From Mobile Phone Monitoring of Depressive States using GPS Traces Analysis to Data-Driven Behaviour Change Interventions

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Outline

• Motivation
• Our Approach
• MoodTraces Application
• Results
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Impact of Depression on Society

- In high-income countries up to 90% of people who die by suicide are affected by mental disorders (WHO Report 2014)

- Depression is the most common mental disorder associated with suicidal behavior (WHO Report 2014)

- 1 in 10 employees in the United Kingdom had taken time off at some point in their working lives because of depression problems (European Depression Association Report 2012)
Depression Diagnosis and Monitoring

• Currently, psychologists rely mainly on self-assessment questionnaires.
• Some disadvantages of this methodology:
  – time-consuming
  – expensive
  – it often relies on the patient’s recollections and self-representation, hence prone to errors
Depression Diagnosis and Monitoring

• Currently based on self-assessment questionnaires.
• Some disadvantages of this methodology:
  – time-consuming
  – expensive
  – it often relies on the patient’s recollections and self-representation, hence prone to errors

• Can we build a complementary technology to support depression diagnosis and monitoring?
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Depression Monitoring through Smartphones

- Why smartphone?
  - Pervasive
  - Highly personal
  - Equipped with many sensors

- Hence they can unobtrusively collect data, anytime and anywhere!
Depression Monitoring through Smartphones

- Why smartphone?
  - Pervasive
  - Highly personal
  - Equipped with many sensors

- Hence they can unobtrusively collect data, anytime and anywhere!

- Location data

Credits: psdgraphics.com and Wired]
• PHQ score: quantification of the depressive state
• Can the mobility trace from Feb. 21 to Feb. 28 say something about the PHQ score at Feb. 28?
Mobility Traces vs. PHQ Score

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- Can the mobility trace from Feb. 21 to Feb. 28 say something about the PHQ score at Feb. 28?
Mobility Metrics

- Mobility trace: a sequence of stops and moves
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  1) The total distance covered
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  3) The radius of gyration
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  4) The standard deviation of the displacements
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  5) The maximum distance from home
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  6) The number of different places visited
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  7) The number of different significant places visited
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  5) The maximum distance from home
  6) The number of different places visited
  7) The number of different significant places visited
  8) The routine index
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MoodTraces

- Android application collecting:
  - Location data
  - Answers to daily questionnaires
MoodTraces

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- Remarks:
  - Questionnaires are needed only to collect ground truth data for training and evaluation,
  - **No user interaction in the final system**
**Questionnaire collection process**

### Patient Health Questionnaire (PHQ-8)

<table>
<thead>
<tr>
<th>Over the last 2 weeks, how often have you been bothered by any of the following problems?</th>
<th>Nearly every day (3 points)</th>
<th>More than half the days (2 points)</th>
<th>Several days (1 point)</th>
<th>Not at all (0 points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little interest or pleasure in doing things</td>
<td></td>
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<td></td>
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<tr>
<td>Feeling down, depressed, or hopeless</td>
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<tr>
<td>Trouble falling or staying asleep, or sleeping too much</td>
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<tr>
<td>Feeling tired or having little energy</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Poor appetite or overeating</td>
<td></td>
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<tr>
<td>Feeling bad about yourself—or that you are a failure or have let yourself or your family down</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trouble concentrating on things, such as reading the newspaper or watching television</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Moving or speaking so slowly that other people could have noticed. Or being so fidgety or restless that you have been moving around a lot more than usual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PHQ-8 questionnaire:**

- 8-item questionnaire
- Frequency of the occurrence of a specific depressive symptom during the last 2 weeks
- Each question is associated with a score between 0 and 3
- PHQ score = sum of individual scores
- Cut points of 5, 10, 15 and 20 for mild, moderate, moderately severe and severe levels of depression
Collected Data

- Data collected from September 3, 2014, to June 14, 2015
- Total of 184 users installed MoodTraces, and 46 users had it running in their phones at June 14, 2015
- Final dataset includes 28 users
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Correlation

Histogram of the correlation for $T_{\text{HIST}} = 14$ days
Correlation

Histogram of the correlation for $T_{\text{HIST}} = 14$ days and $T_{\text{HOR}} = 0$ days

Histogram of the associated $p$ values
Prediction Analysis

- PHQ score is transformed into a 0-1 label
  - Label=1 if and only if the PHQ score is larger than the average PHQ score of that user plus one standard deviation

- We train and test personalized SVM classifiers and a unique SVM classifier
  - Leave-one-out cross validation approach

- Performance metrics:
  - Sensitivity (true positive rate)
  - Specificity (true negative rate)
Sensitivity and Specificity Histograms

Histograms sensitivity for different values of $T_{\text{HIST}}$ ($T_{\text{HOR}} = 0$)

- $T_{\text{HIST}} : 1$ day
- $T_{\text{HIST}} : 7$ days
- $T_{\text{HIST}} : 14$ days

![Histograms for different values of $T_{\text{HIST}}$](image)
Sensitivity and Specificity Histograms

Histograms sensitivity for different values of $T_{HIST}$ ($T_{HOR} = 0$)

- $T_{HIST}$: 1 day
  - Number of users vs. Sensitivity

- $T_{HIST}$: 7 days
  - Number of users vs. Sensitivity

- $T_{HIST}$: 14 days
  - Number of users vs. Sensitivity

Histograms specificity for different values of $T_{HIST}$ ($T_{HOR} = 0$)

- $T_{HIST}$: 1 day
  - Number of users vs. Specificity

- $T_{HIST}$: 7 days
  - Number of users vs. Specificity

- $T_{HIST}$: 14 days
  - Number of users vs. Specificity
Sensitivity and Specificity vs. History Interval

Average sensitivity and specificity vs. $T_{HIST}$ ($T_{HOR} = 0$)
Sensitivity and Specificity vs. Horizon Interval

Average sensitivity and specificity vs. $T_{HOR}$ ($T_{HIST} = 14$)
Sensing, Predicting and Influencing Human Behaviour

• Sensed information about human behaviour can be used to build models and to make predictions.
• But also it can be used to influence the behaviour of the individuals themselves.

InterruptMe

• Library for intelligent notification based on context information based on offline and online learning methods:
  – On-device and online learning process
• Possible application: behaviour intervention


Content-driven Notifications

- Not only context but also content
- Analysis of the type of applications and notifications
- Analysis of the social ties of the individual


Context-aware interventions

Real-time data mining

Sensing & user querying
Correlation Vs Causation

• Correlation vs causation problem
• It is not always possible to design experiments, so we need alternatives: quasi-experimental approaches
• We develop a new methodology for extracting causality information from sensor data

Conclusions

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- We showed that for many individuals there is a significant correlation between mobility metrics and PHQ scores.
- We showed that it is possible to develop inference algorithms to predict with a good level of confidence large PHQ score increases from mobility metrics.
Conclusions

- We developed an application to collect location data and answers to daily questionnaires.
- We derived mobility metrics from location data and computed PHQ scores from questionnaire answers.
- We showed that for many individuals there is a significant correlation between mobility metrics and PHQ scores.
- We showed that it is possible to develop inference algorithms to predict with a good level of confidence large PHQ score increases from mobility metrics.
- This pilot study shows promising initial results for the development of automatic and unobtrusive applications for depression diagnosis and monitoring.
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Questions?

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Correlation

- Averages of the absolute values of the correlations and of the p-values

<table>
<thead>
<tr>
<th>Mobility metric</th>
<th>Average abs. correlation</th>
<th>Average p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{HIST} = 1$</td>
<td>$T_{HIST} = 14$</td>
</tr>
<tr>
<td>$D_T$</td>
<td>0.159</td>
<td>0.402</td>
</tr>
<tr>
<td>$D_M$</td>
<td>0.152</td>
<td><strong>0.432</strong></td>
</tr>
<tr>
<td>$G$</td>
<td>0.160</td>
<td>0.343</td>
</tr>
<tr>
<td>$\sigma_{dis}$</td>
<td>0.147</td>
<td>0.417</td>
</tr>
<tr>
<td>$D_H$</td>
<td>0.199</td>
<td>0.358</td>
</tr>
<tr>
<td>$N_{dif}$</td>
<td>0.191</td>
<td>0.360</td>
</tr>
<tr>
<td>$N_{sig}$</td>
<td>0.201</td>
<td>0.336</td>
</tr>
<tr>
<td>$R$</td>
<td><strong>0.227</strong></td>
<td>0.368</td>
</tr>
</tbody>
</table>