Contents

1 Master Thesis

1.1 Startup meeting with Heintz

<2019-01-07 mån>

1.1.1 Initial project- Arrival time prediction with a motion pattern model using GPs

- A working implementation exists from this years TDDE19
- Compare with vector field (position -> velocity), LSTM (from TDDE19)

1.1.2 Areas of improvement from TDDE19

- Sparse GPs

- Synchronisation. Interpolate posterior mean functions, cluster.
- Data augmentation
- Start and stop boundaries
- Multiple stop prediction
- Time table feature

1.1.3 Notes

Heintz had some ideas on interesting problems.

1. Superimposing effects The idea is in isolation train a nominal trajectory, one for rush hour, on for normal traffics, etc. And in some way superimpose the effects, letting us ask questions like "what if we drive this way instead?" or "what if it was winter?".
2. Knowledge extraction Predicting arrival time is fine, but not novel enough. Fortunately, the GP model offers plenty of insight in the data generating process.
   (a) Worst/best scenarios If the model was extended to work for multiple future stops it could give an estimate of the earliest known arrival time, and the latest known.
   (b) Pattern extraction It would be interesting to extract patterns from the data, both spatially and temporally. For instance: stop lights, traffic jams, average speed (?), speed change. During what circumstances does the predictions have highest variance?

1.1.4 Post meeting talk

Some ideas that felt reasonable after talking to Tiger after the meeting with Heintz.

- Extract events using kernels/convolution over motion patterns
- Extending the application to multiple future stops
- Comparing predictive distribution to the actual arrival times, and the predictions of LSTM/vector field model

1.2 Literature

1.2.1 Related work

1.3 Things to do

1.3.1 TODO Download pdfs of all papers and put them in shared documents

1.3.2 DONE Mail Heintz and Tiger about TP meeting jan 18

1.3.3 DONE Figure out what the heck to do

Talk to Mattias about this. Motivate what value this brings. What is novel about it?

1.3.4 TODO Conduct thorough literature study

- ☐ On the domain, motivate why the problem is interesting question This is currently motivated with a non-peer reviewed article on the importance on
- ☐ On related work, what has been done previously See individual 1.3.5
- ☐ On the chosen solution, motivate why this is valid

1. Trajectory model GPR successfully used for trajectories [**?**]
2. Synchronisation
3. Similarity metric
4. Clustering algorithm
5. Regression model [**?**] claim GPs "a serious competitor for real supervised learning applications"

    - ☒ On the chosen solution, show how this improves on previous work Some ideas are: Explainability, find good or bad patterns/events, speed changes, stops Compared to LSTMs it comes with a posterior Outliers can be detected Best/worst case scenarios

1.3.5 Write down potential solutions on different sub-problems

1. **TODO** Comparing trajectories A distance metric, or some way or measuring closeness is needed for classical clustering algorithms. Motion patterns can be extracted from clusters.

   (a) Papers to read That paper cited by Tiger, finding motion patterns in video frames. By constructing a frame for each segment, the same ideas should be applicable [**?**]

   - Structured dynamic time warping for continuous hand trajectory gesture recognition
   - A Uniform Representation for Trajectory Learning Tasks

   (b) Suggested solutions

   i. Constructing frames and using GPs to interpolate and synchronise After synchronised, the trajectories can be compared. This is preferably done using a symmetric distance metric which can then be used for clustering. what metrics?

   ii. Dynamic Time Warping (DTW) Doesn't actually synchronise, but computes shortest warp path for two trajectories. Has time and space complexity $\mathcal{O}(NM)$ where N, \(M)\ are the lengths of the sequences.

   iii. Converting to SIT with fixed start and using sum of Euclidian distances Based on this paper. With a fixed start the trajectories should be spatially synchronised. The speed of points could be interpolated.

2. **TODO** Clustering trajectories The number of clusters are unknown. Spectral clustering can be used with a similarity metric, DBSCAN needs a proper distance metric.

   (a) Papers to read

   - Comparison of Similarity Measures for Trajectory Clustering in Outdoor Surveillance Scenes
   - Discovering similar multidimensional trajectories They present a new similarity measurement based on LCSS, which is designed to be resilient to noise. Is not a proper metric. Furthermore, they also highlight a lot of the problems with comparing trajectories.

- Understanding vehicular traffic behaviour from video Discusses several different unsupervised techniques. Trajectory based included, but also borrows ideas from topic modeling in NLP.
- [**?**]
- Learning and Classification of Trajectories in Dynamic Scenes Old stuff that used HMM. But interesting approach of fitting a Gaussian mixture model to "points of interest" (POI), which could be the start and end of a trajectory in the scope of this thesis. These POI could be used to construct frames for synchronising trajectories.

(b) Suggested solutions

i. Spectral Clustering Can be used with DTW/LCSS as descibed in [**?**]. Realistically, the evaluation would be done by hand picking trajectories and manually asserting correct behaviour.
DTW does not guarantee that the triangle inequality holds. question

ii. Inverse GP Likelihood approach The approach used in [**?**] and in the the project from this autumn. Based on having a probabilistic model for each motion pattern and classifying using maximum likelihood

3. **TODO** Creating motion patterns

4. **TODO** Classifying clusters

(a) Papers to read One of the ones Tiger sent. Go fetch

(b) Suggested solutions

- MAP with uniform cluster prior. Requires a probabilistic model. Assign to cluster k such that \[

$\_\{\mathrm{GP_k}]1\frac{}{n\sum_{\mathrm{i=i}}^{\mathrm{n}}}\ \mathrm{P}(\mathrm{GP_k}(\mathrm{x_i},\ \mathrm{y_i})\mid \mathrm{GP_k})\mathrm{P_k}\ \backslash]$

5. **TODO** Extending to multiple stops

(a) Papers to read Theory behind simple additive model using Laplace approximation [**?**]

(b) Suggested solutions

i. An additive model using Laplace approximation in posterior mode. Everything would be normally distributed and computable in closed form. The posterior arrival time of segment $k+1$ would be $AT_k + AT_{k+1}$ where AT_k and AT_{k+1} are the Laplace approximations in the mode of the posteriors for the corresponding model $\mathcal{M}$. For $\mathcal{M}_k$ the posterior is computed for the current state, and for $\mathcal{M}_{k+1}$ it is computed either for the first data point in the frame (if frames are implemented) or for the mean value for the first data point in the $k+1$ segment. This would require a model for $P(\mathcal{M}_{k+1} \mid \mathcal{M}_k)$, which could be as simple as $\mathcal{M}_{k+1} \sim Dir(\alpha_{\mathcal{M}_k})$, where $\alpha_{\mathcal{M}_k}$ is acquired by counting and normalising model transitions. This would be meaningless without proper clustering, unfortunately.

6. **TODO** Extracting events from motions patterns
   (a) Papers to read
   (b) Suggested solutions Convolution/correlation from hand-crafted event-kernels [**?**]
7. **TODO** Model evaluation
   (a) Arrival time prediction
      - Against vector field model [**?**]
      - Against TDDE19 implementation of [**?**]
      - Use metrics MAE/MAPE
   (b) Motion Pattern Clustering
      - If pattern extraction works, check if they contain same patterns?
      - ?
8. **TODO** Outlier detection

1.3.6 TODO Write thesis plan

Think in terms of a divide-and-conquer approach. What problems exist and in what order do they need to be solved?

☐ Introduction

- ☐ Related work
- ☐ Time plan

1.4 Questions

A place to quickly jot down questions so they are not forgotten.

1.4.1 For Tiger

This section contain questions for Mattias Tiger, supervisor of this thesis project.

1. Formulation to motivate novelty of project
   (a) Question It is sort of doing arrival time prediction, but also motion pattern extraction but also analysis of said motion patterns. Most papers found only prove a single point, while this project builds upon several techniques.
   What is the problem though? How should this be formulated in the thesis? Is it "Finding ways to improve public transport routes", "Learning motion pattern from trajectories", "Motion pattern analysis", "...."?.
   (b) Answer Making a competitive GP model is interesting on it's own. Further motivating this with the ways the motion patterns and predictions can be used. He also said to write more than reasonable think on applications of the models.
2. What distances are available for trajectories? Spectral clustering can be done with similarity measures that are not proper distances.

1.4.2 For Heintz

This section contain questions for Fredrik Heintz, examiner of this thesis project.

1.5 Computer SSH

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