Production Line Performance

Project work in Languages and Algorithms for Artificial Intelligence class (Module 2)

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Datasets

Test datasets

- **Arrest**: Contains statistics, in arrests per 100.000 residents, for assault, murder, and rape in each of the 50 US states in 1973. It also gives the percent of the population living in urban areas.
- **Adult**: Aims at separating people whose income is greater than 50 thousands dollars per year from the rest.

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Actual dataset

- **Bosch**: Aims at predicting internal failures using thousands of measurements and tests made for each component along different assembly lines.

Preprocessing

- The Bosch dataset includes 3 subsets: numerical, categorical and time data.
- As stated in [2], the categorical data is extremely sparse, and thus not exploited in subsequent stages.
- Our first analysis will be focused on just **numerical data**:
  - 968 anonymized features
  - 1 183 747 labeled examples
  - 0.58% of failed products
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Data exploration

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- **Stage I**: This step clusters data with similar processes together into process groups.
- **Stage II**: This step uses supervised learning to predict the failed products. Each cluster is treated as an independent dataset and has its own classifier.

Two-stage approach

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- **Stage II**: This step uses supervised learning to predict the failed products. Each cluster is treated as an independent dataset and has its own classifier.

- **Common**: Columns containing null values and constant values in each row are dropped.
- **Clustering**: Values are binarized (0 meaning null value and 1 meaning not null value) and *PCA* is applied to binarized features.
- **Classification**: A *feature imputation* method (mean value over the column), followed by *feature standardization* (zero mean, unit variance) and *PCA*, is applied over non-binary values in each cluster.
- **Prediction**: A new example follows the same preprocessing scheme as the whole dataset.

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PCA

Custom implementation of the *PCA* workflow, taking into account:

- *Features assembly* and *features standardization*.
- Selection of the minimum number of principal components *explaining* the given percentage of *variance* in the data (defaults to 95%).
- *Transformation matrix* storage, so that new examples can be easily converted into principal components.

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Clustering

The chosen clustering algorithm is `k-means`, since density-based methods (like `DBSCAN`) are still not available in Spark. So, the following issues needed to be addressed:

- **Problem**: Automatically select the right amount of clusters:
  - *Silhouette* and *elbow* methods are not ideal, since they require human analysis.
  - Spark 3.0.0 dropped support for *inertia* computation, maintaining only evaluation by silhouette scores.
- **Solution**: Ad-hoc implementation of the *Gap statistic* method, described in [1].

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Gap statistic

- For $k = 1, .., K$, where K is the maximum number of clusters, perform k-means and compute the resulting inertia I_k.
- Generate B reference datasets by sampling from a uniform distribution over each feature, where the support is directly identified by features ranges. Then, for $k = 1, .., K$ and $b = 1, .., B$, perform k-means and compute the resulting inertia I_{kb}. Finally, estimate $E^*[log(I_{kb})]$ as $\frac{1}{B}\sum_b log(I_{kb})$.
- Compute the Gap score as $Gap(k) = E^*[log(I_{kb})] - log(I_k)$.
- Compute the standard deviation sd_k of $log(I_{kb})$ and define $s_k = sd_k * \sqrt{1 + \frac{1}{B}}$.
- Select the minimum k s.t. $Gap(k) - Gap(k+1) + s_{k+1} \geq 0$.

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Classification

Classifiers

- **Implemented models**: Decision Tree, **Random Forest** and Gradient Boosted Tree.
- **Training strategy**: Hyper-parameters selected by cross-validation on a parameter grid, mainly consisting of the following:
    - Maximum *depth* of each tree, ranging from 1 to 30 with step 5.
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Different evaluation strategies, based on a custom *confusion matrix* computation:

- **Accuracy**: $\frac{TP+TN}{TP+FP+FN+TN}$ (not well-suited to the Bosch dataset, given its high class imbalance).
- **F_1-score**: $2 \times \frac{PPV \times TPR}{PPV+TPR}$, where $PPV = \frac{TP}{TP+FP}$ and $TPR = \frac{TP}{TP+FN}$.
- **Area under ROC**: The two-dimensional area underneath the entire ROC curve (TPR/FPR at varying thresholds) from $(0,0)$ to $(1,1)$, where $FPR = \frac{FP}{FP+TN}$.
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Execution

Cloud issues

- `Spark 3.0.0` is not yet available on the AWS `EMR` service (the last version that can be used is `2.4.4`).
- Spark 3.0.0 could be manually installed to `EC2` clusters, but the `Flintrock` service already provides some shortcuts to create the desidered clusters and automatically install the selected Spark/Hadoop version.
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  - CPU: 2.3 Ghz 8-Core Intel Core i9
  - RAM: 16 GB 2667 MHz DDR4
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Thank you for your attention

References

Robert Tibshirani, Guenther Walther, and Trevor Hastie.
Estimating the number of clusters in a dataset via the gap statistic.
63:411–423, 2000.

Darui Zhang, Bin Xu, and Jasmine Wood.
Predict failures in production lines: A two-stage approach with clustering and supervised learning.
pages 2070–2074, 12 2016.