# Data Context and Sharded Data

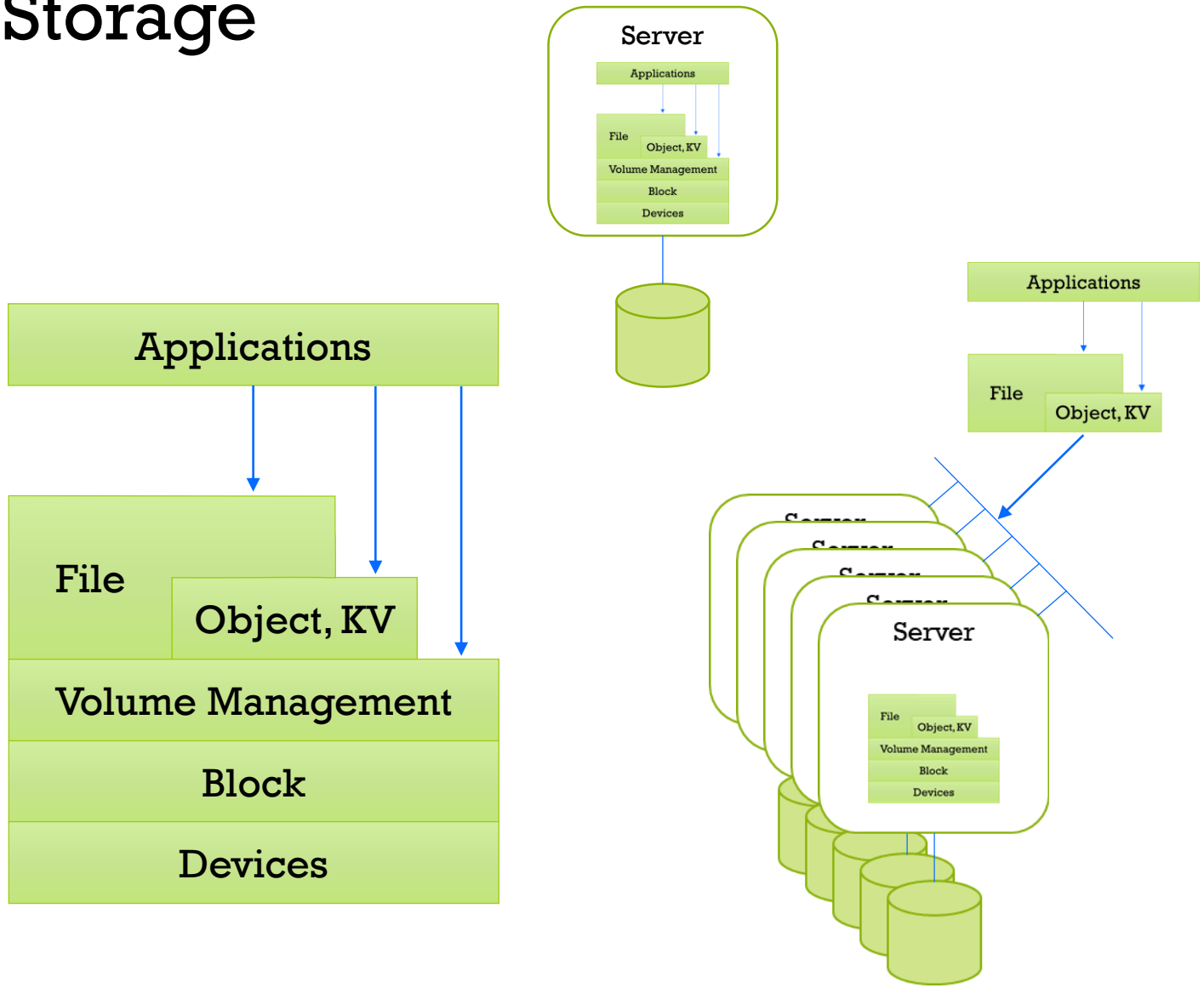
EC for HDD Computational Storage

# Agenda

- Foundational Concepts
  - Storage Stack
  - Data Availability Strategies
  - Computational Storage and Functions
- Importance of Context in Sharded Data
- Research

# Storage Stack Virtualizes Storage

- Application data traverses through a complicated storage stack on its way to persistent storage
- The stack can be on a single server or distributed across a network of server
- At the physical storage device data can be unrecognizable
  - Sliced, copied, encoded, compressed, tiered and distributed
  - Application is ignorant of this
  - Software stack inherently provides information hiding



# Data Availability

## Mirroring

- Full copies made
- Application Data context at the device is maintained

## Encoding

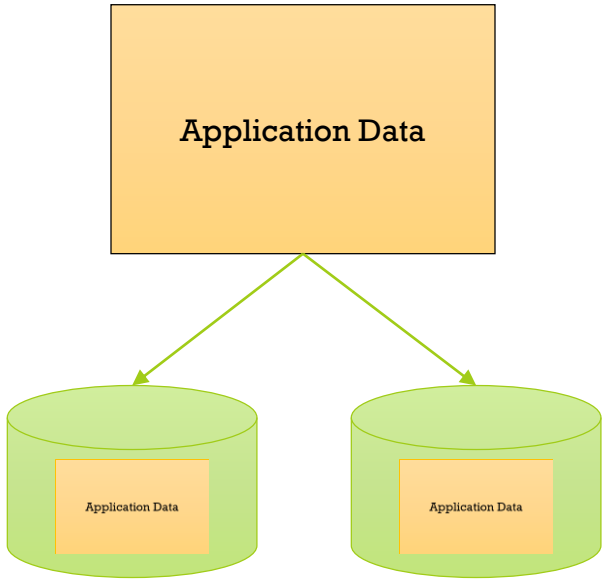
- Data is partitioned, encoded and stored on different devices
- Full copies not needed to protect data
- Application Data context at the device is lost

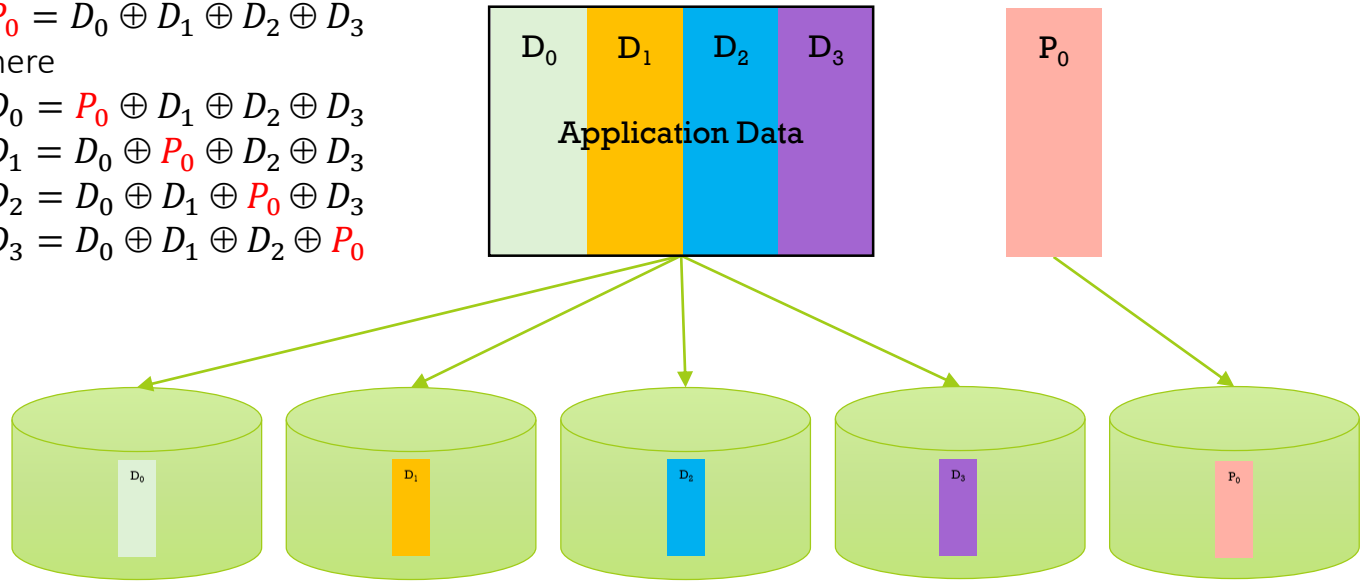
Calculate

$$P_0 = D_0 \oplus D_1 \oplus D_2 \oplus D_3$$

where

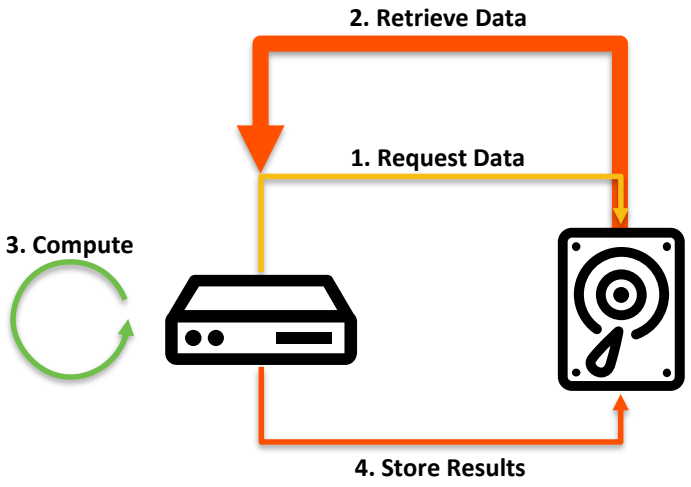
$$D_0 = P_0 \oplus D_1 \oplus D_2 \oplus D_3$$
$$D_1 = D_0 \oplus P_0 \oplus D_2 \oplus D_3$$
$$D_2 = D_0 \oplus D_1 \oplus P_0 \oplus D_3$$
$$D_3 = D_0 \oplus D_1 \oplus D_2 \oplus P_0$$



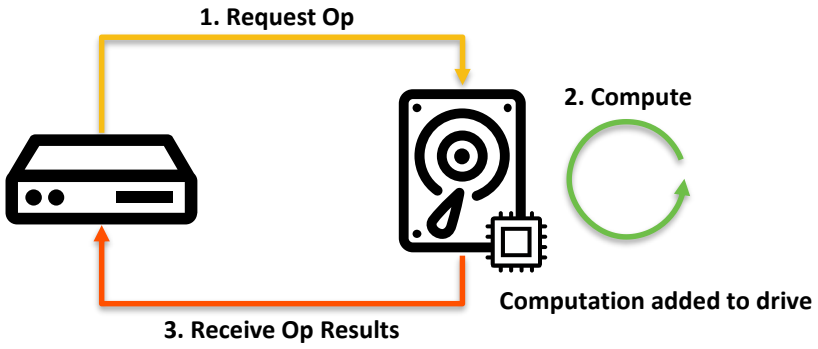
# Computational Storage

- Data analysis requires moving data from storage to the compute
  - Compute requests the data to be transferred
  - Data is transferred from the storage
  - Analysis is performed
  - Results are stored




Standard Storage

- When datasets become large it can be easier to move the compute to the data in the storage
  - Compute requests a computation storage function be executed against the data
  - Results are returned
  - Large transfers are avoided




Computational Storage

# Computational Storage Functions

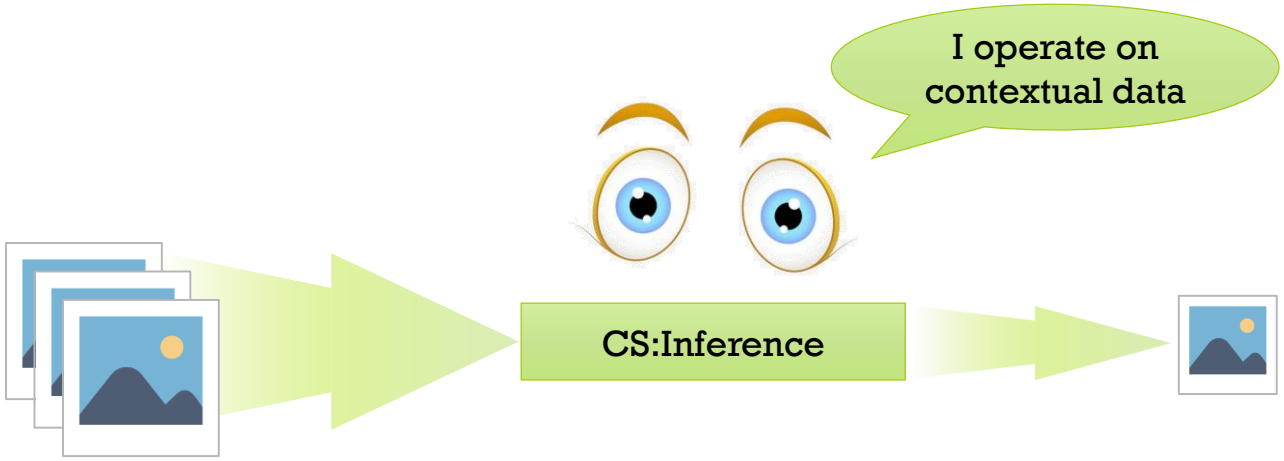
- Two strategies for Computational Storage functions

## Data in the Dark

- CS Functions have NO encoded knowledge of the data layout
- Data is just a byte stream, can be arbitrarily cut into pieces
- Ex: Compression, encryption, dedup, simple byte searches, etc
- Most CS solutions are this type, require simpler runtime

## Data in the Light

- CS Functions REQUIRE encoded knowledge of the data layout
- Data has context, organization, requires metadata
- Data can NOT be arbitrarily cut into pieces
- Ex: Data queries, image inference, data analysis, etc.
- Requires more complex runtime, like containers



# Data Reliability and Computational Storage Functions

- Two Strategies for Data Reliability
  - Data Mirroring
    - Units of user data remain intact, but copied across storage resources
    - Can easily be used for both Data in the Dark and **Data in the Light** computational storage functions
  - Encoding
    - Units of user data are arbitrarily cut into pieces and distributed across storage resources
    - Semantic meaning or context of the data is lost
    - Can be used for Data in the Dark computational storage functions
    - Nobody has yet shown any solution for eraser coding using **Data in the Light** computational storage functions

# Erasure Coding Problem - Deep dive

**Data in the Light**

Sample Dataset in memory

Data

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ | $C_{17}$ | $C_{18}$ | $C_{19}$ | $C_{20}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{25}$ | ... | $C_{n-4}$ | $C_{n-3}$ | $C_{n-2}$ | $C_{n-1}$ | $C_n$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_1$ | 25 | 56 | 16 | 71 | 10 | 66 | 65 | 73 | 57 | 57 | 51 | 0 | 48 | 64 | 10 | 93 | 29 | 86 | 60 | 64 | 24 | 93 | 2 | 4 | 49 | | 46 | 35 | 73 | 89 | 49 |
| $R_2$ | 49 | 63 | 85 | 33 | 45 | 94 | 74 | 19 | 59 | 47 | 29 | 97 | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | | 99 | 28 | 37 | 60 | 49 |
| $R_3$ | 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | | 58 | 43 | 36 | 52 | 90 |
| $R_4$ | 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | | 41 | 38 | 97 | 74 | 96 |
| $R_5$ | 66 | 23 | 83 | 56 | 52 | 99 | 11 | 96 | 26 | 50 | 79 | 12 | 14 | 75 | 44 | 92 | 2 | 41 | 84 | 94 | 3 | 57 | 95 | 47 | 18 | | 18 | 65 | 62 | 69 | 11 |
| $R_6$ | 60 | 0 | 99 | 35 | 65 | 27 | 2 | 1 | 84 | 41 | 59 | 28 | 9 | 14 | 59 | 23 | 50 | 38 | 23 | 63 | 20 | 10 | 81 | 65 | 18 | | 56 | 37 | 39 | 42 | 2 |
| ⋮ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| $R_{m-4}$ | 40 | 56 | 25 | 69 | 4 | 85 | 93 | 45 | 12 | 31 | 36 | 96 | 88 | 39 | 67 | 10 | 88 | 66 | 93 | 83 | 6 | 38 | 44 | 47 | 16 | | 91 | 29 | 36 | 14 | 40 |
| $R_{m-3}$ | 12 | 76 | 96 | 31 | 1 | 1 | 57 | 13 | 60 | 34 | 93 | 22 | 92 | 50 | 93 | 62 | 37 | 68 | 54 | 89 | 83 | 71 | 63 | 2 | 24 | | 24 | 88 | 46 | 4 | 22 |
| $R_{m-2}$ | 28 | 2 | 77 | 37 | 2 | 0 | 78 | 49 | 4 | 53 | 84 | 75 | 2 | 47 | 6 | 5 | 49 | 86 | 28 | 75 | 17 | 81 | 0 | 87 | 17 | | 38 | 26 | 80 | 58 | 50 |
| $R_{m-1}$ | 3 | 20 | 58 | 45 | 56 | 89 | 99 | 27 | 3 | 26 | 20 | 58 | 68 | 77 | 45 | 39 | 28 | 28 | 17 | 97 | 24 | 34 | 20 | 74 | 57 | | 33 | 31 | 59 | 40 | 55 |
| $R_m$ | 29 | 68 | 50 | 94 | 92 | 9 | 48 | 59 | 45 | 68 | 41 | 7 | 25 | 13 | 70 | 17 | 34 | 96 | 8 | 91 | 97 | 6 | 20 | 68 | 45 | | 70 | 12 | 57 | 91 | 35 |

# Erasure Coding Problem - Deep Dive

**Data in the Light**

## Sample Dataset in memory

| Metadata | |
|---|---|
| Dimensions | |
| Columns | n |
| Rows | m |
| Format | RowOrder |
| Column Names | |
| $C_1$ | 'Characteristic1' |
| $C_2$ | 'Characteristic2' |
| $C_3$ | 'Characteristic3' |
| ... | |
| $C_n$ | 'CharacteristicN' |
| Row Names | |
| $R_1$ | 'Particle1' |
| $R_2$ | 'Particle2' |
| $R_3$ | 'Particle3' |
| ... | |
| $R_m$ | 'ParticleM' |

Data

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ | $C_{17}$ | $C_{18}$ | $C_{19}$ | $C_{20}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{25}$ | ... | $C_{n-4}$ | $C_{n-3}$ | $C_{n-2}$ | $C_{n-1}$ | $C_n$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_1$ | 25 | 56 | 16 | 71 | 10 | 66 | 65 | 73 | 57 | 57 | 51 | 0 | 48 | 64 | 10 | 93 | 29 | 86 | 60 | 64 | 24 | 93 | 2 | 4 | 49 | | 46 | 35 | 73 | 89 | 49 |
| $R_2$ | 49 | 63 | 85 | 33 | 45 | 94 | 74 | 19 | 59 | 47 | 29 | 97 | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | | 99 | 28 | 37 | 60 | 49 |
| $R_3$ | 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | | 58 | 43 | 36 | 52 | 90 |
| $R_4$ | 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | | 41 | 38 | 97 | 74 | 96 |
| $R_5$ | 66 | 23 | 83 | 56 | 52 | 99 | 11 | 96 | 26 | 50 | 79 | 12 | 14 | 75 | 44 | 92 | 2 | 41 | 84 | 94 | 3 | 57 | 95 | 47 | 18 | | 18 | 65 | 62 | 69 | 11 |
| $R_6$ | 60 | 0 | 99 | 35 | 65 | 27 | 2 | 1 | 84 | 41 | 59 | 28 | 9 | 14 | 59 | 23 | 50 | 38 | 23 | 63 | 20 | 10 | 81 | 65 | 18 | | 56 | 37 | 39 | 42 | 2 |
| ⋮ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| $R_{m-4}$ | 40 | 56 | 25 | 69 | 4 | 85 | 93 | 45 | 12 | 31 | 36 | 96 | 88 | 39 | 67 | 10 | 88 | 66 | 93 | 83 | 6 | 38 | 44 | 47 | 16 | | 91 | 29 | 36 | 14 | 40 |
| $R_{m-3}$ | 12 | 76 | 96 | 31 | 1 | 1 | 57 | 13 | 60 | 34 | 93 | 22 | 92 | 50 | 93 | 62 | 37 | 68 | 54 | 89 | 83 | 71 | 63 | 2 | 24 | | 24 | 88 | 46 | 4 | 22 |
| $R_{m-2}$ | 28 | 2 | 77 | 37 | 2 | 0 | 78 | 49 | 4 | 53 | 84 | 75 | 2 | 47 | 6 | 5 | 49 | 86 | 28 | 75 | 17 | 81 | 0 | 87 | 17 | | 38 | 26 | 80 | 58 | 50 |
| $R_{m-1}$ | 3 | 20 | 58 | 45 | 56 | 89 | 99 | 27 | 3 | 26 | 20 | 58 | 68 | 77 | 45 | 39 | 28 | 28 | 17 | 97 | 24 | 34 | 20 | 74 | 57 | | 33 | 31 | 59 | 40 | 55 |
| $R_m$ | 29 | 68 | 50 | 94 | 92 | 9 | 48 | 59 | 45 | 68 | 41 | 7 | 25 | 13 | 70 | 17 | 34 | 96 | 8 | 91 | 97 | 6 | 20 | 68 | 45 | | 70 | 12 | 57 | 91 | 35 |

# Erasure Coding Problem - Deep Dive

**Data in the Light**

Questions you might ask the Dataset in memory

| Metadata | |
|---|---|
| Dimensions | |
| Columns | n |
| Rows | m |
| Format | RowOrder |
| Column Names | |
| $C_1$ | 'Characteristic1' |
| $C_2$ | 'Characteristic2' |
| $C_3$ | 'Characteristic3' |
| ... | |
| $C_n$ | 'CharacteristicN' |
| Row Names | |
| $R_1$ | 'Particle1' |
| $R_2$ | 'Particle2' |
| $R_3$ | 'Particle3' |
| ... | |
| $R_m$ | 'ParticleM' |

Data

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ | $C_{17}$ | $C_{18}$ | $C_{19}$ | $C_{20}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{25}$ | ... | $C_{n-4}$ | $C_{n-3}$ | $C_{n-2}$ | $C_{n-1}$ | $C_n$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_1$ | 25 | 56 | 16 | 71 | 10 | 66 | 65 | 73 | 57 | 57 | 51 | 0 | 48 | 64 | 10 | 93 | 29 | 86 | 60 | 64 | 24 | 93 | 2 | 4 | 49 | | 46 | 35 | 73 | 89 | 49 |
| $R_2$ | 49 | 63 | 85 | 33 | 45 | 94 | 74 | 19 | 59 | 47 | 29 | 97 | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | | 99 | 28 | 37 | 60 | 49 |
| $R_3$ | 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | | 58 | 43 | 36 | 52 | 90 |
| $R_4$ | 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | | 41 | 38 | 97 | 74 | 96 |
| $R_5$ | 66 | 23 | 83 | 56 | 52 | 99 | 11 | 96 | 26 | 50 | **79** | 12 | 14 | 75 | 44 | 92 | 2 | 41 | 84 | 94 | 3 | 57 | 95 | 47 | 18 | | 18 | 65 | 62 | 69 | 11 |
| $R_6$ | 60 | 0 | 99 | 35 | 65 | 27 | 2 | 1 | 84 | 41 | **59** | 28 | 9 | 14 | 59 | 23 | 50 | 38 | 23 | 63 | 20 | 10 | 81 | 65 | 18 | | 56 | 37 | 39 | 42 | 2 |
| ⋮ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| $R_{m-4}$ | 40 | 56 | 25 | 69 | 4 | 85 | 93 | 45 | 12 | 31 | 36 | 96 | 88 | 39 | 67 | 10 | 88 | 66 | 93 | 83 | 6 | 38 | 44 | 47 | 16 | | 91 | 29 | 36 | 14 | 40 |
| $R_{m-3}$ | 12 | 76 | 96 | 31 | 1 | 1 | 57 | 13 | 60 | 34 | **93** | 22 | 92 | 50 | 93 | 62 | 37 | 68 | 54 | 89 | 83 | 71 | 63 | 2 | 24 | | 24 | 88 | 46 | 4 | 22 |
| $R_{m-2}$ | 28 | 2 | 77 | 37 | 2 | 0 | 78 | 49 | 4 | 53 | **84** | 75 | 2 | 47 | 6 | 5 | 49 | 86 | 28 | 75 | 17 | 81 | 0 | 87 | 17 | | 38 | 26 | 80 | 58 | 50 |
| $R_{m-1}$ | 3 | 20 | 58 | 45 | 56 | 89 | 99 | 27 | 3 | 26 | 20 | 58 | 68 | 77 | 45 | 39 | 28 | 28 | 17 | 97 | 24 | 34 | 20 | 74 | 57 | | 33 | 31 | 59 | 40 | 55 |
| $R_m$ | 29 | 68 | 50 | 94 | 92 | 9 | 48 | 59 | 45 | 68 | 41 | 7 | 25 | 13 | 70 | 17 | 34 | 96 | 8 | 91 | 97 | 6 | 20 | 68 | 45 | | 70 | 12 | 57 | 91 | 35 |

**All particles where Characteristic11 > 57 = [Particle5, Particle6, …, ParticleM-3, ParticleM-4]**

# Erasure Coding Problem - Deep Dive

**Data in the Light**

File layout

File

Metadata

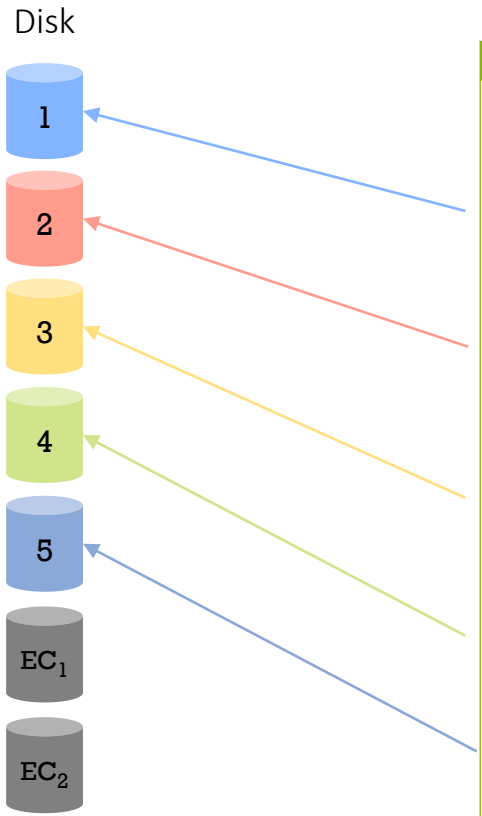
Data

| n | m | R | ‘Characteristic1’ | | | | ‘Characteristic2’ | | | | ‘Characteristic3’ | | | | … | ‘CharacteristicN’ | | | | ‘Particle1’ | | ‘Particle2’ | | ‘Particle3’ | | … | ‘ParticleM’ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 56 | 16 | 71 | 10 | 66 | 65 | 73 | 57 | 57 | 51 | 0 | 48 | 64 | 10 | 93 | 29 | 86 | 60 | 64 | 24 | 93 | 2 | 4 | 49 | 46 | 35 | 73 | 89 | 49 |
| 49 | 63 | 85 | 33 | 45 | 94 | 74 | 19 | 59 | 47 | 29 | 97 | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | 99 | 28 | 37 | 60 | 49 |
| 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | 58 | 43 | 36 | 52 | 90 |
| 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | 41 | 38 | 97 | 74 | 96 |
| 66 | 23 | 83 | 56 | 52 | 99 | 11 | 96 | 26 | 50 | 79 | 12 | 14 | 75 | 44 | 92 | 2 | 41 | 84 | 94 | 3 | 57 | 95 | 47 | 18 | 18 | 65 | 62 | 69 | 11 |
| 60 | 0 | 99 | 35 | 65 | 27 | 2 | 1 | 84 | 41 | 59 | 28 | 9 | 14 | 59 | 23 | 50 | 38 | 23 | 63 | 20 | 10 | 81 | 65 | 18 | 56 | 37 | 39 | 42 | 2 |
| 40 | 56 | 25 | 69 | 4 | 85 | 93 | 45 | 12 | 31 | 36 | 96 | 88 | 39 | 67 | 10 | 88 | 66 | 93 | 83 | 6 | 38 | 44 | 47 | 16 | 91 | 29 | 36 | 14 | 40 |
| 12 | 76 | 96 | 31 | 1 | 1 | 57 | 13 | 60 | 34 | 93 | 22 | 92 | 50 | 93 | 62 | 37 | 68 | 54 | 89 | 83 | 71 | 63 | 2 | 24 | 24 | 88 | 46 | 4 | 22 |
| 28 | 2 | 77 | 37 | 2 | 0 | 78 | 49 | 4 | 53 | 84 | 75 | 2 | 47 | 6 | 5 | 49 | 86 | 28 | 75 | 17 | 81 | 0 | 87 | 17 | 38 | 26 | 80 | 58 | 50 |
| 3 | 20 | 58 | 45 | 56 | 89 | 99 | 27 | 3 | 26 | 20 | 58 | 68 | 77 | 45 | 39 | 28 | 28 | 17 | 97 | 24 | 34 | 20 | 74 | 57 | 33 | 31 | 59 | 40 | 55 |
| 29 | 68 | 50 | 94 | 92 | 9 | 48 | 59 | 45 | 68 | 41 | 7 | 25 | 13 | 70 | 17 | 34 | 96 | 8 | 91 | 97 | 6 | 20 | 68 | 45 | 70 | 12 | 57 | 91 | 35 |

# Erasure Coding Problem - Deep Dive

**Data in the Light**

## Ondisk Erasure Encoded layout 5+2




File

| n | m | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle1' | | 'Particle2' | | 'Particle3' | | ... | 'ParticleM' | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 56 | 16 | 71 | 10 | 66 | 65 | 73 | 57 | 57 | 51 | 0 | 48 | 64 | 10 | 93 | 29 | 86 | 60 | 64 | 24 | 93 | 2 | 4 | 49 | 46 | 35 | 73 | 89 | 49 |
| 49 | 63 | 85 | 33 | 45 | 94 | 74 | 19 | 59 | 47 | 29 | 97 | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | 99 | 28 | 37 | 60 | 49 |
| 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | 58 | 43 | 36 | 52 | 90 |
| 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | 41 | 38 | 97 | 74 | 96 |
| 66 | 23 | 83 | 56 | 52 | 99 | 11 | 96 | 26 | 50 | 79 | 12 | 14 | 75 | 44 | 92 | 2 | 41 | 84 | 94 | 3 | 57 | 95 | 47 | 18 | 18 | 65 | 62 | 69 | 11 |
| 60 | 0 | 99 | 35 | 65 | 27 | 2 | 1 | 84 | 41 | 59 | 28 | 9 | 14 | 59 | 23 | 50 | 38 | 23 | 63 | 20 | 10 | 81 | 65 | 18 | 56 | 37 | 39 | 42 | 2 |
| 40 | 56 | 25 | 69 | 4 | 85 | 93 | 45 | 12 | 31 | 36 | 96 | 88 | 39 | 67 | 10 | 88 | 66 | 93 | 83 | 6 | 38 | 44 | 47 | 16 | 91 | 29 | 36 | 14 | 40 |
| 12 | 76 | 96 | 31 | 1 | 1 | 57 | 13 | 60 | 34 | 93 | 22 | 92 | 50 | 93 | 62 | 37 | 68 | 54 | 89 | 83 | 71 | 63 | 2 | 24 | 24 | 88 | 46 | 4 | 22 |
| 28 | 2 | 77 | 37 | 2 | 0 | 78 | 49 | 4 | 53 | 84 | 75 | 2 | 47 | 6 | 5 | 49 | 86 | 28 | 75 | 17 | 81 | 0 | 87 | 17 | 38 | 26 | 80 | 58 | 50 |
| 3 | 20 | 58 | 45 | 56 | 89 | 99 | 27 | 3 | 26 | 20 | 58 | 68 | 77 | 45 | 39 | 28 | 28 | 17 | 97 | 24 | 34 | 20 | 74 | 57 | 33 | 31 | 59 | 40 | 55 |
| 29 | 68 | 50 | 94 | 92 | 9 | 48 | 59 | 45 | 68 | 41 | 7 | 25 | 13 | 70 | 17 | 34 | 96 | 8 | 91 | 97 | 6 | 20 | 68 | 45 | 70 | 12 | 57 | 91 | 35 |

# Erasure Coding Problem - Deep Dive

**Data in the Light**

## Computational Storage EC Problem

Disk

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | 99 | 28 | 37 | 60 | 49 |
| 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | 58 | 43 | 36 | 52 | 90 |
| 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | | | | | | |

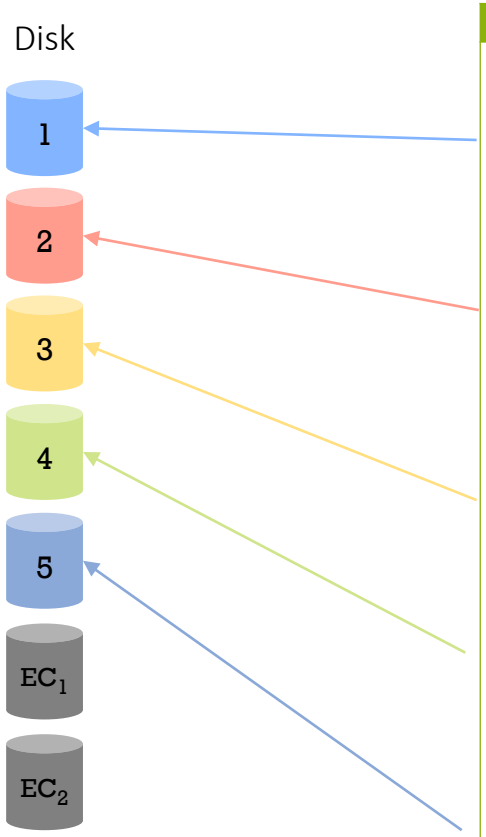
Semantically uninteresting

- There is no context to the data
- Just random data
- Question cannot be answered
  - All particles where Characteristic11 > 57

# Erasure Coding Problem - Deep Dive

**Data in the Light**

Ondisk Erasure Encoded layout 5+2 PLUS Row Groups




File

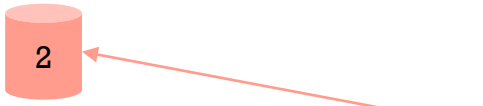
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $n_1$ | $m_1$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle1' | | 'Particle2' | | ... | | | | | | |
| 25 | 56 | 16 | 71 | 10 | 66 | 65 | 73 | 57 | 57 | 51 | 0 | 48 | 64 | 10 | 93 | 29 | 86 | 60 | 64 | 24 | 93 | 2 | 4 | 49 | 46 | 35 | 73 | 89 | 49 | |
| 49 | 63 | 85 | 33 | 45 | 94 | 74 | 19 | 59 | 47 | 29 | 97 | 61 | 3 | 54 | 75 | 55 | 96 | 3 | 45 | 85 | 56 | 40 | 28 | 19 | 99 | 28 | 37 | 60 | 49 | |
| $n_2$ | $m_2$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle3' | | 'Particle4' | | ... | | | | | | |
| 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | 58 | 43 | 36 | 52 | 90 | |
| 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | 41 | 38 | 97 | 74 | 96 | |
| $n_3$ | $m_3$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle5' | | 'Particle6' | | ... | | | | | | |
| 66 | 23 | 83 | 56 | 52 | 99 | 11 | 96 | 26 | 50 | 79 | 12 | 14 | 75 | 44 | 92 | 2 | 41 | 84 | 94 | 3 | 57 | 95 | 47 | 18 | 18 | 65 | 62 | 69 | 11 | |
| 60 | 0 | 99 | 35 | 65 | 27 | 2 | 1 | 84 | 41 | 59 | 28 | 9 | 14 | 59 | 23 | 50 | 38 | 23 | 63 | 20 | 10 | 81 | 65 | 18 | 56 | 37 | 39 | 42 | 2 | |
| $n_4$ | $m_4$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle7' | | 'Particle8' | | ... | | | | | | |
| 40 | 56 | 25 | 69 | 4 | 85 | 93 | 45 | 12 | 31 | 36 | 96 | 88 | 39 | 67 | 10 | 88 | 66 | 93 | 83 | 6 | 38 | 44 | 47 | 16 | 91 | 29 | 36 | 14 | 40 | |
| 12 | 76 | 96 | 31 | 1 | 1 | 57 | 13 | 60 | 34 | 93 | 22 | 92 | 50 | 93 | 62 | 37 | 68 | 54 | 89 | 83 | 71 | 63 | 2 | 24 | 24 | 88 | 46 | 4 | 22 | |
| $n_5$ | $m_5$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle9' | | 'Particle10' | | ... | | | | | | |
| 28 | 2 | 77 | 37 | 2 | 0 | 78 | 49 | 4 | 53 | 84 | 75 | 2 | 47 | 6 | 5 | 49 | 86 | 28 | 75 | 17 | 81 | 0 | 87 | 17 | 38 | 26 | 80 | 58 | 50 | |
| 3 | 20 | 58 | 45 | 56 | 89 | 99 | 27 | 3 | 26 | 20 | 58 | 68 | 77 | 45 | 39 | 28 | 28 | 17 | 97 | 24 | 34 | 20 | 74 | 57 | 33 | 31 | 59 | 40 | 55 | |

# Erasure Coding Problem - Deep Dive

**Data in the Light**

## Computational Storage EC Problem Now

Disk




| $n_2$ | $m_2$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | … | 'CharacteristicN' | | | | 'Particle3' | | 'Particle4' | | | … | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | 58 | 43 | 36 | 52 | 90 |
| 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | 41 | 38 | 97 | 74 | 96 |

Semantically interesting

- Can reconstitute the row group in memory
- Question CAN be answered for this row group
  - All particles where Characteristic11 > 57 = [empty set]

# Erasure Coding Problem - Deep Dive

**Data in the Light**

## Computational Storage EC Problem Now

2

| $n_2$ | $m_2$ | R | 'Characteristic1' | | | | 'Characteristic2' | | | | 'Characteristic3' | | | | ... | 'CharacteristicN' | | | | 'Particle3' | | 'Particle4' | | ... | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 | 58 | 43 | 36 | 52 | 90 |
| 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 | 41 | 38 | 97 | 74 | 96 |

| Metadata | |
|---|---|
| Dimensions | |
| Columns | $n_2$ |
| Rows | $m_2$ |
| Format | RowOrder |
| Column Names | |
| $C_1$ | 'Characteristic1' |
| $C_2$ | 'Characteristic2' |
| $C_3$ | 'Characteristic3' |
| ... | |
| $C_n$ | 'CharacteristicN' |
| Row Names | |
| $R_3$ | 'Particle3' |
| $R_v$ | 'Particle4' |

Semantically interesting

- Can reconstitute the row group in memory
- Question CAN be answered for this row group
  - All particles where Characteristic11 > 57 = [empty set]

Row Group

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ | $C_{17}$ | $C_{18}$ | $C_{19}$ | $C_{20}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{25}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_3$ | 49 | 91 | 29 | 14 | 12 | 50 | 24 | 7 | 41 | 10 | 39 | 76 | 67 | 57 | 20 | 33 | 0 | 7 | 82 | 92 | 36 | 21 | 67 | 50 | 96 |
| $R_4$ | 20 | 17 | 32 | 56 | 76 | 51 | 92 | 58 | 49 | 75 | 19 | 53 | 39 | 59 | 28 | 10 | 48 | 59 | 89 | 55 | 41 | 75 | 4 | 58 | 46 |

| $C_{n-4}$ | $C_{n-3}$ | $C_{n-2}$ | $C_{n-1}$ | $C_n$ |
|---|---|---|---|---|
| 58 | 43 | 36 | 52 | 90 |
| 41 | 38 | 97 | 74 | 96 |

# Research

- Methods for application data sharding while maintaining context
- Methods for understanding the storage virtualization at the application layer
  - Final per device shard size
  - Storage stack mapping mechanisms