
LensKit Documentation

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LensKit is a set of Python tools for experimenting with and studying recommender systems. It provides support for training, running, and evaluating recommender algorithms in a flexible fashion suitable for research and education.

LensKit for Python (also known as LKPY) is the successor to the Java-based LensKit project.

INSTALLATION

To install the current release with Anaconda (recommended):

```
conda install -c lenskit lenskit
```

Or you can use `pip`:

```
pip install lenskit
```

To use the latest development version, install directly from GitHub:

```
pip install git+https://github.com/lenskit/lkpy
```

Then see [Getting Started](#).

RESOURCES

- [Mailing list](#), etc.
- [Source and issues on GitHub](#)

2.1 Getting Started

This notebook gets you started with a brief nDCG evaluation with LensKit for Python.

2.1.1 Setup

We first import the LensKit components we need:

```
[1]: from lenskit.datasets import ML100K
    from lenskit import batch, topn, util
    from lenskit import crossfold as xf
    from lenskit.algorithms import Recommender, als, item_knn as knn
    from lenskit import topn
```

And Pandas is very useful:

```
[2]: import pandas as pd
```

```
[3]: %matplotlib inline
```

2.1.2 Loading Data

We're going to use the ML-100K data set:

```
[4]: ml100k = ML100K('ml-100k')
    ratings = ml100k.ratings
    ratings.head()
```

```
[4]:
```

	user	item	rating	timestamp
0	196	242	3	881250949
1	186	302	3	891717742
2	22	377	1	878887116
3	244	51	2	880606923
4	166	346	1	886397596

2.1.3 Defining Algorithms

Let's set up two algorithms:

```
[5]: algo_ii = knn.ItemItem(20)
     algo_als = als.BiasedMF(50)
```

2.1.4 Running the Evaluation

In LensKit, our evaluation proceeds in 2 steps:

1. Generate recommendations
2. Measure them

If memory is a concern, we can measure while generating, but we will not do that for now.

We will first define a function to generate recommendations from one algorithm over a single partition of the data set. It will take an algorithm, a train set, and a test set, and return the recommendations.

Note: before fitting the algorithm, we clone it. Some algorithms misbehave when fit multiple times.

Note 2: our algorithms do not necessarily implement the `Recommend` interface, so we adapt them. This fills in a default candidate selector.

The code function looks like this:

```
[6]: def eval(aname, algo, train, test):
     fittable = util.clone(algo)
     fittable = Recommender.adapt(fittable)
     fittable.fit(train)
     users = test.user.unique()
     # now we run the recommender
     recs = batch.recommend(fittable, users, 100)
     # add the algorithm name for analyzability
     recs['Algorithm'] = aname
     return recs
```

Now, we will loop over the data and the algorithms, and generate recommendations:

```
[7]: all_recs = []
     test_data = []
     for train, test in xf.partition_users(ratings[['user', 'item', 'rating']], 5, xf.
     ↪SampleFrac(0.2)):
         test_data.append(test)
         all_recs.append(eval('ItemItem', algo_ii, train, test))
         all_recs.append(eval('ALS', algo_als, train, test))
```

With the results in place, we can concatenate them into a single data frame:

```
[8]: all_recs = pd.concat(all_recs, ignore_index=True)
     all_recs.head()
```

```
[8]:   item    score  user  rank Algorithm
0   285  4.543364    5     1  ItemItem
1  1449  4.532999    5     2  ItemItem
2  1251  4.494639    5     3  ItemItem
3   114  4.479512    5     4  ItemItem
4   166  4.399639    5     5  ItemItem
```

To compute our analysis, we also need to concatenate the test data into a single frame:

```
[9]: test_data = pd.concat(test_data, ignore_index=True)
```

We analyze our recommendation lists with a `RecListAnalysis`. It takes care of the hard work of making sure that the truth data (our test data) and the recommendations line up properly.

We do assume here that each user only appears once per algorithm. Since our crossfold method partitions users, this is fine.

```
[10]: rla = topn.RecListAnalysis()
      rla.add_metric(topn.ndcg)
      results = rla.compute(all_recs, test_data)
      results.head()
```

```
/home/MICHAELEKSTRAND/anaconda3/envs/lkpy-dev/lib/python3.7/site-packages/pandas/core/
↳ indexing.py:1494: PerformanceWarning: indexing past lexsort depth may impact_
↳ performance.
      return self._getitem_tuple(key)
```

```
[10]:
```

		ndcg
user	Algorithm	
1	ALS	0.265268
	ItemItem	0.259708
2	ALS	0.148335
	ItemItem	0.081890
3	ALS	0.026615

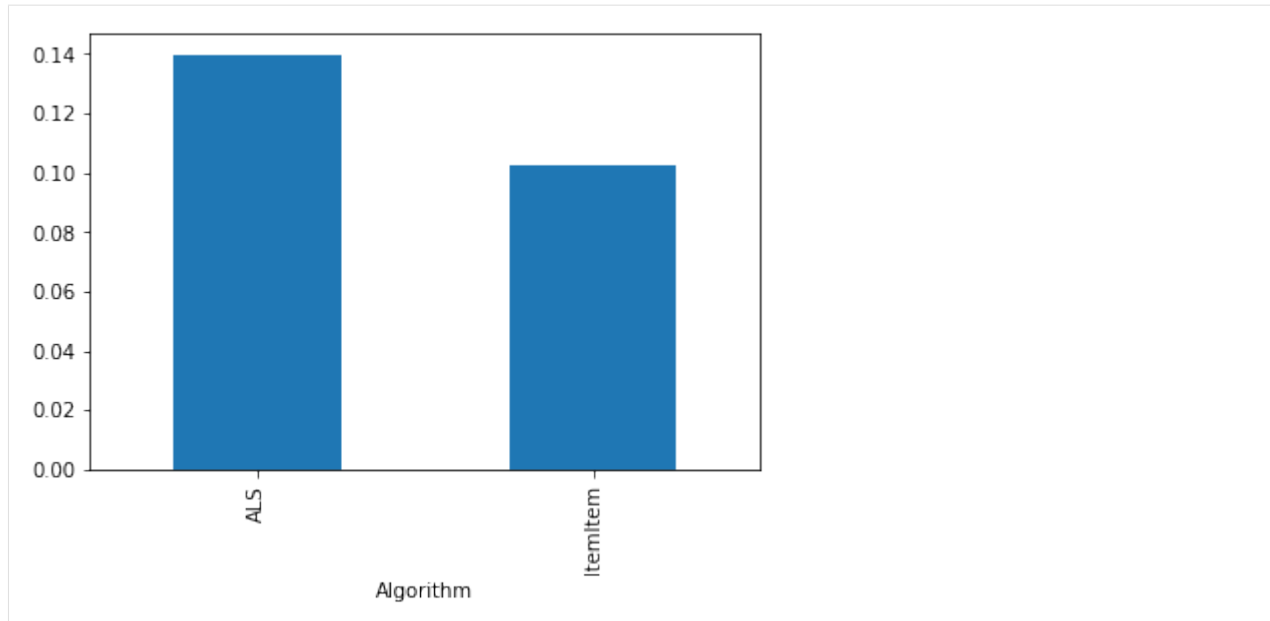
Now we have nDCG values!

```
[11]: results.groupby('Algorithm').ndcg.mean()
```

```
[11]: Algorithm
      ALS      0.139689
      ItemItem  0.102075
      Name: ndcg, dtype: float64
```

```
[12]: results.groupby('Algorithm').ndcg.mean().plot.bar()
```

```
[12]: <matplotlib.axes._subplots.AxesSubplot at 0x7f03842f8860>
```



[]:

2.2 Algorithm Interfaces

LKPY's batch routines and utility support for managing algorithms expect algorithms to implement consistent interfaces. This page describes those interfaces.

The interfaces are realized as abstract base classes with the Python `abc` module. Implementations must be registered with their interfaces, either by subclassing the interface or by calling `abc.ABCMeta.register()`.

2.2.1 Serialization

Like SciKit models, all LensKit algorithms are pickleable, and this is how we recommend saving models to disk for later use. This can be done with `pickle`, but we recommend using `binpickle` for more automatically-optimized storage. For example, to save a fully-configured ALS module with fairly aggressive ZSTD compression:

```
algo = Recommender.adapt(ImplicitMF(50))
algo.fit(ratings)
binpickle.dump(algo, binpickle.codecs.Blosc('zstd', 9))
```

2.2.2 Base Algorithm

Algorithms follow the SciKit fit-predict paradigm for estimators, except they know natively how to work with Pandas objects.

The *Algorithm* interface defines common methods.

class `lenskit.algorithms.Algorithm`

Base class for LensKit algorithms. These algorithms follow the SciKit design pattern for estimators.

abstract fit (*ratings*, ***kwargs*)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

get_params (*deep=True*)

Get the parameters for this algorithm (as in scikit-learn). Algorithm parameters should match constructor argument names.

The default implementation returns all attributes that match a constructor parameter name. It should be compatible with `scikit.base.BaseEstimator.get_params()` method so that LensKit algorithms can be cloned with `scikit.base.clone()` as well as `lenskit.util.clone()`.

Returns the algorithm parameters.

Return type `dict`

2.2.3 Recommendation

The *Recommender* interface provides an interface to generating recommendations. Not all algorithms implement it; call *Recommender.adapt()* on an algorithm to get a recommender for any algorithm that at least implements *Predictor*. For example:

```
pred = Bias(damping=5)
rec = Recommender.adapt(pred)
```

Note: We are rethinking the ergonomics of this interface, and it may change in LensKit 0.6. We expect keep compatibility in the `lenskit.batch.recommend()` API, though.

class `lenskit.algorithms.Recommender`

Recommends lists of items for users.

classmethod `adapt` (*algo*)

Ensure that an algorithm is a *Recommender*. If it is not a recommender, it is wrapped in a `lenskit.basic.TopN` with a default candidate selector.

Note: Since 0.6.0, since algorithms are fit directly, you should call this method **before** calling *Algorithm.fit()*, unless you will always be passing explicit candidate sets to *recommend()*.

Parameters *algo* (*Predictor*) – the underlying rating predictor.

abstract recommend (*user*, *n=None*, *candidates=None*, *ratings=None*)

Compute recommendations for a user.

Parameters

- **user** – the user ID

- **n** (*int*) – the number of recommendations to produce (*None* for unlimited)
- **candidates** (*array-like*) – The set of valid candidate items; if *None*, a default set will be used. For many algorithms, this is their *CandidateSelector*.
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns a frame with an *item* column; if the recommender also produces scores, they will be in a *score* column.

Return type *pandas.DataFrame*

2.2.4 Candidate Selection

Some recommenders use a *candidate selector* to identify possible items to recommend. These are also treated as algorithms, mainly so that they can memorize users’ prior ratings to exclude them from recommendation.

class *lenskit.algorithms.CandidateSelector*

Select candidates for recommendation for a user, possibly with some additional ratings.

UnratedItemCandidateSelector is the default and most common implementation of this interface.

abstract candidates (*user*, *ratings=None*)

Select candidates for the user.

Parameters

- **user** – The user key or ID.
- **ratings** (*pandas.Series* or *array-like*) – Ratings or items to use instead of whatever ratings were memorized for this user. If a *pandas.Series*, the series index is used; if it is another array-like it is assumed to be an array of items.

static rated_items (*ratings*)

Utility function for converting a series or array into an array of item IDs. Useful in implementations of *candidates()*.

2.2.5 Rating Prediction

class *lenskit.algorithms.Predictor*

Predicts user ratings of items. Predictions are really estimates of the user’s like or dislike, and the *Predictor* interface makes no guarantees about their scale or granularity.

predict (*pairs*, *ratings=None*)

Compute predictions for user-item pairs. This method is designed to be compatible with the general SciKit paradigm; applications typically want to use *predict_for_user()*.

Parameters

- **pairs** (*pandas.DataFrame*) – The user-item pairs, as *user* and *item* columns.
- **ratings** (*pandas.DataFrame*) – user-item rating data to replace memorized data.

Returns The predicted scores for each user-item pair.

Return type *pandas.Series*

abstract predict_for_user (*user*, *items*, *ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

2.3 Crossfold preparation

The LKPY *crossfold* module provides support for preparing data sets for cross-validation. Crossfold methods are implemented as functions that operate on data frames and return generators of (*train*, *test*) pairs (*lenskit.crossfold.TTPair* objects). The train and test objects in each pair are also data frames, suitable for evaluation or writing out to a file.

Crossfold methods make minimal assumptions about their input data frames, so the frames can be ratings, purchases, or whatever. They do assume that each row represents a single data point for the purpose of splitting and sampling.

Experiment code should generally use these functions to prepare train-test files for training and evaluating algorithms. For example, the following will perform a user-based 5-fold cross-validation as was the default in the old LensKit:

```
import pandas as pd
import lenskit.crossfold as xf
ratings = pd.read_csv('ml-20m/ratings.csv')
ratings = ratings.rename(columns={'userId': 'user', 'movieId': 'item'})
for i, tp in enumerate(xf.partition_users(ratings, 5, xf.SampleN(5))):
    tp.train.to_csv('ml-20m.exp/train-%d.csv' % (i,))
    tp.train.to_parquet('ml-20m.exp/train-%d.parquet' % (i,))
    tp.test.to_csv('ml-20m.exp/test-%d.csv' % (i,))
    tp.test.to_parquet('ml-20m.exp/test-%d.parquet' % (i,))
```

2.3.1 Row-based splitting

The simplest preparation methods sample or partition the rows in the input frame. A 5-fold *partition_rows()* split will result in 5 splits, each of which extracts 20% of the rows for testing and leaves 80% for training.

lenskit.crossfold.partition_rows (*data*, *partitions*, *, *rng_spec=None*)

Partition a frame of ratings or other data into train-test partitions. This function does not care what kind of data is in *data*, so long as it is a Pandas DataFrame (or equivalent).

Parameters

- **data** (*pandas.DataFrame*) – Ratings or other data you wish to partition.
- **partitions** (*int*) – The number of partitions to produce.
- **rng_spec** – The random number generator or seed (see *lenskit.util.rng()*).

Returns an iterator of train-test pairs

Return type iterator

lenskit.crossfold.sample_rows (*data*, *partitions*, *size*, *disjoint=True*, *, *rng_spec=None*)

Sample train-test a frame of ratings into train-test partitions. This function does not care what kind of data is in *data*, so long as it is a Pandas DataFrame (or equivalent).

We can loop over a sequence of train-test pairs:

```
>>> from lenskit import datasets
>>> ratings = datasets.MovieLens('ml-latest-small').ratings
>>> for train, test in sample_rows(ratings, 5, 1000):
...     print(len(test))
1000
1000
1000
1000
1000
```

Sometimes for testing, it is useful to just get a single pair:

```
>>> train, test = sample_rows(ratings, None, 1000)
>>> len(test)
1000
>>> len(test) + len(train) - len(ratings)
0
```

Parameters

- **data** (*pandas.DataFrame*) – Data frame containing ratings or other data to partition.
- **partitions** (*int* or *None*) – The number of partitions to produce. If *None*, produce a *_single_* train-test pair instead of an iterator or list.
- **size** (*int*) – The size of each sample.
- **disjoint** (*bool*) – If *True*, force samples to be disjoint.
- **rng_spec** – The random number generator or seed (see `lenskit.util.rng()`).

Returns An iterator of train-test pairs.

Return type iterator

2.3.2 User-based splitting

It's often desirable to use users, instead of raw rows, as the basis for splitting data. This allows you to control the experimental conditions on a user-by-user basis, e.g. by making sure each user is tested with the same number of ratings. These methods require that the input data frame have a *user* column with the user names or identifiers.

The algorithm used by each is as follows:

1. Sample or partition the set of user IDs into *n* sets of test users.
2. For each set of test users, select a set of that user's rows to be test rows.
3. **Create a training set for each test set consisting of the non-selected rows from each** of that set's test users, along with all rows from each non-test user.

`lenskit.crossfold.partition_users` (*data*, *partitions:* *int*, *method:* `lenskit.crossfold.PartitionMethod`, *, *rng_spec=None*)

Partition a frame of ratings or other data into train-test partitions user-by-user. This function does not care what kind of data is in *data*, so long as it is a Pandas DataFrame (or equivalent) and has a *user* column.

Parameters

- **data** (*pandas.DataFrame*) – a data frame containing ratings or other data you wish to partition.

- **partitions** (*int*) – the number of partitions to produce
- **method** (*PartitionMethod*) – The method for selecting test rows for each user.
- **rng_spec** – The random number generator or seed (see `lenskit.util.rng()`).

Returns iterator: an iterator of train-test pairs

```
lenskit.crossfold.sample_users (data, partitions: int, size: int, method:
                                lenskit.crossfold.PartitionMethod, disjoint=True, *,
                                rng_spec=None)
```

Create train-test partitions by sampling users. This function does not care what kind of data is in *data*, so long as it is a Pandas DataFrame (or equivalent) and has a *user* column.

Parameters

- **data** (*pandas.DataFrame*) – Data frame containing ratings or other data you wish to partition.
- **partitions** (*int*) – The number of partitions.
- **size** (*int*) – The sample size.
- **method** (*PartitionMethod*) – The method for obtaining user test ratings.
- **rng_spec** – The random number generator or seed (see `lenskit.util.rng()`).

Returns An iterator of train-test pairs (as *TTPair* objects).

Return type iterator

Selecting user test rows

These functions each take a *method* to decide how select each user's test rows. The method is a function that takes a data frame (containing just the user's rows) and returns the test rows. This function is expected to preserve the index of the input data frame (which happens by default with common means of implementing samples).

We provide several partition method factories:

```
lenskit.crossfold.SampleN (n, rng_spec=None)
    Randomly select a fixed number of test rows per user/item.
```

Parameters

- **n** (*int*) – the number of test items to select
- **rng** – the random number generator or seed

```
lenskit.crossfold.SampleFrac (frac, rng_spec=None)
    Randomly select a fraction of test rows per user/item.
```

Parameters **frac** (*float*) – the fraction items to select for testing.

```
lenskit.crossfold.LastN (n, col='timestamp')
    Select a fixed number of test rows per user/item, based on ordering by a column.
```

Parameters **n** (*int*) – The number of test items to select.

```
lenskit.crossfold.LastFrac (frac, col='timestamp')
    Select a fraction of test rows per user/item.
```

Parameters **frac** (*double*) – the fraction of items to select for testing.

2.3.3 Utility Classes

class `lenskit.crossfold.PartitionMethod`

Partition methods select test rows for a user or item. Partition methods are callable; when called with a data frame, they return the test rows.

abstract `__call__` (*udf*)

Subset a data frame.

Parameters *udf* (`pandas.DataFrame`) – The input data frame of rows for a user or item.

Returns The data frame of test rows, a subset of *udf*.

Return type `pandas.DataFrame`

class `lenskit.crossfold.TTPair`

Train-test pair (named tuple).

property `test`

Test data for this pair.

property `train`

Train data for this pair.

2.4 Batch-Running Recommenders

The functions in `lenskit.batch` enable you to generate many recommendations or predictions at the same time, useful for evaluations and experiments.

The batch functions can parallelize over users.

Note: Scripts calling the batch recommendation or prediction facilities must be *protected*; that is, they should not directly perform their work when run, but should define functions and call a `main` function when run as a script, with a block like this at the end of the file:

```
def main():
    # do the actual work

if __name__ == '__main__':
    main()
```

This is to ensure compatibility with the parallel processing code, including in future LensKit versions. If you are using the batch functions from a Jupyter notebook, you should be fine - the Jupyter programs are appropriately protected.

2.4.1 Recommendation

`lenskit.batch.recommend` (*algo*, *users*, *n*, *candidates=None*, *, *n_jobs=None*, ***kwargs*)

Batch-recommend for multiple users. The provided algorithm should be a `algorithms.Recommender`.

Parameters

- **algo** – the algorithm
- **users** (*array-like*) – the users to recommend for
- **n** (*int*) – the number of recommendations to generate (None for unlimited)

- **candidates** – the users’ candidate sets. This can be a function, in which case it will be passed each user ID; it can also be a dictionary, in which case user IDs will be looked up in it. Pass `None` to use the recommender’s built-in candidate selector (usually recommended).
- **n_jobs** (*int*) – The number of processes to use for parallel recommendations. Passed as `n_jobs` to `joblib.Parallel`. The default, `None`, will result in a call to `util.proc_count`(``None``())`, so the process will be the process sequential `_unless_` called inside the `joblib.parallel_backend()` context manager or the `LK_NUM_PROCS` environment variable is set.

Returns A frame with at least the columns `user`, `rank`, and `item`; possibly also `score`, and any other columns returned by the recommender.

2.4.2 Rating Prediction

`lenskit.batch.predict` (*algo, pairs, *, n_jobs=None, **kwargs*)

Generate predictions for user-item pairs. The provided algorithm should be a `algorithms.Predictor` or a function of two arguments: the user ID and a list of item IDs. It should return a dictionary or a `pandas.Series` mapping item IDs to predictions.

To use this function, provide a pre-fit algorithm:

```
>>> from lenskit.algorithms.basic import Bias
>>> from lenskit.metrics.predict import rmse
>>> from lenskit import datasets
>>> ratings = datasets.MovieLens('ml-latest-small').ratings
>>> bias = Bias()
>>> bias.fit(ratings[:~1000])
<lenskit.algorithms.basic.Bias object at ...>
>>> preds = predict(bias, ratings[~1000:])
>>> preds.head()
   user  item  rating  timestamp  prediction
99004   664   8361    3.0  1393891425    3.288286
99005   664   8528    3.5  1393891047    3.559119
99006   664   8529    4.0  1393891173    3.573008
99007   664   8636    4.0  1393891175    3.846268
99008   664   8641    4.5  1393890852    3.710635
>>> rmse(preds['prediction'], preds['rating'])
0.8326992222...
```

Parameters

- **algo** (`lenskit.algorithms.Predictor`) – A rating predictor function or algorithm.
- **pairs** (`pandas.DataFrame`) – A data frame of (user, item) pairs to predict for. If this frame also contains a `rating` column, it will be included in the result.
- **n_jobs** (*int*) – The number of processes to use for parallel batch prediction. Passed as `n_jobs` to `joblib.Parallel`. The default, `None`, will result in a call to `util.proc_count`(``None``())`, so the process will be the process sequential `_unless_` called inside the `joblib.parallel_backend()` context manager or the `LK_NUM_PROCS` environment variable is set.

Returns a frame with columns `user`, `item`, and `prediction` containing the prediction results. If `pairs` contains a `rating` column, this result will also contain a `rating` column.

Return type `pandas.DataFrame`

2.4.3 Scripting Evaluation

The *MultiEval* class is useful to build scripts that evaluate multiple algorithms or algorithm variants, simultaneously, across multiple data sets. It can extract parameters from algorithms and include them in the output, useful for hyperparameter search.

For example:

```
from lenskit.batch import MultiEval
from lenskit.crossfold import partition_users, SampleN
from lenskit.algorithms import basic, als
from lenskit.datasets import MovieLens
from lenskit import topn
import pandas as pd
```

Generate the train-test pairs:

```
ml = MovieLens('ml-latest-small')
pairs = list(partition_users(ml.ratings, 5, SampleN(5)))
```

Set up and run the MultiEval experiment:

```
eval = MultiEval('my-eval', recommend=20)
eval.add_datasets(pairs, name='ML-Small')
eval.add_algorithms(basic.Popular(), name='Pop')
eval.add_algorithms([als.BiasedMF(f) for f in [20, 30, 40, 50]],
                    attrs=['features'], name='ALS')
eval.run()
```

Now that the experiment is run, we can read its outputs.

First the run metadata:

```
runs = pd.read_csv('my-eval/runs.csv')
runs.set_index('RunId', inplace=True)
runs.head()
```

Then the recommendations:

```
recs = pd.read_parquet('my-eval/recommendations.parquet')
recs.head()
```

```
D:\Anaconda3\lib\site-packages\pyarrowpandas_compat.py:698: FutureWarning: .
  ↳ labels was deprecated in version 0.24.0. Use .codes instead.
    labels = getattr(columns, 'labels', None) or [
D:\Anaconda3\lib\site-packages\pyarrowpandas_compat.py:725: FutureWarning: the_
  ↳ 'labels' keyword is deprecated, use 'codes' instead
    return pd.MultiIndex(levels=new_levels, labels=labels, names=columns.names)
D:\Anaconda3\lib\site-packages\pyarrowpandas_compat.py:742: FutureWarning: .
  ↳ labels was deprecated in version 0.24.0. Use .codes instead.
    labels, = index.labels
```

In order to evaluate the recommendation list, we need to build a combined set of truth data. Since this is a disjoint partition of users over a single data set, we can just concatenate the individual test frames:

```
truth = pd.concat((p.test for p in pairs), ignore_index=True)
```

Now we can set up an analysis and compute the results.

```
rla = topn.RecListAnalysis()
rla.add_metric(topn.ndcg)
ndcg = rla.compute(recs, truth)
ndcg.head()
```

Next, we need to combine this with our run data, so that we know what algorithms and configurations we are evaluating:

```
ndcg = ndcg.join(runs[['AlgoClass', 'features']], on='RunId')
ndcg.head()
```

The Popular algorithm has NaN feature count, which groupby doesn't like; let's fill those in.

```
ndcg.loc[ndcg['AlgoClass'] == 'Popular', 'features'] = 0
```

And finally, we can compute the overall average performance for each algorithm configuration:

```
ndcg.groupby(['AlgoClass', 'features'])['ndcg'].mean()
```

```
AlgoClass  features
BiasedMF   20.0      0.015960
           30.0      0.022558
           40.0      0.025901
           50.0      0.028949
Popular    0.0      0.091814
Name: ndcg, dtype: float64
```

Multi-Eval Class Reference

```
class lenskit.batch.MultiEval(path, *, predict=True, recommend=100, candidates=None,
                               save_models=False, eval_n_jobs=None, combine=True,
                               **kwargs)
```

A runner for carrying out multiple evaluations, such as parameter sweeps.

Parameters

- **path** (str or `pathlib.Path`) – the working directory for this evaluation. It will be created if it does not exist.
- **predict** (*bool*) – whether to generate rating predictions.
- **recommend** (*int*) – the number of recommendations to generate per user. Any false-y value (`None`, `False`, `0`) will disable top-n. The literal value `True` will generate recommendation lists of unlimited size.
- **candidates** (*function*) – the default candidate set generator for recommendations. It should take the training data and return a candidate generator, itself a function mapping user IDs to candidate sets. Pass `None` to use the default candidate set configured for each algorithm (recommended).
- **save_models** (*bool or str*) – save individual estimated models to disk. If `True`, models are pickled to `.pkl` files; if `'gzip'`, they are pickled to gzip-compressed `.pkl.gz` files; if `'joblib'`, they are pickled with `joblib.dump()` to uncompressed `.jlpkl` files.
- **eval_n_jobs** (*int or None*) – Value to pass to the `n_jobs` parameter in `lenskit.batch.predict()` and `lenskit.batch.recommend()`.

- **combine** (*bool*) – whether to combine output; if `False`, output will be left in separate files, if `True`, it will be in a single set of files (runs, recommendations, and predictions).

add_algorithms (*algorithms*, *attrs*=[], ***kwargs*)

Add one or more algorithms to the run.

Parameters

- **algorithms** (*algorithm or list*) – the algorithm(s) to add.
- **attrs** (*list of str*) – a list of attributes to extract from the algorithm objects and include in the run descriptions.
- **kwargs** – additional attributes to include in the run descriptions.

add_datasets (*data*, *name*=None, *candidates*=None, ***kwargs*)

Add one or more datasets to the run.

Parameters

- **data** – The input data set(s) to run. Can be one of the following:
 - A tuple of (train, test) data.
 - An iterable of (train, test) pairs, in which case the iterable is not consumed until it is needed.
 - A function yielding either of the above, to defer data load until it is needed.

Data can be either data frames or paths; paths are loaded after detection using `util.read_df_detect()`.

- **kwargs** – additional attributes pertaining to these data sets.

collect_results ()

Collect the results from non-combined runs into combined output files.

persist_data ()

Persist the data for an experiment, replacing in-memory data sets with file names. Once this has been called, the sweep can be pickled.

run (*runs*=None, ***, *progress*=None)

Run the evaluation.

Parameters

- **runs** (*int or set-like*) – If provided, a specific set of runs to run. Useful for splitting an experiment into individual runs. This is a set of 1-based run IDs, not 0-based indexes.
- **progress** – A `tqdm.tqdm()`-compatible progress function.

run_count ()

Get the number of runs in this evaluation.

2.5 Evaluating Recommender Output

LensKit's evaluation support is based on post-processing the output of recommenders and predictors. The `batch` utilities provide support for generating these outputs.

We generally recommend using `Jupyter` notebooks for evaluation.

2.5.1 Prediction Accuracy Metrics

The `lenskit.metrics.predict` module contains prediction accuracy metrics. These are intended to be used as a part of a Pandas split-apply-combine operation on a data frame that contains both predictions and ratings; for convenience, the `lenskit.batch.predict()` function will include ratings in the prediction frame when its input user-item pairs contains ratings. So you can perform the following to compute per-user RMSE over some predictions:

```
from lenskit.datasets import MovieLens
from lenskit.algorithms.basic import Bias
from lenskit.batch import predict
from lenskit.metrics.predict import rmse

ratings = MovieLens('ml-small').ratings.sample(frac=10)
test = ratings.iloc[:1000]
train = ratings.iloc[1000:]
algo = Bias()
algo.fit(train)
preds = predict(algo, pairs)
user_rmse = preds.groupby('user').apply(lambda df: rmse(df.prediction, df.rating))
user_rmse.mean()
```

Metric Functions

Prediction metric functions take two series, *predictions* and *truth*.

`lenskit.metrics.predict.rmse(predictions, truth, missing='error')`

Compute RMSE (root mean squared error).

Parameters

- **predictions** (`pandas.Series`) – the predictions
- **truth** (`pandas.Series`) – the ground truth ratings from data
- **missing** (`string`) – how to handle predictions without truth. Can be one of 'error' or 'ignore'.

Returns the root mean squared approximation error

Return type double

`lenskit.metrics.predict.mae(predictions, truth, missing='error')`

Compute MAE (mean absolute error).

Parameters

- **predictions** (`pandas.Series`) – the predictions
- **truth** (`pandas.Series`) – the ground truth ratings from data
- **missing** (`string`) – how to handle predictions without truth. Can be one of 'error' or 'ignore'.

Returns the mean absolute approximation error

Return type double

Working with Missing Data

LensKit rating predictors do not report predictions when their core model is unable to predict. For example, a nearest-neighbor recommender will not score an item if it cannot find any suitable neighbors. Following the Pandas convention, these items are given a score of NaN (when Pandas implements better missing data handling, it will use that, so use `pandas.Series.isna()`/`pandas.Series.notna()`, not the `isnan` versions).

However, this causes problems when computing predictive accuracy: recommenders are not being tested on the same set of items. If a recommender only scores the easy items, for example, it could do much better than a recommender that is willing to attempt more difficult items.

A good solution to this is to use a *fallback predictor* so that every item has a prediction. In LensKit, `lenskit.algorithms.basic.Fallback` implements this functionality; it wraps a sequence of recommenders, and for each item, uses the first one that generates a score.

You set it up like this:

```
cf = ItemItem(20)
base = Bias(damping=5)
algo = Fallback(cf, base)
```

2.5.2 Top-*N* Evaluation

LensKit's support for top-*N* evaluation is in two parts, because there are some subtle complexities that make it more difficult to get the right data in the right place for computing metrics correctly.

Top-*N* Analysis

The `lenskit.topn` module contains the utilities for carrying out top-*N* analysis, in conjunction with `lenskit.batch.recommend()` and its wrapper in `lenskit.batch.MultiEval`.

The entry point to this is `RecListAnalysis`. This class encapsulates an analysis with one or more metrics, and can apply it to data frames of recommendations. An analysis requires two data frames: the recommendation frame contains the recommendations themselves, and the truth frame contains the ground truth data for the users. The analysis is flexible with regards to the columns that identify individual recommendation lists; usually these will consist of a user ID, data set identifier, and algorithm identifier(s), but the analysis is configurable and its defaults make minimal assumptions. The recommendation frame does need an `item` column with the recommended item IDs, and it should be in order within a single recommendation list.

The truth frame should contain (a subset of) the columns identifying recommendation lists, along with `item` and, if available, `rating` (if no rating is provided, the metrics that need a rating value will assume a rating of 1 for every item present). It can contain other items that custom metrics may find useful as well.

For example, a recommendation frame may contain:

- `DataSet`
- `Partition`
- `Algorithm`
- `user`
- `item`

- rank
- score

And the truth frame:

- DataSet
- user
- item
- rating

The analysis will use this truth as the relevant item data for measuring the accuracy of the recommendation lists. Recommendations will be matched to test ratings by data set, user, and item, using *RecListAnalysis* defaults.

class `lenskit.topn.RecListAnalysis` (*group_cols=None*)

Compute one or more top-N metrics over recommendation lists.

This method groups the recommendations by the specified columns, and computes the metric over each group. The default set of grouping columns is all columns *except* the following:

- item
- rank
- score
- rating

The truth frame, `truth`, is expected to match over (a subset of) the grouping columns, and contain at least an `item` column. If it also contains a `rating` column, that is used as the users' rating for metrics that require it; otherwise, a rating value of 1 is assumed.

Warning: Currently, `RecListAnalysis` will silently drop users who received no recommendations. We are working on an ergonomic API for fixing this problem.

Parameters `group_cols` (*list*) – The columns to group by, or `None` to use the default.

add_metric (*metric*, *, *name=None*, ***kwargs*)

Add a metric to the analysis.

A metric is a function of two arguments: the a single group of the recommendation frame, and the corresponding truth frame. The truth frame will be indexed by item ID. Many metrics are defined in `lenskit.metrics.topn`; they are re-exported from `lenskit.topn` for convenience.

Parameters

- **metric** – The metric to compute.
- **name** – The name to assign the metric. If not provided, the function name is used.
- ****kwargs** – Additional arguments to pass to the metric.

compute (*recs*, *truth*, *, *include_missing=False*)

Run the analysis. Neither data frame should be meaningfully indexed.

Parameters

- **recs** (*pandas.DataFrame*) – A data frame of recommendations.
- **truth** (*pandas.DataFrame*) – A data frame of ground truth (test) data.

- **include_missing** (*bool*) – True to include users from truth missing from recs. Matches are done via group columns that appear in both *recs* and *truth*.

Returns The results of the analysis.

Return type `pandas.DataFrame`

Metrics

The `lenskit.metrics.topn` module contains metrics for evaluating top-*N* recommendation lists.

Classification Metrics

These metrics treat the recommendation list as a classification of relevant items.

`lenskit.metrics.topn.precision` (*recs*, *truth*)
 Compute recommendation precision.

`lenskit.metrics.topn.recall` (*recs*, *truth*)
 Compute recommendation recall.

Ranked List Metrics

These metrics treat the recommendation list as a ranked list of items that may or may not be relevant.

`lenskit.metrics.topn.recip_rank` (*recs*, *truth*)
 Compute the reciprocal rank of the first relevant item in a list of recommendations.
 If no elements are relevant, the reciprocal rank is 0.

Utility Metrics

The NDCG function estimates a utility score for a ranked list of recommendations.

`lenskit.metrics.topn.ndcg` (*recs*, *truth*, *discount=<ufunc 'log2'>*)
 Compute the normalized discounted cumulative gain.

Discounted cumulative gain is computed as:

$$\text{DCG}(L, u) = \sum_{i=1}^{|L|} \frac{r_{ui}}{d(i)}$$

This is then normalized as follows:

$$\text{nDCG}(L, u) = \frac{\text{DCG}(L, u)}{\text{DCG}(L_{\text{ideal}}, u)}$$

Parameters

- **recs** – The recommendation list.
- **truth** – The user’s test data.
- **discount** (*ufunc*) – The rank discount function. Each item’s score will be divided the discount of its rank, if the discount is greater than 1.

We also expose the internal DCG computation directly.

```
lenskit.metrics.topn._dcg(scores, discount=<ufunc 'log2'>)
```

Compute the Discounted Cumulative Gain of a series of recommended items with rating scores. These should be relevance scores; they can be 0, 1 for binary relevance data.

This is not a true top-N metric, but is a utility function for other metrics.

Parameters

- **scores** (*array-like*) – The utility scores of a list of recommendations, in recommendation order.
- **discount** (*ufunc*) – the rank discount function. Each item’s score will be divided the discount of its rank, if the discount is greater than 1.

Returns the DCG of the scored items.

Return type double

2.5.3 Loading Outputs

We typically store the output of recommendation runs in LensKit experiments in CSV or Parquet files. The `lenskit.batch.MultiEval` class arranges to run a set of algorithms over a set of data sets, and store the results in a collection of Parquet files in a specified output directory.

There are several files:

runs.parquet The `_runs_`, algorithm-dataset combinations. This file contains the names & any associated properties of each algorithm and data set run, such as a feature count.

recommendations.parquet The recommendations, with columns `RunId`, `user`, `rank`, `item`, and `rating`.

predictions.parquet The rating predictions, if the test data includes ratings.

For example, if you want to examine nDCG by neighborhood count for a set of runs on a single data set, you can do:

```
import pandas as pd
from lenskit.metrics import topn as lm

runs = pd.read_parquet('eval-dir/runs.parquet')
recs = pd.read_parquet('eval-dir/recs.parquet')
meta = runs.loc[:, ['RunId', 'max_neighbors']]

# compute each user's nDCG
user_ndcg = recs.groupby(['RunId', 'user']).rating.apply(lm.ndcg)
user_ndcg = user_ndcg.reset_index(name='nDCG')
# combine with metadata for feature count
user_ndcg = pd.merge(user_ndcg, meta)
# group and aggregate
nbr_ndcg = user_ndcg.groupby('max_neighbors').nDCG.mean()
nbr_ndcg.plot()
```

2.6 Data Set Utilities

The `lenskit.datasets` module provides utilities for reading a variety of commonly-used LensKit data sets. It does not package or automatically download them, but loads them from a local directory where you have unpacked the data set. Each data set class or function takes a `path` parameter specifying the location of the data set.

The normal mode of operation for these utilities is to provide a class for the data set; this class then exposes the data set's data as attributes. These attributes are cached internally, so e.g. accessing `MovieLens.ratings` twice will only load the data file once.

These data files have normalized column names to fit with LensKit's general conventions. These are the following:

- User ID columns are called `user`.
- Item ID columns are called `item`.
- Rating columns are called `rating`.
- Timestamp columns are called `timestamp`.

Other column names are unchanged. Data tables that provide information about specific things, such as a table of movie titles, are indexed by the relevant ID (e.g. `MovieLens.ratings` is indexed by `item`).

2.6.1 MovieLens Data Sets

The GroupLens research group provides several data sets extracted from the MovieLens service [ML]. These can be downloaded from <https://grouplens.org/datasets/movielens/>.

class `lenskit.datasets.MovieLens` (`path='data/ml-20m'`)

Code for reading current MovieLens data sets, including ML-20M, ML-Latest, and ML-Latest-Small.

Parameters `path` (`str` or `pathlib.Path`) – Path to the directory containing the data set.

property links

The movie link table, connecting movie IDs to external identifiers. It is indexed by movie ID.

```
>>> mlsmall = MovieLens('ml-latest-small')
>>> mlsmall.links
      imdbId  tmdbId
item
1         114709      862
2         113497     8844
3         113228     15602
4         114885     31357
5         113041     11862
...
[9125 rows x 2 columns]
```

property movies

The movie table, with titles and genres. It is indexed by movie ID.

```
>>> mlsmall = MovieLens('ml-latest-small')
>>> mlsmall.movies
      genres                                     title
item
1         Toy Story (1995)
↪Adventure|Animation|Children|Comedy|Fantasy
2         Jumanji (1995)
↪Adventure|Children|Fantasy
```

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```

3          Comedy|Romance      Grumpier Old Men (1995)
↳
4          Comedy|Drama|Romance  Waiting to Exhale (1995)
↳
5          Comedy              Father of the Bride Part II (1995)
↳
...
[9125 rows x 2 columns]
```

property ratings

The rating table.

```

>>> mlsmall = MovieLens('ml-latest-small')
>>> mlsmall.ratings
      user  item  rating  timestamp
0        1    31     2.5  1260759144
1        1  1029     3.0  1260759179
2        1  1061     3.0  1260759182
3        1  1129     2.0  1260759185
4        1  1172     4.0  1260759205
...
[100004 rows x 4 columns]
```

property tag_genome

The tag genome table, recording inferred item-tag relevance scores. This gets returned as a wide Pandas data frame, with rows indexed by item ID.

property tags

The tag application table, recording user-supplied tags for movies.

```

>>> mlsmall = MovieLens('ml-latest-small')
>>> mlsmall.tags
      user  ...  timestamp
0        15  ...  1138537770
1        15  ...  1193435061
2        15  ...  1170560997
3        15  ...  1170626366
4        15  ...  1141391765
...
[1296 rows x 4 columns]
```

class `lenskit.datasets.ML100K` (*path*='data/ml-100k')

The MovieLens 100K data set. This older data set is in a different format from the more current data sets loaded by *MovieLens*.

property available

Query whether the data set exists.

property movies

Return the user data (from `u.user`).

```

>>> ml = ML100K('ml-100k')
>>> ml.movies
      item  title  release  ...  War  Western
1         Toy Story (1995)  01-Jan-1995  ...    0    0
2         GoldenEye (1995)  01-Jan-1995  ...    0    0
```

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```
3          Four Rooms (1995) 01-Jan-1995 ... 0 0
4          Get Shorty (1995) 01-Jan-1995 ... 0 0
5          Copycat (1995) 01-Jan-1995 ... 0 0
...
[1682 rows x 23 columns]
```

property ratings

Return the rating data (from `u.data`).

```
>>> ml = ML100K('ml-100k')
>>> ml.ratings
      user  item  rating  timestamp
0      196   242     3.0   881250949
1      186   302     3.0   891717742
2       22   377     1.0   878887116
3      244    51     2.0   880606923
4      166   346     1.0   886397596
...
[100000 rows x 4 columns]
```

property users

Return the user data (from `u.user`).

```
>>> ml = ML100K('ml-100k')
>>> ml.users
      age gender  occupation  zip
user
1      24     M  technician  85711
2      53     F    other     94043
3      23     M    writer     32067
4      24     M  technician  43537
5      33     F    other     15213
...
[943 rows x 4 columns]
```

class `lenskit.datasets.ML1M` (*path*='data/ml-1m')
MovieLens 1M data set.

Note: Some documentation examples use ML-10M100K; that is because this class shares implementation with the 10M data set.

property movies

Return the movie data (from `movies.dat`). Indexed by movie ID.

```
>>> ml = ML10M()
>>> ml.movies
      genres  title
item
1      Toy Story (1995)
↳ Adventure|Animation|Children|Comedy|Fantasy
2      Jumanji (1995)
↳ Adventure|Children|Fantasy
3      Grumpier Old Men (1995)
↳ Comedy|Romance
```

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```

4          Comedy|Drama|Romance      Waiting to Exhale (1995)
↳
5          Comedy                    Father of the Bride Part II (1995)
↳
...
[10681 rows x 2 columns]
```

property ratings

Return the rating data (from `ratings.dat`).

```

>>> ml = ML10M()
>>> ml.ratings
      user  item  rating  timestamp
0         1   122     5.0   838985046
1         1   185     5.0   838983525
2         1   231     5.0   838983392
3         1   292     5.0   838983421
4         1   316     5.0   838983392
...
[10000054 rows x 4 columns]
```

property users

Return the movie data (from `users.dat`). Indexed by user ID.

```

>>> ml = ML1M()
>>> ml.users
      gender  age   zip
user
1         F    1  48067
2         M   56  70072
3         M   25  55117
4         M   45  02460
5         M   25  55455
...
[6040 rows x 3 columns]
```

class `lenskit.datasets.ML10M` (*path*='data/ml-10M100K')

MovieLens 10M100K data set.

property movies

Return the movie data (from `movies.dat`). Indexed by movie ID.

```

>>> ml = ML10M()
>>> ml.movies
      genres                                     title
item
1          Toy Story (1995)
↳Adventure|Animation|Children|Comedy|Fantasy
2          Jumanji (1995)
↳Adventure|Children|Fantasy
3          Grumpier Old Men (1995)
↳Comedy|Romance
4          Waiting to Exhale (1995)
↳Comedy|Drama|Romance
5          Father of the Bride Part II (1995)
↳Comedy
```

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```
...
[10681 rows x 2 columns]
```

property ratings

Return the rating data (from `ratings.dat`).

```
>>> ml = ML10M()
>>> ml.ratings
      user  item  rating  timestamp
0         1   122     5.0   838985046
1         1   185     5.0   838983525
2         1   231     5.0   838983392
3         1   292     5.0   838983421
4         1   316     5.0   838983392
...
[10000054 rows x 4 columns]
```

2.7 Algorithms

LKPY provides general algorithmic concepts, along with implementations of several algorithms. These algorithm interfaces are based on the SciKit design patterns [SKAPI], adapted for Pandas-based data structures.

2.7.1 Basic and Utility Algorithms

The `lenskit.algorithms.basic` module contains baseline and utility algorithms for nonpersonalized recommendation and testing.

Personalized Mean Rating Prediction

class `lenskit.algorithms.basic.Bias` (*items=True, users=True, damping=0.0*)

Bases: `lenskit.algorithms.Predictor`

A user-item bias rating prediction algorithm. This implements the following predictor algorithm:

$$s(u, i) = \mu + b_i + b_u$$

where μ is the global mean rating, b_i is item bias, and b_u is the user bias. With the provided damping values β_u and β_i , they are computed as follows:

$$\mu = \frac{\sum_{r_{ui} \in R} r_{ui}}{|R|} \quad b_i = \frac{\sum_{r_{ui} \in R_i} (r_{ui} - \mu)}{|R_i| + \beta_i} \quad b_u = \frac{\sum_{r_{ui} \in R_u} (r_{ui} - \mu - b_i)}{|R_u| + \beta_u}$$

The damping values can be interpreted as the number of default (mean) ratings to assume *a priori* for each user or item, damping low-information users and items towards a mean instead of permitting them to take on extreme values based on few ratings.

Parameters

- **items** – whether to compute item biases
- **users** – whether to compute user biases

- **damping** (*number or tuple*) – Bayesian damping to apply to computed biases. Either a number, to damp both user and item biases the same amount, or a (user,item) tuple providing separate damping values.

mean__

The global mean rating.

Type `double`

item_offsets__

The item offsets (b_i values)

Type `pandas.Series`

user_offsets__

The item offsets (b_u values)

Type `pandas.Series`

fit (*ratings, **kwargs*)

Train the bias model on some rating data.

Parameters **ratings** (*DataFrame*) – a data frame of ratings. Must have at least *user*, *item*, and *rating* columns.

Returns the fit bias object.

Return type *Bias*

predict_for_user (*user, items, ratings=None*)

Compute predictions for a user and items. Unknown users and items are assumed to have zero bias.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, will be used to recompute the user’s bias at prediction time.

Returns scores for the items, indexed by item id.

Return type `pandas.Series`

Most Popular Item Recommendation

The *Popular* algorithm implements most-popular-item recommendation.

class `lenskit.algorithms.basic.Popular` (*selector=None*)

Bases: `lenskit.algorithms.Recommender`

Recommend the most popular items.

Parameters **selector** (*CandidateSelector*) – The candidate selector to use. If *None*, uses a new *UnratedItemCandidateSelector*.

item_pop__

Item rating counts (popularity)

Type `pandas.Series`

fit (*ratings, **kwargs*)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

recommend (*user*, *n=None*, *candidates=None*, *ratings=None*)
 Compute recommendations for a user.

Parameters

- **user** – the user ID
- **n** (*int*) – the number of recommendations to produce (*None* for unlimited)
- **candidates** (*array-like*) – The set of valid candidate items; if *None*, a default set will be used. For many algorithms, this is their *CandidateSelector*.
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns a frame with an *item* column; if the recommender also produces scores, they will be in a *score* column.

Return type *pandas.DataFrame*

Random Item Recommendation

The *Random* algorithm implements random-item recommendation.

class *lenskit.algorithms.basic.Random* (*selector=None*, *rng_spec=None*)

Bases: *lenskit.algorithms.Recommender*

A random-item recommender.

selector

Selects candidate items for recommendation. Default is *UnratedItemCandidateSelector*.

Type *CandidateSelector*

rng_spec

Seed or random state for generating recommendations. Pass 'user' to deterministically derive per-user RNGS from the user IDs for reproducibility.

fit (*ratings*, ***kwargs*)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

recommend (*user*, *n=None*, *candidates=None*, *ratings=None*)
 Compute recommendations for a user.

Parameters

- **user** – the user ID
- **n** (*int*) – the number of recommendations to produce (*None* for unlimited)
- **candidates** (*array-like*) – The set of valid candidate items; if *None*, a default set will be used. For many algorithms, this is their *CandidateSelector*.
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns a frame with an *item* column; if the recommender also produces scores, they will be in a *score* column.

Return type *pandas.DataFrame*

Top-N Recommender

The *TopN* class implements a standard top-*N* recommender that wraps a *Predictor* and *CandidateSelector* and returns the top *N* candidate items by predicted rating. It is the type of recommender returned by *Recommender.adapt()* if the provided algorithm is not a recommender.

class *lenskit.algorithms.basic.TopN* (*predictor*, *selector=None*)

Bases: *lenskit.algorithms.Recommender*, *lenskit.algorithms.Predictor*

Basic recommender that implements top-*N* recommendation using a predictor.

Note: This class does not do anything of its own in *fit()*. If its predictor and candidate selector are both fit, the top-*N* recommender does not need to be fit.

Parameters

- **predictor** (*Predictor*) – The underlying predictor.
- **selector** (*CandidateSelector*) – The candidate selector. If *None*, uses *UnratedItemCandidateSelector*.

fit (*ratings*, ***kwargs*)

Fit the recommender.

Parameters

- **ratings** (*pandas.DataFrame*) – The rating or interaction data. Passed changed to the predictor and candidate selector.
- **kwargs** (*args*,) – Additional arguments for the predictor to use in its training process.

predict (*pairs*, *ratings=None*)

Compute predictions for user-item pairs. This method is designed to be compatible with the general SciKit paradigm; applications typically want to use *predict_for_user()*.

Parameters

- **pairs** (*pandas.DataFrame*) – The user-item pairs, as *user* and *item* columns.
- **ratings** (*pandas.DataFrame*) – user-item rating data to replace memorized data.

Returns The predicted scores for each user-item pair.

Return type *pandas.Series*

predict_for_user (*user, items, ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

recommend (*user, n=None, candidates=None, ratings=None*)

Compute recommendations for a user.

Parameters

- **user** – the user ID
- **n** (*int*) – the number of recommendations to produce (*None* for unlimited)
- **candidates** (*array-like*) – The set of valid candidate items; if *None*, a default set will be used. For many algorithms, this is their *CandidateSelector*.
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns a frame with an *item* column; if the recommender also produces scores, they will be in a *score* column.

Return type *pandas.DataFrame*

Unrated Item Candidate Selector

UnratedItemCandidateSelector is a candidate selector that remembers items users have rated, and returns a candidate set consisting of all unrated items. It is the default candidate selector for *TopN*.

class *lenskit.algorithms.basic.UnratedItemCandidateSelector*

Bases: *lenskit.algorithms.CandidateSelector*

CandidateSelector that selects items a user has not rated as candidates. When this selector is fit, it memorizes the rated items.

items _

All known items.

Type *pandas.Index*

users _

All known users.

Type *pandas.Index*

user_items _

Items rated by each known user, as positions in the *items* index.

Type *CSR*

candidates (*user, ratings=None*)

Select candidates for the user.

Parameters

- **user** – The user key or ID.
- **ratings** (*pandas.Series* or *array-like*) – Ratings or items to use instead of whatever ratings were memorized for this user. If a *pandas.Series*, the series index is used; if it is another array-like it is assumed to be an array of items.

fit (*ratings*, ***kwargs*)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

Fallback Predictor

The `Fallback` rating predictor is a simple hybrid that takes a list of composite algorithms, and uses the first one to return a result to predict the rating for each item.

A common case is to fill in with *Bias* when a primary predictor cannot score an item.

class `lenskit.algorithms.basic.Fallback` (*algorithms*, **others*)

Bases: `lenskit.algorithms.Predictor`

The `Fallback` algorithm predicts with its first component, uses the second to fill in missing values, and so forth.

fit (*ratings*, ***kwargs*)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

predict_for_user (*user*, *items*, *ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

Memorized Predictor

The `Memorized` recommender is primarily useful for test cases. It memorizes a set of rating predictions and returns them.

class `lenskit.algorithms.basic.Memorized`(*scores*)

Bases: `lenskit.algorithms.Predictor`

The memorized algorithm memorizes scores provided at construction time.

fit (*args, **kwargs)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (`pandas.DataFrame`) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

predict_for_user (*user*, *items*, *ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (`pandas.Series`) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type `pandas.Series`

2.7.2 k-NN Collaborative Filtering

LKPY provides user- and item-based classical k-NN collaborative Filtering implementations. These lightly-configurable implementations are intended to capture the behavior of the Java-based LensKit implementations to provide a good upgrade path and enable basic experiments out of the box.

Item-based k-NN

class `lenskit.algorithms.item_knn.ItemItem`(*nbrs*, *min_nbrs=1*, *min_sim=1e-06*, *save_nbrs=None*, *center=True*, *aggregate='weighted-average'*)

Bases: `lenskit.algorithms.Predictor`

Item-item nearest-neighbor collaborative filtering with ratings. This item-item implementation is not terribly configurable; it hard-codes design decisions found to work well in the previous Java-based LensKit code.

Parameters

- **nbrs** (*int*) – the maximum number of neighbors for scoring each item (None for unlimited)
- **min_nbrs** (*int*) – the minimum number of neighbors for scoring each item

- **min_sim** (*double*) – minimum similarity threshold for considering a neighbor
- **save_nbrs** (*double*) – the number of neighbors to save per item in the trained model (None for unlimited)
- **center** (*bool*) – whether to normalize (mean-center) rating vectors. Turn this off when working with unary data and other data types that don’t respond well to centering.
- **aggregate** – the type of aggregation to do. Can be *weighted-average* or *sum*.

item_index__
the index of item IDs.

Type *pandas.Index*

item_means__
the mean rating for each known item.

Type *numpy.ndarray*

item_counts__
the number of saved neighbors for each item.

Type *numpy.ndarray*

sim_matrix__
the similarity matrix.

Type *matrix.CSR*

user_index__
the index of known user IDs for the rating matrix.

Type *pandas.Index*

rating_matrix__
the user-item rating matrix for looking up users’ ratings.

Type *matrix.CSR*

fit (*ratings*, ***kwargs*)
Train a model.

The model-training process depends on *save_nbrs* and *min_sim*, but *not* on other algorithm parameters.

Parameters **ratings** (*pandas.DataFrame*) – (user,item,rating) data for computing item similarities.

predict_for_user (*user*, *items*, *ratings=None*)
Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

User-based k-NN

class `lenskit.algorithms.user_knn.UserUser` (*nnbrs*, *min_nbrs*=1, *min_sim*=0, *center*=True, *aggregate*='weighted-average')

Bases: `lenskit.algorithms.Predictor`

User-user nearest-neighbor collaborative filtering with ratings. This user-user implementation is not terribly configurable; it hard-codes design decisions found to work well in the previous Java-based LensKit code.

Parameters

- **nnbrs** (*int*) – the maximum number of neighbors for scoring each item (None for unlimited)
- **min_nbrs** (*int*) – the minimum number of neighbors for scoring each item
- **min_sim** (*double*) – minimum similarity threshold for considering a neighbor
- **center** (*bool*) – whether to normalize (mean-center) rating vectors. Turn this off when working with unary data and other data types that don't respond well to centering.
- **aggregate** – the type of aggregation to do. Can be `weighted-average` or `sum`.

user_index _

User index.

Type `pandas.Index`

item_index _

Item index.

Type `pandas.Index`

user_means _

User mean ratings.

Type `numpy.ndarray`

rating_matrix _

Normalized user-item rating matrix.

Type `matrix.CSR`

transpose_matrix _

Transposed un-normalized rating matrix.

Type `matrix.CSR`

fit (*ratings*, ***kwargs*)

“Train” a user-user CF model. This memorizes the rating data in a format that is usable for future computations.

Parameters **ratings** (`pandas.DataFrame`) – (user, item, rating) data for collaborative filtering.

Returns a memorized model for efficient user-based CF computation.

Return type UUModel

predict_for_user (*user*, *items*, *ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict

- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, will be used to recompute the user’s bias at prediction time.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

2.7.3 Classic Matrix Factorization

LKPY provides classical matrix factorization implementations.

- *Common Support*
- *Alternating Least Squares*
- *FunkSVD*

Common Support

The `mf_common` module contains common support code for matrix factorization algorithms. These classes, *MFPredictor* and *BiasMFPredictor*, define the parameters that are estimated during the *Algorithm.fit()* process on common matrix factorization algorithms.

class `lenskit.algorithms.mf_common.MFPredictor`

Common predictor for matrix factorization.

user_index__

Users in the model (length=:math:m).

Type *pandas.Index*

item_index__

Items in the model (length=:math:n).

Type *pandas.Index*

user_features__

The $m \times k$ user-feature matrix.

Type *numpy.ndarray*

item_features__

The $n \times k$ item-feature matrix.

Type *numpy.ndarray*

lookup_items (*items*)

Look up the indices for a set of items.

Parameters **items** (*array-like*) – the item IDs to look up.

Returns the item indices. Unknown items will have negative indices.

Return type *numpy.ndarray*

lookup_user (*user*)

Look up the index for a user.

Parameters **user** – the user ID to look up

Returns the user index.

Return type `int`

property `n_features`

The number of features.

property `n_items`

The number of items.

property `n_users`

The number of users.

score (*user*, *items*)

Score a set of items for a user. User and item parameters must be indices into the matrices.

Parameters

- **user** (*int*) – the user index
- **items** (*array-like of int*) – the item indices
- **raw** (*bool*) – if True, do return raw scores without biases added back.

Returns the scores for the items.

Return type `numpy.ndarray`

class `lenskit.algorithms.mf_common.BiasMFPredictor`

Common model for biased matrix factorization.

user_index__

Users in the model (length=:math:m).

Type `pandas.Index`

item_index__

Items in the model (length=:math:n).

Type `pandas.Index`

global_bias__

The global bias term.

Type `double`

user_bias__

The user bias terms.

Type `numpy.ndarray`

item_bias__

The item bias terms.

Type `numpy.ndarray`

user_features__

The $m \times k$ user-feature matrix.

Type `numpy.ndarray`

item_features__

The $n \times k$ item-feature matrix.

Type `numpy.ndarray`

score (*user*, *items*, *raw=False*)

Score a set of items for a user. User and item parameters must be indices into the matrices.

Parameters

- **user** (*int*) – the user index
- **items** (*array-like of int*) – the item indices
- **raw** (*bool*) – if `True`, do return raw scores without biases added back.

Returns the scores for the items.

Return type `numpy.ndarray`

Alternating Least Squares

LensKit provides alternating least squares implementations of matrix factorization suitable for explicit feedback data. These implementations are parallelized with Numba, and perform best with the MKL from Conda.

```
class lenskit.algorithms.als.BiasedMF (features, *, iterations=20, reg=0.1, damp-
                                     ing=5, bias=True, method='cd', rng_spec=None,
                                     progress=None)
```

Bases: `lenskit.algorithms.mf_common.BiasMFPredictor`

Biased matrix factorization trained with alternating least squares [ZWSP2008]. This is a prediction-oriented algorithm suitable for explicit feedback data.

It provides two solvers for the optimization step (the *method* parameter):

'cd' (the default) Coordinate descent [TPT2011], adapted for a separately-trained bias model and to use weighted regularization as in the original ALS paper [ZWSP2008].

'lu' A direct implementation of the original ALS concept [ZWSP2008] using LU-decomposition to solve for the optimized matrices.

See the base class `BiasMFPredictor` for documentation on the estimated parameters you can extract from a trained model.

Parameters

- **features** (*int*) – the number of features to train
- **iterations** (*int*) – the number of iterations to train
- **reg** (*float*) – the regularization factor; can also be a tuple (*ureg*, *ireg*) to specify separate user and item regularization terms.
- **damping** (*float*) – damping factor for the underlying mean
- **bias** (*bool* or *Bias*) – the bias model. If `True`, fits a Bias with damping damping.
- **method** (*str*) – the solver to use (see above).
- **rng_spec** – Random number generator or state (see `lenskit.util.random.rng()`).
- **progress** – a `tqdm.tqdm()`-compatible progress bar function

fit (*ratings*, ***kwargs*)

Run ALS to train a model.

Parameters **ratings** – the ratings data frame.

Returns The algorithm (for chaining).

fit_iters (*ratings*, ***kwargs*)

Run ALS to train a model, returning each iteration as a generator.

Parameters `ratings` – the ratings data frame.

Returns The algorithm (for chaining).

predict_for_user (*user*, *items*, *ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

class `lenskit.algorithms.als.ImplicitMF` (*features*, *, *iterations=20*, *reg=0.1*, *weight=40*,
method='cg', *rng_spec=None*, *progress=None*)

Bases: *lenskit.algorithms.mf_common.MFPredictor*

Implicit matrix factorization trained with alternating least squares [HKV2008]. This algorithm outputs ‘predictions’, but they are not on a meaningful scale. If its input data contains `rating` values, these will be used as the ‘confidence’ values; otherwise, confidence will be 1 for every rated item.

'cd' (the default) Conjugate gradient method [TPT2011].

'lu' A direct implementation of the original implicit-feedback ALS concept [HKV2008] using LU-decomposition to solve for the optimized matrices.

See the base class *MFPredictor* for documentation on the estimated parameters you can extract from a trained model.

Parameters

- **features** (*int*) – the number of features to train
- **iterations** (*int*) – the number of iterations to train
- **reg** (*double*) – the regularization factor
- **weight** (*double*) – the scaling weight for positive samples (α in [HKV2008]).
- **rng_spec** – Random number generator or state (see *lenskit.util.random.rng()*).
- **progress** – a `tqdm.tqdm()`-compatible progress bar function

fit (*ratings*, ***kwargs*)

Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

predict_for_user (*user*, *items*, *ratings=None*)

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type *pandas.Series*

FunkSVD

FunkSVD is an SVD-like matrix factorization that uses stochastic gradient descent, configured much like coordinate descent, to train the user-feature and item-feature matrices.

```
class lenskit.algorithms.funksvd.FunkSVD (features, iterations=100, *, lrate=0.001,
                                         reg=0.015, damping=5, range=None, bias=True,
                                         random_state=None)
```

Bases: *lenskit.algorithms.mf_common.BiasMFPredictor*

Algorithm class implementing FunkSVD matrix factorization. FunkSVD is a regularized biased matrix factorization technique trained with featurewise stochastic gradient descent.

See the base class *BiasMFPredictor* for documentation on the estimated parameters you can extract from a trained model.

Parameters

- **features** (*int*) – the number of features to train
- **iterations** (*int*) – the number of iterations to train each feature
- **lrate** (*double*) – the learning rate
- **reg** (*double*) – the regularization factor
- **damping** (*double*) – damping factor for the underlying mean
- **bias** (*Predictor*) – the underlying bias model to fit. If True, then a *basic.Bias* model is fit with damping.
- **range** (*tuple*) – the (min, max) rating values to clamp ratings, or None to leave predictions unclamped.
- **random_state** – The random state for shuffling the data prior to training.

```
fit (ratings, **kwargs)
```

Train a FunkSVD model.

Parameters **ratings** – the ratings data frame.

```
predict_for_user (user, items, ratings=None)
```

Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type `pandas.Series`

2.7.4 Hierarchical Poisson Factorization

This module provides a LensKit bridge to the `hpfrec` library implementing hierarchical Poisson factorization [GHB2013].

class `lenskit.algorithms.hpf.HPF` (*features*, ***kwargs*)
 Hierarchical Poisson factorization, provided by `hpfrec`.

Parameters

- **features** (*int*) – the number of features
- ****kwargs** – arguments passed to `hpfrec.HPF`.

fit (*ratings*, ***kwargs*)
 Train a model using the specified ratings (or similar) data.

Parameters

- **ratings** (*pandas.DataFrame*) – The ratings data.
- **kwargs** – Additional training data the algorithm may require. Algorithms should avoid using the same keyword arguments for different purposes, so that they can be more easily hybridized.

Returns The algorithm object.

predict_for_user (*user*, *items*, *ratings=None*)
 Compute predictions for a user and items.

Parameters

- **user** – the user ID
- **items** (*array-like*) – the items to predict
- **ratings** (*pandas.Series*) – the user’s ratings (indexed by item id); if provided, they may be used to override or augment the model’s notion of a user’s preferences.

Returns scores for the items, indexed by item id.

Return type `pandas.Series`

2.7.5 Implicit

This module provides a LensKit bridge to Ben Frederickson’s `implicit` library implementing some implicit-feedback recommender algorithms, with an emphasis on matrix factorization.

class `lenskit.algorithms.implicit.ALS` (**args*, ***kwargs*)
 LensKit interface to `implicit.als`.

class `lenskit.algorithms.implicit.BPR` (**args*, ***kwargs*)
 LensKit interface to `implicit.bpr`.

2.7.6 Basic Algorithms

<code>basic.Bias([items, users, damping])</code>	A user-item bias rating prediction algorithm.
<code>basic.Popular([selector])</code>	Recommend the most popular items.
<code>basic.TopN(predictor[, selector])</code>	Basic recommender that implements top-N recommendation using a predictor.
<code>basic.Fallback(algorithms, *others)</code>	The Fallback algorithm predicts with its first component, uses the second to fill in missing values, and so forth.
<code>basic.UnratedItemCandidateSelector</code>	<code>CandidateSelector</code> that selects items a user has not rated as candidates.
<code>basic.Memorized(scores)</code>	The memorized algorithm memorizes scores provided at construction time.

2.7.7 k-NN Algorithms

<code>user_knn.UserUser(nnbrs[, min_nbrs, ...])</code>	User-user nearest-neighbor collaborative filtering with ratings.
<code>item_knn.ItemItem(nnbrs[, min_nbrs, ...])</code>	Item-item nearest-neighbor collaborative filtering with ratings.

2.7.8 Matrix Factorization

<code>als.BiasedMF(features, *[, iterations, reg, ...])</code>	Biased matrix factorization trained with alternating least squares [ZWSP2008].
<code>als.ImplicitMF(features, *[, iterations, ...])</code>	Implicit matrix factorization trained with alternating least squares [HKV2008].
<code>funksvd.FunkSVD(features[, iterations, ...])</code>	Algorithm class implementing FunkSVD matrix factorization.

External Library Wrappers

<code>implicit.BPR(*args, **kwargs)</code>	LensKit interface to <code>implicit.bpr</code> .
<code>implicit.ALS(*args, **kwargs)</code>	LensKit interface to <code>implicit.als</code> .
<code>hpf.HPF(features, **kwargs)</code>	Hierarchical Poisson factorization, provided by hpfred .

2.7.9 References

2.8 Random Number Generation

Current best practice for reproducible science in machine learning — including, but not limited to, recommender systems — is to use fixed random seeds so results can be reproduced precisely. This is useful both for reproducing the results themselves and for debugging.

To test for seed sensitivity, the entire experiment can be re-run with a different random seed and the conclusions compared.

LensKit is built to support this experimental design, making consistent use of configurable random number generators throughout its algorithm implementations. When run against NumPy 1.17 or later, it uses the new `numpy.random.Generator` and `numpy.random.SeedSequence` facilities to provide consistent random number generation and initialization. LensKit is compatible with older versions of NumPy, but the RNG reproducibility logic will not fully function, and some functions will not work.

Developers *using* LensKit will be primarily interested in the `init_rng()` function, so they can initialize LensKit's random seed. LensKit components using randomization also take an `rng` option, usually in their constructor, to set the seed on a per-operation basis; if the script is straightforward and performs LensKit operations in a deterministic order (e.g. does not train multiple models in parallel), initializing the global RNG is sufficient.

Developers writing new LensKit algorithms that use randomization will also need pay attention to the `rng()` function, along with `derivable_rng()` and `derive_seed()` if predictions or recommendations, not just model training, requires random values. Their constructors should take a parameter `rng_spec` to specify the RNG initialization.

2.8.1 Seeds

LensKit random number generation starts from a global root seed, accessible with `get_root_seed()`. This seed can be initialized with `init_rng()`.

```
lenskit.util.random.init_rng(seed, *keys, propagate=True)
```

Initialize the random infrastructure with a seed. This function should generally be called very early in the setup.

Parameters

- **seed** (*int or numpy.random.SeedSequence*) – The random seed to initialize with.
- **keys** – Additional keys, to use as a `spawn_key` on NumPy 1.17. Passed to `derive_seed()`.
- **propagate** (*bool*) – If `True`, initialize other RNG infrastructure. This currently initializes:
 - `np.random.seed()`
 - `random.seed()`

If `propagate=False`, LensKit is still fully seeded — no component included with LensKit uses any of the global RNGs, they all use RNGs seeded with the specified seed.

Returns The random seed.

```
lenskit.util.random.derive_seed(*keys, base=None)
```

Derive a seed from the root seed, optionally with additional seed keys.

Parameters

- **keys** (*list of int or str*) – Additional components to add to the spawn key for reproducible derivation. If unspecified, the seed's internal counter is incremented.
- **base** (*numpy.random.SeedSequence*) – The base seed to use. If `None`, uses the root seed.

```
lenskit.util.random.get_root_seed()
```

Get the root seed.

Returns The LensKit root seed.

Return type `numpy.random.SeedSequence`

2.8.2 Random Number Generators

These functions create actual RNGs from the LensKit global seed or a user-provided seed. They can produce both new-style `numpy.random.Generator` RNGs and legacy `numpy.random.mtrand.RandomState`; the latter is needed because some libraries, such as Pandas and scikit-learn, do not yet know what to do with a new-style RNG.

`lenskit.util.random.rng(seed=None, *, legacy=False)`

Get a random number generator. This is similar to `sklearn.utils.check_random_seed()`, but it usually returns a `numpy.random.Generator` instead.

Parameters

- **seed** – The seed for this RNG. Can be any of the following types:
 - `int`
 - `None`
 - `numpy.random.SeedSequence`
 - `numpy.random.mtrand.RandomState`
 - `numpy.random.Generator`
- **legacy** (*bool*) – If `True`, return `numpy.random.mtrand.RandomState` instead of a new-style `numpy.random.Generator`.

Returns A random number generator.

Return type `numpy.random.Generator`

`lenskit.util.random.derivable_rng(spec, *, legacy=False)`

Get a derivable RNG, for use cases where the code needs to be able to reproducibly derive sub-RNGs for different keys, such as user IDs.

Parameters **spec** – Any value supported by the `seed` parameter of `rng()`, in addition to the following values:

- the string `'user'`
- a tuple of the form `(seed, 'user')`

Either of these forms will cause the returned function to re-derive new RNGs.

Returns A function taking one (or more) key values, like `derive_seed()`, and returning a random number generator (the type of which is determined by the `legacy` parameter).

Return type function

2.9 Utility Functions

These utility functions are useful for data processing.

2.9.1 Matrix Utilities

We have some matrix-related utilities, since matrices are used so heavily in recommendation algorithms.

Building Ratings Matrices

`lenskit.matrix.sparse_ratings` (*ratings*, *scipy=False*, *, *users=None*, *items=None*)
 Convert a rating table to a sparse matrix of ratings.

Parameters

- **ratings** (*pandas.DataFrame*) – a data table of (user, item, rating) triples.
- **scipy** – if `True`, return a SciPy matrix instead of *CSR*.
- **users** (*pandas.Index*) – an index of user IDs.
- **items** (*pandas.Index*) – an index of items IDs.

Returns a named tuple containing the sparse matrix, user index, and item index.

Return type *RatingMatrix*

class `lenskit.matrix.RatingMatrix`

A rating matrix with associated indices.

matrix

The rating matrix, with users on rows and items on columns.

Type *CSR* or `scipy.sparse.csr_matrix`

users

mapping from user IDs to row numbers.

Type *pandas.Index*

items

mapping from item IDs to column numbers.

Type *pandas.Index*

Compressed Sparse Row Matrices

We use CSR-format sparse matrices in quite a few places. Since SciPy’s sparse matrices are not directly usable from Numba, we have implemented a Numba-compiled CSR representation that can be used from accelerated algorithm implementations.

class `lenskit.matrix.CSR` (*nrows=None*, *ncols=None*, *nnz=None*, *ptrs=None*, *inds=None*,
vals=None, *N=None*)

Simple compressed sparse row matrix. This is like `scipy.sparse.csr_matrix`, with a couple of useful differences:

- It is backed by a Numba jitclass, so it can be directly used from Numba-optimized functions.
- The value array is optional, for cases in which only the matrix structure is required.
- The value array, if present, is always double-precision.

You generally don’t want to create this class yourself with the constructor. Instead, use one of its class methods.

If you need to pass an instance off to a Numba-compiled function, use *N*:

```
_some_numba_fun(csr.N)
```

We use the indirection between this and the Numba jitclass so that the main CSR implementation can be pickled, and so that we can have class and instance methods that are not compatible with jitclass but which are useful from interpreted code.

N

the Numba jitclass backing (has the same attributes and most methods).

Type `_CSR`

nrows

the number of rows.

Type `int`

ncols

the number of columns.

Type `int`

nnz

the number of entries.

Type `int`

rowptrs

the row pointers.

Type `numpy.ndarray`

colinds

the column indices.

Type `numpy.ndarray`

values

the values

Type `numpy.ndarray`

classmethod `empty(shape, row_nnz, *, rpdtype=<class 'numpy.int32'>)`

Create an empty CSR matrix.

Parameters

- **shape** (*tuple*) – the array shape (rows,cols)
- **row_nnz** (*array-like*) – the number of nonzero entries for each row

filter_nnz (*filt*)

Filter the values along the full NNZ axis.

Parameters **filt** (*ndarray*) – a logical array of length *nnz* that indicates the values to keep.

Returns The filtered sparse matrix.

Return type `CSR`

classmethod `from_coo(rows, cols, vals, shape=None, rpdtype=<class 'numpy.int32'>)`

Create a CSR matrix from data in COO format.

Parameters

- **rows** (*array-like*) – the row indices.

- **cols** (*array-like*) – the column indices.
- **vals** (*array-like*) – the data values; can be `None`.
- **shape** (*tuple*) – the array shape, or `None` to infer from row & column indices.

classmethod `from_scipy` (*mat*, *copy=True*)

Convert a scipy sparse matrix to an internal CSR.

Parameters

- **mat** (*scipy.sparse.spmatrix*) – a SciPy sparse matrix.
- **copy** (*bool*) – if `False`, reuse the SciPy storage if possible.

Returns a CSR matrix.

Return type *CSR*

normalize_rows (*normalization*)

Normalize the rows of the matrix.

Note: The normalization *ignores* missing values instead of treating them as 0.

Note: This method is not available from Numba.

Parameters **normalization** (*str*) – The normalization to perform. Can be one of:

- `'center'` - center rows about the mean
- `'unit'` - convert rows to a unit vector

Returns The normalization values for each row.

Return type *numpy.ndarray*

row (*row*)

Return a row of this matrix as a dense ndarray.

Parameters **row** (*int*) – the row index.

Returns the row, with 0s in the place of missing values.

Return type *numpy.ndarray*

row_cs (*row*)

Get the column indices for the stored values of a row.

row_extent (*row*)

Get the extent of a row in the underlying column index and value arrays.

Parameters **row** (*int*) – the row index.

Returns (*s*, *e*), where the row occupies positions [*s*, *e*) in the CSR data.

Return type *tuple*

row_nnz ()

Get a vector of the number of nonzero entries in each row.

Note: This method is not available from Numba.

Returns the number of nonzero entries in each row.

Return type `numpy.ndarray`

row_vs (*row*)

Get the stored values of a row.

rowinds () → `numpy.ndarray`

Get the row indices from this array. Combined with *colinds* and *values*, this can form a COO-format sparse matrix.

Note: This method is not available from Numba.

subset_rows (*begin*, *end*)

Subset the rows in this matrix.

to_scipy ()

Convert a CSR matrix to a SciPy `scipy.sparse.csr_matrix`. Avoids copying if possible.

Parameters **self** (*CSR*) – A CSR matrix.

Returns A SciPy sparse matrix with the same data.

Return type `scipy.sparse.csr_matrix`

ttranspose (*values=True*)

Transpose a CSR matrix.

Note: This method is not available from Numba.

Parameters **values** (*bool*) – whether to include the values in the transpose.

Returns the transpose of this matrix (or, equivalently, this matrix in CSC format).

Return type *CSR*

class `lenskit.matrix._CSR` (*nrows*, *ncols*, *nnz*, *ptrs*, *inds*, *vals*)

Internal implementation class for *CSR*. If you work with CSRs from Numba, you will use this.

Note that the *values* array is always present (unlike the Python shim), but is zero-length if no values are present. This eases Numba type-checking.

2.9.2 Math utilities

Solvers

`lenskit.math.solve.dposv(A, b, lower=False)`

Interface to the BLAS dposv function. A Numba-accessible version without error checking is exposed as `_dposv()`.

`lenskit.math.solve.solve_tri(A, b, transpose=False, lower=True)`

Solve the system $Ax = b$, where A is triangular. This is equivalent to `scipy.linalg.solve_triangular()`, but does *not* check for non-singularity. It is a thin wrapper around the BLAS dtrsv function.

Parameters

- **A** (`ndarray`) – the matrix.
- **b** (`ndarray`) – the target vector.
- **transpose** (`bool`) – whether to solve $Ax = b$ or $A^T x = b$.
- **lower** (`bool`) – whether A is lower- or upper-triangular.

Numba-accessible internals

`lenskit.math.solve._dposv(A, b, lower)`

`lenskit.math.solve._dtrsv(lower, trans, a, x)`

2.9.3 Miscellaneous

Miscellaneous utility functions.

`lenskit.util.clone(algo)`

Clone an algorithm, but not its fitted data. This is like `scikit.base.clone()`, but may not work on arbitrary SciKit estimators. LensKit algorithms are compatible with SciKit clone, however, so feel free to use that if you need more general capabilities.

This function is somewhat derived from the SciKit one.

```
>>> from lenskit.algorithms.basic import Bias
>>> orig = Bias()
>>> copy = clone(orig)
>>> copy is orig
False
>>> copy.damping == orig.damping
True
```

`lenskit.util.cur_memory()`

Get the current memory use for this process

`lenskit.util.max_memory()`

Get the maximum memory use for this process

`lenskit.util.proc_count(core_div=2)`

Get the number of desired jobs for multiprocessing operations. This does not affect Numba or MKL multi-threading.

This count can come from a number of sources: * The `LK_NUM_PROCS` environment variable * The number of CPUs, divided by `core_div` (default 2)

Parameters `core_div` (*int* or *None*) – The divisor to scale down the number of cores; *None* to turn off core-based fallback.

Returns The number of jobs desired.

Return type *int*

2.10 Errors and Diagnostics

2.10.1 Logging

LensKit algorithms and evaluation routines report diagnostic data using the standard Python `logging` framework. Loggers are named after the corresponding Python module, and all live under the `lenskit` namespace.

Algorithms usually report erroneous or anomalous conditions using Python exceptions and warnings. **Evaluation code**, such as that in `lenskit.batch`, typically reports such conditions using the logger, as the common use case is to be running them in a script.

2.10.2 Warnings

In addition to Python standard warning types such as `warnings.DeprecationWarning`, LensKit uses the following warning classes to report anomalous problems in use of LensKit.

class `lenskit.DataWarning`

Warning raised for detectable problems with input data.

2.11 Algorithm Implementation Tips

Implementing algorithms is fun, but there are a few things that are good to keep in mind.

In general, development follows the following:

1. Correct
2. Clear
3. Fast

In that order. Further, we always want LensKit to be *usable* in an easy fashion. Code implementing algorithms, however, may be quite complex in order to achieve good performance.

2.11.1 Performance

We use Numba to optimize critical code paths and provide parallelism in a number of cases, such as ALS training. See the ALS source code for examples.

We also directly use MKL sparse matrix routines when available for some operations. Whenever this is done in the main LensKit code base, however, we also provide fallback implementations when the MKL is not available. The k-NN recommenders both demonstrate different versions of this. The `_mkl_ops` module exposes MKL operations; we implement them through C wrappers in the `mkl_ops.c` file, that are then called through FFI. This extra layer is because the raw MKL calls are quite complex to call via FFI, and are not particularly amenable to use with Numba. We re-expose simplified interfaces that are also usable with Numba.

2.11.2 Pickling and Sharing

LensKit uses Python pickling (or JobLib's modified pickling in `joblib.dump()`) quite a bit to save and reload models and to share model data between concurrent processes. This generally just works, and you don't need to implement any particular save/load logic in order to have your algorithm be savable and sharable.

There are a few exceptions, though.

If your algorithm updates state after fitting, this should *not* be pickled. An example of this would be caching predictions or recommendations to save time in subsequent calls. Only the model parameters and estimated parameters should be pickled. If you have caches or other ephemeral structures, override `__getstate__` and `__setstate__` to exclude them from the saved data and to initialize caches to empty values on unpickling.

If your model excludes secondary data structures from pickling, such as a reverse index of user-item interactions, then you should only exclude them when pickling for serialization. When pickling for model sharing (see `lenskit.sharing.in_share_context()`), you should include the derived structures so they can also be shared.

If your algorithm uses subsidiary models as a part of the training process, but does not need them for prediction or recommendation (for example, `lenskit.algorithms.als.BiasMF`'s use of `lenskit.algorithms.basic.Bias` in `fit`, during which it copies the bias model's internal state to its own fields), then consider overriding `__getstate__` to remove the underlying model or replace it with a cloned copy (with `lenskit.util.clone()`) to reduce serialized disk space (and deserialized memory use).

2.11.3 Random Number Generation

See `lenskit.util.random` for documentation on how to use random number generation.

In general, algorithms using randomization should have an `rng` parameter that takes a seed or RNG, and pass this to `lenskit.util.random.rng()` to get a random number generator. Algorithms that use randomness at predict or recommendation time, not just training time, should support the value `'user'` for the `rng` parameter, and if it is passed, derive a new seed for each user using `lenskit.util.random.derive_seed()` to allow reproducibility in the face of parallelism for common experimental designs. `lenskit.util.random.derivable_rng()` automates this logic.

2.11.4 Memory Map Friendliness

LensKit uses `joblib.Parallel` to parallelize internal operations (when it isn't using Numba). Joblib is pretty good about using shared memory to minimize memory overhead in parallel computations, and LensKit has some tricks to maximize this use. However, it does require a bit of attention in your algorithm implementation.

The easiest way to make this fail is to use many small NumPy or Pandas data structures. If you have a dictionary of `np.ndarray` objects, for instance, it will cause a problem. This is because each array will be memory-mapped, and each map will *reopen* the file. Having too many active open files will cause your process to run out of file descriptors on many systems. Keep your object count to a small, ideally fixed number; in `lenskit.algorithms.basic.UnratedItemSelector`, we do this by storing user and item indexes along with a `matrix.CSR` containing the items rated by each user. The old implementation had a dictionary mapping user IDs to ``ndarray``s with each user's rated items. This is a change from $|U| + 1$ arrays to 5 arrays.

2.12 LensKit Internals

These modules are primarily for internal infrastructural support in Lenskit. Neither LensKit users nor algorithm developers are likely to need to use this code directly.

2.12.1 Model Sharing

The `lenskit.sharing` module provides utilities for managing models and sharing them between processes, particularly for the multiprocessing in `lenskit.batch`.

Sharing Mode

The only piece **algorithm developers** usually need to directly handle is the concept of 'sharing mode' when implementing custom pickling logic. To save space, it is reasonable to exclude intermediate data structures, such as caches or inverse indexes, from the pickled representation of an algorithm, and reconstruct them when the model is loaded.

However, LensKit's multi-process sharing *also* uses pickling to capture the object state while using shared memory for `numpy.ndarray` objects. In these cases, the structures should be pickled, so they can be shared between model instances.

To support this, we have the concept of *sharing mode*. Code that excludes objects when pickling should call `in_share_context()` to determine if that exclusion should actually happen.

```
lenskit.sharing.in_share_context()
```

Query whether sharing mode is active. If `True`, we are currently in a `sharing_mode()` context, which means model pickling will be used for cross-process sharing.

```
lenskit.sharing.sharing_mode()
```

Context manager to tell models that pickling will be used for cross-process sharing, not model persistence.

Model Store API

Model stores handle persisting models into shared memory, cleaning up shared memory, and making objects available to other classes.

LensKit users and algorithm implementers will generally not need to use this code themselves, unless they are implementing their own batch processing logic.

`lenskit.sharing.get_store(reuse=True, *, in_process=False)`

Get a model store, using the best available on the current platform. The resulting store should be used as a context manager, as in:

```
>>> with get_store() as store:
...     pass
```

This function uses the following priority list for locating a suitable store:

1. The currently-active store, if `reuse=True`
2. A no-op store, if `in_process=True`
3. `SHMModelStore`, if on Python 3.8
4. `JoblibModelStore`

Parameters

- **reuse** (*bool*) – If a store is active (with a `with` block), use that store instead of creating a new one.
- **in_process** (*bool*) – If `True`, then create a no-op store for use without multiprocessing.

Returns the model store.

Return type *BaseModelStore*

class `lenskit.sharing.BaseModelStore`

Bases: *lenskit.sharing.BaseModelClient*

Base class for storing models for access across processes.

Stores are also context managers that initialize themselves and clean themselves up. As context managers, they are also re-entrant, and register themselves so that `create_store()` can re-use existing managers.

abstract client()

Get a client for the model store. Clients are cheap to pass to child processes for multiprocessing.

Returns the model client.

Return type *BaseModelClient*

init()

Initialize the store.

abstract put_model(model)

Store a model in the model store.

Parameters **model** (*object*) – the model to store.

Returns a key to retrieve the model with *BaseModelClient.get_model()*

put_serialized(path, binpickle=False)

Deserialize a model and load it into the store.

The base class method unpickles `path` and calls *put_model()*.

Parameters

- **path** (*str* or *pathlib.Path*) – the path to deserialize
- **binpickle** – if True, deserialize with `binpickle.load()` instead of pickle.

shutdown()

Shut down the store

class `lenskit.sharing.BaseModelClient`

Bases: *object*

Model store client to get models given keys. Clients must be able to be cheaply pickled and de-pickled to enable worker processes to access them.

abstract `get_model(key)`

Get a model from the model store.

Parameters **key** – the model key to retrieve.

Returns The model, previously stored with `BaseModelStore.put_model()`, wrapped in a *SharedObject* to manage underlying resources.

Return type *SharedObject*

class `lenskit.sharing.SharedObject(obj)`

Bases: *object*

Wrapper for a shared object that can release it when the object is no longer needed.

Objects of this type are context managers, that return the *shared object* (not themselves) when entered.

Any other references to *object*, or its contents, **must** be released before calling `release()` or exiting the context manager. Among other things, that means that you will need to delete its variable:

```
with client.get_model(k) as model:
    # model here is the actual model object wrapped by the SharedObject
    # returned by get_model
    pass          # actually do the things you want to do
del model        # release model, so the shared object can be closed
```

Be careful of stray references to the model object! Some things we have seen causing stray references include:

- passing the algorithm to a logger (call `str()` on it explicitly), at least in the test harness

The default implementation uses `sys.getrefcount()` to provide debugging support to help catch stray references.

object

the underlying shared object.

release()

Release the shared object. Automatically called by `__exit__()`, so in normal use of a shared object with a `with` statement, this method is not needed.

The base class implementation simply deletes the object reference. Subclasses should override this method to handle their own release logic.

Model Store Implementations

We provide several model store implementations.

Memory Mapping

The memory-mapped-file store works on any supported platform and Python version. It uses Joblib's memory-mapped Pickle extension to store models on disk and use their storage to back memory-mapped views of major data structures.

```
class lenskit.sharing.file.FileModelStore(* , path=None, reserialize=True)
    Bases: lenskit.sharing.BaseModelStore, lenskit.sharing.file.FileClient
```

Model store using BinPickle's memory-mapping pickle support.

Parameters

- **path** – the path to use; otherwise uses a new temp directory under `util.scratch_dir()`.
- **reserialize** – if True (the default), models passed to `put_serialized()` are re-serialized in the BinPickle storage, even if they are binpickle files.

```
class lenskit.sharing.file.FileClient
    Bases: lenskit.sharing.BaseModelClient
```

Client using BinPickle's memory-mapping pickle support.

Shared Memory

This store uses Python 3.8's `multiprocessing.shared_memory` module, along with out-of-band buffer support in Pickle Protocol 5, to pass model data through shared memory.

```
class lenskit.sharing.sharedmem.SHMModelStore
    Bases: lenskit.sharing.BaseModelStore, lenskit.sharing.sharedmem.SHMClient
```

Model store using shared memory and Pickle Protocol 5.

This model store only works in Python 3.8 and later, as it requires both the new `multiprocessing.shared_memory` module and Pickle Protocol 5. It also depends on a Numpy version new enough to support Protocol 5 pickles.

Parameters

- **path** – the path to use; otherwise uses a new temp directory under `util.scratch_dir()`.
- **reserialize** – if True (the default), models passed to `put_serialized()` are re-serialized in the SHM storage.

```
class lenskit.sharing.sharedmem.SHMClient
    Bases: lenskit.sharing.BaseModelClient
```

2.13 Release Notes

2.13.1 0.9.0

- Tested with Python 3.8 and Pandas 1.0

RNG Infrastructure

LensKit 0.9 brings a new random number generation infrastructure to support reproducible experiments.

Deprecated Feature Removal

We removed the following previously-deprecated features:

- `write_parquet`
- `UnratedCandidates`

Unused Feature Removal

We removed some unused features that were causing maintenance problems:

- Removed direct support for Dask-based parallelism (ssupot for Dask frames in `RecListAnalysis` remains)

2.13.2 0.8.4

This release cleans up dependency problems to make it easier to reliably install LensKit. We remove some unused utility code that had compatibility problems.

- Remove `CSR.sort_values` - we were no longer using this function, and it failed to compile with Numba 0.46.
- Change dependency versions

2.13.3 0.8.3

- Deprecated `lenskit.util.write_parquet`
- Made `MultiEval` use directories of parquet files, instead of appending to a single file, for writing multiple results to improve performance without `fastparquet`.
- Updated Numba dependency to fix incompatibilities (#129).

2.13.4 0.8.0

See the [GitHub milestone](#) for full change list.

Infrastructure Updates

- Dropped support for Python 3.5
- Removed `*args` from `Algorithm.fit`, so additional data must be provided via keyword arguments
- Made `Algorithm.fit` implementations consistently take `**kwargs` for hybrid flexibility

Algorithm Updates

- Substantial performance and stability improvements to item-item
- Added a coordinate descent solver to explicit-feedback ALS and made it the default. The old LU-based solver is still available with `method='lu'`.
- Added a conjugate gradient solver to implicit-feedback ALS and made it the default.
- Added a random recommender

2.13.5 0.7.0

See the [GitHub milestone](#) for full change list.

- Use [Joblib](#) for parallelism in batch routines.
- `nprocs` arguments are renamed to `n_jobs` for consistency with Joblib.
- Removed `parallel` option on `MultiEval` algorithms, as it was unused.
- Made `MultiEval` default to using each recommender's default candidate set, and adapt algorithms to recommenders prior to evaluation.
- Make `MultiEval` require named arguments for most things.
- Add support to `MultiEval` to save the fit models.
- `RecListAnalysis` can optionally ensure all test users are returned, even if they lack recommendation lists.
- Performance improvements to algorithms and evaluation.

2.13.6 0.6.1

See the [GitHub milestone](#) for full change list.

- Fix inconsistency in both code and docs for recommend list sizes for top- N evaluation.
- Fix user-user to correctly use `sum` aggregate.
- Improve performance and documentation

2.13.7 0.6.0

See the [GitHub milestone](#) for a summary of what's happening!

- The `save` and `load` methods on algorithms have been removed. Just pickle fitted models to save their data. This is what SciKit does, we see no need to deviate.
- The APIs and model structures for top- N recommendation is reworked to enable algorithms to produce recommendations more automatically. The `Recommender` interfaces now take a `CandidateSelector` to determine default candidates, so client code does not need to compute candidates on their own. One effect of this is that the `batch.recommend` function no longer requires a candidate selector, and there can be problems if you call `Recommender.adapt` before fitting a model.
- Top- N evaluation has been completely revamped to make it easier to correctly implement and run evaluation metrics. Batch recommend no longer attaches ratings to recommendations. See [Top- \$N\$ evaluation](#) for details.
- Batch recommend & predict functions now take `nprocs` as a keyword-only argument.
- Several bug fixes and testing improvements.

Internal Changes

These changes should not affect you if you are only consuming LensKit's algorithm and evaluation capabilities.

- Rewrite the `CSR` class to be more ergonomic from Python, at the expense of making the NumPy jitclass indirect. It is available in the `.N` attribute. Big improvement: it is now picklable.

2.13.8 0.5.0

LensKit 0.5.0 modifies the algorithm APIs to follow the SciKit design patterns instead of our previous custom patterns. Highlights of this change:

- Algorithms are trained in-place — we no longer have distinct model objects.
- Model data is stored as attributes on the algorithm object that end in `_`.
- Instead of writing `model = algo.train_model(ratings)`, call `algo.fit(ratings)`.

We also have some new capabilities:

- Ben Frederickson's Implicit library

2.13.9 0.3.0

A number of improvements, including replacing Cython/OpenMP with Numba and adding ALS.

2.13.10 0.2.0

A lot of fixes to get ready for RecSys.

2.13.11 0.1.0

Hello, world!

INDICES AND TABLES

- genindex
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