Multi-transportation-mode Path Inference Filter MPIF

F. Belletti

UC Berkeley

Outline

HMM models and inference

- Problem formulation
- Single mode path inference
- Multi-mode extension

Presenting the problem

Problem formulation

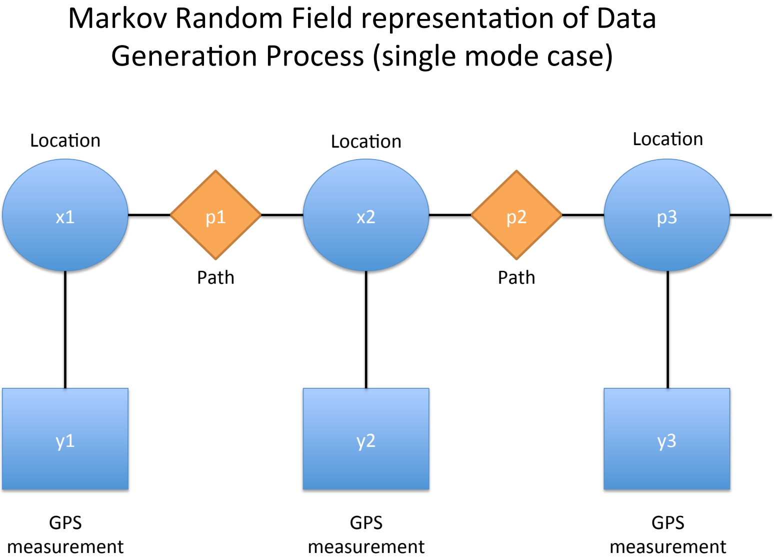
- An agent moves on a map
- We observe noisy GPS measurements
- We want to infer:
  - The agent's exact locations
  - The agent's transportation mode
- We want to estimate:
  - The agent's transportation mode preference
  - The agent's travel time utility function

Single mode path inference

- User's actual locations: $(x_t)_{t=1:T}$
- User's observed locations: $(y_t)_{t=1:T}$
- User's actual path: $(p_t)_{t=1:T-1}$

Data generation structure in the single mode case

Single mode path inference



Path inference (1/3)

Single mode path inference

- Each GPS measurement is projected onto the transportation network on the L_{max} closest links
  - $y_t \rightarrow \begin{bmatrix} x_t^1 \\ x_t^2 \\ \vdots \\ x_t^{L_{max}} \end{bmatrix}$
  - Assume gaussian noise, potential of x_t^i is $GPS\left(x_t^i\right) = exp\left(-\frac{\left(y_t - x_t^i\right)^2}{2\sigma^2}\right)$
- For each couple $\left(x_t^i, x_t^j\right)$, compute all possible paths given the maximum speed threshold
  - Modified version of Yen's algorithm based on modified A^*

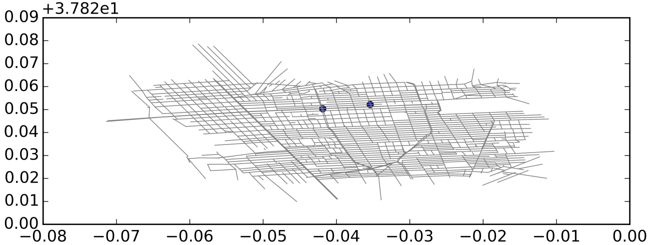
Path inference (2/3)

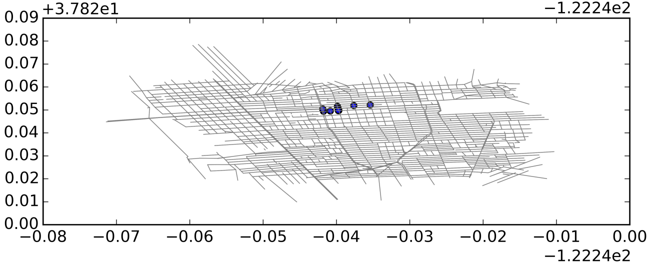
Single mode path inference

- For each path $p_t^{i,j,k}$, compute path's potential:
  - $U\left(p_t^{i,j,k}\right) = exp\left(-\theta^T feat\left(p_t^{i,j,k}\right)\right)$
- For now, $feat\left(p_t^{i,j,k}\right) =$ Travel time approximated by Avg speed $\times$ Length
  - Other features can be added such as number of traffic lights on the path etc.
- σ, θ need parameter tuning

Threshold path finding

Single mode path inference





Path inference (3/3)

Single mode path inference

- Location marginal potential $\overline{q}_t^i \propto \pi\left(x_t^i \mid y_{1:T}\right)$, path marginal potential $\overline{r}_t^i \propto \pi\left(p_t^j \mid y_{1:T}\right)$
- Forward probabilities: $\overrightarrow{q}_t^i \propto \pi\left(x_t^i \mid y_{1:t}\right)$, $\overrightarrow{r}_t^j \propto \pi\left(p_t^j \mid y_{1:t}\right)$
  - Viterbi: $\overrightarrow{q}_1^i \propto \pi\left(x_1^i \mid y_1\right) = GPS\left(x_1^i\right)$, $\overrightarrow{r}_t^j = U\left(p_t^j\right) \overrightarrow{q}_t^{\text{origin}(j)}$, $\overrightarrow{q}_t^i \propto GPS\left(x_t^i \mid y_t\right) \sum_{j:i=\text{dest}(j)} \overrightarrow{r}_{t-1}^j$
- Backward probabilities: $\overleftarrow{q}_t^i \propto \pi\left(x_t^i \mid y_{t+1:T}\right)$, $\overleftarrow{r}_t^i \propto \pi\left(p_t^j \mid y_{t+1:T}\right)$
  - Viterbi: backward with $\overleftarrow{q}_T^i = 1$
- Marginals: $\overline{q}_t^i = \overrightarrow{q}_t^i \times \overleftarrow{q}_t^i$
- Normalize potentials

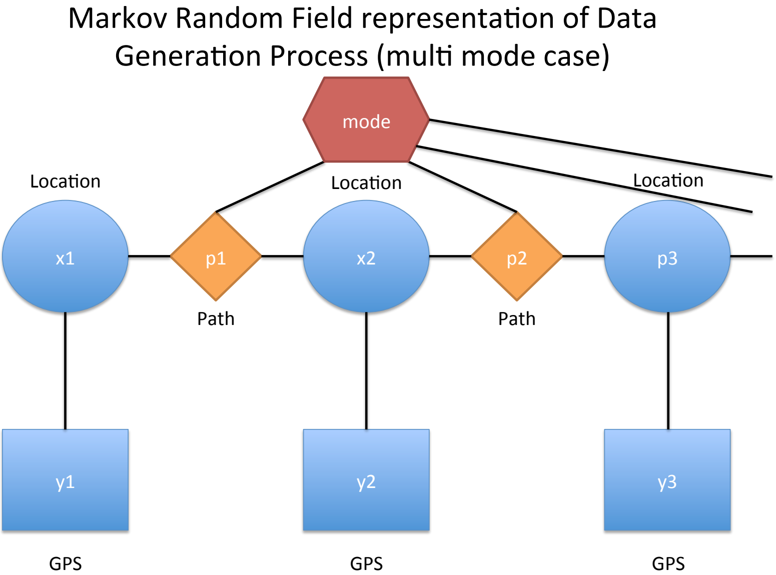
Multi mode path inference

Single mode path inference

- User's actual locations: $(x_t)_{t=1:T}$
- User's observed locations: $(y_t)_{t=1:T}$
- User's actual path: $(p_t)_{t=1:T-1}$
- User's actual mode: m, similar throughout the path

Data generation structure in the single mode case

Single mode path inference



Multi mode path inference (1/3)

Single mode path inference

- Each GPS measurement is projected onto **the corresponding transportation network** on the L_{max} closest links
  - $y_t \rightarrow \begin{bmatrix} x_t^{1,m_1} & x_t^{1,m_2} & \cdots & x_t^{1,m_N} \\ x_t^{2,m_1} & x_t^{2,m_2} & \cdots & x_t^{2,m_N} \\ \vdots & \vdots & \cdots & \vdots \\ x_t^{L_{max},m_1} & x_t^{L_{max},m_2} & \cdots & x_t^{L_{max},m_N} \end{bmatrix}$, (stack the states and modes)
- For each couple $\left(x_t^i, x_t^j\right)$, **each transportation network**, compute all possible paths given the **corresponding maximum speed** threshold

Path inference (2/3)

Single mode path inference

- For each path, each mode p_t^{i,j,k,m_n}, compute path's potential:
  - $U\left(p_t^{i,j,k,m_n}\right) = exp\left(-\theta^T feat\left(p_t^{i,j,k,m_n}, m_n\right)\right)$
- For now, $feat\left(p_t^{i,j,k}, m_n\right)$ takes into mode specific features:
  - Avoiding hills when biking
  - Avoiding traffic lights when driving

Path inference (3/3)

Single mode path inference

- Run the same forward and backward procedures for each mode separately
- For a given mode, potential $= \sum_i \overline{q}_t^i$ (any t)
- Multiply each mode potential by the mode prior preference: $\text{pref}\,(m_n)$
- Normalize potentials

Thank you for your attention!

- References:
  - A Tutorial on Hidden Markov Models and Selected Applications in Speech Recognition, L. R. Rabiner, 1989
  - The path inference filter: model-based low-latency map matching of probe vehicle data, Timothy Hunter, Pieter Abbeel, and Alexandre Bayen, 2012
- Code available on my github repo:
  - bellettif
- Any questions?