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**摘要：** 本讲义出自Simon Ouellette在Spark Summit East 2017上的演讲，主要介绍了在Spark上与时间序列数据进行交互的Scala / Java / Python库——spark-timeseries，演讲中分享了spark-timeseries的总体设计，目前实现的功能，并将提供一些用法示例。

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本讲义出自**Simon Ouellette**在Spark Summit East 2017上的演讲，主要介绍了在Spark上与时间序列数据进行交互的Scala / Java / Python库——spark-timeseries，演讲中分享了spark-timeseries的总体设计，目前实现的功能，并将提供一些用法示例。因为项目还处于早期阶段，演讲也介绍了spark-timeseries当前的缺点和未来spark-timeseries项目的发展路线图。


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## What is spark-timeseries?

https://github.com/sryza/spark-timeseries

- Open source time series library for Apache Spark 2.0
- Sandy Ryza
  - Advanced Analytics with Spark: Patterns for Learning from Data at Scale
  - Senior Data Scientist at Clover Health
- Started in February 2015

## Who am I?

http://faimdata.com

- Chief Data Science Officer at Faimdata
- Contributor to spark-timeseries since September 2015
- Participated in early design discussions (March 2015)
- Been an active user for ~2 years

**Design Question #1**: How do we structure multivariate time series?

Columnar or Row-based?

**Columnar representation**

```
TimeSeriesRDD(
    DateTimeIndex,
    RDD[Vector]
)
```

| DateTime Index | Vector for Series 1 | Vector for Series 2 |
|---|---|---|
| 2:30:01 | 4.56 | 78.93 |
| 2:30:02 | 4.57 | 79.92 |
| 2:30:03 | 4.87 | 79.91 |
| 2:30:04 | 4.48 | 78.99 |

**Row-based representation**

```
RDD[(ZonedDateTime, Vector)]
```

| Vectors | Date/ Time | Series 1 | Series 2 |
|---|---|---|---|
| Vector 1 | 2:30:01 | 4.56 | 78.93 |
| Vector 2 | 2:30:02 | 4.57 | 79.92 |
| Vector 3 | 2:30:03 | 4.87 | 79.91 |
| Vector 4 | 2:30:04 | 4.48 | 78.99 |

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## Columnar vs Row-based

**More efficient in columnar representation:**

- Lagging
- Differencing
- Rolling operations
- Feature generation
- Feature selection
- Feature transformation

**More efficient in row-based representation:**

- Regression
- Clustering
- Classification
- Etc.

## Example: lagging operation

**Row-based representation**

- Time complexity: O(N) (assumes pre-sorted RDD)
- For each row, we need to get values from previous **k** rows

**Columnar representation**

- Time complexity: O(K)
- For each column to lag, we truncate most recent **k** values, and truncate the DateTimeIndex's oldest **k** values.

## Example: regression

- We're estimating: $y_t = \alpha + \sum_I \sum_J \beta_{ij} x_{i(t-j)}$
- The lagged values are typically part of each row, because they are pre-generated as new features.
- **Stochastic Gradient Descent**: we iterate on examples and estimate error gradient to adjust weights, which means that we care about rows, not columns.
- To avoid shuffling, the partitioning must be done such that all elements of a row are together in the same partition (so the gradient can be computed locally).

## Current solution

- Core representation is columnar.
- Utility functions to go to/from row-based.
- **Reasoning**: spark-timeseries operations are mostly time-related, i.e. columnar. Row-based operations are about relationships between the variables (ML/statistical), thus external to spark-timeseries.

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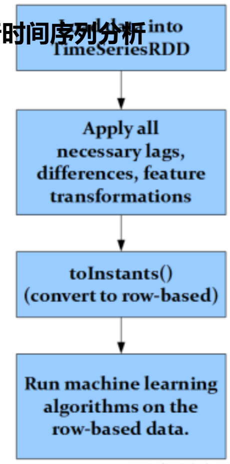
Typical time series analytics workflow:

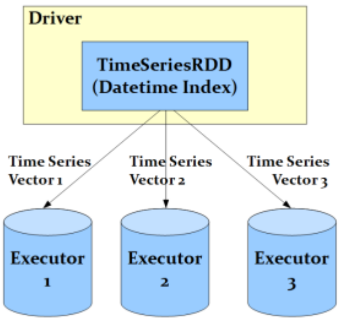



**Design Question #2**: How do we partition the multi-variate time series for distributed processing?

Across features, or across time?

## Current design

Assumption: a single time series must fit inside executory memory!




## Current design

Assumption: a single time series must fit inside executory memory!

```
TimeSeriesRDD (
    DatetimeIndex,
    RDD[(K, Vector)]
)

IrregularDatetimeIndex (
    Array[Long],      // Other limitation: Scala arrays = 2^32 elements
    java.time.ZoneId
)
```

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# Future Improvements

- Creation of a new TimeSeriesRDD-like class that will be longitudinally (i.e. across time) partitioned rather than horizontally (i.e. across features).
- Keep both types of partitioning, on a case-by-case basis.

**Design Question #3**: How do we lag, difference, etc.?

Re-sampling, or index-preserving?

# Option #1: re-sampling

**Before**

| Irregular Time | y value at t | x value at t |
|---|---|---|
| 1:30:05 | 51.42 | 4.87 |
| 1:30:07.86 | 52.37 | 4.99 |
| 1:30:07.98 | 53.22 | 4.95 |
| 1:30:08.04 | 55.87 | 4.97 |
| 1:30:12 | 54.84 | 5.12 |
| 1:30:14 | 49.88 | 5.10 |

**After (1 second lag)**

| Uniform Time | y value at t | x value at (t – 1) |
|---|---|---|
| 1:30:06 | 51.42 | 4.87 |
| 1:30:07 | 51.42 | 4.87 |
| 1:30:08 | 53.22 | 4.87 |
| 1:30:09 | 55.87 | 4.95 |
| 1:30:10 | 55.87 | 4.97 |
| 1:30:11 | 55.87 | 4.97 |
| 1:30:12 | 54.84 | 4.97 |
| 1:30:13 | 54.84 | 5.12 |
| 1:30:14 | 49.88 | 5.12 |

# Option #2: Index preserving

**Before**

| Irregular Time | y value at t | x value at t |
|---|---|---|
| 1:30:05 | 51.42 | 4.87 |
| 1:30:07.86 | 52.37 | 4.99 |
| 1:30:07.98 | 53.22 | 4.95 |
| 1:30:08.04 | 55.87 | 4.97 |
| 1:30:12 | 54.84 | 5.12 |
| 1:30:14 | 49.88 | 5.10 |

**After (1 second lag)**

| Irregular Time | y value at t | x value at (t – 1) |
|---|---|---|
| 1:30:05 | 51.42 | N/A |
| 1:30:07.86 | 52.37 | 4.87 |
| 1:30:07.98 | 53.22 | 4.87 |
| 1:30:08.04 | 55.87 | 4.87 |
| 1:30:12 | 54.84 | 4.97 |
| 1:30:14 | 49.88 | 5.12 |

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# Current functionality

- Option #1: resample() function for lagging/differencing by upsampling/downsampling.
  – Custom interpolation function (used when downsampling)

- Conceptual problems:
  – Information loss and duplication (downsampling)
  – Bloating (upsampling)

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# Current functionality

- Option #2: functions to lag/difference irregular time series based on arbitrary time intervals. (preserves index)

- Same thing: custom interpolation function can be passed for when downsampling occurs.

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## Overview of current API

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## High-level objects

- TimeSeriesRDD
- TimeSeries
- TimeSeriesStatisticalTests
- TimeSeriesModel
- DatetimeIndex
- UnivariateTimeSeries

## TimeSeriesRDD

- collectAsTimeSeries
- filterStartingBefore, filterStartingAfter, slice
- filterByInstant
- quotients, differences, lags
- fill: fills NaNs by specified interpolation method (*linear, nearest, next, previous, spline, zero*)
- mapSeries
- seriesStats: min, max, average, std. deviation
- toInstants, toInstantsDataFrame
- resample
- rollSum, rollMean
- saveAsCsv, saveAsParquetDataFrame

## TimeSeriesStatisticalTests

- Stationarity tests:
  - Augmented Dickey-Fuller (adftest)
  - KPSS (kpsstest)
- Serial auto-correlation tests:
  - Durbin-Watson (dwtest)
  - Breusch-Godfrey (bgtest)
  - Ljung-Box (lbtest)
- Breusch-Pagan heteroskedasticity test (bptest)
- Newey-West variance estimator (neweyWestVarianceEstimator)

## TimeSeriesModel

- AR, ARIMA
- ARX, ARIMAX (i.e. with exogenous variables)
- Exponentially weighted moving average
- Holt-winters method (triple exp. smoothing)
- GARCH(1,1), ARGARCH(1,1,1)

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# Others

- Java bindings
- Python bindings
- YAHOO financial data parser

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# Code example #1

| Time | Y | X |
|---|---|---|
| 12:45:01 | 3.45 | 25.0 |
| 12:46:02 | 4.45 | 30.0 |
| 12:46:58 | 3.45 | 40.0 |
| 12:47:45 | 3.00 | 35.0 |
| 12:48:05 | 4.00 | 45.0 |

Y is stationary
X is integrated of order 1

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# Code example #1

```scala
val ts = TimeSeriesRDD.timeSeriesRDDFromCsv("mydata.csv", sc)

val newIndex = ts.index.islice(1, ts.index.size)

val tsTransformed = ts.mapSeries(vec => {
  val result = TimeSeriesStatisticalTests.adftest(vec, 0, "c")
  if (result._2 > 0.05) differencesAtLag(vec, 1) else vec
}, newIndex).lags(2, Map(("y" -> true)))

val instantsAsLPs = tsTransformed.toInstants().map(row =>
  LabeledPoint(row._2(0), Vectors.dense(row._2.toArray.drop(1))))

val algo = new LassoWithSGD().setIntercept(true)
algo.optimizer.setRegParam(0.5)
val model = algo.run(instantsAsLPs)
```

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## Code example #1

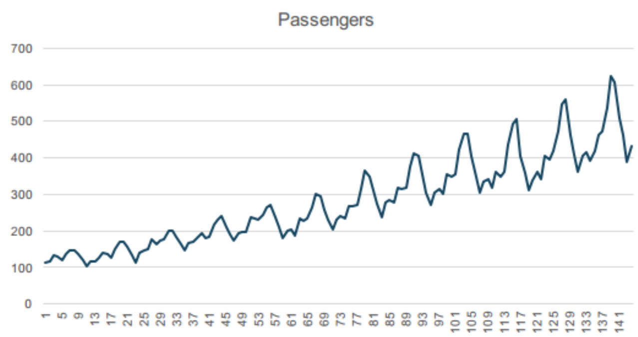
| Time | y | d(x) | Lag1(y) | Lag2(y) | Lag1(d(x)) | Lag2(d(x)) |
|---|---|---|---|---|---|---|
| 12:45:01 | 3.45 | | | | | |
| 12:46:02 | 4.45 | 5.0 | 3.45 | | | |
| 12:46:58 | 3.45 | 10.0 | 4.45 | 3.45 | 5.0 | |
| 12:47:45 | 3.00 | -5.0 | 3.45 | 4.45 | 10.0 | 5.0 |
| 12:48:05 | 4.00 | 10.0 | 3.00 | 3.45 | -5.0 | 10.0 |

## Code example #2

- We will use Holt-Winters to forecast some seasonal data.
- Holt-winters: exponential moving average applied to level, trend and seasonal component of the time series, then combined into global forecast.

$$
\begin{aligned}
l_x &= \alpha(y_x - s_{x-L}) + (1-\alpha)(l_{x-1} + b_{x-1}) && \text{level} \\
b_x &= \beta(l_x - l_{x-1}) + (1-\beta)b_{x-1} && \text{trend} \\
s_x &= \gamma(y_x - l_x) + (1-\gamma)s_{x-L} && \text{seasonal} \\
\hat{y}_{x+m} &= l_x + mb_x + s_{x-L+1+(m-1)mod(L)} && \text{forecast}
\end{aligned}
$$

## Code example #2



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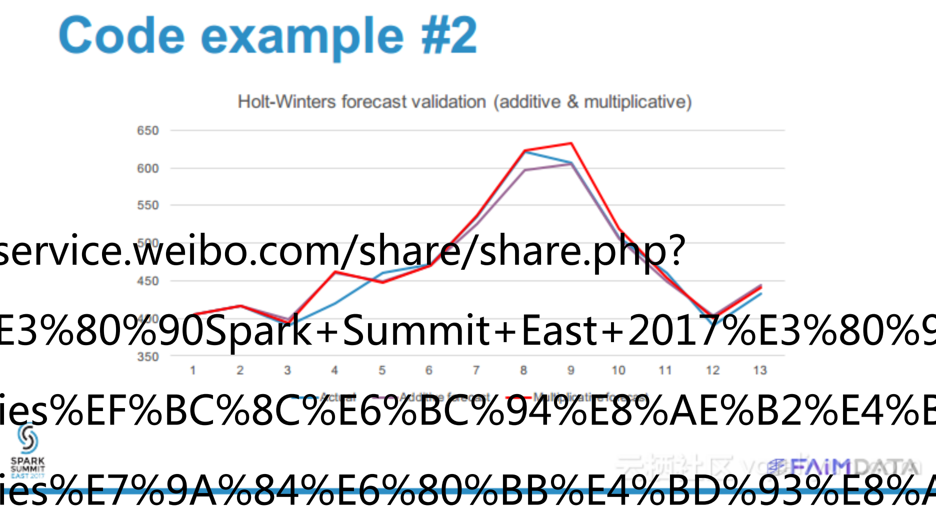


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