A Study of Heterogeneity in Recommendations for a Social Music Service

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26th September 2010, Barcelona, Spain

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The Beatles were an iconic rock group from Liverpool, England. They are frequently cited as the most commercially successful and critically acclaimed band in modern history, with innovative music, a cultural impact that helped define the 1960s and an enormous influence on music that is still felt today. Currently, The Beatles are one of the two musical acts to sell more than 1 billion records, with only Elvis Presley having been able to achieve the same feat.

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3	Let It Be	11,024
4	Help!	10,652
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7	Something	9,343
8	All You Need Is Love	9,139
9	Eleanor Rigby	8,875
10	Hey Jude	8,763
11	Yellow Submarine	8,691
12	Lucy in the Sky With Diamonds	8,624
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1st research question

Which sources of information
in social systems
are more valuable for recommendation?

Tags?

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Track listenings?

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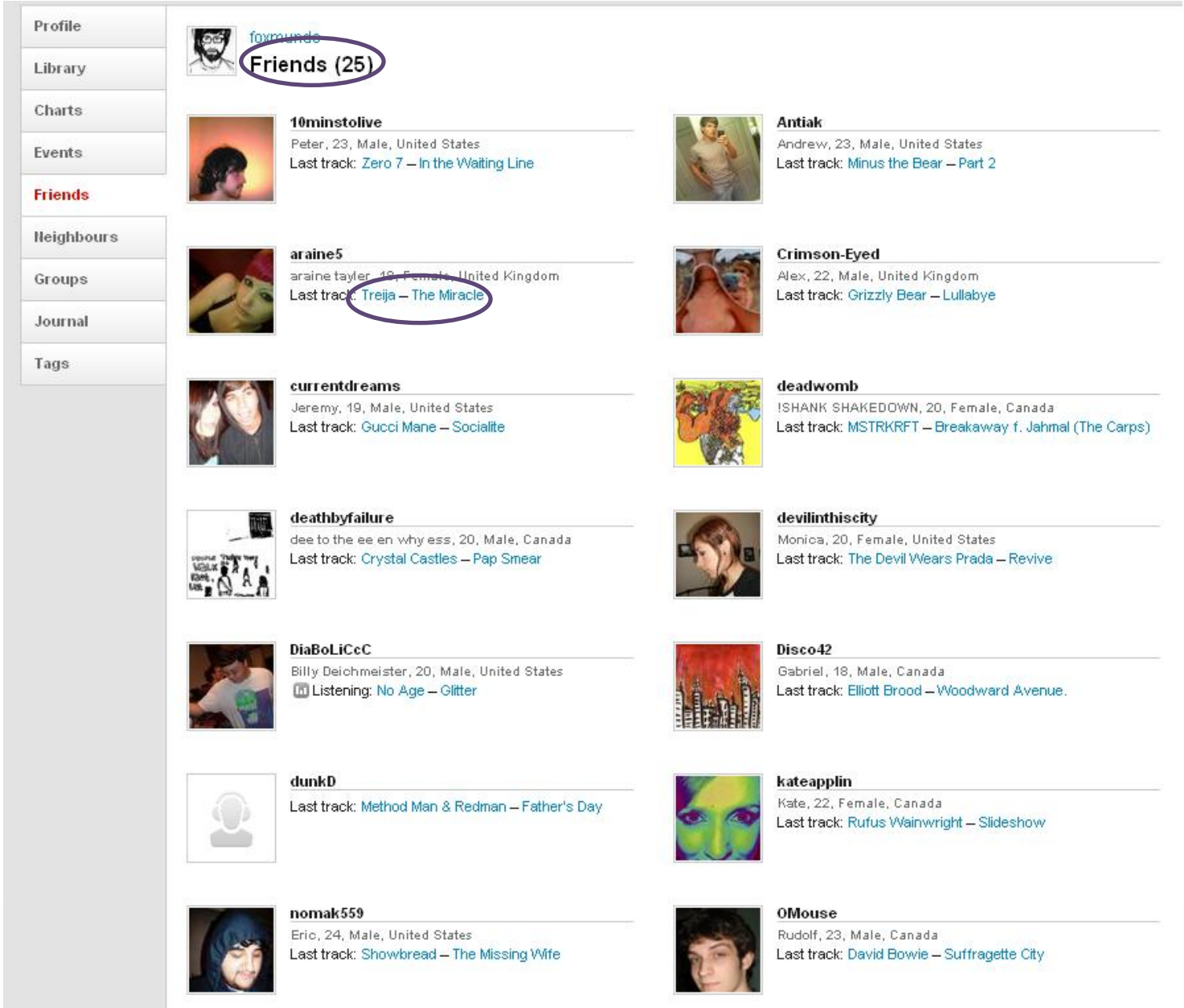
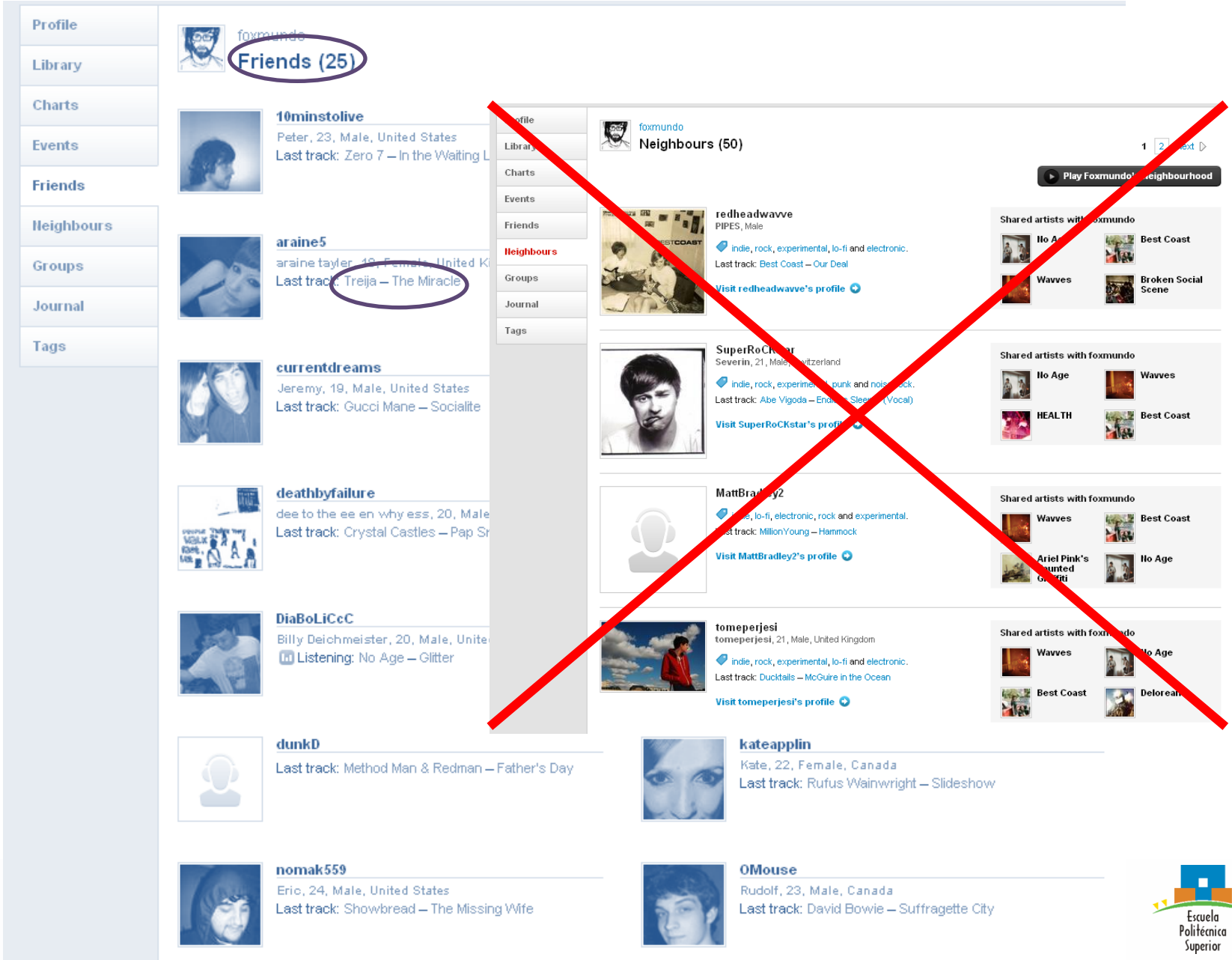
Social contacts?



Social contacts?



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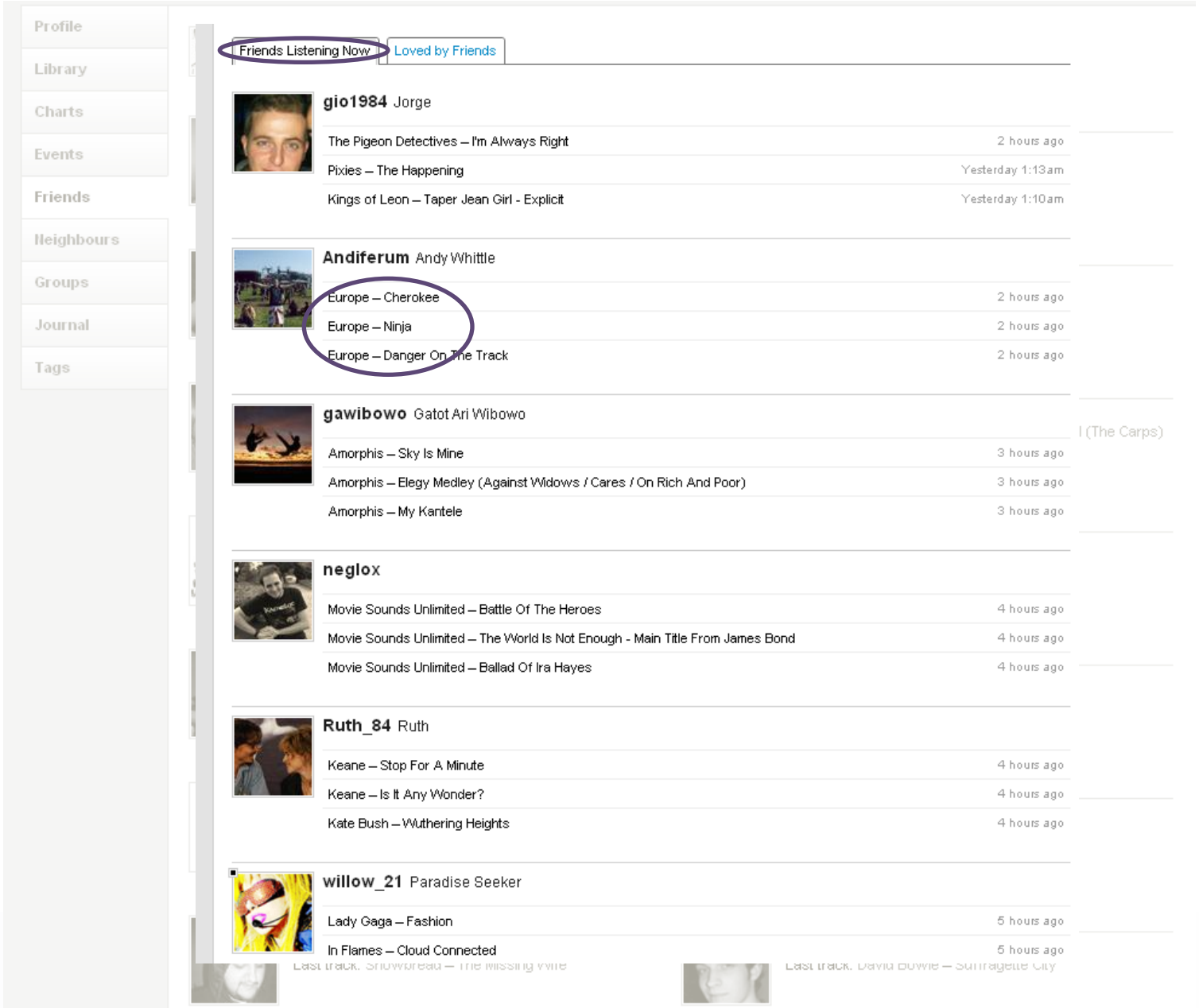
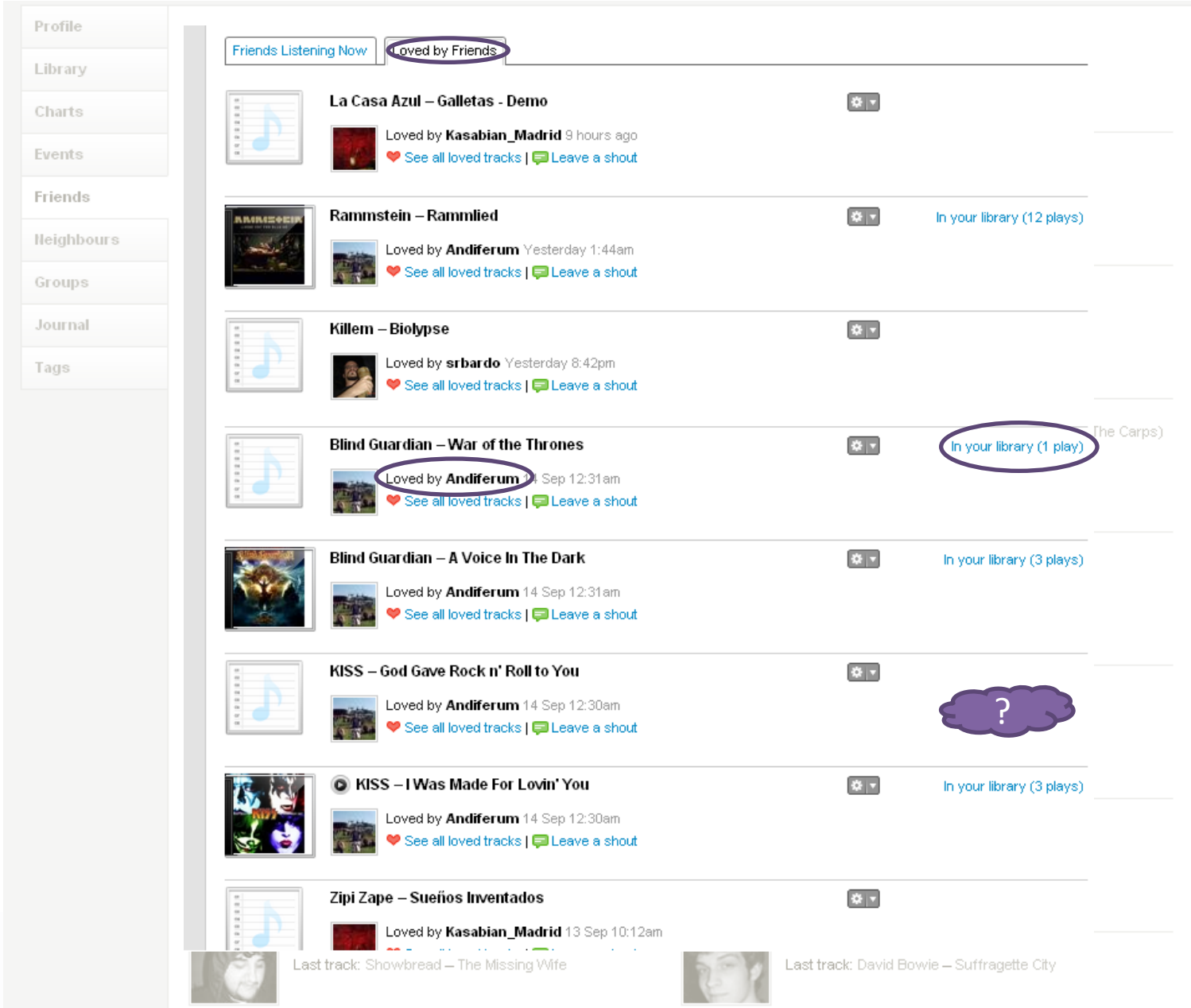
Social contacts?



Social contacts?



How can we address the problem?

- **RQ1**: Which sources of information in social systems are more valuable for recommendation?
  - Performance metrics
    - Precision
    - Recall
    - Discounted Cumulative Gain

2nd research question

Do recommenders in social systems really offer heterogeneous item suggestions, from which hybrid strategies could benefit?

How can we address this problem?

- **RQ2**: Do recommenders in social systems really offer heterogeneous item suggestions, from which hybrid strategies could benefit?

  - Non performance metrics
    - Coverage
    - Overlap
    - Diversity
    - Novelty

Methodology

- Implement different recommenders
  - Content-based (CB) ← collaborative tags
  - Collaborative-filtering (CF) ← track listenings
  - Social-based ← social contacts

- Evaluate the implemented recommenders
  - Performance metrics
  - Non-performance metrics

Evaluated recommenders

- Content-based recommenders (CB) ← collaborative tags
  - TF-based recommender
  - BM25-based recommender
  - TF-IDF cosine-based recommender
  - BM25 cosine-based recommender

- Collaborative filtering recommenders (CF) ← track listenings
  - User-based recommender (N=15)
  - Item-based recommender

- Social recommenders ← social contacts
  - Social recommender: friends as neighbours
  - Social+CF recommender

Performance metrics

- Precision
  - Recommended items that are relevant for the user
  - P@N (considering items in the top N results)
- Recall
  - Relevant items that are recommended
  - R@N (considering items in the top N results)
- Discounted cumulative gain
  - Relevant items should appear higher in the result list

Non-performance metrics (I)

- Coverage
  - Fraction of items a recommender can provide predictions for
  - E.g., CF cannot deal with new items, CB with untagged items, …
- Diversity
  - (Relevant) Items recommended that are not very popular nor very unpopular
  - Other diversity definitions have to be investigated
- Novelty
  - Relevant but non popular items
  - Other novelty definitions have to be investigated

Non-performance metrics (II)

- Overlap
  - Proportion of (relevant) recommended items provided by two recommenders
  - Two metrics: Jaccard-based, Ranking-based

- Relative diversity
  - (Relevant) Items recommended by a recommender once the user has already seen another result list

Evaluation protocol

1. Split the track set for each user (5-fold cross validation)
   - 80% for training set
   - 20% for test set

2. Build recommenders using training set

3. Evaluate all recommenders for each user:
   - 3.1. Predict a score for all items in the test set
   - 3.2. Rank the items according to the predicted score
   - 3.3. Compute performance and non-performance metrics

Results (I)

- Performance values
  - Best: CB
  - Worst: user based-CF (too much sparsity)

Recommender	MAP	NDCG
BM25 Cosine	**0.014**	0.212
TF-IDF Cosine	0.012	**0.220**
User based CF	0.002	0.076

- Non performance values
  - Best coverage: CB
  - Highest diversity: social
  - Highest novelty: social / CF
  - …

Recommender	Coverage	Diversity	Novelty
BM25 Cosine	**0.017**	0.015	0.003
TF-IDF Cosine	**0.017**	0.018	0.004
User based CF	0.015	0.005	0.001
Social	0.013	**0.054**	**0.005**

Results (I) – New experiments!

Recommender	Coverage	Diversity	Novelty
BM25 Cosine	**0.208**	3.67	5.66
TF-IDF Cosine	**0.208**	3.88	5.74
User based CF	0.061	6.65	6.27
Social	0.074	**6.72**	6.26
Item based CF	0.008	2.75	**6.97**

Recommender	Coverage	Diversity	Novelty
BM25 Cosine	**0.017**	0.015	0.003
TF-IDF Cosine	**0.017**	0.018	0.004
User based CF	0.015	0.005	0.001
Social	0.013	**0.054**	**0.005**

Results (II)

- Non performance values (cont'd)
  - Overlap: only among CBs and between CF and social
    - Not too much between social and CF
    - Cosine seems to be more influential than the weighting function

Jaccard overlap	TF	BM25	BM25 Cosine	TF-IDF Cosine
TF	--	0.005	0.005	0.009
BM25	--	--	0.011	0.008
BM25 Cosine	--	--	--	**0.015**
TF-IDF Cosine	--	--	--	--

  - Relative diversity: only among CBs and between CF and social
    - Not conclusive, further analysis required

Conclusions

- **RQ1**: Which sources of information in social systems are more valuable for recommendation?
  - **Tags** provide very effective recommendations

- **RQ2**: Do recommenders in social systems really offer heterogeneous item suggestions, from which hybrid strategies could benefit?
  - **Yes!** *And* each source of information captures a different characteristic
    - Tags → Coverage
    - Friends → Diversity
    - Track listenings → Novelty

Future work

- Use the obtained results and conclusions to build hybrid recommenders
  - Well performing, with good coverage, offering diverse and novel item suggestions… (a perfect recommender?)
  - Every source of information has to be used

- Compare the non performance metric definitions with others in the literature
  - Check different approximations for our definitions

- Extend our empirical study
  - Different datasets
  - More recommenders

Thank you

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Research questions

- RQ1. Which sources of information available in social systems are more valuable for recommendation?
  - Performance metrics (precision and recall)

- RQ2. Do recommendation approaches exploiting different sources of information in social systems really offer heterogeneous item suggestions, from which hybrid strategies could benefit?
  - Non-performance metrics (coverage, overlap, diversity and novelty)

Performance metrics (with definitions)

- Precision
  - Recommended items that are relevant for the user
  - P@N (considering items in the top N results)

$$\text{precision} = \frac{|\text{relevant items retrieved}|}{|\text{retrieved items}|}$$

- Recall
  - Relevant items that are recommended
  - R@N (considering items in the top N results)

$$\text{recall} = \frac{|\text{relevant items retrieved}|}{|\text{relevant items}|}$$

- Discounted cumulative gain
  - Relevant items should appear higher in the result list

$$\text{NDCG}_N = N_k \sum_{m=1}^{k} \frac{2^{rel(d_m)} - 1}{\log_2(1+m)}$$

Non-performance metrics (I)

- Coverage
  - Fraction of items a recommender can provide predictions
  - E.g., CF cannot deal with new items, CB with untagged items, …

$$cvg(a) = \frac{|S_a|}{|\mathcal{I}|} \qquad cvg^R(a) = \frac{|S_a^R|}{|\cup_{u \in U} R_u|}$$

- Diversity
  - (Relevant) Items recommended which are not very popular nor very unpopular

$$div(a) = \frac{1}{|\mathcal{U}|} \sum_{u \in \mathcal{U}} div_u(a)$$

$$div_u(a) = H_u(a) = -\sum_{i \in \overline{S}_{a,u}^R} p_{u,i} \cdot \log p_{u,i}$$

$$p_{u,i} = \frac{\sum_{a \in \mathcal{A}} \delta(a,u,i)}{|\mathcal{A}|},$$

where $\delta(a,u,i) = 1$ iff $\in \overline{S}_{a,u}^R$, and 0 otherwise.

- Novelty
  - Relevant but non popular items

$$p_i = \frac{|\{v \in \mathcal{U}: i \in R_v\}|}{|\mathcal{U}|}$$

$$nov(a) = \frac{1}{|\mathcal{U}|} \sum_{u \in \mathcal{U}} nov_u(a)$$

$$nov_u(a) = H_u(a) = -\sum_{i \in \overline{S}_{a,u}^R} p_i \cdot \log p_i ,$$

Non-performance metrics (II)

- Overlap
  - Proportion of (relevant) recommended items provided by two recommenders
  - Two metrics: Jaccard-based, Ranking-based

$$ove_jacc(a,b) = \frac{1}{|\mathcal{U}|}\sum_{u\in\mathcal{U}} ove_jacc_u(a,b) \qquad ove_rank(a,b) = \frac{1}{|\mathcal{U}|}\sum_{u\in\mathcal{U}} ove_rank_u(a,b)$$

$$ove_jacc_u(a,b) = \frac{\left|\overline{S}^R_{a,u} \cap \overline{S}^R_{b,u}\right|}{\left|\overline{S}^R_{a,u} \cup \overline{S}^R_{b,u}\right|} \qquad ove_rank_u(a,b) = \frac{1}{N}\sum\nolimits_{i\in\overline{S}^R_{a,u}\cap\overline{S}^R_{b,u}} \left(1 - \frac{\left|\tau_{a,u}(i) - \tau_{b,u}(i)\right|}{N-1}\right)$$

- Relative diversity
  - (Relevant) Items recommended by a recommender once the user has already seen another result list

$$div(a,b) = \frac{1}{|\mathcal{U}|}\sum_{u\in\mathcal{U}} div_u(a,b)$$

$$div_u(a,b) = H_u(a|b) = \sum\nolimits_{i\in\overline{S}^R_{a,u}\cap\overline{S}^R_{b,u}} p_{a,u,i}\cdot\log\frac{p_{a,u,i}}{p_{b,u,i}} \qquad p_{a,u,i} = \frac{1}{\left|\overline{S}^R_{a,u}\right|}$$

Notation

Let R_u be the set of items relevant for user u, and let A be the set of recommendation algorithms to be evaluated.

We define $L_{a,u}$, the ranked list of recommendations provided to user u by algorithm $a \in$ A, as:

$$L_{a,u} = \{(u, i, \tau): i \in \mathrm{I}, \tau > 0\},$$

where τ is the ranking position of item i in the recommendation list based on the predicted item utility $g_a(u, i)$, having $\tau_{a,u}(i) < \tau_{a,u}(j) \Rightarrow g_a(u, i) \geq g_a(u, j), \forall i, j \in \mathrm{I}$.

We denote by $S_{a,u}$ the set of items that belong to $L_{a,u}$:

$$S_{a,u} = \{i: (u, i, \cdot) \in L_{a,u}\}$$

Finally, we define $S_{a,u}^R$ as the set of those items belonging to $S_{a,u}$ that are relevant for user u. That is:

$$S_{a,u}^R = S_{a,u} \cap R_u = \{i: (u, i, \cdot) \in L_{a,u}, i \in R_u\}$$

The previous definitions $S_{a,u}$ and $S_{a,u}^R$ for a given recommendation algorithm a are extended to consider all users with the following expressions:

$$S_a = \bigcup_{u \in U} S_{a,u}, \quad S_a^R = \bigcup_{u \in U} S_{a,u}^R$$

Since some of the non-performance metrics explained below only depend on the top N recommendations provided by each algorithm a, we define $\overline{S}_{a,u}$, $\overline{S}_{a,u}^R$, $\overline{S}_a$ and $\overline{S}_a^R$ as, respectively, $S_{a,u}$, $S_{a,u}^R$, S_a and S_a^R on the set $L_{a,u}^N$ of top N recommendations for user u, where:

$$L_{a,u}^N = \{(\cdot, \cdot, \tau) \in L_{a,u}, \tau \leq N\}$$

Evaluated recommenders (I)

- Content-based recommenders
  - TF-based recommender

$$g(u_m, i_n) = tf_u(u_m, i_n) = \frac{\sum_{l:i_{n,l}>0} tf_{u_m}(t_l)}{\max_{u \in \mathcal{U}, t \in \mathcal{T}} \left(tf_u(t)\right)}$$

  - BM25-based recommender

$$g(u_m, i_n) = bm25_u(u_m, i_n) = \sum_{(l|i_{n,l}>0)} bm25_{u_m}(t_l)$$

  - TF-IDF cosine-based recommender

$$g(u_m, i_n) = cos_{tf\text{-}idf}(u_m, i_n) = \frac{\sum_l tf_{u_m}(t_l) \cdot iuf(t_l) \cdot tf_{i_n}(t_l) \cdot iif(t_l)}{\sqrt{\sum_l \left(tf_{u_m}(t_l) \cdot iuf(t_l)\right)^2} \cdot \sqrt{\sum_l \left(tf_{i_n}(t_l) \cdot iif(t_l)\right)^2}}$$

  - BM25 cosine-based recommender

$$g(u_m, i_n) = cos_{bm25}(u_m, i_n) = \frac{\sum_l \left(bm25_{u_m}(t_l) \cdot bm25_{i_n}(t_l)\right)}{\sqrt{\sum_l \left(bm25_{u_m}(t_l)\right)^2} \cdot \sqrt{\sum_l \left(bm25_{i_n}(t_l)\right)^2}}$$

Evaluated recommenders (II)

- Collaborative filtering recommenders
  - User-based recommender (N=15)

$$g(u_m, i_n) = \mathrm{C} \sum_{v \in N[u_m,k]} sim(u_m, v) \times rat(v, i_n)$$

$N[u_m, k]$ denotes the set (with size k) of neighbours of u_m

$$sim(u,v) = \frac{\sum_i \left(rat(u,i) - \overline{rat}(u)\right)\left(rat(v,i) - \overline{rat}(v)\right)}{\sqrt{\sum_i \left(rat(u,i) - \overline{rat}(u)\right)^2}\sqrt{\sum_i \left(rat(v,i) - \overline{rat}(v)\right)^2}}$$

  - Item-based recommender

$$g(u_m, i_n) = \mathrm{C} \sum_{j \in I_m} sim(i_n, j) \times rat(u, j)$$

where I_m is the set of items rated by user u_m

Evaluated recommenders (III)

- Social recommenders
  - Only social recommender: friends as neighbours

$$N[u_m, k] = N[u_m] = \{v \in \mathcal{U}: v \text{ is friend of } u_m\}$$

  - Social+CF recommender

$$N[u_m, k] = \{v \in \mathcal{U}: v \text{ is friend of } u_m\} \cup \{v \in \mathcal{U}: sim(u_m, v) \geq \rho_m\}$$

where $\rho_m > 0$ is the minimum similarity to be satisfied between the active user and his/her most similar neighbours

Results (II) – New experiments!

- Non performance values (cont'd)
  - Overlap: only among CBs and between CF and social
    - Not too much between social and CF
    - Cosine is more influential than the weighting function
  - Relative diversity: only among CBs and between CF and social
    - BM25 cosine compares the best

Jaccard overlap	TF	BM25	BM25 Cosine	TF-IDF Cosine
TF	--	0.26	0.26	0.44
BM25	--	--	0.30	0.26
BM25 Cosine	--	--	--	0.39
TF-IDF Cosine	--	--	--	--

Relative diversity	TF	BM25	BM25 Cosine	TF-IDF Cosine
TF	--	-0.04	0.08	0.15
BM25	0.02	--	0.07	0.05
BM25 Cosine	-0.18	-0.27	--	-0.29
TF-IDF Cosine	-0.36	-0.15	0.16	--