# Apache Arrow Tensor Arrays

A toolchain for tensor transport and storage

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February 2, 2025

## Overview

## Arrow Extension Types

- Arrow allows for user extension types
- Arrow project also provides some "well-known extension types" or canonical extension types in the `arrow.*` namespace
- Current extension types are: `arrow.fixed_shape_tensor`, `arrow.variable_shape_tensor`, `arrow.json`, `arrow.opaque`, `arrow.bool8`

# Fixed Shape Tensor - memory layout

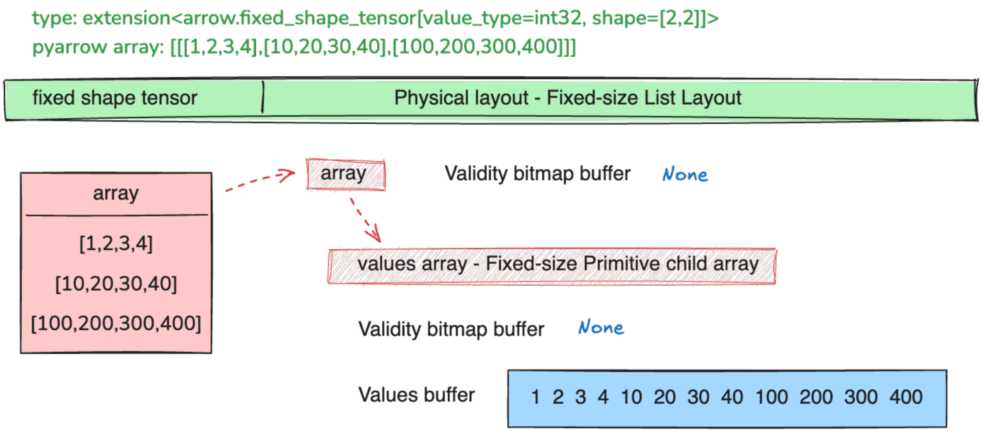

type: extension<arrow.fixed_shape_tensor[value_type=int32, shape=[2,2]]>
pyarrow array: [[[1,2,3,4],[10,20,30,40],[100,200,300,400]]]
fixed shape tensor
Physical layout - Fixed-size List Layout
array
[1,2,3,4]
[10,20,30,40]
[100,200,300,400]
array
Validity bitmap buffer
None
values array - Fixed-size Primitive child array
Validity bitmap buffer
None
Values buffer
1 2 3 4 10 20 30 40 100 200 300 400

Figure: Fixed Shape Tensor memory layout

## Fixed Shape Tensor

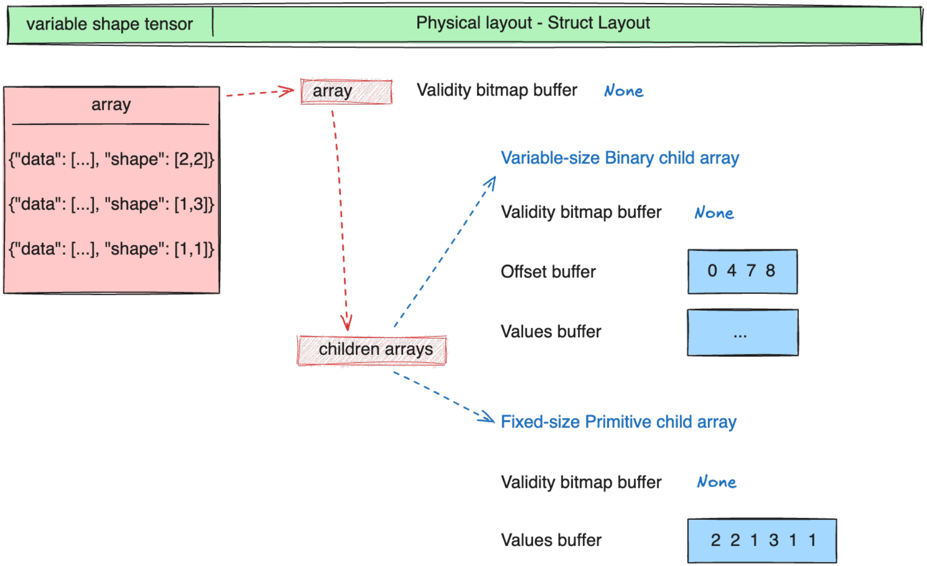
- Based on fixed size list array layout (`FixedSizeList[value_type, list_size]`)
- Every cell of the array is a multidimensional tensor of the same shape and type
- Type parameters: `data type` and `shape` of individual tensor elements
- Optional parameters: `dim_names`, `permutation`
- Elements in a fixed shape tensor extension array are stored in row-major/C-contiguous order

## FixedShapeTensorArray metadata serialized

Examples

```
{
   "shape":[100, 200, 500 ],
   "dim_names": ["C", "H", "W"],
   "permutation": [2, 0, 1]
}
```

# Variable Shape Tensor - memory layout


variable shape tensor
Physical layout - Struct Layout
array
{"data": [...], "shape": [2,2]}
{"data": [...], "shape": [1,3]}
{"data": [...], "shape": [1,1]}
array
Validity bitmap buffer
None
children arrays
Variable-size Binary child array
Validity bitmap buffer
None
Offset buffer
0 4 7 8
Values buffer
...
Fixed-size Primitive child array
Validity bitmap buffer
None
Values buffer
2 2 1 3 1 1

## Variable Shape Tensor

- Based on struct array layout (`StructArray[List[value_type], FixedSizeList<int32>[ndim]]`)
- Every cell of the array is a multidimensional tensor with the same type and number of dimensions
- Type parameters: `data type`
- Data are stored as `StructArray`
    - `data` is a List holding tensor elements
    - `shape` is a `VariableSizeList<int32>[ndim]`
- Optional parameters: `dim_names`, `permutation` and `uniform_shape`
- Elements in a variable shape tensor extension array are stored in row-major/C-contiguous order

## FixedShapeTensorArray metadata serialized

Examples

```
{
    "dim_names": ["H", "W", "C"],
    "uniform_shape": [400, null, 3],
    "permutation": [2, 0, 1]
}
```

## Create a FixedShapeTensorArray

Examples

```
>>> import pyarrow as pa
>>> tensor_type = pa.fixed_shape_tensor(pa.int32(), (2, 2))
>>> arr = [[1, 2, 3, 4], [10, 20, 30, 40], [100, 200, 300, 400]]
>>> storage = pa.array(arr, pa.list_(pa.int32(), 4))
>>> tensor_array = pa.ExtensionArray.from_storage(tensor_type, storage)
```

## Create a FixedShapeTensorArray

**Examples**

```
>>> tensor_array
<pyarrow.lib.FixedShapeTensorArray object at ...>
[
  [
    1,
    2,
    3,
    4
  ],
  ...
]
```

## Move to NumPy ndarray

### Examples

```
>>> tensor_array.to_numpy_ndarray()
array([[[  1,   2],
        [  3,   4]],

       [[ 10,  20],
        [ 30,  40]],

       [[100, 200],
        [300, 400]]], dtype=int32)
```

## Move back to PyArrow

Examples

```
>>> pa.FixedShapeTensorArray.from_numpy_ndarray(
...         tensor_array.to_numpy_ndarray()
... )
<pyarrow.lib.FixedShapeTensorArray object at ...>
[
  [
    1,
    2,
    3,
    4
  ],
  ...
]
```

## DLPack protocol

- Enables device aware data interchange between array/tensor libraries
- Currently producer side of DLPack implemented for pyarrow Array
- Future plan: Implementation of producing and consuming part for `Tensor` class and `FixedShapeTensorArray.to_tensor()` method to connect `FixedShapeTensorArray` with libraries supporting DLPack (NumPy, CuPy, Tensorflow, PyTorch, JAX, MXNet, TVM, mpi4py, Paddle, etc.)

## The End