SynCron

Efficient Synchronization Support for Near-Data-Processing Architectures

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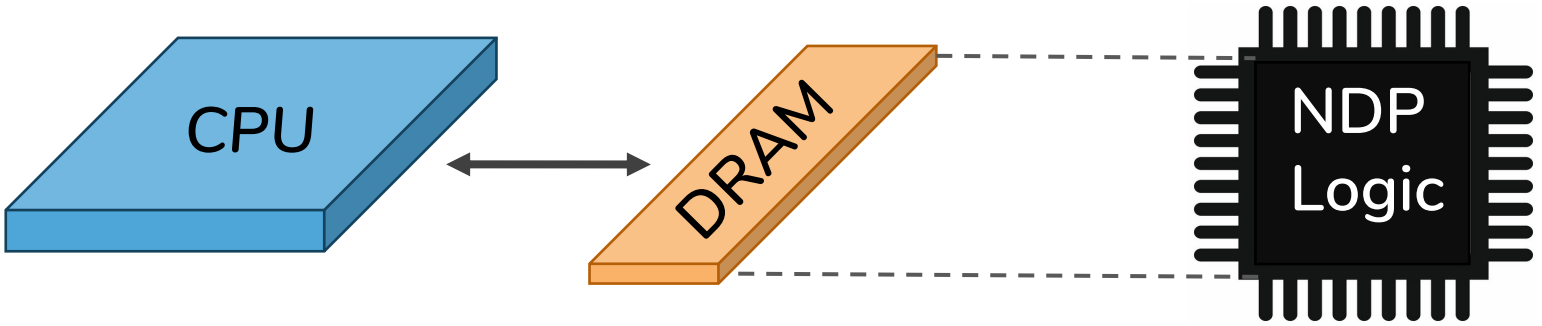
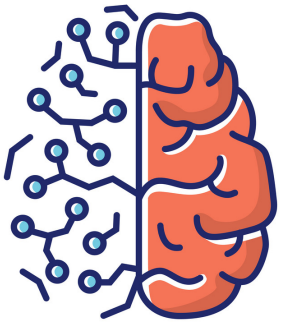
Near-Data-Processing (NDP) Systems

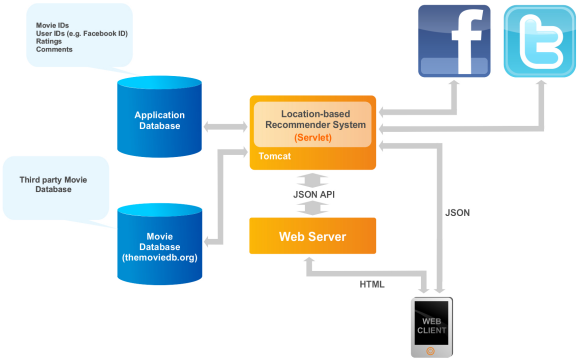


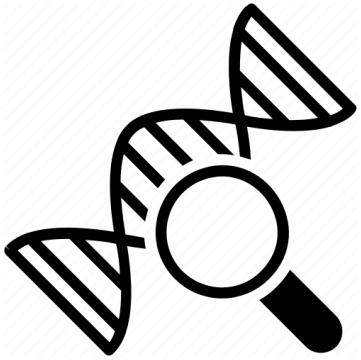
Graph Analytics



Neural Networks

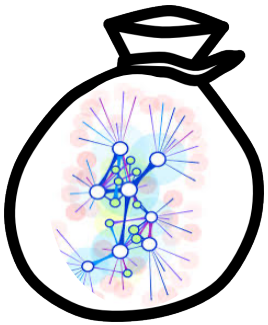
Recommendation Systems





Bioinformatics

Synchronization is Necessary

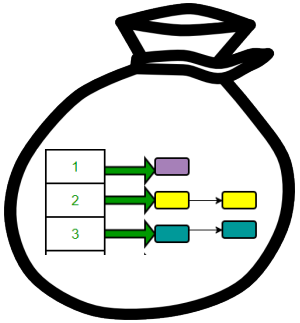


Graph Analytics

Bioinformatics

Databases

Image Processing



Concurrent Data Structures

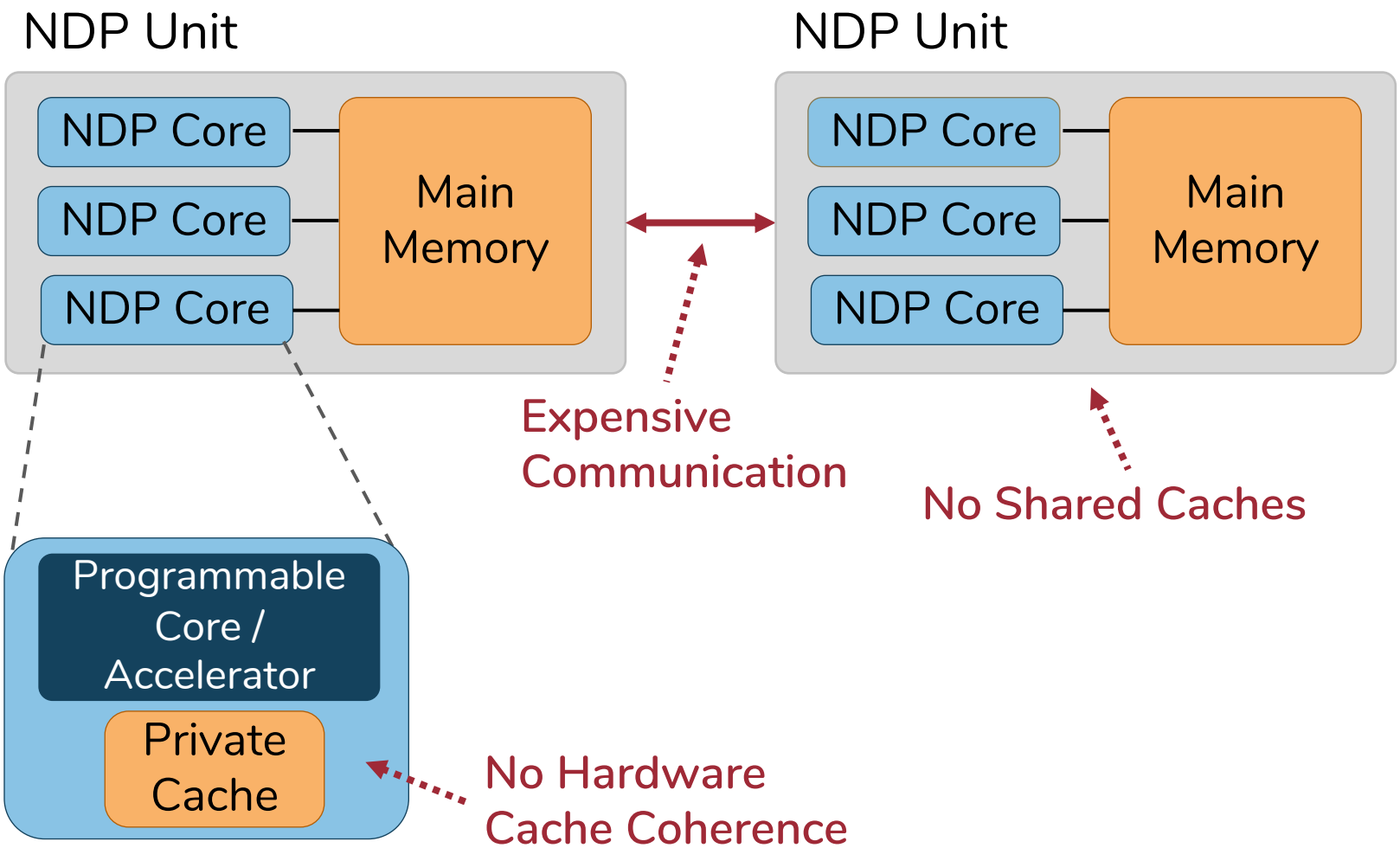
Single Source Shortest Path (SSSP)

Locks

Barriers

```
for v in Graph:
    for u in neighbors[v]:
        if distance[v] + edge_weight[v, u] < distance[u]
            lock_acquire(u)
            if distance[v] + edge_weight[v, u] < distance[u]
                distance[u] = distance[v] + edge_weight[v, u]
            lock_release(u)
```

Challenge: Efficient Synchronization



SynCron

The first end-to-end synchronization solution for NDP architectures

SynCron's Benefits:

1. High System Performance
2. Low Hardware Cost
3. Programming Ease
4. General Synchronization Support

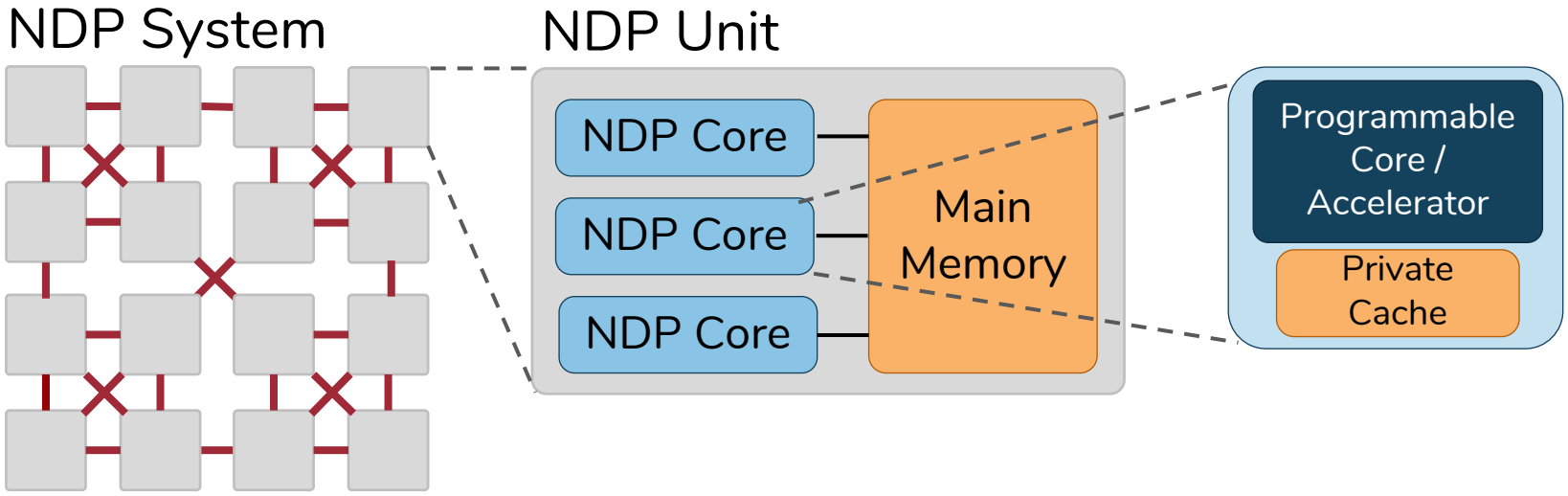
Outline

NDP Synchronization Solution Space

Our Mechanism: SynCron

Evaluation

Baseline NDP Architecture



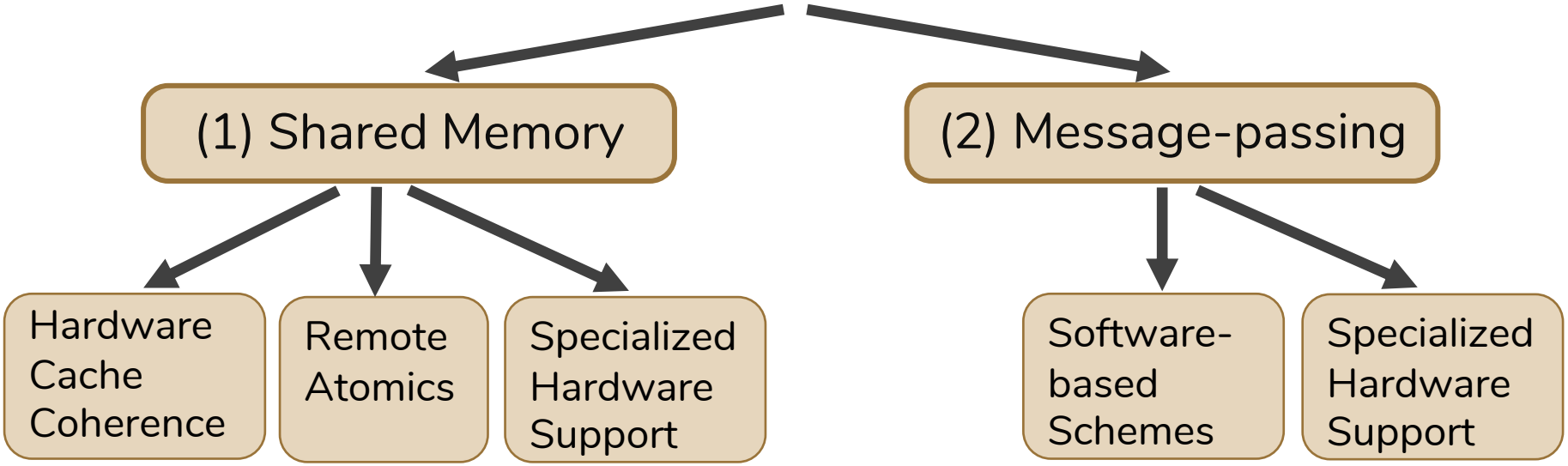
Synchronization challenges in NDP systems:

(1) Lack of hardware cache coherence support

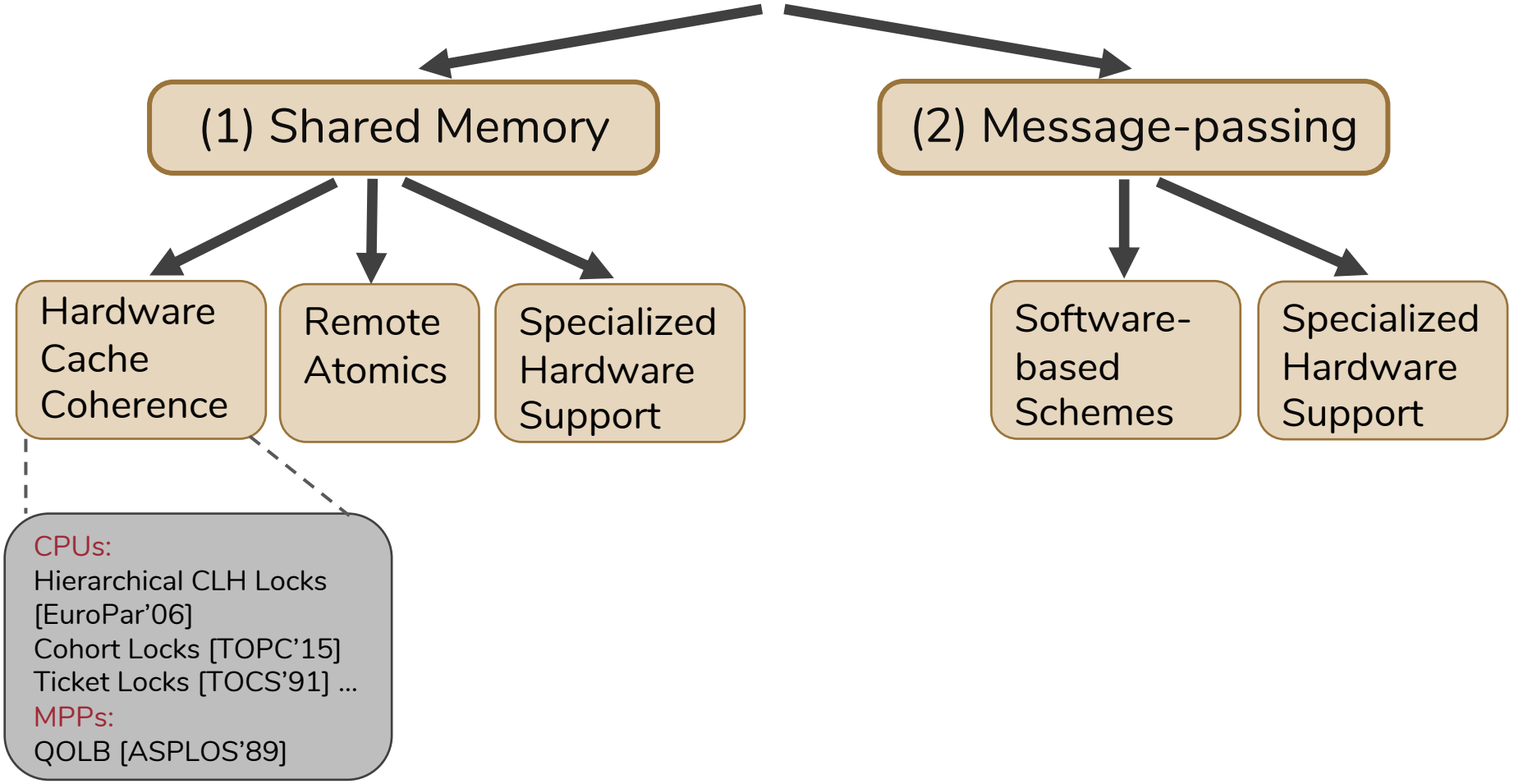
(2) Expensive communication across NDP units

(3) Lack of a shared level of cache memory

NDP Synchronization Solution Space

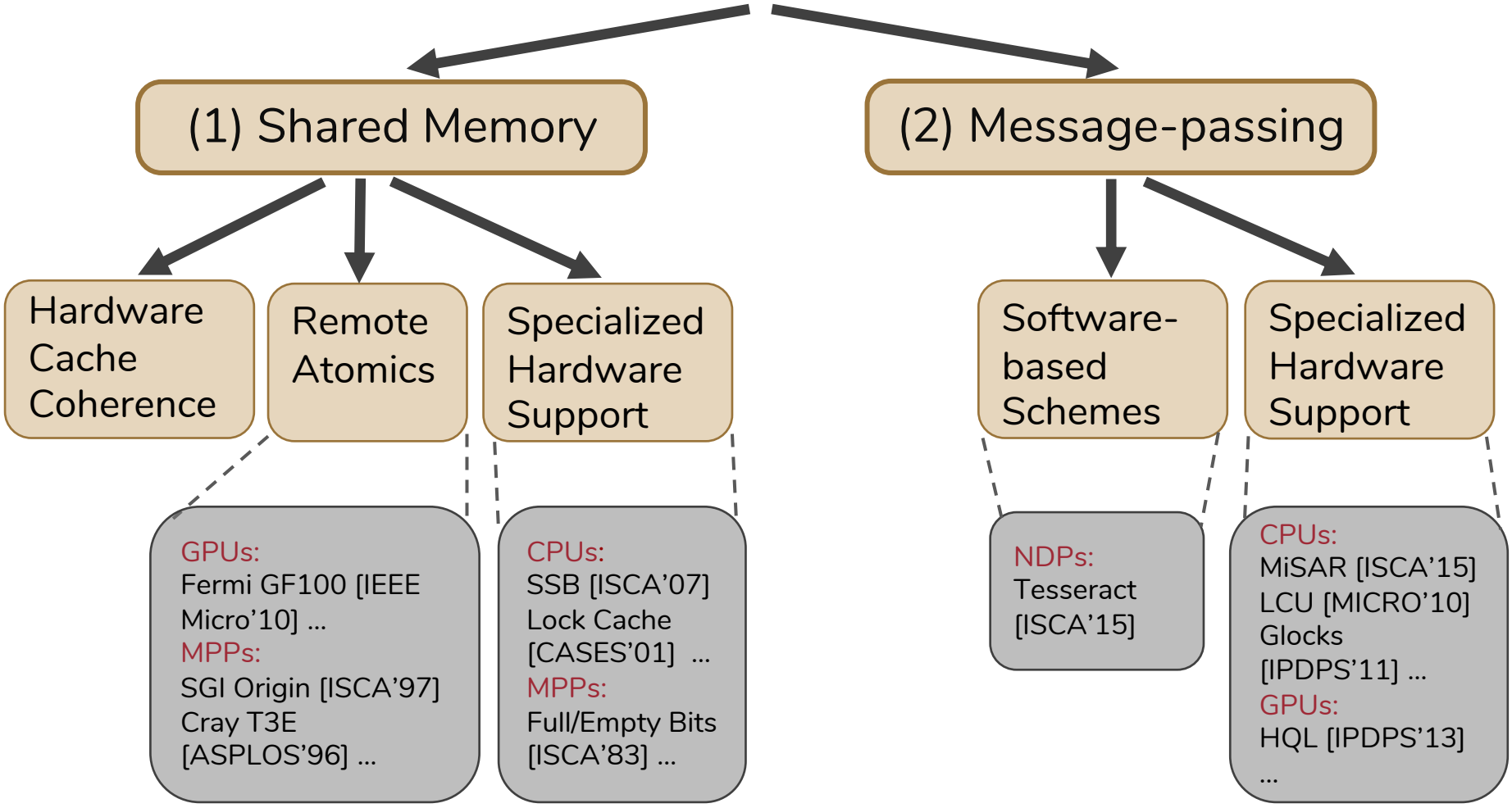


NDP Synchronization Solution Space



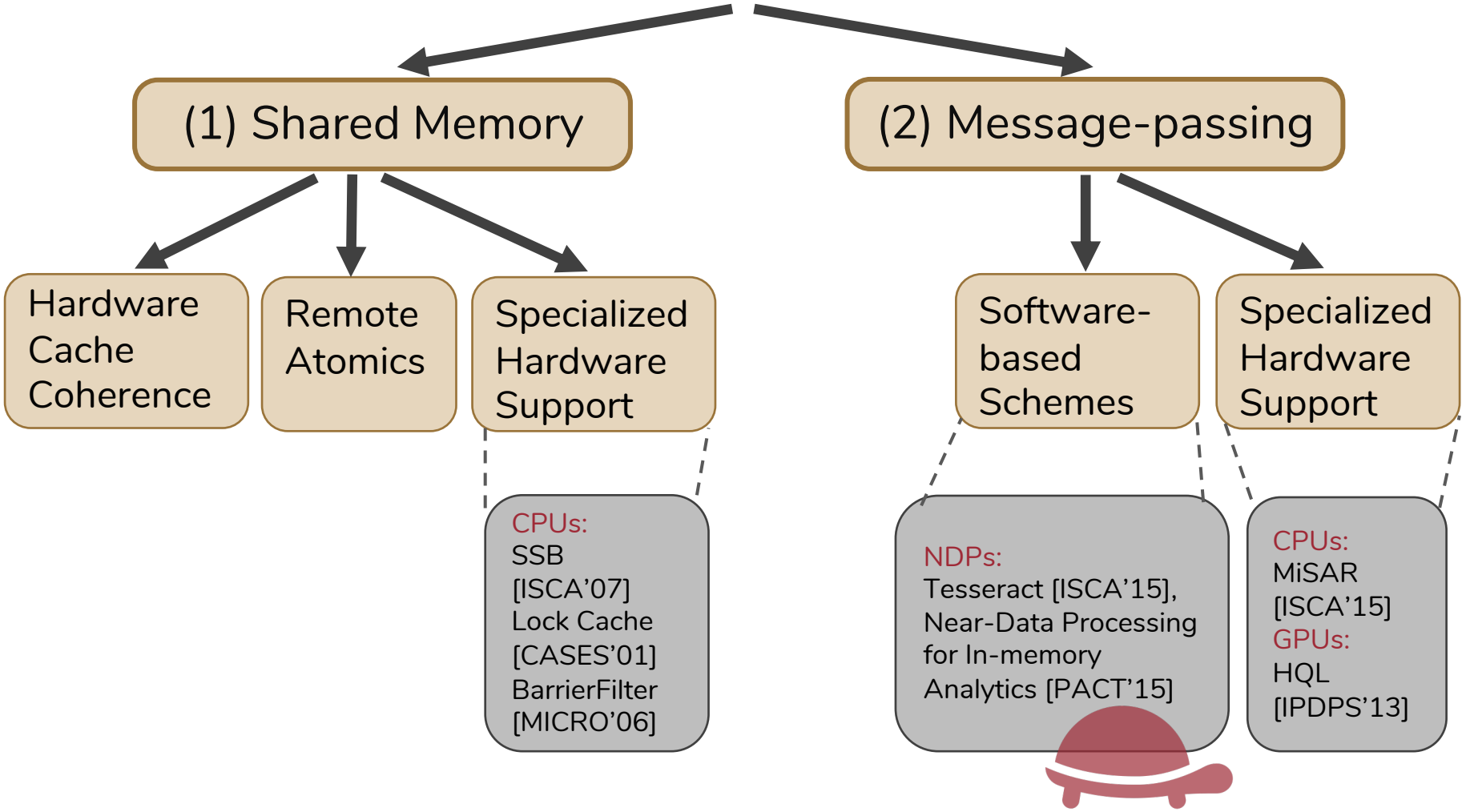
Lack of hardware cache coherence support

NDP Synchronization Solution Space



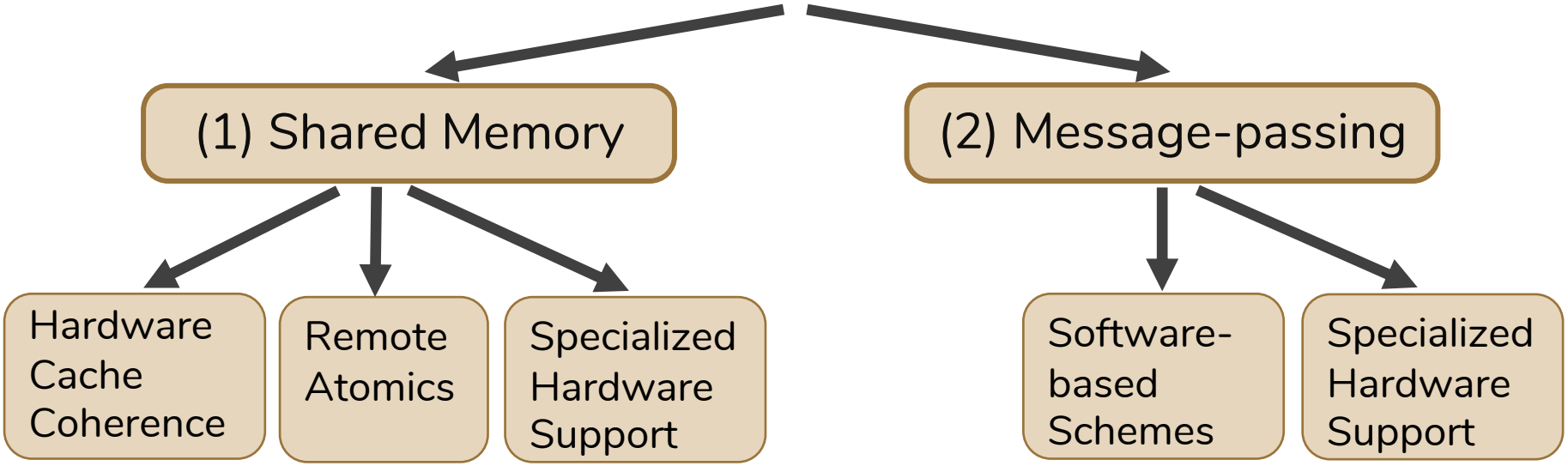
Expensive communication across NDP units

NDP Synchronization Solution Space



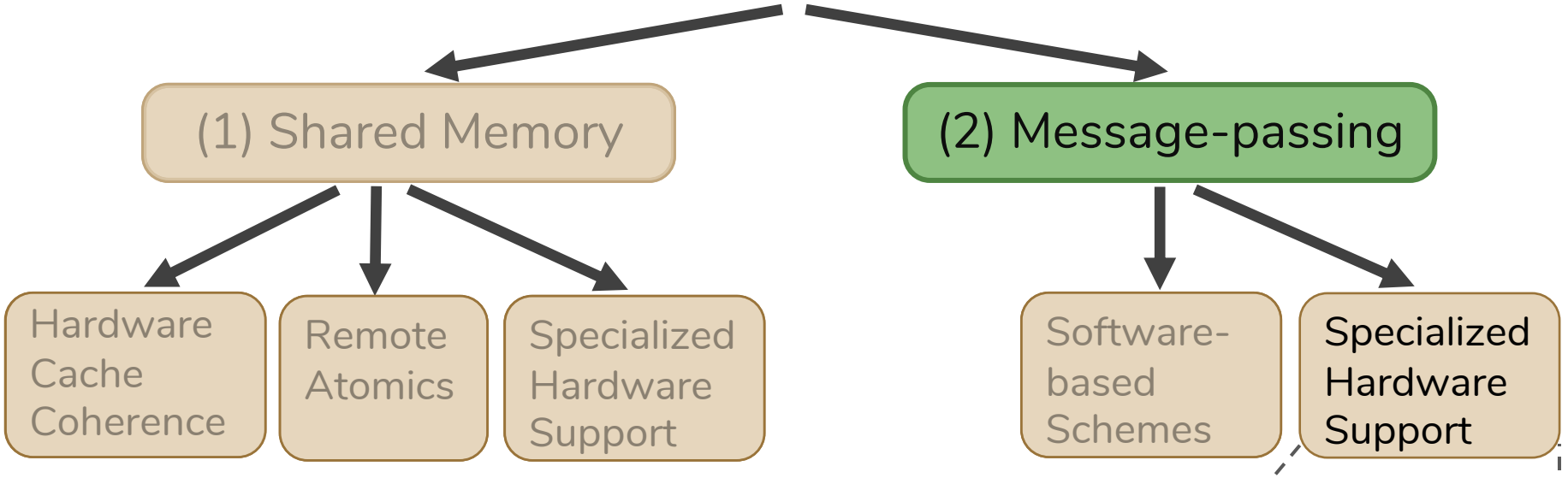
Lack of a shared level of cache memory

NDP Synchronization Solution Space



Prior schemes are not suitable or efficient for NDP systems

NDP Synchronization Solution Space

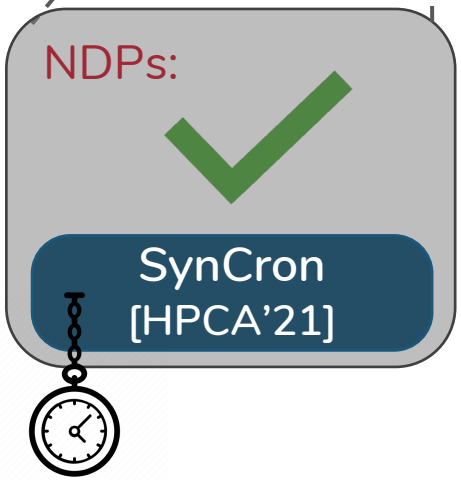


SynCron's Design Choices

Hardware Message-passing
to Avoid Synchronization via Shared Memory

Hierarchical Communication
to Eliminate Expensive Network Traffic

Specialized Cache Structure
to Minimize Latency Costs



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Our Mechanism: SynCron

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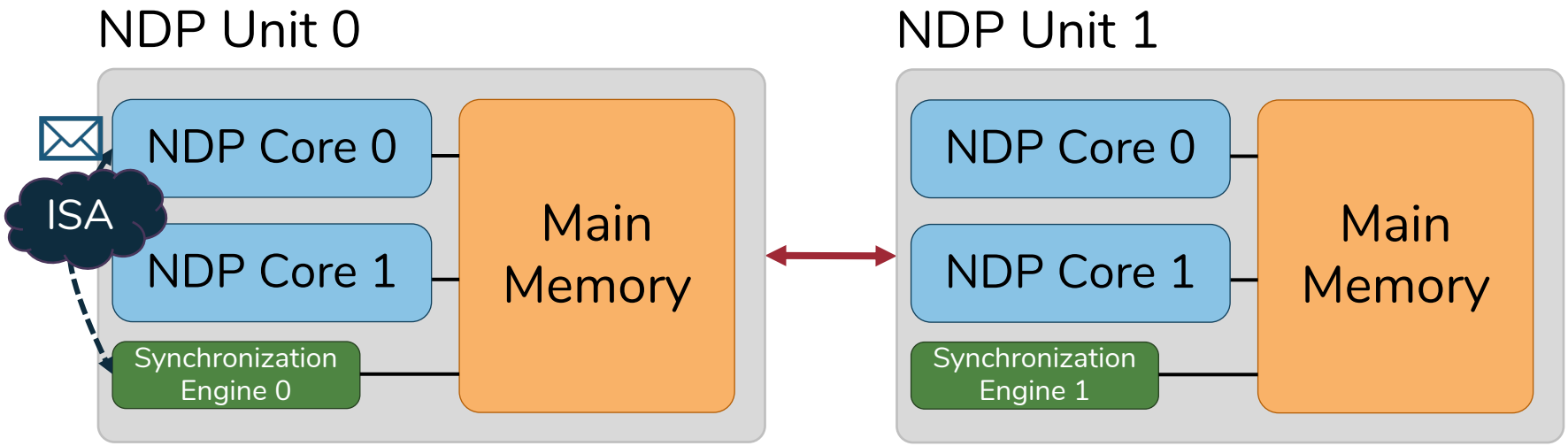
SynCron: Overview

SynCron consists of four key techniques:

1. Hardware support for synchronization acceleration
2. Direct buffering of synchronization variables
3. Hierarchical message-passing communication
4. Integrated hardware-only overflow management

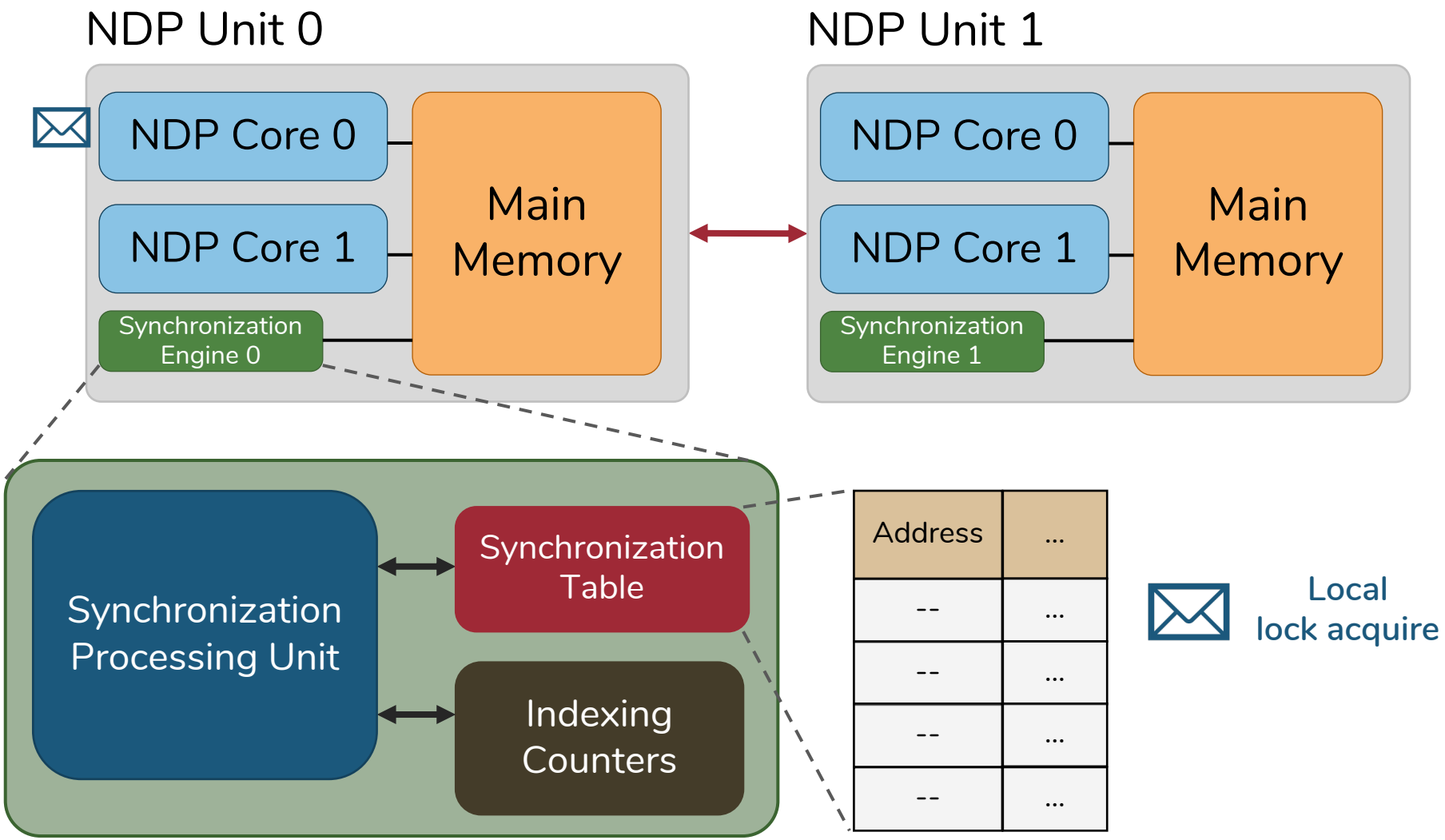
1. Hardware Synchronization Support



Local lock acquire

- ✓ No Complex Cache Coherence Protocols
- ✓ No Expensive Atomic Operations
- ✓ Low Hardware Cost

2. Direct Buffering of Variables



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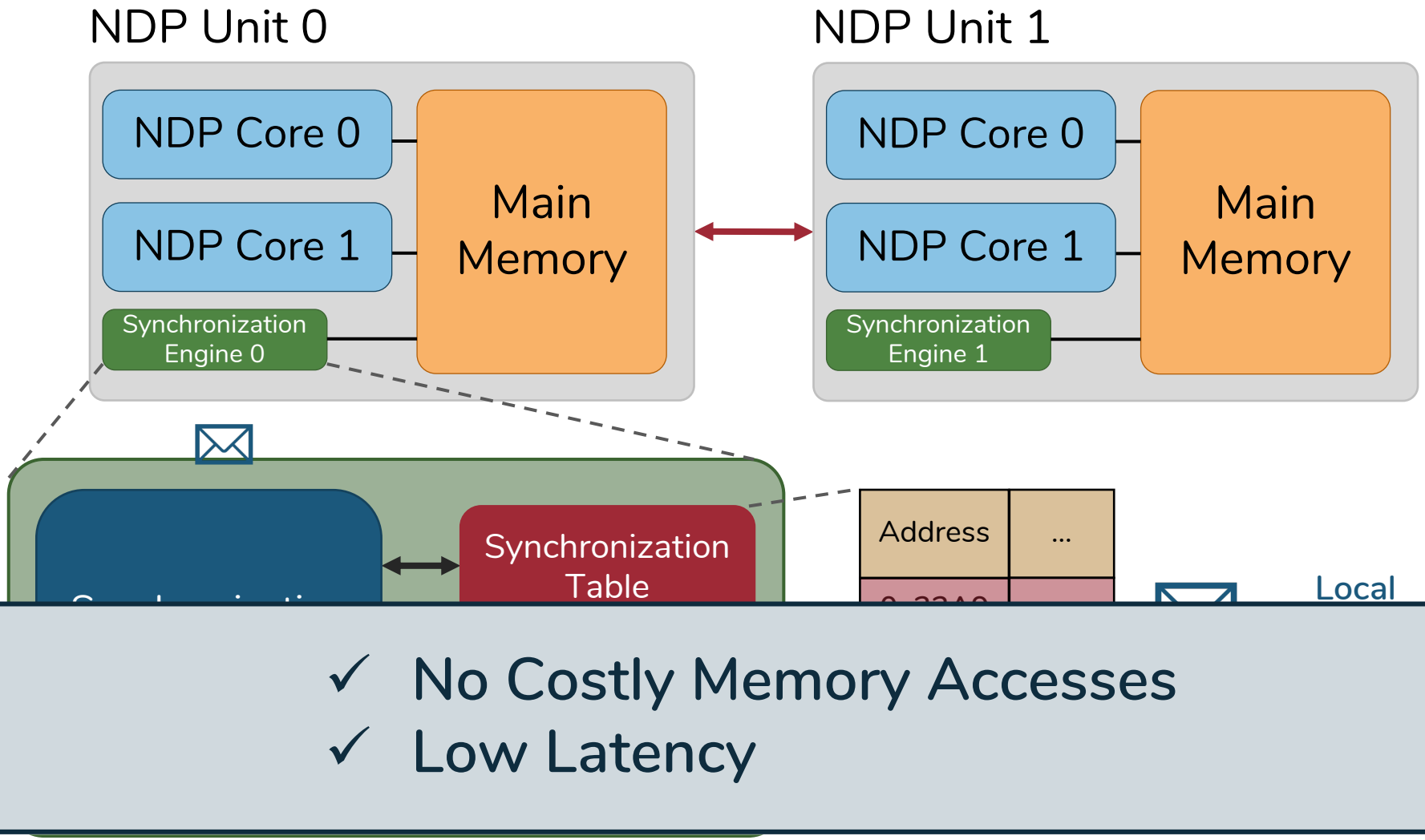
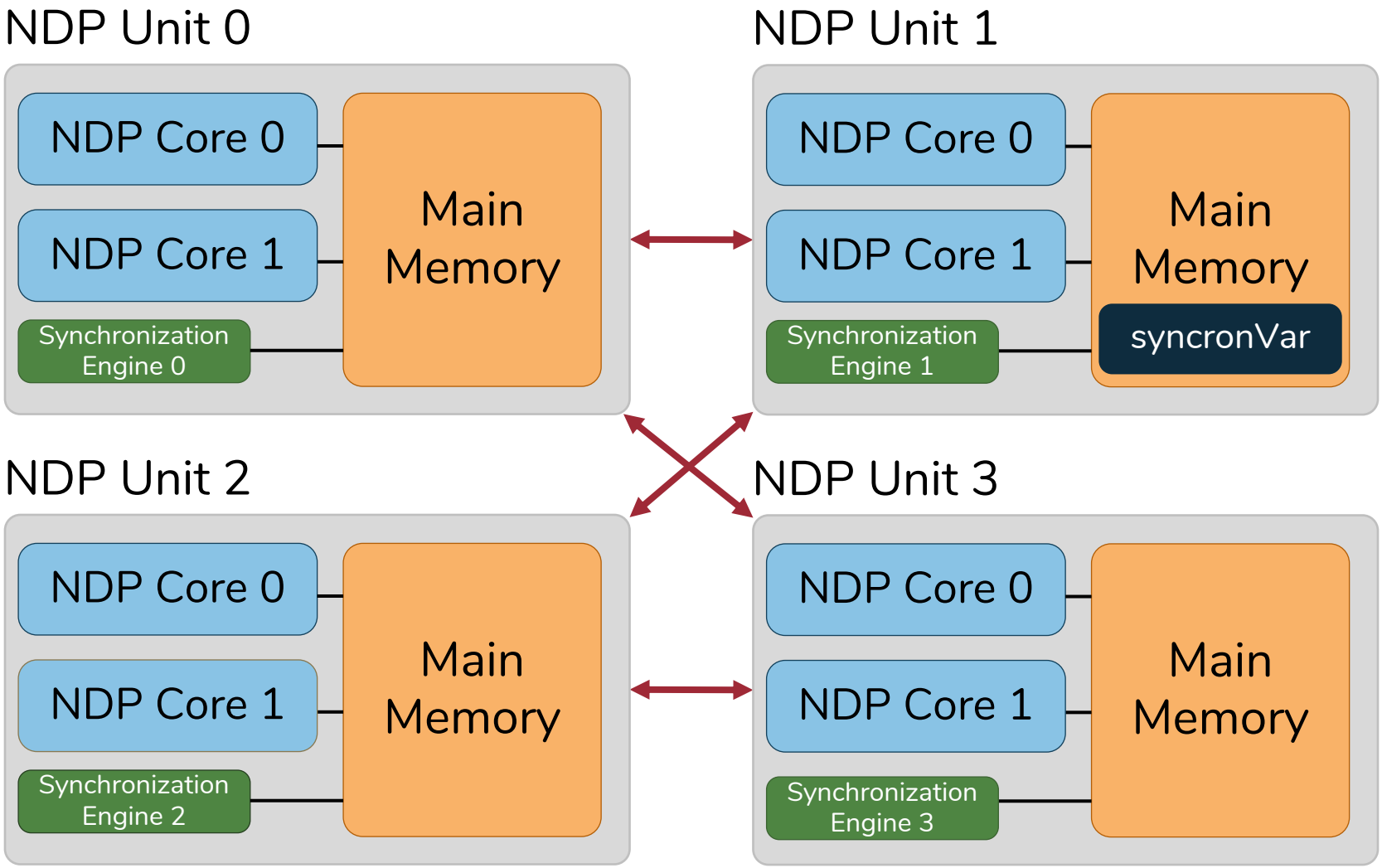


- ✓ No Costly Memory Accesses
- ✓ Low Latency

3. Hierarchical Communication



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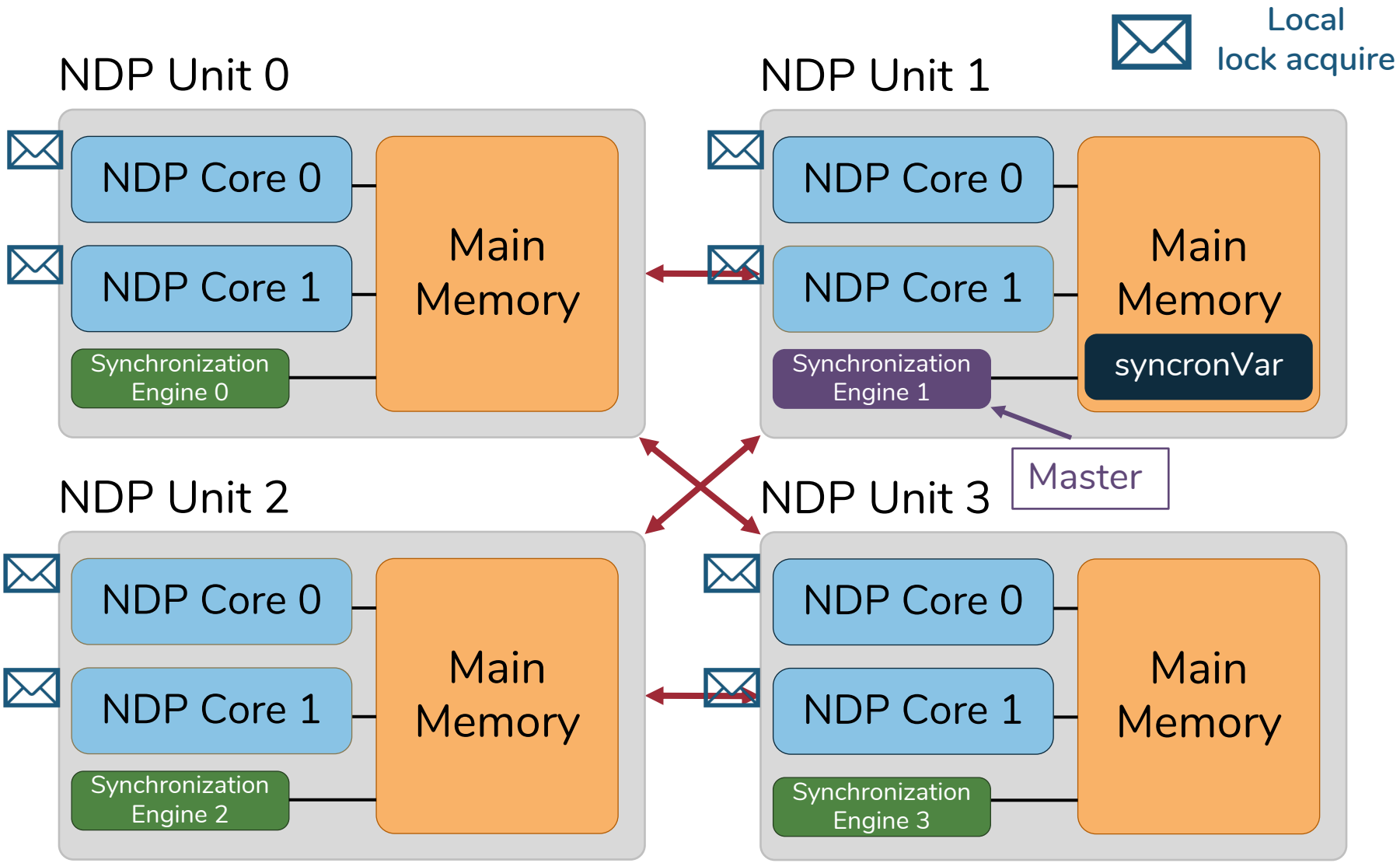

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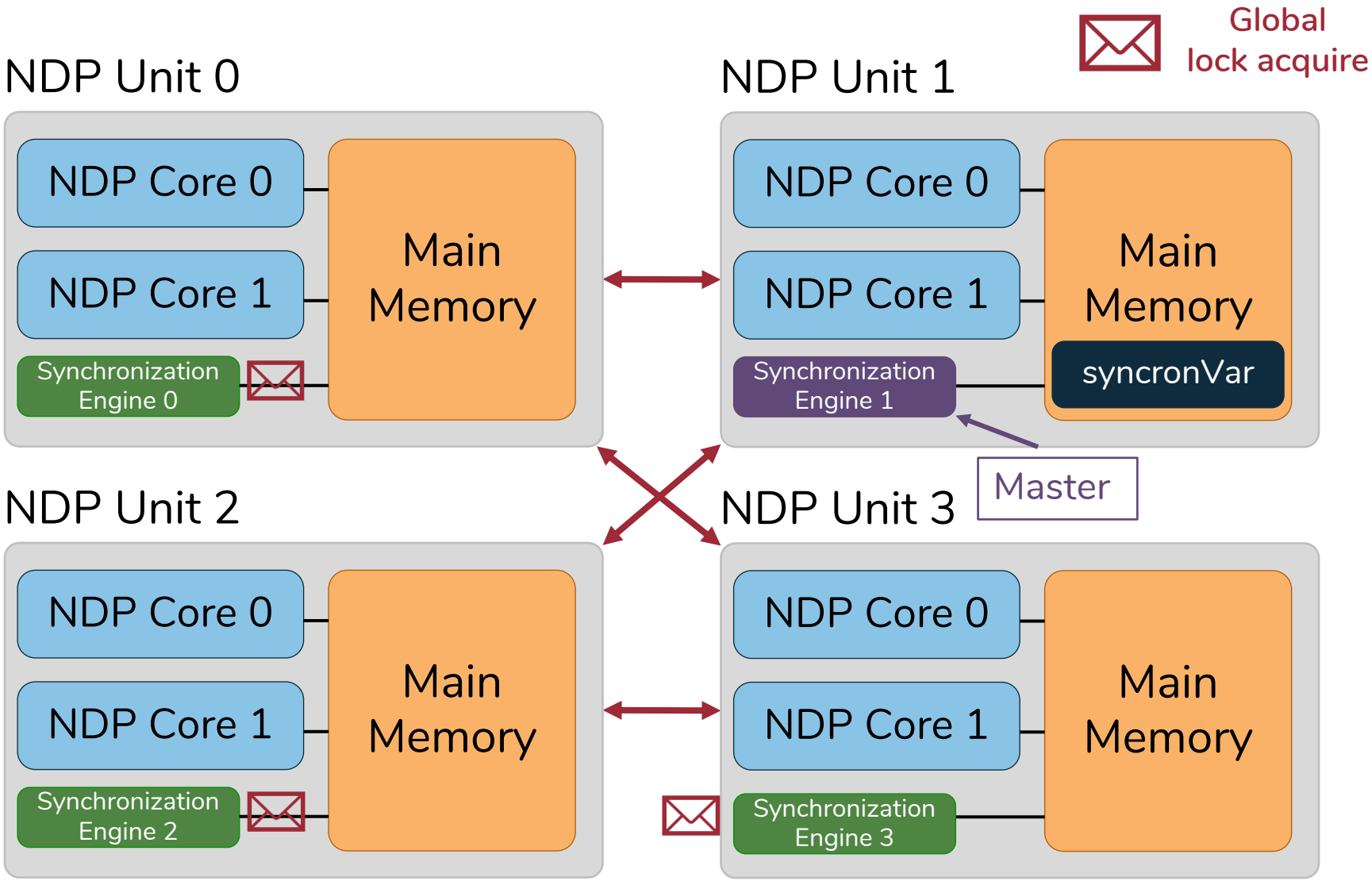
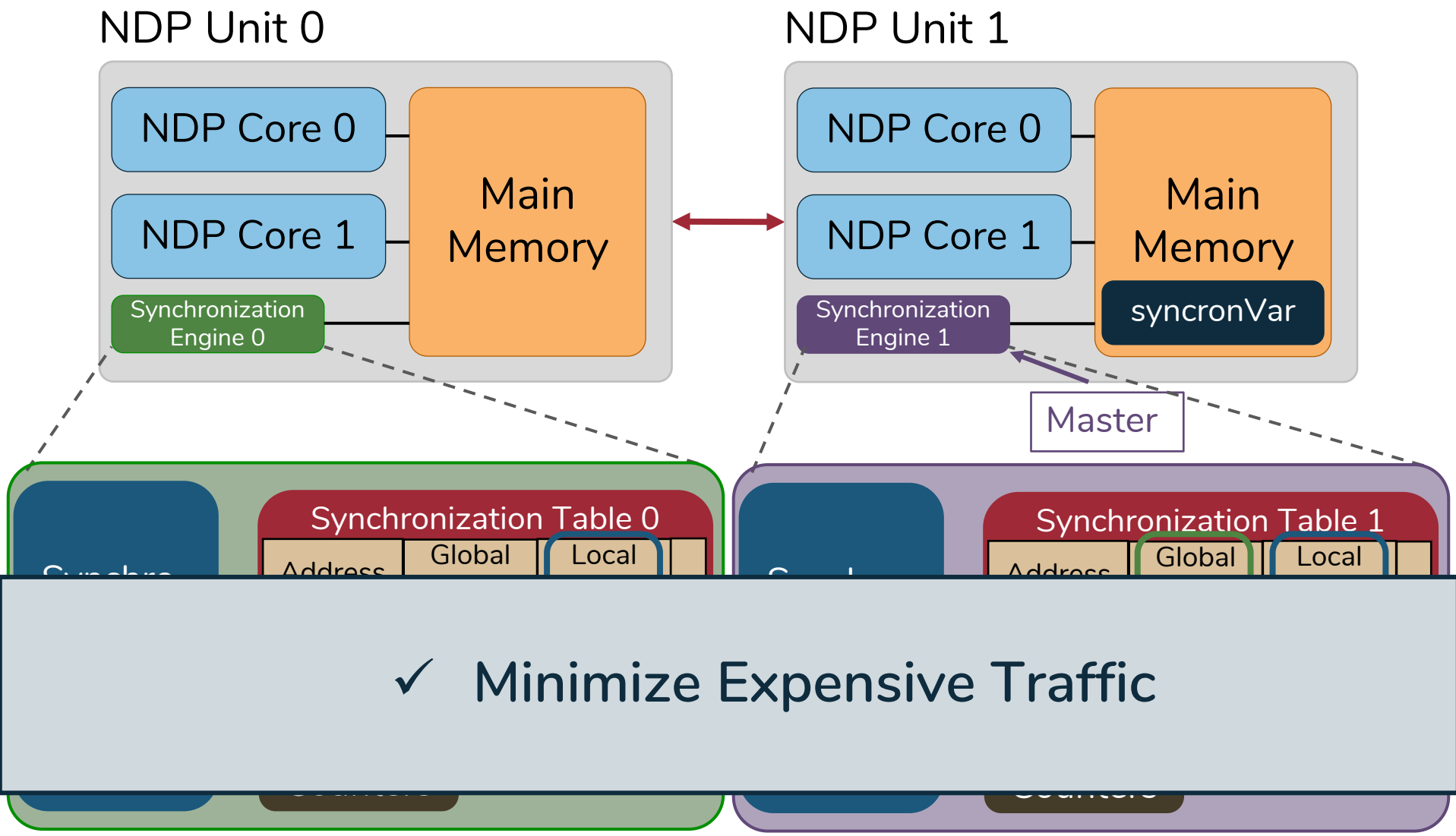
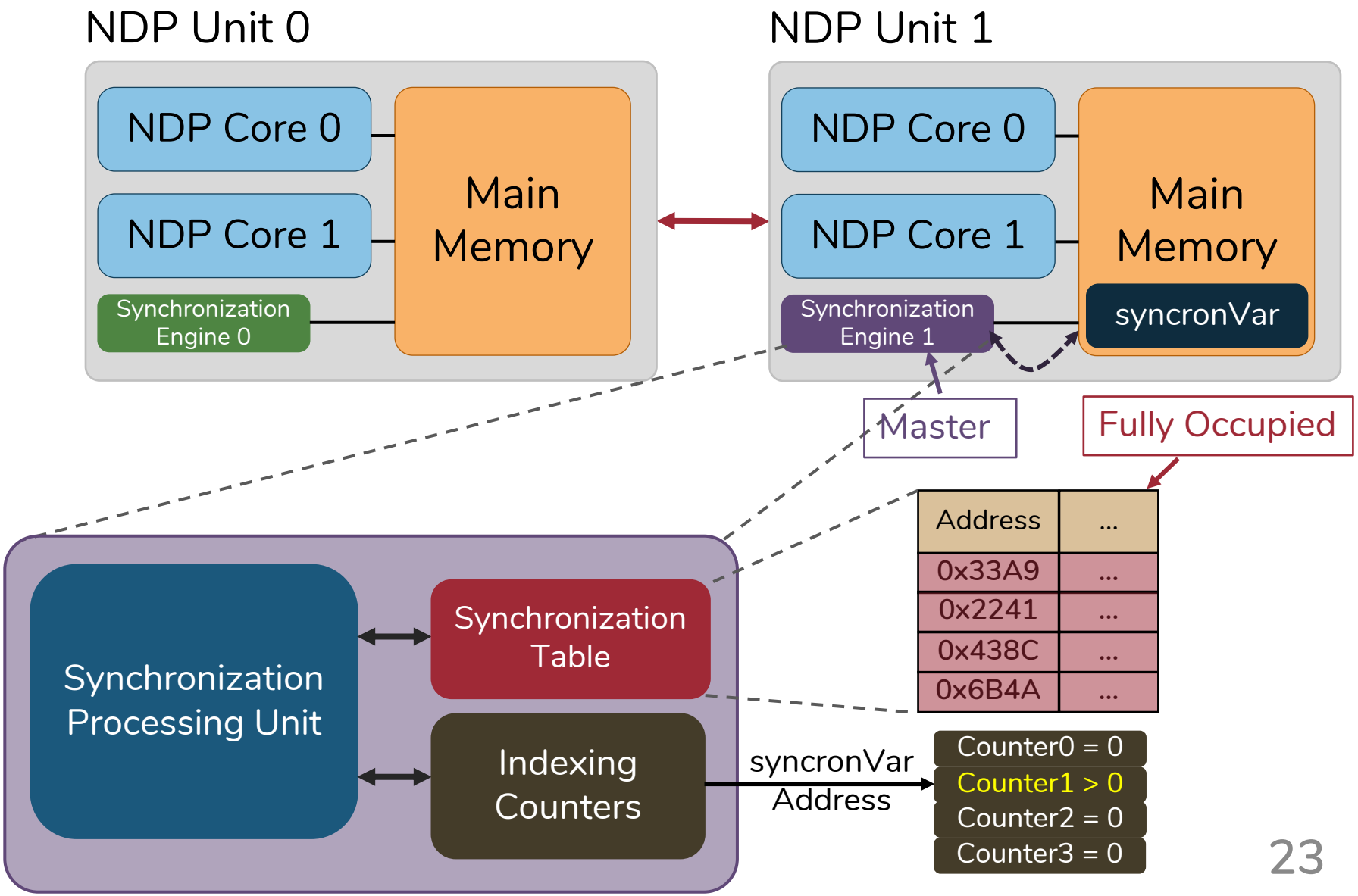


3. Hierarchical Communication



✓ Minimize Expensive Traffic

4. Integrated Overflow Management



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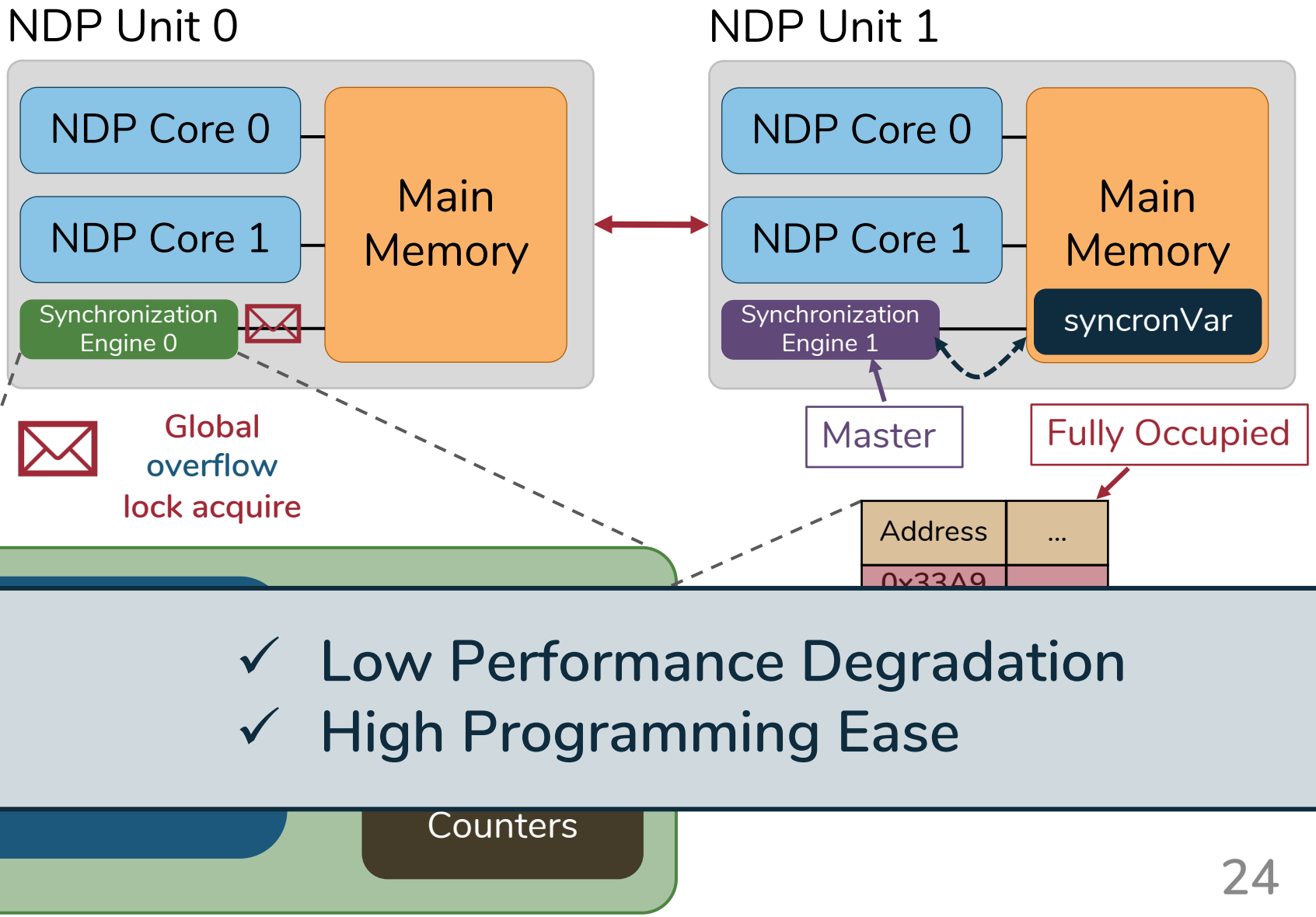


- ✓ Low Performance Degradation
- ✓ High Programming Ease

SynCron's Supported Primitives

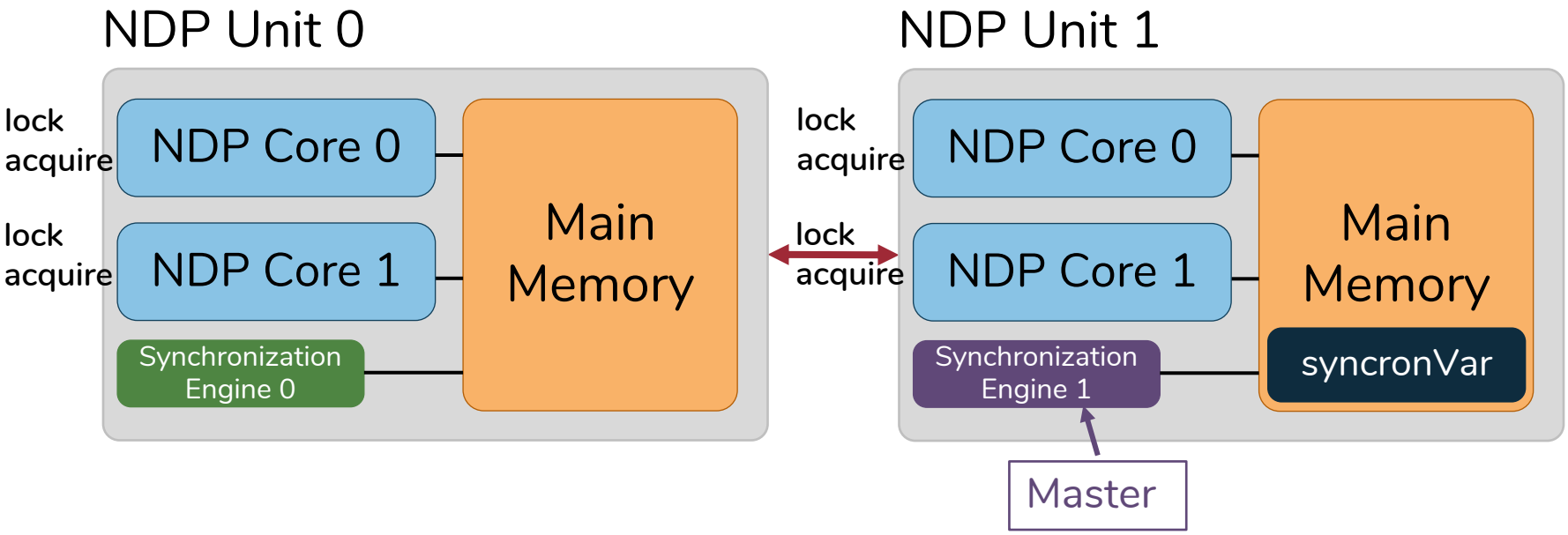
Lock primitive
- lock_acquire()
- lock_release ()

Barrier primitive
- barrier_wait_within_NDP_unit()
- barrier_wait_across_NDP_units()

Semaphore primitive
- sem_wait()
- sem_post()

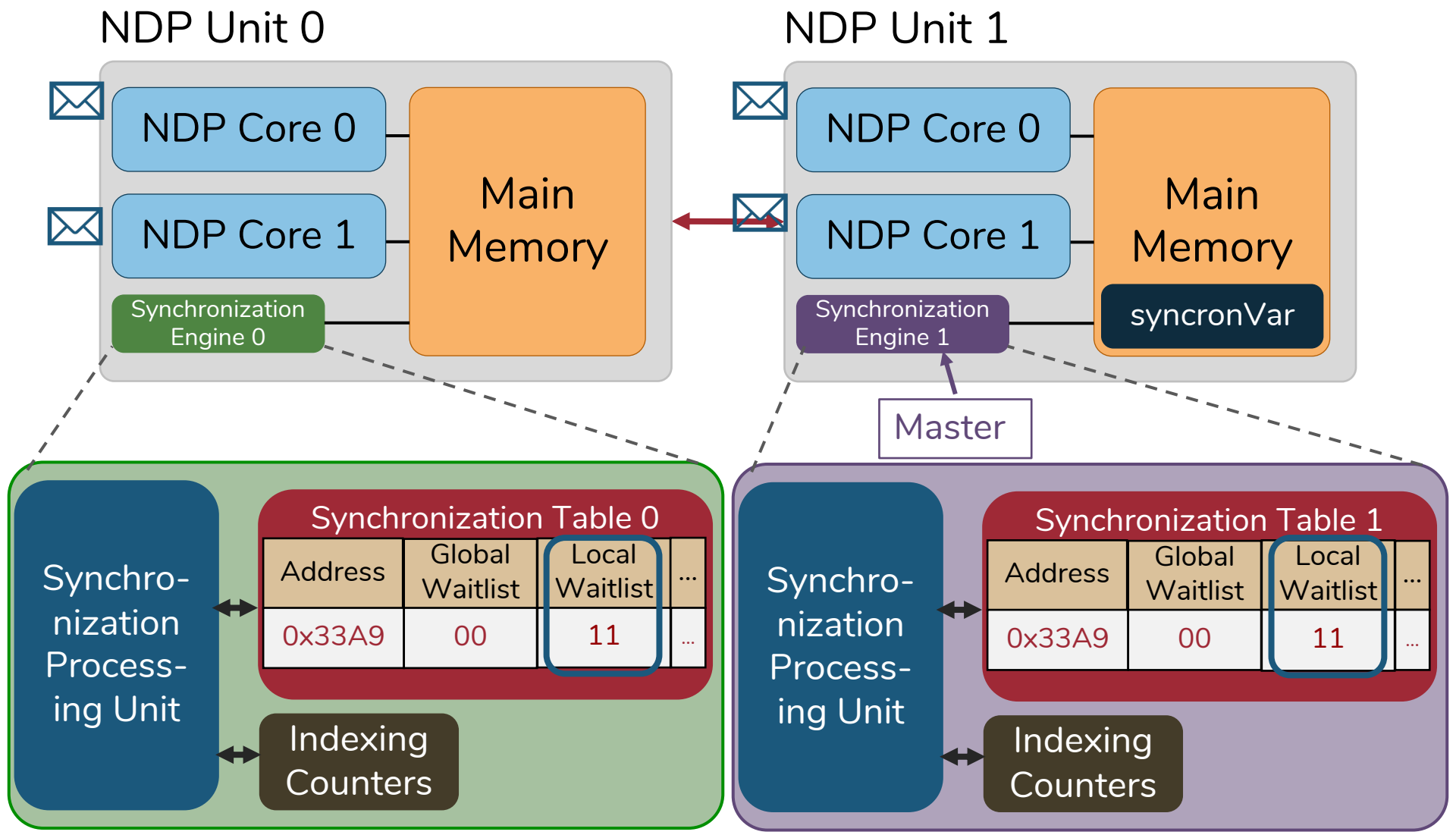
Condition variable primitive
- cond_wait()
- cond_signal()
- cond_broadcast()

Lock Operation

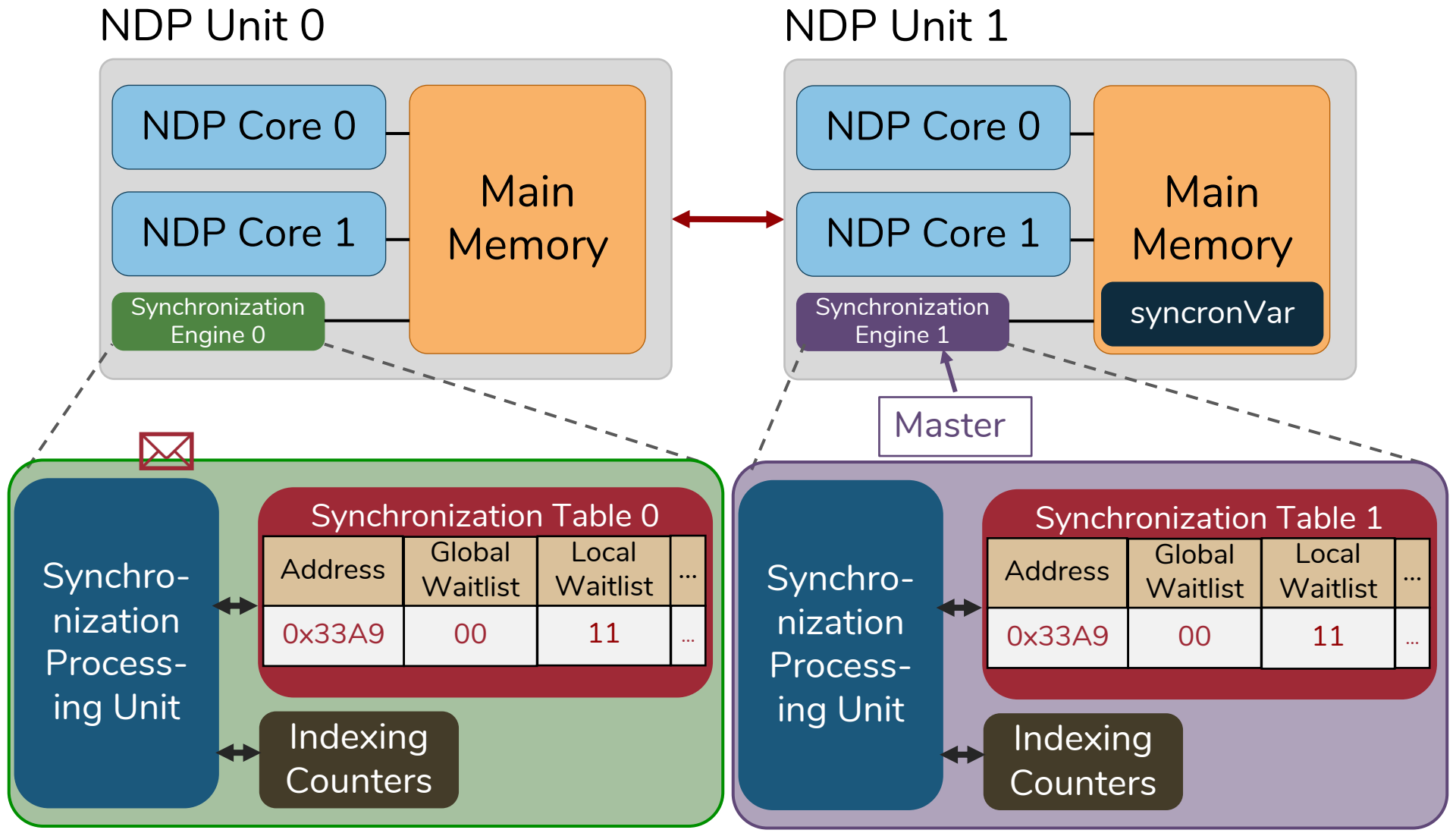


All NDP cores compete for the same lock variable

Lock Operation



Lock Operation



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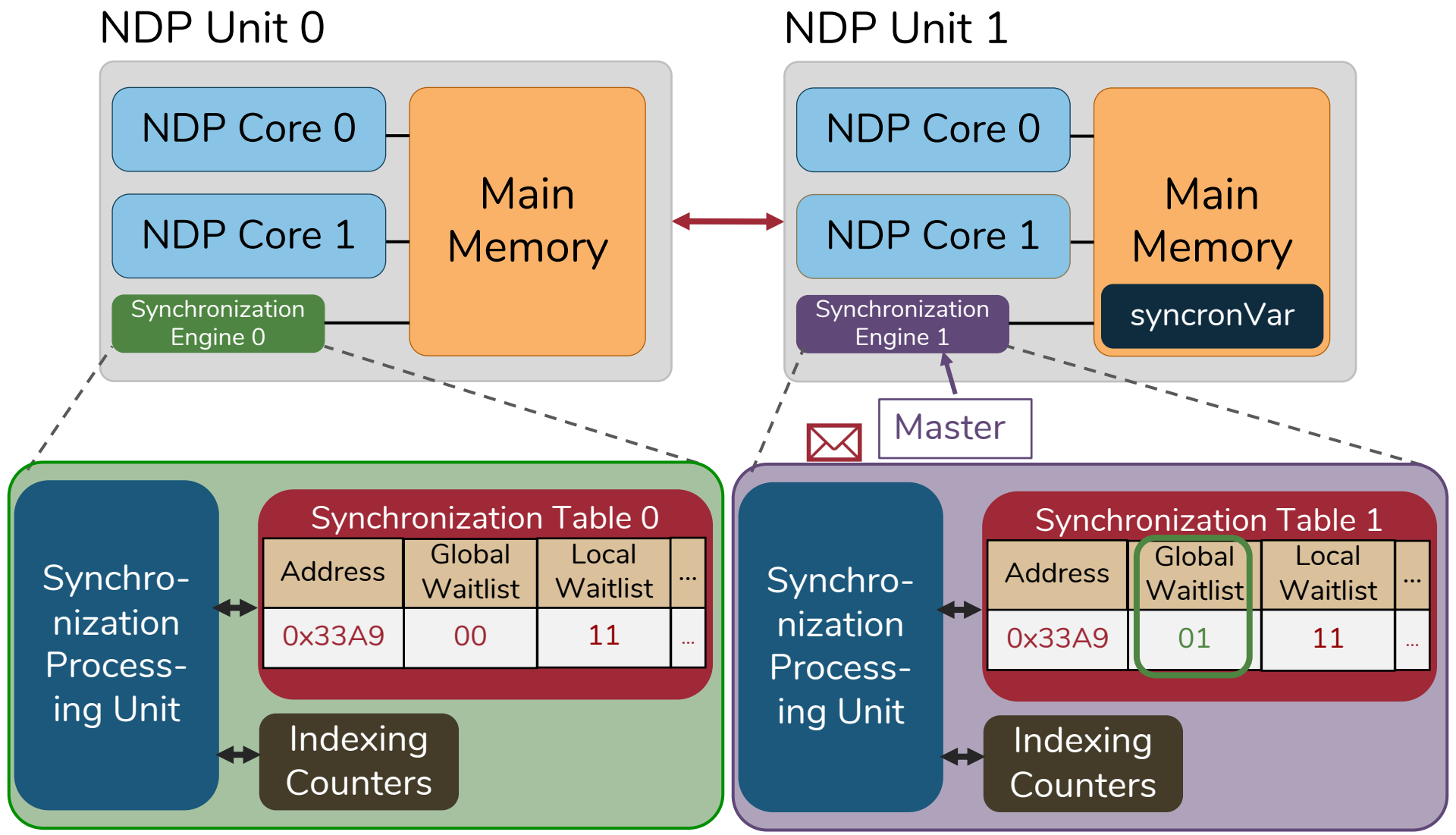
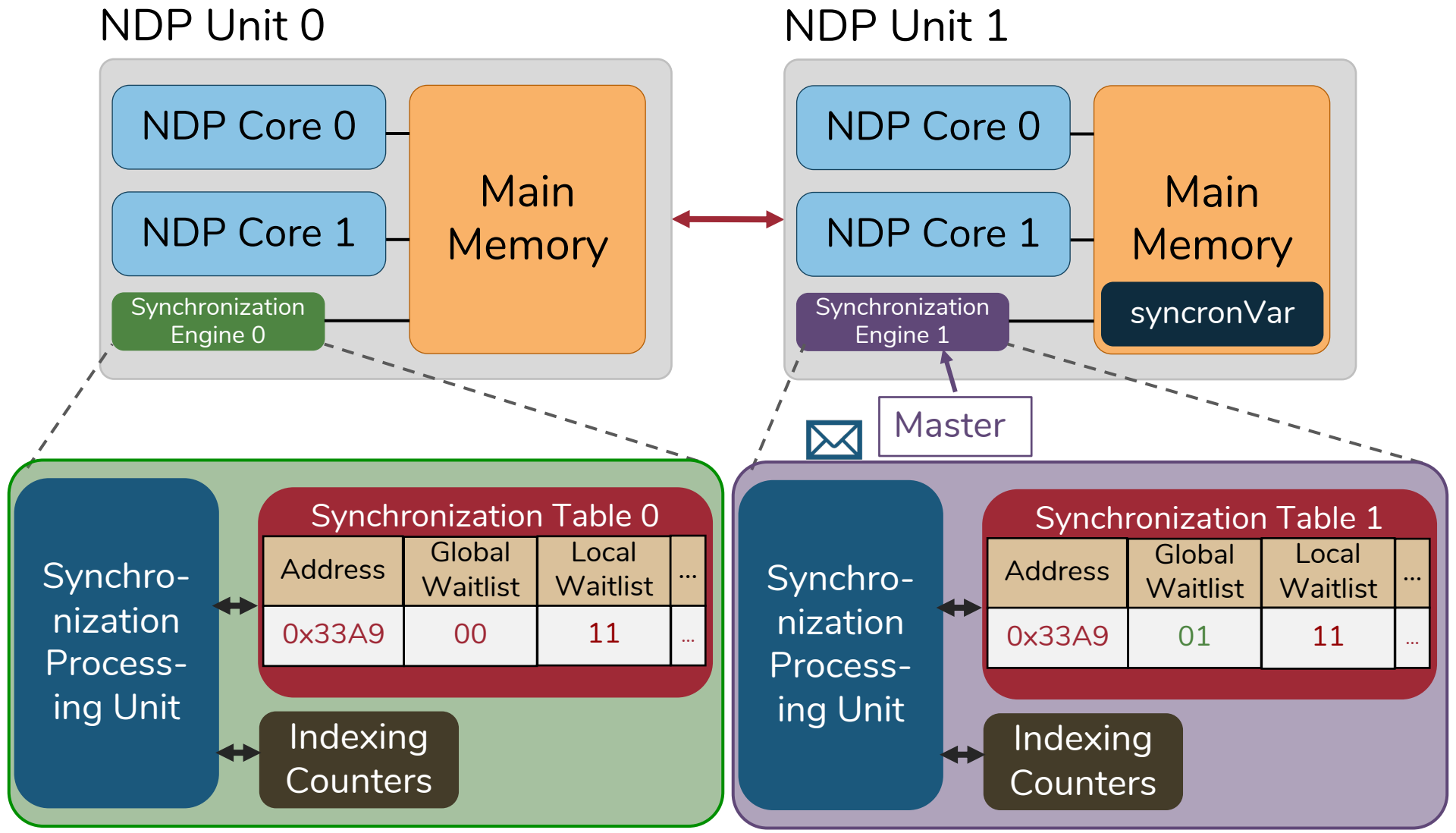
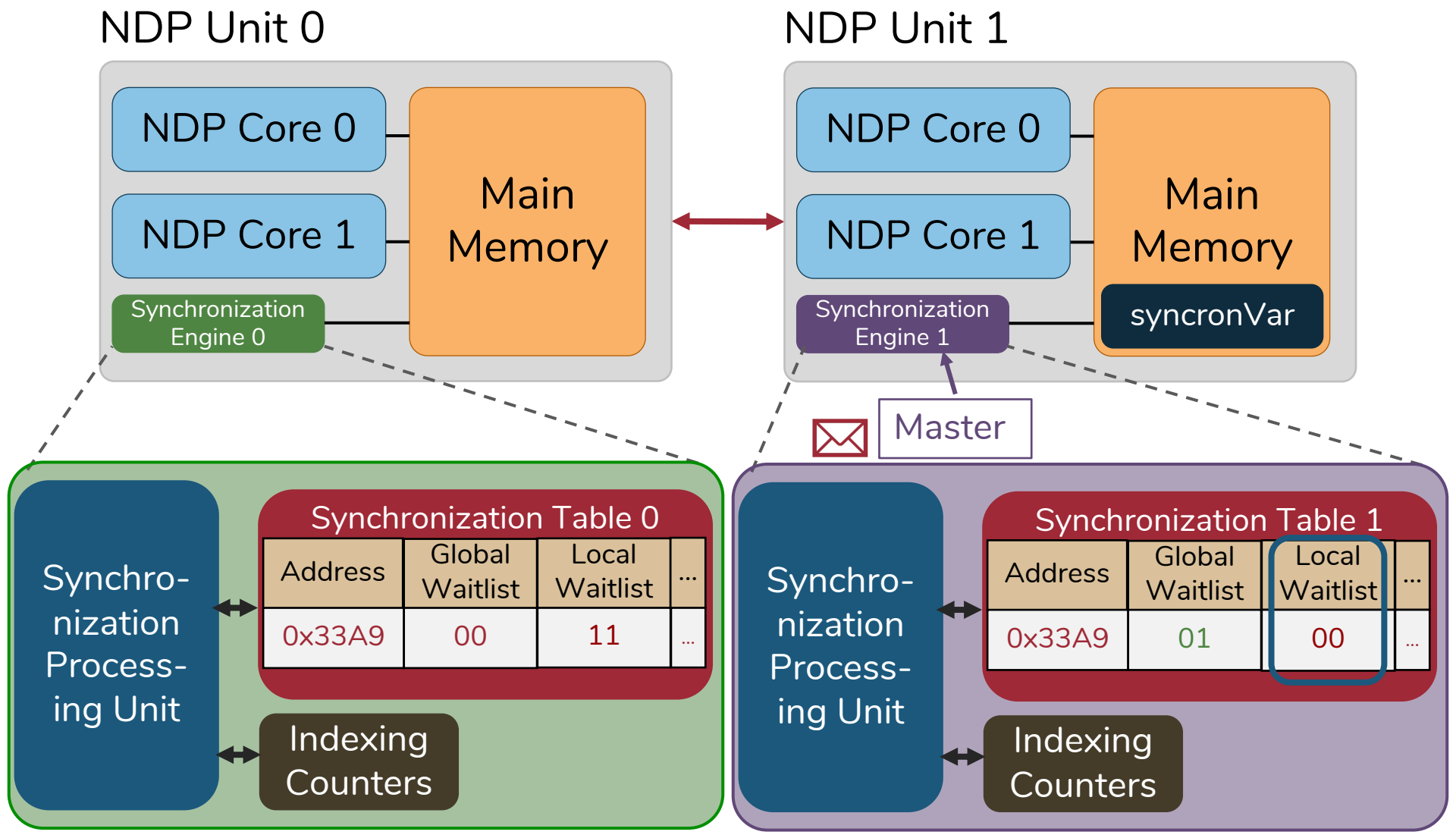


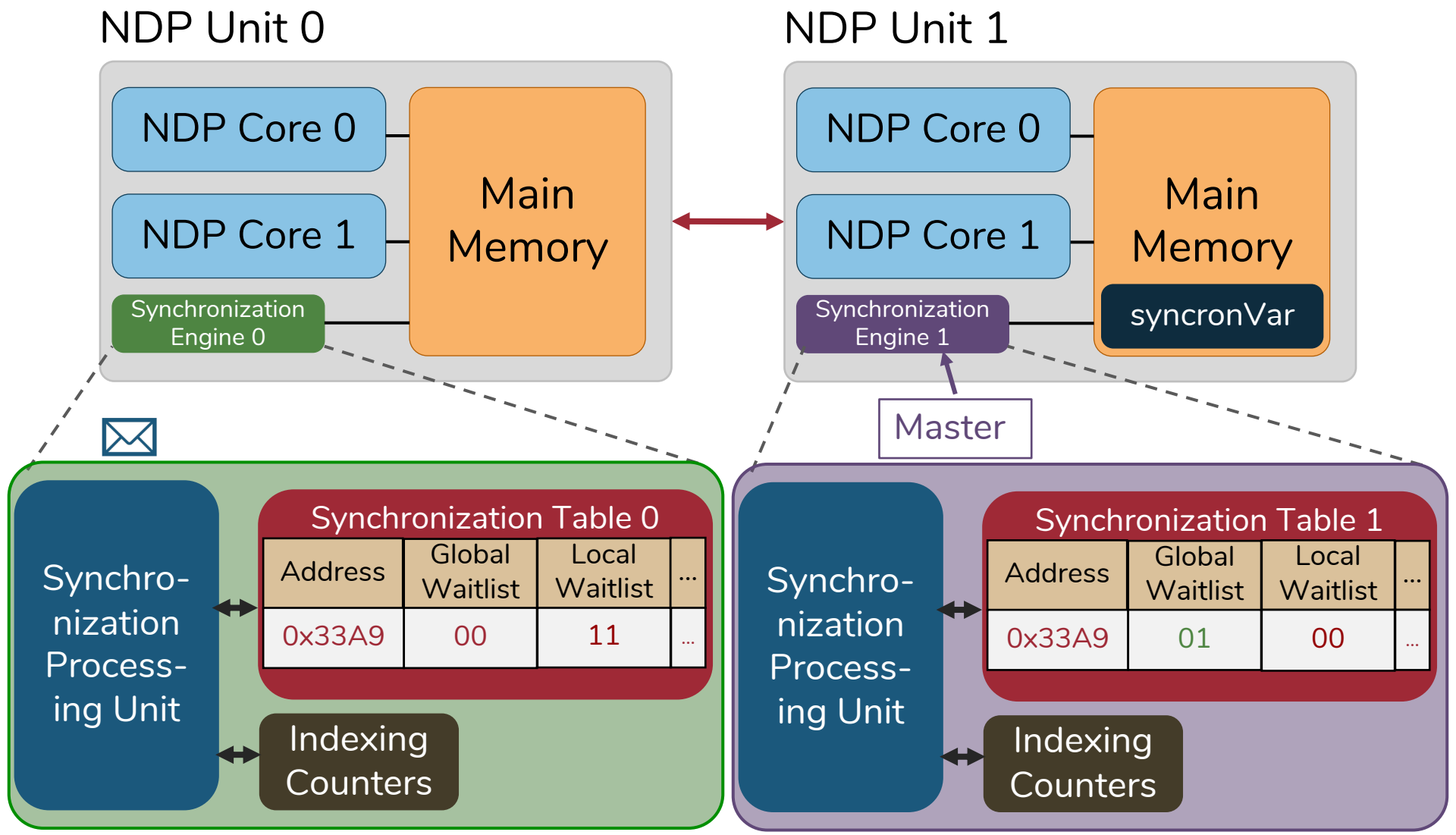
Lock Operation



Lock Operation



Lock Operation



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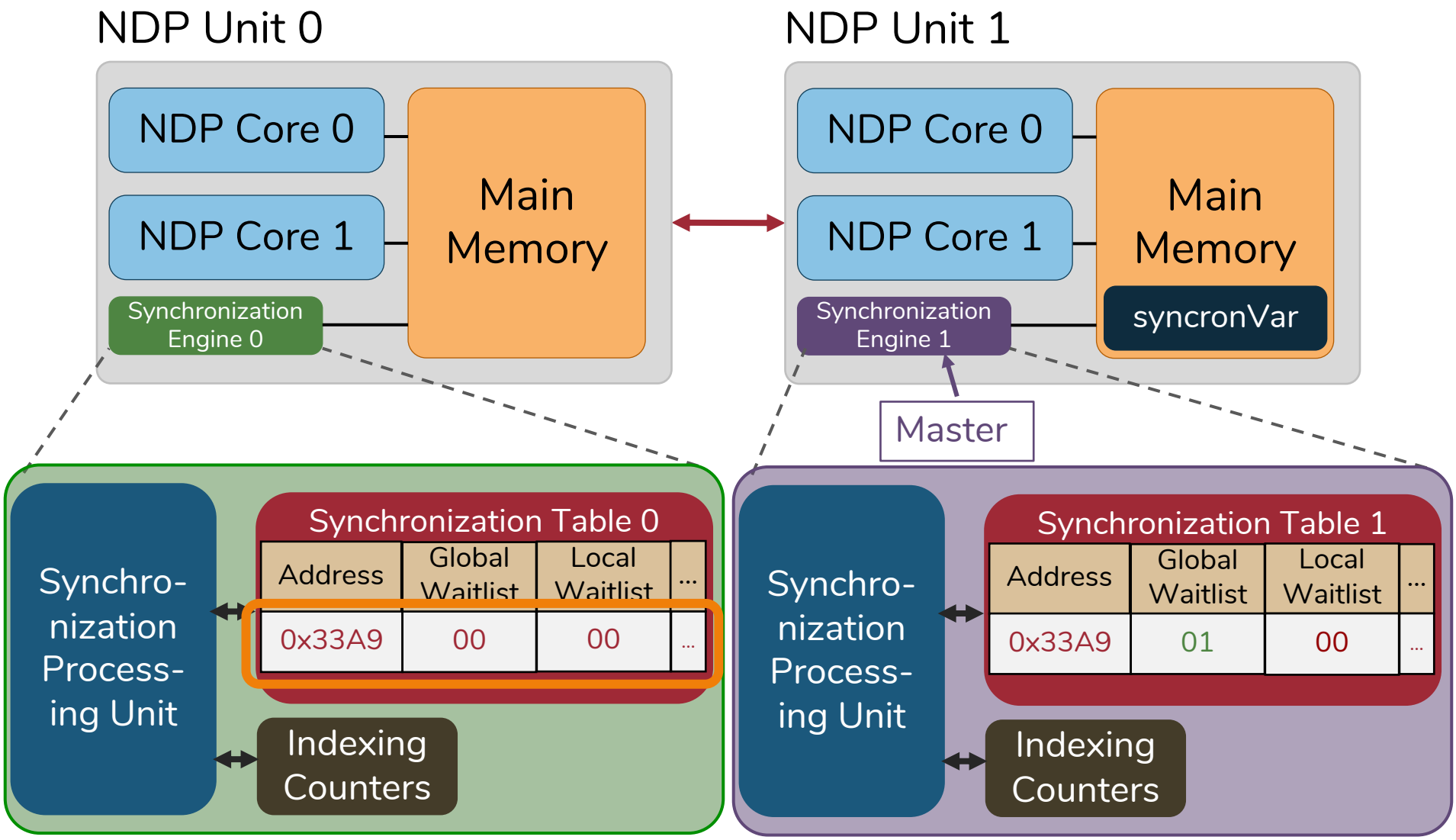

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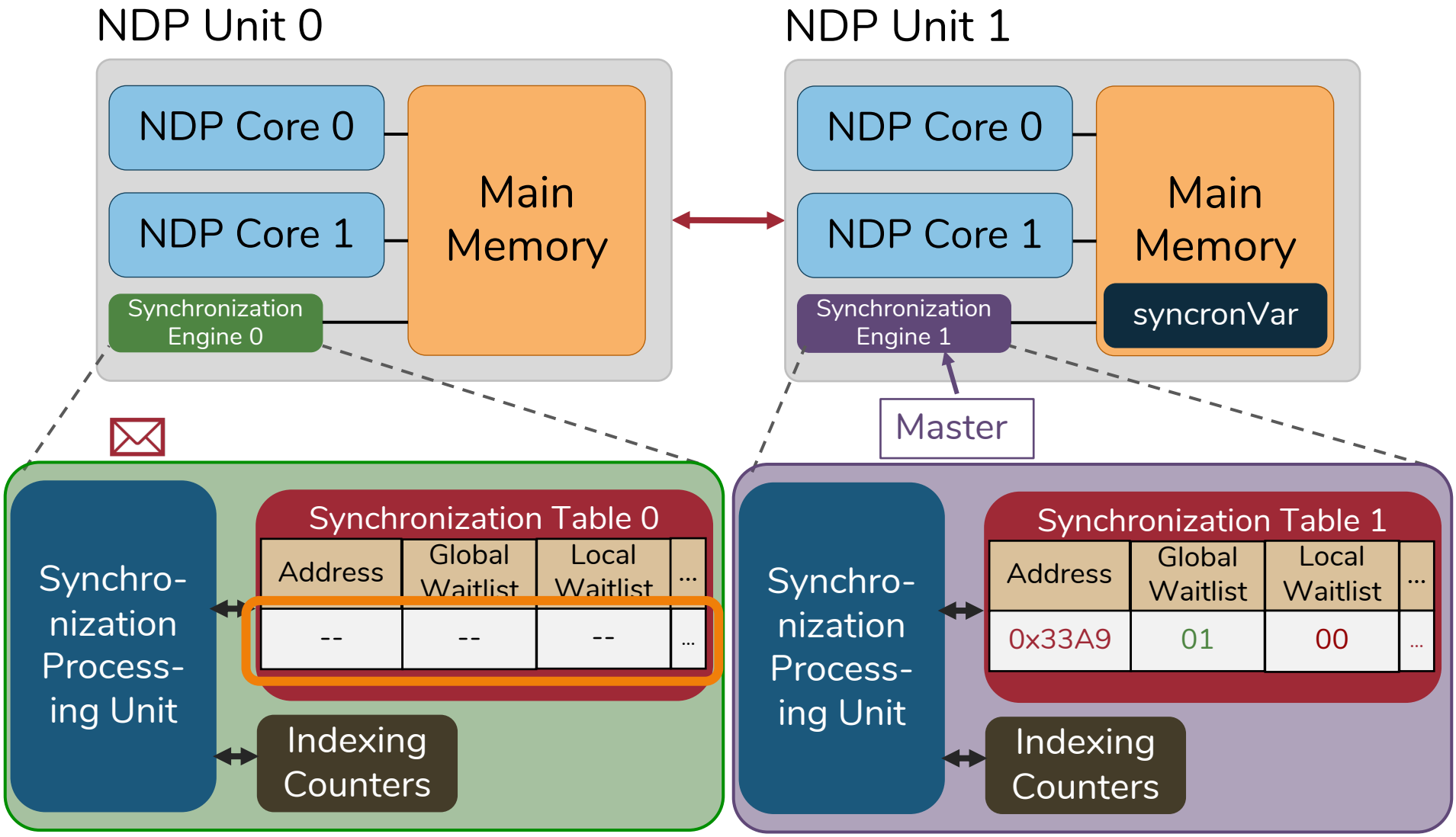

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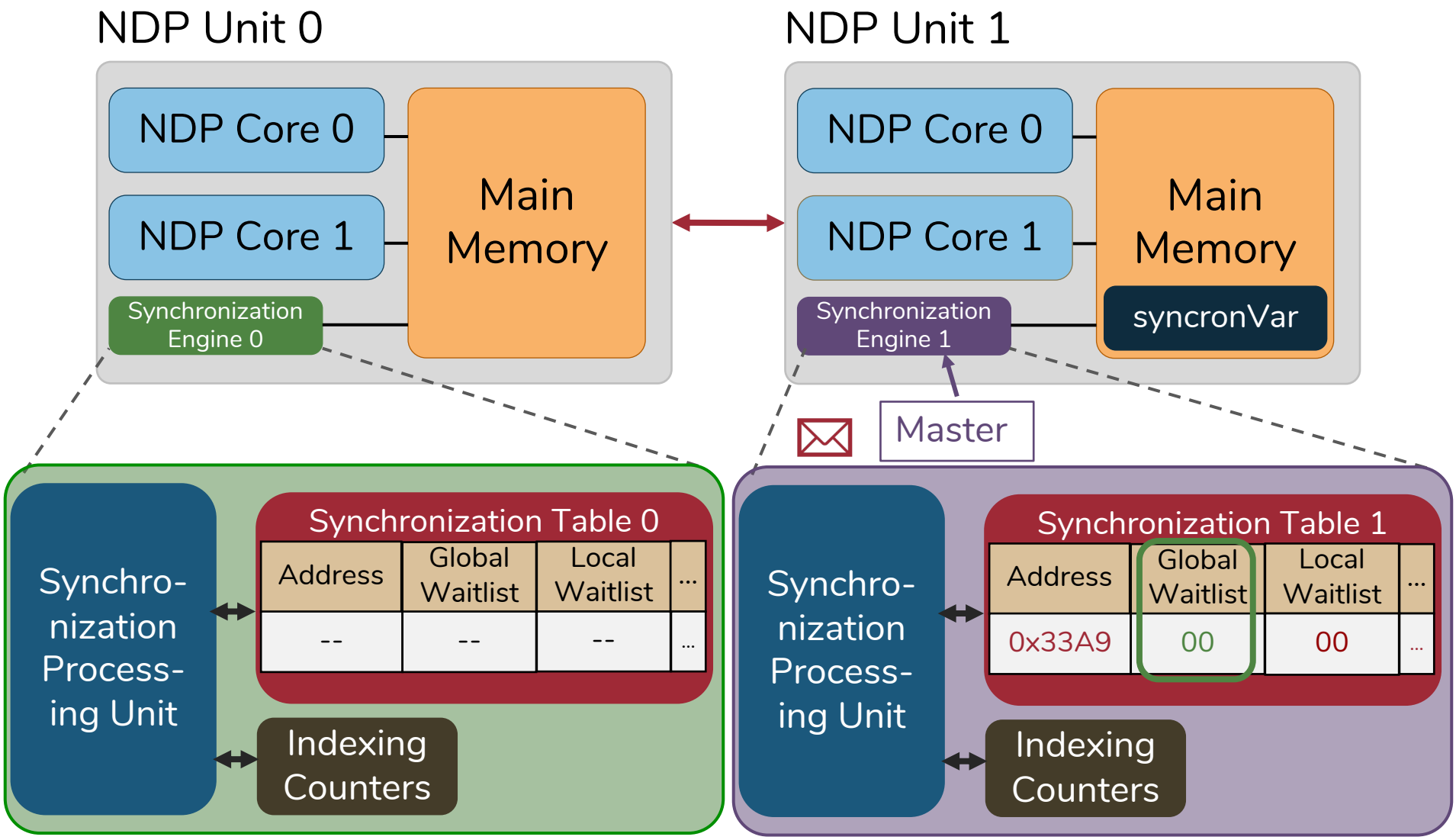

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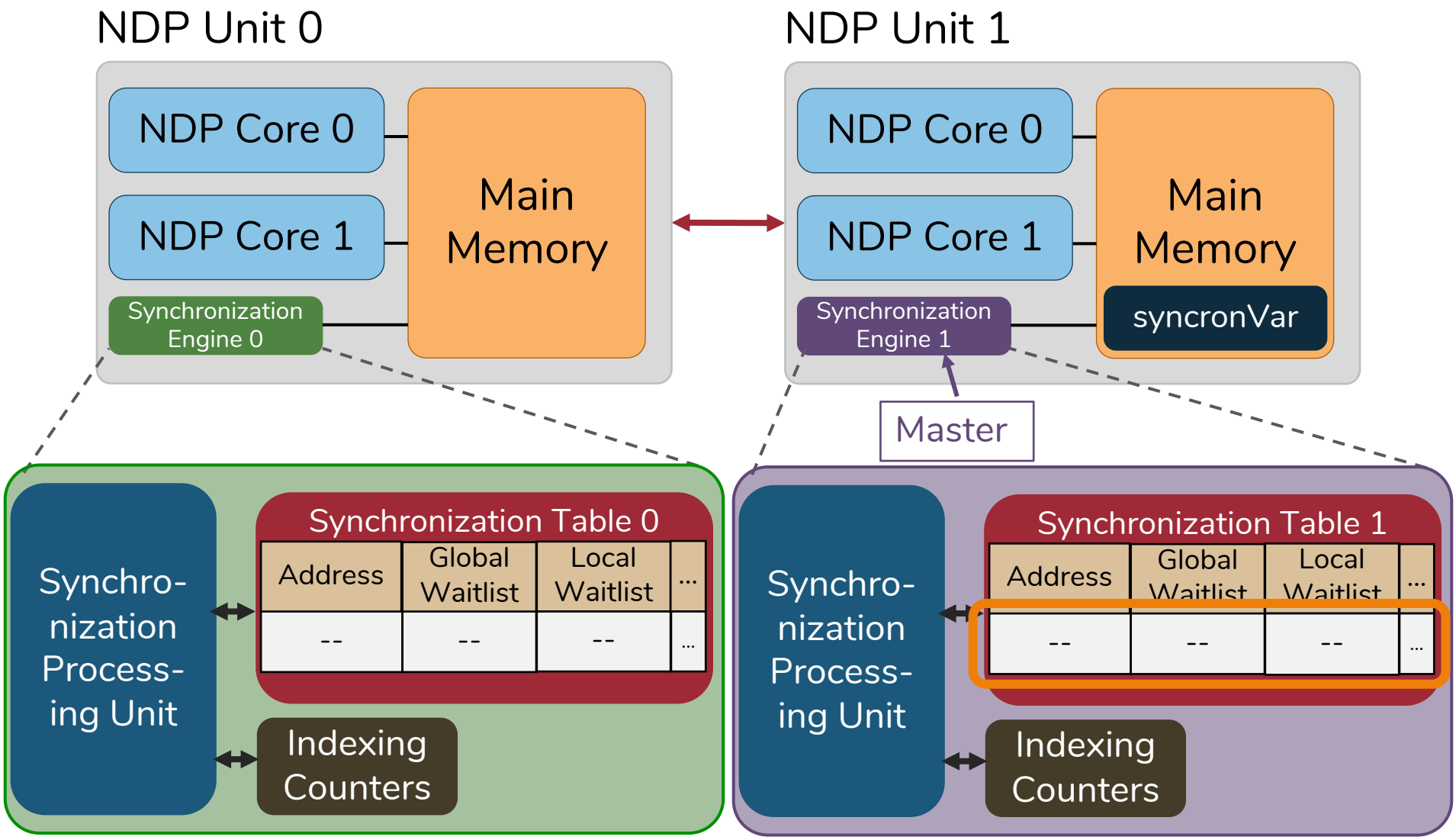
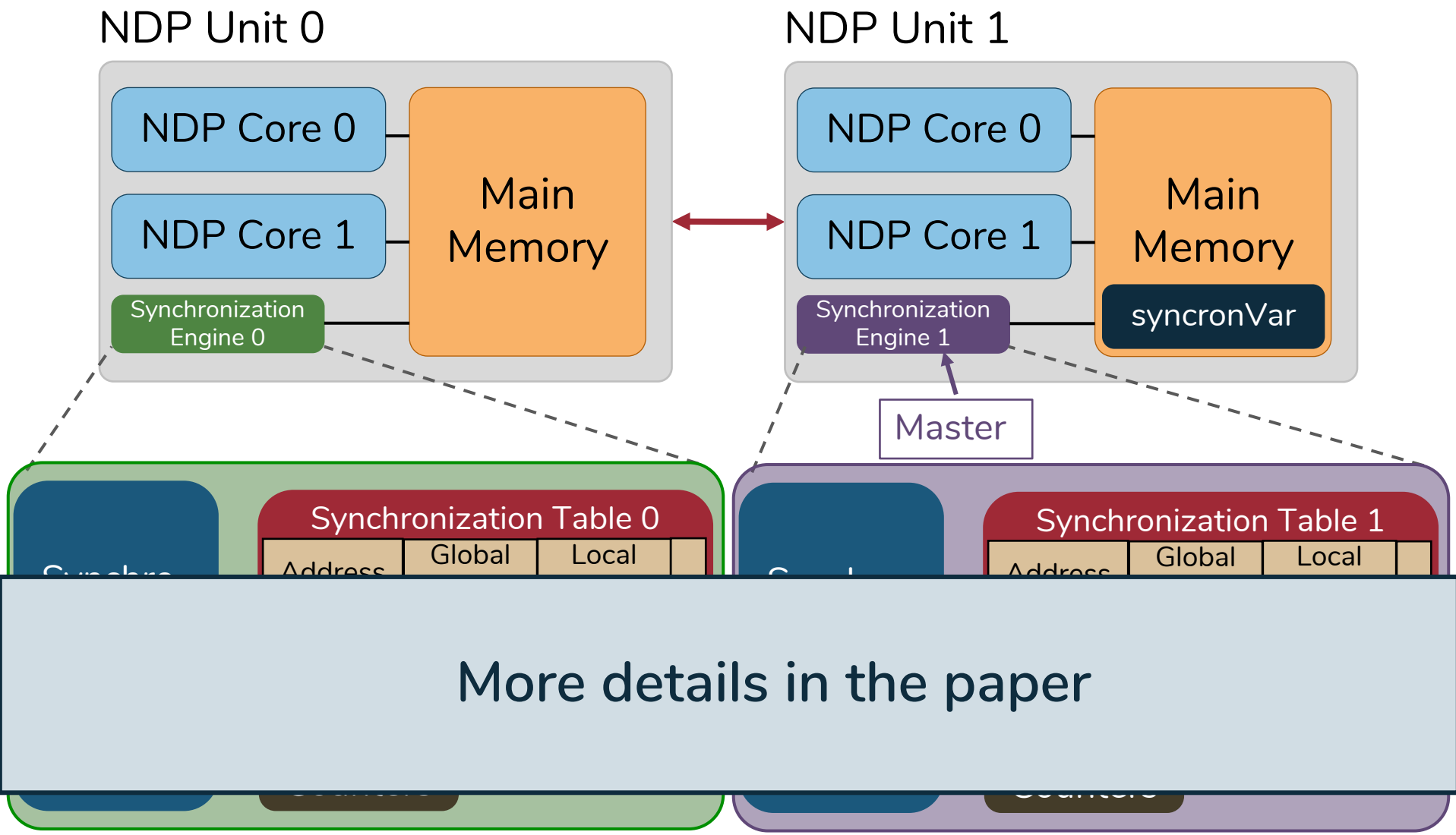


Lock Operation



More details in the paper

Outline

NDP Synchronization Solution Space

Our Mechanism: SynCron

Evaluation

Evaluation Methodology

- Simulators:
  - Zsim [Sanchez+, ISCA'13]
  - Ramulator [Kim+, CAL'15]
- System Configuration:
  - 4x NDP units of 16 in-order cores
  - 16KB L1 Data + Instr. Cache
  - 4GB HBM memory
- SynCron's Default Parameters:
  - Synchronization Processing Unit @1GHz
  - 12-cycle worst-case latency for a message to be served [Aladdin]
  - 64 entries in Synchronization Table, 1-cycle latency [CACTI]
  - 256 entries in indexing counters 2-cycle latency [CACTI]
- Workloads:
  - 9x Pointer-chasing Data Structures from ASCYLIB [David+, ASPLOS'15]
  - 6x Graph Applications from Crono [Ahmad+, IISWC'15]
  - Time Series Analysis from Matrix Profile [Yeh+, ICDM'16]

Comparison Points for SynCron

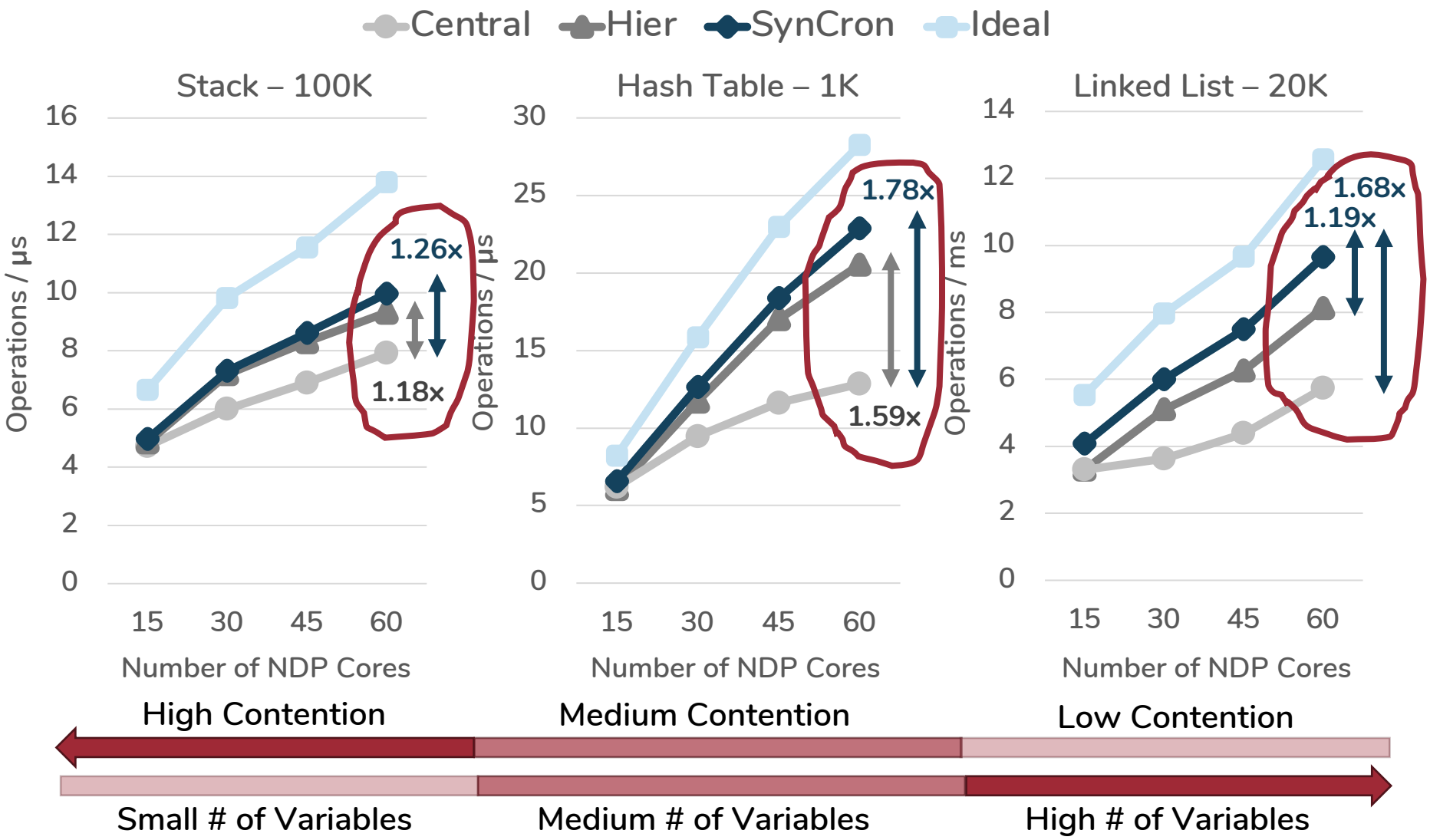
1. SynCron

2. Central [Ahn+, ISCA'15]:
   - Synchronization Server: One NDP core of the NDP system
   - Centralized hardware message-passing communication

3. Hier [Gao+, PACT'15 / Tang+, ASPLOS'19]:
   - Synchronization Servers: One NDP core per NDP unit
   - Hierarchical hardware message-passing communication

4. Ideal
   - Zero overhead for synchronization

Throughput of Pointer Chasing



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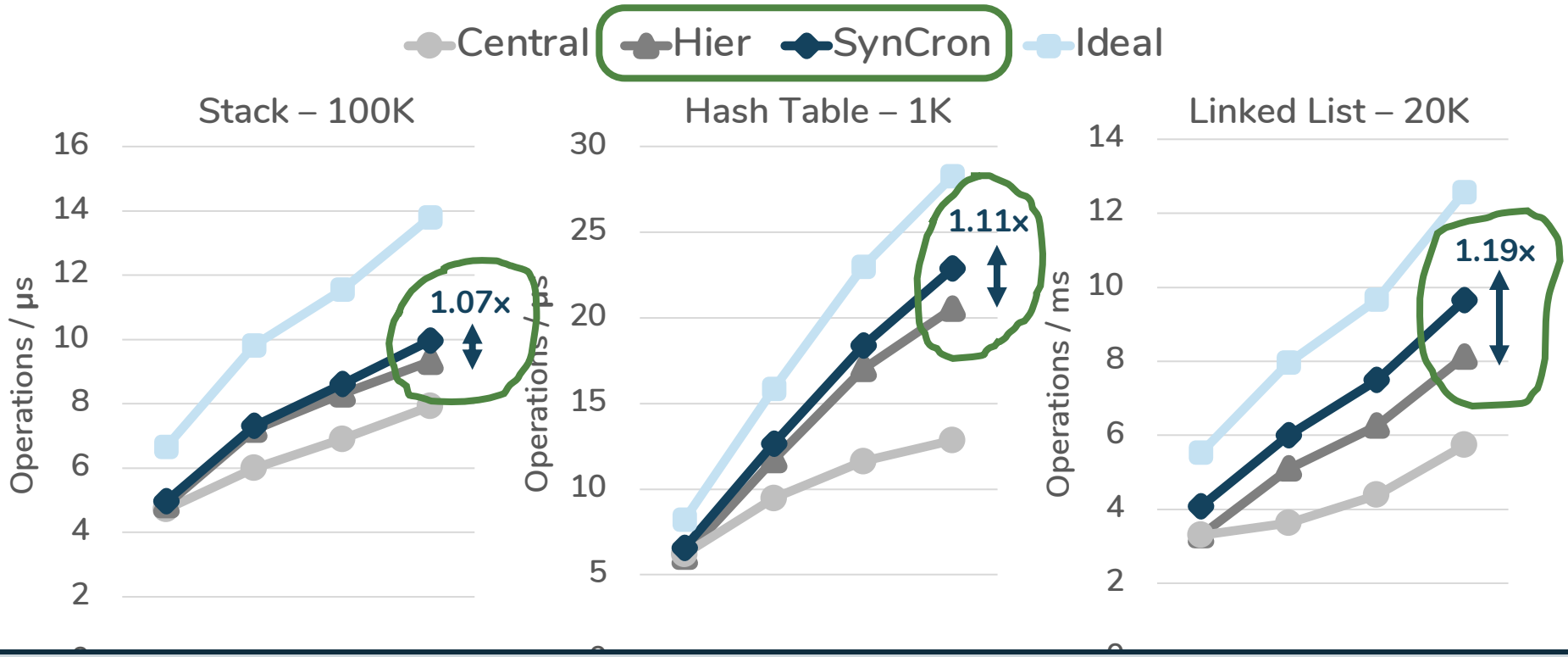
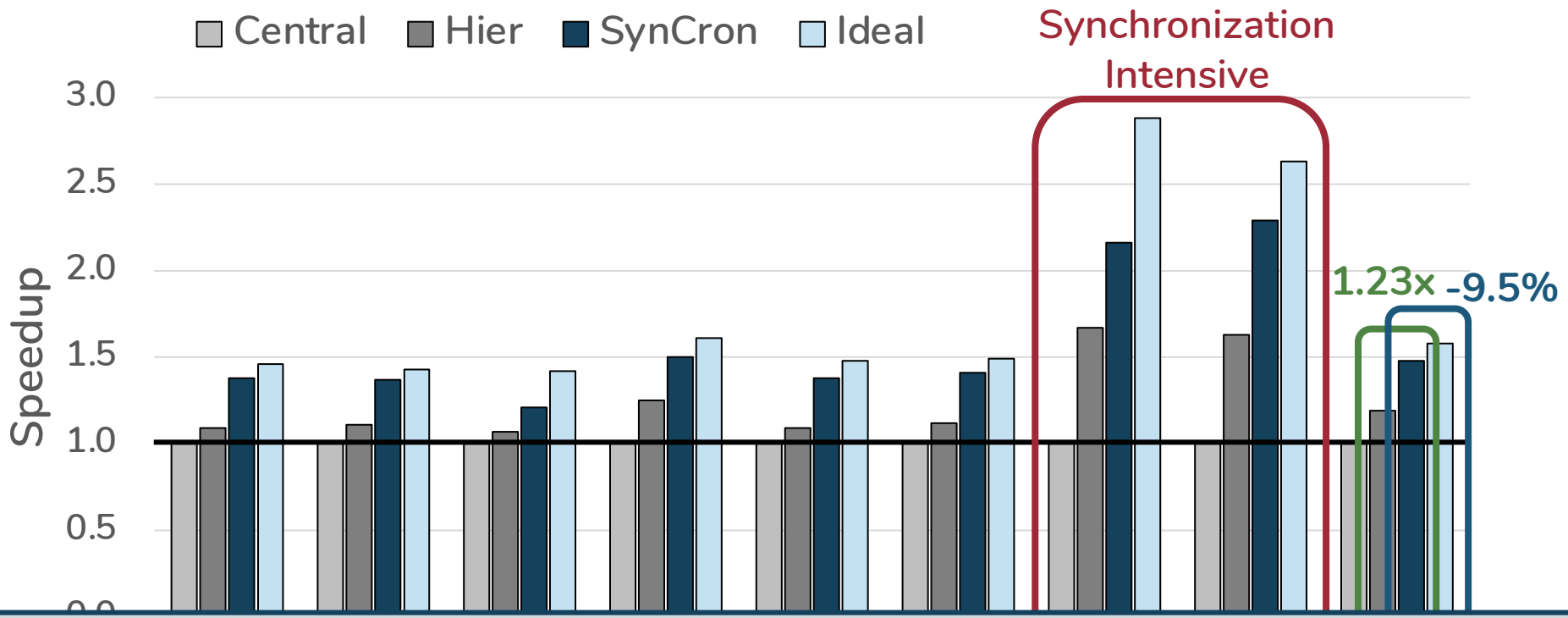


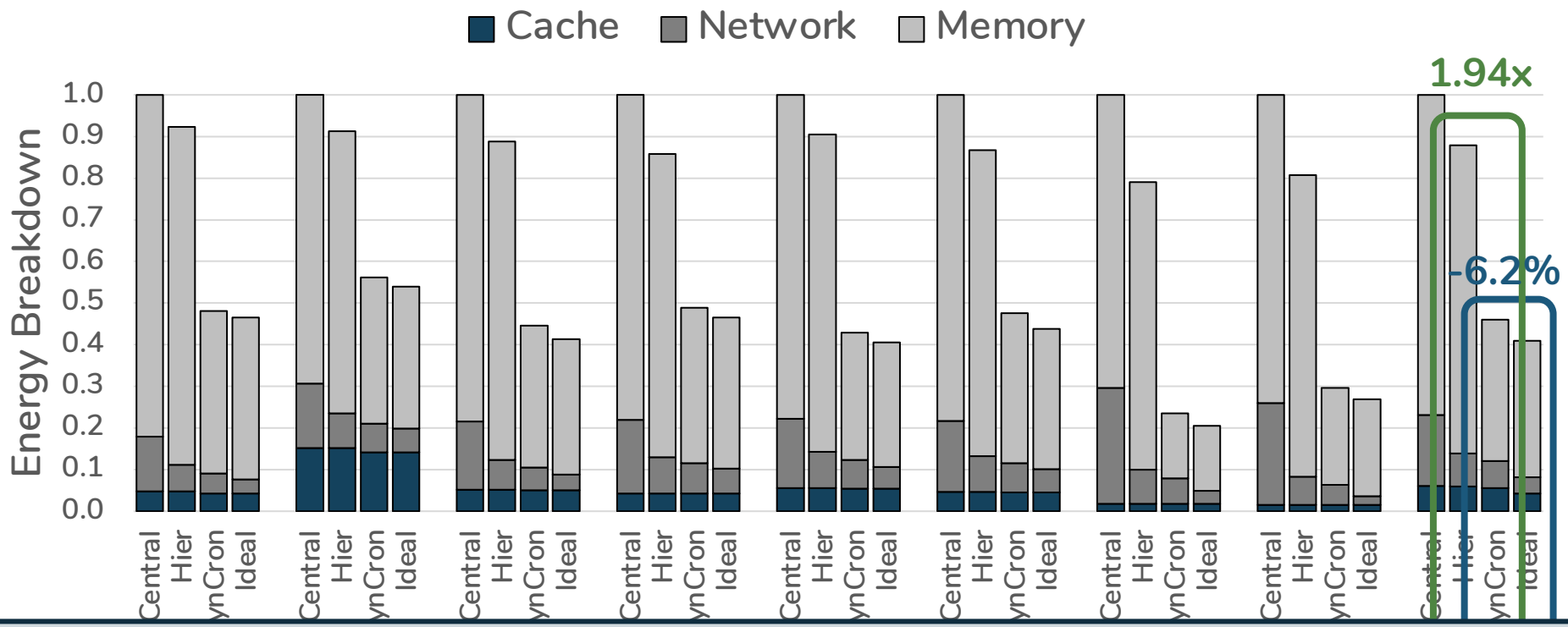
SynCron achieves the highest throughput under all scenarios

Speedup in Real Applications



SynCron performs best across all real applications

System Energy in Real Applications



SynCron reduces system energy significantly

Area and Power Overheads

		Synchronization Engine	ARM Cortex A7
Technology		40nm	28nm
Area	9.78%	Total: 0.0461mm2	Total: 0.45mm2
Power	2.70%	2.7mW	100mW

SynCron has low area and power overheads

Sensitivity Studies

- Different memory technologies (HBM, HMC, DDR4)
- Various data placement techniques
- Various transfer latencies on links across NDP units
- Overflow management cost
- Various sizes for the Synchronization Table

SynCron is effective for a wide variety of configurations

Summary & Conclusion

- Synchronization is a major system challenge for NDP systems
- Prior schemes are not suitable or efficient for NDP systems
- SynCron is the first end-to-end synchronization solution for NDP architectures
- Syncron consists of four key techniques:
  i. Hardware support for synchronization acceleration
  ii. Direct buffering of synchronization variables
  iii. Hierarchical message-passing communication
  iv. Integrated hardware-only overflow management
- SynCron's benefits: 90.5% and 93.8% of performance and energy of an Ideal zero-overhead scheme
- SynCron is highly-efficient, low-cost, easy-to-use, and general to support many synchronization primitives

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