Machine Learning Engineer Nanodegree

Capstone Project

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I. Definition

Project Overview

I choose the Kaggle “Zillow Prize: Zillow’s Home Value Prediction” round 1 competition (https://www.kaggle.com/c/zillow-prize-1#evaluation) as my capstone project. Zillow is a US real estate firm that has an in-house house value prediction model Zestimate. In the first round of the competition, participants need to be able to build up a model to use given features to predict the log error between the actual transaction price and the Zestimate valuation.

Related dataset is provided by Kaggle (https://www.kaggle.com/c/zillow-prize-1/data), including data of properties of over 3 million houses, that is a collection of features for each parcel\_id; and Zestimate prediction error data of actual sales, each sale record includes error, sale-date and the parcel\_id involved. There are two versions of these data, properties evaluated at beginning of 2016 and actual sales of 2016, and that for 2017. Be noted that the Zestimate predicted prices are generated by the same model, but with different properties data for 2016 sales and 2017 sales. Training data includes all sales of 2016 months 1 – 9, part of sales of 2016 months 10 – 12; all sales of 2017 months 1 – 8 and part of sales 2017 month 9. Training data release is divided into 2 rounds, the first contains only 2016 data, which is available since the beginning of the competition; the second is 2017 data, which only takes place 2 weeks before deadline. As part of Kaggle rules, there are 2 testing datasets, the public Leaderboard (Public LB), which is used by participants to view their models’ out-of-sample performance before final submission; and the private Leaderboard (Private LB), which is the evaluation dataset to get participants’ final score and ranking. Public LB’s data is not available, but participants can view the performance of models on this dataset multiple times. Private LB’s data is not available neither and participants can only choose 2 models before deadline for submission on this dataset to view the score and use the better one of the two to get final ranking. For Zillow Prize-1, Public LB contains part of sales of 2016 months 10 – 12 and Private LB contains part of sales of 2017 months 10 and 12 and all sales of 2017 month 11. Be noted that competition deadline is 2017 Oct. 17th, so Private LB is a truly out-of-sample evaluation, with no potential leakage.

For this capstone report, I am not going to chronologically record all the stuff I have done for the competition, it was quite a mess and would be confusing. Instead, I will only record several most valuable trials. Regarding dataset, I will directly use the combined version of 2016 and 2017, as it seems trivial to document the fact that model performance gets better when I get more training data as 2017 data gets released.

Problem Statement

This is a classic supervised learning problem, with training data of properties of each transaction, including properties of parcel being transacted and time of transaction, as input x and log difference between Zestimate and actual transaction price, i.e. log error = log(Zestimate) – log(SalePrice), as output y. And it is a regression problem, and target y, the log error, is continuously distributed. Be noted that while each parcel has a fixed features specification, it could be traded many times and each time the transaction value could be different, also, since we do not know which houses are actually traded in the testing dataset, participants need to make prediction for all of over 3 million houses for both 2016 and 2017 for each month of 10, 11, and 12, and Kaggle will pick up those with actual sales on given year-month combination to evaluate performance.

Metrics

There is a requested model performance evaluation metric in this competition: average Mean Absolute Error between the model predicted log error and true log error, i.e. . It is reasonable to use MAE instead of MSE here, as MSE implicitly gives more weight on samples that have larger absolute error to predict the logerror. Here the logerror distribution is highly heavy tailed, and very likely we will do badly on those extreme values than others. So if using MSE, we will try to improve prediction on those large logerror samples while sacrificing accuracy on others, i.e. for parcel value prediction, it will sacrifice overall accuracy when trying to do better on those we do very bad before, which I believe would not be a preferred solution for business. Using MAE means one unit error reduction in those with large errors is equally valuable to us as in those with small errors.

II. Analysis

Data Exploration

We have total of 57 raw features in the provided property data, data exploration is conducted on these features only. Since we are predicting the errors of a fine-tuned model, we don’t really expect any remaining significant linear patterns between features and prediction target. And as mentioned later, since boosted-tree model is used here, we don’t worry about collinearity. So instead of first looking at a corr matrix among features and target, we directly look at each one of the features in the following three angles:

1. Feature vs. log error patterns from local regression. A good feature should see different patterns of mean-log error at different area.
2. Feature vs. abs log error patterns from local regression. Abs log error is not directly related to original problem, but due to heavy tailed log error distribution, we could significantly improve results if we could predict well on the large error area. A potential improvement is to first predict where Zestimate makes a large error and we can build a different model for that.
3. Density: significance of contribution of feature to prediction should consider the sample density in the ‘patterned’ area.

Features are subjectively classified into 4 categories, ranked from 1 to 4:

1. Very good features, with low missing rate and good patterns against log error at high density area.
2. Good features, they have class-1 potential but with higher missing rate or not significant pattern.
3. High cardinal, categorical features with high cardinality.
4. Bad features, either very high missing rate (over 90%) or hardly any pattern.

All the details could be found in data\_explore.html, and summarization of key information could be found in data/features\_info.csv, be noted that a better readable naming is created for each feature and this will be used in the rest part of the project.

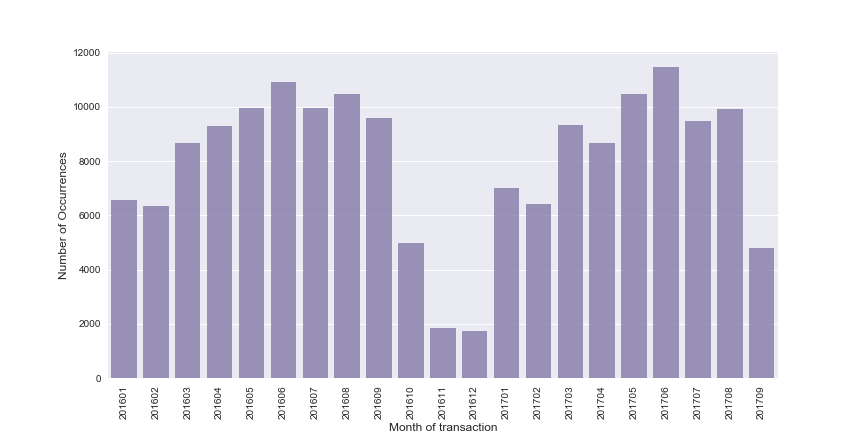
It is worth noting that this hand-labeling of features turns out to be no more efficient than boosted-tree’s feature importance analysis. It helps no more than providing a more concrete idea of what we have in hand. In fact these plots could be misleading in the following 2 aspects:

1. For highly concentrated numerical features, ‘pattern’ across the whole value domain could overshadow the local structures at high-density area that we really care about (e.g. area\_living\_type\_12).
2. Scale of pattern-plot could be dominated by the abnormal-behaving low-density area and difference at high-density area gets visually shrunk (e.g. type\_air\_conditioning).

Exploratory Visualization

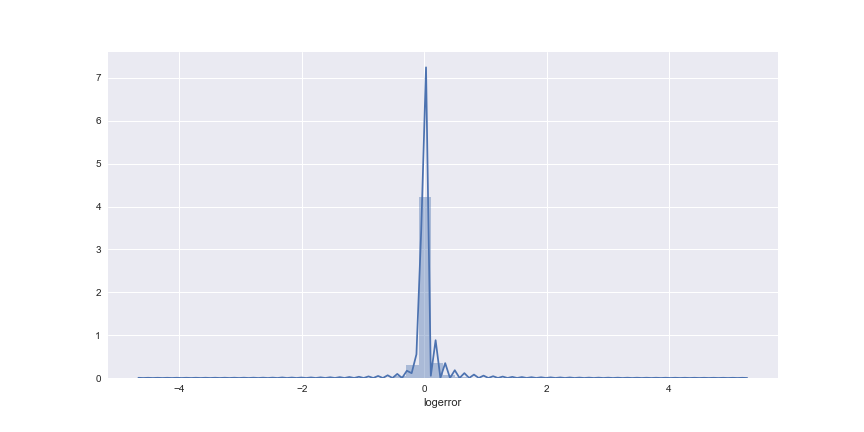
First we get an idea of overall training data.

Let’s take a look at number of samples of each month:



As described in data set section, only part of 2016, 10, 11, 12 data is provided in training. Seasonality effect is strong, and sample size distribution needs to be considered for CV design against seasonality.

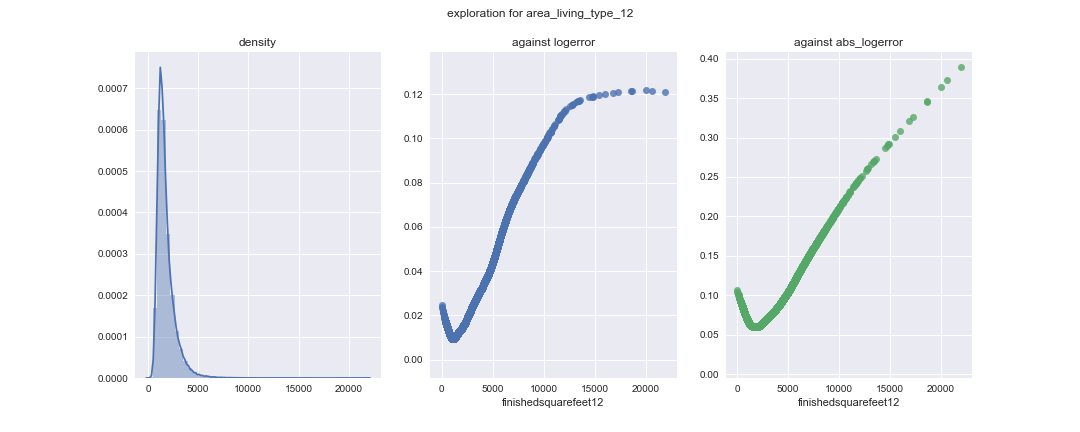
And the distribution of log errors:



Zestimate does a good job, the log error is already noise-like, well symmetric, close to zero; but heavy tailed, meaning outlier might need to be handled.

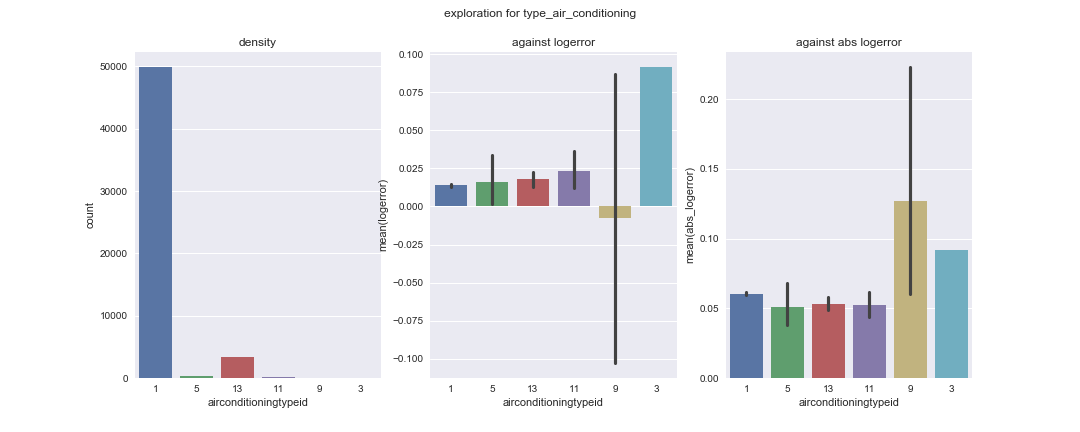
Also, we present visualization of one example feature of each of class 1, 2, and 4. There is no visualization of high-cardinal features.

1. Class-1: area\_living\_type\_12



With low missing rate, area\_living\_type\_12 looks like a good feature.

1. Class-2: type\_air\_conditioning



Missing rate is around 70%, high density area is only type-1 and type-13. There is slight difference between the mean-log-error of the two groups. Type 13 has sample size of around 3k, so tree can make several valid splits in there and potentially capture the pattern.

1. Class-4: area\_living\_type\_15



This is a special feature, besides the over 90% missing rate, it seems the pattern is weak in the high density area. However, later in feature importance analysis, it turns out to be quite useful.

Algorithms and Techniques

I choose to use GBDT (Gradient Boosted Gradient Tree) model family to solve the problem. Tree is non-linear and sufficiently expressive, and boosting mitigates over-fitting. Random Forest is less ideal in the sense that trees are not related to each other, new trees does make use of information of previous ones. AdaBoost does not fit well as its main contribution is to make smart combinations of existing weak predictors, while we are building the model from scratch, another algorithm is needed to first find those predictors. After all, the most direct reason for choosing GBDT is its reputation in the Kaggle community, GBDT model family has been proved well effective in multiple contests.

Idea of GBDT is that, each new predictor fits to gradient of the loss function to previous predictors’ prediction results. Think of the process of training of GBDT as Gradient Descending to find parameters of other models like neural network, just the parameters GBDT looks for are the predicted values for each tree leaf. The three GBDT mentioned in the report are XGBoost[[1]](#endnote-1), LightGBM[[2]](#endnote-2) and CatBoost[[3]](#endnote-3).

XGBoost makes use of both first and second derivative of loss function to minimize it, while traditional GBDT uses only first derivative. And there are many other useful features, like including regularization in both size of predictions and tree complexity, see reference for all details. It worth mentioning in details of leaf-wise tree and depth-wise tree. XGBoost (and LightGBM below) is leaf-wise tree, and CatBoost is depth-wise. During the process of finding the best structure of each tree, depth-wise algo will look for the best splits for each node at depth n before going to depth n+1, while leaf-wise algo will search through all the leaf nodes at each iteration, find the best split for each, then pick the one with most improvement for this iteration. So leaf-wise algo normally will find a much deeper tree then depth-wise algo,

LightGBM is a computationally improved version of XGBoost in terms of strategic subsampling and taking advantage of sparse features. So it is much faster, but less accurate in training. However it turns out to be no worse in prediction with testing data, which could be possibly explained by less overfitting from less accuracy. It worth mentioning that LightGBM provides automatic handling of categorical features by sorting the classes by gradient information[[4]](#endnote-4) and try splits only at class boundaries.

CatBoost uses a different strategy in mainly 3 aspects: (1), depth-wise tree; (2), categorical features are also auto-handled, but it uses a customized logic to transform them into numerical features; (3), special handling of biases in GBDT[[5]](#endnote-5). From code, it uses a different way to achieve L2 regularization, and it seems only first order derivative is used.

For my model, LightGBM is chosen against XGBoost for mainly two reasons:

1. XGBoost’s default API does not have MAE as loss function. Although API for customized loss function is provided, without sureness of correct implementation, I would go with LightGBM, where MAE can be directly configured.
2. XGBoost has to handle categorical variables with one-hot encoding. It is less ideal for four reasons that I can think of:
   1. There is no way to directly handle high-cardinal features.
   2. With sub-sampling on features, such setup would give higher weights on categorical features.
   3. For categorical features with more than 4 classes, with one-hot encoding, each split can only look at one class, which loses the big picture of the whole structure.
   4. It expands number of effective columns, which expands data-size (important here as we have over 3 million rows to predict).

Several important hyper parameters that I tuned:

* Learning\_rate: learning rate for GBDT is of the same meaning as Gradient Descending, i.e. how fast the ‘parameters’ update in each iteration. This parameter exists for both LightGBM and CatBoost.
* Number\_leaf: this parameter only exists for LightGBM. For leaf-wise algo, number\_leaf is a more characteristic feature to represent complexity.
* Depth: CatBoost is depth-wise tree, so, as mentioned above, only depth parameter is provided, and we use this to control tree complexity.
* Min\_data\_in\_leaf: this is a regularization parameter and only exists in LightGBM. With this parameter, a node will not be considered for splitting when number of samples it contains is too small, so that overfitting is mitigated. Be noted, LightGBM also provides L1 and L2 regularization parameters, which I choose to leave as 0. From some testing trails in parameter search, these regularization parameters compensate for each other, e.g. holding everything else the same, small min\_data\_in\_leaf and large L1 param can give similar results as a large min\_data\_in\_leaf and small L1 param; so tuning one regularization param is sufficient.
* L2\_leaf\_reg: this is CatBoost’s regularization param. It handles overfitting is an uncommon way. From source code, update value of each leaf node in a RegressionTree is given is given as sum(sample\_value) / (n\_sample + l2\_leaf\_reg). Its effect is having much stronger regularization effect for smaller nodes than big nodes.

Also, the CV framework needs to be carefully designed. Since we cannot choose all models for private LB submission, a ‘best’ model (actually Kaggle allows you to choose two ‘best’ models) has to be chosen without knowing models’ performance in testing dataset. Due to the risk of overfitting to public LB, ‘best’ model should not be solely judged from public LB ranking, a scientific local CV provides valuable information.

Because the data for public LB and private LB are collected for a specific time period, seasonality and change model’s predictive power over time needs to be considered. To be specific, public LB only includes 2016 10, 11 and 12 whose training data is noticeably less than the others (please refer to model\_iteration.ipynb); private LB only includes 2017 10, 11, and 12 which has no corresponding training data at all. So 3 types of CV are used to evaluate models locally (month 4, 5, 6 are chosen for reason discussed in Implementation section):

1. n\_folds CV on all data, stratified by month.
2. Targeting for public LB, part of data of 2016 4, 5, 6 is held out as validation and the rest is included in training, and all data of 2017 4, 5, 6 is not used at all.
3. Targeting for private LB, all data of 2017 4, 5, 6 is held out as validation, and only part of 2016 4, 5, 6 is used for training, rest is not used at all.

So for each model version, we make up to 7 outputs:

CV\_stratified\_avg, CV\_public\_LB, CV\_private\_LB;

public\_LB\_score, public\_LB\_rank, private\_LB\_score, private\_LB\_rank.

Benchmark

I choose 2 benchmarks for this problem.

First is median prediction. Since the target is already noise-like, a naïve median prediction provides a baseline.

Second is a raw LightGBM model, ‘raw’ meaning we take no feature engineering and uses only provided properties as features, even it is well expected that seasonality effect exists, Let’s check the contribution from handling seasonality in model refinement section. Even it is said that ‘raw’ features are used, preprocessing of raw features as described in Data Processing section is also applied in this benchmark model. Besides features used, hyper parameters have been tuned with random-search, details will be explained in implementation section.

Performance of the benchmarks and all the other model trials will be demonstrated in the Results section.

III. Methodology

Data Preprocessing

General preprocessing of properties (handling of 1-6 is in data\_prep.py, and 7 is handled in model prep function in cat\_boost\_models.py and lgb\_models.py respectively):

1. Transform num-typed and bool-typed categorical features to string-type. For example, FIPS is read as 4-digit int, and pool\_count only has values of 0-1. This transformation may not be necessary, but it ensures avoiding any potential floating-point precision issues and achieves cleanness of data-types.
2. Extract information from census\_tract\_and\_block data. Raw\_census\_tract\_and\_block is float-like and census\_tract\_and\_block is int-like. But if we carefully look at the values of those numbers, it could be told that each contains 3 pieces of information:
   1. First 4 digits are the same of FIPS, which is duplicated information.
   2. Next 6 digits (in raw\_census\_tract\_and\_block, it is in xxxx.xx format, which makes the info interpreted as a float) are census\_tract code.
   3. Last 4 digits are block code.

So these two columns are extracted as raw\_census, raw\_block and census, block columns.

1. Cleaning small groups of categorical features. For categorical features, there are some groups values that only appear in testing dataset but not in training dataset. How the model implementation handles these values in predicting has not been explained in model doc, and did took all the trouble to look into source code, so I simply set their values to nan when predicting for testing data set.
2. Cleaning area\_garage and num\_garage. There is some obvious inconsistency between these two variables, where there exist houses with zero number of garages but having non-zero garage area. This kind of rows makes up of around 6 percent of all properties data. Missing ratio of area\_garage is around 70%, so I think it provides sufficient information to fill in zero-garage area according to number of garages. So for such a row, given its number of garage, use average of garage area of all other samples with the same number of garage to fill in for its garage area.
3. Propagating of area\_pool from num\_pool. First of all, number of pool only takes values of 1 and NA, so it is reasonable to take NA as 0 pool, then num\_pool has no missing. On the other hand, original area\_pool has over 99% of missing rate, unlike garage case it is hard to fill in other area\_pool data. So I simply fill in NA area\_pool as 0 for rows with 0 num\_pool, so that 0 pool\_area and NA pool\_area can be differentiated.
4. Fill in NA with 0. For num\_fireplace and num\_34\_bathroom, data only contains NA but no 0, so I think it is reasonable to consider NA as 0 for them.
5. Following pairs of features contain almost the same information.
   1. num\_bathroom\_assessor – num\_bathroom
   2. code\_county – fips
   3. area\_living\_type\_12 – area\_living\_finished\_calc
   4. area\_firstfloor\_assessor – area\_firstfloor\_zillow

So I only kept one (later one in the listing above) for each pair.

Details for each one of the features could be found in data\_explore.html.

Preprocessing for LightGBM:

LightGBM auto-handles categorical variables, just need:

1. Categorical features has to have their values being mapped to an int.
2. Model should know which features are used as categorical, I choose to mark data-type of these features as ‘category’ in pandas.DataFrame.

One thing to take special care is that, we need to make sure the created mapping from string labels to int is consistent in all datasets, i.e. testing & training, 2016 data and 2017 data.

Preprocessing for CatBoost:

CatBoost also auto-handles categorical variables. The handling is easier than LightGBM, just need to provide the indexes of categorical columns. So we need to keep information of that. Another thing is handling of NA for numerical variables, I have not tried the effect of leaving NAs there, just to mimic the Python examples on CatBoost Github, I set NAs to -999, which is fine here as all the variables are non-negative.

Be noted that extreme values are not handles in this section because all the training data are from actual transactions. Let’s first see how the original data performs, then see how extreme values affects model behavior in refinement section.

Implementation

Both LightGBM and CatBoost have provided handy API to perform cv, training and prediction. The versions I use are 2.0.5 for LightGBM and 0.2.5 for CatBoost. These are not the lasted published versions, I use the same versions as those I used when I participated the competition.

Parameter tuning:

Hyper-parameters of each model are tuned through random search. Given a parameter set, cv function would provide the average evaluation metric, which is MAE as described in definition section, across number of folds, which I choose to be 5 for both LightGBM and CatBoost. Total number of iterations is set to be high, 12000 for LightGBM and 3000 for CatBoost, and an early stopping condition is set, 100 for LightGBM and 50 for CatBoost. Early stopping works as following, folds average MAE is calculated at each iteration, so at iteration n, we have the metric value as V(n), then for each of V(n + 1) to V(n + m), if none of them gets a better performance than V(n), the cv process will be recorded as terminated at n, and m here is the early-stopping-rounds parameter. The returned value of cv is a list of evaluation metrics, one value for each iteration, so besides the final performance of a certain parameter set input, we also get the corresponding number-rounds parameter by checking the length of the output. I have set the stratification flag to False, if it is set to True, the folds data would be balanced according to a certain group. I don’t think it is necessary here because the data set is sufficiently large and here cv is just for parameter search, a more careful design would have been performed in the real cv process. I do 100 random searches for each model, and pick the best one(s) to use.

Random-searched parameters for LightGBM:

* Learning\_rate: log linear 0.1 \*\* Uniform(1, 3). It has max of 0.1 and min of 0.001, but gives more trails at small end in the linear space between min and max.
* Min\_data\_in\_leaf: Uniform(100, 600).
* Num\_leaf: Uniform(30, 80).

Random-searched parameters for CatBoost, CatBoost has been advertised as default parameters would perform well in many problems, so I am not going too much away from default.

* Learning\_rate: default 0.03, I am searching log linear 0.1 \*\* Uniform(1.1, 2), 0.1 \*\* 1.1 is somewhere around 0.08.
* Depth: default 6, I am searching Uniform(5, 10).
* L2\_leaf\_reg: default 3, I am searching Uniform(2, 10).

There is no strict reasoning of the choice of the searching range of the parameters above. They are just set around some benchmark, which is default values for CatBoost, and values used in some public Kernels in the competition forum for LightGBM.

Feature Importance:

Feature importance analysis is only performed under LightGBM.

In this section, the process for which metrics, algorithms, and techniques that you implemented for the given data will need to be clearly documented. It should be abundantly clear how the implementation was carried out, and discussion should be made regarding any complications that occurred during this process. Questions to ask yourself when writing this section:

- \_Is it made clear how the algorithms and techniques were implemented with the given datasets or input data?\_

- \_Were there any complications with the original metrics or techniques that required changing prior to acquiring a solution?\_

- \_Was there any part of the coding process (e.g., writing complicated functions) that should be documented?\_

Refinement

Tricks ordered by importance:

1, feature selection.

2, feature engineering (grouping categorical features, paired features, num\_ features as categorical, simple nan impute for full\_bathroom.)

3, row selection, remove row outliers.

4, grouping high-group-number categorical features, make them usable.

5, seasonality handling.

5, 2-step modeling, first predict large abs error, then fit / apply two different set of models.

6, missing value imputation by algorithm from property data. (predict missing column with other columns).

In this section, you will need to discuss the process of improvement you made upon the algorithms and techniques you used in your implementation. For example, adjusting parameters for certain models to acquire improved solutions would fall under the refinement category. Your initial and final solutions should be reported, as well as any significant intermediate results as necessary. Questions to ask yourself when writing this section:

- \_Has an initial solution been found and clearly reported?\_

- \_Is the process of improvement clearly documented, such as what techniques were used?\_

- \_Are intermediate and final solutions clearly reported as the process is improved?\_

IV. Results

\_(approx. 2-3 pages)\_

Model Evaluation and Validation

In this section, the final model and any supporting qualities should be evaluated in detail. It should be clear how the final model was derived and why this model was chosen. In addition, some type of analysis should be used to validate the robustness of this model and its solution, such as manipulating the input data or environment to see how the model’s solution is affected (this is called sensitivity analysis). Questions to ask yourself when writing this section:

- \_Is the final model reasonable and aligning with solution expectations? Are the final parameters of the model appropriate?\_

- \_Has the final model been tested with various inputs to evaluate whether the model generalizes well to unseen data?\_

- \_Is the model robust enough for the problem? Do small perturbations (changes) in training data or the input space greatly affect the results?\_

- \_Can results found from the model be trusted?\_

Justification

In this section, your model’s final solution and its results should be compared to the benchmark you established earlier in the project using some type of statistical analysis. You should also justify whether these results and the solution are significant enough to have solved the problem posed in the project. Questions to ask yourself when writing this section:

- \_Are the final results found stronger than the benchmark result reported earlier?\_

- \_Have you thoroughly analyzed and discussed the final solution?\_

- \_Is the final solution significant enough to have solved the problem?\_

V. Conclusion

\_(approx. 1-2 pages)\_

Free-Form Visualization

In this section, you will need to provide some form of visualization that emphasizes an important quality about the project. It is much more free-form, but should reasonably support a significant result or characteristic about the problem that you want to discuss. Questions to ask yourself when writing this section:

- \_Have you visualized a relevant or important quality about the problem, dataset, input data, or results?\_

- \_Is the visualization thoroughly analyzed and discussed?\_

- \_If a plot is provided, are the axes, title, and datum clearly defined?\_

Reflection

In this section, you will summarize the entire end-to-end problem solution and discuss one or two particular aspects of the project you found interesting or difficult. You are expected to reflect on the project as a whole to show that you have a firm understanding of the entire process employed in your work. Questions to ask yourself when writing this section:

- \_Have you thoroughly summarized the entire process you used for this project?\_

- \_Were there any interesting aspects of the project?\_

- \_Were there any difficult aspects of the project?\_

- \_Does the final model and solution fit your expectations for the problem, and should it be used in a general setting to solve these types of problems?\_

Improvement

In this section, you will need to provide discussion as to how one aspect of the implementation you designed could be improved. As an example, consider ways your implementation can be made more general, and what would need to be modified. You do not need to make this improvement, but the potential solutions resulting from these changes are considered and compared/contrasted to your current solution. Questions to ask yourself when writing this section:

- \_Are there further improvements that could be made on the algorithms or techniques you used in this project?\_

- \_Were there algorithms or techniques you researched that you did not know how to implement, but would consider using if you knew how?\_

- \_If you used your final solution as the new benchmark, do you think an even better solution exists?\_

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\*\*Before submitting, ask yourself. . .\*\*

- Does the project report you’ve written follow a well-organized structure similar to that of the project template?

- Is each section (particularly \*\*Analysis\*\* and \*\*Methodology\*\*) written in a clear, concise and specific fashion? Are there any ambiguous terms or phrases that need clarification?

- Would the intended audience of your project be able to understand your analysis, methods, and results?

- Have you properly proof-read your project report to assure there are minimal grammatical and spelling mistakes?

- Are all the resources used for this project correctly cited and referenced?

- Is the code that implements your solution easily readable and properly commented?

- Does the code execute without error and produce results similar to those reported?

1. Tianqi Chen and Carlos Guestrin. XGBoost: A Scalable Tree Boosting System. In 22nd SIGKDD Conference on Knowledge Discovery and Data Mining, 2016 [↑](#endnote-ref-1)
2. Guolin Ke, Qi Meng, Thomas Finley, Taifeng Wang, Wei Chen, Weidong Ma, Qiwei Ye, and Tie-Yan Liu. LightGBM: A Highly Efficient Gradient Boosting Decision Tree. In Advances in Neural Information Processing Systems (NIPS), pp. 3149-3157. 2017. [↑](#endnote-ref-2)
3. <https://tech.yandex.com/catboost/doc/dg/concepts/about-docpage/> [↑](#endnote-ref-3)
4. <https://github.com/Microsoft/LightGBM/issues/699> [↑](#endnote-ref-4)
5. Anna Veronika Dorogush, Andrey Gulin, Gleb Gusev, Nikita Kazeev, Liudmila Ostroumova Prokhorenkova, Aleksandr Vorobev. Fighting biases with dynamic boosting. arXiv:1706.09516 [↑](#endnote-ref-5)