Location Prediction

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Learning Objectives

- Know why location prediction is important
- Understand basics of human movement
- Creation of data set as basis for prediction
- Understand techniques for location prediction
- Realize simple prediction-based application
Context-Aware Applications

- Applications that adapt to *context*
- Context includes:
  - User behavior
    - Where the user goes
    - What the user does
  - Environment
    - Available connectivity
    - Charging opportunities
    - Location

Observations:
- Location links facts
- Predicting location ⇒ predicting future context
Context-Aware Applications

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- Context includes:
  - User behavior
    - Where the user goes
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  - Environment
    - Available connectivity
    - Charging opportunities
    - Location
- Observations:
  - *Location* links facts
  - Predicting location $\Rightarrow$ predicting future context
Example Use of Context Prediction

- Automatically turn heater on when user heads home
- Predict presence of friends nearby
- Vary QoS according to future energy availability
- Prefetching messages or alerts / delaying uploads
Prefetching

- Potential benefits:
  - Saves energy
  - Conserves data allowance
  - Reduces network congestion
  - Reduces latency
  - Hides spotty network coverage
  - Reduces dependency on centralized infrastructure


Prefetching

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- More than nice to have: potential emergent behavior
  - Reducing latency changes how people interact with programs\(^1\)
  - Users conservative about energy and bandwidth use\(^2\)

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Location for Context-aware Applications

- Requirements
  - Current *place* (home, work, etc.)
  - Geographic coordinates not always required
    - potential for increased privacy / energy savings
Location for Context-aware Applications

- **Requirements**
  - Current *place* (home, work, etc.)
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- **GPS**
  - Energy intense
  - No indoor coverage
  - Urban canyons

- **Cell towers as landmarks**
  - Available for “free”
  - Requires *cleaning*
    - Tower transitions when stationary
Overview

- Main location ("home") appears as a black line (bottom)
- Regular activities appear as dotted lines
- 4 trips - minor regime changes
  - Week 3 & week 11 to same location
  - Similar route, but note newly discovered towers
  - Week 7/8 & Week 15 trips probably with plane
“home” at night (except second Wed. night)

At “work” during the day

Path to and from “work” is similar, but see new towers

“activity” Monday evenings
Induced Cell Tower Network on a Single Day

- 3 major areas of activity
- Device connects to multiple towers in each area; many transitions
  - Device samples nearby cells
  - Core & periphery towers
- Effect more pronounced with more data

“Activity” (1 h) 

“Work” (9 h)

“Home” (9 h)
Tower Sampling Experiment

- Is the device really stationary during some transitions?

- # Towers seen during each **wall charge** (> 30 min.)
  - 6289 wall charges across all traces
  - Median: 2 (MAD: 1.48)
  - Upper quartile: 4
Tower Sampling is Real

- Locations not covered by a single tower
- Phone appears to sample towers in its vicinity

Conclusions
- Cell tower data higher resolution than places
- Tower transitions do not correspond to user movement
- Need to aggregate towers to identify:
  - Landmarks
  - User movement
Time Spent at Each Tower (1/2)

- CCDF plots of the total time spent at a tower (by user)
- 44 of the fits (75%) are significant fits to a power law

Users may visits thousands of towers, but spend nearly all of their time at a few locations
Time Spent at Each Tower (2/2)

- CDF of time at top towers
- Top few towers dominate
Approaches for mapping Tower $\rightarrow$ Place

- Collapse oscillation sequences
  - Relatively simple heuristic
- Place detection
Place Detection

Observation:
- Places automatically carved out via user movement
- Places are islands of high dwell time
Related Work (1/2): Geography

- Scellato et al., Kim et al.
  - Place a 2-D Gaussian at each GPS sample & normalize
  - Islands above a threshold (15% of max) $\Rightarrow$ place
  - Recall:
    - Tower dwell time consistent with a power law
    $\Rightarrow$ 15% will only identify 1–3 places!
Related Work (2/2): Network Theory

- Eagle et al.
  - Community detection
    - Partition graph such that the number of edges between subgraphs is lower than expected
  - Makes places too large (include routes)
  - Computationally expensive and thus can only be run offline
A Good Strategy

- Identify graph structures that are typical of places:
  - Primary characteristic: High density subgraphs
  - Look for cliques, size $\geq 4$
When to Run

Look for new subgraphs *whenever* there is a new edge

- Only need to look near the edge

⇒ fast

⇒ appropriate for online use
Naming

- When merging, use longest used name
  - Example: \(a: 3 \text{ h}, b: 4 \text{ h} \implies b\)
  - But, if tower \(b\) called \(b\) for 0.5 h and \(x\) for 3.5 h, then use \(x\)
- Overlapping clusters usually share a name
- Example: 5-clique missing 1 edge \(\implies\) two 4-cliques

\[
\begin{array}{c}
\text{c} \\
\text{d} \\
\text{e} \\
\end{array}
\begin{array}{c}
\text{b} \\
\text{a} \\
\end{array}
\]
Project

You implemented an (background) App that:

- Frequently records user’s location\(^3\)
- Location method is up to you (Cell tower, WLAN, GPS, multiple)
- Possibly record auxiliary data (power status, usage, etc.)
- Exported data via CSV, MQTT or HTTP
- Imported GPS locations into GIS database

You should have 2-3 week mobility data by now!

Now implement tools to (if applicable):

- Convert CSV to (graphviz/dot) transition graph
- Cluster cell towers into locations
- Compute location dwell time statistics

\(^3\)Ideally, batch write to disk to save battery!
Location Prediction: Related Work Overview

- Most work focused on predicting *next* tower
  - Relevant to network management
  - Approaches:
    - Markov chain (François et al., Song et al.)
    - Graphical models (Eagle et al.)
    - LZ-based predictor (Song et al.)

- Location in $x$ hours:
  - Non-linear time series (NextPlace, Scellato et al.)
  - Recognize routes (Laasonen)
  - $P(\text{place}|\text{tod})$ (Burbey and Martin)
    - Simple scheme
    - Extensions by Walfield et al. work best
      $\Rightarrow$ We will focus on this scheme
Simple Idea

- Solve: \( \arg\max_{t \in T} P(t|c) \)
  - \( t \): tower aggregate
  - \( c \): a set of conditions

Why \( \arg\max \)?
- Simplicity of evaluation
- NextPlace does it
- Easily modified to return rank or whole CPT, if appropriate
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Evaluation

- Every half hour, make a series of predictions
- Predictions for 0.5 h, 1.5 h, ..., 23.5 hours in the future
- Prediction correct if predicted aggregate visited within $\pm 15$ min of prediction time

- Only attempt a prediction if $c$ has $\geq 2$ h of data
- Larger reduces attempts
- Too large ($\geq 8$ h) also reduces precision
- Rarely visited locations apparently highly predictive
  - e.g., after shopping, user goes home
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Baseline 1/2

Unconditional predictor
- Current dominant aggregate
- Probably where user usually sleeps

Results consistent with power law behavior
Note: x axis is prediction offset, not time of day

Current tower predictor

Strong tendency to stay at a location for at least half an hour

Increase for $\Delta > 17h \implies$ diurnal behavior
Time of Day

\[
\langle h \rangle: \text{Correct } \frac{1}{2} = 0.704 \ (\text{MAD: 0.244}); \overline{\text{Attempts}} = 0.999
\]

- **Idea:** daily routines
- **Condition on current hour or half hour**
  - Both perform similarly
  - We prefer hour due to smaller CPT
Time of Day and Day of Week

$\langle h, d \rangle$: Correct $1/2 = 0.667$ (MAD: 0.294); Attempts = 0.705

- Reduction in performance! (66.7% vs. 70.4% for $\langle h \rangle$)
- Low number of attempts (70.5%)
- Just considering long traces (at least 16 weeks):
  - Score: 74.1%
  - Attempts: 95.8%

$\Rightarrow$ data too spread out!
Time of Day and Work Day

\[ \langle h, w \rangle \text{ (west) : Correct } \frac{1}{2} = 0.728 \text{ (MAD: 0.211); Attempts } = 0.983 \]

- Just distinguish between workdays and days of rest
- Increase in performance (72.8% vs. 70.4% for \( \langle h \rangle \))
- High portion of attempts
Time of Day and Work Day

- Just distinguish between workdays and days of rest
- Increase in performance (72.8% vs. 70.4% for $\langle h \rangle$)
- High portion of attempts
- Also tried country-specific days of rest, same performance
- Perhaps bias?
- Ideally learn workdays from data

$\langle h, w \rangle$ (west): Correct $1/2 = 0.728$ (MAD: 0.211); Attempts $= 0.983$
Regimes

- Weak location-dependent predictor
- Regime classification
  0 Dominant tower over past 24 hours
  1 Current tower’s primary regime \((\text{argmax } P(r|t))\)
## Regime-based Predictor

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Correct Attempts</th>
<th>Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\langle h, w \rangle)</td>
<td>72.8%</td>
<td>98.3%</td>
</tr>
<tr>
<td>(\langle r, h \rangle)</td>
<td>77.6%</td>
<td>91.7%</td>
</tr>
<tr>
<td>(\langle r, h, d \rangle)</td>
<td>76.7%</td>
<td>55.8%</td>
</tr>
<tr>
<td>(\langle r, h, w \rangle)</td>
<td>81.1%</td>
<td>86.9%</td>
</tr>
</tbody>
</table>

- **Significant improvement in correct attempts**
- **Trade-off: Fewer attempts**
Current Tower Aggregate-based Predictor

- Strong location-dependent predictor
- Note:
  - $\langle c \rangle$ is the current tower predictor (our baseline)
  - Need a temporal reference, e.g., the prediction offset ($\Delta$)
## Evaluation

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</tr>
<tr>
<td>$\langle h, \Delta, c \rangle$</td>
<td>81.3%</td>
<td>73.8%</td>
</tr>
<tr>
<td>$\langle h, d, \Delta, c \rangle$</td>
<td>81.4%</td>
<td>38.2%</td>
</tr>
<tr>
<td>$\langle h, w, \Delta, c \rangle$</td>
<td>83.0%</td>
<td>66.1%</td>
</tr>
</tbody>
</table>

- Slight improvement in correct attempts
- Tradeoff: significant decrease in portion of attempts
Aging

- Idea: Adapt to changes in behavior
- Approaches:
  1. Keep last $x$ days of data
  2. Keep last $x$ days per *primary* condition
     - Idea: behavior at secondary regimes likely stable
     - Example: parents’ or remote office visited every few months
Aging Evaluation

- Used approach 2
- Tried different amounts of aging
  - 1, 2, 3, 4, 6 weeks

Results:

- Aging $\langle h \rangle$: 1 week improved precision from 70.4% to 75%
- Aging $r$-based predictors: status quo for 3–4 weeks
- Aging $c$-based predictors: status quo for 3–4 weeks

Conclusion:

- Conditioning on $r$ or $c$ already captures dynamic behavior

Recommendation:

- 3–4 weeks of aging to reduce amount of data stored
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Combining Predictors

- If a predictor doesn’t have enough data, fallback to another
- Prefer high precision predictors
- Results:
  - > 99% attempts
  - $\langle r, h, w \rangle, \langle r, h \rangle, \langle r \rangle$: 80% correct
  - $\langle h, w, c, \Delta \rangle, \langle h, c, \Delta \rangle, \langle r, h, w \rangle, \langle r, h \rangle, \langle r \rangle$: 79% correct
Combining Predictors

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- Prefer high precision predictors
- Results:
  - > 99% attempts
  - \( \langle r, h, w \rangle, \langle r, h \rangle, \langle r \rangle \): 80% correct
  - \( \langle h, w, c, \Delta \rangle, \langle h, c, \Delta \rangle, \langle r, h, w \rangle, \langle r, h \rangle, \langle r \rangle \): 79% correct
- Per prediction offset-based predictors:
  - 0.5\(h\): Current tower aggregate baseline (93%)
  - 1.5\(h\) – 2.5\(h\): Current tower-aggregate based (80% – 85%)
  - > 2.5\(h\): Regime-based (78% – 80%)
  - Result (24\(h\)): 82%
Project

1. Design high-level location prediction API
2. Implement baseline predictor
3. Implement current tower-aggregate predictor ($1 - 2.5h$)
4. Use prediction to:
   - Enable/disable home heating (project!)
   - Prefetch weather data (going to Bern or skiing?)
   - Disable GSM/WLAN ("user rarely uses it on the train")
   - Make suggestions for when to schedule appointments
   - ...
API Design Hints

- Start by defining “Location” abstraction
- Input for location prediction is time in future
- Plan for “no prediction” as possible answer!
- Output may include level of uncertainty or multi-set with probabilities

Your final design will likely depend on your method to record locations and your application!
Exam reminder

1. Submit your code ≈ 1 week before the oral exams
2. In that case, you will be asked questions about the project:
   ▶ What your project does (explain to co-examiners!)
   ▶ Examination on how it works in depth
   ▶ Critical discussion based on my code review prior to the exam
3. Otherwise, any theory that was taught is fair game
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