TWO SIGMA

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Apache Arrow: In-memory data processing and system interoperability

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Me

- Currently: Software Architect at Two Sigma Investments
- Creator of Python pandas project
- PMC member for Apache Arrow and Apache Parquet
- Author of *Python for Data Analysis*
- Other Python projects: Ibis, Feather, statsmodels

Changing hardware landscape

- Intel has released first production 3D Xpoint SSD
  - Reported 1000x faster than NAND, less expensive than RAM

- Convergence between RAM vs. shared memory / mmap performance

Changing software landscape

- Next-gen ML / AI frameworks (TensorFlow, Torch, etc.)
- Open source architectures for machine learning in production
  - Streaming / batch data processing pipelines
  - Data cleaning and feature engineering
  - Model fitting / scoring / serving

“Zero-copy” memory interfaces

- Enables computational tools to process a dataset **without any additional serialization**, or transfer to a different memory space
- Can do random access on a dataset that does not fit in RAM

- Another interpretation: reading a dataset is a **metadata-only conversion**

Apache Arrow

- Started early 2016, broad open source collaboration to define standards for in-memory analytical data processing

- A cross-language development platform for in-memory data
- Memory format specification for columnar (tabular) datasets
- Zero-copy memory sharing tools (for shared memory, memory maps)
- Languages (so far): C, C++, Java, Ruby, Python, JavaScript

What does Apache Arrow give you?

- **Cache-efficient columnar memory:** optimized for CPU affinity and SIMD / parallel processing, O(1) random value access

- **Zero-copy messaging / IPC:** Language-agnostic metadata, batch/file-based and streaming binary formats

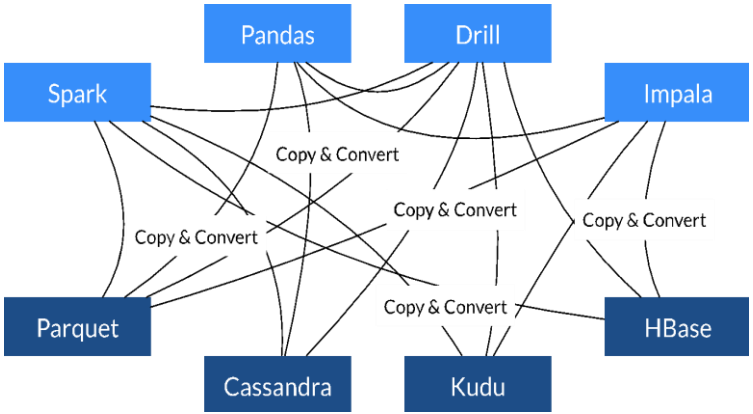
- **Complex schema support**: Flat and nested data types

Challenges to zero-copy memory sharing

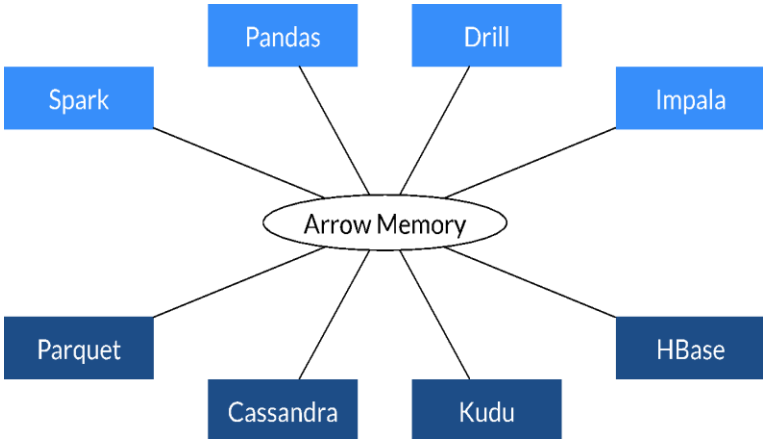
- Cross-language issues
  - Type metadata + logical types
  - Byte/bit-level memory layout
- Language-specific issues
  - In-memory data structures
  - Memory allocation and sharing constructs

High performance data interchange

Today

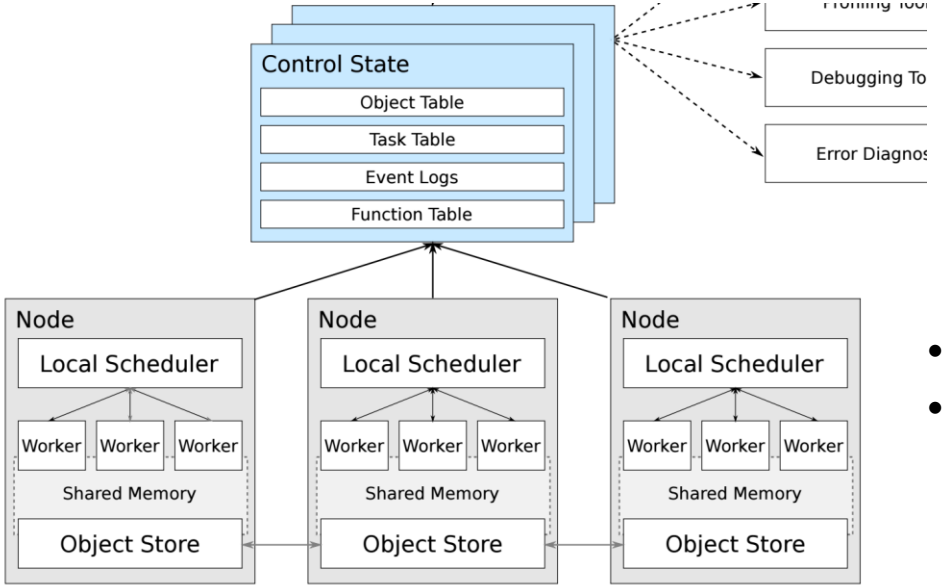


With Arrow



Source: Apache Arrow

Example use: Ray ML framework from Berkeley RISELab



- Shared memory-based object store
- Zero-copy tensor reads using Arrow libraries

Source: https://arxiv.org/abs/1703.03924

Tensors and Tables

- 2 data structures best suited for zero-copy sharing
  - **Tensors**: N-dimensional, homogeneously-typed arrays
  - **Tables**: Column-oriented, heterogeneously typed

- These data structures can be defined using common memory and metadata primitives

Arrow in C++

- Reusable memory management and IO subsystem for native code applications
- Layered in multiple components
  - Memory management
  - Type metadata / schemas
  - Array / Table containers
  - IO interfaces
  - Zero-copy IPC / messaging

Arrow C++: Memory management

- `arrow::Buffer`
  - RAII-based memory lifetime with `std::shared_ptr<Buffer>`
  - `arrow::MemoryMappedBuffer:` for memory maps
- `arrow::MemoryPool`
  - Abstract memory allocator for tracking all allocations

Arrow C++: Type metadata

- `arrow::DataType`
  - Base class for fixed size, variable size, and nested datatypes
- `arrow::Field`
  - Type + name + additional metadata
- `arrow::Schema`
  - Collection of fields

Arrow C++: Array / Table containers

- `arrow::Array`
  - 1-dimensional columnar arrays: `Int32Array, ListArray, StructArray,` etc.
  - Support for dictionary-encoded arrays
- `arrow::RecordBatch`
  - Collection of equal-length arrays
- `arrow::Column`
  - Logical table “column” as chunked array
- `arrow::Table`
  - Collection of columns

Arrow C++: IO interfaces

- `arrow::{InputStream, OutputStream}`
- `arrow::RandomAccessFile`
  - Abstract file interface
- `arrow::MemoryMappedFile`
  - Zero-copy reads to `arrow::Buffer`
- Specific implementations for OS files, HDFS, etc.

Arrow C++: Messaging / IPC

- Metadata read/write using Google's Flatbuffers library
- Encapsulated Message type
  - Write record batches, read with zero-copy
- `RecordBatchFileWriter, RecordBatchFileReader`
  - Random access / "batch" binary format
- `RecordBatchStreamWriter, RecordBatchStreamReader`
  - Streaming binary format

`arrow::Tensor`

- Targeting interoperability with memory layouts as used in NumPy, TensorFlow, Torch, or other standard tensor-based frameworks
  - data: **`arrow::Buffer`**
  - shape: dimension sizes
  - strides: memory ordering
- Zero-copy reads using Arrow's shared memory tools

Example use: pandas 2.0

- In-planning rearchitecture of pandas's internals
  - libpandas — largely Python-agnostic C++11 library
  - Decoupling pandas data structures from NumPy tensors
- Support analytics targeting native Arrow memory
  - Multicore / parallel algorithms
  - Leverage latest SIMD intrinsics
- Lazy-loading DataFrames from primary input formats
  - CSV, JSON, HDF5, Apache Parquet