# Spatiotemporal modelling of physical activity for understanding function, disability and health

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## 1. Introduction

Insufficient physical activity has long been shown to be associated with increased risk of several major health disorders such as obesity, diabetes, cancer, coronary heart disease, and hypertension. Till recently, physical activity and participation levels in daily life had to be assessed through self-reported information, while only physical ability, not actual real world behavior, can be determined in clinical settings. Now, with miniature physical activity monitoring sensors that people can carry, it is relatively easy to objectively determine how people move and interact with their free-living environments. These devices have ushered in a new approach to measure function and disability in free-living environments (Herrmann et al. 2011).

However, it is important to remember that a holistic approach to human health requires not just measurements of physical activity levels, but also the personal and external environmental factors influencing activity choices. WHO has thus adopted the International Classification of Functioning, Disability and Health (ICF) “biopsychosocial” model, which conceptualizes a person's level of functioning as a dynamic interaction between his or her health conditions, physical and social environmental factors, and personal factors (WHO 2001).

The current trend in physical activity and function measurement research is to ask subjects to carry portable GPS units to map the locations of activities to reveal the environmental context of their activities. However, simple mapping of GPS tracks cannot reveal as much about activity patterns because the continuous temporal dimension is largely ignored. Instead, we adopt an integrated space-time analytical framework and situate physical activity in the space-time continuum, which is obviously much more appropriate for recognizing dynamic activity patterns. We are developing computational methods to model activity and capture as much of the personal and environmental contextual details as available from other datasets. In this paper, we review a novel function/disability measurement framework called Movement and Activity in Physical Space (MAPS) that we adhere to, and then discuss its enhancement in Section 2 and experimental validation (Section 3) with space-time data modeling and analysis capabilities.

## 2. Enhancing MAPS with spatiotemporal capabilities

As summarized in Figure 1, the MAPS system is currently composed of 14 quantitative variables including two composite scores (used most frequently) to measure different aspects of an individual's function in the free-living environment (Herrmann et al. 2011; Farnsworth et al. 2014). MAPS requires an individual to diligently record continuous accelerometer data for measuring physical activity intensity and volume, GPS tracks for associating activities with their host geographic features (e.g., home, school, restaurant, park), and descriptive travel logs to validate known and identify missing sites from the GPS record. GPS tracks are overlaid on freely available base maps, and time-synced with accelerometer readings to convert raw physical activity counts into the more informative function measures. All analyses must be based on at least 3 days of activity records for statistical validity and reliability of MAPS variables. Despite benefits of MAPS for measuring function, variable calculation is tedious, taking several hours and at least two human operators. The current set of 14 variables is also lopsidedly focused on activity counts, and GPS data are used only to determine activity sites, but not activity patterns. The MAPS system needs to be extended with new variables and also computationally upgraded to enable processing of large datasets.

| MAPS System Variables | |
|---|---|
| Total Physical Activity | Total Recorded Time |
| Physical Activity at Locations | Time at Locations |
| Physical Activity at Home | Time at Home |
| Total Step Counts | Total Trip Count |
| Step Counts at Locations | Instrumental Trip Count |
| Step Counts at Home | Discretionary Trip Count |
| MAPS Intensity Score ($MAPS_I$) | MAPS Volume Score ($MAPS_V$) |

$MAPS_{I/V}$ scores are calculated based on the same formula:

$$MAPS_{I/V} = \frac{\sum_{T=1}^{m}\left[\sum_{L=1}^{n}\left(\frac{A_L}{t_L}\right)\right]}{T}$$

where $t_L$ is the time spent at a location L other than home (determined from GPS and travelogue analysis), $A_L$ is a measure of activity (determined from accelerometer readings) at location L, and T is the total number of days used to average daily activity scores. Depending on whether $A_L$ is measured in activity counts (intensity) or step counts (volume), $MAPS_I$ or $MAPS_V$ score can be calculated.

Figure 1. MAPS system variables.

As evident from research in the last decade on modeling people's mobility, physical activity analysis also requires moving beyond standard raster and vector spatial data models to more sophisticated, well-known spatiotemporal data models such as trajectories, space-time paths, lifelines, events, diaries, and activity spaces (technical details eschewed here for lack of space). The spatiotemporal framework enables simultaneous consideration of the space and time dimensions of i) physical activity (intensity, duration), ii) contextual environmental conditions (e.g., location, time, weather, air quality, amenities, crime risk), and iii) personal background (medical and general life details). Apart from computational implementation, the obvious challenge is how to integrate activity records with environmental and personal conditions for detecting individual-environment interaction patterns in space-time. Some obvious benefits that justify such research include interactive exploration of datasets through special queries and space-time visualizations, semi-automation of many tedious steps in the data processing workflow, context-aware 'smart' analysis of larger datasets, and being able to express general semantics of activity patterns in the context of function assessment. We are also exploring spatiotemporal uncertainty modeling to systematically account for impacts of errors in GPS records due to missing tracks and positioning errors.

We are implementing our spatiotemporal data modeling and analysis concepts using TerraLib[1], an open-source C++ GIS software library since it already has basic spatiotemporal data modeling capabilities. For mapping and 3D visualization of space-time data, we currently depend on the commercial ArcGIS 10.0 software suite, and the freely available extension "Extended Time-Geographic Framework Tools Extension" (ArcGIS 10.0 version) designed for modeling and visualizing activities in physical and virtual space.[2]

## 3. Experimental framework

MAPS studies initially involved only adult individuals collecting data using accelerometers and GPS units over several days. The data are processed, as described above, to generate MAPS variable scores to assess level of functionality in daily life. The subject groups can be healthy adults, older adults, and those suffering from specific disorders such as multiple sclerosis, diabetes, arthritis, paraplegia, and low vision. The experimental set up for studying adults in their everyday setting is in marked contrast to studying movements in small activity spaces. For example, we are also conducting experiments, using GPS and accelerometers, to record physical activity intensity, duration, location and social engagement of 3rd – 5th grade children as they play during school recess. The first round of pilot experiments also includes complete video recording to gain deeper understanding of children's activities during recess, but our ultimate objective is to extract physical activity information only from portable GPS and accelerometer datasets, and spatiotemporal data modeling, since video footage collection and processing is too resource intensive. The knowledge gained from playground experiments will be used to suggest interventions for increasing physical activity in children to counter the epidemic of childhood obesity.

The two categories of experiments with free moving adults and children moving in a playground warrant different data modeling and analytical strategies. Studying individuals for several days leads to much larger activity spaces and the determination of contextual environmental factors is quite critical for function assessment. We model such activities as lifelines (composed of discrete time steps in space) with associated contextual thematic information needed for function assessment. In contrast, children's movements during recess are bound within small activity spaces, characterized by highly dynamic movement patterns, and also need to be studied in relation to other

[1] TerraLib website: http://terralib.org
[2] Project website for downloading: http://web.utk.edu/~sshaw/NSF-Project-Website/download.htm

children's movements. The fast-paced children's movements are modeled as spatiotemporally continuous trajectories with much greater positional accuracy needs; however trajectories do not have associated thematic contextual information. These are just two example of why spatiotemporal modeling is essential for MAPS.

GPS errors (5m - 30m typically or missing completely) are a serious concern in our experiments. For large activity space experiments, human operators can generally infer the correct mapped feature (activity site) from mapping and travel log consultation. However, fully automating the selection of the correct geographic feature is far from trivial as crisp rules cannot be specified and errors seem to be influenced by movement rates. As shown in Figure 2, positional errors of 10-15 meters are common for GPS units in continuous motion. Thus, children's playground activities can be assigned to the wrong play area, and estimates of distances and velocities will be questionable. For both sets of experiments, we are using the spatiotemporal approach to uncertainty modeling based on trajectories, lifelines, and activity spaces so that we can reason about how to interpolate the missing segments of intentional movements of people in space-time—not how to interpolate missing GPS points for a track.

## 4. Summary

Our research brings together researchers and integrates knowledge from health sciences, GIScience and geography. We are addressing both scientific and computational problems for modeling physical activity and measuring individuals' function in real life. We are enhancing the MAPS system which was conceived based on the WHO ICF model with much needed spatiotemporal capabilities. At the workshop, we will share more details and seek feedback about our implementation of the spatiotemporal data models and analysis functions for enhancing MAPS.

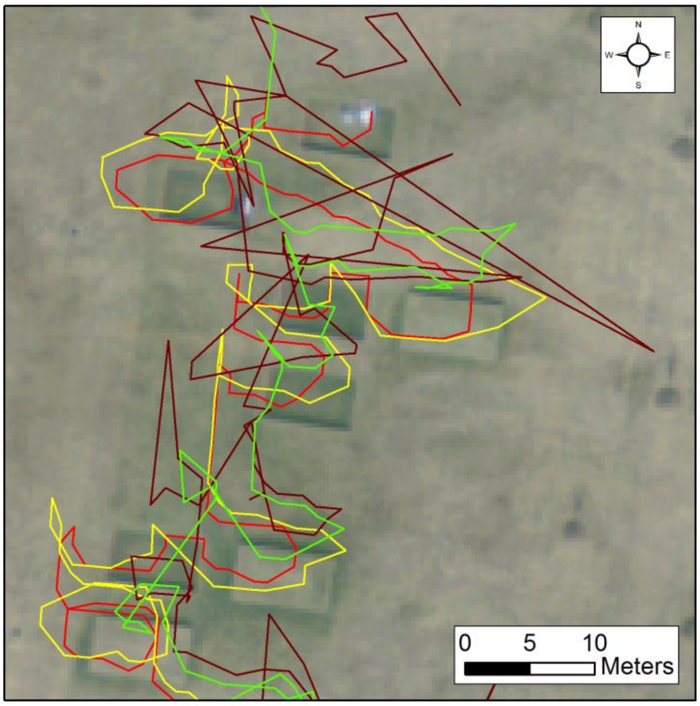


Figure 2. Visualization of GPS track errors for rectilinear walks along edges of rectangular structures (visible in the aerial photo).

## References

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