What can PyArrow do for you

Array interchange, storage, compute and transport

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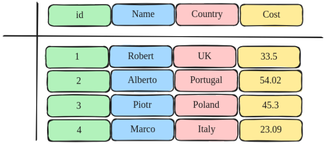
Overview

1. Introduction
2. Array Interchange
3. Storage
4. Compute
5. Transport

What is Arrow

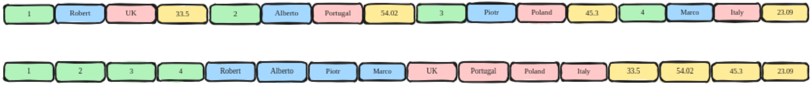
Columnar memory layout

- Tables in memory can be stored as rows or columns
- Columns are better suited for analytical workloads due to cache locality, memory prefetching, SIMD vectorizations and cheap schema manipulation



id	Name	Country	Cost
1	Robert	UK	33.5
2	Alberto	Portugal	54.02
3	Piotr	Poland	45.3
4	Marco	Italy	23.09

Figure: Table composed of arrays



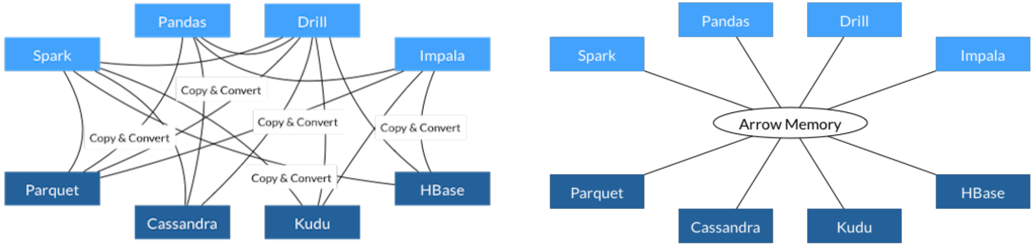
1	Robert	UK	33.5	2	Alberto	Portugal	54.02	3	Piotr	Poland	45.3	4	Marco	Italy	23.09
1	2	3	4	Robert	Alberto	Piotr	Marco	UK	Portugal	Poland	Italy	33.5	54.02	45.3	23.09

Figure: Row major layout (top) vs column major layout (bottom)

What is Arrow

Arrow

- Set of implementations in multiple languages with added components to enable efficient storage, processing and movement of data



(a) Without common memory layout (n^2 connectors)

(b) With Arrow memory layout

What is PyArrow

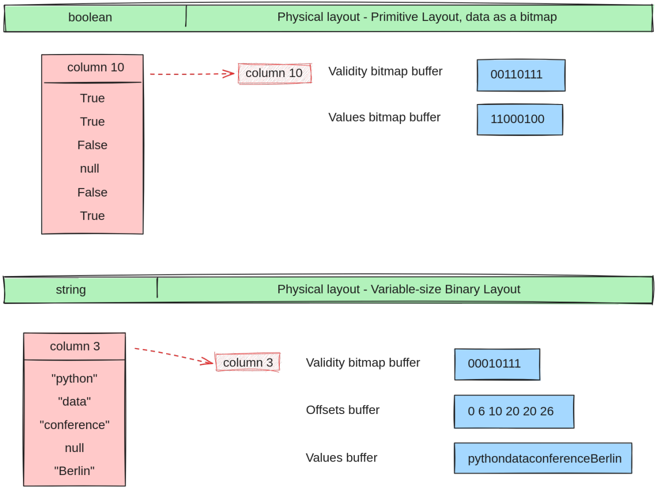
PyArrow

- Python bindings for Arrow C++ implementations
- First-class integration with NumPy, pandas, and built-in Python objects
- Include leaf libraries that add additional functionality such as reading Apache Parquet files into Arrow structures

PyArrow Array

- Central data structure in Arrow
- A contiguous, one-dimensional sequence of values with known length
- All values have the same type

PyArrow Array memory layout



boolean

Physical layout - Primitive Layout, data as a bitmap

column 10

True

True

False

null

False

True

column 10

Validity bitmap buffer

00110111

Values bitmap buffer

11000100

string

Physical layout - Variable-size Binary Layout

column 3

"python"

"data"

"conference"

null

"Berlin"

column 3

Validity bitmap buffer

00010111

Offsets buffer

0 6 10 20 20 26

Values buffer

pythondataconferenceBerlin

https://arrow.apache.org/docs/format/Intro.html

From NumPy to PyArrow

Examples

```
>>> import numpy as np
>>> numpy_array = np.arange(5)
>>> numpy_array
array([0, 1, 2, 3, 4])
>>> import pyarrow as pa
>>> pa.array(numpy_array)
<pyarrow.lib.Int64Array object at ...>
[
  0,
  1,
  2,
  3,
  4
]
```

From NumPy to PyArrow

Pointing to the same data → zero-copy!

Zero-copy

```
>>> numpy_array.__array_interface__['data'][0]
5568689760

>>> pa.array(numpy_array).buffers()[1].address
5568689760
```

From PyArrow to Pandas

Examples

```
>>> pyarrow_array = pa.array(numpy_array)
>>> pyarrow_array.to_pandas()
0    0
1    1
2    2
3    3
4    4
dtype: int64

>>> pyarrow_array.to_pandas().to_numpy().__array_interface__["data"][0]
5568689760
```

From Pyarrow to Polars

Examples

```
>>> import polars as pl
>>> pl.from_arrow(pyarrow_array)
shape: (5,)
Series: '' [i64]
[
        0
        1
        2
        3
        4
]

>>> pl.from_arrow(pyarrow_array)._get_buffer_info()[0]
5568689760
```

From Pyarrow to DataFusion and DuckDB

Examples

```
>>> pyarrow_table = pa.table({"arr": pyarrow_array})

>>> from datafusion import SessionContext
>>> ctx = SessionContext()
>>> ctx.from_arrow(pyarrow_table)

>>> import duckdb
>>> duckdb.query("SELECT * FROM pyarrow_table")
```

.. and nanoarrow, narwhals, arro3, ibis, quak, ...

From PyArrow to PyTorch via DLPack

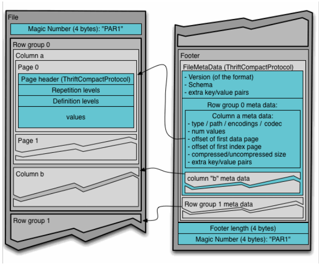
Examples

```
>>> import torch
>>> torch.from_dlpack(pyarrow_array)
tensor([0, 1, 2, 3, 4])
>>> torch.from_dlpack(pyarrow_array).data_ptr()
5568689760
```

Parquet

Parquet file format

- Column-oriented file format designed for efficient data storage and retrieval
- Provides efficient data compression and encoding schemes with enhanced performance to handle complex data in bulk
- Optional encryption
- Use of metadata allows for reading subsets of columns or even rows


File
Magic Number (4 bytes): "PAR1"
Row group 0
Column a
Page 0
Page header (ThriftCompactProtocol)
Repetition levels
Definition levels
values
Page 1
Column b
Row group 1
Footer
FileMetaData (ThriftCompactProtocol)
- Version (of the format)
- Schema
- extra key/value pairs
Row group 0 meta data:
Column a meta data:
- type / path / encodings / codec
- num values
- offset of first data page
- offset of first index page
- compressed/uncompressed size
- extra key/value pairs
column "b" meta data
Row group 1 meta data
Footer length (4 bytes)
Magic Number (4 bytes): "PAR1"

Read and write images to Parquet

Examples

```
>>> import pyarrow as pa
>>> import pyarrow.parquet as pq
>>> from PIL import Image
>>> from urllib.request import urlopen
>>> urls = [f"https://picsum.photos/seed/{i}/1/1" for i in range(3)]
>>> images = np.stack([Image.open(urlopen(url)) for url in urls])
>>> image_array = pa.FixedShapeTensorArray.from_numpy_ndarray(images)
>>> table = pa.table({"idx": range(len(urls)), "url": urls,
>>>                   "image": image_array})
>>> pq.write_table(table, "example.parquet", compression=None)
>>> read_table = pq.read_table("example.parquet")
>>> read_table == table
True
```

Read subset of rows

Examples

```
>>> import pyarrow.parquet as pq
>>> pq.read_table("example.parquet",
>>>               columns=["image"],
>>>               filters=[
>>>                   ("idx", ">", 1),
>>>                   ("idx", "<", 3),
>>>               ])
pyarrow.Table
image: extension<arrow.fixed_shape_tensor[value_type=uint8,
shape=[1,1,3], permutation=[0,1,2]]>
----
image: [[[93,93,91]]]
```

Write and read from cloud object storage (S3, GCS, HDFS, ..)

Examples

```
>>> # This requires ~/.aws/credentials file for authentication
>>> import pyarrow as pa
>>> import pyarrow.parquet as pq
>>> table = pa.table({"idx": [0, 1, 3], "letter": ["a", "b", "c"]})
>>> s3_uri = "s3://<bucket>/<filepath>"
>>> pq.write_table(table, s3_uri)
>>> read_table = pq.read_table(s3_uri)
>>> print(read_table.to_pandas().iloc[:3, 0:3].to_markdown())
|    |   idx | letter    |
|---:|------:|:----------|
|  0 |     0 | a         |
|  1 |     1 | b         |
|  2 |     3 | c         |
```

Write encrypted

Examples

```python
import pyarrow.parquet.encryption as pe
import pyarrow.parquet as pq
import pyarrow as pa
from pyarrow.tests.parquet.encryption import InMemoryKmsClient

def kms_factory(kms_connection_configuration):
    return InMemoryKmsClient(kms_connection_configuration)
FOOTER_KEY = b"0123456789112345".decode("UTF-8")
FOOTER_KEY_NAME = "footer_key"
COL_KEY = b"1234567890123450".decode("UTF-8")
COL_KEY_NAME = "image_key"
kms_connection_config = pe.KmsConnectionConfig(
    custom_kms_conf = {
        FOOTER_KEY_NAME: FOOTER_KEY,
        COL_KEY_NAME: COL_KEY,
    }
)
encryption_config = pe.EncryptionConfiguration(
    footer_key=FOOTER_KEY_NAME,
    column_keys={COL_KEY_NAME: ["idx"]},
    encryption_algorithm="AES_GCM_V1",
)
crypto_factory = pe.CryptoFactory(kms_factory)
encryption_properties = crypto_factory.file_encryption_properties(kms_connection_config, encryption_config)

table = pa.table({"idx": [0, 1, 3], "letter": ["a", "b", "c"]})
with pq.ParquetWriter("encrypted.parquet", table.schema, encryption_properties=encryption_properties) as writer:
    writer.write_table(table)
```

Read encrypted

Examples

```python
import pyarrow.parquet.encryption as pe
import pyarrow.parquet as pq
from pyarrow.tests.parquet.encryption import InMemoryKmsClient

def kms_factory(kms_connection_configuration):
    return InMemoryKmsClient(kms_connection_configuration)
FOOTER_KEY = b"0123456789112345".decode("UTF-8")
FOOTER_KEY_NAME = "footer_key"
COL_KEY = b"1234567890123450".decode("UTF-8")
COL_KEY_NAME = "image_key"
kms_connection_config = pe.KmsConnectionConfig(
    custom_kms_conf = {
        FOOTER_KEY_NAME: FOOTER_KEY,
        COL_KEY_NAME: COL_KEY,
    }
)
crypto_factory = pe.CryptoFactory(kms_factory)
decryption_properties = crypto_factory.file_decryption_properties(kms_connection_config)

result = pq.ParquetFile("encrypted.parquet", decryption_properties=decryption_properties)
result_table = result.read()
```

Compute

Compute operations like filtering or transforming data in arrays and tables are provided by the `pa.compute` module.

- Standard Compute Functions
- Grouped Aggregations
- Table and Dataset Joins
- Filtering by Expressions

Last three classes of operations are supported on Tables and/or Datasets. Standard compute functions also support Arrow arrays.

Compute functions reference

arrow.apache.org/docs/python/api/compute.html

Example 1

Computing `Sum` and `Mean/Min/Max` values of an array

Examples

```
>>> import pyarrow as pa
>>> import pyarrow.compute as pc
>>> a = pa.array([1, 1, 2, 3])
>>> pc.sum(a)
<pyarrow.Int64Scalar: 7>
>>> pc.min(a)
<pyarrow.Int64Scalar: 1>
```

Example 2

Data transformations with `pa.equal`

Examples

```
>>> import pyarrow as pa
>>> import pyarrow.compute as pc
>>> a = pa.array([1, 1, 2, 3])
>>> b = pa.array([4, 1, 2, 8])
>>> pc.equal(a, b)
<pyarrow.lib.BooleanArray object at 0x112a721a0>
[
  false,
  true,
  true,
  false
]
```

Example 2

Data transformations with `pa.multiply` array ans scalar

Examples

```
>>> y = pa.scalar(9.3)
>>> pc.multiply(a, y)
<pyarrow.lib.DoubleArray object at 0x112a721a0>
[
  9.3,
  9.3,
  18.6,
  27.900000000000002
]
```

Example 2

Data transformations with `pa.multiply` two arrays

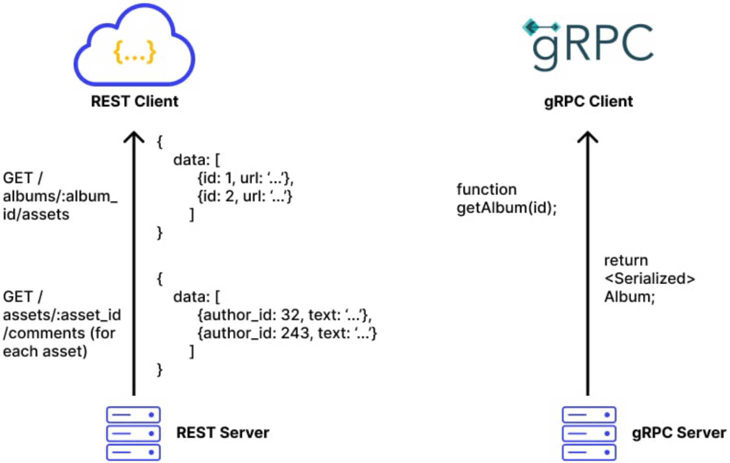
Examples

```
>>> pc.multiply(a, b)
<pyarrow.lib.Int64Array object at 0x114af31c0>
[
  4,
  1,
  4,
  24
]
```

Flight RPC

- A RPC framework for high-performance data services based on the Arrow columnar format
- Defines a generic RPC vocabulary for building custom applications and services
- Data transfer is streaming, both client-side and server-side
- Example: Arrow-native storage servers, execution engines. . .
- Arrow Flight SQL enables sending requests as SQL

Flight RPC



REST Client

GET / albums/:album_id/assets

```
{
   data: [
      {id: 1, url: '...'},
      {id: 2, url: '...'}
   ]
}
```

GET / assets/:asset_id /comments (for each asset)

```
{
   data: [
      {author_id: 32, text: '...'},
      {author_id: 243, text: '...'}
   ]
}
```

REST Server

gRPC

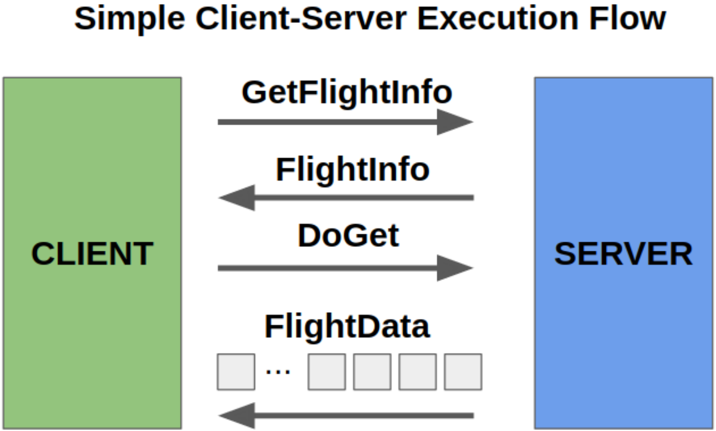
gRPC Client

function getAlbum(id);

return <Serialized> Album;

gRPC Server

Flight RPC


Simple Client-Server Execution Flow
CLIENT
GetFlightInfo
FlightInfo
DoGet
FlightData
...
SERVER

For more ideas see cookbook

https://arrow.apache.org/cookbook/py

PRs welcome!

The End