PART 02 Sensing Everyday Places and Paths

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Overview
As mobile devices have become capable of locating themselves almost all the time, a variety of mobile applications have emerged that seek to continuously track a user's location context. For instance, geo-reminders allow us to set and receive a to-do list whenever we enter or leave a particular place. Social applications plan to provide services for seamlessly sharing whereabouts, querying users that are presently located at an art gallery, and inferring hotspots by the frequency of physical visits by users. Tracks generated by humans also provide useful information for map building, traffic estimation, and ride sharing. Moreover, automatically detected visit and travel behaviors can help studies of human spatial and temporal behavior, and support research for urban planning, sustainability, epidemics, and health care. Interestingly, all these applications can benefit from continuously understanding and keeping track of location as people normally do: places and paths. By automatically learning the places that one visits throughout one's daily life, noticing when one enters and leaves these places, and remembering paths one travels between them, we can unleash many interesting applications.

Approach
The key challenges we face to provide such service are 1) accurately detecting places closer to our semantics, 2) automatically parsing travel paths from day-long location traces, and 3) minimizing energy consumption. We overcome these challenges by designing a robust place detection algorithm, a sensitive movement detector, and an on-demand path tracker. A place detection algorithm attempts to automatically find places (colloquial representations of locations such as “my office” or “5th floor cafe”) that carries a semantic meaning to an individual user. Semantic places are directly inferred from pervasive radio signals by periodically scanning neighboring beacons. To reduce energy consumed during a stay at a place, scans are suspended while a movement detector detects no movement from a more energy-efficient inertial sensor. A path is defined as a set of time series coordinates that interconnects places. Paths are tracked by acquiring periodic position fixes from position systems only when traveling between places.

System(s) Description and/or Experiments
As SensLoc runs in the background of the mobile device, places are gradually learned as a user visits them and spends a substantial amount of time. A new place is learned by saving its place signature whenever a visit to an unknown place is detected, and sometime later in the day asking the user to confirm and tag a name, such as “home”, “Fred's office”, or “Organic foods @westwood”. A user can recall the place by looking at the visit time, presented as enter and leave time, and the associated geographic coordinate, plotted on a map, provided as a hint. Revisited places are recognized using previously saved place signatures. Entrance to and departure from selected places are notified to applications requesting the place detection service. When a user leaves a place, path tracking (if enabled) is initiated until the user arrives at another place. Any positioning system available on the device can be used including GPS or systems supported by energy-efficient mechanisms to track paths. If path recording is requested, paths are saved, and provided to various applications requesting the service. Unrecorded path tracking can also provide real-time current positions to navigation and location-based search applications with minimum delay by periodically updating the user's current position. This is also when real-time positions are most likely used (e.g., when I'm mobile), and quick responses are most appreciated (e.g., when I'm lost).

Figure 1 presents the overall architecture of SensLoc. The system consists of three main building blocks to provide its service while reducing its energy requirements: place detector, movement detector, and path tracker. The place detector regularly scans neighboring radio beacons to detect place visits when the radio environment stabilizes indicating an entrance. Once an entrance is determined, the place detector consults with the place database to recognize the place and triggers the movement detector to find opportunities to sleep. If no movement is detected, the movement detector signals the place detector to sleep, and awakens it when a movement is detected again. When the place detector senses that the surrounding radio environment is changing, it declares a place departure, saves the visit history, turns off the movement detector, and powers on the path tracker. Path tracking is initiated and records the path to the path database (if enabled) until the next place visit. Path tracker can also hint the place detector to sleep when the user is traveling at high speeds, and unlikely to approach a place anytime soon. We use Wi-Fi access points (APs) to sense places, accelerometer to detect movements, and GPS to track paths.
To evaluate our framework, we gathered three different data sets from both real-life and scripted-tours. Five individuals collected data for a week and two people for four weeks as they went about their normal lives. A scripted-tour data set comprised of 50 visits to 25 different places people go often near a campus. Each volunteer also kept a written diary of places they visited with enter and exit times. Using these data sets, we evaluate SensLoc's effectiveness in detecting place visits, tracking travel paths, and its overall energy consumption during a daily operation. While the performance and cost indeed depends on a user's surrounding and travel patterns, we show that SensLoc consistently outperforms previous place learning techniques, promptly tracks paths, and saves significant energy.

Accomplishments
Our results show that SensLoc can both semantically and energy-efficiently provide location context to applications by using a combination of acceleration, Wi-Fi, and GPS sensors to find semantic places, detect user movements, and track travel paths. Place visits and path travels are inferred from raw sensor data, which is energy-efficiently achieved by leveraging our tendency to spend about 90% of the time indoors and 10% in a vehicle or at outdoors. Precision and recall of detecting semantic places are both improved compared to the previous state-of-the-art PlaceSense [1] approach by additionally exploiting signal strength changes of the surrounding beacons and adapting parameters to the neighboring beacon density. The accuracy gains are particularly noticeable when a user's routine includes back-to-back visits to nearby indoor places (e.g., rooms on different floors) that shares even a single strong beacon. SensLoc's enhanced place detection algorithm also improves the detected place entrance and departure times by over 2.3 times the precision of previous approaches. However, at some places where beacon signals are weak and unstable, PlaceSense, which only considers the presence of beacons, detects places more robustly. Path tracking is only initiated when a user is traveling between places, which allows us to achieve highly efficient duty cycling of positioning systems (e.g., GPS 8.3% active time), and still covers 95% of the travel distance. This not only saves energy but also boosts the overall quality of the collected position estimates. Lastly, the average power consumption of SensLoc is about 54.8 mW, which is 6.2 times less than that of collecting GPS periodically. On average, accelerometer, Wi-Fi, and GPS are activated for about 20-22, 2-4, and 1-2 hours everyday, respectively.

Future Directions
We believe we have solved some of the major practicality issues with continuous location tracking, and illustrated that an approach with a holistic and semantic point of view may provide a realistic solution for many applications. Our results also suggest that there is still more room for improvement to push the place detection performance even further. Adaptive approaches intermixing several place learning techniques based on the radio environment and the application needs may allow us to cover the remaining 5% places that are challenging. Using more energy-efficient sensors may also reduce the energy cost. For example, cell tower information, which almost comes for free, can replace Wi-Fi scans, if mobile service providers become less reluctant in disclosing cell tower information and more platforms provide common APIs to scan every neighboring cell towers. However, we think most research should focus on developing an application stack with a well-defined set of APIs, and create a feedback loop with the users that could tell us what is really important to address. The outcome of these field studies will expose application demands and provide nuances to tune the system for particular uses or situations.