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Skyhook:
Programmable storage for databases
Vault'19

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CROSS | CENTER FOR RESEARCH IN OPEN SOURCE SOFTWARE

- Bridges gap between student research & open source projects
- Funded by Sage Weil endowment & corporate memberships
- Goals
  - Leverage OSS culture in university research
  - Incubate work beyond graduation to reach critical mass
- cross.ucsc.edu

TOSHIBA
SEAGATE
Western Digital.
HUAWEI
SAMSUNG

What is programmable storage?

- For Skyhook - ***Pushdown*** some data management tasks into the storage layer
  - Transformations (process/format data)
  - Indexing, statistics, re-sharding
- Skyhook uses Ceph object storage
  - Open source, extensible, originated at UCSC
- See Programmability.us for more info

Ceph Distributed Object Storage

- Distributed, scalable, fault-tolerant
  - Widely available in the cloud
- Objects are the core entity (read/write/replicate)
  - Other API wrappers on top: file, block, S3
- LIBRADOS object library
  - Users can interact directly with objects
  - Create user-defined object classes (read/write)

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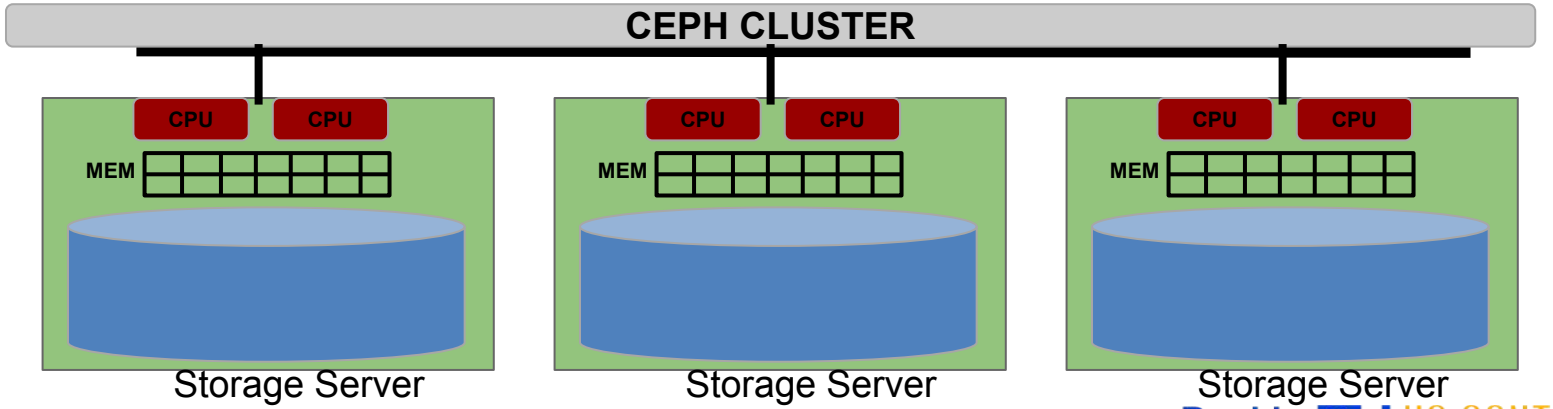
Data Storage in Ceph Cluster



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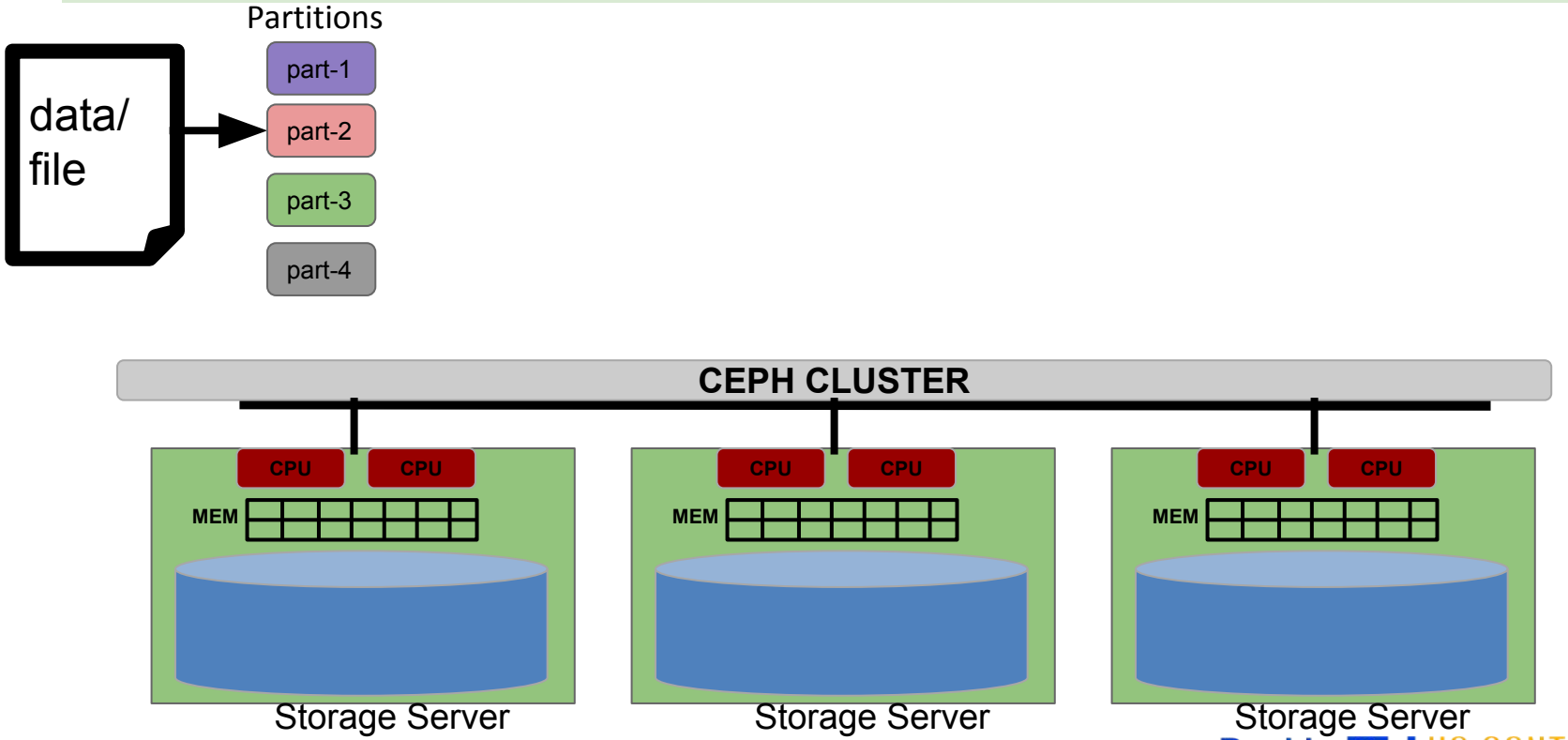

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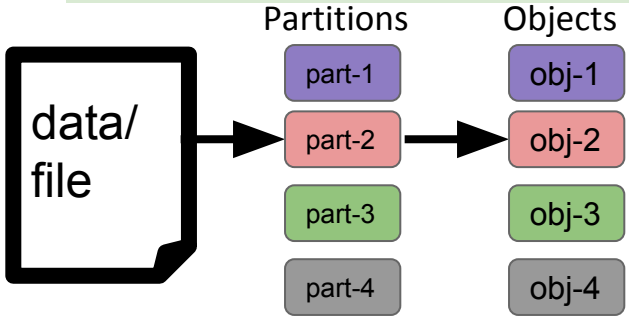

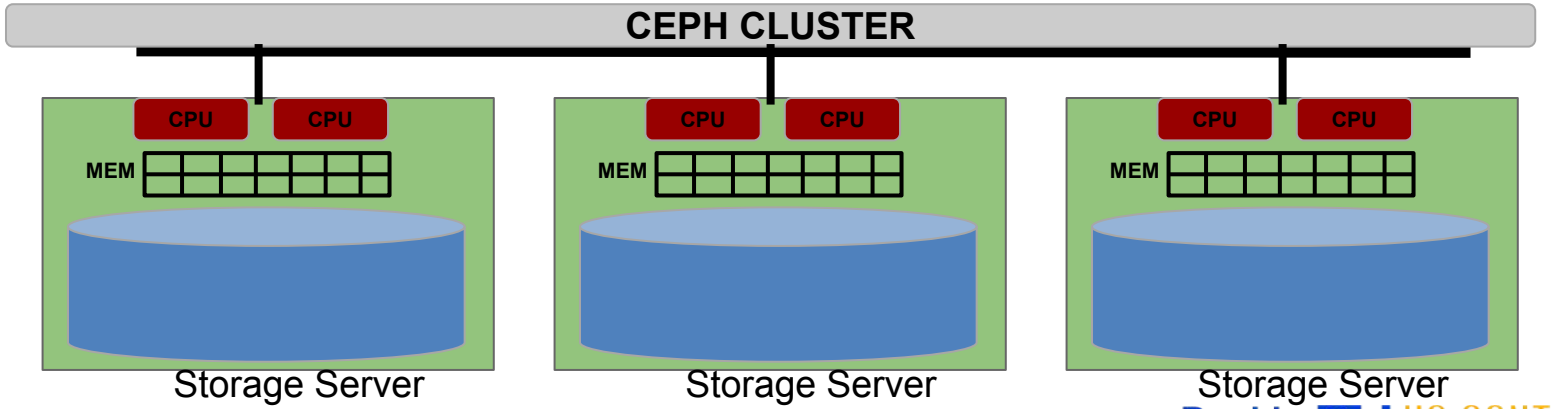

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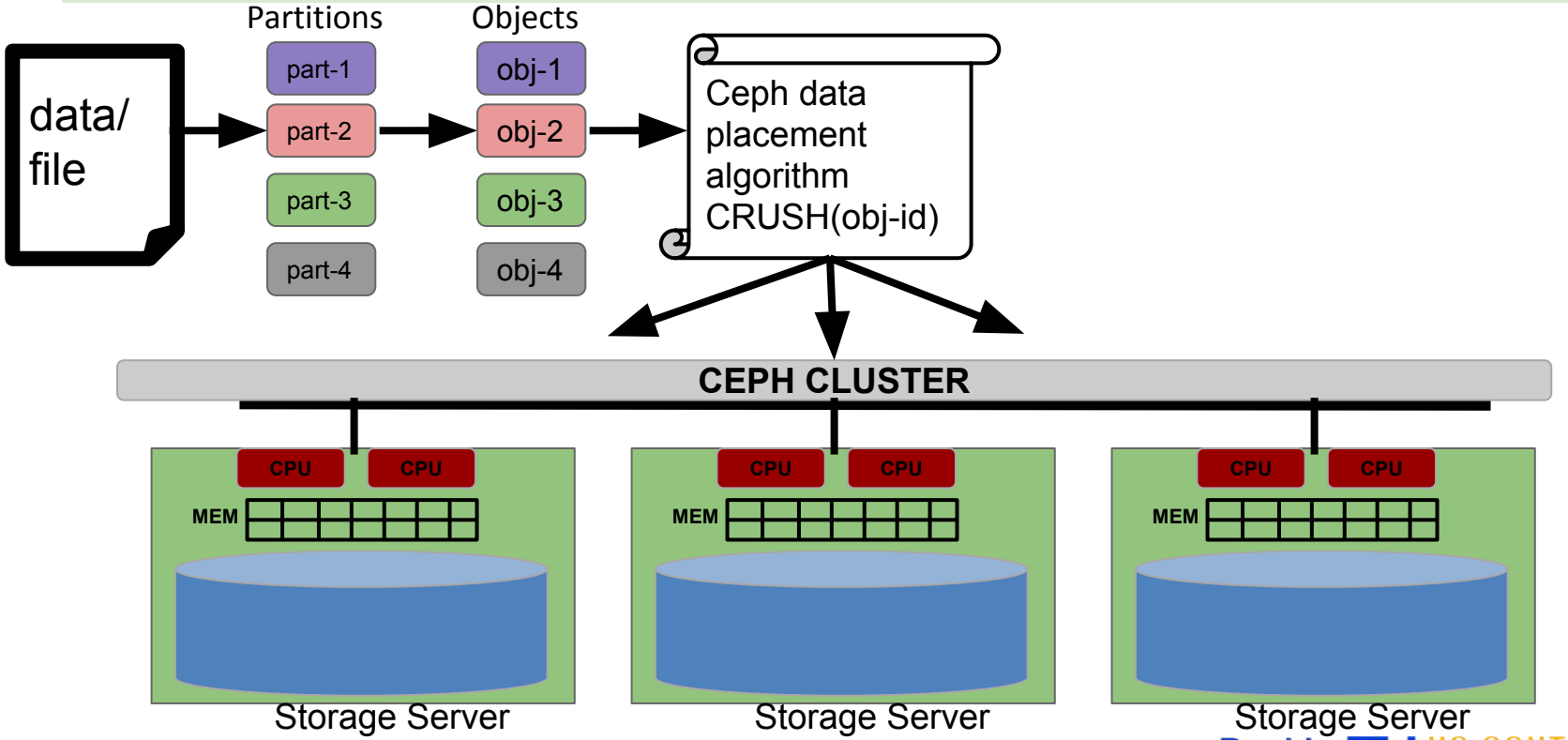

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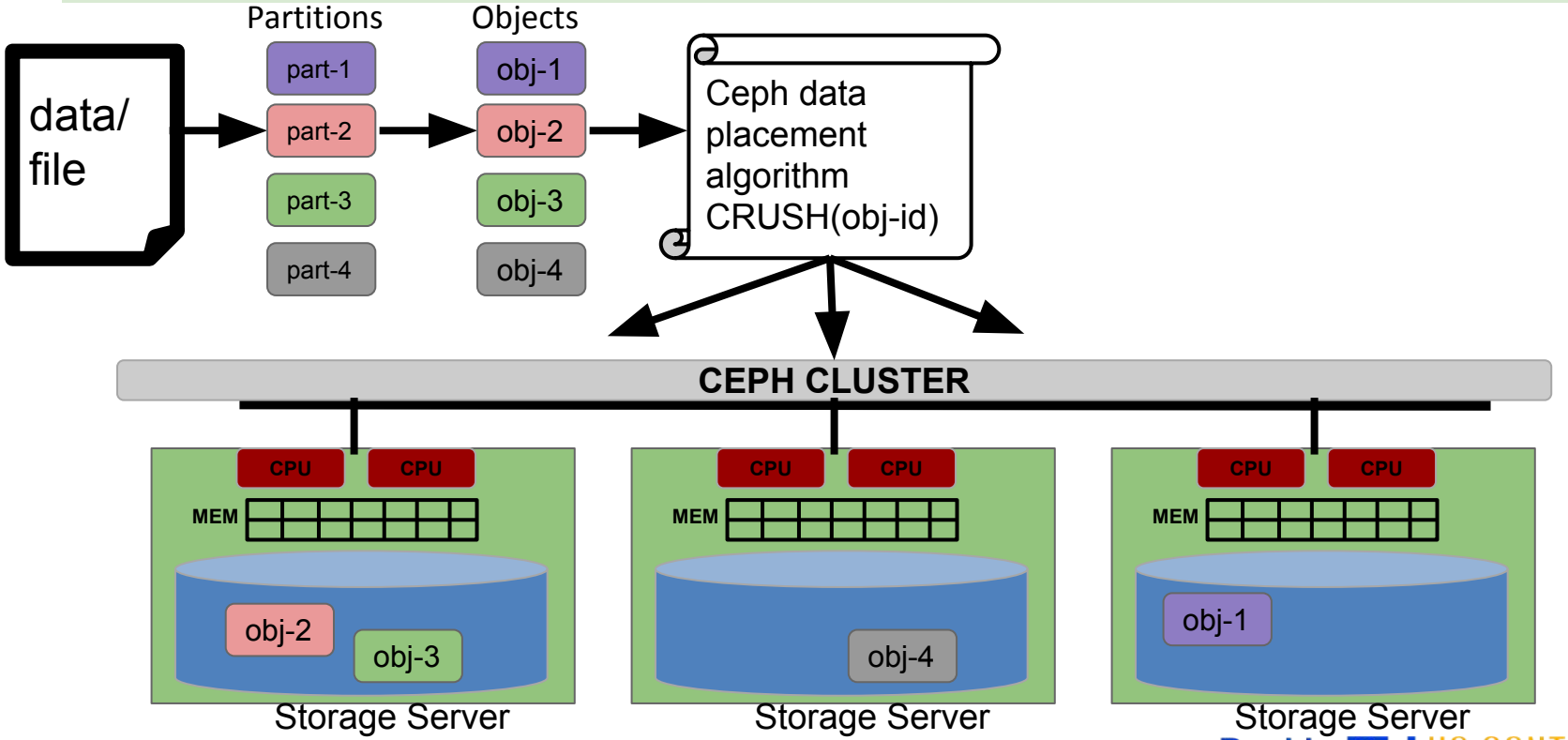

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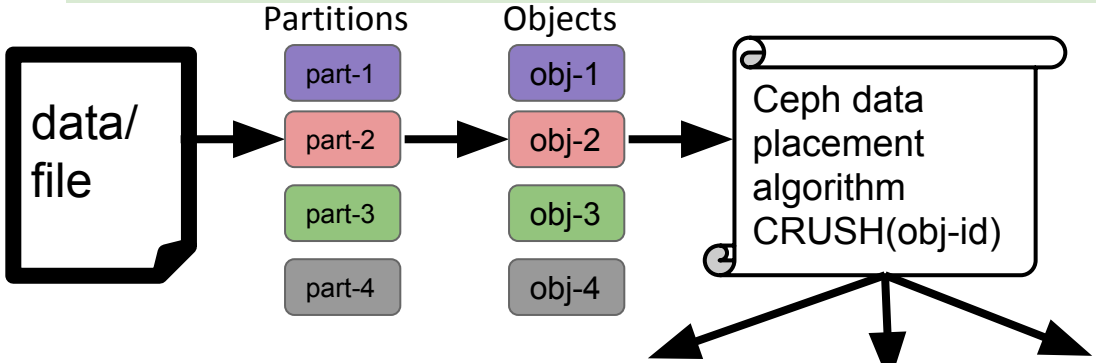
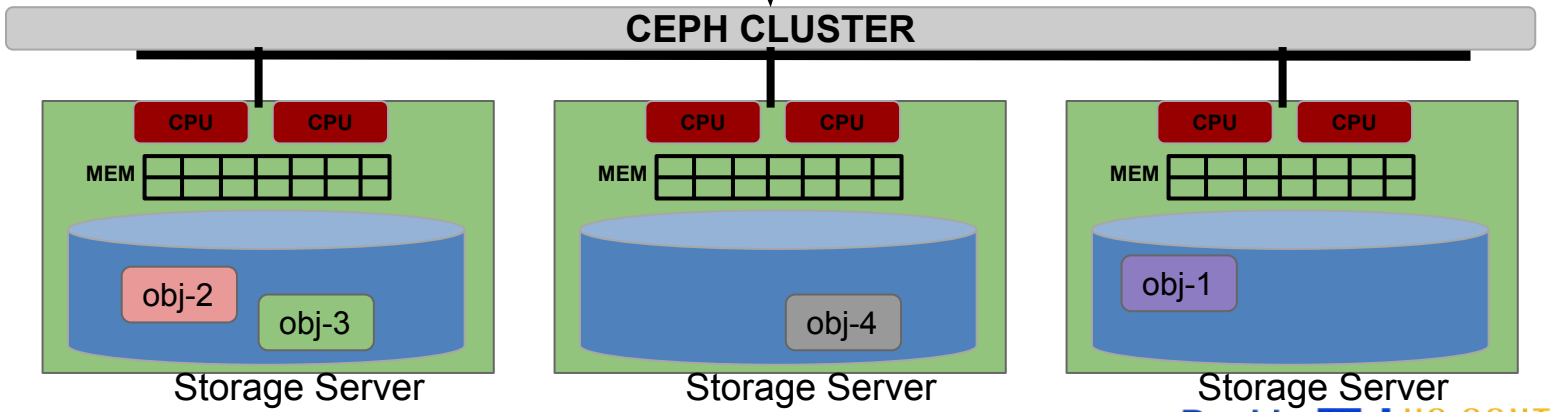


- Primary copy replication
- Writes: atomic+transactional
- Given object name
  - Client can calculate location
- Partial reads/writes of objects
- Automatically redistributes data during failures/add/remove servers



How does this help us?

- Ceph storage provides transparent
  - Data distribution/scaling
  - Fault tolerance/recovery
- Remote processing on storage servers
  - **via custom object classes**
- Query-able metadata on storage servers
  - **via local indexing mechanism** (RocksDB)

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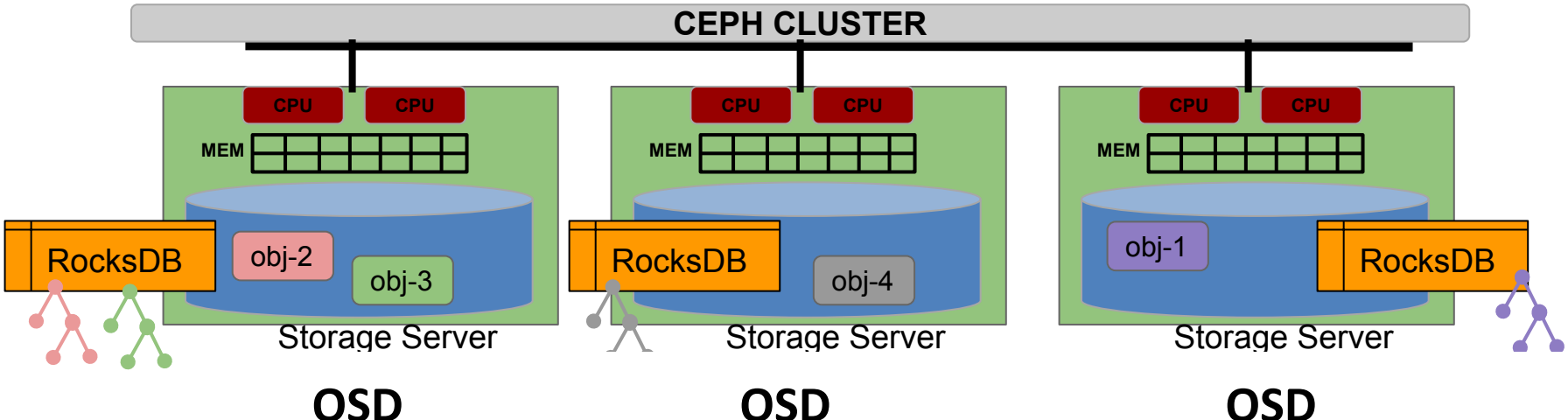
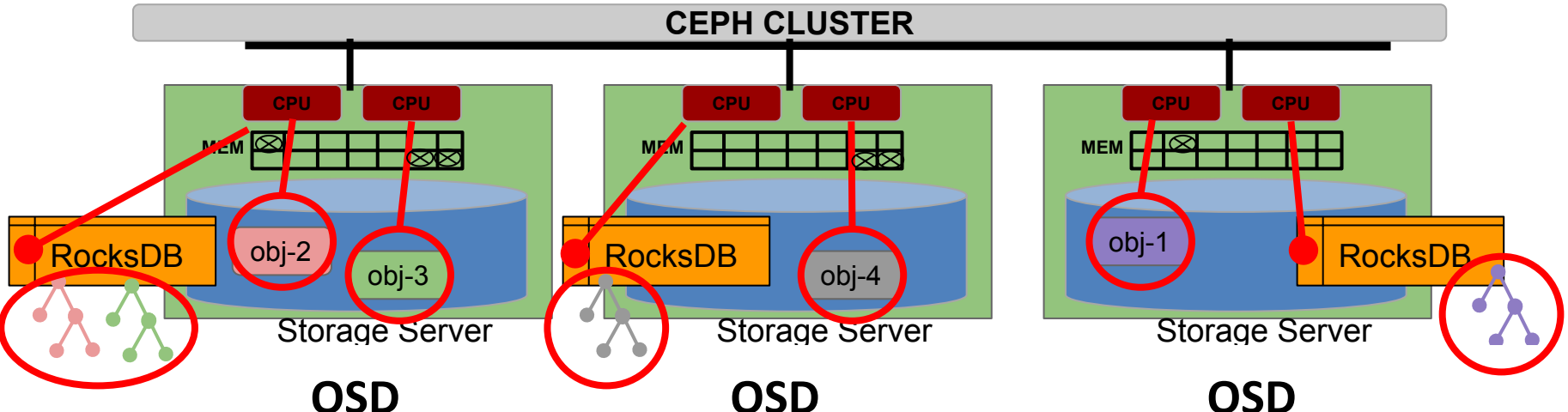
Remote Processing + Indexing

- Execution of custom object classes and indexing is performed by Ceph storage servers (OSDs)



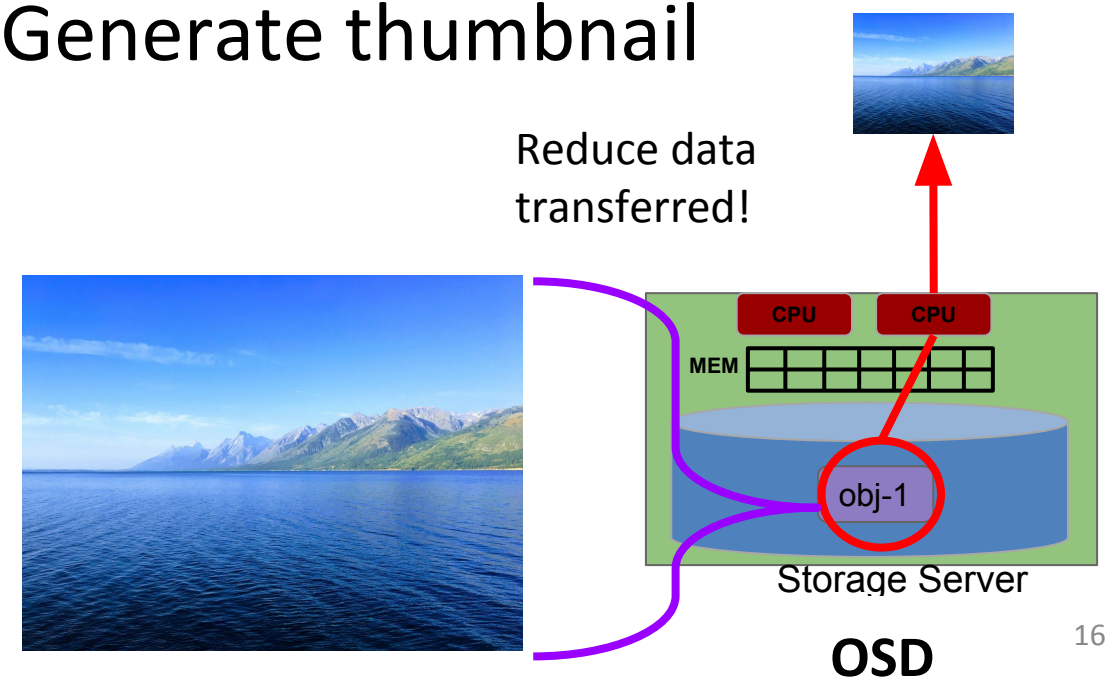
Remote Processing + Indexing

- Execution of custom object classes and indexing is performed by Ceph storage servers (OSDs)
- Utilizes remote resources



Remote Processing Example

- Full size image stored in object
  - Custom read: Generate thumbnail
- Other examples
  - Checksum
  - Filter/Regex
  - Aggregate
  - Transform
  - Reorg data



Ceph Custom Object Classes (CLS)

C++ interface

```
int compute_md5(cls_method_context_t hctx, bufferlist *in,
  bufferlist *out)
  {
    size_t size;
    int ret = cls_cxx_stat(hctx, &size, NULL);
    if (ret < 0)
      return ret;

    bufferlist data;
    ret = cls_cxx_read(hctx, 0, size, data);
    if (ret < 0)
      return ret;

    byte digest[AES::BLOCKSIZE];
    MD5().CalculateDigest(digest, (byte*)data.c_str(),
    data.length());

    out->append(digest, sizeof(digest));
    return 0;
  }
```

Lua interface

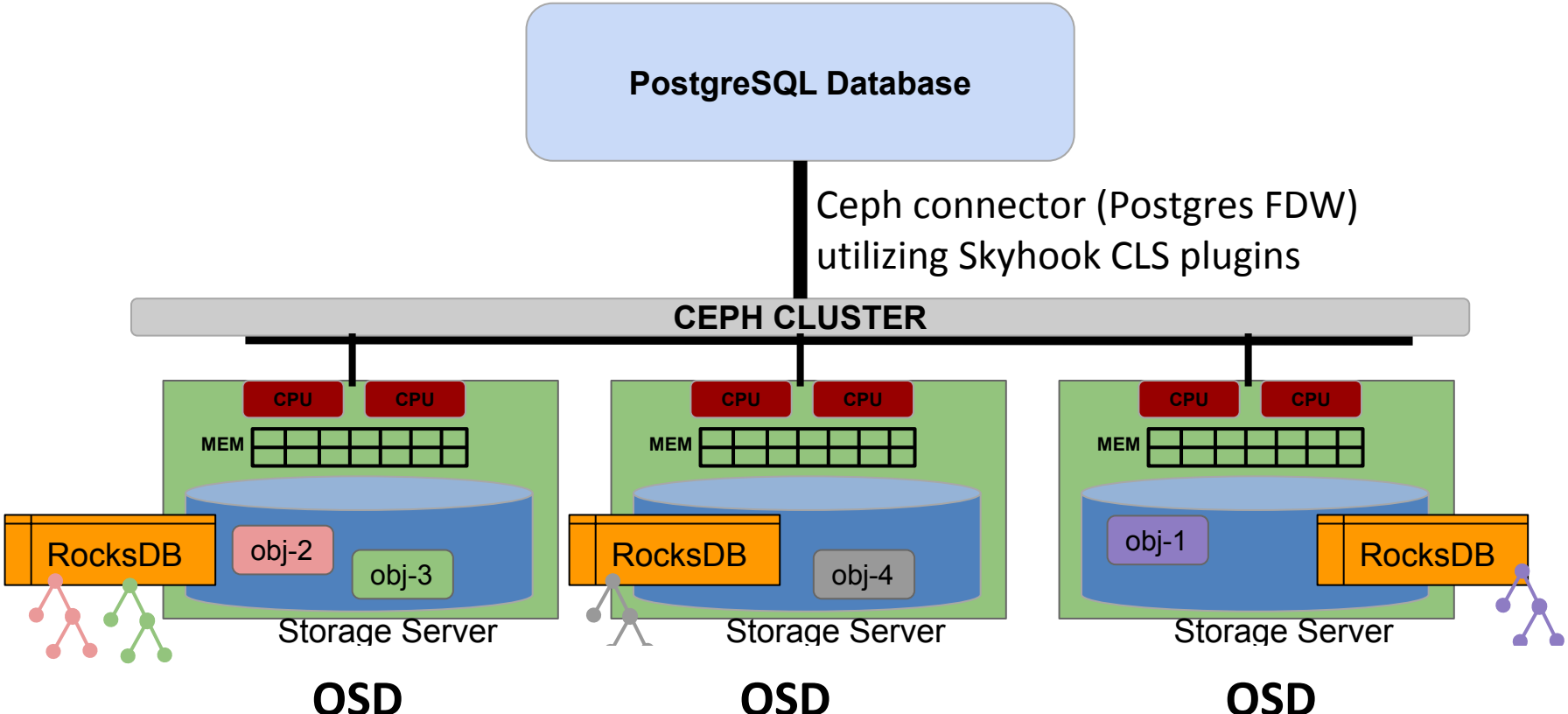
```
local md5 = require 'md5'


  function compute_md5(input, output)
    local data = objclass.read()
    output = md5.sumhexa(data)
  end
```

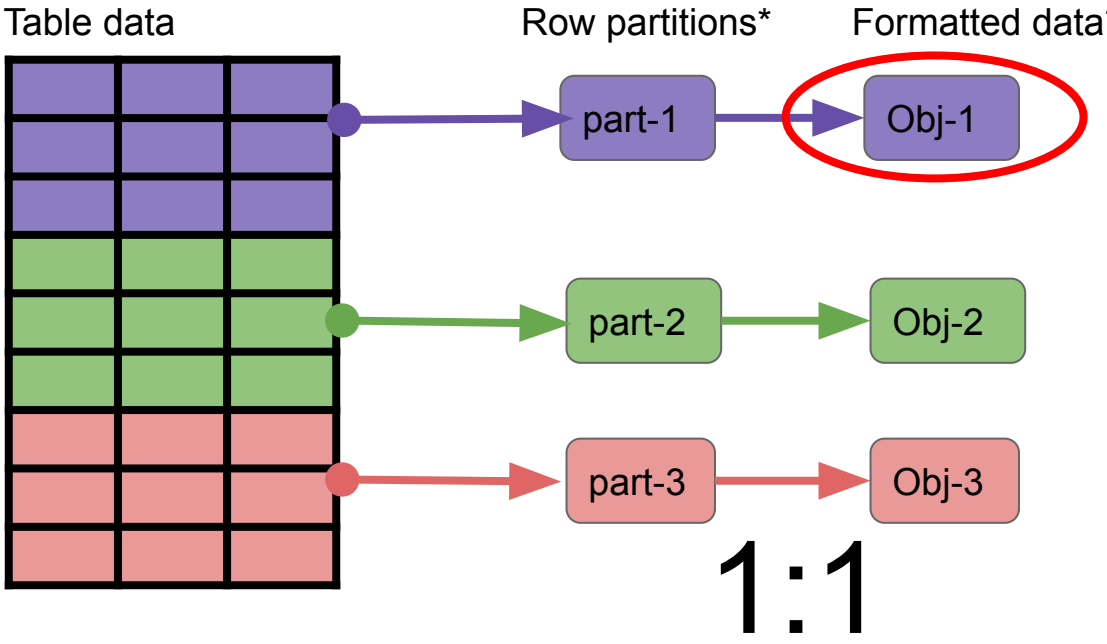
Putting it All Together - Skyhook

- ***Data partitioning***
  - Physical data layout and format
- ***Remote processing***
  - Custom object classes
- ***Remote indexing***
  - Query-able metadata (data vals, stats)

Skyhook Architecture



Skyhook - ***Data partitioning + format***



- Format retains data's semantics (table schema)
- Object names are generated
- Objects are distributed by Ceph based on name
- Object location not stored by Skyhook

*Partition rows with [JumpConsistentHash]

**Partitions formatted as [Google Flatbuffers]

Skyhook - ***Remote Processing***

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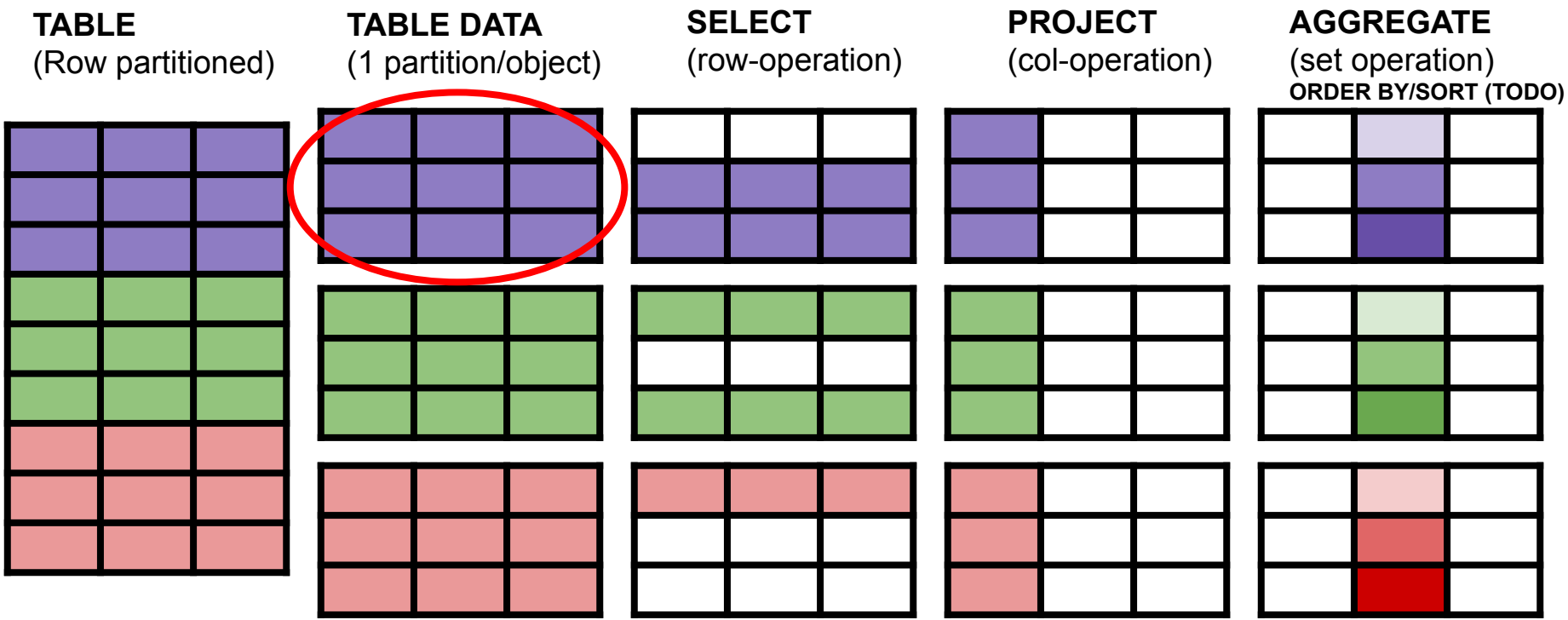
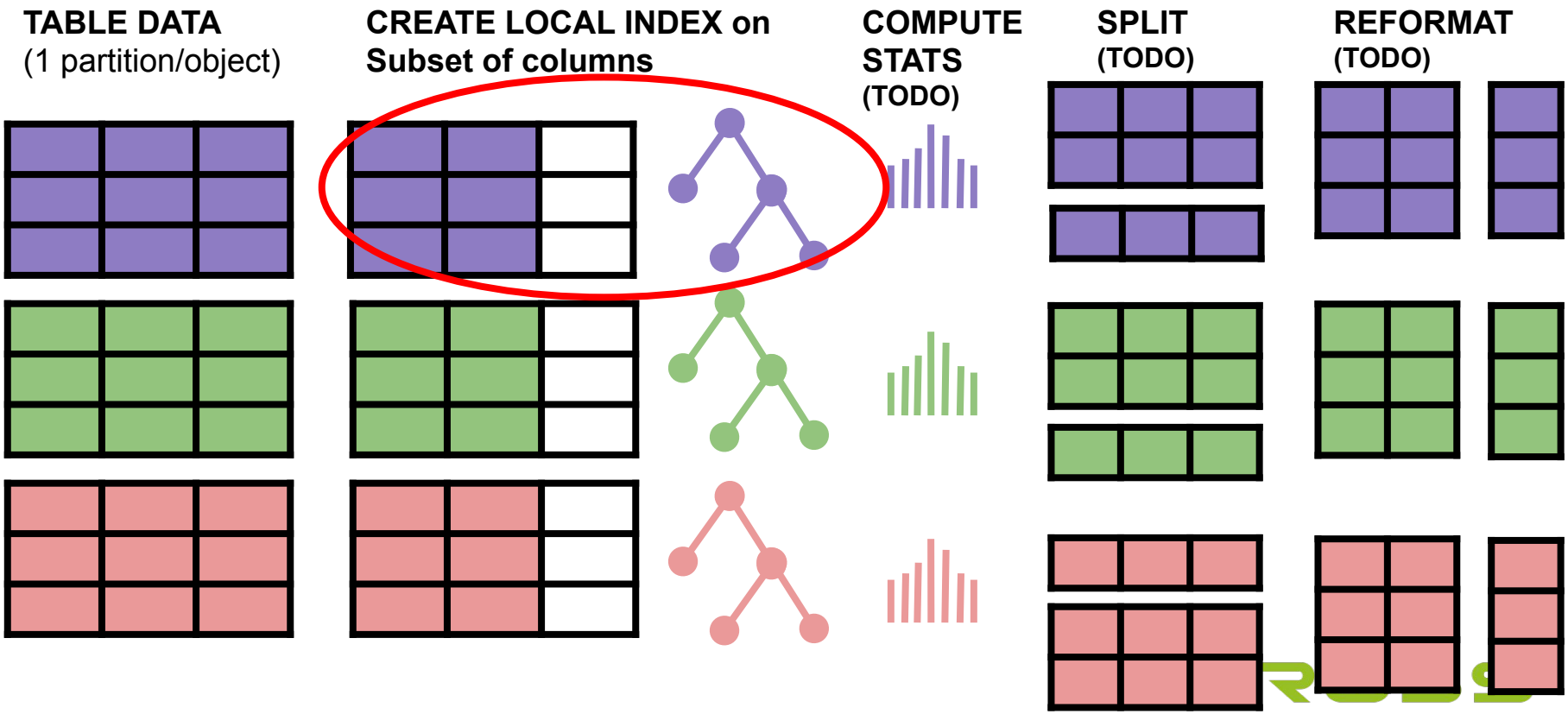


Skyhook - ***Remote Indexing***



Skyhook - Ceph Extensions developed

- Custom object classes (cls)
  - SELECT (`SELECT * from T WHERE a>5`)
  - PROJECT (`SELECT a,b from T`)
  - AGGREGATE (`SELECT min(a)from T WHERE b>5`)
- Query-able Metadata
  - index(a), index(a,b,...), stats(a), min(a), count(a

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Experimental Results

- Dataset: TPC-H lineitem table, 1 billion rows, ~140GB
- Objects: 10K objects ~14MB each (each with local index)
- Queries: Point, range
- Machines: 1 Client node; 1--16 Storage nodes
  - CPU=20 cores (Xeon), MEM=160GB, Net=10GbE, Intel SSDs
- Compare (report average of 3 runs each experiment)
  - Skyhook approach (query processing done in storage servers)
  - Standard approach (query processing done by client/database)

Experimental Results

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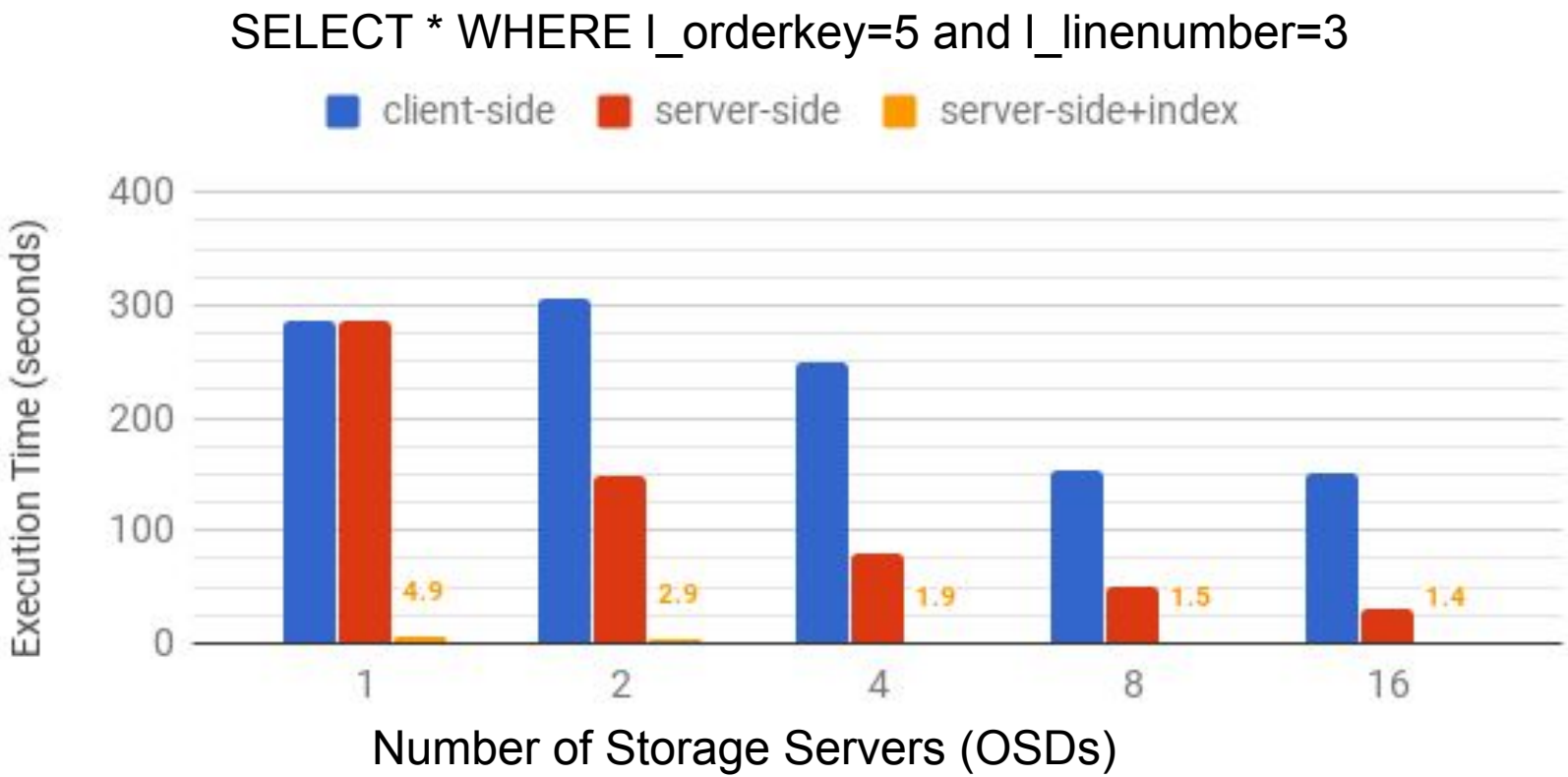
Point Query (single matching row)



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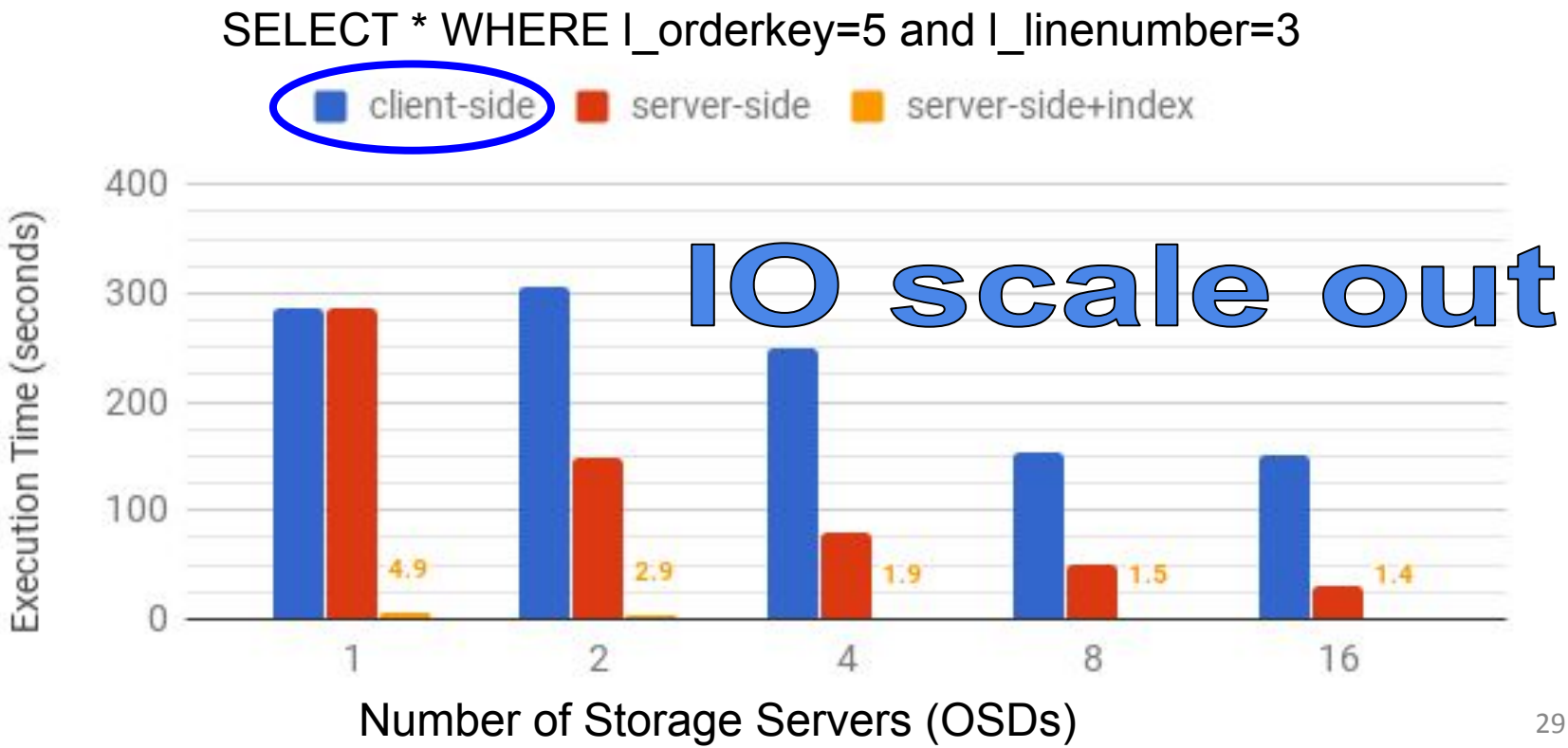
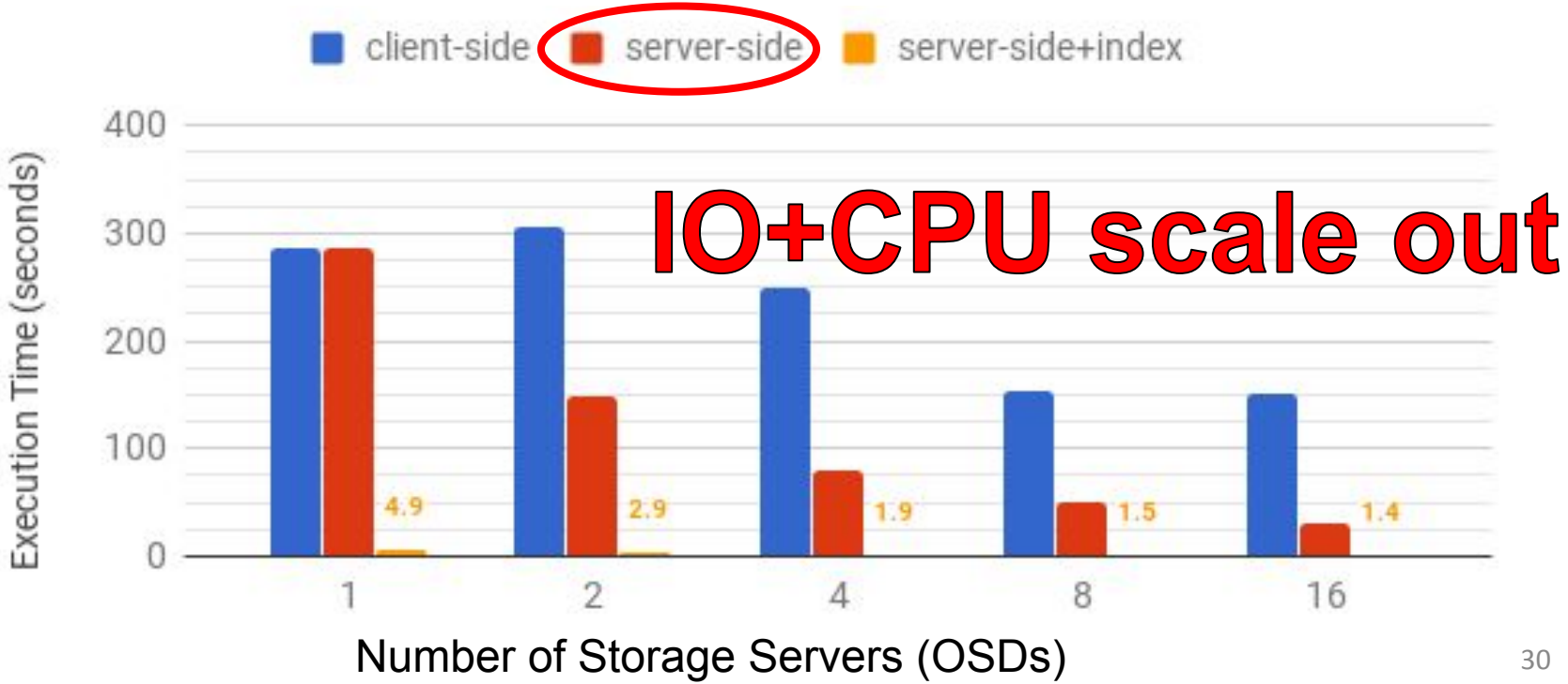


Point Query (single matching row)

SELECT * WHERE l_orderkey=5 and l_linenumber=3



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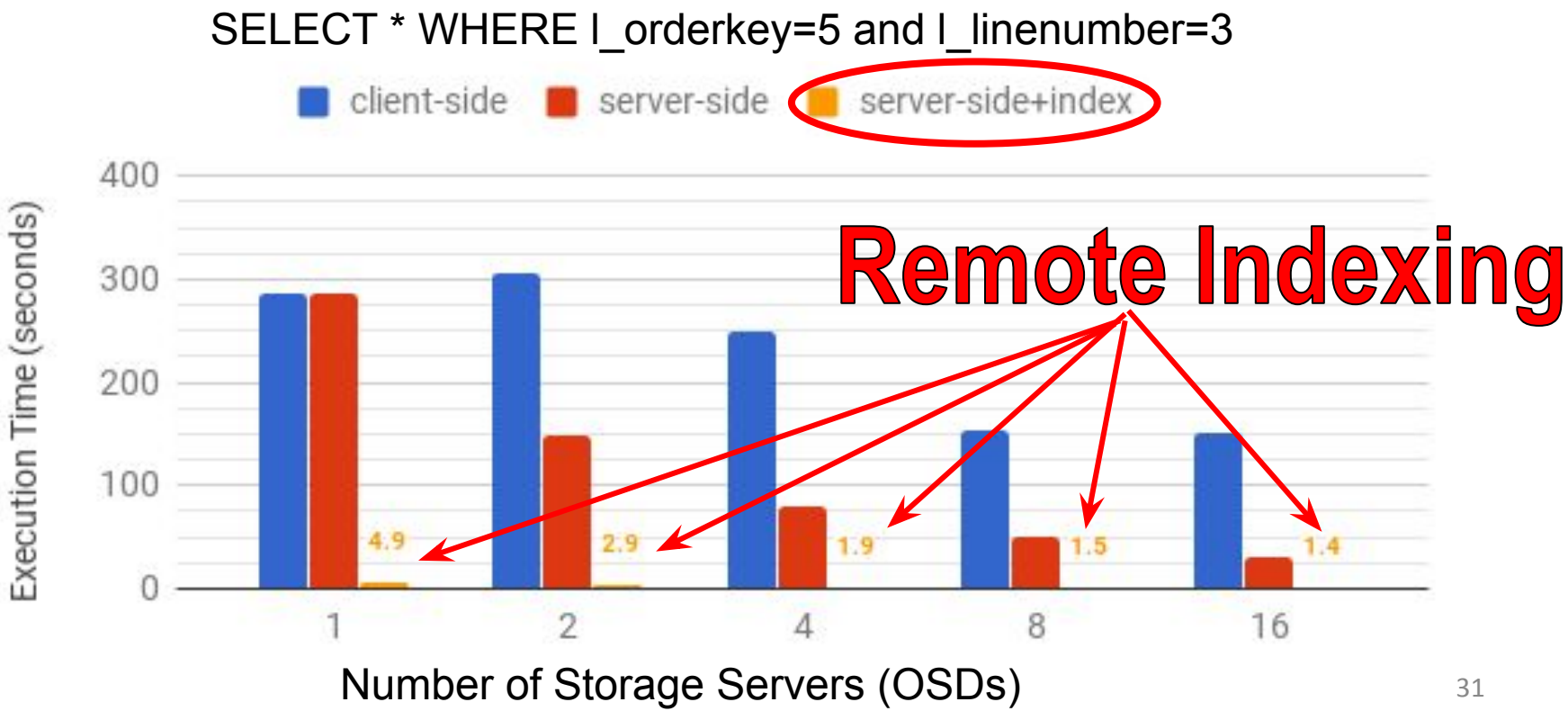

Range Query (selectivity=10%)

```
SELECT * WHERE l_extendedprice > 71000
```

Number of Storage Servers (OSDs)

- Remote processing done:
  - ***Integer comparison***

```
SELECT * WHERE comment like %uriously%
```

Number of Storage Servers (OSDs)

- Remote processing done:
  - ***Regex on text***
  - ***Others?***

Skyhook - Key Takeaways

- Store data partitions in objects, *retain the data's semantics*
  - For RDBMS - a subset of a table (row/col partition)
- Utilize remote resources on storage servers
  - Ceph's custom object classes (read/write)
  - Ceph's local indexing mechanism (RocksDB)

Thank You

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- Center for Research in Open Source Software

More info:

- https://cross.ucsc.edu
- SkyhookDM.com

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