Identification of Artifacts and Interesting Celestial Objects in LAMOST Spectral Survey

Petr Škoda,¹ Ksenia Shakurova,² Jakub Koza,² and Andrej Palička²

¹Astronomical Institute of the Czech Academy of Sciences, Ondřejov, Czech Republic; skoda@sunstel.asu.cas.cz
²Faculty of Information Technology, Czech Technical University, Prague, Czech Republic

Abstract. The LAMOST DR1 survey contains about two million of spectra labelled by its pipeline as stellar objects of common spectral classes. There is, however, a lot of spectra corrupted in some way by both instrumental and processing artifacts, which may mimic spectral properties of interesting celestial objects, namely emission lines of Be stars and quasars.

We have tested several clustering methods as well as outliers analysis on a sample of one hundred thousand spectra using Spark scripts running on Hadoop cluster consisting of twenty-four sixteen-core nodes. This experiment was motivated by an attempt to find rare objects with interesting spectra as outliers most dissimilar from all common spectra.

The result of this time-consuming procedure is a list of several hundred candidates where different artifacts are prominent, but also tens of very interesting emission-line spectra requiring further detailed examination. Many of them may be quasars or even blazars as well as yet unknown Be-stars. It deserves mentioning that most of the work benefitted considerably from technologies of Virtual Observatory.

1. Finding Outliers with Unsupervised Machine Learning

Machine learning is the field of informatics, closely related to the advanced statistical inference, which tries to build models of data by learning from sample inputs and make predictions based on such learned models. It is divided mainly into supervised and unsupervised methods.

Unsupervised learning (unlike supervised one requiring the labels assigned to part of data) tries to identify similar patterns (typically different clusters based on some similarity metrics) in data automatically without the human intervention. The outliers are entities which cannot be assigned to any of such cluster (so they represent the single member clusters).

In big spectral archives, where it is almost impossible to investigate every spectrum visually, the yet unknown rare objects with strange features, or even sources with yet undiscovered physical mechanism may be in principle found using this method. In any case a lot of random instrumental artifacts will be found as well as every one is unique and thus very rare. The artifacts caused by systematic errors of the same nature, which repeats very often, may be collected by clustering as well.
2. LOF Method for Finding Outliers

The Local Outlier Factor method (LOF) introduced by Breunig et al. (2000) is based on an idea to compare local density of an object to the local densities of its neighbours. The local density is estimated by the typical distance $\varepsilon$ at which a point can be "reached" from its neighbors:

One of the key terms for LOF is the $k$-distance and reachability distance of $k$ nearest neighbours: for any $k > 0$ the $k$-distance of object $p$ is the distance $d(p,o)$ between $p$ and an object $o \in D$ such that:

- for at least $k$ objects $o' \in D \setminus p$ it holds that $d(p,o') \leq d(p,o)$;
- for at most $k - 1$ objects $o' \in D \setminus p$ it holds that $d(p,o') < d(p,o)$.

It is the distance of the object $p$ to the $k$-th nearest neighbor, but set of the $k$ nearest neighbor ($N_k(p)$) includes all objects at this distance (it can contain more than $k$ objects). Using $k$-distance the reachability distance can be defined as

$$ reach-distance_k(p,o) = \max(k-distance(o), d(p,o)) $$

(1)

The local reachability density of object $p$ is defined as

$$ lrd_k(p) = \frac{1}{\sum_{o \in N_k(p)} \text{reach-distance}_k(p,o)} $$

(2)

The local outlier factor of $p$ is defined as

$$ \text{LOF}_k(p) = \frac{\sum_{o \in N_k(p)} \frac{lrd(o)}{lrd_k(p)}}{|N_k(p)|} $$

(3)

If the LOF is considerably larger than 1, the object is an outlier, if it is about 1, the object is comparable with others.

3. LAMOST Spectral Surveys

The LAMOST telescope (Cui et al. 2012) has been delivering one of currently largest mega-collections of spectra (similar to Sloan Digital Sky Survey). The sixteen LAMOST spectrographs are fed by 4000 fibres positioned by micro-motors. Its publicly accessible Data Release 1 (see Luo et al. 2015) contains altogether 2,204,696 spectra, with a spectral resolving power about 1800, covering the range 3690-9100 Å. The LAMOST pipeline classified 1,944,329 of them as stellar ones.

4. Ondřejov CCD700 Archive

There is a lot of objects in the Universe that show specific shapes of some important spectral lines, especially multiple emission lines caused by circumstellar disk, such as Be and B[e] stars, cataclysmic variables or young stellar objects.
The unique source is the archive of spectra obtained with 700mm camera of the coudè spectrograph of the 2m Perek Telescope at Ondřejov observatory, a part of the Astronomical Institute of the Czech Academy of Sciences. The archive (named CCD700) contains about twenty thousand spectra of mainly Be stars and other emission-line objects exposed in spectral range 6250–6700 Å with spectral resolving power about 13000.

5. Input Spectra and Their Preprocessing

The important part of data preparation before applying machine learning is the data preprocessing. In our case the spectra have to be normalized to the continuum (rectified), cut to the same wavelength range and re-binned into the same grid of wavelength points. This gives us the number of so called Feature Vectors (FV). As we want to compare the same algorithm on both Ondřejov CCD700 and LAMOST spectra, we have to cut the LAMOST ones to the similar wavelength range (about 6250–6750 Å) as those from CCD700. The result of the preprocessing is the big CSV file with all spectral intensities interpolated to the same wavelength grid. This (big) CSV is uploaded on a computing cluster running Spark.

6. Massively Parallelized Processing Using Spark

The Apache Spark is a set of libraries written in SCALA language, adapted for calling from PYTHON, running on number of computing nodes in parallel. We have used the academic cluster MetaCentrum consisting of twenty-four sixteen-core nodes (the number of nodes assigned by the system is however unknown, dependent on a availability and load of the cluster).

The data were distributed across all nodes by HDFS filesystem of Hadoop infrastructure. The special Spark-based version of LOF method was developed by K.S. (Shakurova 2016) for this task. The experiments were run on all, almost 20 000 Ondřejov CCD700 spectra and then on about 120 000 spectra randomly selected from those labelled as star in LAMOST DR1.

7. Results

Our experiments proved that the LOF method was able to find in the CCD700 archive all interesting cases of spectra like sharp emissions, asymmetric double peak emission or even noisy late type stars spectra. In the LAMOST data, contaminated by a lot of spoiled spectra, it can identify those with random instrumental artifacts, but also some spurious ones, which may represent interesting objects deserving further investigation. An example on Fig. 1 shows the noisy spectrum classified by the LAMOST pipeline as late type M7 class star, however (after zooming) it clearly presents the combination of absorption and emission profile in Oxygen OI lines seen typically in Be stars (see Fig. 2).
8. Conclusions

Big spectral archives are good source of data suitable for machine learning of interesting objects according to their characteristic spectral line shape. The outlier finding methods as LOF may be successfully used for searching instrumental artifacts but also the results need further detailed examination as they may hide interesting scientific objects. The application of the method may benefit considerably from massive parallelization using Spark on Hadoop cluster.

Acknowledgments. This work was supported by grant LD-15113 of Ministry of Education, Youth and Sports of the Czech Republic. This research is based on spectra from Ondřejov 2m Perek telescope and public LAMOST DR1 survey. Access to computing and storage facilities owned by parties and projects contributing to the National Grid Infrastructure MetaCentrum, provided under the programme "Projects of Large Research, Development, and Innovations Infrastructures" (CESNET LM2015042), is greatly appreciated.

References

Breunig, M. M., Kriegel, H. P., Ng, R. T., & Sander, J. 2000, in ACM SIGMOD (ACM), vol. 29, 93
Cui, X.-Q., et al. 2012, Research in Astronomy and Astrophysics, 12, 1197
Luo, A.-L., et al. 2015, Research in Astronomy and Astrophysics, 15, 1095
Shakurova, K. 2016, Master thesis, Czech Technical University in Prague, Faculty of Information Technology