# CSE 640 Project:Exploring AutoEncoders for Collaborative Filtering

Group 27

May 8, 2023

## Papers Selected

1. AutoRec: Autoencoders Meet Collaborative Filtering [4]

   This paper proposes a new CF model called AutoRec which is based on AutoEncoders. They experiment on two modesl: U-AutoRec and I-AutoRec.

2. Training Deep AutoEncoders for Collaborative Filtering [2]

   The authors propose a autoencoder based model called DeepAutoRec. They demonstrate that a 6 layered AutoRec generalises better than the shallow ones, use of regularization techniques is beneficial and propose a new training algorithm.

3. Variational Autoencoders for Collaborative Filtering [3]

   Authors introduce a generative model with multinomial likelihood and use Bayesian inference for parameter estimation. They call the model VAE.

4. Enhancing VAEs for Collaborative Filtering: Flexible Priors & Gating Mechanisms [1]

   Authors propose 4 new models. Vamp: Variational autoencoder with a VampPrior as the prior distribution instead of the original standard normal prior. H + Vamp: Hierarchical VAE with the VampPrior, the difference to the Vamp model is that it has hierarchical stochastic units to model the latent representation H + Vamp (Gated): Additional gating mechanisms are applied to the H + Vamp above. Multi-VAE (Gated): The Multi-VAE model with gating mechanisms

We have chosen these four papers because they all use common machine learning technique of autoencoders. Moreover, they are from core A star conferences. DeepAutorec uses Autorec model as baseline. Similarly, Enhanced VAE paper compares its model's performance with standard VAE of third paper.

## Datasets

We ran all the models on Books Crossing and Anime Dataset

1. Booskcrossing

   Consists of 272,679 interactions (explicit / implicit) from 2,946 users on 17,384 books. Ratings: 1,295 users and 14,684 books (62,657 ratings applied) History: 2,946 users and 17,384 books (272,679 accesses) Ratings are between 1 - 10. Implicit feedback are represented by 1. Simple demographic info for the users (age, gender, occupation, zip) is also available.

2. Anime

   Consists of 520,610 interactions (play / purchase) from 5,000 users on 7,718 animes. History: 5,000 users and 7,390 games (520,610 interactions). Ratings: 4,714 users and 7,157 animes (419,944 interactions). Range of ratings: 1 - 10

## Experiments

For each of the models, the genral flow of experiments was as follows- first of all hyperparameter tuning was carried out for a particular model. This was followed by a 5 fold cross validation to obtain best models obtained.

1. Autorec

   Tables 1-4 contain the activation hyperparameter tuning results. Tables 5-8 depict the cross validation results on both the datasets for I-AutoRec and U-Autorec.

2. Deep autorec

   Tables 9-16 contain the hyperparameter tuning results for layer depth,width,dropout. Tables 17 and 18 depict the cross validation results on both the datasets on the final model.

| First | Last | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|---|
| Linear | Linear | 8.841 | 4.306 | 1.192 |
| Linear | Sigmoid | 22.0562 | 21.7444 | 3.000 |
| Linear | Relu | 29.2856 | 21.744 | 3.000 |
| Sigmoid | Linear | 5.1944 | 3.4324 | 1.043 |
| Sigmoid | Sigmoid | 22.3122 | 21.744 | 3.000 |
| Sigmoid | Relu | 5.08596 | 3.3999 | 1.0371 |
| Relu | Linear | **3.7644** | **3.007** | **0.949** |
| Relu | Sigmoid | 22.0098 | 21.7444 | 3.000 |
| Relu | Relu | 6.893 | 5.276 | 1.284 |

Table 1: Activation tuning, U-AutoRec on Books

| First | Last | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|---|
| Linear | Linear | 3.9395 | 2.869 | 1.325 |
| Linear | Sigmoid | 41.604 | 41.541 | 5.641 |
| Linear | Relu | 54.128 | 41.541 | 5.641 |
| Sigmoid | Linear | 2.73198 | 1.893 | 1.086 |
| Sigmoid | Sigmoid | 41.699 | 41.541 | 5.641 |
| Sigmoid | Relu | 2.8502 | 1.930 | 1.095 |
| Relu | Linear | **2.3051** | **1.973** | **1.0764** |
| Relu | Sigmoid | 41.597 | 41.541 | 5.641 |
| Relu | Relu | 11.1702 | 8.801 | 2.224 |

Table 2: Activation tuning, U-AutoRec on Anime

3. VAE

   Tables 19 through 23 contain the hyperparameter tuning results for bookscrossing for layer depth, initial learning rate, weight decay, anneal steps tunning, sampling layer size. Tables 24 depict the cross validation results on Bookscrossing of the final model. Tables 25 through 30 contain the hyperparameter tuning results for Anime dataset for layer depth, initial learning rate, weight decay, anneal steps tunning, dropout, and anneal cap. Tables 31 depict the cross validation results on Anime dataset of the final model.

4. Enhanced VAE Tables 32 and 33 contain the hyperparameter tuning experients on the books dataset. Table 34 shows the final results for

| First | Last | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|---|
| Linear | Linear | 1.831 | 1.210 | 0.756 |
| Linear | Sigmoid | 16.043 | 16.004 | 4.000 |
| Linear | Relu | 20.039 | 12.714 | 3.189 |
| Sigmoid | Linear | 0.0865 | 0.003 | 0.045 |
| Sigmoid | Sigmoid | 16.089 | 16.004 | 4.000 |
| Sigmoid | Relu | **0.0875** | **0.002** | **0.041** |
| Relu | Linear | 0.5574 | 0.363 | 0.450 |
| Relu | Sigmoid | 16.055 | 16.004 | 4.000 |
| Relu | Relu | 0.5655 | 0.393 | 0.511 |

Table 3: Activation tuning, I-AutoRec on Books

| First | Last | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|---|
| Linear | Linear | **2.2416** | **1.760** | **0.817** |
| Linear | Sigmoid | 2.26888 | 1.765 | 0.814 |
| Linear | Relu | 3.07679 | 2.240 | 0.891 |
| Sigmoid | Linear | 2.269 | 1.753 | 0.8153 |
| Sigmoid | Sigmoid | 3.10365 | 2.253 | 0.900 |
| Sigmoid | Relu | 3.034585 | 2.224 | 0.886 |
| Relu | Linear | 3.04586 | 2.230 | 0.894 |
| Relu | Sigmoid | 3.07772 | 2.2449 | 0.889 |
| Relu | Relu | 3.0385 | 2.230 | 0.895 |

Table 4: Activation tuning, I-AutoRec on Anime

| | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| Fold 1 | 2.169 | 1.56 | 0.533 |
| Fold 2 | 2.031 | 1.555 | 0.532 |
| Fold 3 | 2.135 | 1.575 | 0.538 |
| Fold 4 | 2.051 | 1.542 | 0.534 |
| Fold 5 | 2.104 | 1.614 | 0.554 |
| Average | 2.098 | 1.57 | 0.538 |

Table 5: Cross validation for U Autorec for books dataset

| | **MSE** | **MSE(clipped)** | **RMSE(clipped)** |
|---|---|---|---|
| Fold 1 | 1.601 | 0.671 | 0.324 |
| Fold 2 | 1.587 | 0.667 | 0.326 |
| Fold 3 | 1.511 | 0.658 | 0.322 |
| Fold 4 | 1.662 | 0.663 | 0.322 |
| Fold 5 | 1.421 | 0.652 | 0.32 |
| Average | 1.556 | 0.662 | 0.322 |

Table 6: Cross validation for U Autorec for books dataset

| | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| Fold 1 | 1.443 | 1.115 | 0.579 |
| Fold 2 | 1.604 | 1.218 | 0.578 |
| Fold 3 | 1.624 | 1.227 | 0.585 |
| Fold 4 | 1.682 | 1.34 | 0.649 |
| Fold 5 | 1.539 | 1.183 | 0.585 |
| Average | 1.578 | 1.216 | 0.595 |

Table 7: U Autorec 5 fold cross validation for Anime Dataset

| | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| Fold 1 | 2.284 | 1.437 | 0.809 |
| Fold 2 | 2.16 | 1.363 | 0.787 |
| Fold 3 | 2.29 | 1.445 | 0.818 |
| Fold 4 | 2.325 | 1.393 | 0.803 |
| Fold 5 | 2.223 | 1.415 | 0.805 |
| Average | 2.256 | 1.41 | 0.804 |

Table 8: I Autorec 5 fold cross validation for anime

| Layers | MSE | MSE (clipped) | RMSE (clipped) |
|---|---|---|---|
| 2 | 3464.480 | 36.551 | 1.269 |
| 4 | 2022.020 | 27.891 | 1.294 |
| 6 | 592.838 | 15.374 | 1.245 |
| 8 | 185.701 | 8.676 | 1.228 |
| 10 | 29.233 | 3.421 | 1.219 |
| 12 | 29.745 | 3.430 | 1.217 |

Table 9: Layer depth tuning (books)

| Layers | MSE | MSE (clipped) | RMSE (clipped) |
|---|---|---|---|
| 2 | 54.165 | 6.251 | 1.676 |
| 4 | 31.539 | 4.810 | 1.683 |
| 6 | 10.456 | 2.657 | 1.543 |
| 8 | 5.789 | 1.914 | 1.512 |
| 10 | 3.364 | 1.351 | 1.296 |
| 12 | 2.400 | 1.088 | 1.084 |

Table 10: Layer depth tuning (anime)

| Width | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| 128 | 215006.515 | 294.851 | 1.233 |
| 256 | 149637.406 | 245.263 | 1.233 |
| 512 | 90557.5 | 189.858 | 1.232 |
| 1024 | 38243.683 | 121.65 | 1.2449 |

Table 11: Layer width tuning(books)

| Width | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| 128 | 63.632 | 6.397 | 2.064 |
| 256 | 46.316 | 5.413 | 1.937 |
| 512 | 51.378 | 5.82 | 1.723 |
| 1024 | 41.228 | 5.092 | 2.516 |

Table 12: Layer width tuning (anime)

| Dropout | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| 0 | 730.733 | 17.178 | 1.233 |
| 0.5 | 23.225 | 2.861 | 1.213 |
| 0.65 | 108.780 | 6.539 | 1.236 |
| 0.8 | 39.396 | 3.9545 | 1.223 |

Table 13: Dropout tuning (books)

| Dropout | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|
| 0 | 5.526 | 1.811 | 1.436 |
| 0.5 | 3.025 | 1.252 | 1.222 |
| 0.65 | 2.744 | 1.187 | 1.182 |
| 0.8 | 2.840 | 1.200 | 1.178 |

Table 14: Dropout tuning (anime)

| First | Last | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|---|
| elu | linear | 18856.894 | 86.333 | 1.243 |
| elu | sigmoid | 22.046 | 3.017 | 3.0001 |
| relu | linear | 572024.687 | 482.482 | 1.233 |
| relu | sigmoid | 22.051 | 3.017 | 3 |
| selu | linear | 2205.954 | 29.133 | 1.308 |
| selu | sigmoid | 22.039 | 3.017 | 3 |
| tanh | linear | 8.524 | 1.335 | 1.281 |
| tanh | sigmoid | 22.888 | 3.051 | 3 |
| sigmoid | linear | 8.558 | 1.336 | 1.282 |
| Sigmoid | sigmoid | 22.904 | 3.051 | 3 |
| elu | selu | 18295.125 | 86.082 | 1.233 |
| relu | selu | 555634.25 | 475.376 | 1.234 |
| selu | selu | 2735.957 | 32.943 | 1.24 |
| tanh | selu | **8.199** | **1.308** | **1.254** |
| sigmoid | selu | 8.239 | 1.31 | 1.256 |

Table 15: Deep autorec activation tuning (books)

| First | Last | MSE | MSE(clipped) | RMSE(clipped) |
|---|---|---|---|---|
| elu | linear | 69.383 | 7.193 | 1.693 |
| elu | sigmoid | 41.59 | 5.642 | 5.641 |
| elu | selu | 123.141 | 9.659 | 1.695 |
| relu | linear | 783.484 | 24.411 | 1.691 |
| relu | sigmoid | 41.59 | 5.642 | 5.641 |
| relu | selu | 632.26 | 21.92 | 1.69 |
| selu | linear | 28.821 | 4.558 | 1.673 |
| selu | sigmoid | 41.584 | 5.642 | 5.641 |
| selu | selu | 39.45 | 5.392 | 1.685 |
| tanh | linear | 3.478 | 1.15 | 1.1461 |
| tanh | sigmoid | 42.005 | 5.654 | 5.641 |
| tanh | selu | 3.37 | 1.144 | 1.14 |
| sigmoid | linear | 3.485 | 1.145 | 1.141 |
| sigmoid | sigmoid | 42.02 | 5.655 | 5.641 |
| sigmoid | selu | **3.366** | **1.137** | **1.133** |

Table 16: Deep autorec activation tuning (anime)

| | MSE | MSE(clipped) | RMSE(clipped) | Baseline |
|---|---|---|---|---|
| Fold 1 | 4.481 | 0.447 | 0.412 | 0.533 |
| Fold 2 | 4.182 | 0.446 | 0.41 | 0.532 |
| Fold 3 | 4.345 | 0.462 | 0.422 | 0.538 |
| Fold 4 | 4.2 | 0.449 | 0.414 | 0.534 |
| Fold 5 | 4.48 | 0.463 | 0.425 | 0.554 |
| Average | 4.337 | 0.453 | 0.416 | 0.538 |

Table 17: Deep Autorec 5 fold cross validation on Books dataset

| | MSE | MSE(clipped) | RMSE(clipped) | Baseline |
|---|---|---|---|---|
| Fold 1 | 1.833 | 0.417 | 0.415 | 0.579 |
| Fold 2 | 2.355 | 0.424 | 0.423 | 0.578 |
| Fold 3 | 3.079 | 0.417 | 0.415 | 0.585 |
| Fold 4 | 3.316 | 0.416 | 0.414 | 0.649 |
| Fold 5 | 2.948 | 0.423 | 0.421 | 0.585 |
| Average | 2.706 | 0.4194 | 0.417 | 0.595 |

Table 18: Deep Autorec 5 fold cross validation for Anime Dataset

| **Layers** | **NDCG@100** | **Recall@20** | **Recall@50** |
|---|---|---|---|
| 3 | **0.125** | 0.100 | 0.153 |
| 5 | 0.112 | 0.078 | 0.134 |
| 7 | 0.097 | 0.072 | 0.114 |
| 9 | 0.088 | 0.057 | 0.102 |

Table 19: VAE layer depth tuning (books)

| **Initial LR** | **NDCG@100** | **Recall@20** | **Recall@50** |
|---|---|---|---|
| 1e-4 | 0.116 | 0.083 | 0.14 |
| 1e-3 | **0.125** | 0.100 | 0.153 |
| 1e-2 | 0.097 | 0.072 | 0.108 |
| 1e-1 | 0.05 | 0.034 | 0.064 |

Table 20: VAE learning rate tuning (books)

| Weight Decay | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 0 | **0.125** | 0.100 | 0.153 |
| 1e-4 | 0.125 | 0.95 | 0.144 |
| 1e-3 | 0.125 | 0.094 | 0.143 |
| 1e-2 | 0.083 | 0.062 | 0.085 |
| 1e-1 | 0.056 | 0.036 | 0.063 |

Table 21: VAE weight decay tuning (books)

| Steps | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 400,000 | 0.125 | 0.095 | 0.143 |
| 200,000 | 0.125 | 0.100 | 0.153 |
| 20,000 | **0.127** | 0.104 | 0.154 |
| 2,000 | 0.127 | 0.094 | 0.152 |

Table 22: VAE anneal tuning(books)

| Size | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 150 | 0.131 | 0.092 | 0.145 |
| 300 | **0.143** | 0.110 | 0.160 |
| 600 | 0.142 | 0.107 | 0.162 |
| 1200 | 0.138 | 0.105 | 0.156 |
| 2400 | 0.135 | 0.110 | 0.155 |

Table 23: VAE sampling layer size tuning(books)

| Fold | NDCG@100 | NDCG@20 | Recall@50 | Recall@20 |
|---|---|---|---|---|
| 1 | 0.141 (0.010) | 0.111 (0.010) | 0.159 (0.012) | 0.116 (0.010) |
| 2 | 0.142 (0.009) | 0.112 (0.009) | 0.160 (0.012) | 0.121 (0.010) |
| 3 | 0.140 (0.010) | 0.107 (0.009) | 0.158 (0.012) | 0.113 (0.010) |
| 4 | 0.141 (0.010) | 0.110 (0.009) | 0.161 (0.012) | 0.116 (0.010) |
| 5 | 0.144 (0.010) | 0.113 (0.009) | 0.161 (0.012) | 0.117 (0.010) |

Table 24: 5 fold cross validation of VAE on books dataset

| Layers | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 2 | 0.454 | 0.429 | 0.518 |
| 3 | 0.397 | 0.322 | 0.478 |
| 4 | 0.405 | 0.369 | 0.473 |

Table 25: VAE number of layers tuning (anime)

| Initial LR | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 1e-4 | 0.292 | 0.259 | 0.35 |
| 1e-3 | 0.405 | 0.369 | 0.473 |
| 1e-2 | 0.295 | 0.247 | 0.378 |

Table 26: VAE learning rate tuning (anime)

| Weight Decay | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 1e-4 | 0.393 | 0.359 | 0.349 |
| 1e-3 | 0.392 | 0.358 | 0.348 |
| 1e-2 | 0.375 | 0.348 | 0.331 |
| 1e-1 | 0.366 | 0.327 | 0.311 |

Table 27: VAE weight decay tuning (anime)

| Steps | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 400,000 | 0.366 | 0.327 | 0.312 |
| 200,000 | 0.366 | 0.327 | 0.311 |
| 20,000 | **0.360** | 0.325 | 0.306 |
| 2,000 | 0.322 | 0.295 | 0.271 |

Table 28: VAE Anneal tuning (anime)

| Dropout | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 0 | 0.424 | 0.399 | 0.370 |
| 0.25 | 0.423 | 0.394 | 0.37 |
| 0.5 | 0.422 | 0.395 | 0.371 |
| 0.75 | 0.422 | 0.397 | 0.367 |

Table 29: VAE dropout tuning (anime)

| Anneal Cap | NDCG@100 | Recall@20 | Recall@50 |
|---|---|---|---|
| 2e-1 | 0.422 | 0.395 | 0.371 |
| 4e-1 | 0.421 | 0.394 | 0.371 |
| 6e-1 | 0.421 | 0.394 | 0.371 |
| 8e-1 | 0.421 | 0.395 | 0.371 |

Table 30: VAE anneal cap (anime)

| Fold | NDCG@100 | NDCG@20 | Recall@50 | Recall@20 |
|---|---|---|---|---|
| 1 | 0.451 | 0.471 | 0.521 | 0.394 |
| 2 | 0.449 | 0.469 | 0.429 | 0.422 |
| 3 | 0.441 | 0.471 | 0.474 | 0.394 |
| 4 | 0.440 | 0.472 | 0.465 | 0.425 |
| 5 | 0.448 | 0.467 | 0.421 | 0.395 |

Table 31: 5 fold cross validation of VAE of anime dataset

| Size | NDCG@100 | Recall@50 | Recall@20 |
|---|---|---|---|
| 100 | 0.08225 | 0.08954 | 0.0685 |
| 200 | 0.10807 | 0.12451 | 0.08452 |
| 300 | 0.11643 | 0.13008 | 0.08692 |
| **500** | **0.15861** | **0.17519** | **0.13047** |
| 1000 | 0.15792 | 0.17452 | 0.12987 |

Table 32: Enhanced VAE layer size tuning(books)

| No. of Latent Features | NDCG@100 | Recall@50 | Recall@20 |
|---|---|---|---|
| (100,100) | **0.06934** | **0.07329** | 0.04483 |
| (200,200) | 0.06637 | 0.06919 | 0.04740 |
| (300,300) | 0.06342 | 0.06527 | 0.05031 |
| (400,400) | 0.06078 | 0.06251 | **0.05098** |

Table 33: EnhancedVAE number of latent features tuning(books)

books dataset. Tables 35 and 36 contain the hyperparameter tuning experients on the anime dataset. Table 37 shows the final results for anime dataset.

## Conclusion

Deep Autorec was able to beat the U-Autorec baseline and Enhanced VAE also showed improvements over the standard VAE model for both the datasets. While H+Vamp model (one of the enhanced VAE model) showed superior performance than standard VAE and other 3 enhanced models on both the datasets.

| Models | NDCG@100 | NDCG@20 | Recall@50 | Recall@20 |
|---|---|---|---|---|
| Baseline (Multi-VAE) | 0.14160 | 0.11060 | 0.15980 | 0.11660 |
| Vamp | 0.14824 | 0.11550 | 0.16368 | 0.12258 |
| HVamp | 0.14973 | 0.11612 | 0.16401 | 0.12462 |
| Multi-VAE (Gated) | 0.14789 | 0.11673 | 0.16947 | 0.12493 |
| **HVamp (Gated)** | **0.15861** | **0.12136** | **0.17519** | **0.13047** |

Table 34: Results of paper 4 on books dataset

| Size | NDCG@100 | Recall@50 | Recall@20 |
|---|---|---|---|
| 100 | 0.456 | 0.478 | 0.408 |
| **300** | **0.466** | **0.489** | **0.42** |
| 500 | 0.459 | 0.481 | 0.411 |
| 750 | 0.449 | 0.472 | 0.404 |
| 1000 | 0.44 | 0.466 | 0.396 |

Table 35: EnhancedVAE layer size tuning(anime)

| Layers | NDCG@100 | Recall@50 | Recall@20 |
|---|---|---|---|
| **1** | **0.466** | **0.489** | **0.42** |
| 2 | 0.461 | 0.485 | 0.417 |
| 3 | 0.454 | 0.474 | 0.407 |
| 4 | 0.442 | 0.463 | 0.399 |

Table 36: Enhanced VAE layer depth tuning(anime)

| Models | NDCG@100 | NDCG@20 | NDCG@10 | Recall@50 | Recall@20 |
|---|---|---|---|---|---|
| Baseline(Multi-VAE) | 0.446 | 0.47 | 0.455 | 0.462 | 0.406 |
| Multi-VAE (gated) | 0.451 | 0.473 | 0.459 | 0.471 | 0.41 |
| HVamp | 0.455 | 0.479 | 0.465 | 0.48 | 0.414 |
| Vamp (gated) | 0.46 | 0.484 | 0.469 | 0.485 | 0.418 |
| H+Vamp (gated) | **0.466** | **0.491** | **0.473** | **0.489** | **0.42** |

Table 37: Results of paper 4 on anime dataset

## References


[1] Kim, D., and Suh, B. Enhancing vaes for collaborative filtering: flexible priors & gating mechanisms. In *Proceedings of the 13th ACM Conference on Recommender Systems* (2019), pp. 403–407.

[2] Kuchaiev, O., and Ginsburg, B. Training deep autoencoders for collaborative filtering. *arXiv preprint arXiv:1708.01715* (2017).

[3] Liang, D., Krishnan, R. G., Hoffman, M. D., and Jebara, T. Variational autoencoders for collaborative filtering. In *Proceedings of the 2018 world wide web conference* (2018), pp. 689–698.

[4] Sedhain, S., Menon, A. K., Sanner, S., and Xie, L. Autorec: Autoencoders meet collaborative filtering. In *Proceedings of the 24th international conference on World Wide Web* (2015), pp. 111–112.