

# Predicting Future Locations

---

Ingrid Burbey  
Bradley Department of Electrical and Computer Engineering  
Virginia Tech  
iburbey@vt.edu

Imagine if you had a software application that could predict your future locations. At the start of the day, it could remind you of where you would be and what you would need. If your friends and colleagues also had this application, it could tell you that you might encounter your friends at lunch or that you would most likely find your colleague in his office in the afternoon. This vision is the basis for my research. I am creating algorithms that predict people's future locations and when they will be at those locations. While some algorithms exist for predicting someone's next location, none predict farther out into the future. My algorithms hope to answer the questions, "Where will you be at a certain time?" and "When will you be at a given location?"

Location is an excellent indication of context. Context-aware applications can proactively provide needed information. One example is the Global Positioning System (GPS) in your car. Because it knows your location, your context, it can immediately attempt to correct you when you stray from the expected path.

In this research, I use IEEE 802.11 wireless access points as reference beacons to determine location[1]. On campus, any wireless device can sense several wireless access points at any given time. It associates, that is, connects to, the one with the strongest signal, which is in most cases an access point that is close geographically. Therefore, if I know your device is associated with a wireless access point that is located in a known location, I can assume that you are located in the same area.

It can be difficult to obtain location data using mobile devices. Turning on the wireless radio in a laptop or Personal Digital Assistant (PDA) uses energy. To increase the battery's life, the wireless radio is left off until it is necessary to associate with an access point to communicate. The location data obtained by access point associations can therefore be spotty and intermittent. Any location prediction algorithm must be able to work with sparse data.

There are advantages of using 802.11 access points for determining location. On college campuses and most populated areas, wireless access points are ubiquitous. Our landscape is covered in location beacons. Unlike GPS, wireless access point location systems work both indoors and outdoors. Because many mobile devices have IEEE 802.11 support built-in, no special equipment needs to be purchased, making this location system inexpensive.

Recall that my first goal is to predict future locations. Many algorithms have been proposed for predicting the **next** location when given a sequence of previous locations [2-7]. These algorithms assume that only one type of information is encoded in the sequence -- in this case, locations. My goal is to incorporate temporal information into these sequences so that we can answer questions about future locations, not just the next location.

Begleiter[8] applied a family of variable order Markov models to predict the identity of a musical selection, building a type of 'name that tune' algorithm. The musical notation that was input into the model contained notes, their starting times and durations. Due to the success of his musical predictor, I concluded that I could apply the same predictor to my sequences which had a similar structure. Where the musical notation had notes, their starting times and their

## Predicting Future Locations

---

duration, my location sequences had locations, starting times at that location and the duration of the stay at that location.

These variable-order Markov models are classified as supervised learning. They 'learn' the correct answers by being given several examples with both the question and the correct answer. Unsupervised learning models 'learn' as they go. Supervised learning models are trained on a portion of the data and the remaining data are used to test the model to see how well it learned.

My data came from the University of California, San Diego. Dr. McNett handed out PDAs to 275 freshman in the fall of 2002 [9]. Each PDA ran a program in the background that, every 20 seconds, recorded the wireless access points that were both sensed and associated. I then pre-processed these logs to derive sequences of times and locations. Ten weeks of log data were collected from the 275 students. Times on the data were rounded down to the closest 10-minute value.

I trained the model on 5 weeks of data and then tested the predictions by asking about the sixth week of data. For each (time, location) pair in the testing data, the time was given as context, and the model was asked to predict the place. The results were very encouraging, with the model able to predict the correct location 93% of the time [10]. If the context given to the model included the preceding time and location as well as the time in question, the predictions were correct 96% of the time.

The second part of my goal is to ask the converse question. Instead of asking questions about *where* someone will be, like "Where is Bob at 1:00?" I want to ask questions such as, "When will Bob be at the office next?" Initially, I thought that the same model would work just as well at answering the *when* question as it did the *where* question. The same model was used in the same manner and the results were dismal, with the model able to predict the time correctly only 13% of the time.

In order to answer the *when* question, I am developing a different, simpler model that yields better results. I have been able to correctly predict *when* 38% of the time. If a 20-minute window is allowed for the correct prediction, the prediction rate rises to 66% correct.

The ultimate goal of this research is a simple but powerful algorithm that predicts future locations and predicts when the user will be at those locations. This predictor can be used as the foundation for useful applications such as reminder systems, systems that assist people, and applications which enable people to meet with their friends and associates. It is my hope that this research contributes to the advance of useful context-aware, pervasive computing applications.

# Predicting Future Locations

---

## REFERENCES

- [1] A. LaMarca, *et al.*, "Place Lab: Device Positioning Using Radio Beacons in the Wild.," presented at the Pervasive 2005, Munich, Germany, 2005.
- [2] S. K. Das, *et al.*, "The role of prediction algorithms in the MavHome smart home architecture," *IEEE Wireless Communications*, vol. 9, pp. 77-84, 2002.
- [3] D. Ashbrook and T. Starner, "Learning significant locations and predicting user movement with GPS," presented at the Sixth International Symposium on Wearable Computers, 2002.
- [4] A. Bhattacharya and S. K. Das, "LeZi-update: an information-theoretic approach to track mobile users in PCS networks," presented at the 5th annual ACM/IEEE international conference on Mobile computing and networking, Seattle, Washington, United States, 1999.
- [5] R. Chellapa, *et al.*, "A comparative study of mobility prediction in fixed wireless networks and mobile ad hoc networks," in *IEEE International Conference on Communications (ICC '03)* 2003, pp. 891-895 vol.2.
- [6] C. Cheng, *et al.*, "Location prediction algorithms for mobile wireless systems," in *Wireless internet handbook: technologies, standards, and application*, ed: CRC Press, Inc., 2003, pp. 245-263.
- [7] J. Ghosh, *et al.*, "On profiling mobility and predicting locations of wireless users," presented at the Second international workshop on Multi-hop ad hoc networks: from theory to reality, Florence, Italy, 2006.
- [8] R. Begleiter, *et al.*, "On Prediction Using Variable Order Markov Models," *Journal of Artificial Intelligence Research*, vol. 22, pp. 385-421, 2004.
- [9] M. McNett and G. M. Voelker. UCSD Wireless Topology Discovery Trace [Online]. Available: <http://sysnet.ucsd.edu/wtd/>
- [10] I. Burbey and T. L. Martin, "Predicting future locations using prediction-by-partial-match," presented at the Proceedings of the first ACM international workshop on Mobile entity localization and tracking in GPS-less environments, San Francisco, California, USA, 2008.