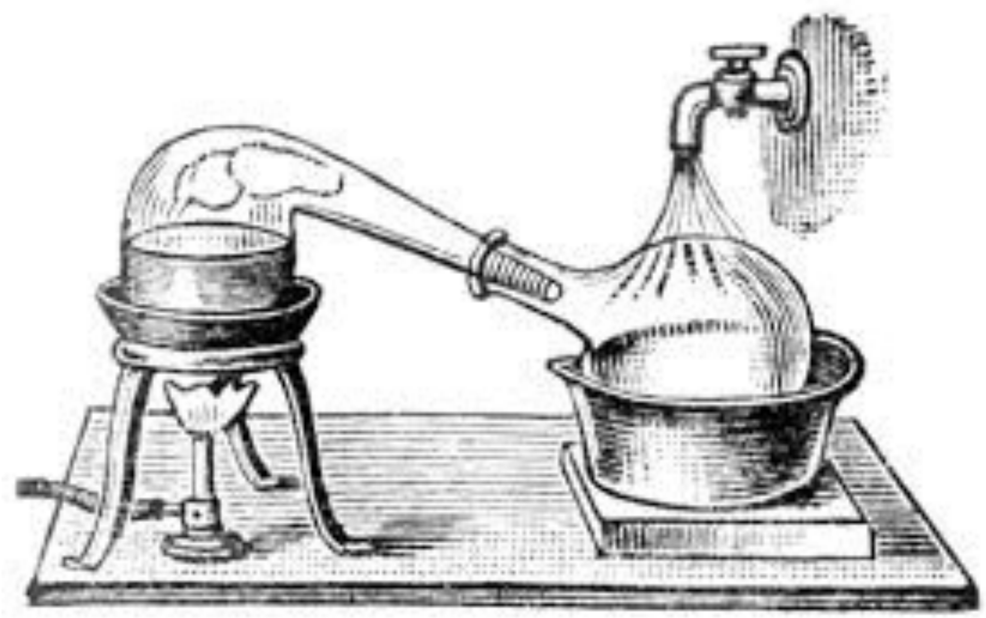
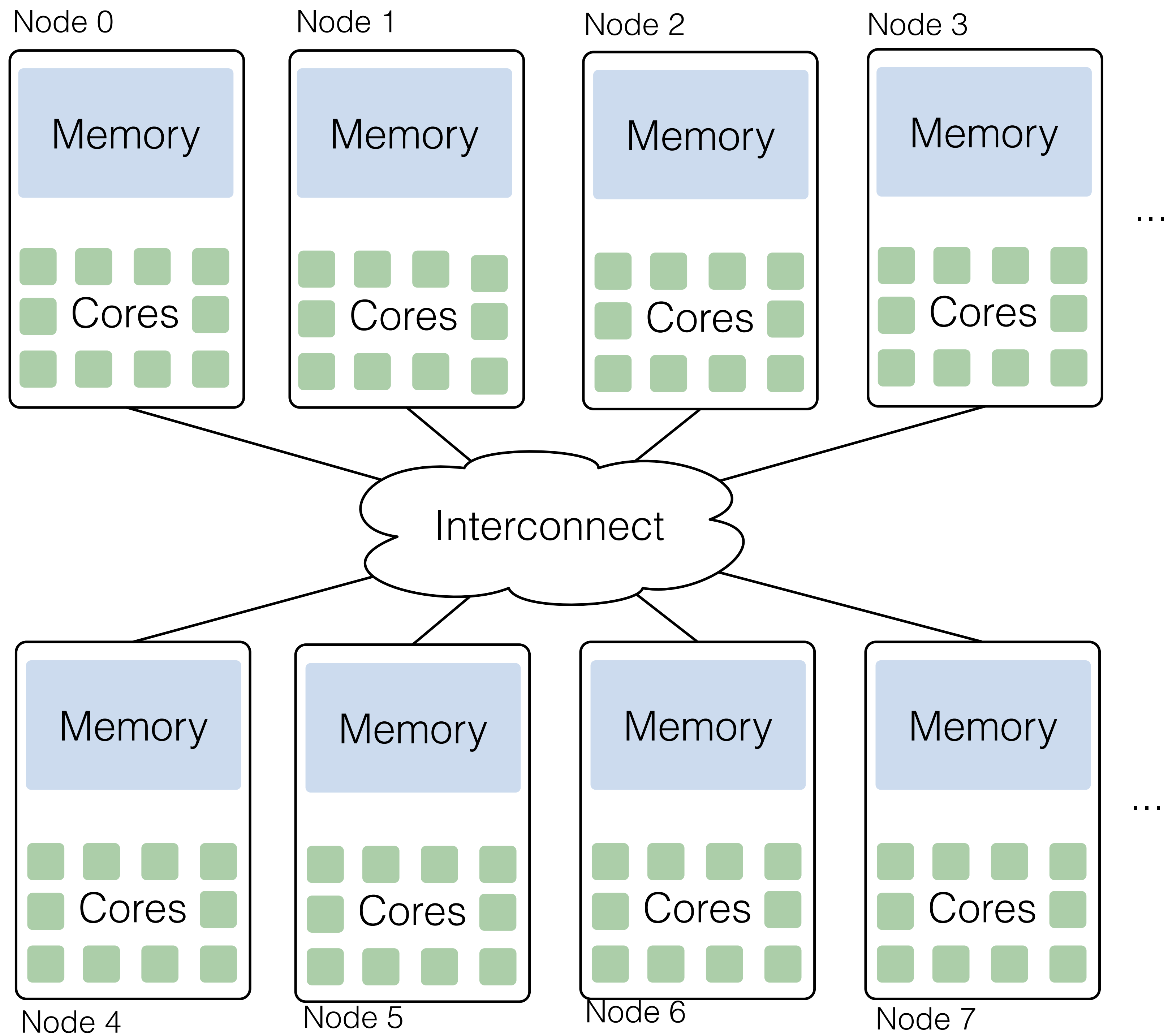
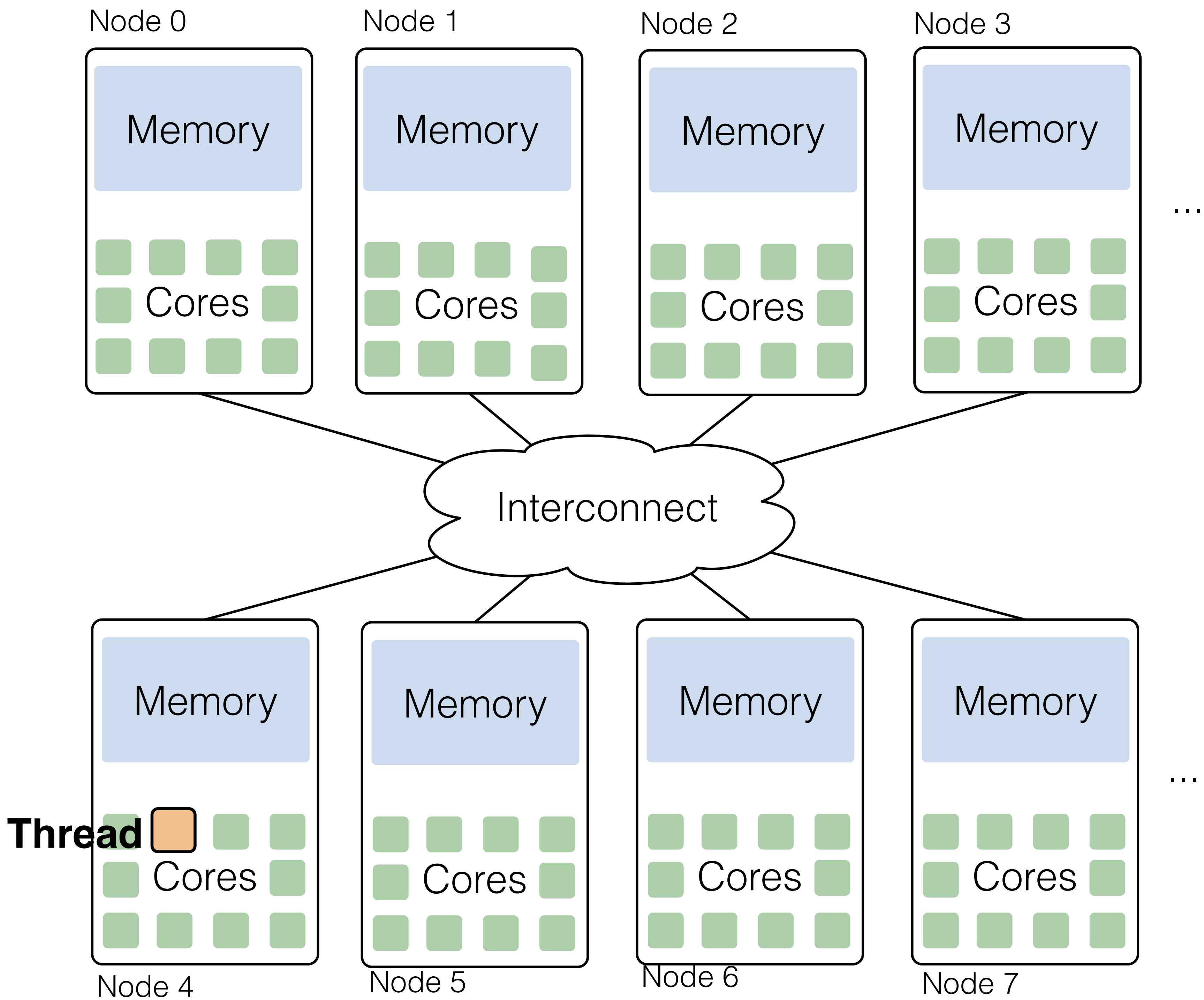


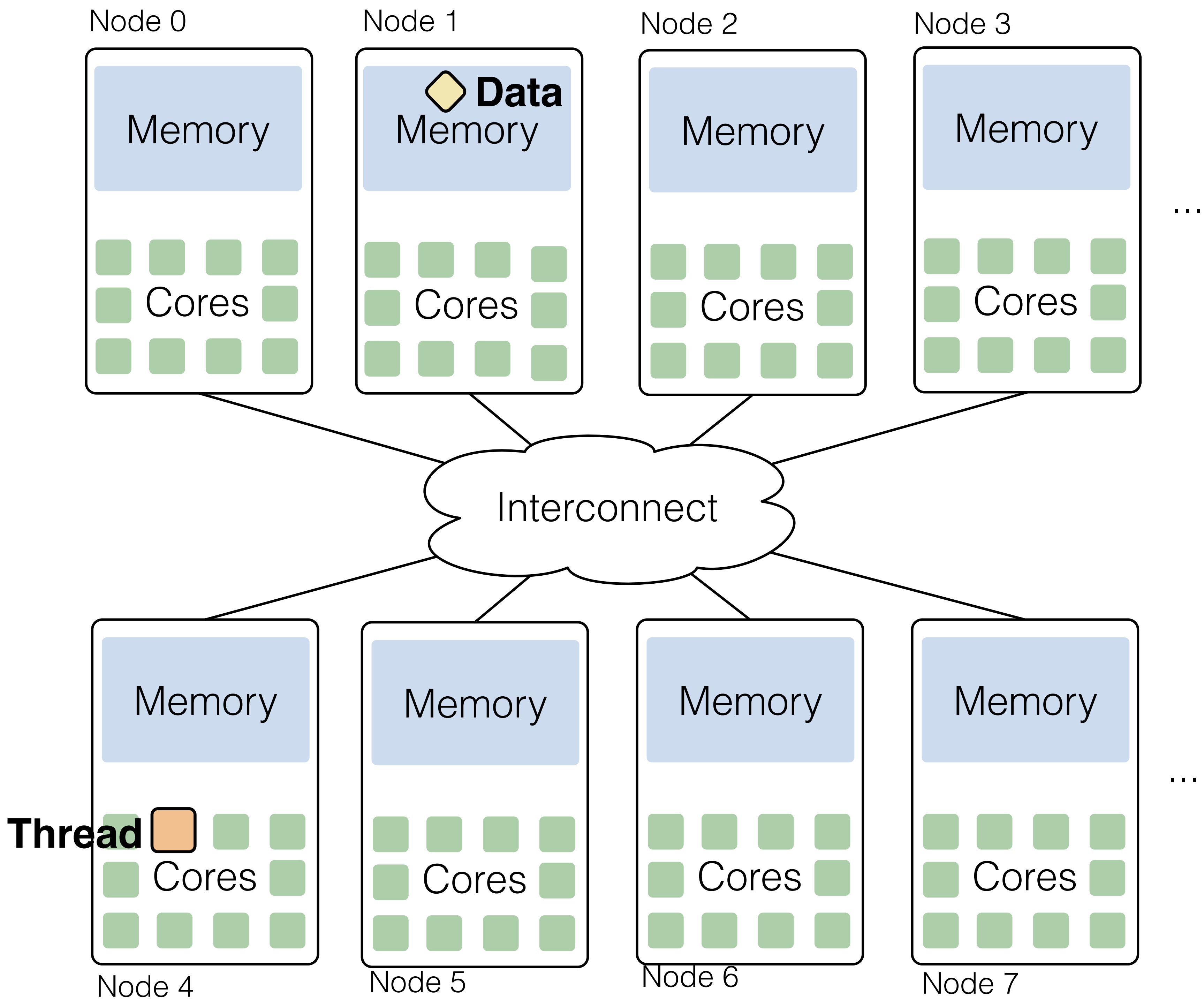
Alembic

Automatic Locality Extraction via Migration

Brandon Holt, Preston Briggs, Luis Ceze, Mark Oskin


Node 0
Node 1
Node 2
Node 3
Memory
Cores
...
Interconnect
Node 4
Node 5
Node 6
Node 7


Node 0
Node 1
Node 2
Node 3
Memory
Cores
...
Interconnect
Thread
Node 4
Node 5
Node 6
Node 7


Node 0
Node 1
Node 2
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Data
Memory
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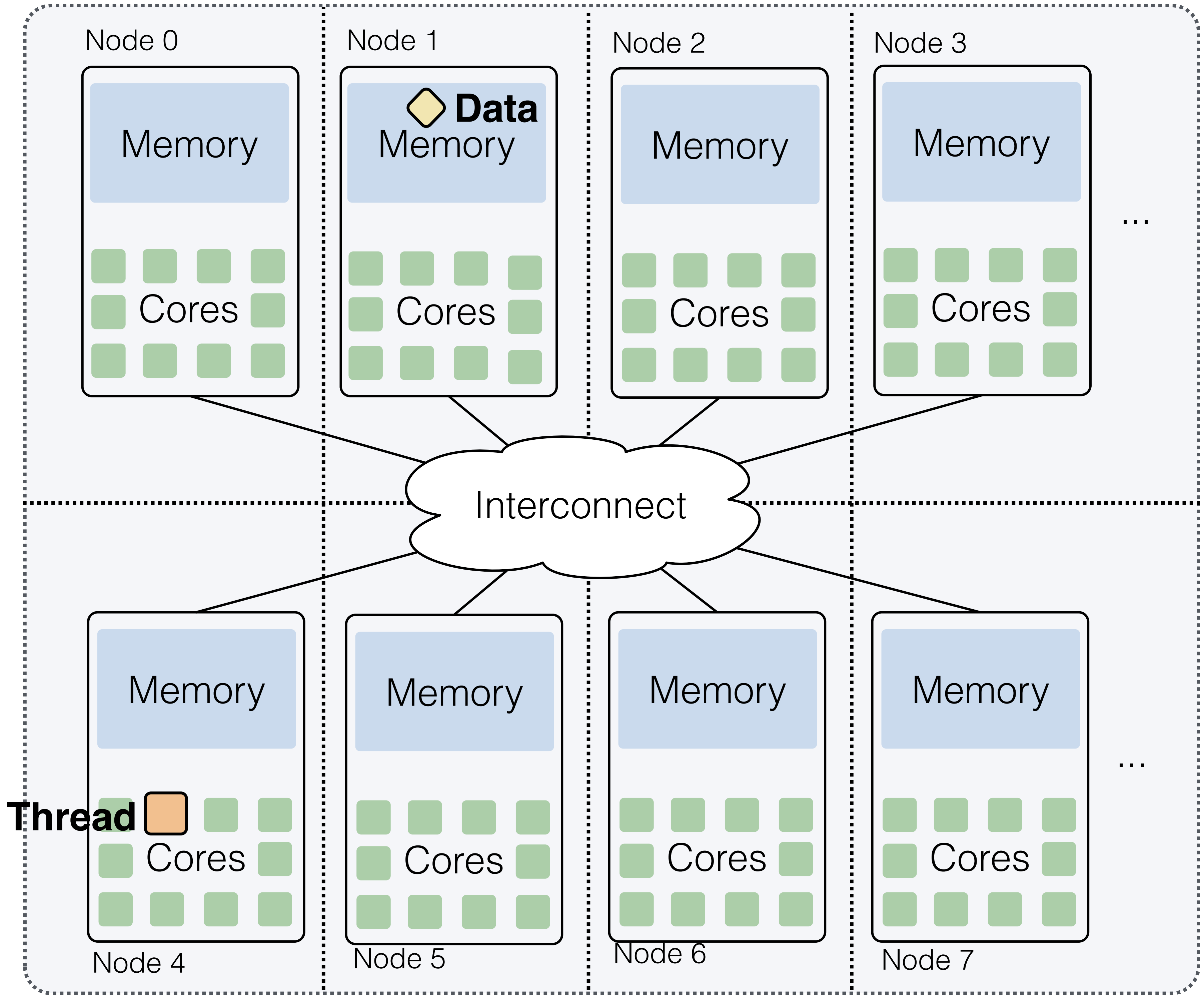
Node 4
Node 5
Node 6
Node 7

Partitioned Global Address Space (PGAS)



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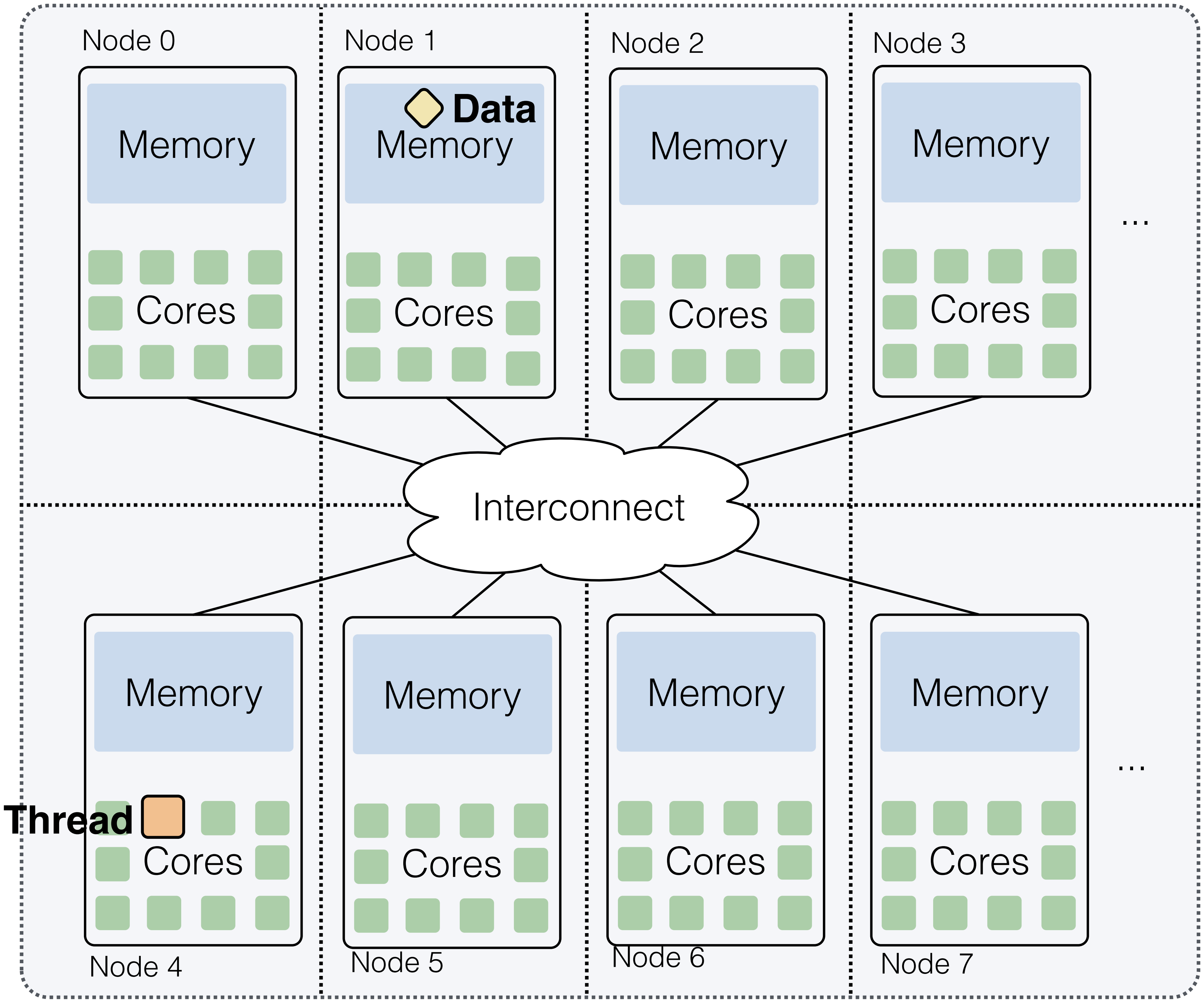
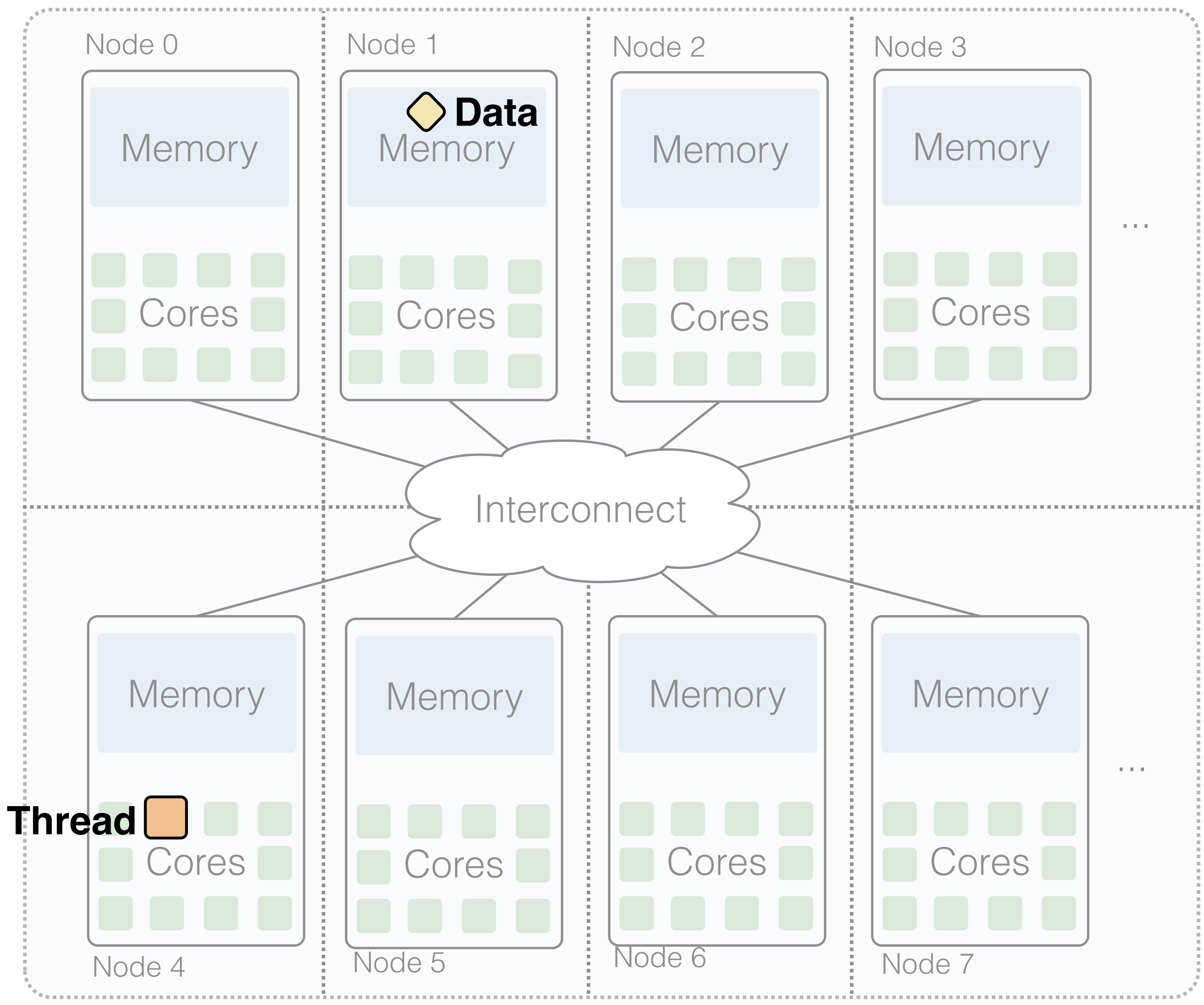


Move data or computation?



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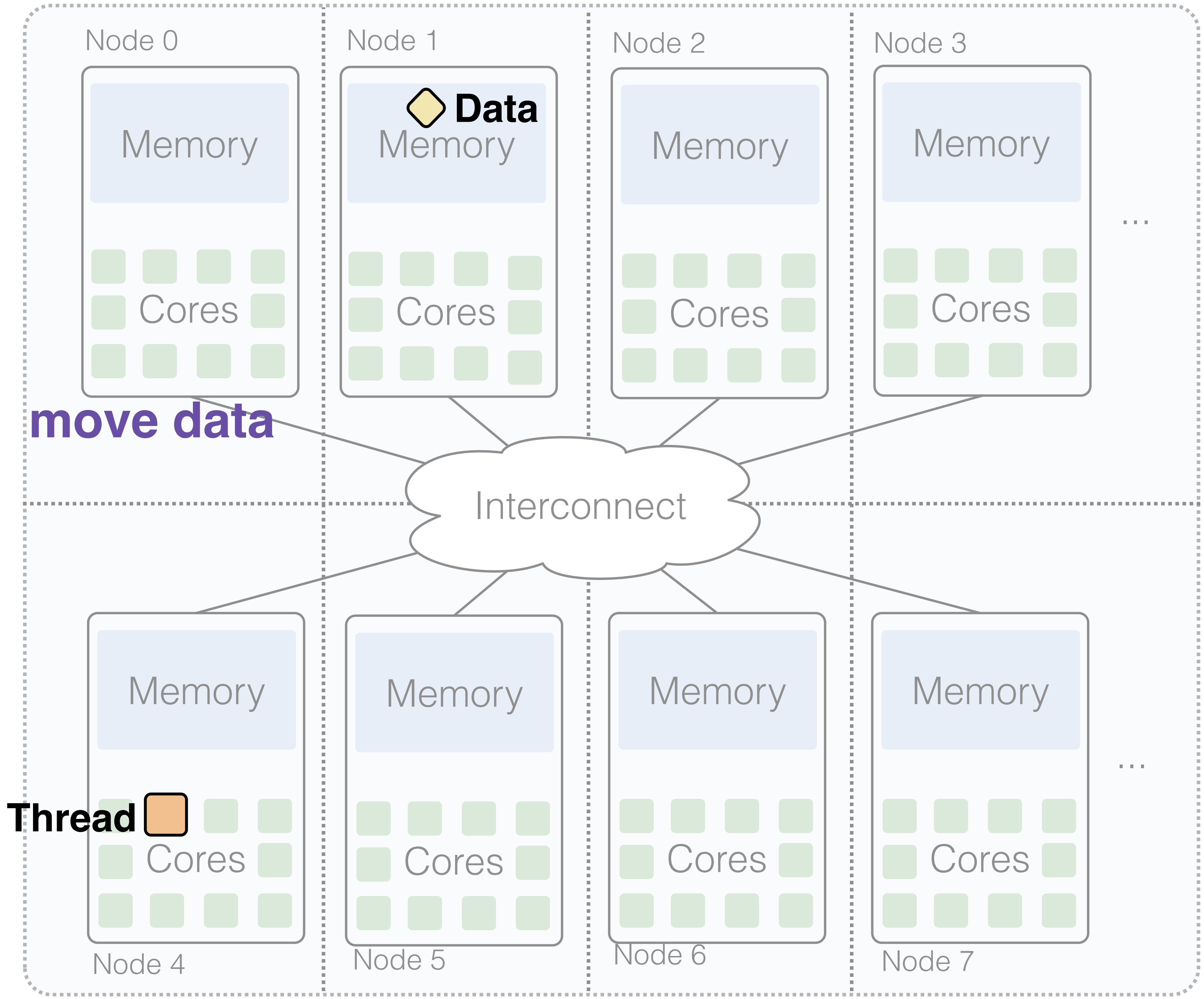

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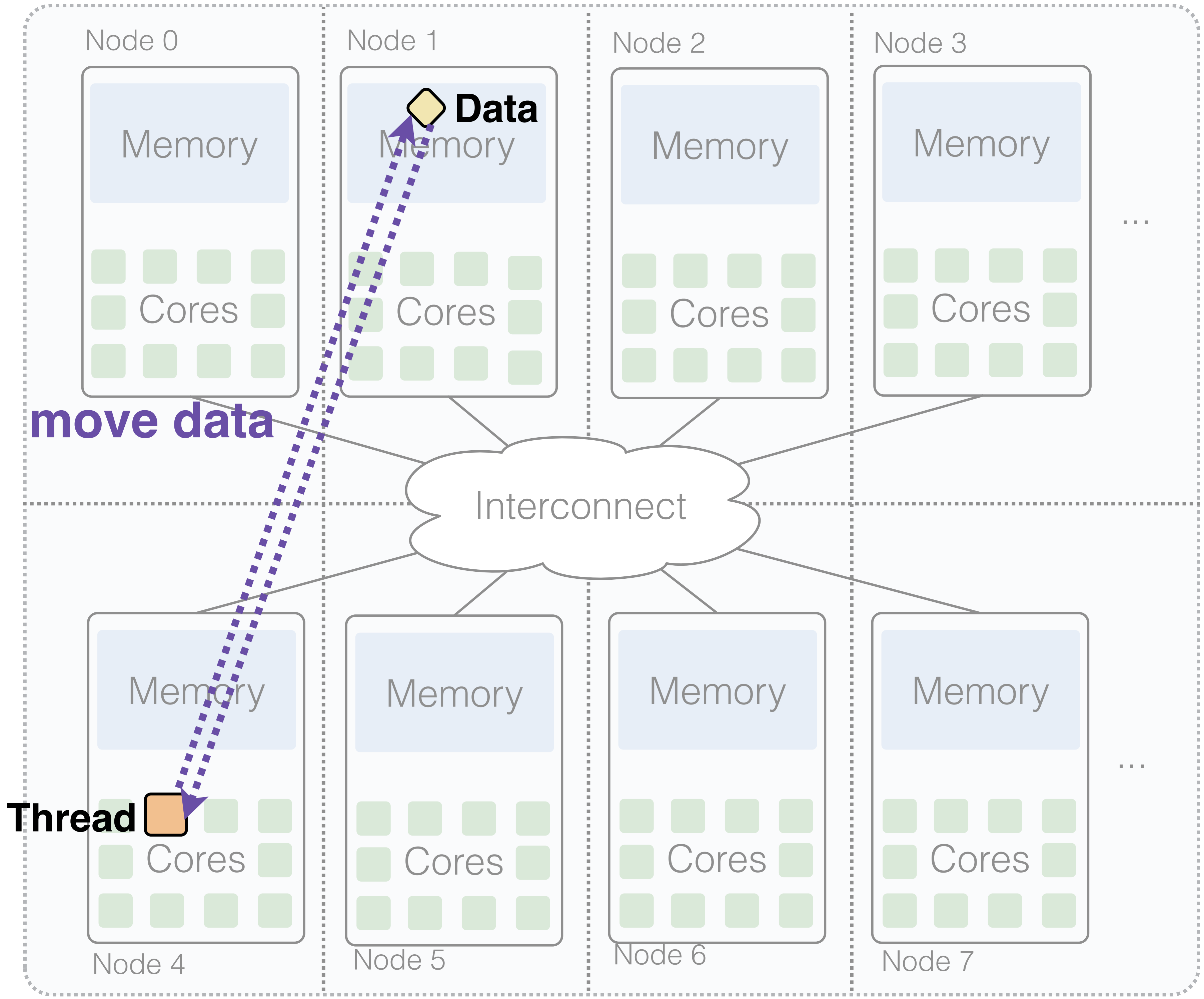

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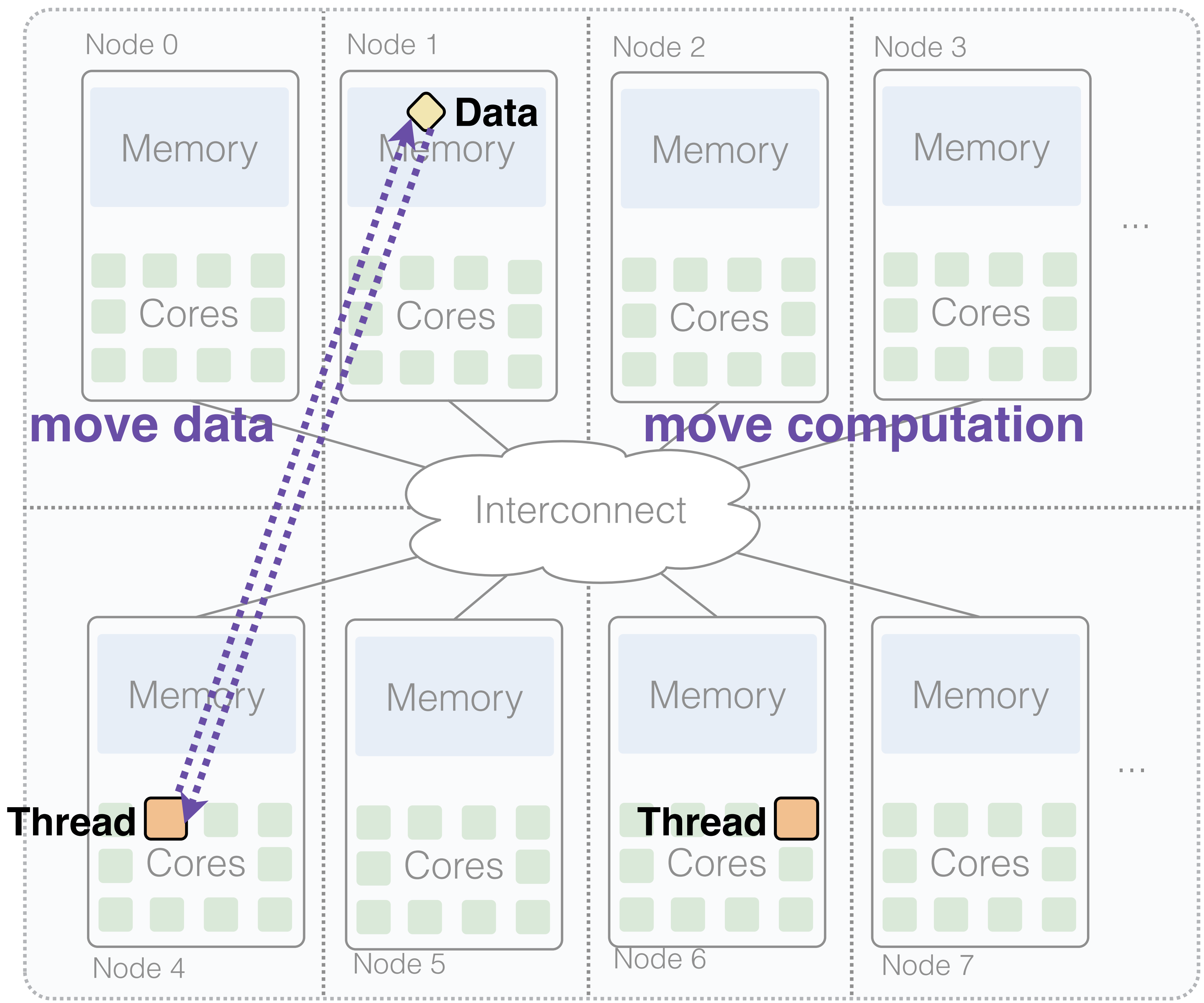

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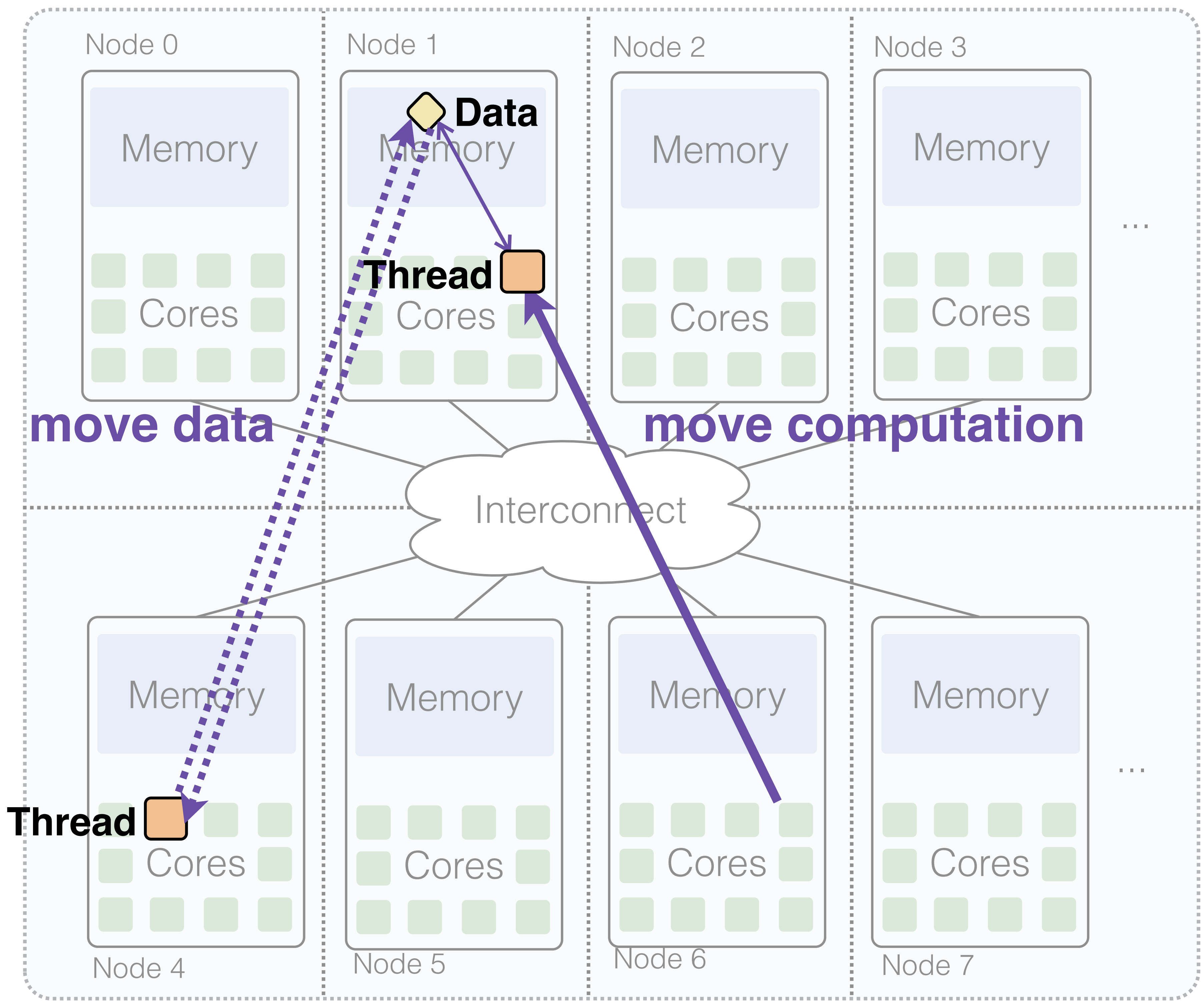

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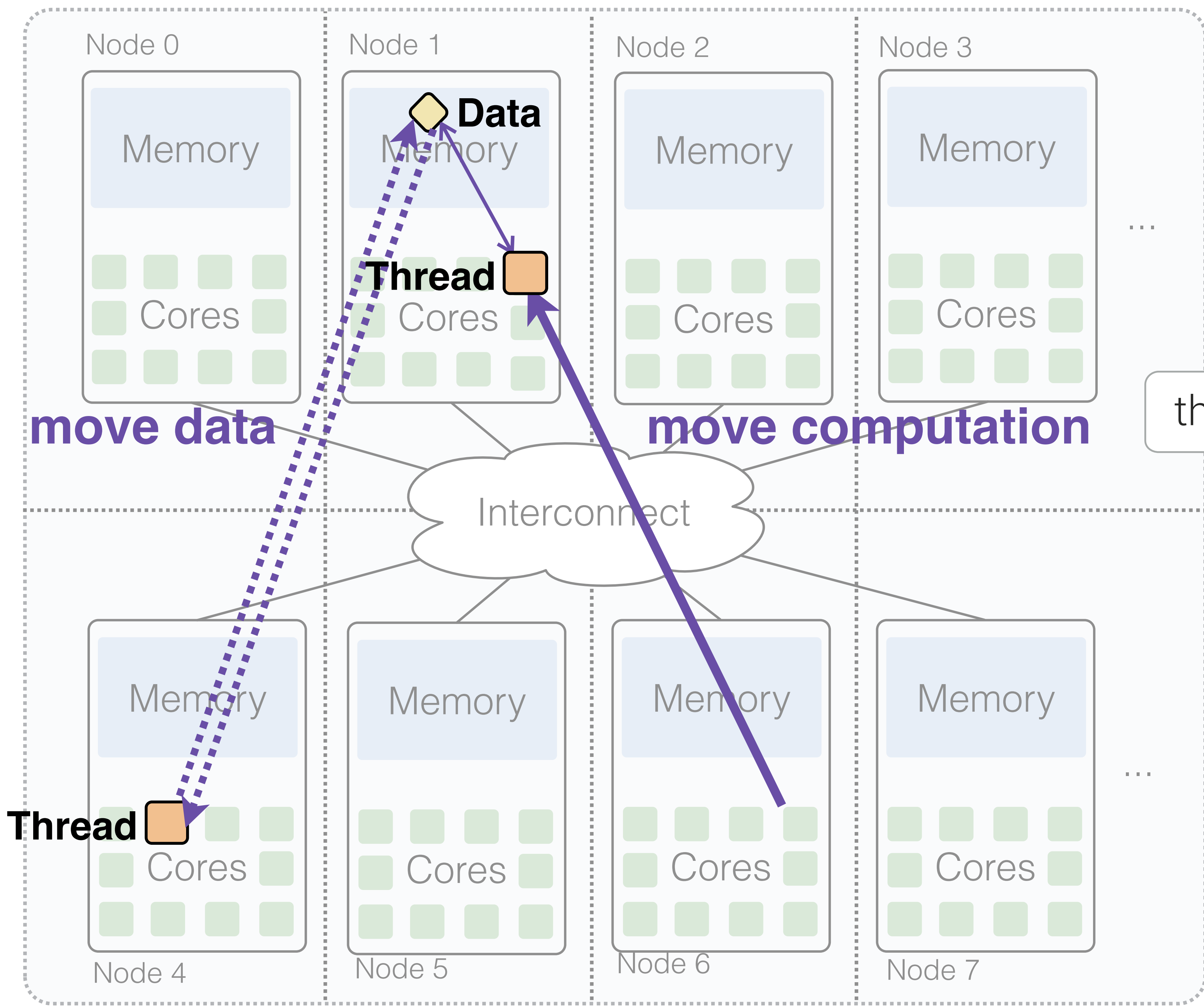

thread migration*

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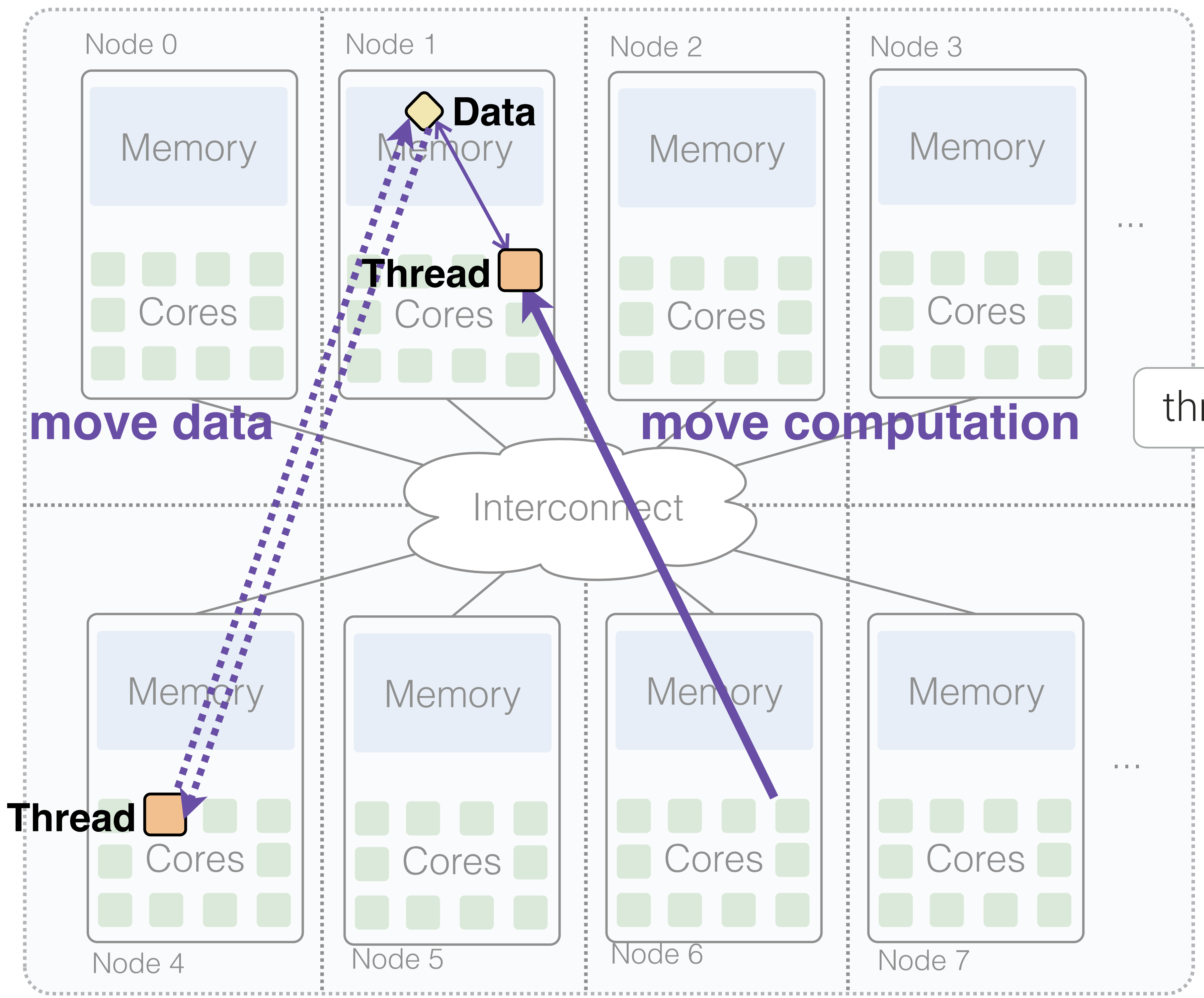

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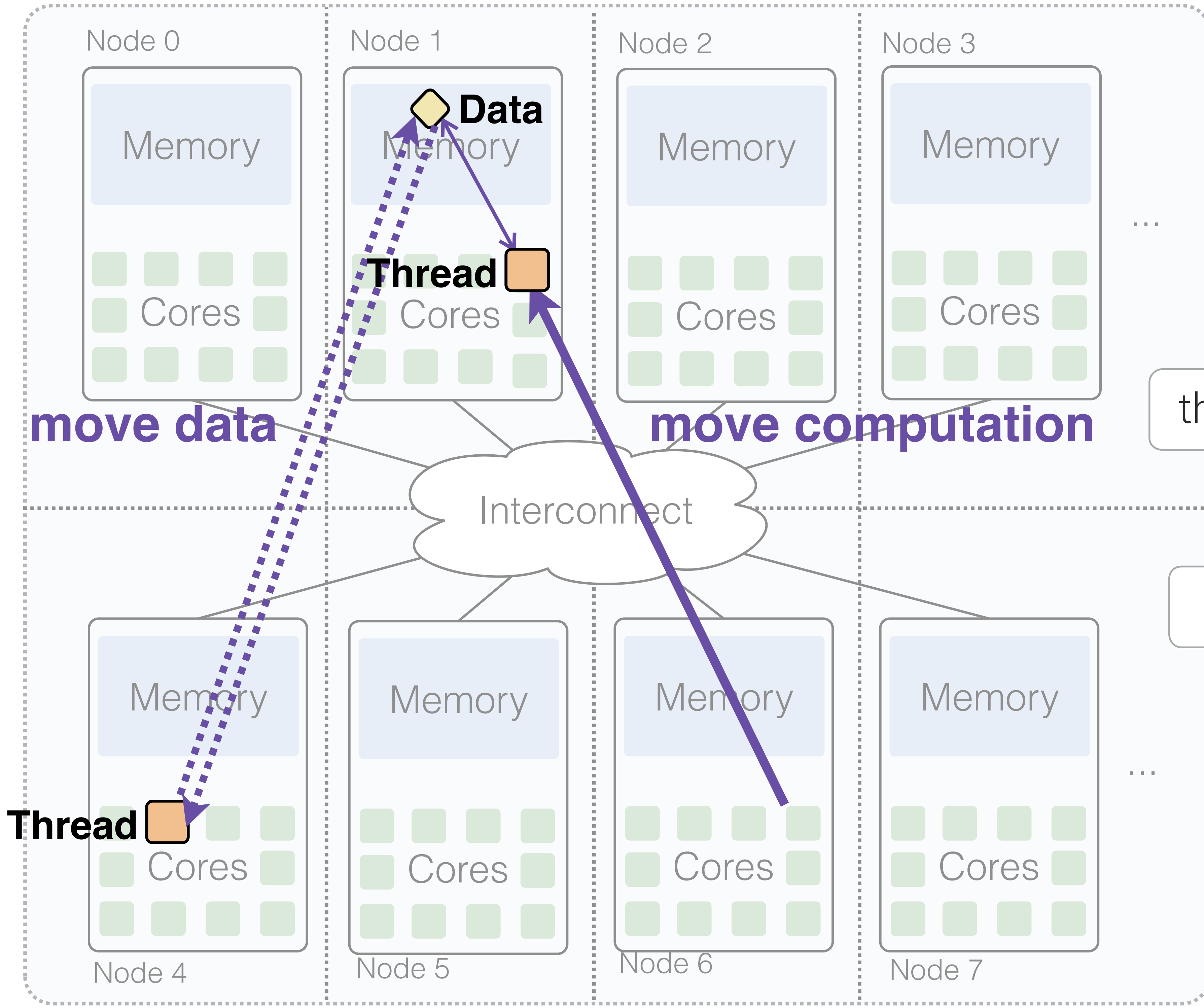

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explicit (`on`/`at`)

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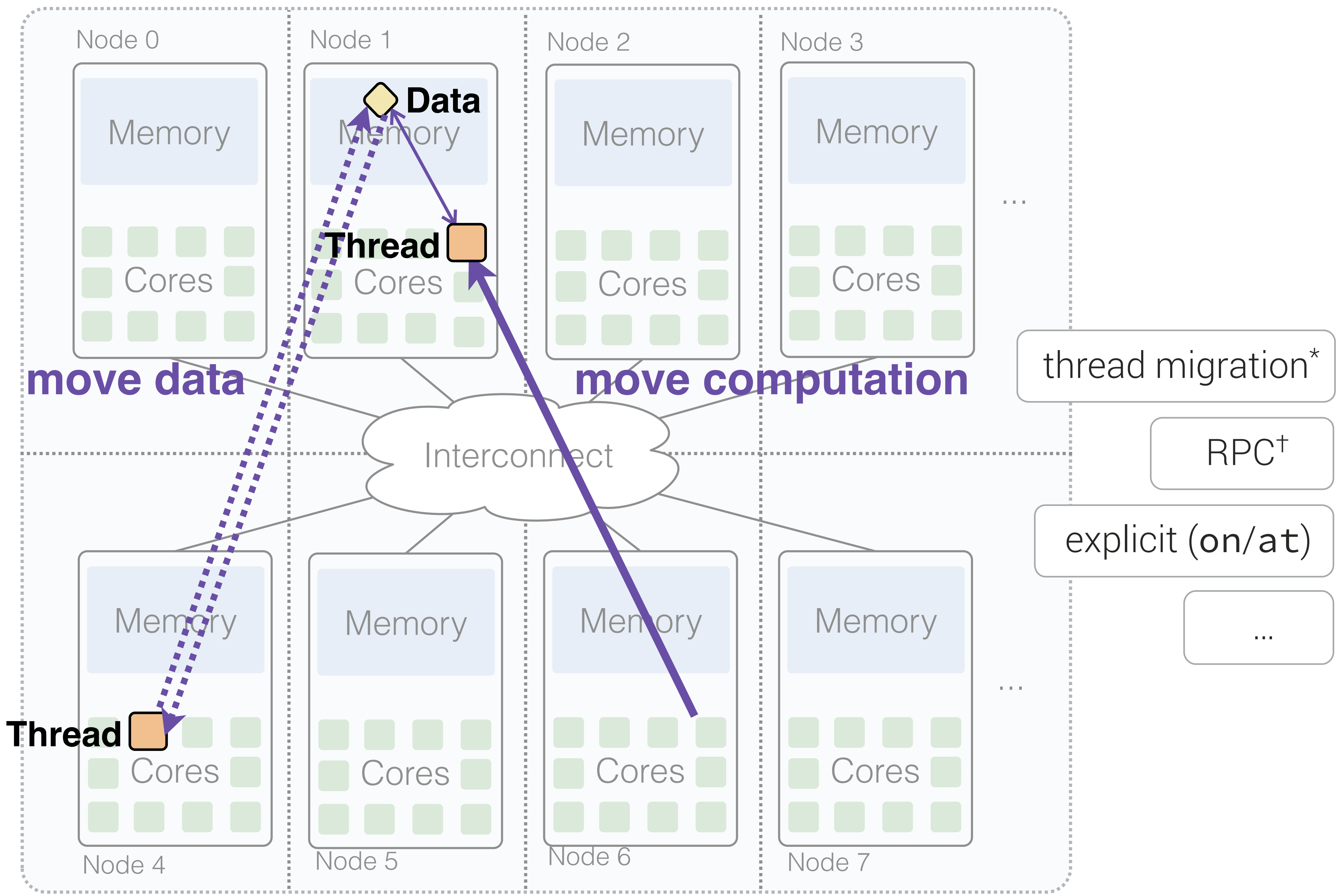

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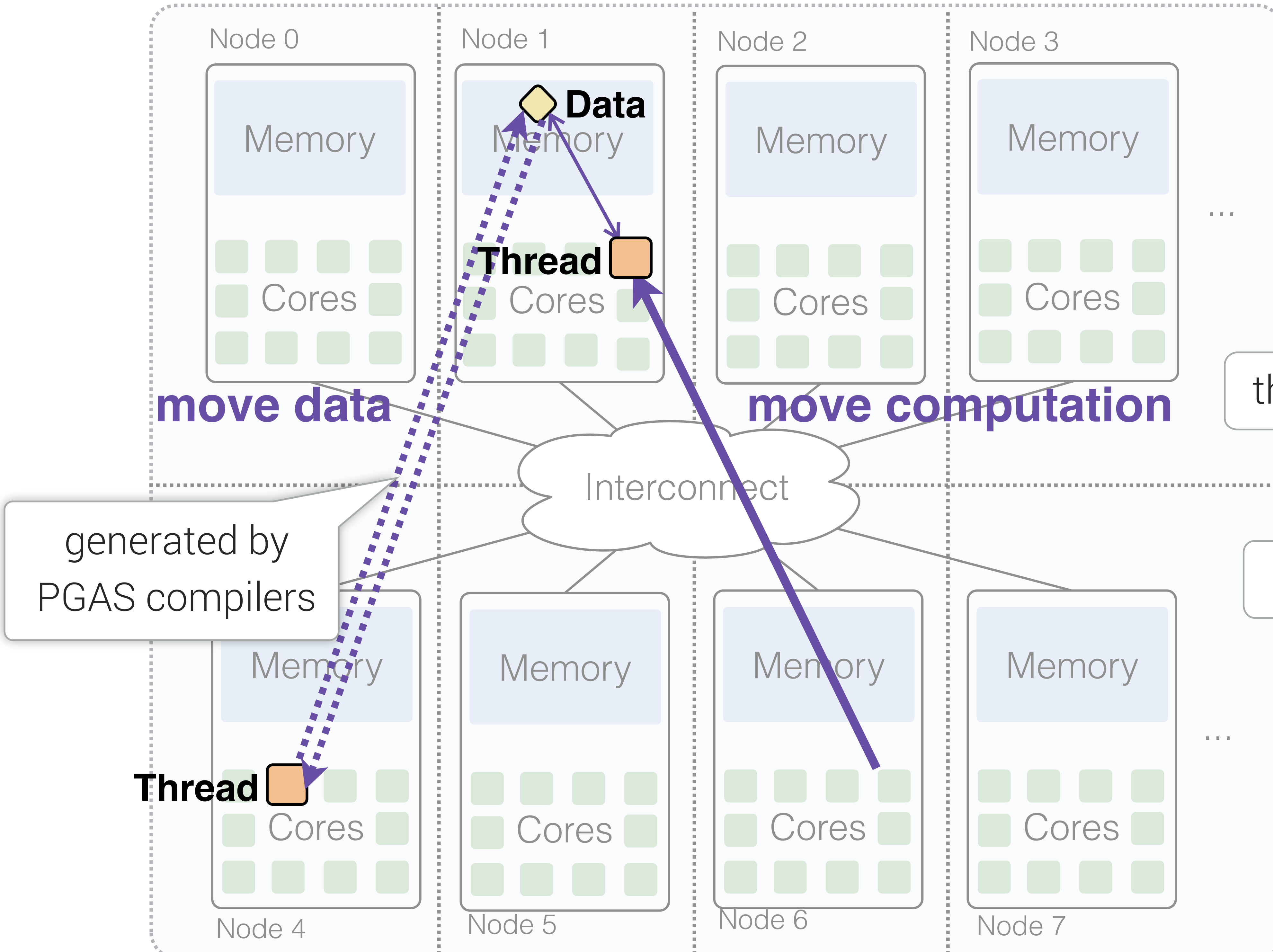

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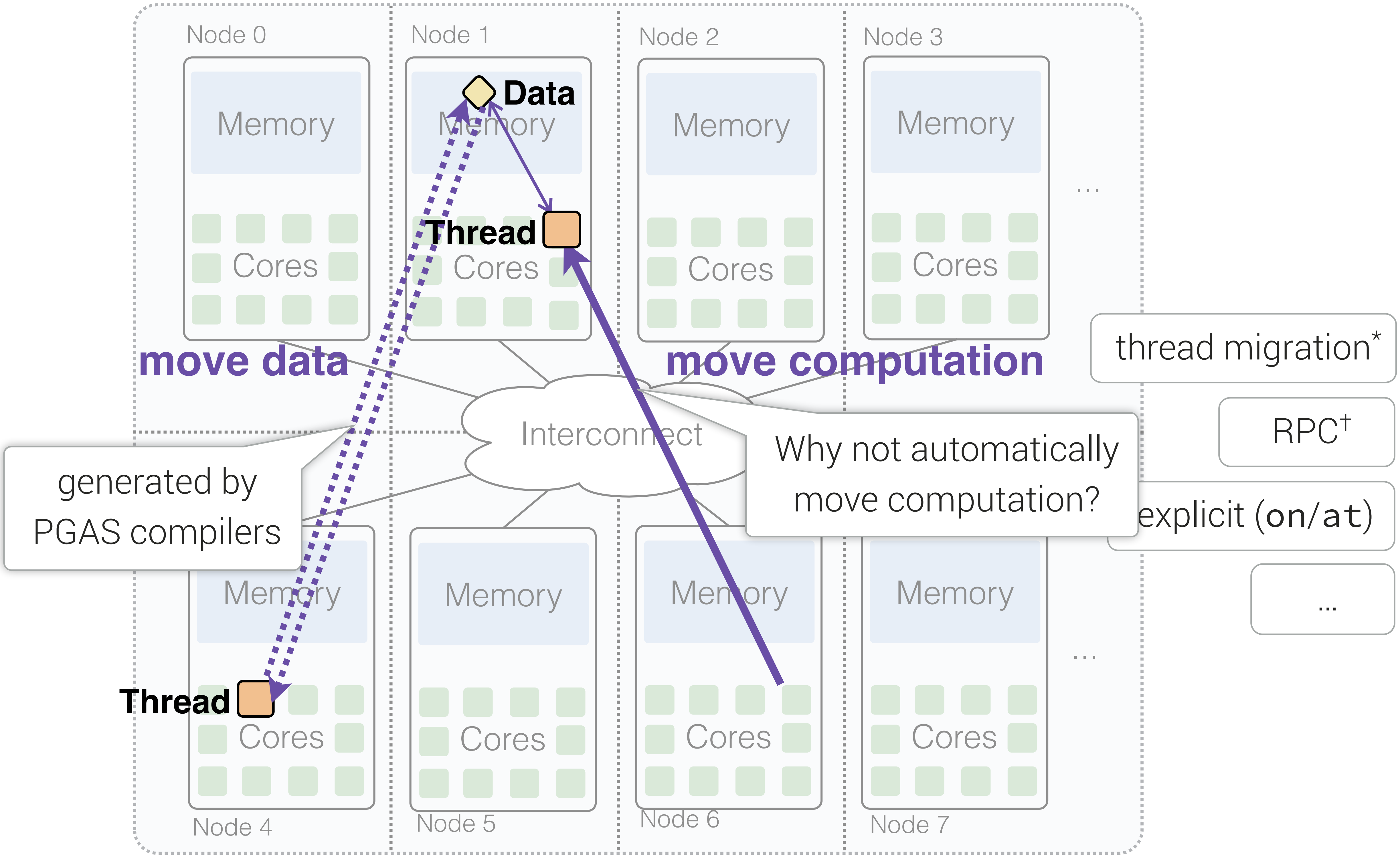

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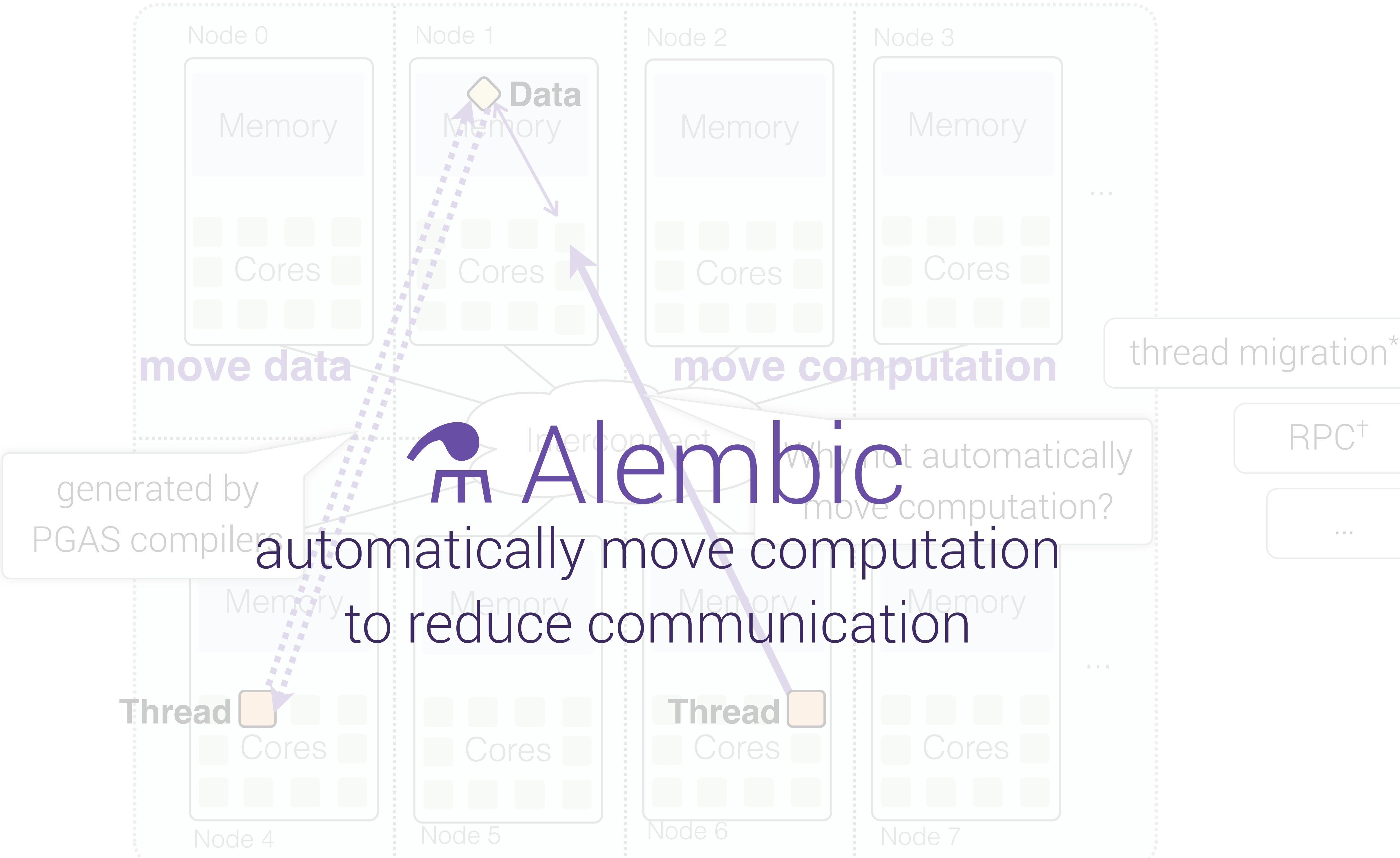

Alembic

automatically move computation
to reduce communication

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Alembic

Static optimizing migration algorithm

- Constrained by anchor points
- Greedy heuristic to reduce communication

Implementation for C++ in LLVM

Evaluation

- ***6x better*** than naive compiler-generated communication
- 82% of hand-tuned performance

Alembic

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- Constrained by anchor points
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Implementation for C++ in LLVM

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algorithm

algorithm

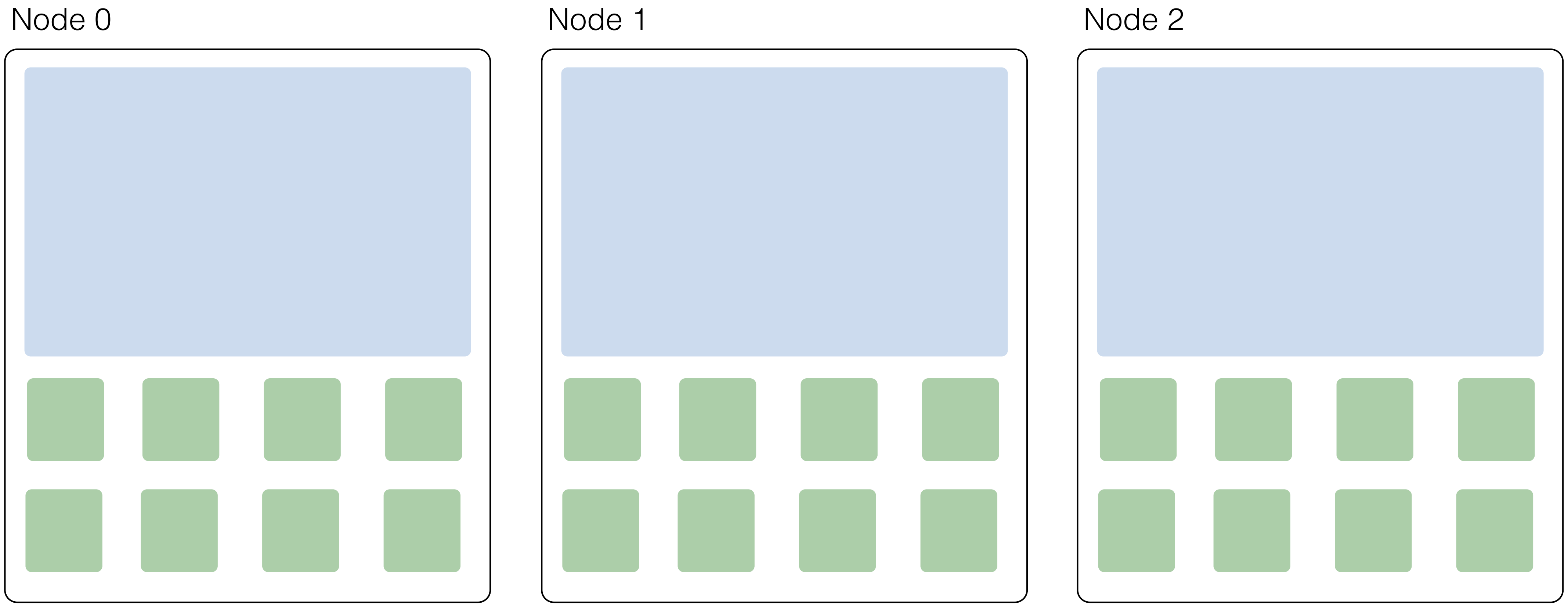
Locality analysis

- Identify *anchor points*
- Partition anchors into *locality sets*

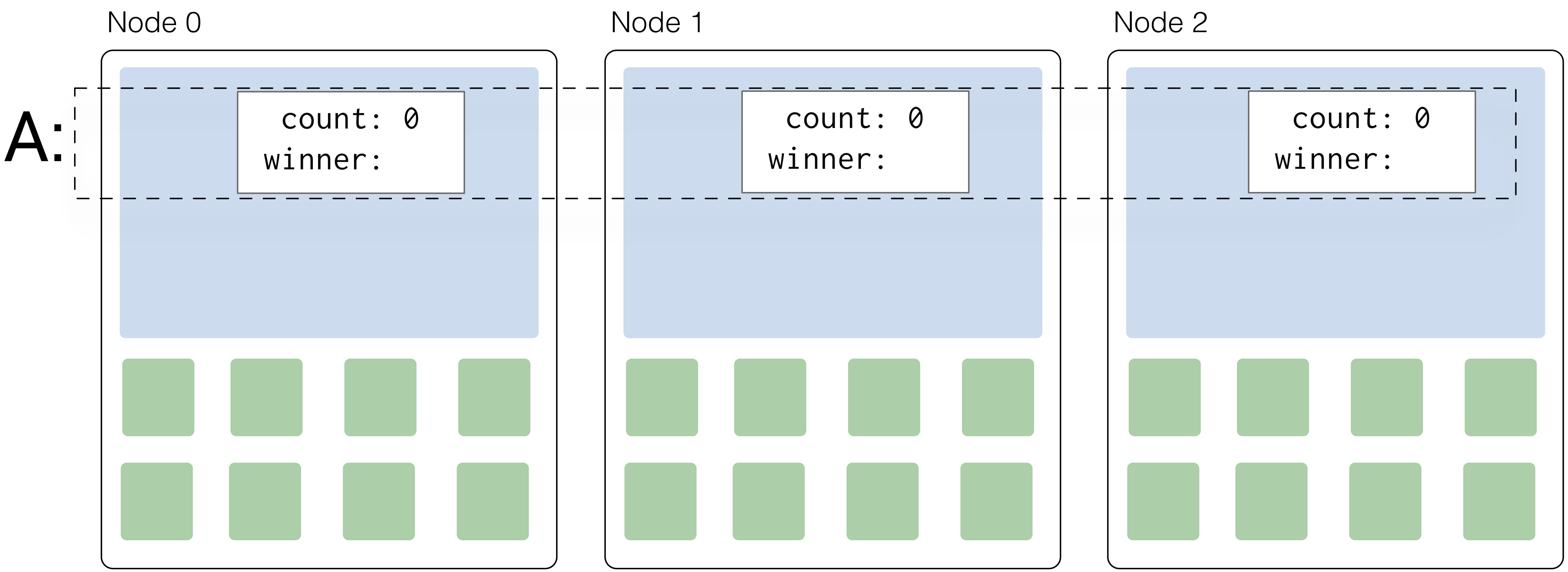
Heuristic region selection

- Divide into regions that *minimize communication*
- Transform task to *migrate* at region boundaries

HOPS Benchmark



HOPS Benchmark



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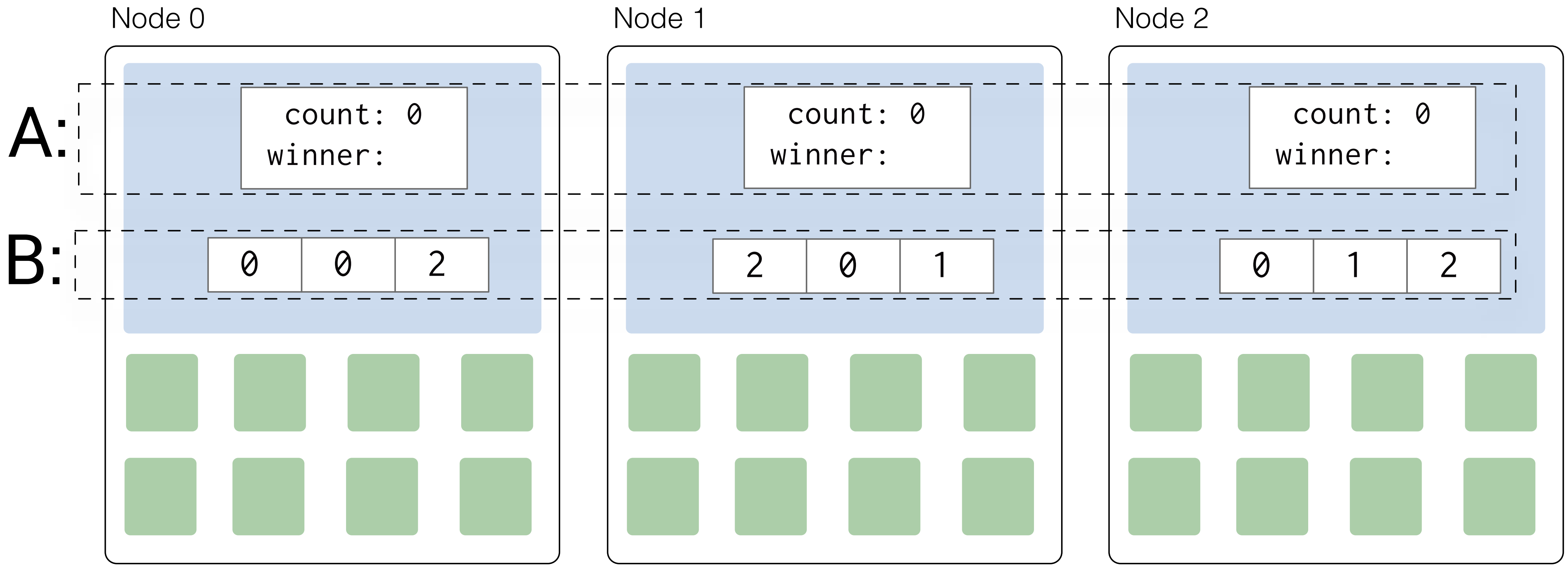

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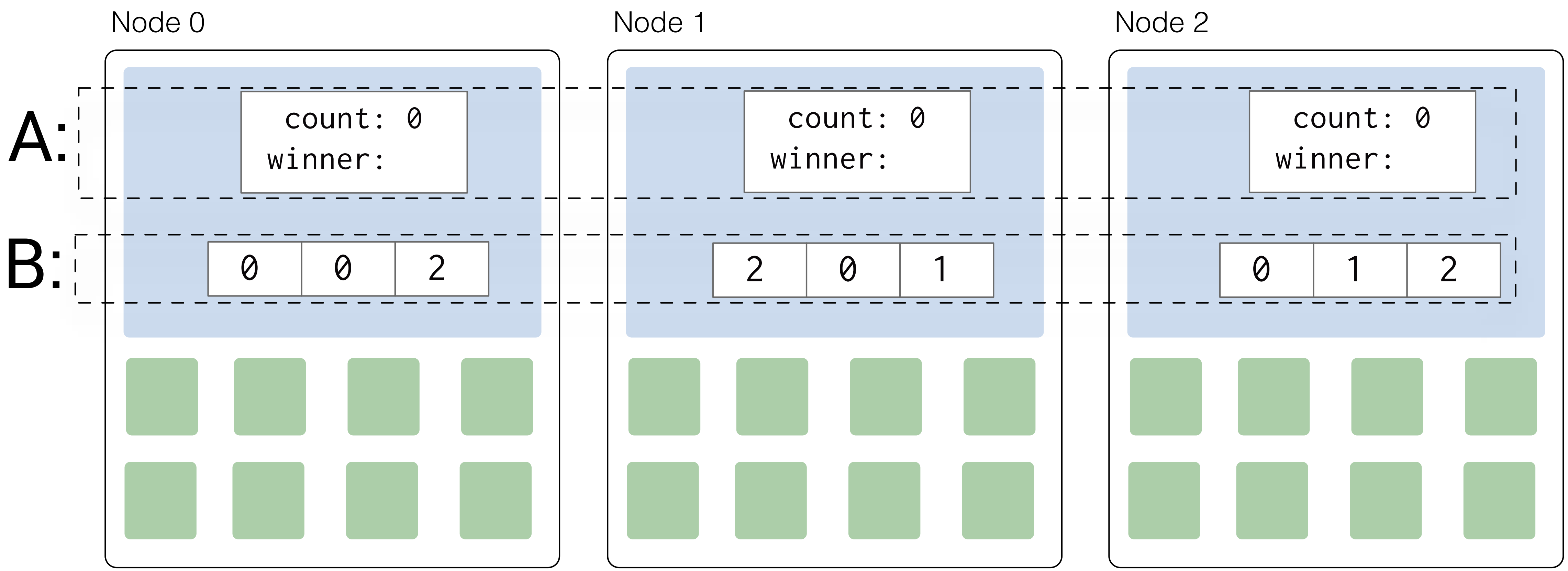


```
forall(0, B.size, [A,B](long i) {
  Counter global* a = A + B[i];
  long prev = fetch_add(&a->count, 1);
  if (prev == 0)    // first to arrive
    a->winner = i; // is winner
});
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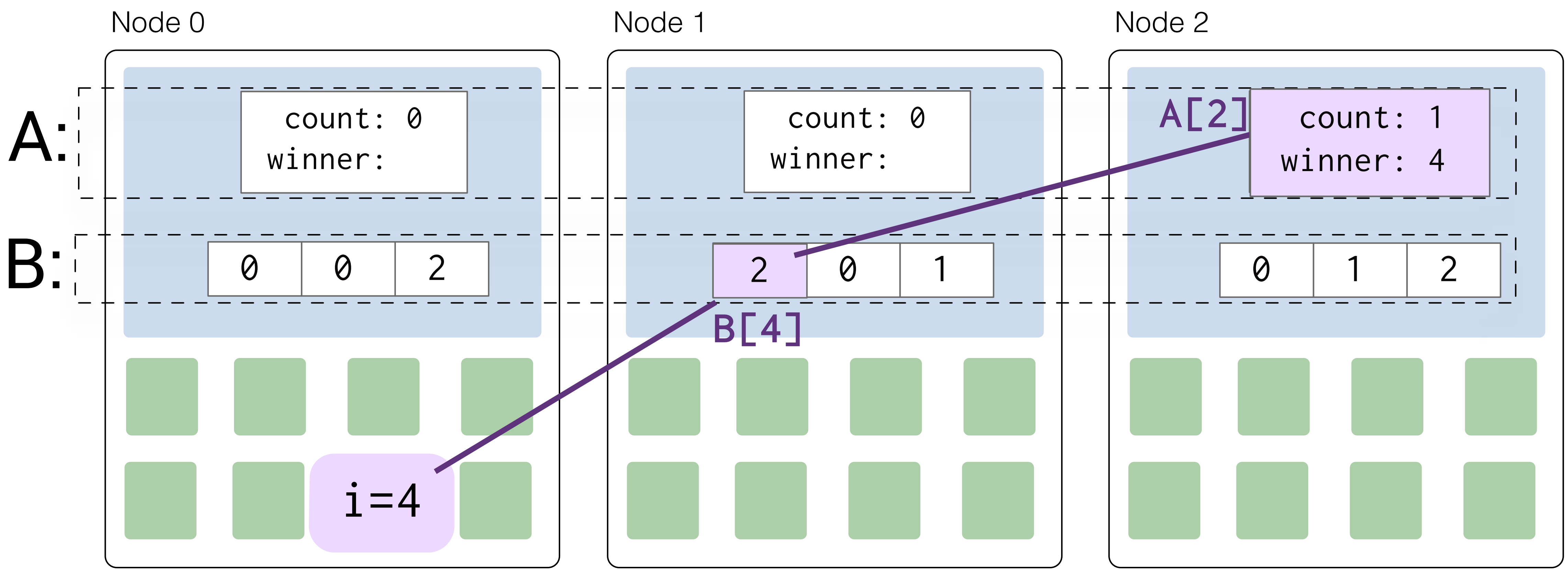


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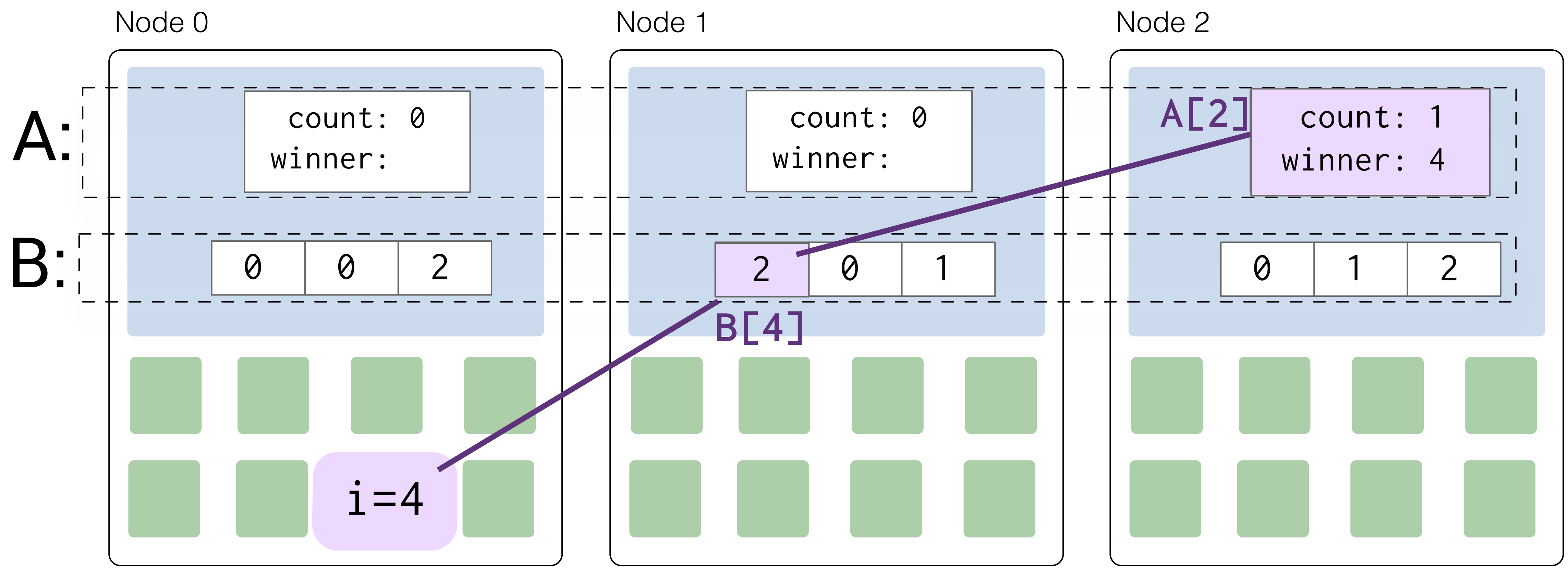


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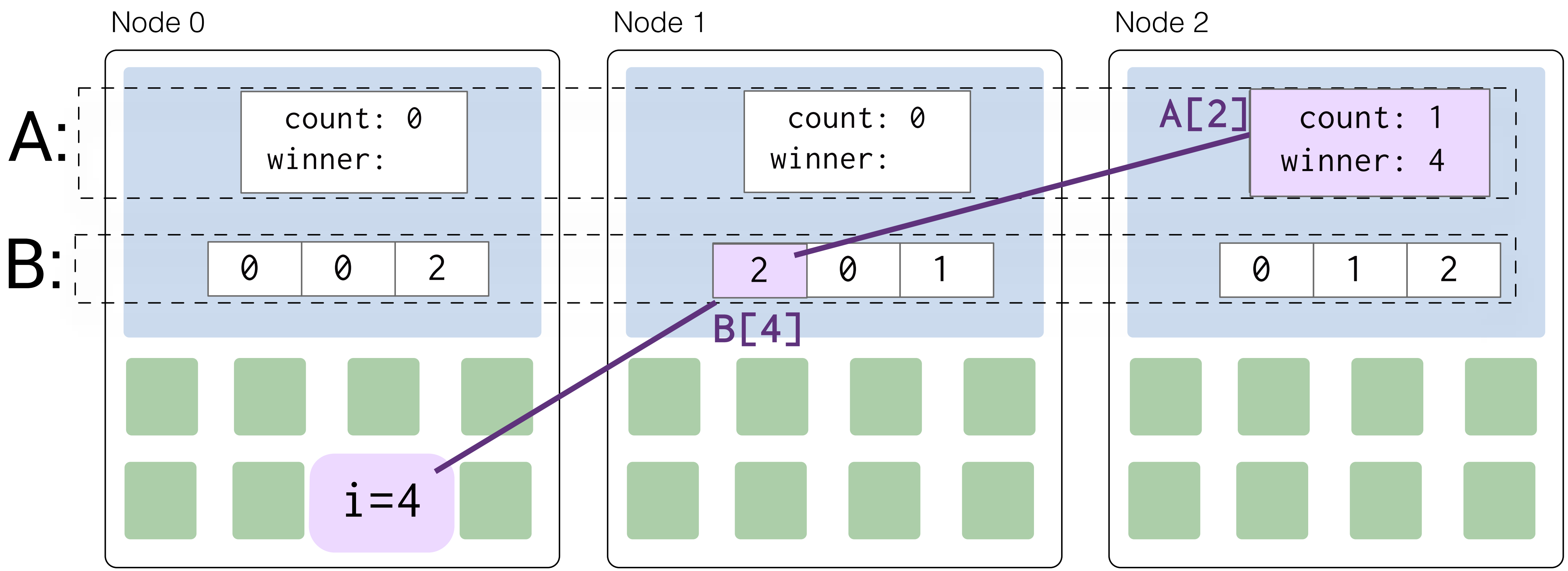
                                  winner
});
```

Anchor points

- memory locations are *owned* by one node
- so memory references are *anchored* to that node
- these are constraints on the thread's execution

HOPS Benchmark

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```

`A`

`i`

`B`

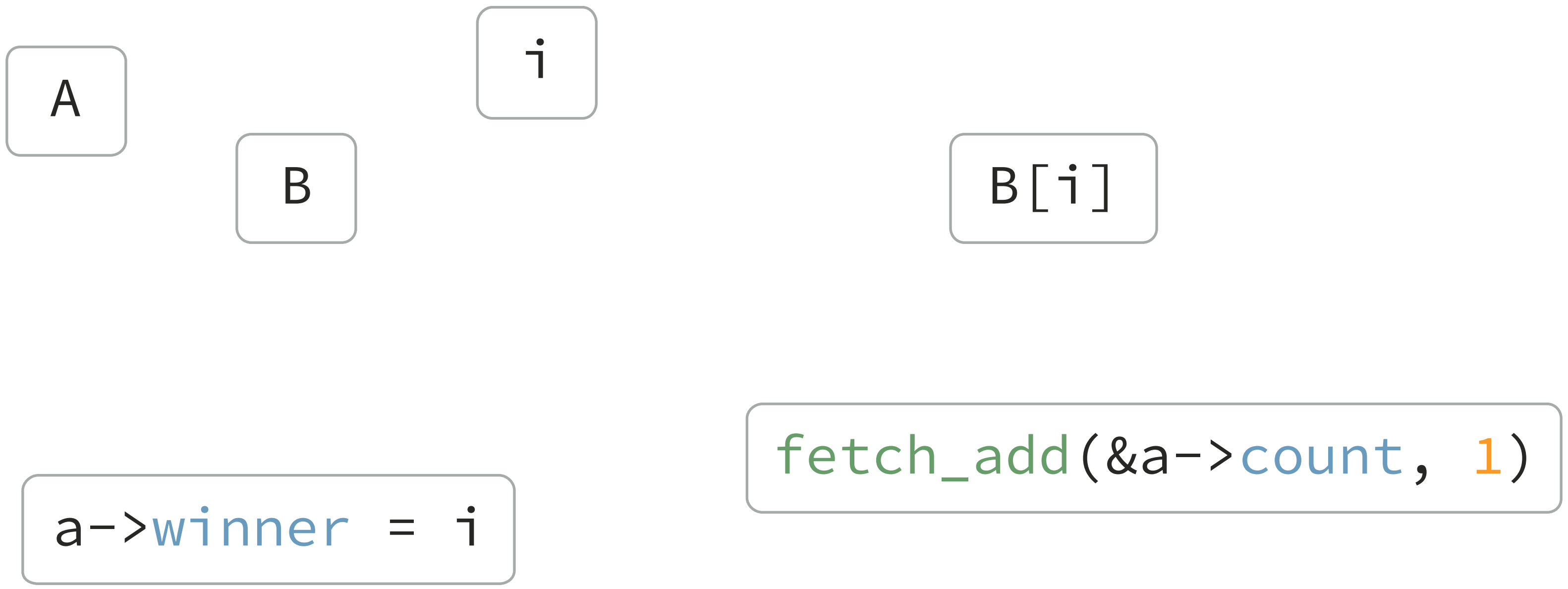
`B[i]`

`fetch_add(&a->count, 1)`

`a->winner = i`

Locality partitioning: *pessimistic value partitioning* (value numbering)*

- each anchor starts in its own set
- merge sets if you can prove they are *congruent*
- for locality partitioning: *congruence* means *on the same node*



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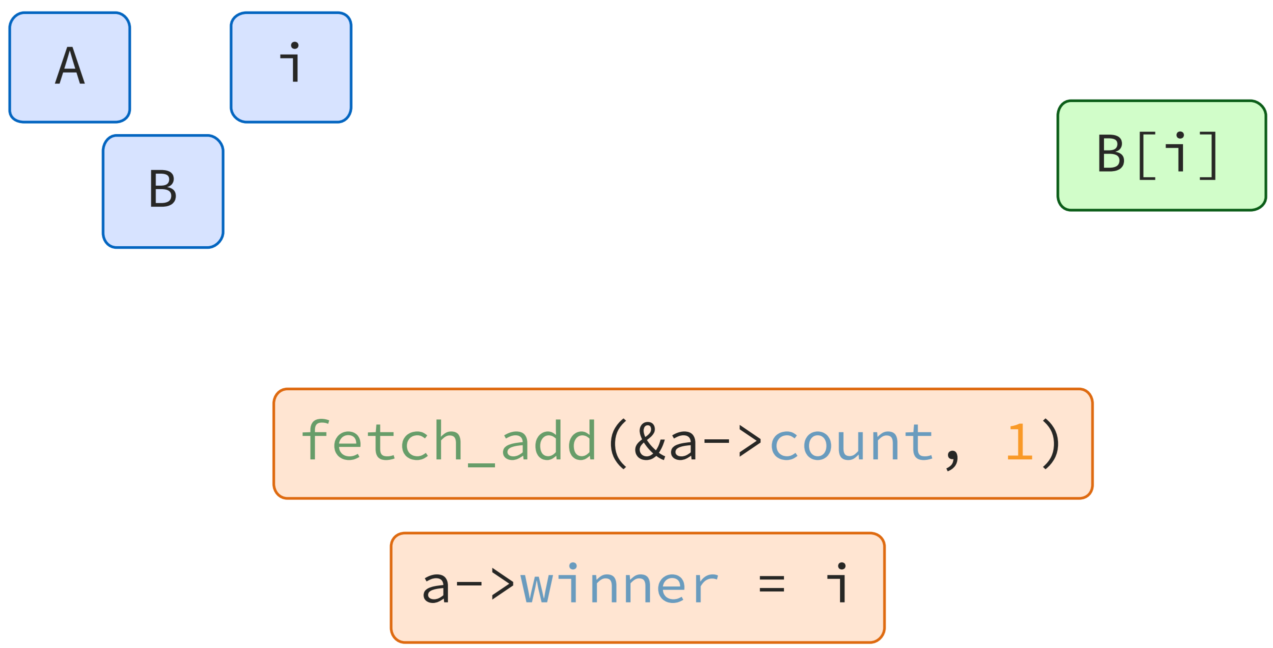

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A i

B

B[i]

```
fetch_add(&a->count, 1)
```

```
a->winner = i
```

Plug in your own
locality-congruence rules!

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Region selection (heuristic optimization)

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contiguous sequence of instructions (or a DAG of basic blocks) which can all execute on the same node

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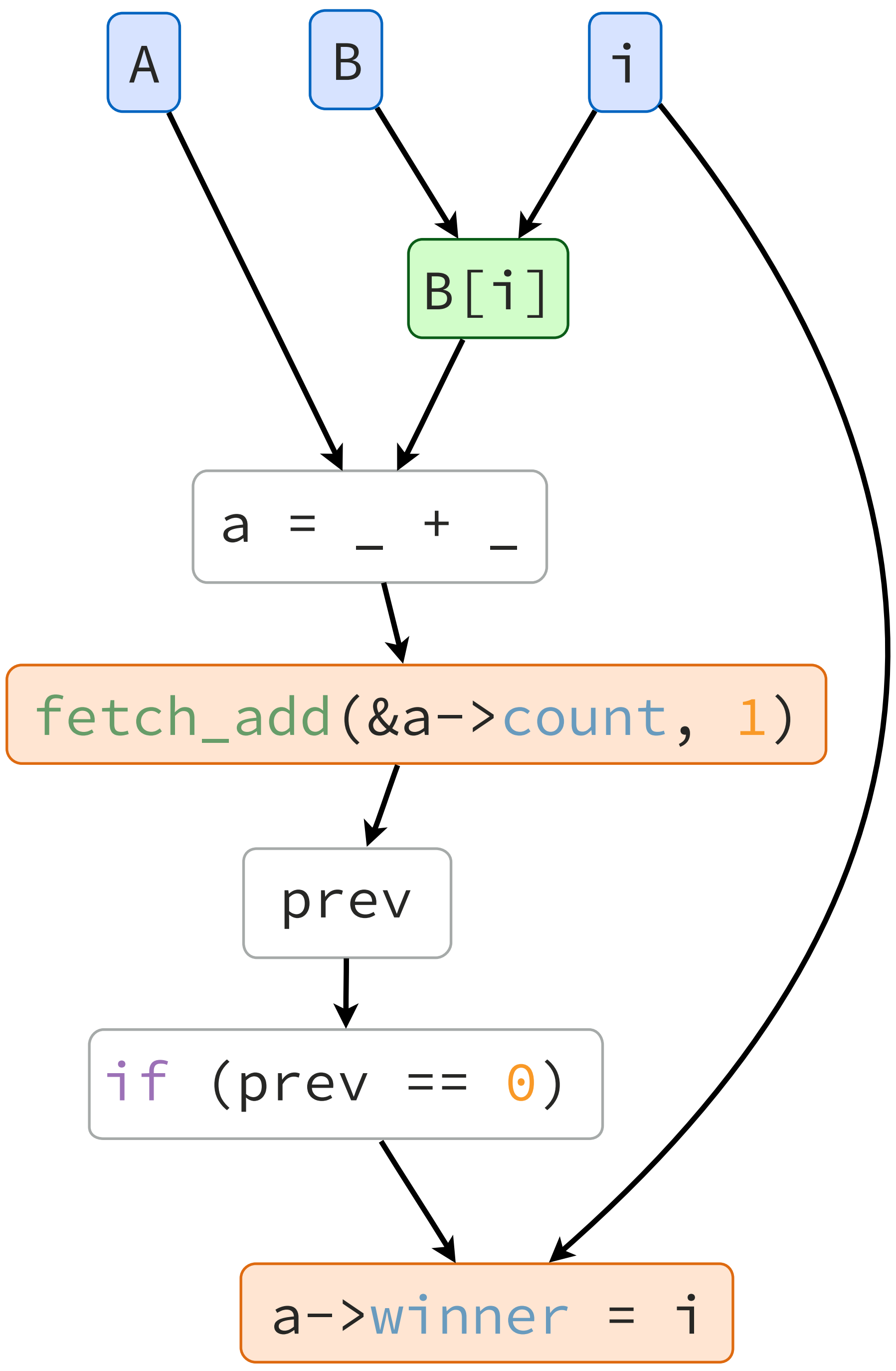

Dependence Graph

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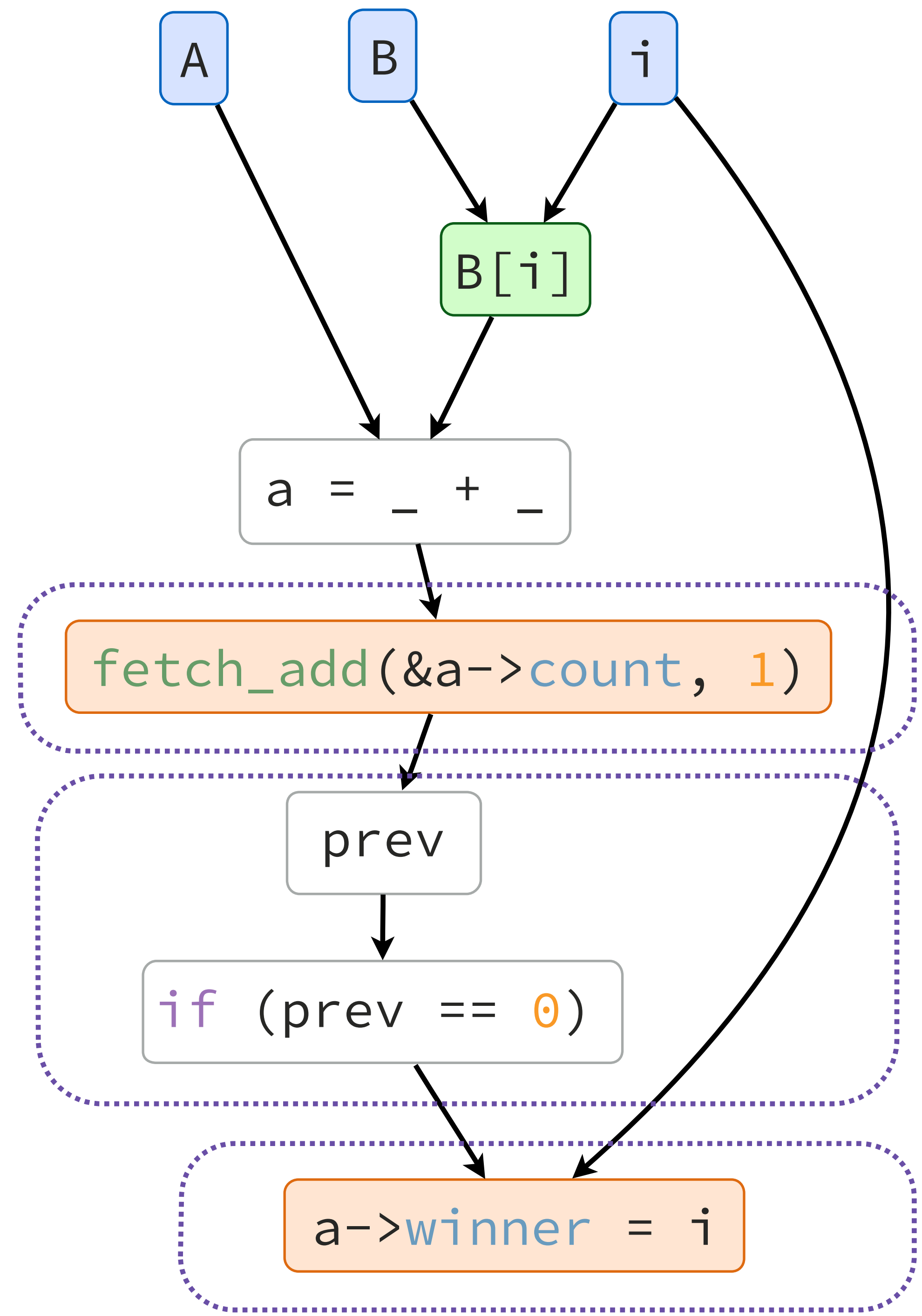

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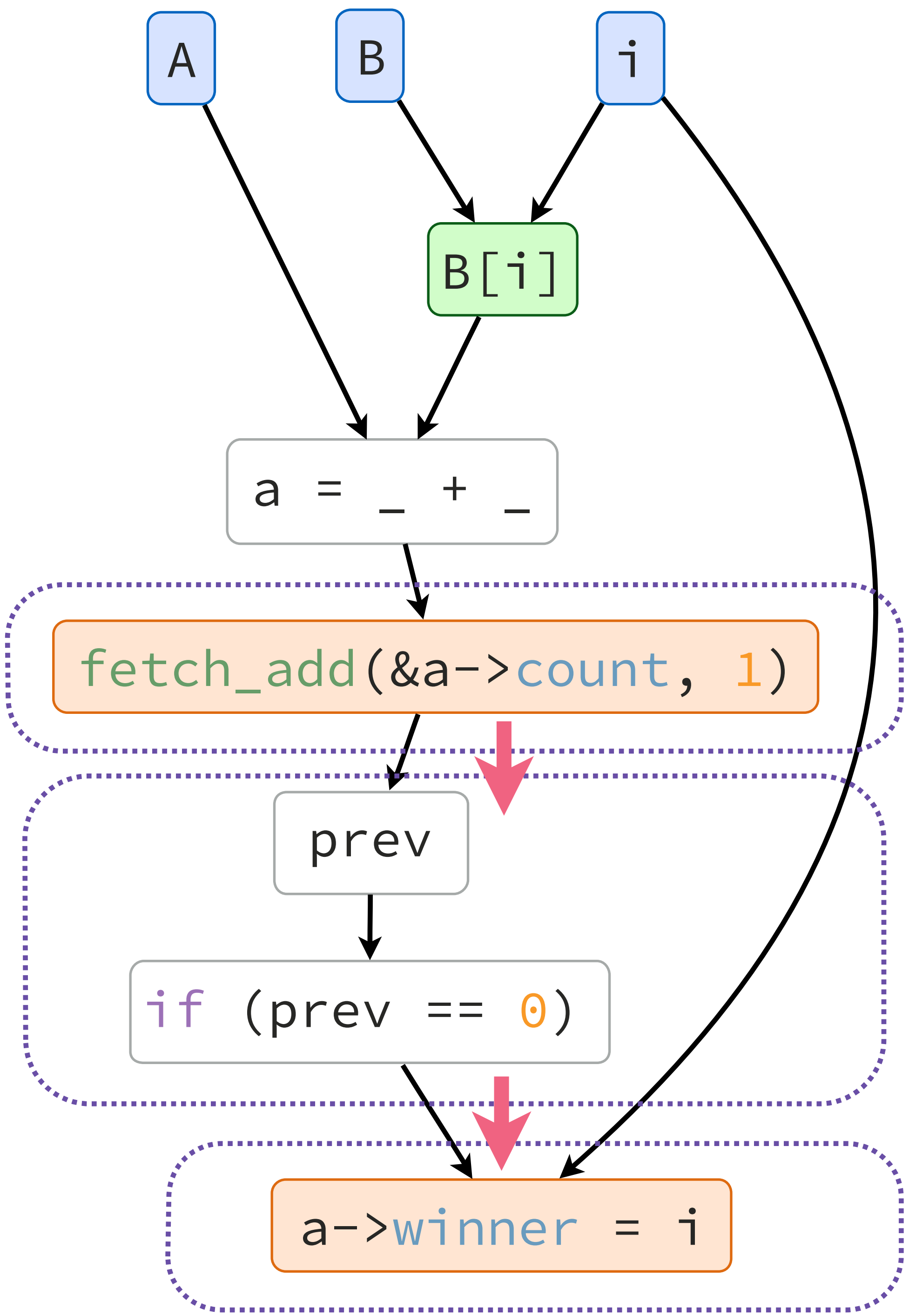

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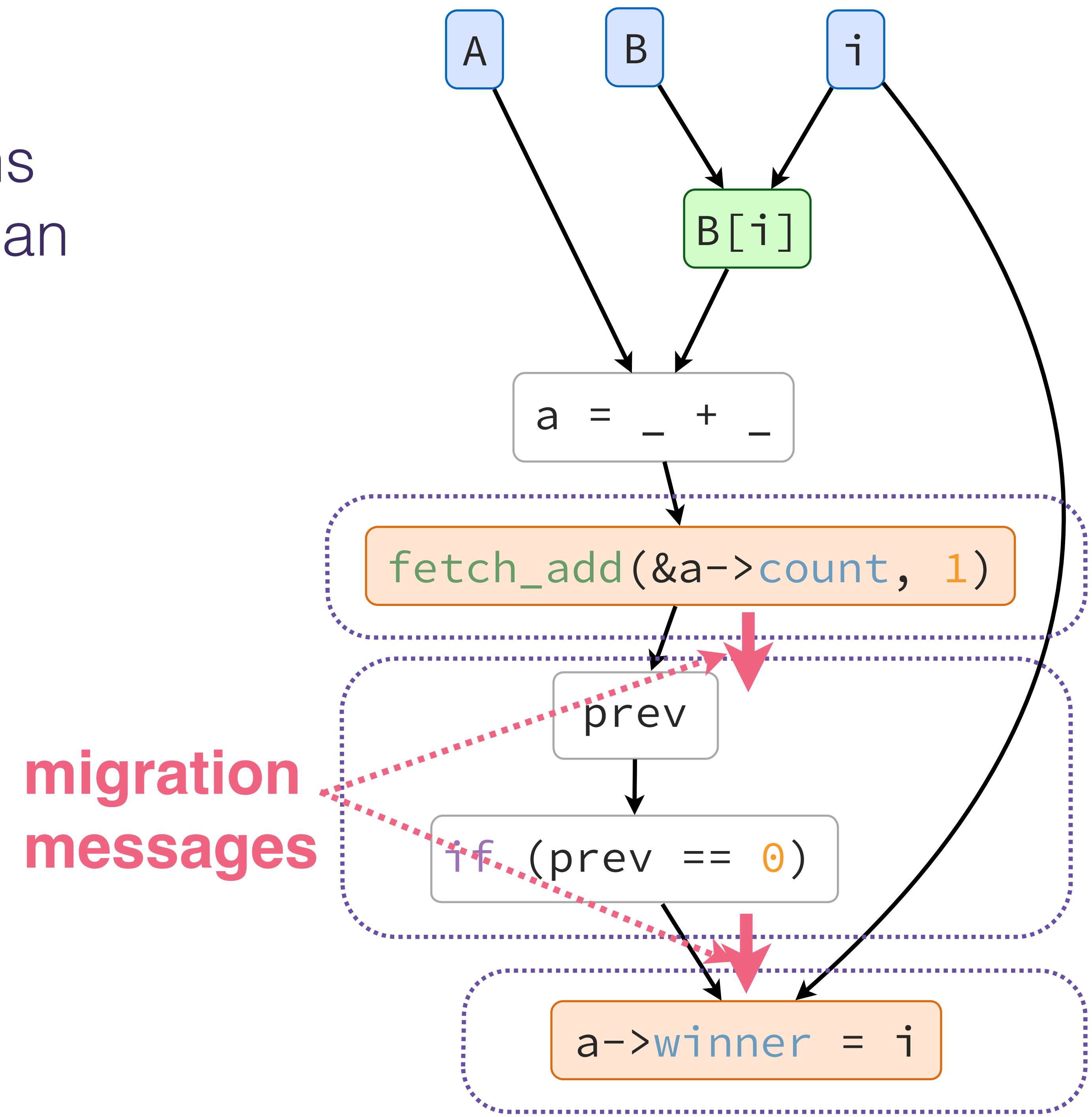

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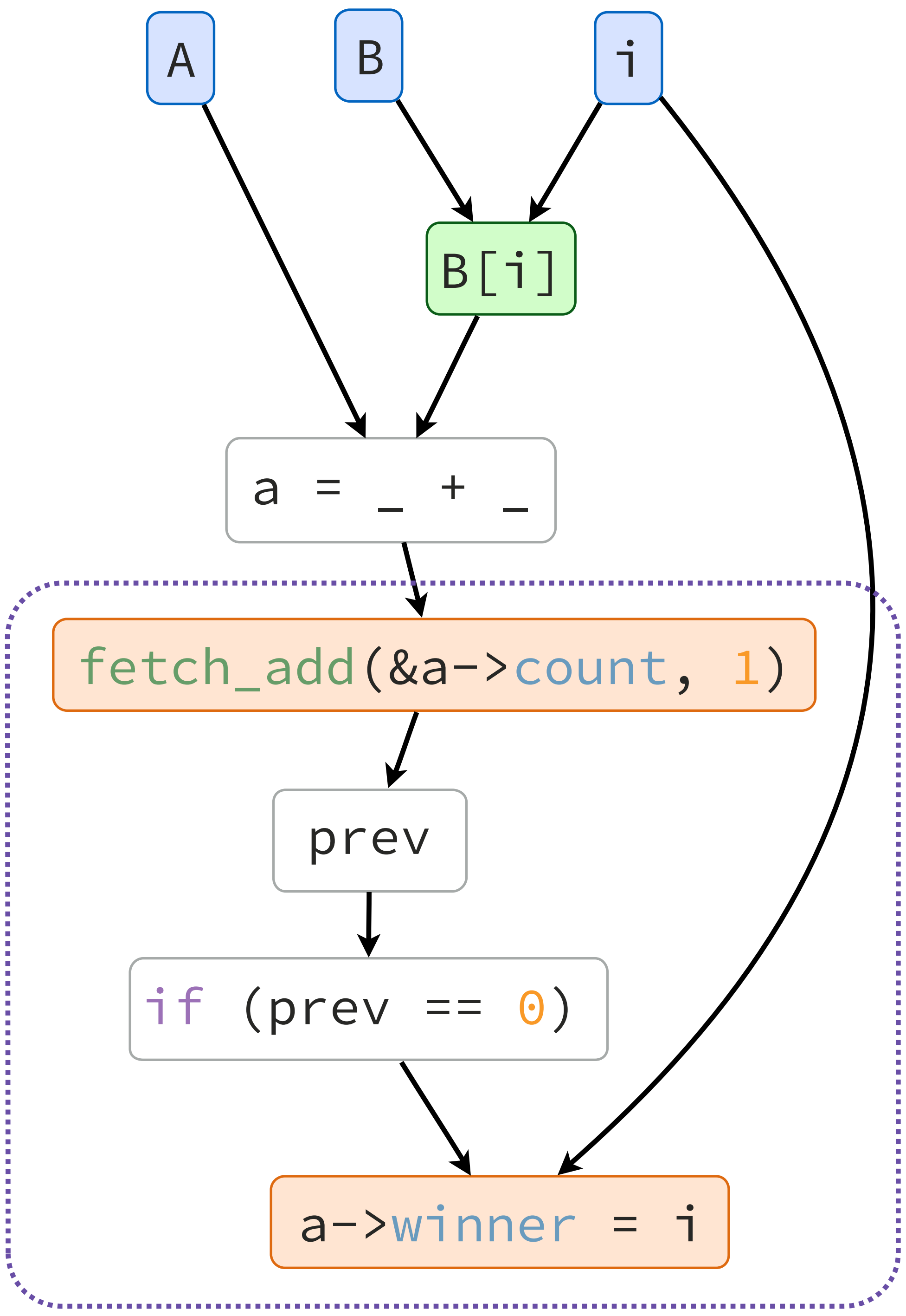

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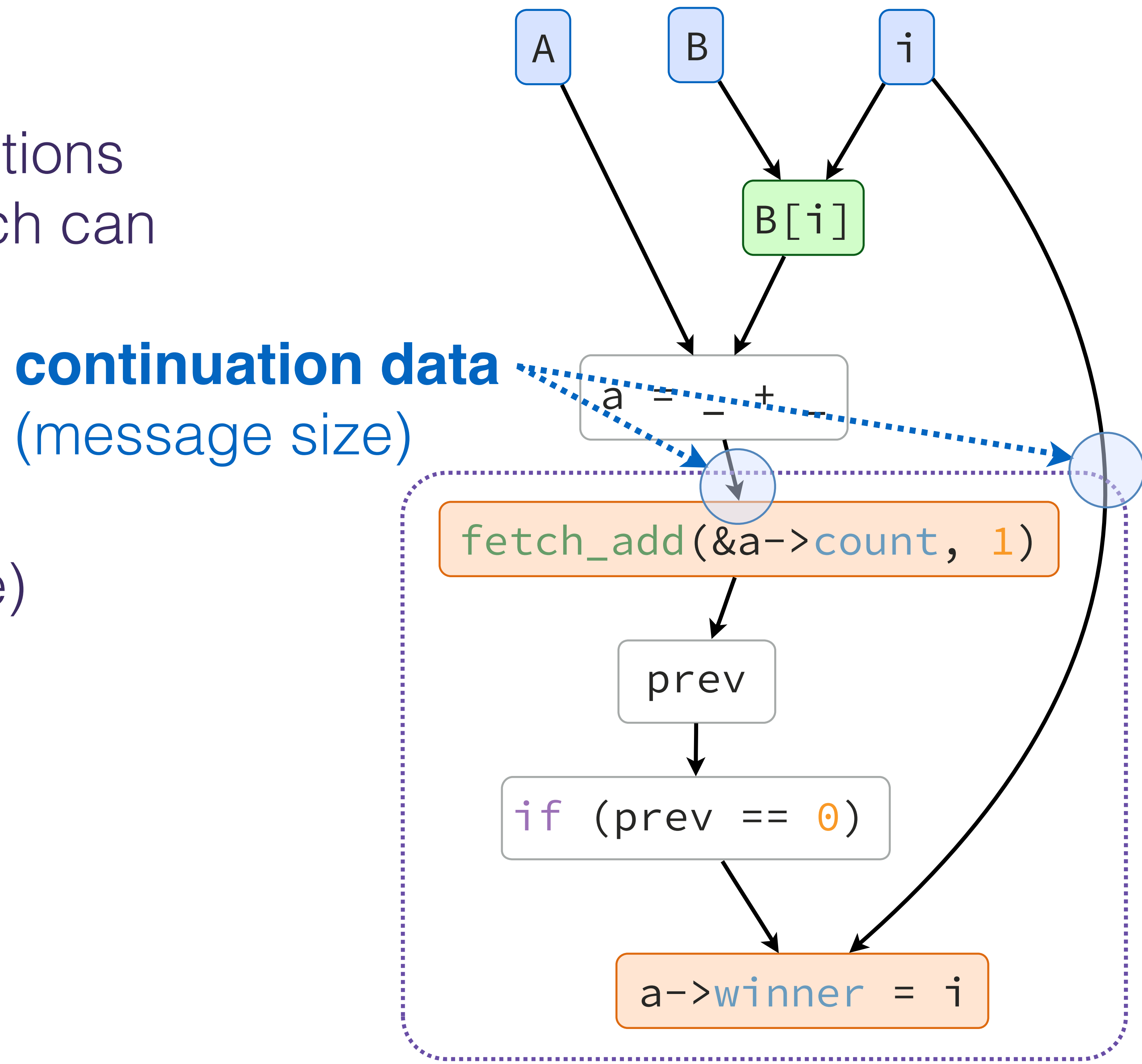

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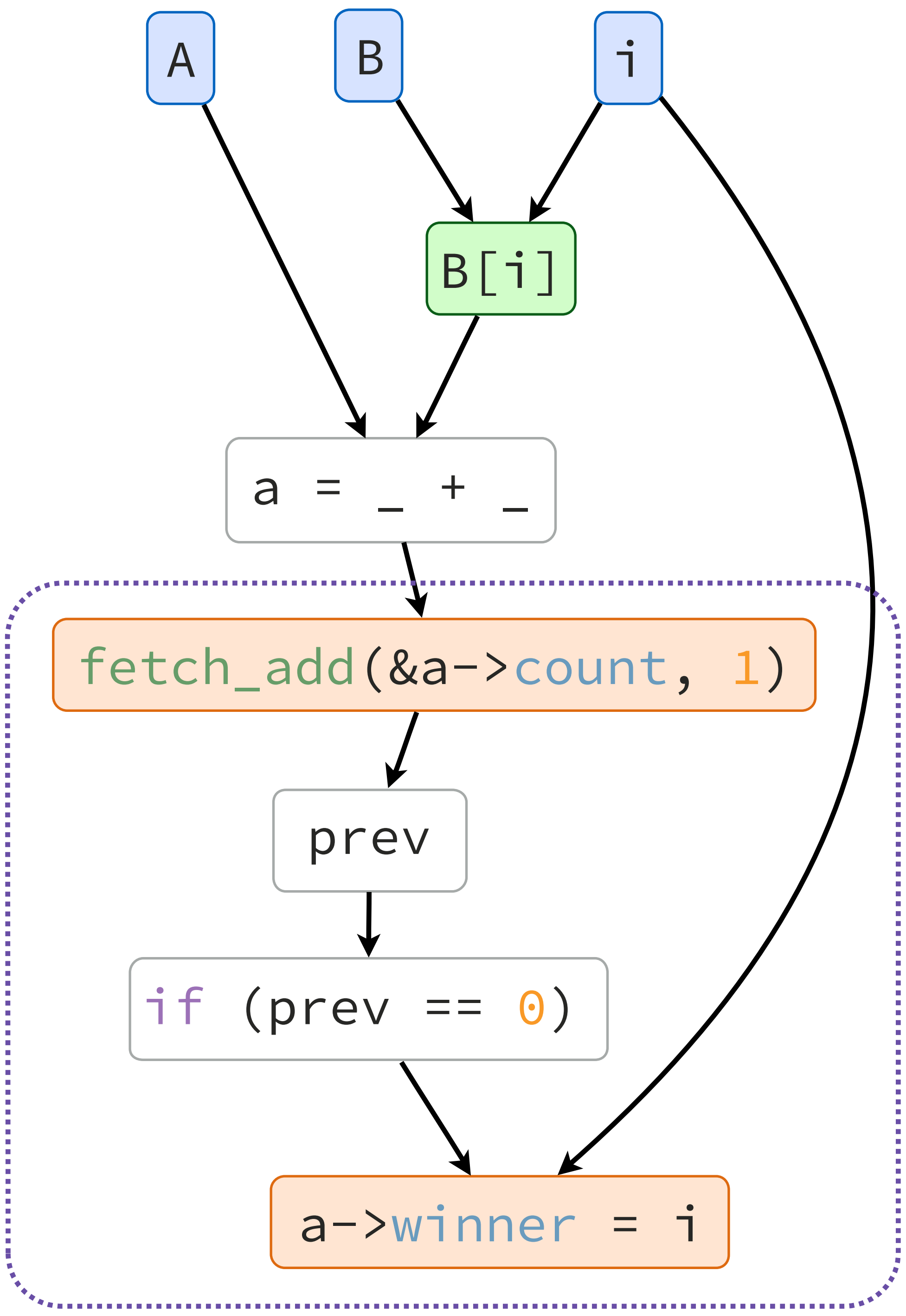
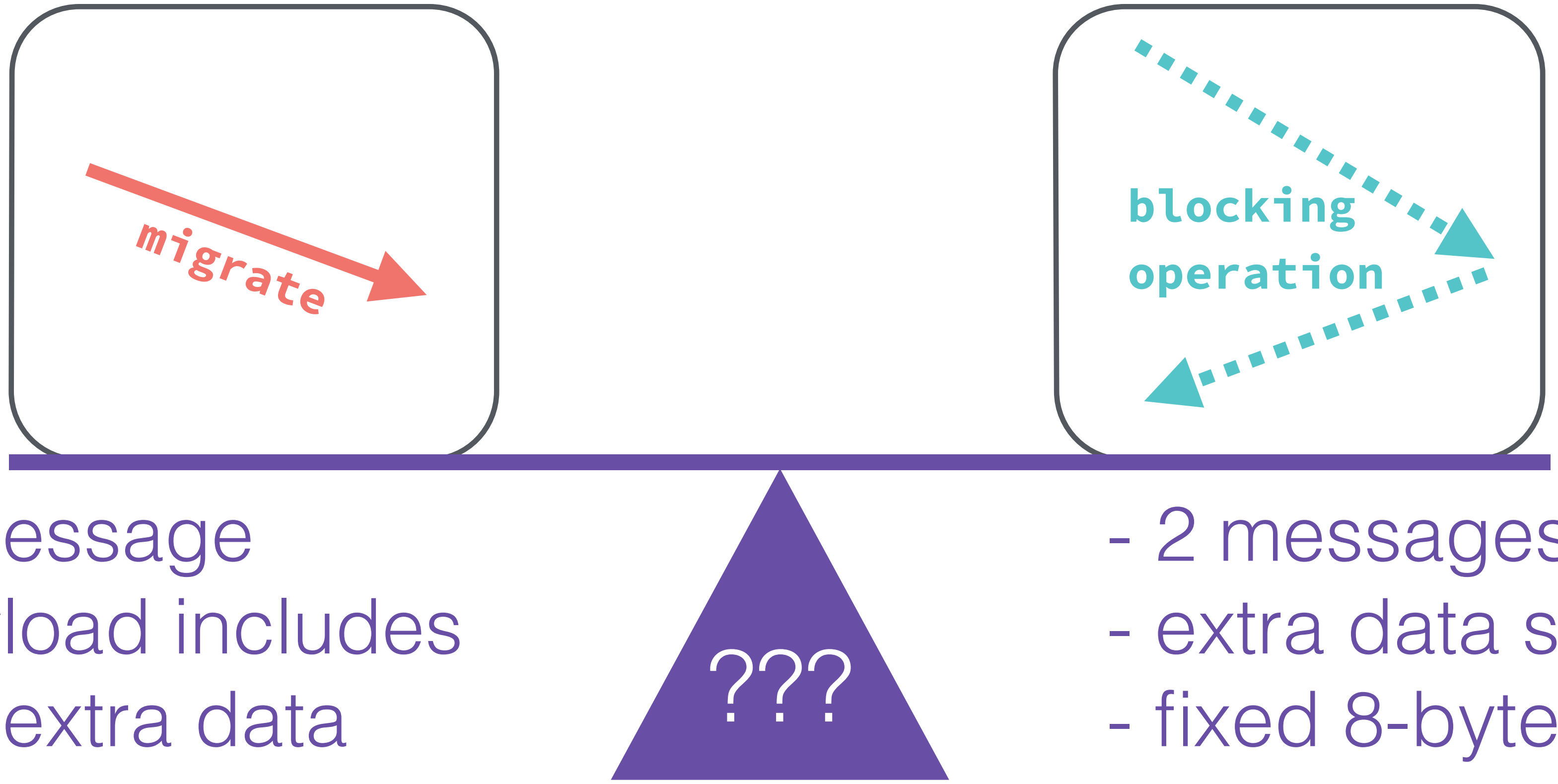


Dependence Graph

Message cost experiment

Modified HOPS to use extra data
after the remote operation



- 1 message
- payload includes the extra data

- 2 messages
- extra data stays
- fixed 8-byte payload

Message cost experiment

Modified HOPS to use extra data
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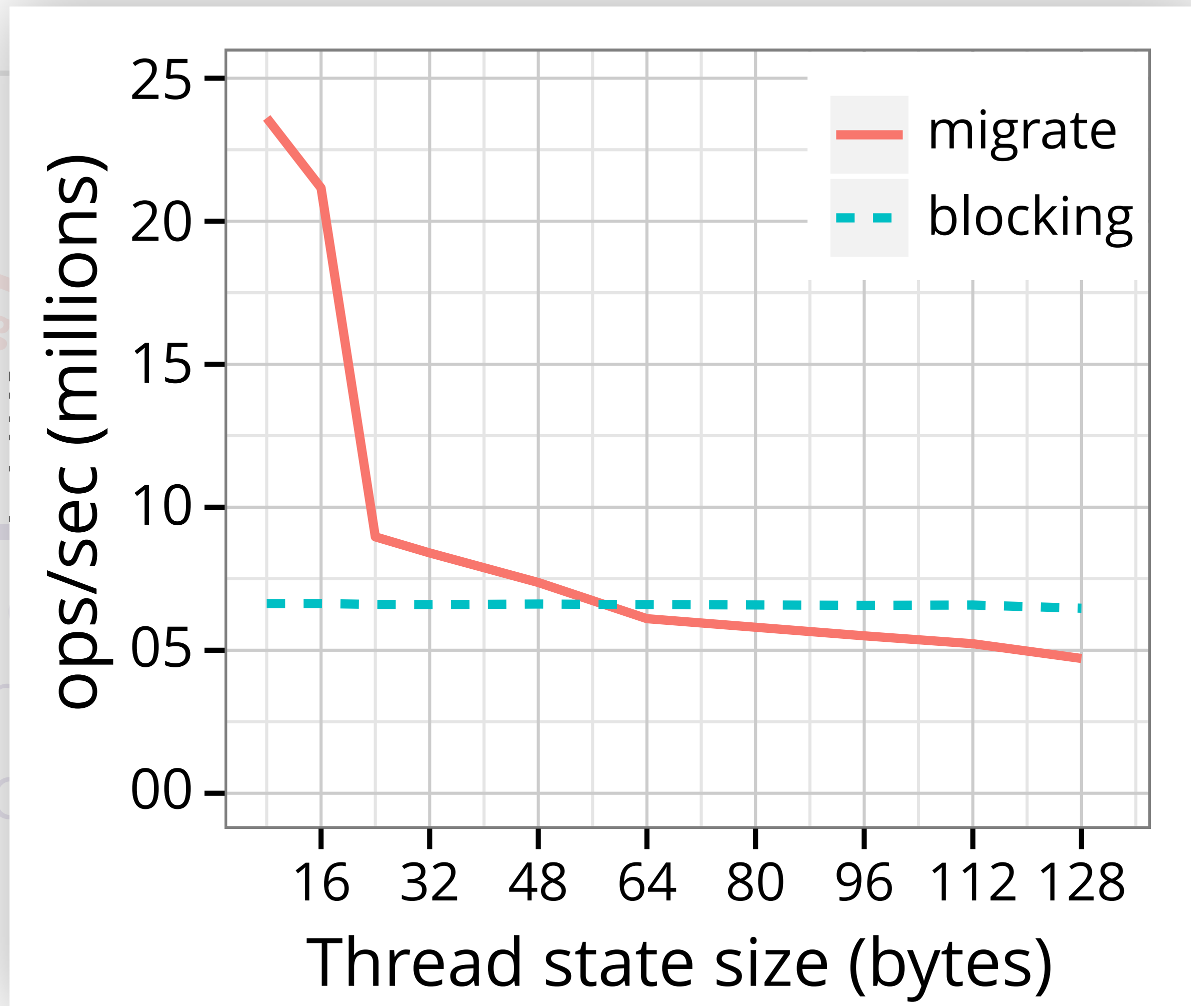

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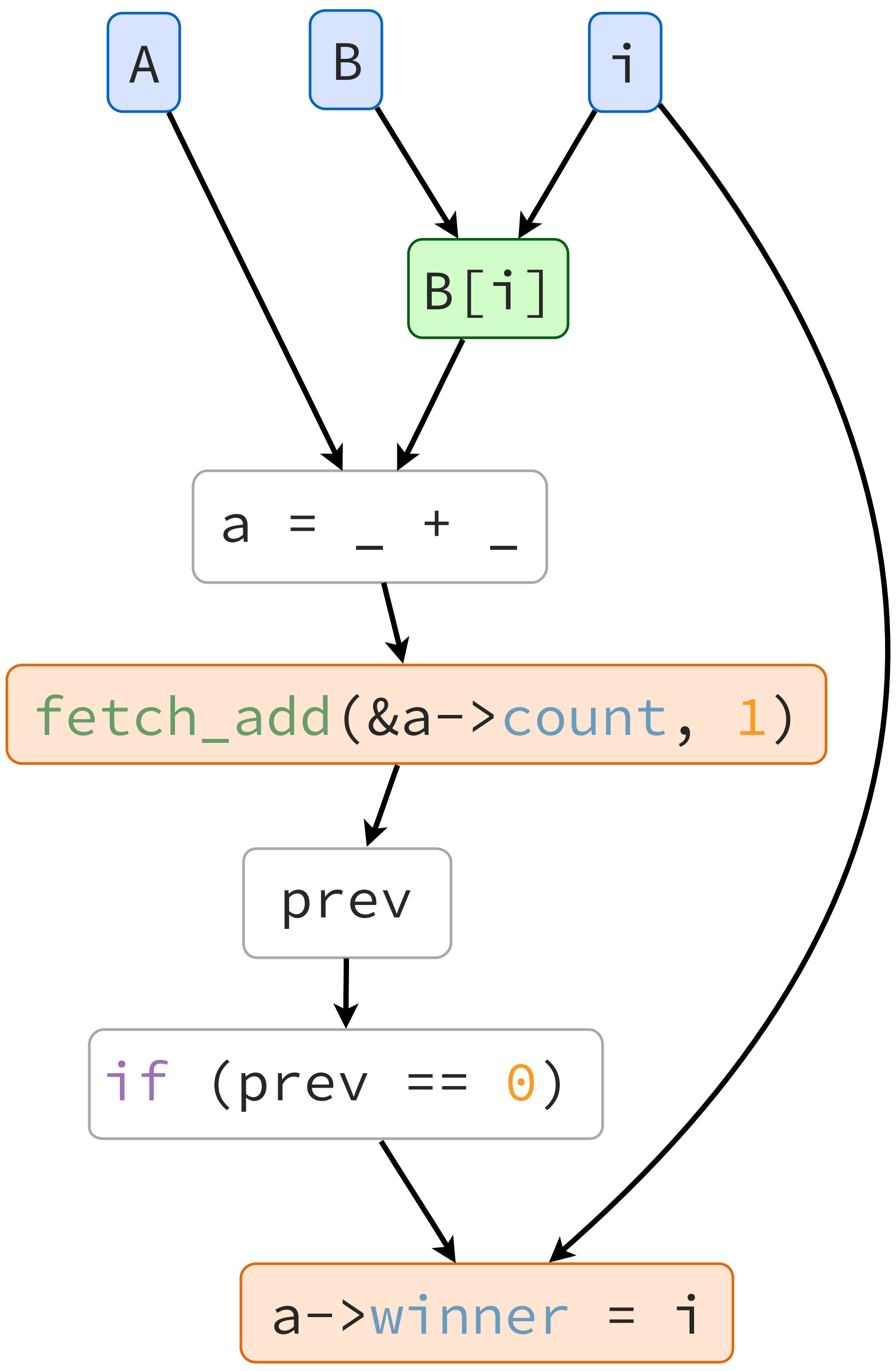
A
B
i
B[i]
a = _ + _
fetch_add(&a->count, 1)
prev
if (prev == 0)
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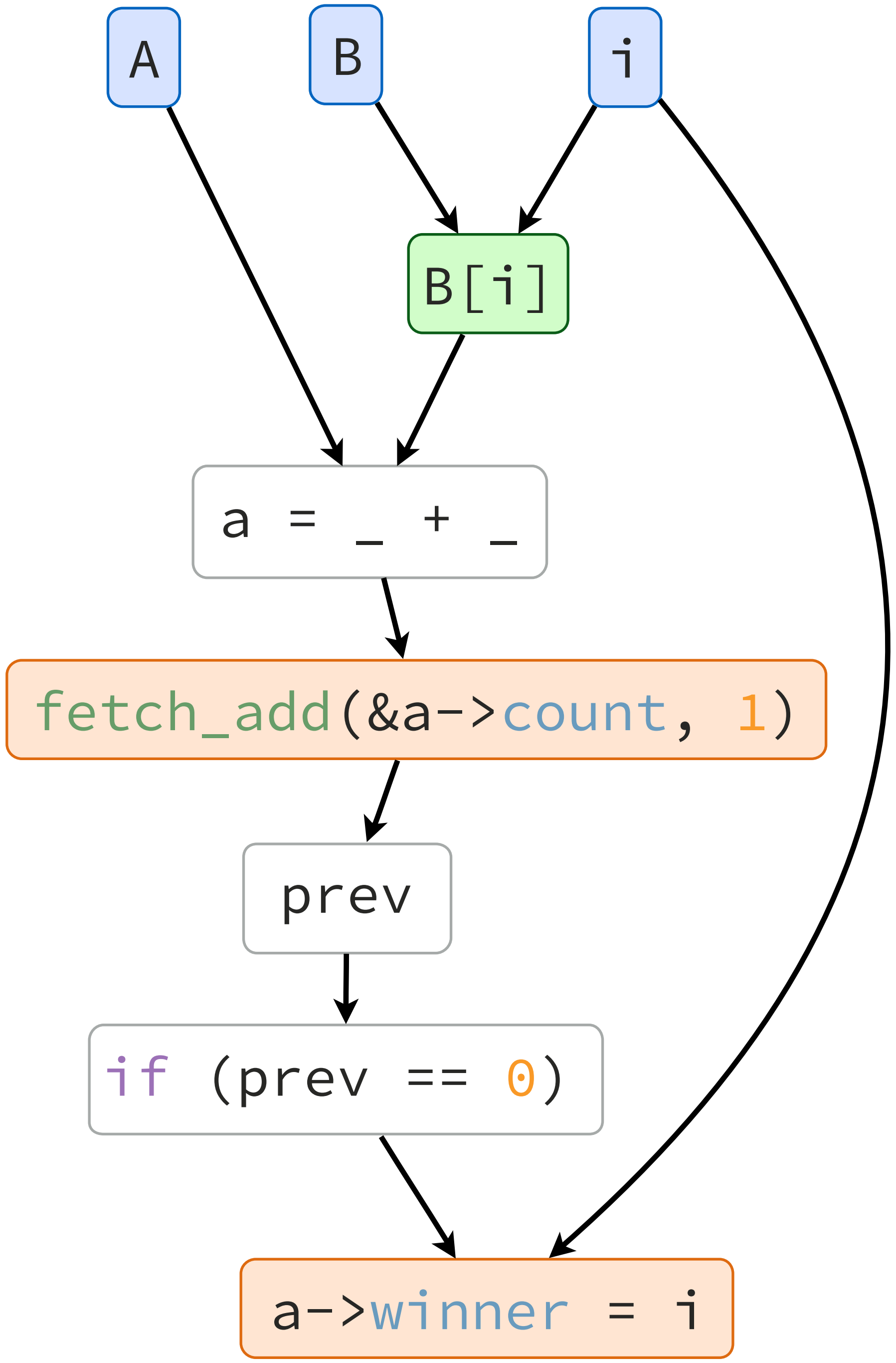

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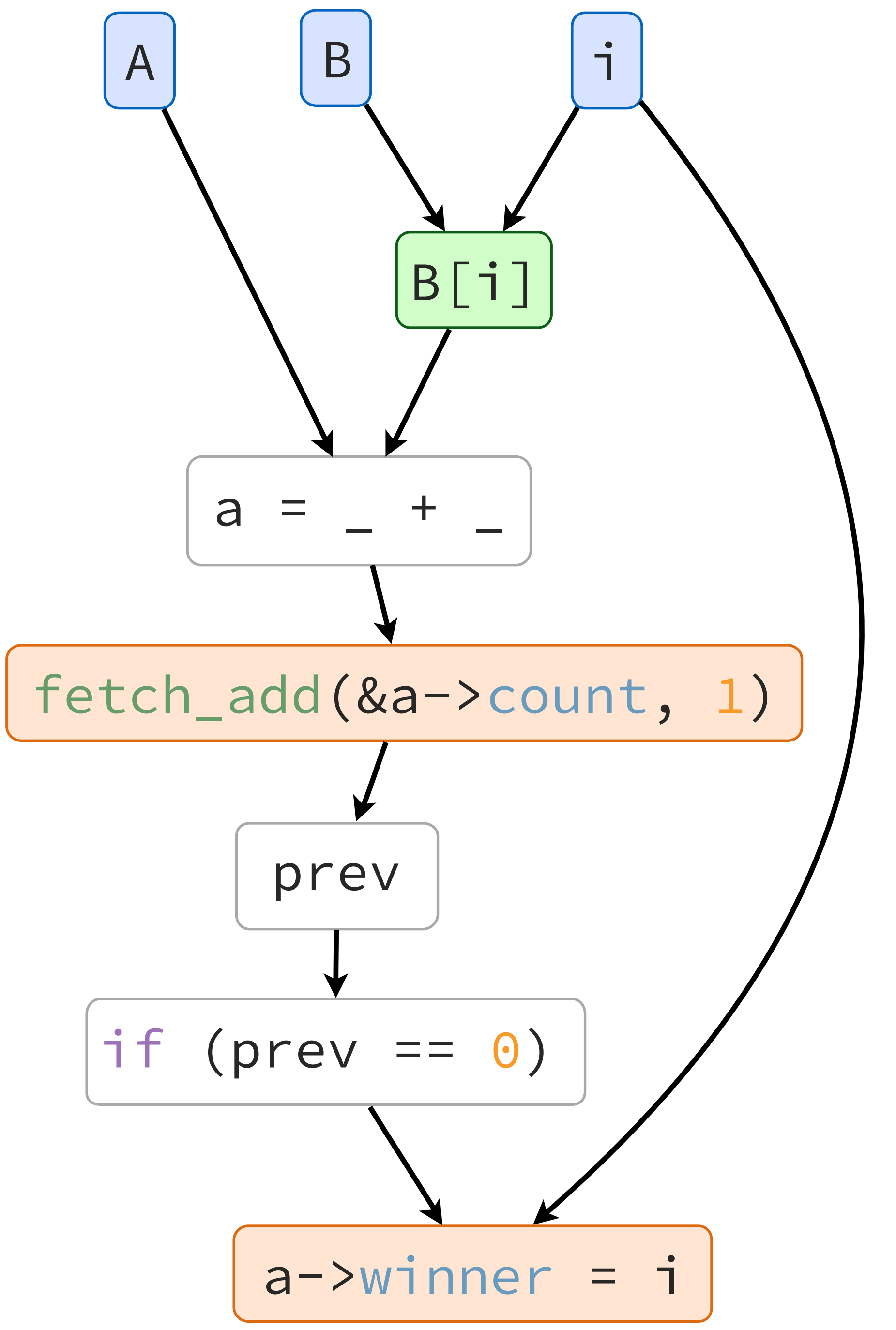

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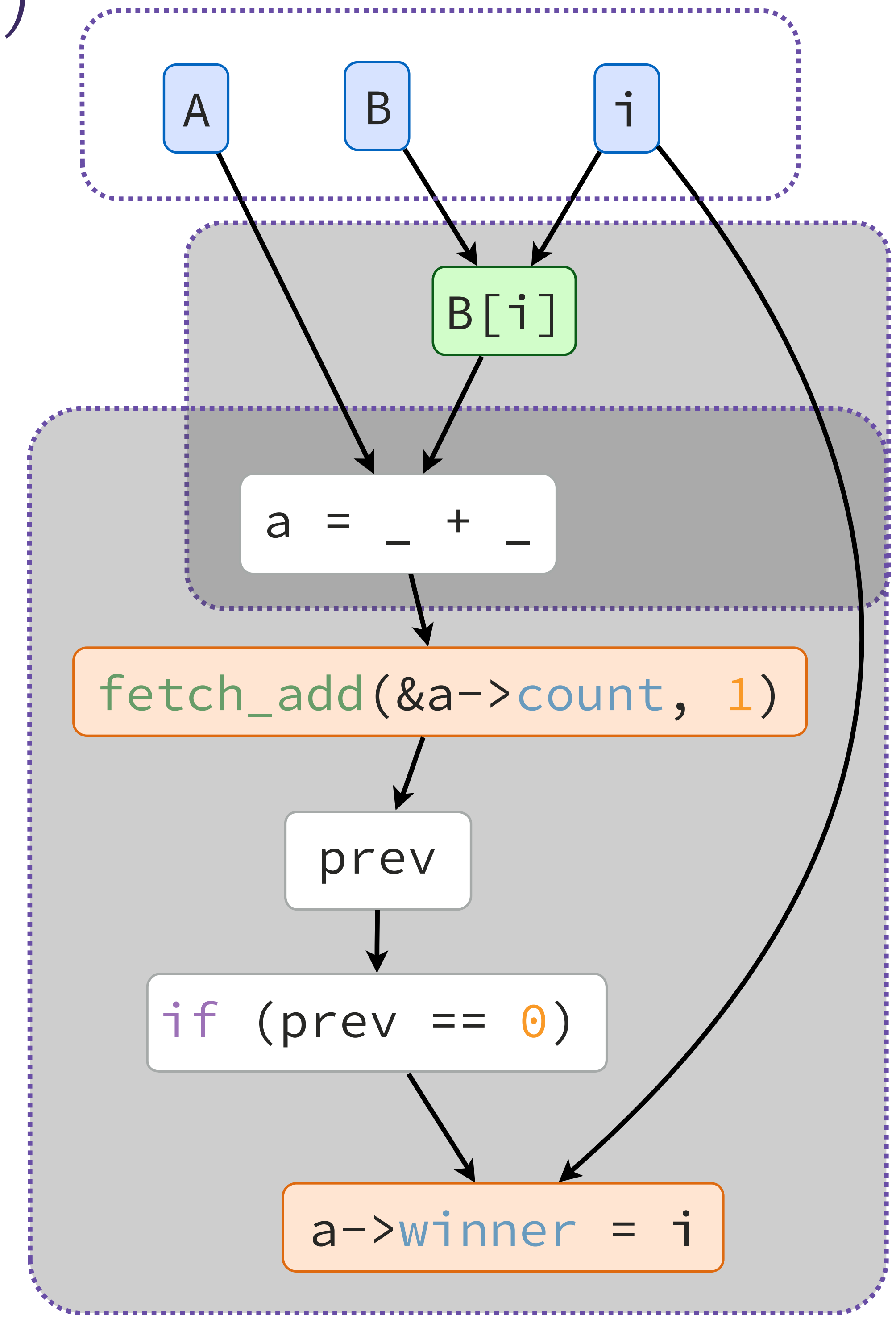

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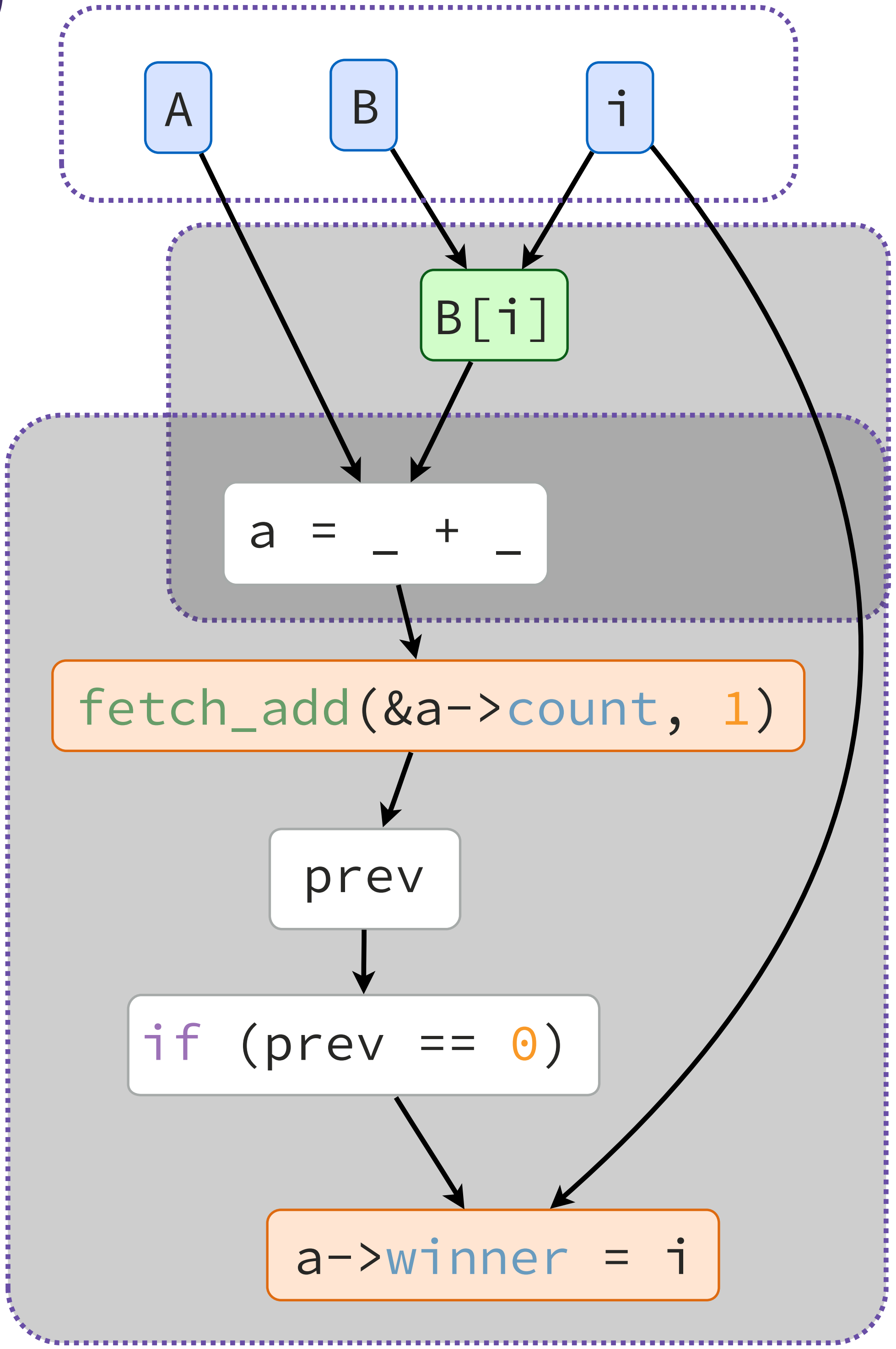
- at region intersections, compute cost heuristic for the possible choices



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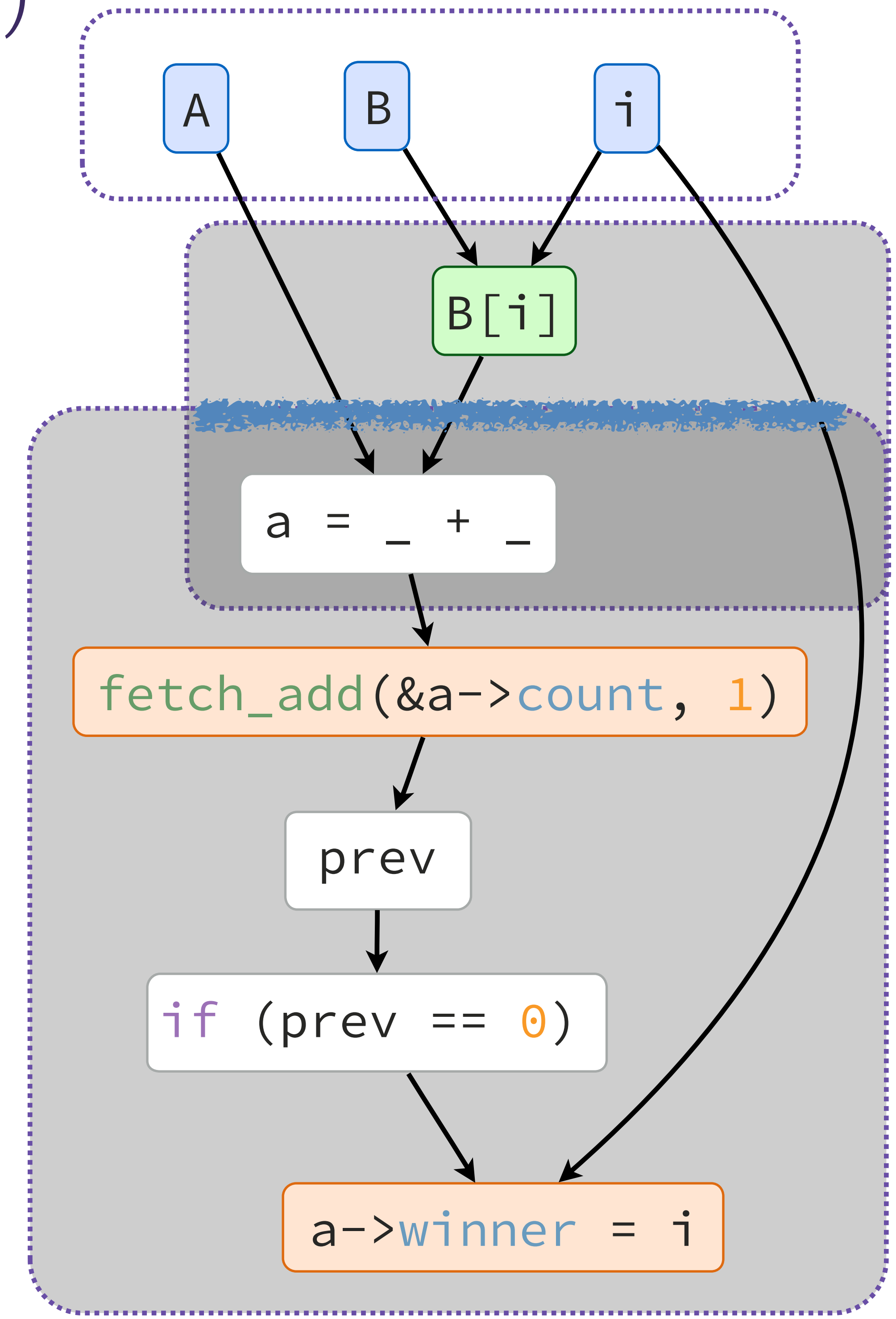

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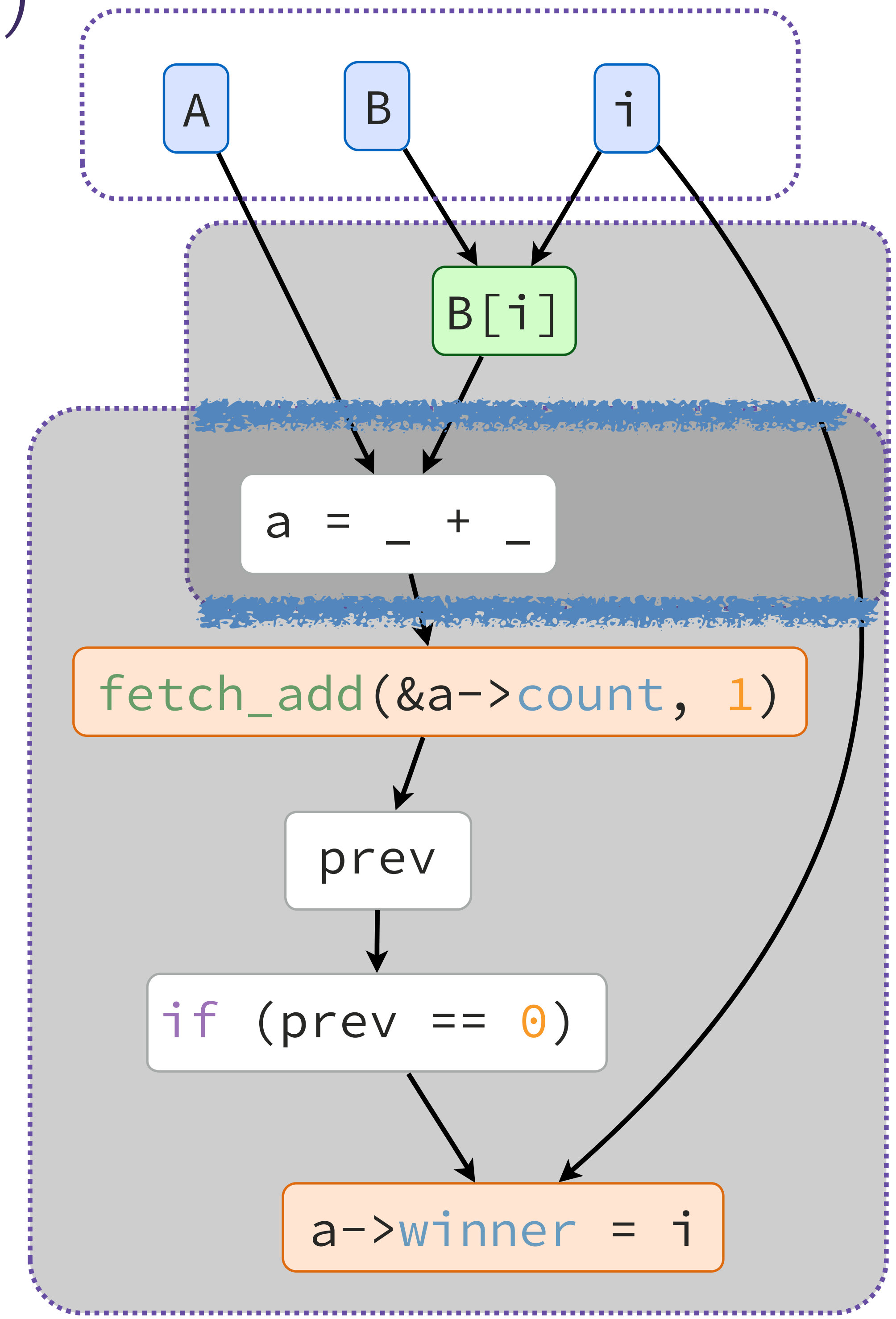

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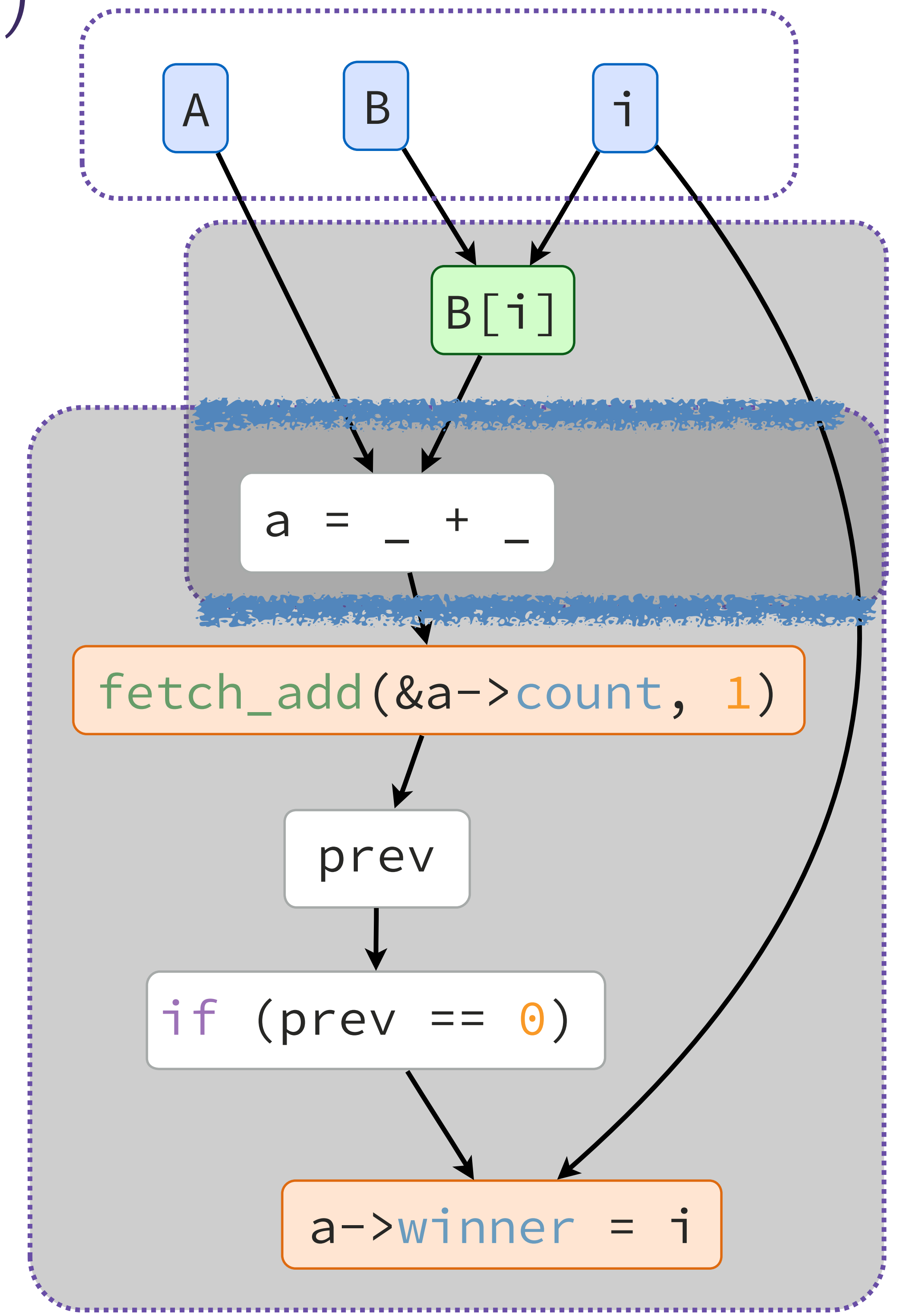

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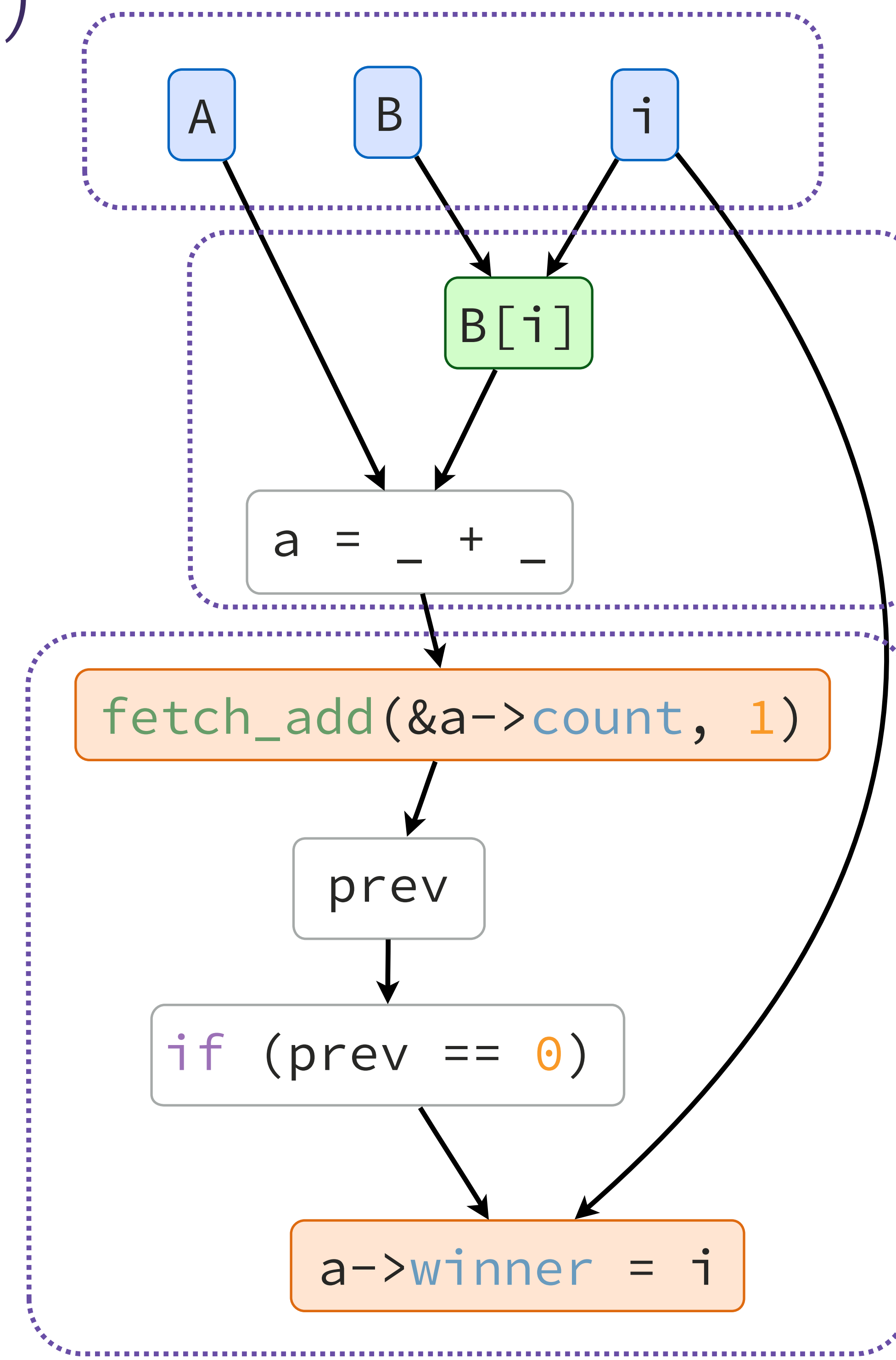

Transform thread to migrate at region boundaries

- create continuations for values that cross regions,
  and pack them into active messages

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[A,B](long i) {
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  long prev = fetch_add(&a->count, 1);
  if (prev == 0)    // first to arrive
    a->winner = i; // is winner
}
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Transform thread to migrate at region boundaries

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[A,B](long i) {
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Alembic

Static optimizing migration algorithm

- Constrained by anchor points
- Greedy heuristic to reduce communication

Implementation for C++ in LLVM

Evaluation

- ***6x better*** than naive compiler-generated communication
- 82% of hand-tuned performance

Implementation

C++ extensions to support global pointers

Anchor point / locality partitioning analysis pass

Region selection and continuation-passing transform pass

Alembic

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Benchmarks

- Ported Grappa applications (irregular, data-intensive, …)

  BFS

  Pagerank

  Connected Components

  Intsort

Performance (12 nodes)

- naive put/get compiler-generated communication
- hand-tuned migration decisions
- Alembic-generated migrations

Benchmarks

- Ported Grappa applications (irregular, data-intensive, …)

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GlobalHashSet symmetric* set;
Graph symmetric* g;

void explore(VertexID r, color_t color) {
  Vertex global* vs = g->vertices();
  phaser.enroll(vs[r].nadj)
  forall<async>(adj(g,vs+r), [=](VertexID j){
    auto& v = vs[j];
    if (cmp_swap(&v.color, -1, color)){
      spawn([=]{ explore(j, color); });
    } else if (v.color != color) {
      Edge edge(color, v.color);
      set->insert(edge);
      phaser.complete(1);
    }
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Performance (12 nodes)

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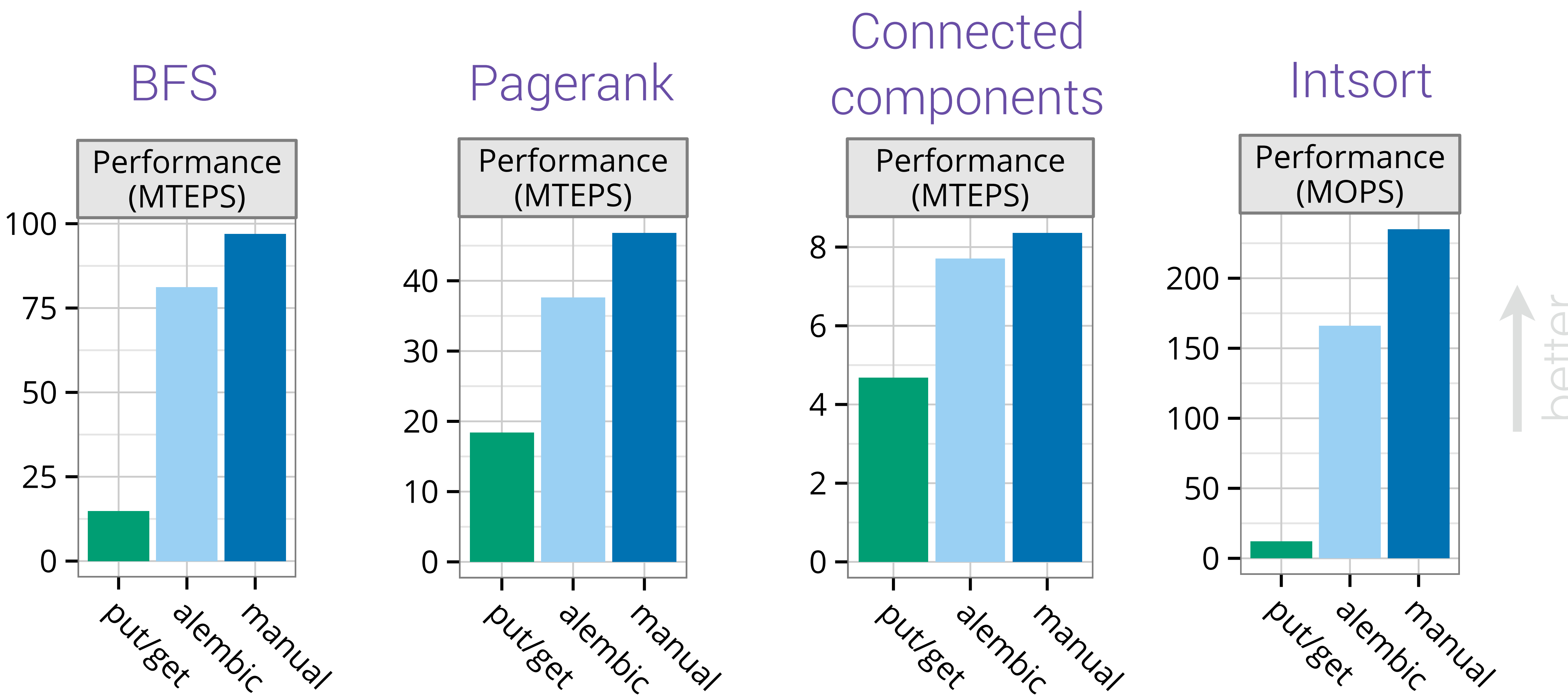
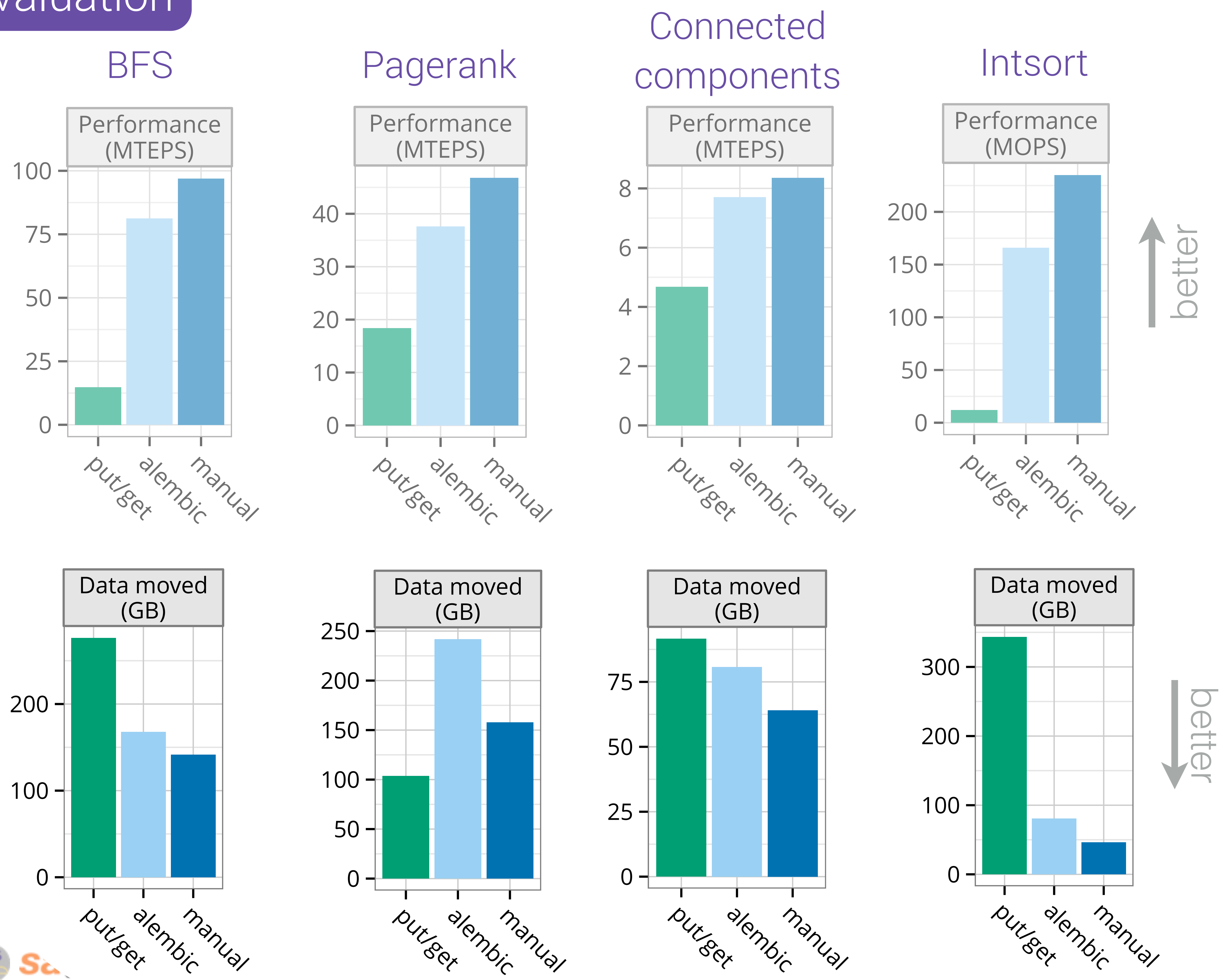
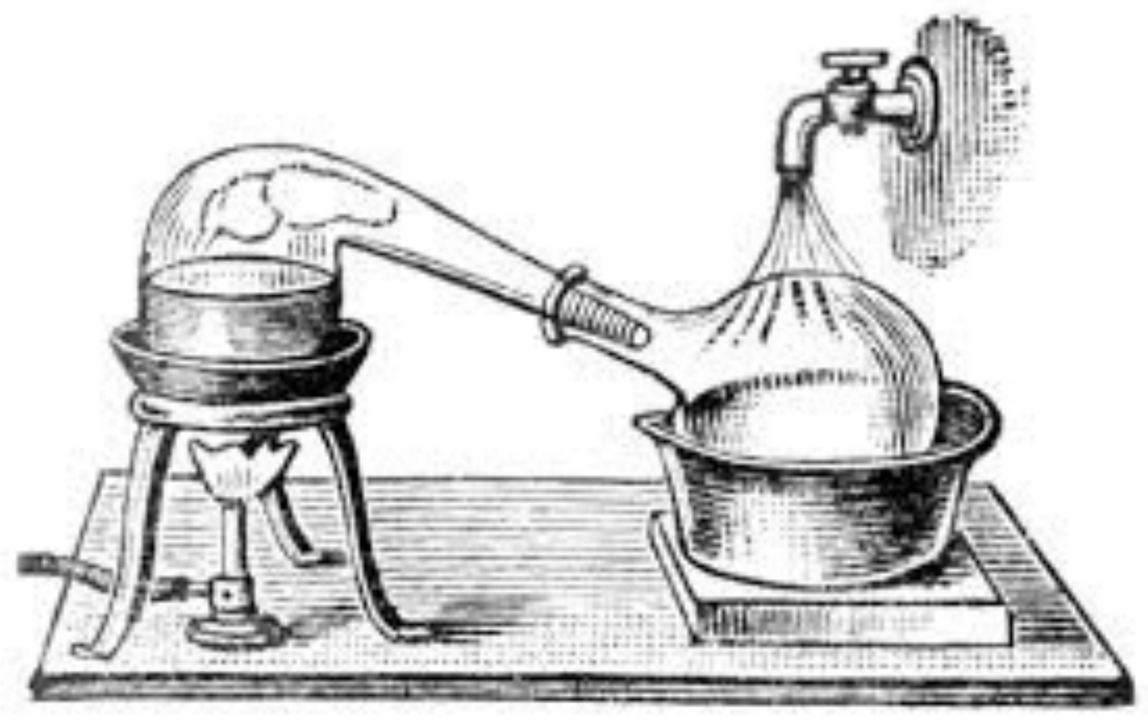


BFS
Pagerank
Connected components
Intsort
Performance (MTEPS)
Performance (MTEPS)
Performance (MTEPS)
Performance (MOPS)
100
75
50
25
0
40
30
20
10
0
8
6
4
2
0
200
150
100
50
0
put/get
alembic
manual
better



BFS
Pagerank
Connected components
Intsort
Performance (MTEPS)
Performance (MOPS)
better
Data moved (GB)
put/get
alembic
manual



Alembic

Algorithm to make automatic migration decisions

- Analyze locality by partitioning *anchors*
- Greedy optimization to reduce communication cost heuristic

LLVM implementation for Grappa C++

Performance — near hand-tuned, much better than PGAS baseline

Brandon Holt, Preston Briggs, Luis Ceze, Mark Oskin