Machine Learning with Python and H2O

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http://h2o.ai/resources/

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Contents

1 Introduction 4

2 What is H2O? 5
  2.1 Example Code ........................................................................ 6
  2.2 Citation ..................................................................................... 6

3 Installation 6
  3.1 Installation in Python ................................................................. 7

4 Data Preparation 7
  4.1 Viewing Data ........................................................................... 9
  4.2 Selection .................................................................................. 10
  4.3 Missing Data ........................................................................... 12
  4.4 Operations ............................................................................... 13
  4.5 Merging .................................................................................. 16
  4.6 Grouping ................................................................................ 17
  4.7 Using Date and Time Data ......................................................... 18
  4.8 Categoricals .......................................................................... 19
  4.9 Loading and Saving Data ......................................................... 21

5 Machine Learning 21
  5.1 Modeling ............................................................................... 21
    5.1.1 Supervised Learning .......................................................... 22
    5.1.2 Unsupervised Learning ...................................................... 23
    5.1.3 Miscellaneous ................................................................. 23
  5.2 Running Models ..................................................................... 23
    5.2.1 Gradient Boosting Machine (GBM) .................................... 24
    5.2.2 Generalized Linear Models (GLM) .................................... 27
    5.2.3 K-means ......................................................................... 30
    5.2.4 Principal Components Analysis (PCA) ............................... 32
  5.3 Grid Search ........................................................................... 33
  5.4 Integration with scikit-learn .................................................... 34
    5.4.1 Pipelines ........................................................................ 34
    5.4.2 Randomized Grid Search .................................................. 36

6 Acknowledgments 38

7 References 38
Introduction

This documentation describes how to use H2O from Python. More information on H2O’s system and algorithms (as well as complete Python user documentation) is available at the H2O website at http://docs.h2o.ai.

H2O Python uses a REST API to connect to H2O. To use H2O in Python or launch H2O from Python, specify the IP address and port number of the H2O instance in the Python environment. Datasets are not directly transmitted through the REST API. Instead, commands (for example, importing a dataset at specified HDFS location) are sent either through the browser or the REST API to perform the specified task.

The dataset is then assigned an identifier that is used as a reference in commands to the web server. After one prepares the dataset for modeling by defining significant data and removing insignificant data, H2O is used to create a model representing the results of the data analysis. These models are assigned IDs that are used as references in commands.

Depending on the size of your data, H2O can run on your desktop or scale using multiple nodes with Hadoop, an EC2 cluster, or Spark. Hadoop is a scalable open-source file system that uses clusters for distributed storage and dataset processing. H2O nodes run as JVM invocations on Hadoop nodes. For performance reasons, we recommend that you do not run an H2O node on the same hardware as the Hadoop NameNode.

H2O helps Python users make the leap from single machine based processing to large-scale distributed environments. Hadoop lets H2O users scale their data processing capabilities based on their current needs. Using H2O, Python, and Hadoop, you can create a complete end-to-end data analysis solution.

This document describes the four steps of data analysis with H2O:

1. installing H2O
2. preparing your data for modeling
3. creating a model using simple but powerful machine learning algorithms
4. scoring your models
What is H2O?

H2O.ai is focused on bringing AI to businesses through software. Its flagship product is H2O, the leading open source platform that makes it easy for financial services, insurance companies, and healthcare companies to deploy AI and deep learning to solve complex problems. More than 9,000 organizations and 80,000+ data scientists depend on H2O for critical applications like predictive maintenance and operational intelligence. The company – which was recently named to the CB Insights AI 100 – is used by 169 Fortune 500 enterprises, including 8 of the world’s 10 largest banks, 7 of the 10 largest insurance companies, and 4 of the top 10 healthcare companies. Notable customers include Capital One, Progressive Insurance, Transamerica, Comcast, Nielsen Catalina Solutions, Macy’s, Walgreens, and Kaiser Permanente.

Using in-memory compression, H2O handles billions of data rows in-memory, even with a small cluster. To make it easier for non-engineers to create complete analytic workflows, H2O’s platform includes interfaces for R, Python, Scala, Java, JSON, and CoffeeScript/JavaScript, as well as a built-in web interface, Flow. H2O is designed to run in standalone mode, on Hadoop, or within a Spark Cluster, and typically deploys within minutes.

H2O includes many common machine learning algorithms, such as generalized linear modeling (linear regression, logistic regression, etc.), Naïve Bayes, principal components analysis, k-means clustering, and word2vec. H2O implements best-in-class algorithms at scale, such as distributed random forest, gradient boosting, and deep learning. H2O also includes a Stacked Ensembles method, which finds the optimal combination of a collection of prediction algorithms using a process known as "stacking." With H2O, customers can build thousands of models and compare the results to get the best predictions.

H2O is nurturing a grassroots movement of physicists, mathematicians, and computer scientists to herald the new wave of discovery with data science by collaborating closely with academic researchers and industrial data scientists. Stanford university giants Stephen Boyd, Trevor Hastie, and Rob Tibshirani advise the H2O team on building scalable machine learning algorithms. And with hundreds of meetups over the past several years, H2O continues to remain a word-of-mouth phenomenon.

Try it out

- Download H2O directly at http://h2o.ai/download.
- Install H2O’s R package from CRAN at https://cran.r-project.org/web/packages/h2o/.
Installation

- **Install the Python package from PyPI at** [https://pypi.python.org/pypi/h2o/](https://pypi.python.org/pypi/h2o/).

Join the community

- **To learn about our training sessions, hackathons, and product updates,** visit [http://h2o.ai](http://h2o.ai).

- **To learn about our meetups,** visit [https://www.meetup.com/topics/h2o/all/](https://www.meetup.com/topics/h2o/all/).

- **Have questions? Post them on Stack Overflow using the h2o tag at** [http://stackoverflow.com/questions/tagged/h2o](http://stackoverflow.com/questions/tagged/h2o).

- **Have a Google account (such as Gmail or Google+)?** Join the open source community forum at [https://groups.google.com/d/forum/h2ostream](https://groups.google.com/d/forum/h2ostream).

- **Join the chat at** [https://gitter.im/h2oai/h2o-3](https://gitter.im/h2oai/h2o-3).

Example Code

Python code for the examples in this document is located here:


Citation

To cite this booklet, use the following:


Installation

H2O requires Java; if you do not already have Java installed, install it from [https://java.com/en/download/](https://java.com/en/download/) before installing H2O.

The easiest way to directly install H2O is via a Python package.
Installation in Python

To load a recent H2O package from PyPI, run:

```
pip install h2o
```

To download the latest stable H2O-3 build from the H2O download page:

1. Go to [http://h2o.ai/download](http://h2o.ai/download).
2. Choose the latest stable H2O-3 build.
3. Click the “Install in Python” tab.
4. Copy and paste the commands into your Python session.

After H2O is installed, verify the installation:

```
import h2o
h2o.init()
# Start H2O on your local machine

# Get help
help(h2o.estimators.glm.H2OGeneralizedLinearEstimator)
help(h2o.estimators.gbm.H2OGradientBoostingEstimator)

# Show a demo
h2o.demo("glm")
h2o.demo("gbm")
```

Data Preparation

The next sections of the booklet demonstrate the Python interface using examples, which include short snippets of code and the resulting output.

In H2O, these operations all occur distributed and in parallel and can be used on very large datasets. More information about the Python interface to H2O can be found at [docs.h2o.ai](http://docs.h2o.ai).

Typically, we import and start H2O on the same machine as the running Python process:

```
import h2o
h2o.init()
```

To connect to an established H2O cluster (in a multi-node Hadoop environment, for example):

```
h2o.init(ip="123.45.67.89", port=54321)
```
To create an H2OFrame object from a Python tuple:

```python
df = h2o.H2OFrame(zip((1, 2, 3), ('a', 'b', 'c'), (0.1, 0.2, 0.3)))
# View the H2OFrame
df
#   C1    C2    C3
# ---- ---- ----
#   1    a    0.1
#   2    b    0.2
#   3    c    0.3
# [3 rows x 3 columns]
```

To create an H2OFrame object from a Python list:

```python
df = h2o.H2OFrame(zip(*[[1, 2, 3], ['a', 'b', 'c'], [0.1, 0.2, 0.3]])
# View the H2OFrame
df
#   C1    C2    C3
# ---- ---- ----
#   1    a    0.1
#   2    b    0.2
#   3    c    0.3
# [3 rows x 3 columns]
```

To create an H2OFrame object from collections.OrderedDict or a Python dict:

```python
df = h2o.H2OFrame({'A': [1, 2, 3], 'B': ['a', 'b', 'c'], 'C': [0.1, 0.2, 0.3]})
# View the H2OFrame
df
#   A    C    B
# ---- ---- ----
#   1    0.1  a
#   2    0.2  b
#   3    0.3  c
# [3 rows x 3 columns]
```

To create an H2OFrame object from a Python dict and specify the column types:

```python
df2 = h2o.H2OFrame.from_python({'A': [1, 2, 3],
                                'B': ['a', 'a', 'b'],
                                'C': ['hello', 'all', 'world'],
                                'D': ['12MAR2015:11:00:00', '13MAR2015:12:00:00', '14MAR2015:13:00:00']},
                                column_types=['numeric', 'enum', 'string', 'time'])
# View the H2OFrame
To display the column types:

```python
df2.types
# {u’A’: u’numeric’, u’B’: u’string’, u’C’: u’enum’, u’D’: u’time’}
```

### Viewing Data

To display the top and bottom of an H2OFrame:

```python
# View top 10 rows of the H2OFrame
df.head()

# --- ----- --- -----------
# 1 hello a 1.42618e+12
# 2 all a 1.42627e+12
# 3 world b 1.42636e+12
#
# [3 rows x 4 columns]
```

```python
# View bottom 5 rows of the H2OFrame
df.tail(5)

# A B C D
# --------- ---------- ----------  ---------
# -0.613035  -0.425327 -1.92774 -2.1201
# -1.26552  -0.241526 -0.0445104 1.90628
# 0.763851  0.0391609 -0.500049 0.35561
# -1.24842  0.912686 -0.61146 1.94607
# 0.781973  0.051883 -0.403075 0.569406
# 1.40085  1.91999  0.514212 -1.47146
# -0.746025 -0.632182 1.274555 -1.35006
# -1.12065  0.374212 0.232229 -0.602646
#
# [10 rows x 4 columns]
```
Data Preparation

To display the column names:

```python
df.columns  # [u'A', u'B', u'C', u'D']
```

To display compression information, distribution (in multi-machine clusters), and summary statistics of your data:

```python
df.describe()
```

### Chunk compression summary:

<table>
<thead>
<tr>
<th>chunk_type</th>
<th>chunkname</th>
<th>count</th>
<th>count_%</th>
<th>size</th>
<th>size_%</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-bit Reals</td>
<td>CBD</td>
<td>4</td>
<td>100</td>
<td>3.4 KB</td>
<td>100</td>
</tr>
</tbody>
</table>

### Frame distribution summary:

<table>
<thead>
<tr>
<th>size</th>
<th>#_rows</th>
<th>#_chunks_per_col</th>
<th>#_chunks</th>
</tr>
</thead>
<tbody>
<tr>
<td>127.0.0.1:54321</td>
<td>3.4 KB</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>mean</td>
<td>3.4 KB</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>min</td>
<td>3.4 KB</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>max</td>
<td>3.4 KB</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>stddev</td>
<td>0 B</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td>3.4 KB</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

### Type statistics:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>real</td>
<td>real</td>
<td>real</td>
</tr>
<tr>
<td>-2.49822</td>
<td>-2.37446</td>
<td>-2.45977</td>
<td>-3.48247</td>
</tr>
<tr>
<td>-0.01062</td>
<td>-0.23159</td>
<td>0.11423</td>
<td>-0.16228</td>
</tr>
<tr>
<td>2.59380</td>
<td>1.91998</td>
<td>3.13014</td>
<td>2.39057</td>
</tr>
<tr>
<td>1.04354</td>
<td>0.90576</td>
<td>0.96133</td>
<td>1.02608</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Selection

To select a single column by name, resulting in an H2OFrame:

```python
df['A']
```
To select a single column by index, resulting in an H2OFrame:

```
1 df[1]
2 #     B
3 #  -------
4 # -0.425327
5 # -0.241526
6 #  0.039161
7 #  0.912686
8 # -1.839950
9 #  0.573736
10 #  0.051883
11 #  1.919987
12 # -0.632182
13 #  0.374212
14 # [100 rows x 1 column]
```

To select multiple columns by name, resulting in an H2OFrame:

```
df[['B','C']]
```

To select multiple columns by index, resulting in an H2OFrame:

```
1 df[0:2]
2 #    A    B
3 #  --------  --------
4 #  -0.613035 -0.425327
5 # -1.265520 -0.241526
6 #  0.763851  0.039161
7 # -1.248425  0.912686
8 #  2.105805 -1.839950
9 #  1.763502  0.573736
10 # -0.781973  0.051883
11 #  1.400853  1.919987
12 # -0.746025 -0.632182
13 # -1.120648  0.374212
14 # [100 rows x 2 columns]
```
To select multiple rows by slicing, resulting in an H2OFrame:

**Note** By default, H2OFrame selection is for columns, so to slice by rows and get all columns, be explicit about selecting all columns:

```r
df[2:7, :]
```

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.31828</td>
<td>0.316926</td>
<td>0.970535</td>
<td>0.218061</td>
</tr>
<tr>
<td>-0.18547</td>
<td>0.207064</td>
<td>1.3229</td>
<td>-0.432614</td>
</tr>
<tr>
<td>-0.424018</td>
<td>-1.72759</td>
<td>0.356871</td>
<td>0.206214</td>
</tr>
<tr>
<td>1.3377</td>
<td>1.10761</td>
<td>-0.280443</td>
<td>0.0964197</td>
</tr>
<tr>
<td>-0.385682</td>
<td>0.190449</td>
<td>0.760816</td>
<td>1.92447</td>
</tr>
</tbody>
</table>

# [5 rows x 4 columns]

To select rows based on specific criteria, use Boolean masking:

```r
df2[ df2["B"] == "a", :]
```

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>hello</td>
<td>a</td>
<td>1.42618e+12</td>
<td></td>
</tr>
<tr>
<td>all</td>
<td>a</td>
<td>1.42627e+12</td>
<td></td>
</tr>
</tbody>
</table>

# [2 rows x 4 columns]

**Missing Data**

The H2O parser can handle many different representations of missing data types, including "" (blank), 'NA', and None (Python). They are all displayed as nan in Python.

To create an H2OFrame from Python with missing elements:

```r
df3 = h2o.H2OFrame.from_python(
    {'A': [1, 2, 3,None,''],
     'B': ['a', 'a', 'b', 'NA', 'NA'],
     'C': ['hello', 'all', 'world', None, None],
     'D': ['12MAR2015:11:00:00',None,'13MAR2015:12:00:00',None,'14MAR2015:13:00:00']},
    column_types=['numeric', 'enum', 'string', 'time'])
```

To determine which rows are missing data for a given column (‘1’ indicates missing):

```r
df3["A"].isna()
```

<table>
<thead>
<tr>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
To change all missing values in a column to a different value:

```python
df3.loc[df3["A"].isna(), "A"] = 5
```

To determine the location of all missing data in an H2OFrame:

```python
df3.isna()
```

---

## Operations

When performing a descriptive statistic on an entire H2OFrame, missing data is generally excluded and the operation is only performed on the columns of the appropriate data type:

```python
df4 = h2o.H2OFrame.from_python(
"{'A': [1, 2, 3, None, ''],
 'B': ['a', 'a', 'b', 'NA', 'NA'],
 'C': ['hello', 'all', 'world', None, None],
 'D': ['12MAR2015:11:00:00', None,
      '13MAR2015:12:00:00', None,
      '14MAR2015:13:00:00']},
column_types=['numeric', 'enum', 'string', 'time'])
```

```python
df4.mean(na_rm=True)
```

When performing a descriptive statistic on a single column of an H2OFrame, missing data is generally not excluded:

```python
df4["A"].mean()
```

```python
df4["A"].mean(na_rm=True)
```

In both examples, a native Python object is returned (list and float respectively in these examples).
When applying functions to each column of the data, an H2OFrame containing the means of each column is returned:

```python
df5 = h2o.H2OFrame.from_python(np.random.randn(100,4).tolist(), column_names=list('ABCD'))
df5.apply(lambda x: x.mean(na_rm=True))
```

# H2OFrame:
## A  B  C  D
### 0.0304506 0.0334168 -0.0374976 0.0520486

When applying functions to each row of the data, an H2OFrame containing the sum of all columns is returned:

```python
df5.apply(lambda row: row.sum(), axis=1)
```

# H2OFrame:
## C1
### -0.388512 1.67669 -2.56216 -0.277616 1.13655 -0.575992 -3.49258 0.776883 -0.778604 2.30617

H2O provides many methods for histogramming and discretizing data. Here is an example using the `hist` method on a single data frame:

```python
df6 = h2o.H2OFrame.from_python(np.random.randn(100,1).tolist())
df6.hist(plot=False)
```

# Parse Progress: [###############################] 100%
## breaks counts mids_true mids density
### -1.51121 nan nan nan 0
### -0.868339 9 -1.07704 -1.18977 0.139997
### -0.225468 12 -0.73561 -0.546904 0.186663
### 0.417403 18 -0.413093 0.0959675 0.279994
### 1.06027 26 -0.10108 0.738839 0.404436
### 1.70315 22 0.214337 1.38171 0.342215
### 2.34602 7 0.607727 2.02458 0.108887
### 2.98889 6 0.860969 2.66745 0.0933313

# [8 rows x 5 columns]
H2O includes a set of string processing methods in the H2OFrame class that make it easy to operate on each element in an H2OFrame.

To determine the number of times a string is contained in each element:

```python
def7 = h2o.H2OFrame.from_python(['Hello', 'World', 'Welcome', 'To', 'H2O', 'World'])
# View the H2OFrame
df7
# C1    C2    C3    C4    C5    C6
# ----- ----- ------- ---- ---- ----
# Hello World Welcome To H2O World
#
# [1 row x 6 columns]
# Find how many times "l" appears in each string
def7.countmatches('l')
# C1    C2    C3    C4    C5    C6
# ---- ---- ---- ---- ---- ----
# 2 1 1 0 0 1
#
# [1 row x 6 columns]
```

To replace the first occurrence of 'l' (lower case letter) with 'x' and return a new H2OFrame:

```python
def7.sub('l','x')
# C1    C2    C3    C4    C5    C6
# ----- ----- ------- ---- ---- ----
# Hexlo Worxd Wexcome To H2O Worxd
```

For global substitution, use `gsub`. Both `sub` and `gsub` support regular expressions.

To split strings based on a regular expression:

```python
def7.strsplit('l+')
# C1    C2    C3    C4    C5    C6    C7    C8    C9    C10
# ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- 
# He o Wor d We come To H2O Wor d
#
# [1 row x 10 columns]
Merging

To combine two H2OFrames together by appending one as rows and return a new H2OFrame:

```python
# Create a frame of random numbers w/ 100 rows
df8 = h2o.H2OFrame.from_python(np.random.randn(100,4).tolist(), column_names=list('ABCD'))

# Create a second frame of random numbers w/ 100 rows
df9 = h2o.H2OFrame.from_python(np.random.randn(100,4).tolist(), column_names=list('ABCD'))

# Combine the two frames, adding the rows from df9 to df8
df8.rbind(df9)
```

```
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.11442</td>
<td>1.31272</td>
<td>0.250418</td>
<td>1.73182</td>
</tr>
<tr>
<td>2</td>
<td>-1.61876</td>
<td>0.428622</td>
<td>-1.16684</td>
<td>-0.032936</td>
</tr>
<tr>
<td>3</td>
<td>0.637249</td>
<td>-0.48904</td>
<td>1.55848</td>
<td>0.669266</td>
</tr>
<tr>
<td>4</td>
<td>0.00355574</td>
<td>-0.40736</td>
<td>-0.979222</td>
<td>-0.395017</td>
</tr>
<tr>
<td>5</td>
<td>0.218243</td>
<td>-0.154004</td>
<td>-0.219537</td>
<td>-0.750664</td>
</tr>
<tr>
<td>6</td>
<td>-0.047789</td>
<td>0.306318</td>
<td>0.557441</td>
<td>-0.319108</td>
</tr>
<tr>
<td>7</td>
<td>-1.45013</td>
<td>-0.614564</td>
<td>0.472257</td>
<td>-0.456181</td>
</tr>
<tr>
<td>8</td>
<td>-0.594333</td>
<td>-0.435832</td>
<td>-0.0257311</td>
<td>0.548708</td>
</tr>
<tr>
<td>9</td>
<td>0.571215</td>
<td>-1.22759</td>
<td>-2.01855</td>
<td>-0.491638</td>
</tr>
<tr>
<td>10</td>
<td>-0.697252</td>
<td>-0.864301</td>
<td>-0.542508</td>
<td>-0.152953</td>
</tr>
</tbody>
</table>

|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 11 | 0.940 | 0.170 | 0.124 | -0.170 | -0.722 | -0.79 | -0.91 | -2.09 |
| 12 | -0.315 | 1.102 | 1.38 | -0.05 |
```

For successful row binding, the column names and column types between the two H2OFrames must match. To combine two H2O frames together by appending one as columns and return a new H2OFrame:

```python
df8.cbind(df9)
```

```
|   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 1 | -0.09 | 0.944 | 0.160 | 0.271 | -0.351 | 1.66 | -2.32 | -0.86 |
| 2 | -0.95 | 0.669 | 0.664 | 1.535 | -0.633 | -1.78 | 0.32 | 1.27 |
| 3 | 0.17 | 0.657 | 0.970 | -0.419 | -1.413 | -0.51 | 0.64 | -1.25 |
| 4 | 0.58 | -0.516 | -1.598 | -1.346 | 0.711 | 1.09 | 0.05 | 0.63 |
| 5 | 1.04 | -0.281 | -0.411 | 0.959 | -0.009 | -0.47 | 0.41 | -0.52 |
| 6 | 0.49 | 0.170 | 0.124 | -0.170 | -0.722 | -0.79 | -0.91 | -2.09 |
| 7 | 1.42 | -0.409 | -0.525 | 2.155 | -0.841 | -0.19 | 0.13 | 0.63 |
| 8 | 0.94 | 1.192 | -1.075 | 0.017 | 0.167 | 0.54 | 0.52 | 1.42 |
| 9 | -0.53 | 0.777 | -1.090 | -2.237 | -0.693 | 0.24 | -0.56 | 1.45 |
| 10 | 0.34 | -0.456 | -1.220 | -0.456 | -0.315 | 1.10 | 1.38 | -0.05 |
```

|   |   |   |   |   |
|---|---|---|---|
| 11 |   |   |   |
| 12 |   |   |   |
| 13 |   |   |   |
| 14 |   |   |   |
| 15 |   |   |   |
| 16 |   |   |   |
H2O also supports merging two frames together by matching column names:

```python
df10 = h2o.H2OFrame.from_python( {
    'A': ['Hello', 'World', 'Welcome', 'To', 'H2O', 'World'],
    'n': [0,1,2,3,4,5]}
)

# Create a single-column, 100-row frame
# Include random integers from 0-5
df11 = h2o.H2OFrame.from_python(np.random.randint(0,6,(100,1)), column_names=list('n'))

# Combine column "n" from both datasets
df11.merge(df10)
```

### Grouping

"Grouping" refers to the following process:

- splitting the data into groups based on some criteria
- applying a function to each group independently
- combining the results into an H2OFrame

To group and then apply a function to the results:

```python
df12 = h2o.H2OFrame(
    { 'A' : ['foo', 'bar', 'foo', 'bar', 'foo', 'bar', 'foo', 'foo'],
    'B' : ['one', 'one', 'two', 'three', 'two', 'two', 'one', 'three'],
    'C' : np.random.randn(8).tolist(),
    'D' : np.random.randn(8).tolist()}
)

# View the H2OFrame
df12
```
To group by multiple columns and then apply a function:

```python
df13 = df12.group_by(['A','B']).sum().frame
```

Use `merge` to join the results into the original H2OFrame:

```python
df12.merge(df13)
```

### Using Date and Time Data

H2O has powerful features for ingesting and feature engineering using time data. Internally, H2O stores time information as an integer of the number of milliseconds since the epoch.

To ingest time data natively, use one of the supported time input formats:
df14 = h2o.H2OFrame.from_python(
    {'D': ['18OCT2015:11:00:00',
          '19OCT2015:12:00:00',
          '20OCT2015:13:00:00']},
    column_types=['time'])

df14.types
    # {u'D': u'time'}

To display the day of the month:

df14['D'].day()
# D
# ---
# 18
# 19
# 20

To display the day of the week:

df14['D'].dayOfWeek()
# D
# ---
# Sun
# Mon
# Tue

Categoricals

H2O handles categorical (also known as enumerated or factor) values in an
H2OFrame. This is significant because categorical columns have specific
treatments in each of the machine learning algorithms.

Using ‘df12’ from above, H2O imports columns A and B as categorical/enumerated/factor types:

df12.types
    # {u'A': u'enum', u'C': u'real', u'B': u'enum', u'D': u'real'}

To determine if any column is a categorical/enumerated/factor type:

df12.anyfactor()
# True

To view the categorical levels in a single column:

df12["A"].levels()
    # ['bar', 'foo']
To create categorical interaction features:

```python
df12.interaction(['A','B'], pairwise=False, max_factors=3, min_occurrence=1)
# A_B
# -------
# foo_one
# bar_one
# foo_two
# other
# foo_two
# other
# foo_one
# other
# [8 rows x 1 column]
```

To retain the most common categories and set the remaining categories to a common ‘Other’ category and create an interaction of a categorical column with itself:

```python
bb_df = df12.interaction(['B','B'], pairwise=False, max_factors=2, min_occurrence=1)
# View H2OFrame
bb_df
# B_B
# ----- 
# one
# one
# two
# other
# two
# one
# other
# [8 rows x 1 column]
```

These can then be added as a new column on the original dataframe:

```python
df15 = df12.cbind(bb_df)
# View H2OFrame
df15
# A C B D B_B
# --- ---------- ----- ---------- ----- 
# foo -0.809171 one 1.79059 one
# bar 0.216644 one 2.88524 one
# foo -0.033664 two 0.61205 two
# bar 0.985545 three 0.357742 other
# foo -2.15563 two 0.0456449 two
# bar -0.0170454 two -1.33625 two
# foo 1.32524 one 0.308092 one
# foo -0.546305 three -0.92675 other
# [8 rows x 5 columns]
```
Loading and Saving Data

In addition to loading data from Python objects, H2O can load data directly from:

- disk
- network file systems (NFS, S3)
- distributed file systems (HDFS)
- HTTP addresses

H2O currently supports the following file types:

- CSV (delimited) files
- ORC
- SVMLite
- Parquet
- ARFF
- XLS
- XLSX
- AVRO

To load data from the same machine running H2O:

```python
1 df = h2o.upload_file("/pathToFile/fileName")
```

To load data from the machine(s) running H2O to the machine running Python:

```python
1 df = h2o.import_file("/pathToFile/fileName")
```

To save an H2OFrame on the machine running H2O:

```python
1 h2o.export_file(df,"/pathToFile/fileName")
```

To save an H2OFrame on the machine running Python:

```python
1 h2o.download_csv(df,"/pathToFile/fileName")
```

Machine Learning

The following sections describe some common model types and features.

Modeling

The following section describes the features and functions of some common models available in H2O. For more information about running these models in
Python using H2O, refer to the documentation on the H2O.ai website or to the booklets on specific models.

H2O supports the following models:

- Deep Learning
- Naïve Bayes
- Principal Components Analysis (PCA)
- K-means
- Stacked Ensembles
- XGBoost
- Generalized Linear Models (GLM)
- Gradient Boosting Machine (GBM)
- Generalized Low Rank Model (GLRM)
- Distributed Random Forest (DRF)
- Word2vec

The list continues to grow, so check www.h2o.ai to see the latest additions.

**Supervised Learning**

**Generalized Linear Models (GLM):** Provides flexible generalization of ordinary linear regression for response variables with error distribution models other than a Gaussian (normal) distribution. GLM unifies various other statistical models, including Poisson, linear, logistic, and others when using $\ell_1$ and $\ell_2$ regularization.

**Distributed Random Forest:** Averages multiple decision trees, each created on different random samples of rows and columns. It is easy to use, non-linear, and provides feedback on the importance of each predictor in the model, making it one of the most robust algorithms for noisy data.

**Gradient Boosting Machine (GBM):** Produces a prediction model in the form of an ensemble of weak prediction models. It builds the model in a stage-wise fashion and is generalized by allowing an arbitrary differentiable loss function. It is one of the most powerful methods available today.

**Deep Learning:** Models high-level abstractions in data by using non-linear transformations in a layer-by-layer method. Deep learning is an example of supervised learning, which can use unlabeled data that other algorithms cannot.

**Naïve Bayes:** Generates a probabilistic classifier that assumes the value of a particular feature is unrelated to the presence or absence of any other feature, given the class variable. It is often used in text categorization.

**Stacked Ensembles:** Using multiple models built from different algorithms, Stacked Ensembles finds the optimal combination of a collection of prediction algorithms using a process known as "stacking."
**XGBoost**: XGBoost is an optimized gradient boosting library that implements machine learning algorithms under the Gradient Boosting Machine (GBM) framework. For many problems, XGBoost is the one of the best GBM frameworks today. In other cases, the H2O GBM algorithm comes out on top. Both implementations are available on the H2O platform.

**Unsupervised Learning**

**K-Means**: Reveals groups or clusters of data points for segmentation. It clusters observations into $k$-number of points with the nearest mean.

**Principal Component Analysis (PCA)**: The algorithm is carried out on a set of possibly collinear features and performs a transformation to produce a new set of uncorrelated features.

**Generalized Low Rank Model (GLRM)**: The method reconstructs missing values and identifies important features in heterogeneous data. It also recognizes a number of interpretations of low rank factors, which allows clustering of examples or of features.

**Anomaly Detection**: Identifies the outliers in your data by invoking the deep learning autoencoder, a powerful pattern recognition model.

**Miscellaneous**

**Word2vec**: Takes a text corpus as an input and produces the word vectors as output. The result is an H2O Word2vec model that can be exported as a binary model or as a MOJO.

**Running Models**

This section describes how to run the following model types:

- Gradient Boosting Machine (GBM)
- Generalized Linear Models (GLM)
- K-means
- Principal Components Analysis (PCA)

This section also shows how to generate predictions.
Gradient Boosting Machine (GBM)

To generate gradient boosting machine models for creating forward-learning ensembles, use H2OGradientBoostingEstimator.

The construction of the estimator defines the parameters of the estimator and the call to H2OGradientBoostingEstimator.train trains the estimator on the specified data. This pattern is common for each of the H2O algorithms.

```python
In [1]: import h2o

In [2]: h2o.init()

Checking whether there is an H2O instance running at http://localhost:54321
..... not found.

Attempting to start a local H2O server...

Java Version: java version "1.8.0_25"; Java(TM) SE Runtime Environment (build 1.8.0_25-b17); Java HotSpot(TM) 64-Bit Server VM (build 25.25-b02, mixed mode)

Starting server from /usr/local/h2o_jar/h2o.jar

Ice root: /var/folders/yl/cq5nhky53hjcl9wrqxt39kz80000gn/T/tmpHpRzVe

JVM stdout: /var/folders/yl/cq5nhky53hjcl9wrqxt39kz80000gn/T/tmpHpRzVe/

JVM stderr: /var/folders/yl/cq5nhky53hjcl9wrqxt39kz80000gn/T/tmpHpRzVe/

Server is running at http://127.0.0.1:54321

Connecting to H2O server at http://127.0.0.1:54321 ... successful.

In [3]: from h2o.estimators.gbm import H2OGradientBoostingEstimator

In [4]: iris_data_path = "http://h2o-public-test-data.s3.amazonaws.com/smalldata/iris/iris.csv"  # load demonstration data

In [5]: iris_df = h2o.import_file(path=iris_data_path)

Parse Progress: [###############################] 100%

Rows:150 Cols:5

Chunk compression summary:
chunktype chunkname count count_% size size_
---------- --------- ----- ------- ---- -----
1-Byte Int C1 1 20 218B 18.890
1-Byte Flt C2 4 80 936B 81.109

Frame distribution summary:
size rows chunks/col chunks
--------------- ---- ---------- ------
127.0.0.1:54321 1.1KB 150 1 5
mean 1.1KB 150 1 5
min 1.1KB 150 1 5
max 1.1KB 150 1 5
stddev 0 B 0 0
total 1.1 KB 150 1 5

--- C1 C2 C3 C4 C5
------- -------- -------- -------- --------
type real real real real enum
```
In [7]: gbm_regressor = H2OGradientBoostingEstimator(distribution="gaussian",
                                 ntree=10, max_depth=3, min_rows=2, learn_rate="0.2")
In [8]: gbm_regressor.train(x=range(1,iris_df.ncol), y=0, training_frame=
                           iris_df)
gbm Model Build Progress: [########################] 100%
In [9]: gbm_regressor
Out[9]: Model Details
H2OGradientBoostingEstimator: Gradient Boosting Machine
Model Summary:
number_of_trees | 10
model_size_in_bytes | 1535
min_depth | 3
max_depth | 3
mean_depth | 3
min_leaves | 7
max_leaves | 8
mean_leaves | 7.8
ModelMetricsRegression: gbm
** Reported on train data. **
MSE: 0.0706936802293
RMSE: 0.265882831769
MAE: 0.219981056849
RMSLE: 0.0391855537448
Mean Residual Deviance: 0.0706936802293
Scoring History:
timestamp duration number_of_trees training_MSE
--- ----------------- ---------- ----------------- --------------
2015-10-30 08:50:00 0.121 sec 1 0.472445
2015-10-30 08:50:00 0.151 sec 2 0.334868
2015-10-30 08:50:00 0.162 sec 3 0.242847
2015-10-30 08:50:00 0.175 sec 4 0.184128
2015-10-30 08:50:00 0.187 sec 5 0.14365
2015-10-30 08:50:00 0.197 sec 6 0.116814
2015-10-30 08:50:00 0.208 sec 7 0.0992098
2015-10-30 08:50:00 0.219 sec 8 0.0864125
Variable Importances:

<table>
<thead>
<tr>
<th>variable</th>
<th>relative_importance</th>
<th>scaled_importance</th>
<th>percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>227.562</td>
<td>1</td>
<td>0.894699</td>
</tr>
<tr>
<td>C2</td>
<td>15.1912</td>
<td>0.0667563</td>
<td>0.0597268</td>
</tr>
<tr>
<td>C5</td>
<td>9.50362</td>
<td>0.0417627</td>
<td>0.037365</td>
</tr>
<tr>
<td>C4</td>
<td>2.08799</td>
<td>0.00917544</td>
<td>0.00820926</td>
</tr>
</tbody>
</table>

To generate a classification model that uses labels, use `distribution="multinomial"`:

```python
def gbm_classify(distribution="multinomial", ntrees=10, max_depth=3, min_rows=2, learn_rate="0.2")
```
Scoring History:

<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>number_of_trees</th>
<th>training_MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.047 sec</td>
<td>1</td>
<td>0.282326</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.068 sec</td>
<td>2</td>
<td>0.179214</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.086 sec</td>
<td>3</td>
<td>0.114954</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.100 sec</td>
<td>4</td>
<td>0.0744726</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.112 sec</td>
<td>5</td>
<td>0.0498319</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.131 sec</td>
<td>6</td>
<td>0.0340885</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.143 sec</td>
<td>7</td>
<td>0.0241071</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.153 sec</td>
<td>8</td>
<td>0.017606</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.165 sec</td>
<td>9</td>
<td>0.0131024</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.180 sec</td>
<td>10</td>
<td>0.00976685</td>
</tr>
</tbody>
</table>

Variable Importances:

<table>
<thead>
<tr>
<th>variable</th>
<th>relative_importance</th>
<th>scaled_importance</th>
<th>percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>192.761</td>
<td>1</td>
<td>0.774374</td>
</tr>
<tr>
<td>C3</td>
<td>54.0381</td>
<td>0.280338</td>
<td>0.217086</td>
</tr>
<tr>
<td>C1</td>
<td>1.35271</td>
<td>0.00701757</td>
<td>0.00543422</td>
</tr>
<tr>
<td>C2</td>
<td>0.773032</td>
<td>0.00401032</td>
<td>0.00310549</td>
</tr>
</tbody>
</table>

Generalized Linear Models (GLM)

Generalized linear models (GLM) are some of the most commonly-used models for many types of data analysis use cases. While some data can be analyzed using linear models, linear models may not be as accurate if the variables are more complex. For example, if the dependent variable has a non-continuous distribution or if the effect of the predictors is not linear, generalized linear models will produce more accurate results than linear models.

Generalized Linear Models (GLM) estimate regression models for outcomes following exponential distributions in general. In addition to the Gaussian (i.e. normal) distribution, these include Poisson, binomial, gamma and Tweedie distributions. Each serves a different purpose and, depending on distribution and link function choice, it can be used either for prediction or classification.

H2O’s GLM algorithm fits the generalized linear model with elastic net penalties. The model fitting computation is distributed, extremely fast, and scales extremely
well for models with a limited number (∼ low thousands) of predictors with non-zero coefficients.

The algorithm can compute models for a single value of a penalty argument or the full regularization path, similar to glmnet. It can compute Gaussian (linear), logistic, Poisson, and gamma regression models. To generate a generalized linear model for developing linear models for exponential distributions, use H2OGeneralizedLinearEstimator. You can apply regularization to the model by adjusting the lambda and alpha parameters.

```python
In [13]: from h2o.estimators.glm import H2OGeneralizedLinearEstimator
In [14]: prostate_data_path = "http://h2o-public-test-data.s3.amazonaws.com/smalldata/prostate/prostate.csv"
In [15]: prostate_df = h2o.import_file(path=prostate_data_path)
Parse Progress: [###################################] 100%
In [16]: prostate_df["RACE"] = prostate_df["RACE"].asfactor()
In [17]: prostate_df.describe()
Rows:380 Cols:9
Chunk compression summary:
chunk_type   chunk_name          count count_percentage  size  size_percentage
------------ ------------------------- ------- ------------------ ------ -------------------
CBS           Bits                    1       11.1111          118 B 1.39381
C1N 1-Byte Integers (w/o NAs)      5      55.5556          2.2 KB 26.4588
C2 2-Byte Integers               1      11.1111          828 B 9.7803
CUD Unique Reals                  1      11.1111          2.1 KB 25.6556
C8D 64-bit Reals                  1      11.1111          3.0 KB 36.7116
Frame distribution summary:
size  number_of_rows number_of_chunks_per_column
------------ ------- -----------------------------
127.0.0.1:54321 8.3 KB 380 1 9
mean 8.3 KB 380 1 9
min 8.3 KB 380 1 9
max 8.3 KB 380 1 9
stddev 0 B 0 0
total 8.3 KB 380 1 9
In [18]: glm_classifier = H2OGeneralizedLinearEstimator(family="binomial", nfolds=10, alpha=0.5)
In [19]: glm_classifier.train(x=["AGE","RACE","PSA","DCAPS"],y="CAPSULE", training_frame=prostate_df)
```
In [20]: glm_classifier
Out[20]: Model Details

H2O Generalized Linear Model
Model Key: GLM_model_python_1446220160417_6

GLM Model: summary

<table>
<thead>
<tr>
<th>family</th>
<th>link</th>
<th>regularization</th>
<th>number_of_predictors_total</th>
<th>number_of_active_predictors</th>
<th>number_of_iterations</th>
<th>training_frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>binomial</td>
<td>logit</td>
<td>Elastic Net (alpha = 0.5, lambda = 3.251E-4)</td>
<td>6</td>
<td>6</td>
<td></td>
<td>py_3</td>
</tr>
</tbody>
</table>

ModelMetricsBinomialGLM: glm

** Reported on train data. **

MSE: 0.202442565125
RMSE: 0.449936178947
LogLoss: 0.591121990582
Null degrees of freedom: 379
Residual degrees of freedom: 374
Null deviance: 512.288840185
Residual deviance: 449.252712842
AIC: 461.252712842
AUC: 0.718954248366
Gini: 0.437908496732

Confusion Matrix (Act/Pred) for max f1 @ threshold = 0.282384349078:

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>80</td>
<td>147</td>
</tr>
<tr>
<td>1</td>
<td>19</td>
<td>134</td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>281</td>
</tr>
</tbody>
</table>

Error Rate:

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.6476</td>
<td>(147.0/227.0)</td>
</tr>
<tr>
<td>1</td>
<td>0.1242</td>
<td>(19.0/153.0)</td>
</tr>
<tr>
<td>Total</td>
<td>0.4368</td>
<td>(166.0/380.0)</td>
</tr>
</tbody>
</table>

Maximum Metrics: Maximum metrics at their respective thresholds

<table>
<thead>
<tr>
<th>metric</th>
<th>threshold</th>
<th>value</th>
<th>idx</th>
</tr>
</thead>
<tbody>
<tr>
<td>max f1</td>
<td>0.282384</td>
<td>0.617849</td>
<td>276</td>
</tr>
<tr>
<td>max f2</td>
<td>0.198777</td>
<td>0.77823</td>
<td>360</td>
</tr>
<tr>
<td>max f0point5</td>
<td>0.415125</td>
<td>0.63667</td>
<td>108</td>
</tr>
<tr>
<td>max accuracy</td>
<td>0.415125</td>
<td>0.705263</td>
<td>108</td>
</tr>
<tr>
<td>max precision</td>
<td>0.998613</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>max recall</td>
<td>0.198777</td>
<td>1</td>
<td>360</td>
</tr>
<tr>
<td>max specificity</td>
<td>0.998613</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>max absolute_mcc</td>
<td>0.415125</td>
<td>0.369123</td>
<td>108</td>
</tr>
<tr>
<td>max min_per_class_accuracy</td>
<td>0.332648</td>
<td>0.656388</td>
<td>175</td>
</tr>
<tr>
<td>max mean_per_class_accuracy</td>
<td>0.377454</td>
<td>0.67326</td>
<td>123</td>
</tr>
</tbody>
</table>

Gains/Lift Table: Avg response rate: 40.26 %

** Reported on cross-validation data. **
K-means

To generate a K-means model for data characterization, use `h2o.kmeans()`. This algorithm does not require a dependent variable.

```python
In [21]: from h2o.estimators.kmeans import H2OKMeansEstimator
In [22]: cluster_estimator = H2OKMeansEstimator(k=3)
In [23]: cluster_estimator.train(x=[0,1,2,3], training_frame=iris_df)
```
kmeans Model Build Progress: ################################### 100%

In [24]: cluster_estimator
Out[24]: Model Details
=======
H2OKMeansEstimator : K-means
Model Key: K-means_model_python_1446220160417_8

Model Summary:

- number_of_rows: 150
- number_of_clusters: 3
- number_of_categorical_columns: 0
- number_of_iterations: 4
- within_cluster_sum_of_squares: 190.757
- total_sum_of_squares: 596
- between_cluster_sum_of_squares: 405.243

ModelMetricsClustering: kmeans
** Reported on train data. **

- MSE: NaN
- RMSE: NaN
- Total Within Cluster Sum of Square Error: 190.756926265
- Total Sum of Square Error to Grand Mean: 596.0
- Between Cluster Sum of Square Error: 405.243073735

Centroid Statistics:

- centroid: 1
- size: 96
- within_cluster_sum_of_squares: 149.733

- centroid: 2
- size: 32
- within_cluster_sum_of_squares: 17.292

- centroid: 3
- size: 22
- within_cluster_sum_of_squares: 23.7318

Scoring History:

- timestamp: 2016-08-25 13:03:36
- duration: 0.005 sec
- iteration: 0
- avg_change_of_std_centroids: nan
- within_cluster_sum_of_squares: 385.505

- timestamp: 2016-08-25 13:03:36
- duration: 0.029 sec
- iteration: 1
- avg_change_of_std_centroids: 1.37093
- within_cluster_sum_of_squares: 173.769

- timestamp: 2016-08-25 13:03:36
- duration: 0.029 sec
- iteration: 2
- avg_change_of_std_centroids: 0.184617
- within_cluster_sum_of_squares: 141.623

- timestamp: 2016-08-25 13:03:36
- duration: 0.030 sec
- iteration: 3
- avg_change_of_std_centroids: 0.00705735
- within_cluster_sum_of_squares: 140.355

- timestamp: 2016-08-25 13:03:36
- duration: 0.030 sec
- iteration: 4
- avg_change_of_std_centroids: 0.00122272
- within_cluster_sum_of_squares: 140.162

- timestamp: 2016-08-25 13:03:36
- duration: 0.031 sec
- iteration: 5
- avg_change_of_std_centroids: 0.000263918
- within_cluster_sum_of_squares: 140.072

- timestamp: 2016-08-25 13:03:36
- duration: 0.031 sec
- iteration: 6
- avg_change_of_std_centroids: 0.000306555
- within_cluster_sum_of_squares: 140.026
Principal Components Analysis (PCA)

To map a set of variables onto a subspace using linear transformations, use `H2OPrincipalComponentAnalysisEstimator`. This is the first step in Principal Components Regression.

```
In [25]: from h2o.estimators.pca import H2OPrincipalComponentAnalysisEstimator

In [26]: pca_decomp = H2OPrincipalComponentAnalysisEstimator(k=2, transform="NONE", pca_method="Power", impute_missing=True)

In [27]: pca_decomp.train(x=range(0,4), training_frame=iris_df)

pca Model Build Progress: [############################################################] 100%

In [28]: pca_decomp

Out[28]: Model Details

Model: PCA

---

H2OPCA : Principal Component Analysis
Model Key: PCA_model_python_1446220160417_10

ModelMetricsPCA: pca

** Reported on train data. **

MSE: NaN
RMSE: NaN

Scoring History from Power SVD:

timestamp duration iterations err

--- -------------- --- --- ---

2018-01-18 08:35:44 0.002 sec 0 29.6462 1
2018-01-18 08:35:44 0.002 sec 1 0.733806 1
2018-01-18 08:35:44 0.002 sec 2 0.0249718 1
2018-01-18 08:35:44 0.002 sec 3 0.000851969 1
2018-01-18 08:35:44 0.002 sec 4 2.90753e-05 1
2018-01-18 08:35:44 0.002 sec 5 1.3487e-06 1
2018-01-18 08:35:44 0.002 sec 6 nan 1
2018-01-18 08:35:44 0.003 sec 7 1.02322 2
2018-01-18 08:35:44 0.003 sec 8 0.0445794 2
2018-01-18 08:35:44 0.003 sec 9 0.00164307 2
2018-01-18 08:35:44 0.003 sec 10 6.27379e-05 2
2018-01-18 08:35:44 0.003 sec 11 2.40329e-06 2
2018-01-18 08:35:44 0.003 sec 12 9.88431e-08 2
2018-01-18 08:35:44 0.003 sec 13 nan 2

<bound method H2OPrincipalComponentAnalysisEstimator.train of >

In [29]: pred = pca_decomp.predict(iris_df)
pca prediction progress: [############################################################] 100%

In [30]: pred.head()  # Projection results

Out[30]:

<table>
<thead>
<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-5.9122</td>
<td>2.30344</td>
</tr>
<tr>
<td>1</td>
<td>-5.57208</td>
<td>1.97383</td>
</tr>
<tr>
<td>2</td>
<td>-5.44648</td>
<td>2.09653</td>
</tr>
<tr>
<td>3</td>
<td>-5.43602</td>
<td>1.87168</td>
</tr>
</tbody>
</table>
Grid Search

H2O supports grid search across hyperparameters:

In [32]: ntree_opt = [5, 10, 15]
In [33]: max_depth_opt = [2, 3, 4]
In [34]: learn_rate_opt = [0.1, 0.2]
In [35]: hyper_parameters = {"ntrees": ntree_opt, "max_depth": max_depth_opt,
"learn_rate": learn_rate_opt}
In [36]: from h2o.grid.grid_search import H2OGridSearch
In [37]: gs = H2OGridSearch(H2OGradientBoostingEstimator(distribution="multinomial"), hyper_params=hyper_parameters)
In [38]: gs.train(x=range(0,iris_df.ncol-1), y=iris_df.ncol-1, training_frame=
iris_df, nfolds=10)

gbm Grid Build Progress: [########################################] 100%

In [39]: print gs.sort_by('logloss', increasing=True)

Grid Search Results:
Model Id Hyperparameters: ["learn_rate", "ntrees", "max_depth"] logloss
-------------------------------------------------------------------
Grid_GBM_model_1446220160417_30 ['0.2, 15, 4'] 0.05105
Grid_GBM_model_1446220160417_27 ['0.2, 15, 3'] 0.0551088
Grid_GBM_model_1446220160417_24 ['0.2, 15, 2'] 0.0697714
Grid_GBM_model_1446220160417_29 ['0.2, 10, 4'] 0.103064
Grid_GBM_model_1446220160417_26 ['0.2, 10, 3'] 0.106232
Grid_GBM_model_1446220160417_23 ['0.2, 10, 2'] 0.120161
Grid_GBM_model_1446220160417_21 ['0.1, 15, 4'] 0.170086
Grid_GBM_model_1446220160417_18 ['0.1, 15, 3'] 0.171218
Grid_GBM_model_1446220160417_15 ['0.1, 15, 2'] 0.181186
Grid_GBM_model_1446220160417_28 ['0.2, 5, 4'] 0.275788
Grid_GBM_model_1446220160417_25 ['0.2, 5, 3'] 0.27708
Integration with scikit-learn

The H2O Python client can be used within scikit-learn pipelines and cross-validation searches. This extends the capabilities of both H2O and scikit-learn. Note that the sklearn and scipy packages are required to use the H2O Python client with scikit-learn.

### Pipelines

To create a scikit-learn style pipeline using H2O transformers and estimators:

```python
In [41]: from h2o.transforms.preprocessing import H2OScaler

In [42]: from sklearn.pipeline import Pipeline

In [44]: # Turn off h2o progress bars
In [45]: h2o.__PROGRESS_BAR__=False

In [46]: h2o.no_progress()

In [47]: # build transformation pipeline using sklearn's Pipeline and H2O transforms
In [48]: pipeline = Pipeline([   ("standardize", H2OScaler()),
    ....:   ("pca", H2OPrincipalComponentAnalysisEstimator(k=2)
    ....:   ),
    ....:   ("gbm", H2OGradientBoostingEstimator(distribution="multinomial"))])

In [49]: pipeline.fit(iris_df[:4],iris_df[4])
Out[49]: Model Details
```

```
H2OPCA : Principal Component Analysis
Model Key: PCA_model_python_1446220160417_32

Importance of components:
   pc1  pc2
------------------------
```
<table>
<thead>
<tr>
<th>Standard deviation</th>
<th>3.22082</th>
<th>0.34891</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of Variance</td>
<td>0.984534</td>
<td>0.0115538</td>
</tr>
<tr>
<td>Cumulative Proportion</td>
<td>0.984534</td>
<td>0.996088</td>
</tr>
</tbody>
</table>

ModelMetricsPCA: pca

** Reported on train data. **

MSE: NaN
RMSE: NaN

** Model Details **

H2OGradientBoostingEstimator : Gradient Boosting Machine
Model Key: GBM_model_python_1446220160417_34

** Model Summary **

<table>
<thead>
<tr>
<th>number_of_trees</th>
<th>number_of_internal_trees</th>
<th>model_size_in_bytes</th>
<th>min_depth</th>
<th>max_depth</th>
<th>mean_depth</th>
<th>min_leaves</th>
<th>max_leaves</th>
<th>mean_leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>150</td>
<td>28170</td>
<td>1</td>
<td>5</td>
<td>4.84</td>
<td>2</td>
<td>13</td>
<td>9.9733</td>
</tr>
</tbody>
</table>

ModelMetricsMultinomial: gbm

** Reported on train data. **

MSE: 0.00162796447355
RMSE: 0.0403480417561
LogLoss: 0.0152718656454
Mean Per-Class Error: 0.0

Confusion Matrix: vertical: actual; across: predicted

<table>
<thead>
<tr>
<th>Iris-setosa</th>
<th>Iris-versicolor</th>
<th>Iris-virginica</th>
<th>Error</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0 / 50</td>
</tr>
<tr>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0 / 50</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0 / 50</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>0 / 150</td>
</tr>
</tbody>
</table>

Top-3 Hit Ratios:

<table>
<thead>
<tr>
<th>k</th>
<th>hit_ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Scoring History:

<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>number_of_trees</th>
<th>training_rmse</th>
<th>training_logloss</th>
<th>training_classification_error</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-08-25 13:50:21</td>
<td>0.006 sec</td>
<td>0.0</td>
<td>0.666666666667</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.09861228867</td>
<td>0.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016-08-25 13:50:21</td>
<td>0.077 sec</td>
<td>1.0</td>
<td>0.603019288754</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.924249463924</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016-08-25 13:50:21</td>
<td>0.096 sec</td>
<td>2.0</td>
<td>0.545137025745</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.788619346614</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Variable Importances:

<table>
<thead>
<tr>
<th>variable</th>
<th>relative_importance</th>
<th>scaled_importance</th>
<th>percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td>448.958</td>
<td>1</td>
<td>0.982184</td>
</tr>
<tr>
<td>PC2</td>
<td>8.1438</td>
<td>0.0181393</td>
<td>0.0178162</td>
</tr>
</tbody>
</table>

Pipeline(steps=[('standardize', <h2o.transforms.preprocessing.H2OScaler object at 0x1088c6a50>), ('pca', ), ('gbm', )])

Randomized Grid Search

To create a scikit-learn style hyperparameter grid search using k-fold cross validation:

```python
# Parameters to test
params = {
    "standardize__center": [True, False],
    "standardize__scale": [True, False],
    "pca__k": [2,3],
    "gbm__ntrees": [10,20],
    "gbm__max_depth": [1,2,3],
    "gbm__learn_rate": [0.1,0.2]
}

custom_cv = H2OKFold(iris_df, n_folds=5, seed=42)

pipeline = Pipeline(["standardize", H2OScaler()])

random_search = RandomizedSearchCV(pipeline, params, n_iter=5, scoring=make_scorer(h2o_r2_score), cv=custom_cv)
```
In [65]: random_search.fit(iris_df[1:], iris_df[0])
Out[65]:
RandomizedSearchCV(cv=<h2o.cross_validation.H2OKFold instance at 0x10ba413d0>,
                     error_score='raise',
                     estimator=Pipeline(steps=[('standardize', <h2o.transforms.
                                                 preprocessing.H2OScaler object at 0x10c0f18d0>), ('pca', ), ('gbm', )]),
                     fit_params={}, iid=True, n_iter=5, n_jobs=1,
                     param_distributions={'pca__k': [2, 3], 'gbm__ntrees': [10, 20], 'standardize_scale': [True, False], 'gbm__max_depth': [1, 2, 3], 'standardize_center': [True, False], 'gbm__learn_rate': [0.1, 0.2]},
                     pre_dispatch='2*n_jobs', random_state=42, refit=True,
                     scoring=make_scorer(h2o_r2_score), verbose=0)

In [66]: print random_search.best_estimator_
Model Details
=============
H2OPCA : Principal Component Analysis
Model Key: PCA_model_python_1446220160417_136
Importance of components:

<table>
<thead>
<tr>
<th></th>
<th>pc1</th>
<th>pc2</th>
<th>pc3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Standard deviation</td>
<td>9.6974</td>
<td>0.091905</td>
</tr>
<tr>
<td>Value</td>
<td>Proportion of Variance</td>
<td>0.9999</td>
<td>0.98098e-05</td>
</tr>
<tr>
<td></td>
<td>Cumulative Proportion</td>
<td>0.9999</td>
<td>0.99999</td>
</tr>
</tbody>
</table>

ModelMetricsPCA: pca
** Reported on train data. **
MSE: NaN
RMSE: NaN
Model Details
=============
H2OGradientBoostingEstimator : Gradient Boosting Machine
Model Key: GBM_model_python_1446220160417_138
Model Summary:

<table>
<thead>
<tr>
<th></th>
<th>number_of_trees</th>
<th>number_of_internal_trees</th>
<th>model_size_in_bytes</th>
<th>min_depth</th>
<th>max_depth</th>
<th>mean_depth</th>
<th>min_leaves</th>
<th>max_leaves</th>
<th>mean_leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
<td>2958</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>3.00957</td>
</tr>
</tbody>
</table>

6.85
ModelMetricsRegression: gbm
** Reported on train data. **
RMSE: 0.193906262445
MAE: 0.155086582663
RMSLE: NaN
Mean Residual Deviance: 0.0375996386155
Scoring History:
<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>number_of_trees</th>
<th>training_rmse</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-08-25 13:58:15</td>
<td>0.000 sec</td>
<td>0.0</td>
<td>0.683404046309</td>
</tr>
<tr>
<td>0.569341466973</td>
<td></td>
<td>0.467041090512</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 13:58:15</td>
<td>0.002 sec</td>
<td>1.0</td>
<td>0.571086656306</td>
</tr>
<tr>
<td>0.469106640643</td>
<td></td>
<td>0.326139969011</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 13:58:15</td>
<td>0.003 sec</td>
<td>2.0</td>
<td>0.483508601652</td>
</tr>
<tr>
<td>0.395952082872</td>
<td></td>
<td>0.233780567872</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 13:58:15</td>
<td>0.004 sec</td>
<td>3.0</td>
<td>0.414549015095</td>
</tr>
<tr>
<td>0.339981133963</td>
<td></td>
<td>0.171850885916</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 13:58:15</td>
<td>0.005 sec</td>
<td>4.0</td>
<td>0.362852508373</td>
</tr>
<tr>
<td>0.298212416346</td>
<td></td>
<td>0.131661942833</td>
<td></td>
</tr>
</tbody>
</table>

Variable Importances:

<table>
<thead>
<tr>
<th>variable</th>
<th>relative_importance</th>
<th>scaled_importance</th>
<th>percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td>160.092</td>
<td>1</td>
<td>0.894701</td>
</tr>
<tr>
<td>PC3</td>
<td>14.8175</td>
<td>0.0925562</td>
<td>0.08281</td>
</tr>
<tr>
<td>PC2</td>
<td>4.0241</td>
<td>0.0251361</td>
<td>0.0224893</td>
</tr>
</tbody>
</table>

Acknowledgments

We would like to acknowledge the following individuals for their contributions to this booklet: Spencer Aiello, Cliff Click, Hank Roark, Ludi Rehak, and Jessica Lanford.

References

H2O.ai Team. H2O website, 2019. URL http://h2o.ai

H2O.ai Team. H2O documentation, 2019. URL http://docs.h2o.ai
