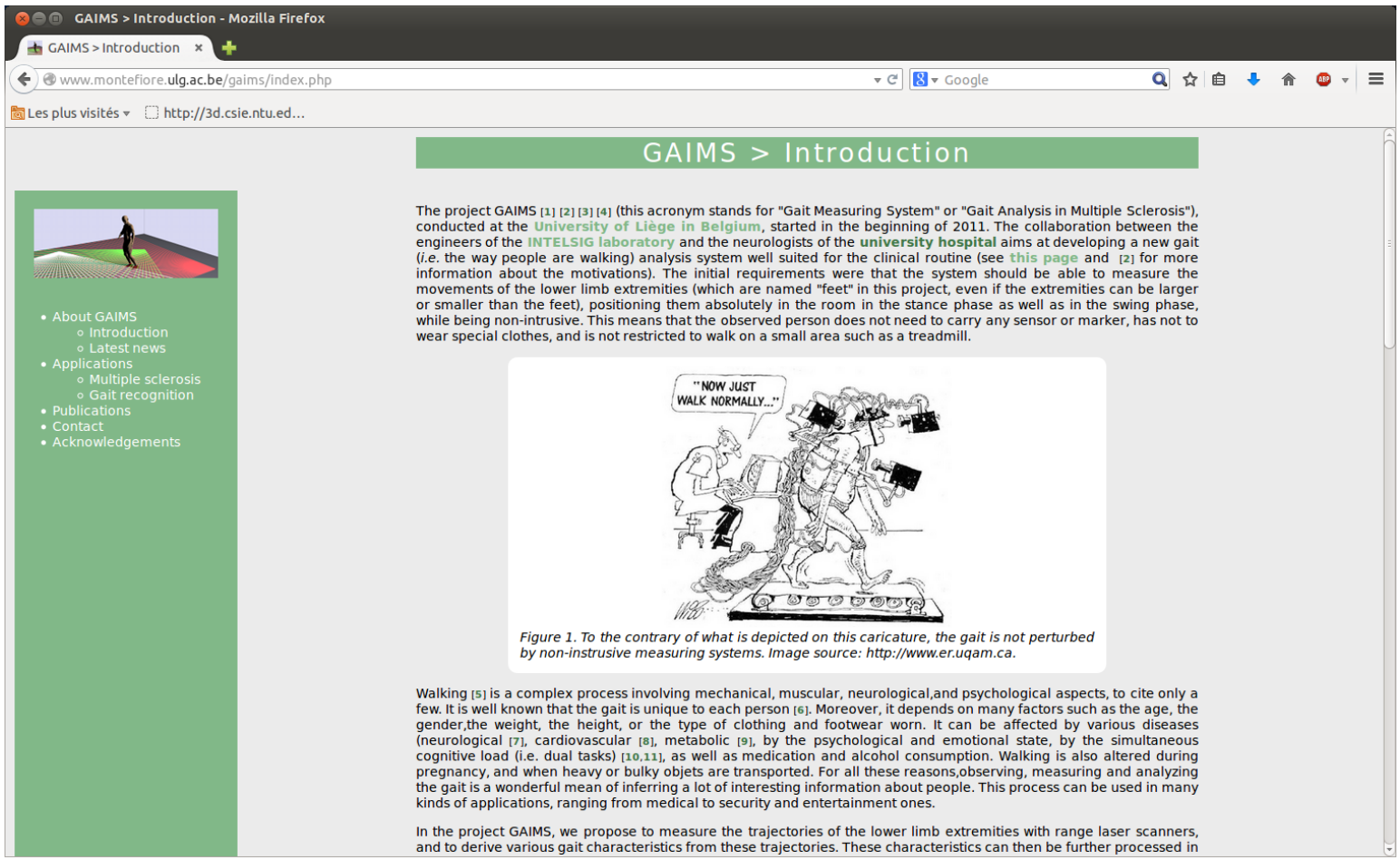
Conclusion

- *GAIMS* is a non-intrusive and reliable system measuring reliable feet trajectories.
- The observed person does not need to be equipped with any active or passive marker, sensor, *etc*.
- It has proven to be useful for medical applications and could also be used for other applications.



For more information

http://www.montefiore.ulg.ac.be/gaims



For more information

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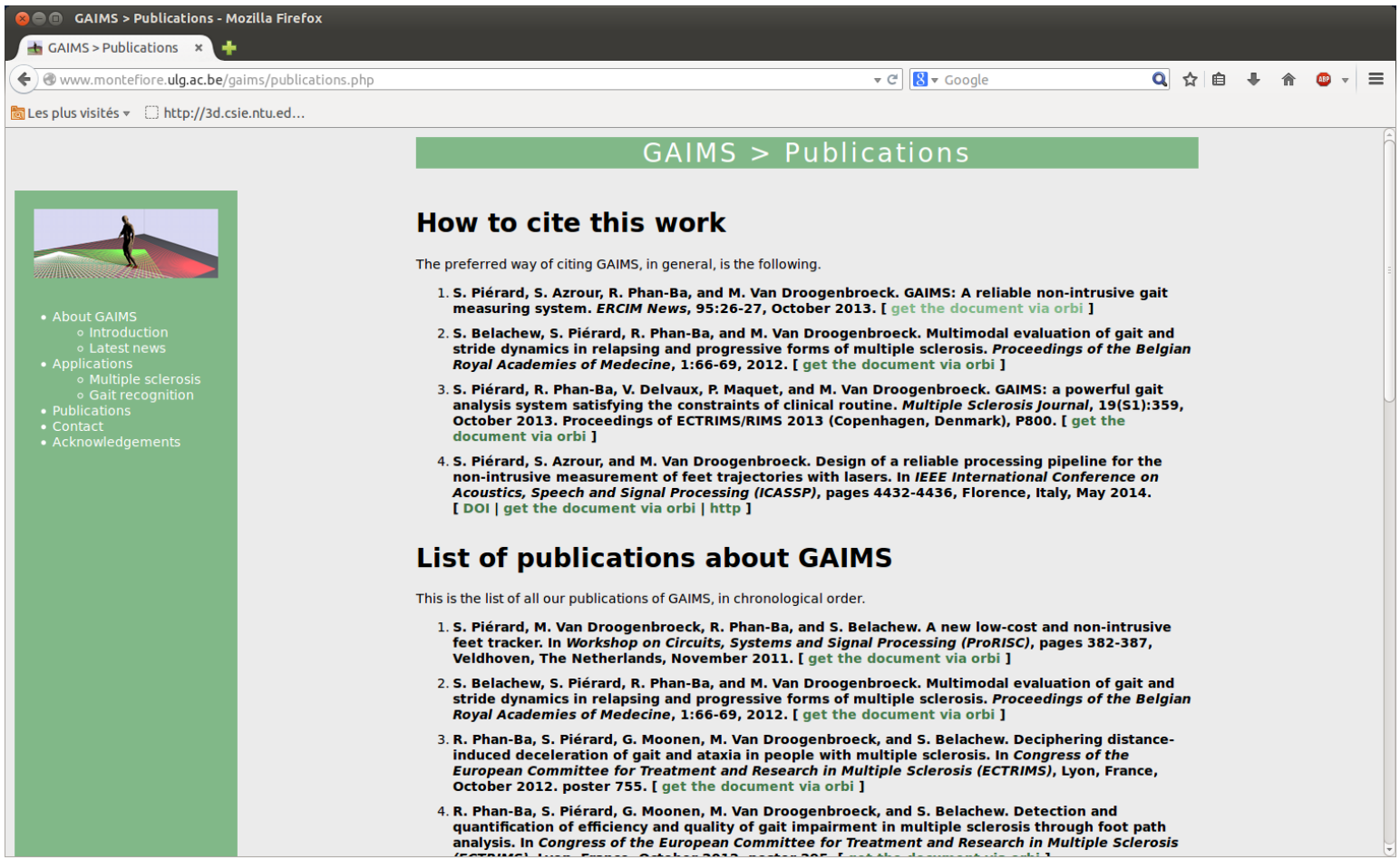
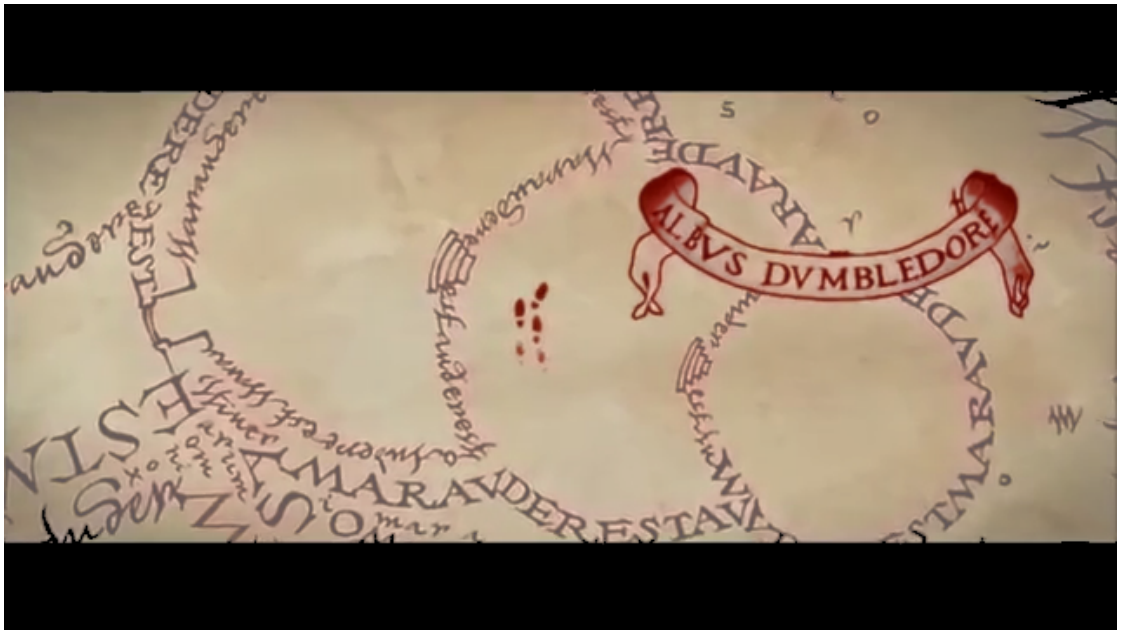


Thank you! Do you have questions?

Now, do you think the marauder's map will stay forever in the imaginary world, or is it already possible to do better with range laser scanners, signal processing, and machine learning?



https://www.youtube.com/watch?v=o3-KM-_fni0

Mischief managed !