

A Study of Heterogeneity in Recommendations for a Social Music Service

Alejandro Bellogín, Iván Cantador, Pablo Castells
{**alejandro.bellogin**, ivan.cantador, pablo.castells}@uam.es

Universidad Autónoma de Madrid
Escuela Politécnica Superior
Information Retrieval Group
<http://ir.ii.uam.es>

Social Music Service: Last.fm

- Artist
- Biography
- Pictures
- Videos
- Albums
- Tracks
- Events
- News
- Charts
- Similar Artists
- Tags
- Listeners
- Journal
- Groups

The Beatles

264,585,910 plays (2,259,243 listeners)

Listening now: [polly_xq](#), [FedorMeloman](#), [mauro6006](#)
27,101 shouts

[+ Add to my Library](#) [Share](#)

Liverpool, England (1960 – 1970)

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.

[Read more...](#) [Edit](#)

Tagged as:

[classic rock](#), [rock](#), [british](#), [60s](#), [pop](#)
[See more...](#)



[See all 872 pictures](#)

[Play The Beatles Radio](#)

Top Tracks

Last Week Last 6 months

1	Across the Universe	13,119
2	Come Together	11,605
3	Let It Be	11,024
4	Help!	10,652
5	Yesterday	10,465
6	Here Comes the Sun	10,413
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
13	While My Guitar Gently Weeps	7,775
14	Can't Buy Me Love	7,574
15	Strawberry Fields Forever	7,525

[See more](#)

Similar Artists



John Lennon



George Harrison



Paul McCartney



Paul McCartney & Ringo Starr



Ringo Starr



Wings



Paul & Linda McCartney

[See more](#)

Listeners



polly_xq
Scrobbling now from [WMP](#)
[The Beatles – I'm a Loser](#)



FedorMeloman
Scrobbling now from [The Last.fm Scrobbler](#)
[The Beatles – The Night Before](#)



mirindA92
Scrobbling now from [foobar2000](#)
[The Beatles – Searchin'](#)



bigdaddyets
Top Listener



michaelwsimpson
Top Listener



dsendecki



foxmundo

1st research question

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

Tags?

- Artist
- Biography
- Pictures
- Videos
- Albums
- Tracks
- Events
- News
- Charts
- Similar Artists
- Tags**
- Listeners
- Journal
- Groups

The Beatles

264,585,910 plays (2,259,243 listeners)

Listening now: [polly_xq](#), [FedorMeloman](#), [mauro6006](#)
27,101 shouts

[+ Add to my Library](#) [Share](#)

Liverpool, England (1960 – 1970)

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.

[Read more...](#) [Edit](#)

Tagged as

[classic rock](#), [rock](#), [british](#), [60s](#), [pop](#)
[See more...](#)



[See all 872 pictures](#)

[Play The Beatles Radio](#)

Top Tracks

Last Week Last 6 months

1	Across the Universe	13,119
2	Come Together	11,605
3	Let It Be	11,024
4	Help!	10,652
5	Yesterday	10,465
6	Here Comes the Sun	10,413
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
13	While My Guitar Gently Weeps	7,775
14	Can't Buy Me Love	7,574
15	Strawberry Fields Forever	7,525

[See more](#)

Similar Artists



John Lennon



George Harrison



Paul McCartney



Paul McCartney & Ringo Starr



Ringo Starr



Wings



Paul & Linda McCartney

[See more](#)

Listeners



polly_xq
Scrobbling now from [WMP](#)
[The Beatles – I'm a Loser](#)



FedorMeloman
Scrobbling now from [The Last.fm Scrobbler](#)
[The Beatles – The Night Before](#)



mirinda92
Scrobbling now from [foobar2000](#)
[The Beatles – Searchin'](#)



bigdaddyets
Top Listener



michaelwsimpson
Top Listener



dsendecki



foxmundo

Track listenings?

- Artist
- Biography
- Pictures
- Videos
- Albums
- Tracks
- Events
- News
- Charts
- Similar Artists
- Tags
- Listeners
- Journal
- Groups

The Beatles

264,585,910 plays (2,259,243 listeners)

Listening now: [polly_xq](#), [FedorMeloman](#), [mauro6006](#)
27,101 shouts

[+ Add to my Library](#) [Share](#)

Liverpool, England (1960 – 1970)

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.

[Read more...](#) [Edit](#)

Tagged as:

[classic rock](#), [rock](#), [british](#), [60s](#), [pop](#)
[See more...](#)



[See all 872 pictures](#)

[Play The Beatles Radio](#)

Similar Artists



John Lennon



George Harrison



Paul McCartney



Paul McCartney & Ringo Starr



Ringo Starr



Wings



Paul & Linda McCartney

[See more](#)

Top Tracks

Last Week Last 6 months

1	Across the Universe	13,119
2	Come Together	11,605
3	Let It Be	11,024
4	Help!	10,652
5	Yesterday	10,465
6	Here Comes the Sun	10,413
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
13	While My Guitar Gently Weeps	7,775
14	Can't Buy Me Love	7,574
15	Strawberry Fields Forever	525

[See more](#)

Listeners



[polly_xq](#)
Scrobbling now from WMP
[The Beatles - I'm a Loser](#)



[FedorMeloman](#)
Scrobbling now from The Last.fm Scrobbler
[The Beatles - The Night Before](#)



[mirinda92](#)
Scrobbling now from foobar2000
[The Beatles - Searchin'](#)



[bigduyets](#)
Top Listener



[michaelwsimpson](#)
Top Listener



















[dsendecki](#)



[foxmundo](#)

Social contacts?

Profile	 foxmundo Friends (25)
Library	
Charts	
Events	
Friends	
Neighbours	
Groups	
Journal	
Tags	

 10minstolive Peter, 23, Male, United States Last track: Zero 7 – In the Waiting Line	 Antiak Andrew, 23, Male, United States Last track: Minus the Bear – Part 2
 araine5 araine taylor, 19, Female, United Kingdom Last track: Treija – The Miracle	 Crimson-Eyed Alex, 22, Male, United Kingdom Last track: Grizzly Bear – Lullabye
 currentdreams Jeremy, 19, Male, United States Last track: Gucci Mane – Socialite	 deadwomb ISHANK SHAKEDOWN, 20, Female, Canada Last track: MSTRKRFT – Breakaway f. Jahmal (The Carps)
 deathbyfailure dee to the ee en why ess, 20, Male, Canada Last track: Crystal Castles – Pap Smear	 devilinthecity Monica, 20, Female, United States Last track: The Devil Wears Prada – Revive
 DiaBoLiCcC Billy Deichmeister, 20, Male, United States  Listening: No Age – Glitter	 Disco42 Gabriel, 18, Male, Canada Last track: Elliott Brood – Woodward Avenue.
 dunkD Last track: Method Man & Redman – Father's Day	 kateapplin Kate, 22, Female, Canada Last track: Rufus Wainwright – Slideshow
 nomak559 Eric, 24, Male, United States Last track: Showbread – The Missing Wife	 OMouse Rudolf, 23, Male, Canada Last track: David Bowie – Suffragette City

Social contacts?

The image shows a music social network interface. On the left is a navigation menu with items: Profile, Library, Charts, Events, Friends, Neighbours, Groups, Journal, and Tags. The main content area is divided into two columns. The left column shows the user's profile 'foxmundo' with 25 friends, and a list of friends including 10minstolive, araine5, currentdreams, deathbyfailure, DiaBoLiCc, dunkD, and nomak559. The right column shows the user's profile 'foxmundo' with 50 neighbours, and a list of neighbours including redheadwawe, SuperRoCKstar, MattBradley2, tomeperjesi, kateapplin, and OMouse. A large red 'X' is drawn across the entire main content area, indicating that the social contacts are not visible or are being removed.

Profile
foxmundo
Friends (25)

10minstolive
Peter, 23, Male, United States
Last track: Zero 7 – In the Waiting L

araine5
araine taylor, 19, Female, United K
Last track: Treija – The Miracle

currentdreams
Jeremy, 19, Male, United States
Last track: Gucci Mane – Socialite

deathbyfailure
dee to the ee en why ess, 20, Male
Last track: Crystal Castles – Pap S

DiaBoLiCc
Billy Deichmeister, 20, Male, Unite
Listening: No Age – Glitter

dunkD
Last track: Method Man & Redman – Father's Day

nomak559
Eric, 24, Male, United States
Last track: Showbread – The Missing Wife

foxmundo
Neighbours (50)

redheadwawe
PIPES, Male
indie, rock, experimental, lo-fi and electronic.
Last track: Best Coast – Our Deal
Visit redheadwawe's profile

SuperRoCKstar
Severin, 21, Male, Switzerland
indie, rock, experimental, punk and noise rock.
Last track: Abe Vigoda – End of Sleep (Vocal)
Visit SuperRoCKstar's profile

MattBradley2
indie, lo-fi, electronic, rock and experimental.
Last track: MillionYoung – Hammock
Visit MattBradley2's profile

tomeperjesi
tomeperjesi, 21, Male, United Kingdom
indie, rock, experimental, lo-fi and electronic.
Last track: Ducktails – McGuire in the Ocean
Visit tomeperjesi's profile

kateapplin
Kate, 22, Female, Canada
Last track: Rufus Wainwright – Slideshow

OMouse
Rudolf, 23, Male, Canada
Last track: David Bowie – Suffragette City

Shared artists with foxmundo
No Age, Best Coast, Waves, Broken Social Scene

Shared artists with foxmundo
No Age, Waves, HEALTH, Best Coast

Shared artists with foxmundo
Waves, Best Coast, Ariel Pink's Haunted Graffiti, No Age

Shared artists with foxmundo
Waves, No Age, Best Coast, Delorean

Social contacts?

Profile

Library

Charts

Events

Friends

Neighbours

Groups

Journal

Tags

Friends Listening Now

Loved by Friends



gio1984 Jorge

The Pigeon Detectives – I'm Always Right 2 hours ago

Pixies – The Happening Yesterday 1:13am

Kings of Leon – Taper Jean Girl - Explicit Yesterday 1:10am



Andiferum Andy Whittle

Europe – Cherokee 2 hours ago

Europe – Ninja 2 hours ago

Europe – Danger On The Track 2 hours ago



gawibowo Gatot Ari Wibowo

Amorphis – Sky Is Mine 3 hours ago

Amorphis – Elegy Medley (Against Widows / Cares / On Rich And Poor) 3 hours ago

Amorphis – My Kantele 3 hours ago

1 (The Carps)



neglox

Movie Sounds Unlimited – Battle Of The Heroes 4 hours ago

Movie Sounds Unlimited – The World Is Not Enough - Main Title From James Bond 4 hours ago

Movie Sounds Unlimited – Ballad Of Ira Hayes 4 hours ago



Ruth_84 Ruth

Keane – Stop For A Minute 4 hours ago

Keane – Is It Any Wonder? 4 hours ago

Kate Bush – Wuthering Heights 4 hours ago



willow_21 Paradise Seeker

Lady Gaga – Fashion 5 hours ago

In Flames – Cloud Connected 5 hours ago

Last track: Snowbread – The Missing Wife

Last track: David Bowie – Sunrayette City

Social contacts?

Profile

Library

Charts

Events

Friends

Neighbours

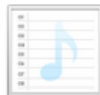
Groups

Journal

Tags

Friends Listening Now

Loved by Friends



La Casa Azul – Galletas - Demo



Loved by **Kasabian_Madrid** 9 hours ago
♥ See all loved tracks | 🗨 Leave a shout



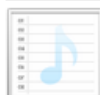
Rammstein – Rammlied



In your library (12 plays)



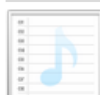
Loved by **Andiferum** Yesterday 1:44am
♥ See all loved tracks | 🗨 Leave a shout



Killem – Biolypse



Loved by **srbarido** Yesterday 8:42pm
♥ See all loved tracks | 🗨 Leave a shout



Blind Guardian – War of the Thrones



In your library (1 play)



Loved by **Andiferum** 14 Sep 12:31am
♥ See all loved tracks | 🗨 Leave a shout



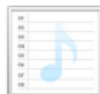
Blind Guardian – A Voice In The Dark



In your library (3 plays)



Loved by **Andiferum** 14 Sep 12:31am
♥ See all loved tracks | 🗨 Leave a shout



KISS – God Gave Rock n' Roll to You



Loved by **Andiferum** 14 Sep 12:30am
♥ See all loved tracks | 🗨 Leave a shout



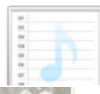
KISS – I Was Made For Lovin' You



In your library (3 plays)



Loved by **Andiferum** 14 Sep 12:30am
♥ See all loved tracks | 🗨 Leave a shout



Zipi Zape – Sueños Inventados



Loved by **Kasabian_Madrid** 13 Sep 10:12am



Last track: Showbread – The Missing Wife



Last track: David Bowie – Suffragette City

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	MAP	
BM25 Cosine	0.014	0.211
TF-IDF Cosine	0.012	0.220
User based CF	0.002	0.076

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

References

- Adomavicius, G., Tuzhilin, A. 2005. *Toward the Next Generation of Recommender Systems: A Survey and Possible Extensions*. IEEE Transactions on Knowledge & Data Engineering, 17(6), 734-749.
- Baeza-Yates, R., Ribeiro-Neto, B. 1999. *Modern Information Retrieval*. Addison Wesley.
- Baltrunas, L., Amatriain, X. 2009. *Towards Time-dependant Recommendation based on Implicit Feedback*. In Proceedings of the RecSys 2009 Workshop on Context-aware Recommender Systems.
- Bonhard P., Sasse M. A. 2006. Knowing Me, Knowing You - Using Profiles and Social Networking to Improve Recommender Systems. BT Technology Journal, 25(3), 84-98.
- Cantador, I., Bellogín, A., Vallet, D. 2010. *Content-based Recommendation in Social Tagging Systems*. In Proceedings of the 4th ACM Conference on Recommender Systems.
- Celma, O. 2008. *Music Recommendation and Discovery in the Long Tail*. PhD thesis, Universitat Pompeu Fabra, Barcelona, Spain.
- He, J., Chu, W. W. 2010. *A Social Network-Based Recommender System (SNRS)*. In Memon, N., Xu, J. J., Hicks, D. L., Chen, H. (Eds.), Data Mining for Social Network Data, 47-74.
- Herlocker, J. L., Konstan, J. A., Borchers, A., Riedl, J. 1999. *An Algorithmic Framework for Performing Collaborative Filtering*. In Proceedings of the 22nd Annual International ACM SIGIR Conf. on Research and Development in Information Retrieval, 230-237.
- Hotho, A., Jäschke, R., Schmitz, C., Stumme, G. 2006. *Information Retrieval in Folksonomies: Search and Ranking*. In Proceedings of the 5th Intl. Semantic Web Conference, 411-426.
- Jarvelin, K., Kekalainen, J. 2002. *Cumulated Gain-based Evaluation of IR Techniques*. ACM Transactions on Info. Systems, 20(4), 422-446.
- Konstas, I., Stathopoulos, V., Jose, J. M. 2009. *On Social Networks and Collaborative Recommendation*. In Proceedings of the 32nd Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, 195-202.
- Liu, F., Lee, H. J. 2010. Use of Social Network Information to Enhance Collaborative Filtering Performance. Expert Systems with Applications, 37(7), 4772-4778.
- Noll, M. G., Meinel, C. 2007. *Web Search Personalization via Social Bookmarking and Tagging*. In Proceedings of the 6th International Semantic Web Conference, 367-380.
- Spärck-Jones, K., Walker, S., Robertson, S. E. 2000. *A Probabilistic Model of Information Retrieval: Development and Comparative Experiments* (parts 1 and 2). Information Processing and Management, 36(6):779-840.
- Zanardi, V., Capra, L. 2008. *Social Ranking: Uncovering Relevant Content using Tag-based Recommender Systems*. In Proc. of the 2nd ACM Conference on Recommender Systems, 51-58.
- Zhou, T., Kuscsik, Z., Liu, J. G., Medo, M., Wakeling, J. R., Zhang, Y. C. 2010. *Solving the Apparent Diversity-accuracy Dilemma of Recommender Systems*. In Proceedings of the National Academy of Sciences of the United States of America, 107(10), 4511-4515.

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

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

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, ...

$$cvg(a) = \frac{|S_a|}{|\mathcal{I}|}$$

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

■ Diversity

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

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

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

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

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

■ Novelty

- Relevant but non popular items

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

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

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

Non-performance metrics (II)

■ Overlap

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

$$ove_jacc(a, b) = \frac{1}{|\mathcal{U}|} \sum_{u \in \mathcal{U}} ove_jacc_u(a, b) \quad ove_rank(a, b) = \frac{1}{|\mathcal{U}|} \sum_{u \in \mathcal{U}} ove_rank_u(a, b)$$
$$ove_jacc_u(a, b) = \frac{|\bar{S}_{a,u}^R \cap \bar{S}_{b,u}^R|}{|\bar{S}_{a,u}^R \cup \bar{S}_{b,u}^R|} \quad ove_rank_u(a, b) = \frac{1}{N} \sum_{i \in \bar{S}_{a,u}^R \cap \bar{S}_{b,u}^R} \left(1 - \frac{|\tau_{a,u}(i) - \tau_{b,u}(i)|}{N - 1} \right)$$

■ Relative diversity

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

$$div(a, b) = \frac{1}{|\mathcal{U}|} \sum_{u \in \mathcal{U}} div_u(a, b)$$
$$div_u(a, b) = H_u(a|b) = \sum_{i \in \bar{S}_{a,u}^R \cap \bar{S}_{b,u}^R} p_{a,u,i} \cdot \log \frac{p_{a,u,i}}{p_{b,u,i}}$$
$$p_{a,u,i} = \frac{1}{|\bar{S}_{a,u}^R|}$$

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:

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

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

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 $\bar{S}_{a,u}$, $\bar{S}_{a,u}^R$, \bar{S}_a and \bar{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

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

- 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

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

- BM25 cosine-based recommender

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

Evaluated recommenders (II)

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

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

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

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

- Item-based recommender

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

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

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

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	--