

# A privacy-friendly recommender system for mobile devices

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**Abstract**—This article tries to create the ideal privacy-friendly recommender system for a mobile device. In doing so it will strive to extend the limits of the trade-off between privacy, accuracy and performance existing in recommender systems. To achieve this the solution will be based on homomorphic encryption.

**Keywords**—Privacy, mobile, recommender

## I. INTRODUCTION

TO allow personalised recommendations, recommender systems need to access privacy-sensitive data from their users. This allows the service provider to retain the data and opens the door for privacy breaches. The privacy breaches, aside from those due to a dishonest provider or a gullible user, could also be due to a lack of data protection from attackers.

There are several approaches to improve the privacy of the user. First and foremost the user could be better educated about the extent his data is kept and used. Secondly, the law could also be more strict concerning the issue. Another option is the use of privacy-friendly algorithms.

The use of the existing solutions however decreases at least either the accuracy of the recommendations or the performance of the algorithm. Considering the mobile setting, it is also important to have an approach that does not require a lot of processing time or data transmission by the client. To see how there could be created a mobile recommender system that could tackle the trade-off, research in existing privacy-friendly solutions was needed.

## II. RESEARCH IN PRIVACY-FRIENDLY RECOMMENDATION ALGORITHMS

There are multiple existing methods to increase privacy in recommender systems. These methods include methods using anonymisation, randomisation, aggregation of user profiles and cryptographic protocols. For each of these we took an indepth look in at least one example and made a comparison between them.

The solution based on anonymisation [1] makes use of agents that communicate anonymously. Even though during requests and the comparison of users' preferences the users themselves stay anonym, anonymity does not guarantee privacy as proven by Narayan [2].

The randomisation algorithm used by Polat and Du [3] does not provide full privacy either as the server can still know in what range the user rated his items, plus it loses accuracy drastically when using small datasets. However this approach does not demand a lot of work at the clientside and does not lose much accuracy.

The use of aggregation of user profiles by Shokri et al. in [4] of-

fers the users the deniability of their preferences but still shows the server their real ratings. It also has a decent accuracy.

A solution with cryptographic protocols with a peer-to-peer character [7] does reach high privacy levels but needs a social network where users are online. This method also requires too much computation on the clientside.

The best bet seems to be the solution using cryptographic protocols and two servers by Erkin et al [5]. This approach based on an earlier solution [6] delivers the best privacy and does not require a lot of computations by the clients. In this regard the cryptographic protocols in this paper were chosen to serve as a start for this solution.

## III. THE PRIVACY-FRIENDLY SOLUTION

For our solution we decided to create a native android application and the servers are made in the programming language Java. They all interact by the HTTP-protocol. As database we used the MovieLens database with 100.000 ratings, 943 users and 1682 items.

The solution in [5] uses two servers, a recommender server and a second server that is deployed by a trusted third party. The client sends his ratings and preferences to the recommender server encrypted by the public Paillier key of the second server. This does not have to take place literally every time he rates an item.

To generate a prediction score for an item, communication is needed between the Paillier and DGK cryptosystems on both servers to sum and count the encrypted ratings of like-minded users. In the original paper [5] the client just divided the two as a prediction score. The like-minded users are calculated by the known Pearson-correlation, which is partly computed by the client. For the computations on the serverside for the Pearson-correlation [5] uses complicated protocols between the two servers like a multiplication protocol and a threshold protocol.

There are several practical decisions that needed to be taken when implementing these protocols, especially on the userside. As opposed to [5] the user should not send his encrypted ratings individually. This would enable the recommender server to know he just rated an item. An option is to choose several random items and include encrypted zero-values for these. However the items could randomly all be chosen in a particular field and thus giving the service provider information. This could be avoided by choosing these items in a smart way, but this leaves values like his preferences and offsets (see later) calculated by an old mean. To have optimal privacy in our application the user sends his ratings and preferences, also called his profile, in one time, with encrypted zero values for all items that aren't rated. For this solution it is necessary that per rating there is another

bit encrypted by the user added to his profile. This encrypted bit  $q_{U_x,i}$  is 1 if the user  $x$  has rated the item  $i$  and 0 if not. This bit makes it possible to count the number of effectively rated items used in our formula (1). The encryption of the values is also best calculated the moment the user sends his profile. If the user directly encrypts after rating an item and sends his encrypted data values later, the server could see which encrypted values are changed. In the original paper [5] calculates a prediction by taking the average value of the ratings for that item from users that score a similarity value above a threshold value. However the protocols used allow an improvement by generating predictions based on a version of a formula used often in user-user collaborative filtering:

$$p_{U_1,i} = \bar{r}_{U_1} + \frac{\sum_{j=2}^n (r_{(U_j,i)} - \bar{r}_{U_j}) \cdot s_{(U_1,U_j)} \cdot q_{(U_j,i)}}{\sum_{j=2}^n s_{(U_1,U_j)} \cdot q_{(U_j,i)}} \quad (1)$$

where  $r_{(U_x,i)}$  denotes the rating value for user  $x$  for item  $i$ ,  $\bar{r}_{U_x}$  the average over all items for user  $x$  and  $p_{U_1,i}$  denotes the prediction from user 1 for item  $i$ . Here the value  $s_{(U_1,U_j)}$  stands for the bit that is calculated by the threshold protocol and this bit is 1 if the user has a similarity above the threshold value. In stead of the rating value itself, the user now sends the encrypted offset from his average  $\bar{r}_{U_1}$ . This value has to be converted to a positive integer for the use of the cryptosystems. This can happen in an easy way  $result = ((r_{(U_j,i)} - \bar{r}_{U_j}) + 5) * 1000$ . Once the sum is taken over all the similar users, the client can revert the conversion by division through 1000 and subtracting 5 per similar user.

#### IV. RESULTS

The predictions of the improved method (the light line) shows significant better scores for accuracy than the method from [5] (the dark line).

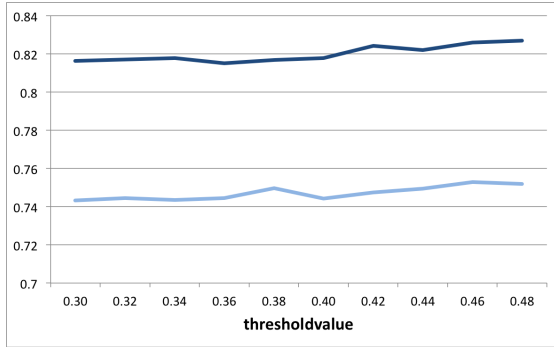


Fig. 1. MAE results over 10.000 predictions over different thresholdvalues

The MAE improved from around 0.82 to around 0.74, this is very close to the MAE of a privacy-unfriendly solution on the same database by [3] which is 0.7146. Since the privacy is improved our solution obtains very high privacy levels. The performance of encrypting the profile on our mobile device is  $O(N + S)$  with  $N$  as number of items and  $S$  as number of preferences. This contains the encryption of a userprofile and thus for each item 2 encryptions and for each preference 1. This encryption was done by our testtablet <sup>1</sup> in 1,52 seconds averaged

<sup>1</sup>Samsung Galaxy Tab4 (7.0) Wi-Fi on Android 4.4.2

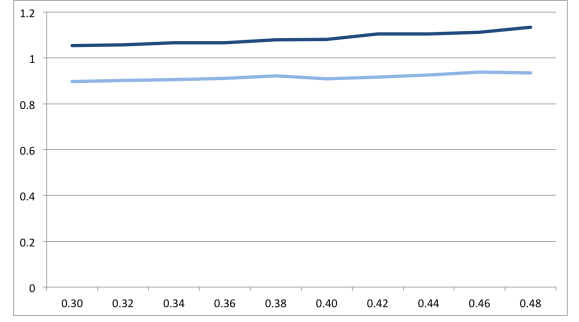


Fig. 2. MSE results over 10.000 predictions over different thresholdvalues

over 10 times. The servers engage in heavy computation, it took our testserver<sup>2</sup> 7 minutes 26 seconds to generate predictions for all 1682 items for one user, when using 30 preferences. This however can still be optimized with the use of a lower-level protocol as it was, looking back, not the best choice of using the HTTP-protocol for the communication between the two servers. Also the user could send less values to the server at once as discussed. This would have an impact on the accuracy of the algorithm but would decrease the work at the serverside and the size of its' database.

#### V. CONCLUSION

The solution provided guarantees a very high level of privacy by the use of encryption with Paillier and DGK and the fact that the server does not know which items are rated by the user. It also offers high accuracy scores without a lot of computation on the clientside. These properties make it ideal for use as a recommender for mobile devices. The servers themselves have to engage in heavy computation but this computation could be further optimized.

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<sup>2</sup>MacBook Pro 4 GB RAM 2.4 GHZ i7 processor