Machine Learning with Python and H2O

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http://h2o.ai/resources/

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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/.
- Install the Python package from PyPI at https://pypi.python.org/pypi/h2o/.

**Join the community**

- To learn about our training sessions, hackathons, and product updates, visit http://h2o.ai.
- To learn about our meetups, visit 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.
- Have a Google account (such as Gmail or Google+)? Join the open source community forum at https://groups.google.com/d/forum/h2ostream.
- Join the chat at https://gitter.im/h2oai/h2o-3.

**Example Code**

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

https://github.com/h2oai/h2o-3/tree/master/h2o-docs/src/booklets/v2_2015/source/Python_Vignette_code_examples

**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/ 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.
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
# Start H2O on your local machine
h2o.init()
# 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.

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
def = 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
def = 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
def = 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
def2 = 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:

```
import h2o
h2o.init()

df2 = h2o.H2OFrame.from_python(df2.tolist(), column_names=['A', 'B', 'C', 'D'])
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:

```
import numpy as np
df = h2o.H2OFrame.from_python(np.random.randn(100,4).tolist(), column_names=list('ABCD'))

df.head()  
# A      B      C      D
# ---    ---    ---    ---
# -0.61  -0.42  -1.93  -2.12
# -1.27  -0.24  -1.96  1.90
# 0.76   0.04  -0.50  0.36
# -1.25  0.91  -0.61  1.95
# 2.11   0.57  -0.41  0.57

# [10 rows x 4 columns]

df.tail(5)
# A      B      C      D
# ---    ---    ---    ---
# 1.00  -1.43  -0.32  0.37
# 1.17  -1.23  -1.71  1.01
# -1.62  -1.14  2.12  -0.28
# -0.74 -0.04  0.22  0.22
# -0.74  1.13  0.73  1.70

# [5 rows x 4 columns]
```
To display the column names:

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

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

```
df.describe()
```

```
# Rows: 100 Cols: 4
# Chunk compression summary:
# chunk_type chunkname count count_% size size_%
# ------------ --------- ----- ------- ---- ------
# 64-bit Reals CBD 4 100 3.4 KB 100
#
# Frame distribution summary:
# size #_rows #_chunks_per_col #_chunks
# --------------- ------ ------ --------------- --------
# 127.0.0.1:54321 3.4 KB 100 1 4
# mean 3.4 KB 100 1 4
# min 3.4 KB 100 1 4
# max 3.4 KB 100 1 4
# stddev 0 B 0 0 0
# total 3.4 KB 100 1 4
#
# A | B | C | D
# ------ | ------ | ------ | ------
# type | real | real | real |
# mins | -2.49822 | -2.37446 | -2.45977 | -3.48247
# mean | -0.01062 | -0.23159 | 0.11423 | -0.16228
# maxs | 2.59380 | 1.91998 | 3.13014 | 2.39057
# sigma | 1.04354 | 0.90576 | 0.96133 | 1.02608
# zeros | 0 | 0 | 0 | 0
# missing | 0 | 0 | 0 | 0
```

**Selection**

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

```
df['A']
```

```
# A
# -------
# -0.613035
# -1.265520
# 0.763851
# -1.248425
# 2.105805
# 1.763502
# -0.781973
# 1.400853
# -0.746025
# -1.120648
# [100 rows x 1 column]
```
To select a single column by index, resulting in an H2OFrame:

```python
df[1]
```

```
#    B
# -----
# -0.425327
# -0.241526
# 0.039161
# 0.912686
# -1.839950
# 0.573736
# 0.051883
# 1.919987
# -0.632182
# 0.374212

# [100 rows x 1 column]
```

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

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

```
#    B    C
# -------  -------
# -0.425327 -1.927737
# -0.241526 -0.044510
# 0.039161 -0.500049
# 0.912686 -0.611460
# -1.839950 0.453875
# 0.573736 -0.309663
# 0.051883 -0.403075
# 1.919987 0.514212
# -0.632182 1.274552
# 0.374212 0.232229

# [100 rows x 2 columns]
```

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

```python
df[0:2]
```

```
#    A    B
# -------  -------
# -0.613035 -0.425327
# -1.265520 -0.241526
# 0.763851  0.039161
# -1.248425  0.912686
# 2.105805 -1.839950
# 1.763502  0.573736
# -0.781973  0.051883
# 1.400853  1.919987
# -0.746025 -0.632182
# -1.120648  0.374212

# [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:

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

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.31828</td>
<td>0.316926</td>
<td>0.970535</td>
<td>0.218061</td>
</tr>
<tr>
<td>2</td>
<td>-0.18547</td>
<td>0.207064</td>
<td>1.3229</td>
<td>-0.432614</td>
</tr>
<tr>
<td>3</td>
<td>-0.424018</td>
<td>-1.72759</td>
<td>0.356871</td>
<td>0.206214</td>
</tr>
<tr>
<td>4</td>
<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:

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

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>hello</td>
<td>1.42618e+12</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>all</td>
<td>1.42627e+12</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:

```python
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):

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

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

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

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

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

<table>
<thead>
<tr>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<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>
<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>
<tr>
<td>#</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[5 rows x 4 columns]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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'])
df4.mean(na_rm=True)
```

```
# [2.0, nan, nan, nan]
```

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

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

```
# [nan]
```

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

```
# [2.0]
```

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
# [1 row x 4 columns]
```

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 -0.277616 1.13655 -0.575992 -3.49258 0.776883 -0.778604 2.30617
# [100 rows x 1 column]
```

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
df7 = 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
df7.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
df7.sub('l','x')
# C1  C2  C3  C4  C5  C6
# ---- ---- ------- ---- ---- ----
# Hello Worxd Welcome To H2O Worxd
```

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

To split strings based on a regular expression:

```python
df7.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)
```

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.14</td>
<td>1.32</td>
<td>0.25</td>
<td>1.73</td>
</tr>
<tr>
<td>2</td>
<td>-1.61</td>
<td>0.43</td>
<td>-1.17</td>
<td>-0.32</td>
</tr>
<tr>
<td>3</td>
<td>0.67</td>
<td>-0.49</td>
<td>1.55</td>
<td>0.67</td>
</tr>
<tr>
<td>4</td>
<td>0.04</td>
<td>-0.41</td>
<td>1.58</td>
<td>-0.73</td>
</tr>
<tr>
<td>5</td>
<td>0.04</td>
<td>0.30</td>
<td>0.57</td>
<td>-0.39</td>
</tr>
<tr>
<td>6</td>
<td>0.64</td>
<td>-0.51</td>
<td>-1.59</td>
<td>-1.34</td>
</tr>
<tr>
<td>7</td>
<td>1.04</td>
<td>-0.28</td>
<td>0.96</td>
<td>-0.01</td>
</tr>
<tr>
<td>8</td>
<td>0.49</td>
<td>0.17</td>
<td>-0.17</td>
<td>-0.72</td>
</tr>
<tr>
<td>9</td>
<td>1.42</td>
<td>-0.41</td>
<td>2.15</td>
<td>-0.84</td>
</tr>
<tr>
<td>10</td>
<td>0.94</td>
<td>1.19</td>
<td>0.01</td>
<td>0.17</td>
</tr>
<tr>
<td>11</td>
<td>-0.53</td>
<td>0.78</td>
<td>-2.23</td>
<td>-0.69</td>
</tr>
<tr>
<td>12</td>
<td>0.34</td>
<td>-0.46</td>
<td>-1.22</td>
<td>-0.31</td>
</tr>
</tbody>
</table>

# [200 rows x 4 columns]

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)
```

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>A0</th>
<th>B0</th>
<th>C0</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.09</td>
<td>0.94</td>
<td>0.16</td>
<td>0.27</td>
<td>-0.35</td>
<td>1.66</td>
<td>-2.32</td>
<td>-0.86</td>
</tr>
<tr>
<td>2</td>
<td>-0.95</td>
<td>0.67</td>
<td>0.66</td>
<td>1.53</td>
<td>-0.63</td>
<td>-1.78</td>
<td>0.32</td>
<td>1.27</td>
</tr>
<tr>
<td>3</td>
<td>0.17</td>
<td>0.65</td>
<td>0.97</td>
<td>-0.42</td>
<td>-1.41</td>
<td>-0.51</td>
<td>0.64</td>
<td>-1.25</td>
</tr>
<tr>
<td>4</td>
<td>0.58</td>
<td>-0.52</td>
<td>-1.59</td>
<td>-1.34</td>
<td>0.71</td>
<td>1.09</td>
<td>0.05</td>
<td>0.63</td>
</tr>
<tr>
<td>5</td>
<td>1.04</td>
<td>-0.28</td>
<td>-0.41</td>
<td>0.95</td>
<td>-0.01</td>
<td>0.47</td>
<td>0.41</td>
<td>-0.52</td>
</tr>
<tr>
<td>6</td>
<td>0.49</td>
<td>0.17</td>
<td>0.12</td>
<td>-0.17</td>
<td>-0.72</td>
<td>-0.79</td>
<td>-0.91</td>
<td>-2.09</td>
</tr>
<tr>
<td>7</td>
<td>1.42</td>
<td>-0.41</td>
<td>2.15</td>
<td>-0.84</td>
<td>0.19</td>
<td>0.13</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.94</td>
<td>1.19</td>
<td>1.07</td>
<td>0.01</td>
<td>0.17</td>
<td>0.54</td>
<td>0.52</td>
<td>1.42</td>
</tr>
<tr>
<td>9</td>
<td>-0.53</td>
<td>0.77</td>
<td>-2.23</td>
<td>-0.69</td>
<td>0.24</td>
<td>-0.56</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.34</td>
<td>-0.46</td>
<td>-1.22</td>
<td>-0.31</td>
<td>1.10</td>
<td>1.38</td>
<td>-0.05</td>
<td></td>
</tr>
</tbody>
</table>

# [100 rows x 8 columns]
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)
```

```
# A n A  
--- -------  
2 Welcome  
5 World   
4 H2O     
2 Welcome 
3 To      
1 World   
1 World   
3 To      
1 World

[100 rows x 2 columns]
```

**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
```

```
# A C B D  
--- ---------- -----  -----------  
foo -0.710095 one  0.253189  
bar -0.165891 one -0.433233  
foo -1.51996 two  1.12321  
bar 2.25083 three 0.512449  
foo -0.618324 two  1.35158  
bar 0.0817828 two  0.00830419
```
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
df = h2o.upload_file("/pathToFileName")
```

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

```python
df = h2o.import_file("/pathToFileName")
```

To save an H2OFrame on the machine running H2O:

```python
h2o.export_file(df,"/pathToFileName")
```

To save an H2OFrame on the machine running Python:

```python
h2o.download_csv(df,"/pathToFileName")
```

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
Machine Learning

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/h2o_techwriter_started_from_python.out
JVM stderr: /var/folders/yl/cq5nhky53hjcl9wrqxt39kz80000gn/T/tmpHpRzVe/h2o_techwriter_started_from_python.err
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%
In [6]: iris_df.describe()
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",
               ntrees=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)

In [9]: gbm_regressor

Out[9]: Model Details

Model Summary:

<table>
<thead>
<tr>
<th></th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>number_of_trees</td>
<td>10</td>
</tr>
<tr>
<td>model_size_in_bytes</td>
<td>1535</td>
</tr>
<tr>
<td>min_depth</td>
<td>3</td>
</tr>
<tr>
<td>max_depth</td>
<td>3</td>
</tr>
<tr>
<td>mean_depth</td>
<td>3</td>
</tr>
<tr>
<td>min_leaves</td>
<td>7</td>
</tr>
<tr>
<td>max_leaves</td>
<td>8</td>
</tr>
<tr>
<td>mean_leaves</td>
<td>7.8</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>number_of_trees</th>
<th>training_MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-10-30 08:50:00 0.121 sec</td>
<td>1</td>
<td>0.472445</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.151 sec</td>
<td>2</td>
<td>0.334868</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.162 sec</td>
<td>3</td>
<td>0.242847</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.175 sec</td>
<td>4</td>
<td>0.184128</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.187 sec</td>
<td>5</td>
<td>0.14365</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.197 sec</td>
<td>6</td>
<td>0.116814</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.208 sec</td>
<td>7</td>
<td>0.0992098</td>
<td></td>
</tr>
<tr>
<td>2015-10-30 08:50:00 0.219 sec</td>
<td>8</td>
<td>0.0864125</td>
<td></td>
</tr>
</tbody>
</table>
To generate a classification model that uses labels, use `distribution="multinomial"`:

```python
In [10]: gbm_classifier = H2OGradientBoostingEstimator(distribution="multinomial", ntrees=10, max_depth=3, min_rows=2, learn_rate="0.2")
In [11]: gbm_classifier.train(x=range(0,iris_df.ncol-1), y=iris_df.ncol-1, training_frame=iris_df)
```

H2OGradientBoostingEstimator : Gradient Boosting Machine
Model Key: GBM_model_python_1446220160417_4

Model Summary:
```
number_of_trees model_size_in_bytes min_depth max_depth
-- ----------------- ----------- -----------
30 3933 1 3
```

ModelMetricsMultinomial: gbm

** Reported on train data. **
```
MSE: 0.00976685303214
RMSE: 0.0988273900907
LogLoss: 0.0782480973696
Mean Per-Class Error: 0.00666666666667
Confusion Matrix: vertical: actual; across: predicted
```

Iris-setosa Iris-versicolor Iris-virginica Error Rate
```
--------- --------- --------- --------- ----------
50 0 0 0 0 / 50
0 49 1 0.02 1 / 50
0 0 50 0 0 / 50
50 49 51 0.0066667 1 / 150
```

Top-3 Hit Ratios:
```
k hit_ratio
--- -----------
1 0.993333
2 1
3 1
```
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

### Scoring History:

<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>number_of_trees</th>
<th>training_MSE</th>
<th>training_logloss</th>
<th>training_classification_error</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.047 sec</td>
<td>1</td>
<td>0.282326</td>
<td>0.758411</td>
<td>0.0266667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.068 sec</td>
<td>2</td>
<td>0.179214</td>
<td>0.550506</td>
<td>0.0266667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.086 sec</td>
<td>3</td>
<td>0.114954</td>
<td>0.412173</td>
<td>0.0266667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.100 sec</td>
<td>4</td>
<td>0.0744726</td>
<td>0.313539</td>
<td>0.02</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.112 sec</td>
<td>5</td>
<td>0.0498319</td>
<td>0.243514</td>
<td>0.02</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.131 sec</td>
<td>6</td>
<td>0.0340885</td>
<td>0.19091</td>
<td>0.0066667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.143 sec</td>
<td>7</td>
<td>0.0241071</td>
<td>0.151394</td>
<td>0.0066667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.153 sec</td>
<td>8</td>
<td>0.017606</td>
<td>0.120882</td>
<td>0.0066667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.165 sec</td>
<td>9</td>
<td>0.0131024</td>
<td>0.0975897</td>
<td>0.0066667</td>
</tr>
<tr>
<td>2015-10-30 08:51:52</td>
<td>0.180 sec</td>
<td>10</td>
<td>0.00976685</td>
<td>0.0782481</td>
<td>0.0066667</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>0.0054322</td>
</tr>
<tr>
<td>C2</td>
<td>0.773032</td>
<td>0.00401032</td>
<td>0.00310549</td>
</tr>
</tbody>
</table>
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)
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 number_of_chunks
------------- ----------------- ----------------- ------------------
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 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

H2OGeneralizedLinearEstimator : Generalized Linear Model
Model Key: GLM_model_python_1446220160417_6

GLM Model: summary

--- -------- ------ ---------------------------------------------
family   link   regularization
number_of_predictors_total number_of_active_predictors
number_of_iterations  training_frame

------------------ --------------------
------------------- ------------------
binomial  logit  Elastic Net (alpha = 0.5, lambda = 3.251E-4 )

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>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>80</td>
<td>147</td>
<td>0.6476 (147.0/227.0)</td>
</tr>
<tr>
<td>1</td>
<td>19</td>
<td>134</td>
<td>0.1242 (19.0/153.0)</td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>281</td>
<td>0.4368 (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>0.636672</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 %

ModelMetricsBinomialGLM: glm
** Reported on cross-validation data. **
MSE: 0.209698776592
RMSE: 0.457928789871
LogLoss: 0.610086165597
Null degrees of freedom: 379
Residual degrees of freedom: 374
Null deviance: 513.330704712
Residual deviance: 463.665485854
AIC: 475.665485854
AUC: 0.688203622124
Gini: 0.376407244249

Confusion Matrix (Act/Pred) for max f1 @ threshold = 0.339885371023:

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>154</td>
<td>73</td>
<td>0.3216 (73.0/227.0)</td>
</tr>
<tr>
<td>53</td>
<td>100</td>
<td>0.3464 (53.0/153.0)</td>
</tr>
<tr>
<td>Total 207</td>
<td>173</td>
<td>0.3316 (126.0/380.0)</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>0.339885</td>
<td>0.613497</td>
<td>172</td>
</tr>
<tr>
<td>max f2</td>
<td>0.172551</td>
<td>0.773509</td>
<td>376</td>
</tr>
<tr>
<td>max f0point5</td>
<td>0.419649</td>
<td>0.615251</td>
<td>105</td>
</tr>
<tr>
<td>max accuracy</td>
<td>0.447491</td>
<td>0.692105</td>
<td>93</td>
</tr>
<tr>
<td>max precision</td>
<td>0.998767</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>max recall</td>
<td>0.172551</td>
<td>1</td>
<td>376</td>
</tr>
<tr>
<td>max specificity</td>
<td>0.998767</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>max absolute_mcc</td>
<td>0.419649</td>
<td>0.338849</td>
<td>105</td>
</tr>
<tr>
<td>max min_per_class_accuracy</td>
<td>0.339885</td>
<td>0.653595</td>
<td>172</td>
</tr>
<tr>
<td>max mean_per_class_accuracy</td>
<td>0.339885</td>
<td>0.666004</td>
<td>172</td>
</tr>
</tbody>
</table>

Gains/Lift Table: Avg response rate: 40.26%

Scoring History:

<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>iteration</th>
<th>log_likelihood</th>
<th>objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-08-25 12:54:20</td>
<td>0.000 sec</td>
<td>0</td>
<td>256.144</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.674064</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 12:54:20</td>
<td>0.055 sec</td>
<td>1</td>
<td>226.961</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.597573</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 12:54:20</td>
<td>0.092 sec</td>
<td>2</td>
<td>224.728</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.591813</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 12:54:20</td>
<td>0.125 sec</td>
<td>3</td>
<td>224.627</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.591578</td>
<td></td>
</tr>
<tr>
<td>2016-08-25 12:54:20</td>
<td>0.157 sec</td>
<td>4</td>
<td>224.626</td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>190.757</td>
<td>596</td>
<td>405.243</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>centroid</th>
<th>size</th>
<th>within_cluster_sum_of_squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96</td>
<td>149.733</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>17.292</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>23.7318</td>
</tr>
</tbody>
</table>

Scoring History:

<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>iteration</th>
<th>avg_change_of_std_centroids</th>
<th>within_cluster_sum_of_squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.005 sec</td>
<td>0</td>
<td>nan</td>
<td>385.505</td>
</tr>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.029 sec</td>
<td>1</td>
<td>1.37093</td>
<td>173.769</td>
</tr>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.029 sec</td>
<td>2</td>
<td>0.184617</td>
<td>141.623</td>
</tr>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.030 sec</td>
<td>3</td>
<td>0.00705735</td>
<td>140.355</td>
</tr>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.030 sec</td>
<td>4</td>
<td>0.00122272</td>
<td>140.162</td>
</tr>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.031 sec</td>
<td>5</td>
<td>0.000263918</td>
<td>140.072</td>
</tr>
<tr>
<td>2016-08-25 13:03:36</td>
<td>0.031 sec</td>
<td>6</td>
<td>0.000306555</td>
<td>140.026</td>
</tr>
</tbody>
</table>
## 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.

```python
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
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:
<table>
<thead>
<tr>
<th>timestamp</th>
<th>duration</th>
<th>iterations</th>
<th>err</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>0</td>
<td>29.6462</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>1</td>
<td>0.733806</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>2</td>
<td>0.0249718</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>3</td>
<td>0.000851969</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>4</td>
<td>2.90753e-05</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>5</td>
<td>1.3487e-06</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.002 sec</td>
<td>6</td>
<td>nan</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>7</td>
<td>1.02322</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>8</td>
<td>0.0445794</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>9</td>
<td>0.00164307</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>10</td>
<td>6.27379e-05</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>11</td>
<td>2.40329e-06</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>12</td>
<td>9.88431e-08</td>
</tr>
<tr>
<td>2018-01-18 08:35:44</td>
<td>0.003 sec</td>
<td>13</td>
<td>nan</td>
</tr>
</tbody>
</table>
```

```python
In [29]: pred = pca_decomp.predict(iris_df)
pca prediction progress: [################################################################] 100%
In [30]: pred.head()  # Projection results
Out[30]:
   PC1   PC2
0 -5.9122 2.30344
1 -5.57208 1.97383
2 -5.44648 2.09653
3 -5.43602 1.87168
```
Grid Search

H2O supports grid search across hyperparameters:

```python
In [32]: ntrees_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": ntrees_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:

<table>
<thead>
<tr>
<th>Model Id</th>
<th>Hyperparameters: ['learn_rate', 'ntrees', 'max_depth']</th>
<th>logloss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_30</td>
<td>['0.2, 15, 4']</td>
<td>0.05105</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_27</td>
<td>['0.2, 15, 3']</td>
<td>0.0551088</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_24</td>
<td>['0.2, 15, 2']</td>
<td>0.0697714</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_29</td>
<td>['0.2, 10, 4']</td>
<td>0.103064</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_26</td>
<td>['0.2, 10, 3']</td>
<td>0.106232</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_23</td>
<td>['0.2, 10, 2']</td>
<td>0.120161</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_21</td>
<td>['0.1, 15, 4']</td>
<td>0.170086</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_18</td>
<td>['0.1, 15, 3']</td>
<td>0.171218</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_15</td>
<td>['0.1, 15, 2']</td>
<td>0.181186</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_28</td>
<td>['0.2, 5, 4']</td>
<td>0.275788</td>
</tr>
<tr>
<td>Grid_GBM_model_1446220160417_25</td>
<td>['0.2, 5, 3']</td>
<td>0.27708</td>
</tr>
</tbody>
</table>
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:
** 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>4.84</td>
<td>2</td>
<td>13</td>
<td>9.97333</td>
<td></td>
</tr>
</tbody>
</table>

** Model Details:**

** H2OGradientBoostingEstimator: Gradient Boosting Machine **

** Model Key: GBM_model_python_1446220160417_34 **

** Model Metrics PCA: pca **

** Reported on train data. **

MSE: NaN
RMSE: NaN

** Model Metrics Multinomial: 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>
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<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>1.09861228867</td>
<td>0.66</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>0.924249463924</td>
<td>0.04</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>0.788619346614</td>
<td>0.04</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
In [57]: from sklearn.grid_search import RandomizedSearchCV
...
In [58]: from h2o.cross_validation import H2OKFold
...
In [59]: from h2o.model.regression import h2o_r2_score
...
In [60]: from sklearn.metrics.scorer import make_scorer
#
# Parameters to test
In [61]: 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]}
In [62]: custom_cv = H2OKFold(iris_df, n_folds=5, seed=42)
In [63]: pipeline = Pipeline([('standardize', H2OScaler()),
              ...
              ("pca", H2OPrincipalComponentAnalysisEstimator(k=2)),
              ...
              ("gbm", H2OGradientBoostingEstimator(
                distribution="gaussian"))])
In [64]: 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>Standard deviation</td>
<td>9.6974</td>
<td>0.091905</td>
<td>0.031356</td>
</tr>
<tr>
<td>Proportion of Variance</td>
<td>0.9999</td>
<td>8.98098e-05</td>
<td>1.04541e-05</td>
</tr>
<tr>
<td>Cumulative Proportion</td>
<td>0.9999</td>
<td>0.99999</td>
<td>1</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>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>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20</td>
<td>2958</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td></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:
### 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>

Pipeline(steps=[('standardize', <h2o.transforms.preprocessing.H2OScaler object at 0x10c1679d0>), ('pca', ), ('gbm', )])

---

### 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](http://h2o.ai), 2019.

H2O.ai Team. [H2O documentation](http://docs.h2o.ai), 2019.


H2O.ai Team. [H2O GitHub Repository](https://github.com/h2oai), 2019.
