Distributed Array Library

Concurrent and Distributed Processing

CC4P1 Concurrent and Distributed Programming

André Pacheco, Arbues Perez, Sergio Pezo

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Agenda

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- Project Goal
- Architecture and Design
- Implementation
- Communication Protocol
- Operation Examples
- Replication and Recovery
- Fault Tolerance
- Demonstration
- Conclusions

Project Goal

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Develop a distributed library

- Distributed arrays: `DArrayInt` and `DArrayDouble`

Project Goal

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- Concurrent and parallel processing

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- No external frameworks

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- Basic fault tolerance

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- Distributed arrays: `DArrayInt` and `DArrayDouble`
- Concurrent and parallel processing
- Communication via native TCP sockets
- No external frameworks
- Basic fault tolerance

Implementations

- Java 8+
- Python 3.6+
- TypeScript (Client)

System Architecture

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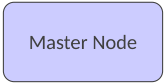

System Architecture

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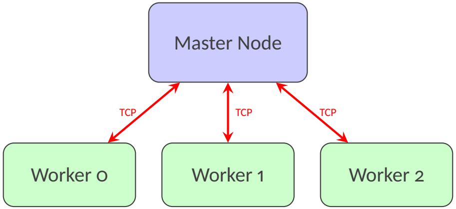

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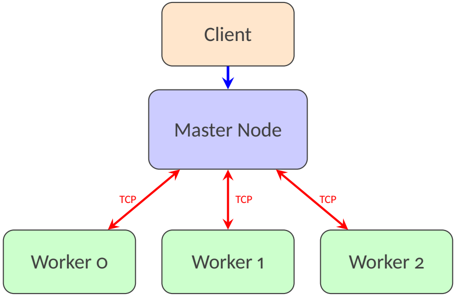

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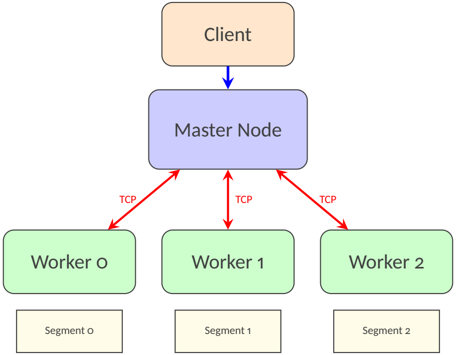

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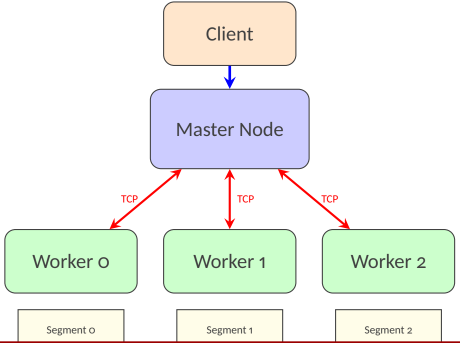

Features

- Master-worker architecture
- Automatic data distribution
- Bidirectional communication

Implementation - Structure

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Java	Python / TypeScript
• `MasterNode.java`	• `master_node.py`

Implementation - Structure

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Java

- `MasterNode.java`
- `WorkerNode.java`

Python / TypeScript

- `master_node.py`
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Implementation - Structure

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Java

- `MasterNode.java`
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- `DArrayInt.java`
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Python / TypeScript

- `master_node.py`
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- `MasterNode.java`
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- `MasterNode.java`
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- `DistributedArrayClient.java`

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Array Segmentation

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Original Array (10,000 elements)

Array Segmentation

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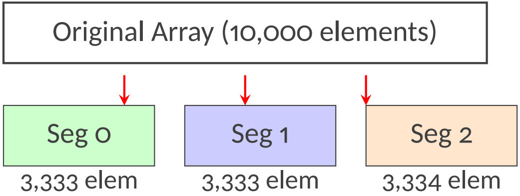

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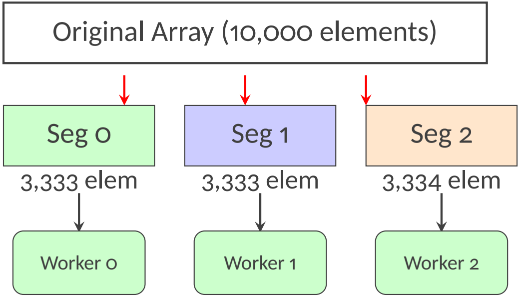

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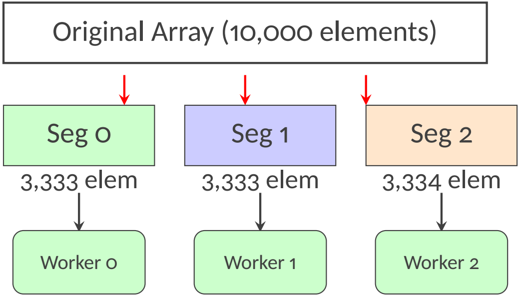

Segmentation Algorithm

- Equal division: $\frac{\text{total}}{\text{workers}}$
- Distributed remainder handling
- Round-robin assignment

Communication Protocol

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JSON Format

```
{
  type: MESSAGE_TYPE,
  from: NODE_ID,
  to: NODE_ID,
  timestamp: 1234567890,
  data: {},
  status: OK
}
```

Communication Protocol

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Message Types

- `REGISTER_WORKER` - Worker registration

Communication Protocol

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Message Types

- `REGISTER_WORKER` - Worker registration
- `DISTRIBUTE_ARRAY` - Segment distribution

Communication Protocol

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Message Types

- REGISTER_WORKER - Worker registration
- DISTRIBUTE_ARRAY - Segment distribution
- PROCESS_SEGMENT - Processing order

Communication Protocol

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- HEARTBEAT - Health check

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- DISTRIBUTE_ARRAY - Segment distribution
- PROCESS_SEGMENT - Processing order
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- REPLICATE_DATA - Segment replication
- RECOVER_DATA - Failure recovery

Parallel Processing

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Worker Node

Parallel Processing

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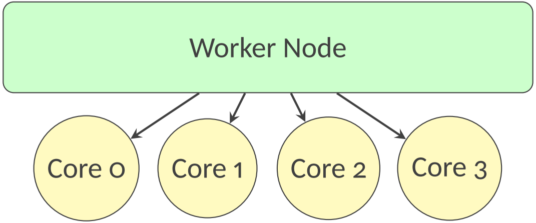

Parallel Processing

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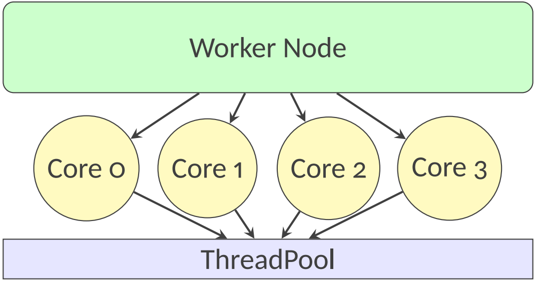

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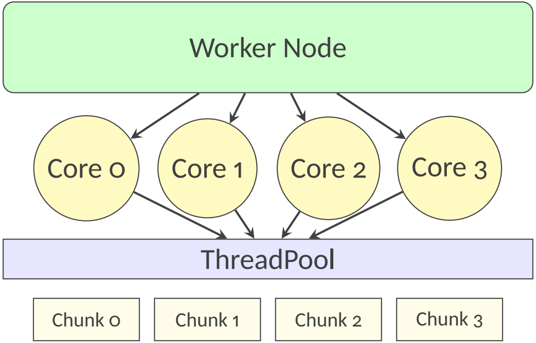

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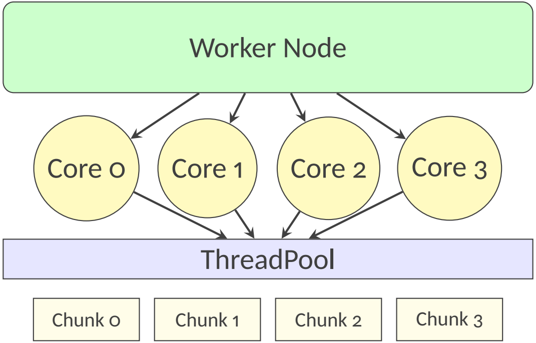

Strategy

- Automatic core detection: `Runtime.availableProcessors()`
- Division of the segment into chunks
- Concurrent processing with ThreadPool
- Synchronization using `Future<T>`

Example 1: Mathematical Operations

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Formula

$$\text{result} = \frac{(\sin(x) + \cos(x))^2}{\sqrt{|x|} + 1}$$

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Java Implementation

- Parallel processing with ThreadPool
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Java Implementation

- Parallel processing with ThreadPool
- Division of the segment into chunks
- Each thread processes its chunk independently

Python Implementation

- Use of ThreadPoolExecutor
- NumPy for vectorized operations
- Concurrent processing by chunks

Example 2: Conditional Evaluation

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Condition

If $x \bmod 3 = 0$ or $500 \leq x \leq 1000$:

$$\text{result} = (x \cdot \log(x)) \bmod 7$$

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- Application of logarithmic transformation
- Preservation of values that do not meet the condition

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- Conditional evaluation for each element
- Application of logarithmic transformation
- Preservation of values that do not meet the condition

Resilience

- Exception handling per thread
- Continuation in case of partial failures
- Consolidation of valid results

Data Replication

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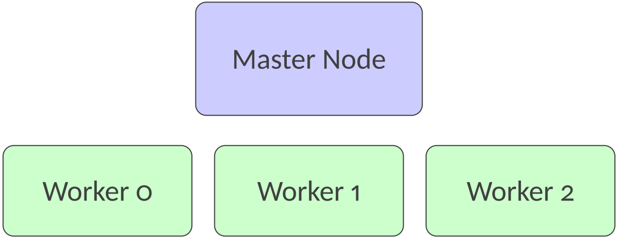

Data Replication

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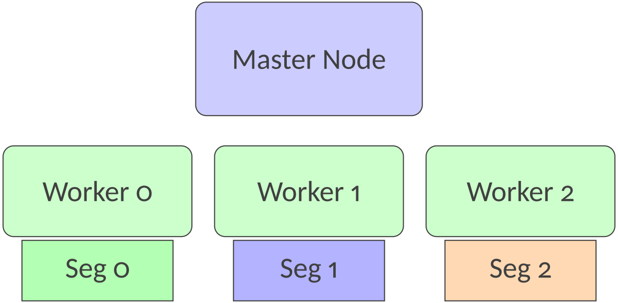

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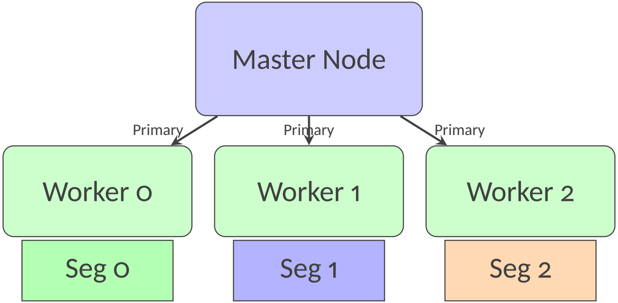

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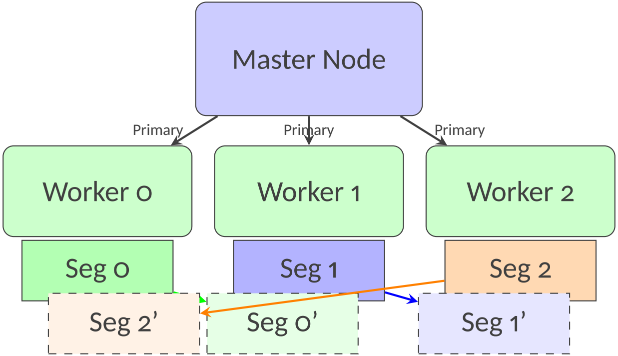

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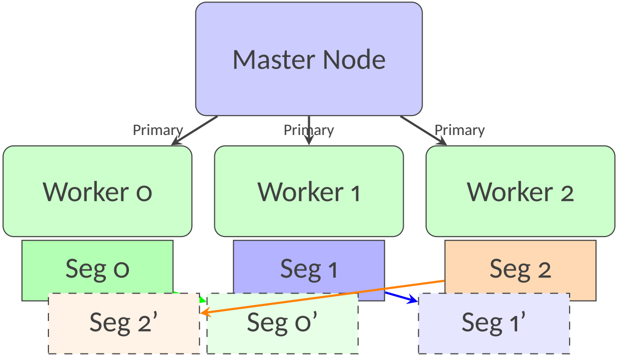

Replication factor = 2 (primary + 1 replica)

Recovery Mechanism

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Failure Detection

1. Heartbeat timeout (10s)

Recovery Mechanism

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Replica Promotion

1. Identify affected segments
2. Promote replicas to primary
3. Update segment mappings

Recovery Mechanism

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New Replica Creation

1. Select available workers
2. Replicate data from primary
3. Maintain replication factor

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Replica Promotion

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Redistribution

1. Balance load among workers
2. Avoid node overload
3. Optimize resource usage

Example 3: Fault Recovery

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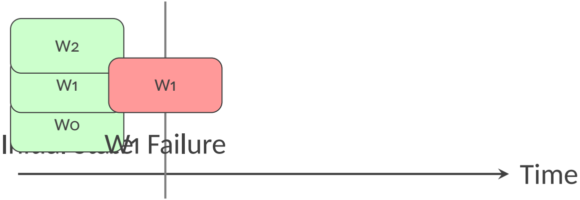

Example 3: Fault Recovery

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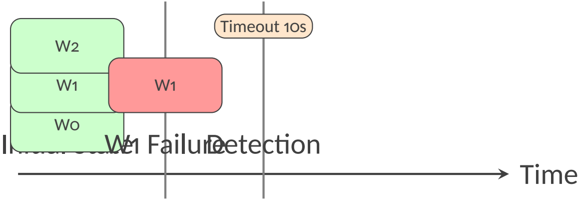

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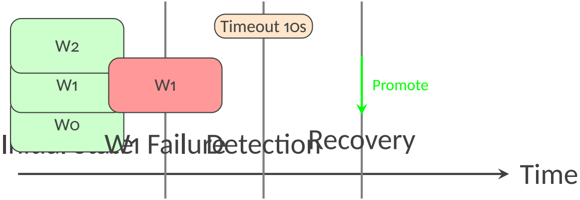

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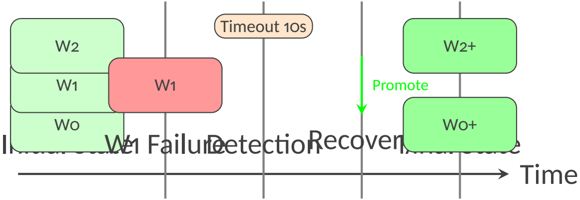

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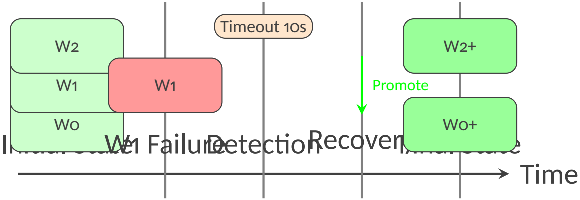

Automatic Process

- No data loss
- Service continuity
- Transparent to the client

Demonstration - Automatic Recovery

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```
$ ./test-recovery.sh
=== Distributed Array Recovery Test ===
Starting Master node on port 5000
Starting Worker-1
Starting Worker-2
Starting Worker-3

=== Creating distributed array ===
Create array response: {status:created,arrayId:myArray}
INFO: Replicated segment 0 to worker-2
INFO: Replicated segment 100 to worker-3
INFO: Replicated segment 200 to worker-1

=== Simulating Worker-2 failure ===
Worker-2 has been terminated!
WARNING: Worker worker-2 failed health check
ERROR: Handling failure of worker: worker-2
```

Fault Tolerance

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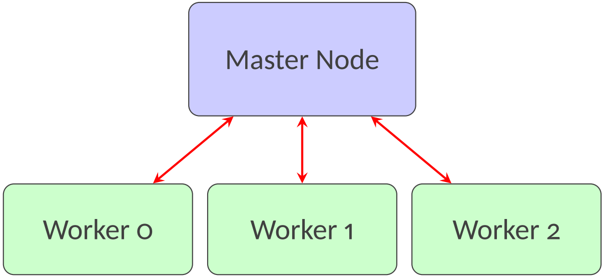

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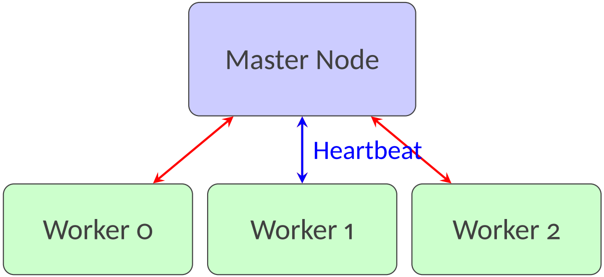

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Fault Tolerance

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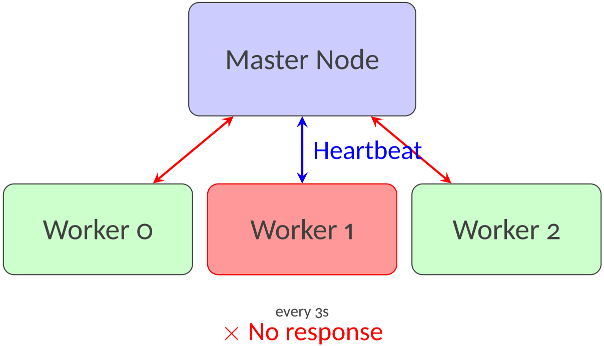

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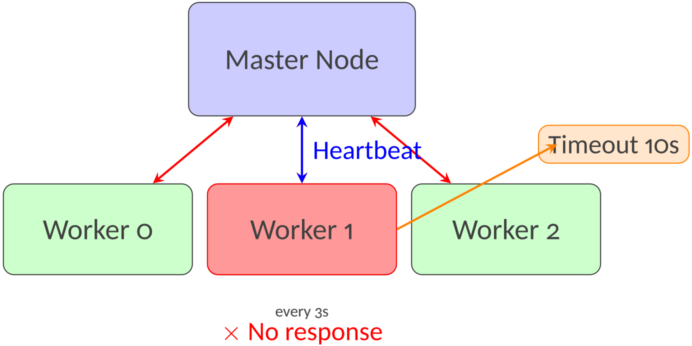

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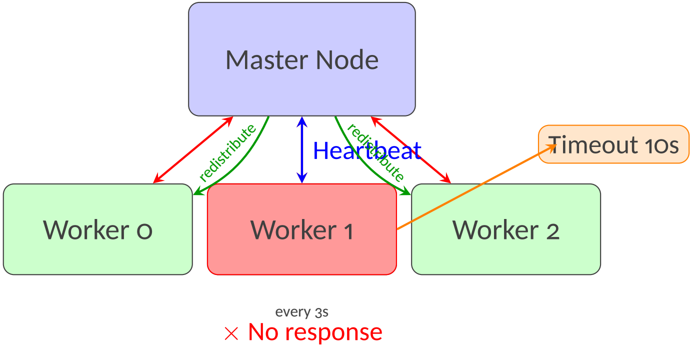

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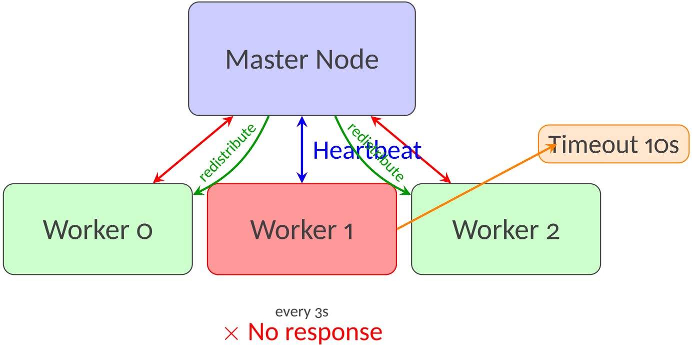

Fault Tolerance System

- Heartbeat: check every 3 seconds
- Detection: 10-second timeout
- Replication: factor 2 (primary + replica)

Demonstration - Cluster Start

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```
$ ./start-java-cluster.sh
Starting Java distributed array cluster...
Starting master node on port 5000...
Master node PID: 12345
Starting worker-0...
Worker-0 PID: 12346
Starting worker-1...
Worker-1 PID: 12347
Starting worker-2...
Worker-2 PID: 12348

Java cluster started successfully!
Master node running on port 5000
3 worker nodes connected
```

TypeScript Client

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Features

- Full client in TypeScript/Node.js

TypeScript Client

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Usage Example

```
$ npm start -- localhost 5000
Connected to master at localhost:5000
Enter commands (type help for usage, exit to quit):
> create-double ts-array 5000
Create array response: {status:created}
> apply ts-array example1
Apply operation response: {status:processing}
```

Demonstration - Interactive Client

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```
$ java -cp out:lib/* client.DistributedArrayClient localhost 5000
Connected to master at localhost:5000
Enter commands (type help for usage, exit to quit):
> create-double math-array 10000
Create array response: {type:OPERATION_COMPLETE,
  data:{arrayId:math-array,status:created}}

> apply math-array example1
Apply operation response: {type:OPERATION_COMPLETE,
  data:{status:processing}}

> get math-array
Get result response: {type:OPERATION_COMPLETE,
  data:{status:complete,result:Operation completed}}
```

System Logs

o

```
master.log
INFO: Master node started on port 5000
INFO: Worker registered: worker-0 from 127.0.0.1
INFO: Worker registered: worker-1 from 127.0.0.1
INFO: Worker registered: worker-2 from 127.0.0.1
INFO: Received array creation request: math-array (10000 elements)
INFO: Array segmented: 3 segments distributed
INFO: Processing operation: example1 on math-array

worker-0.log
INFO: Registered with master node
INFO: Received double array segment: math-array with 3333 elements
INFO: Processing Example 1 using 4 threads
INFO: Completed Example 1 processing for math-array
INFO: Sent result to master
```

Performance and Scalability

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Parallelization

- Use of all cores

Performance and Scalability

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- Efficient ThreadPool

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Metrics (10,000 elements)

- 1 worker: 250ms
- 2 workers: 140ms
- 3 workers: 95ms
- 4 workers: 75ms

Performance and Scalability

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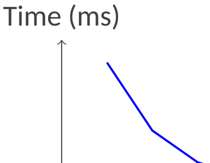

Conclusions

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Achievements

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- Interoperability between languages

Applications

- Large dataset processing
- Distributed scientific calculations
- Parallel data analysis

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Advanced Implemented Features

Questions

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Thank you for your attention

GitHub: `https://github.com/A-PachecoT/distributed-array-lib`