UCI University of California, Irvine

Yak: A High-Performance Big-Data-Friendly Garbage Collector

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Onur Mutlu
ETH Zürich

BIG DATA

BIG DATA

Naiad

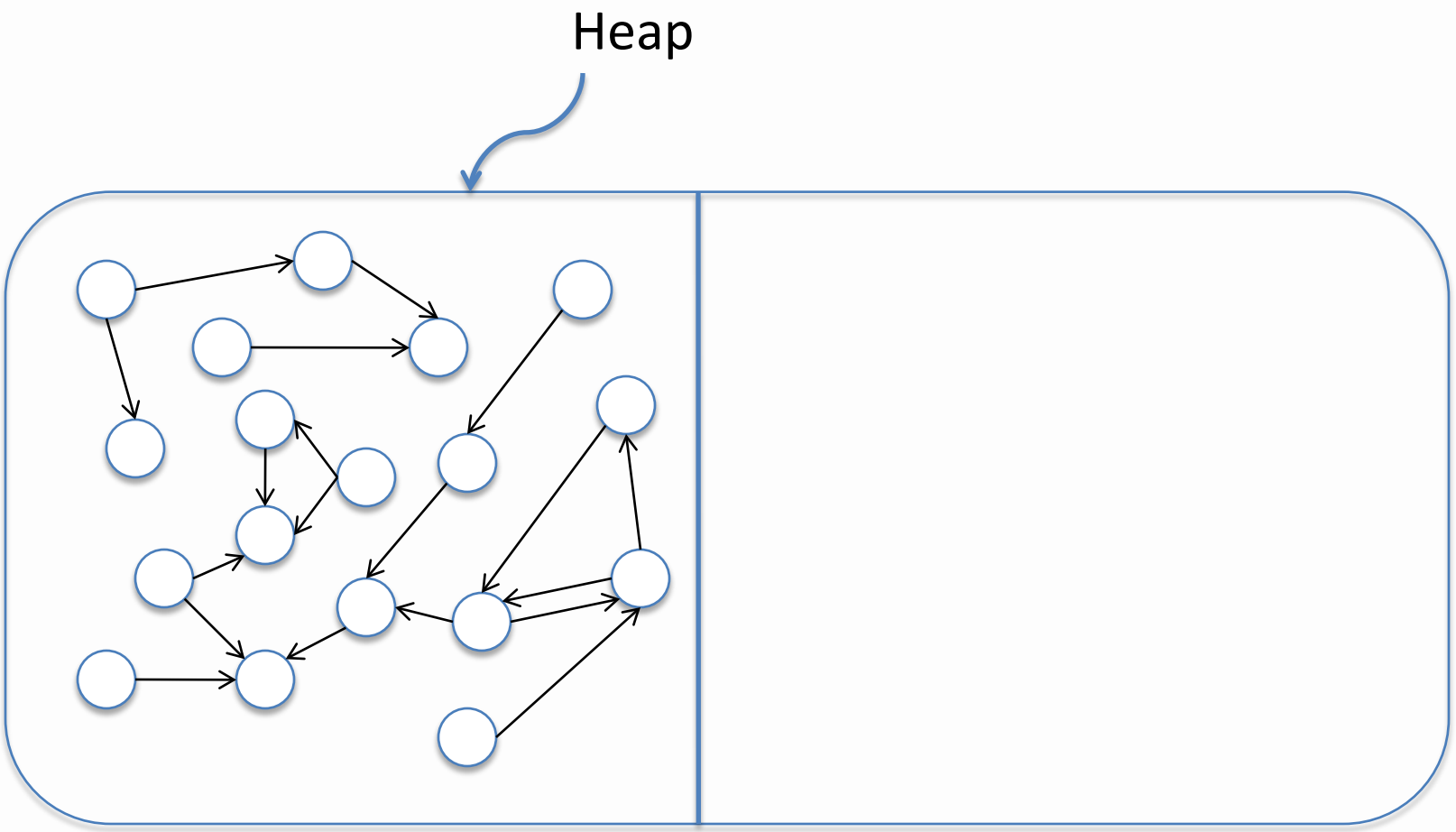
Dryad


Java™


C#


Scala

Background: GC



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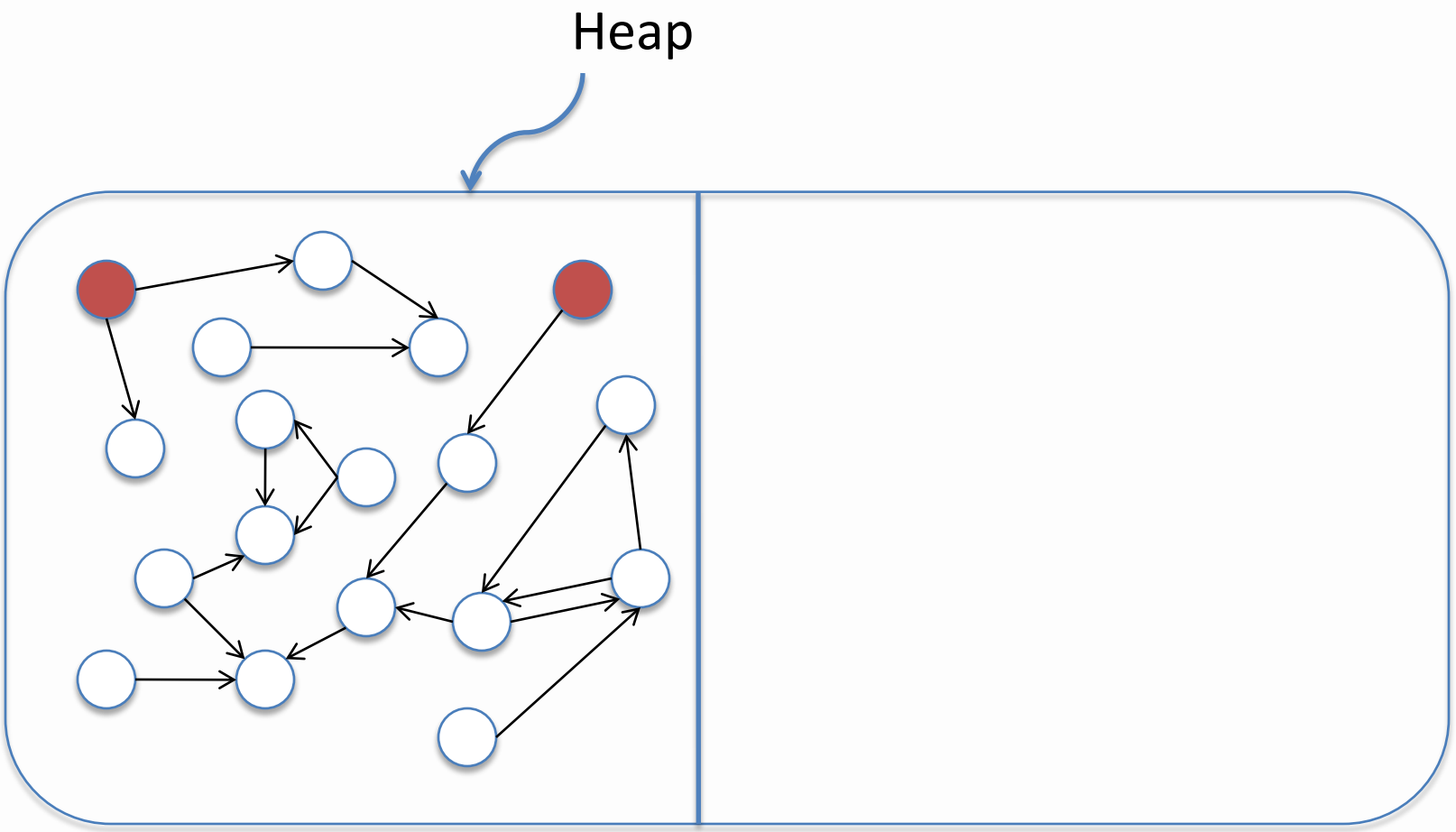

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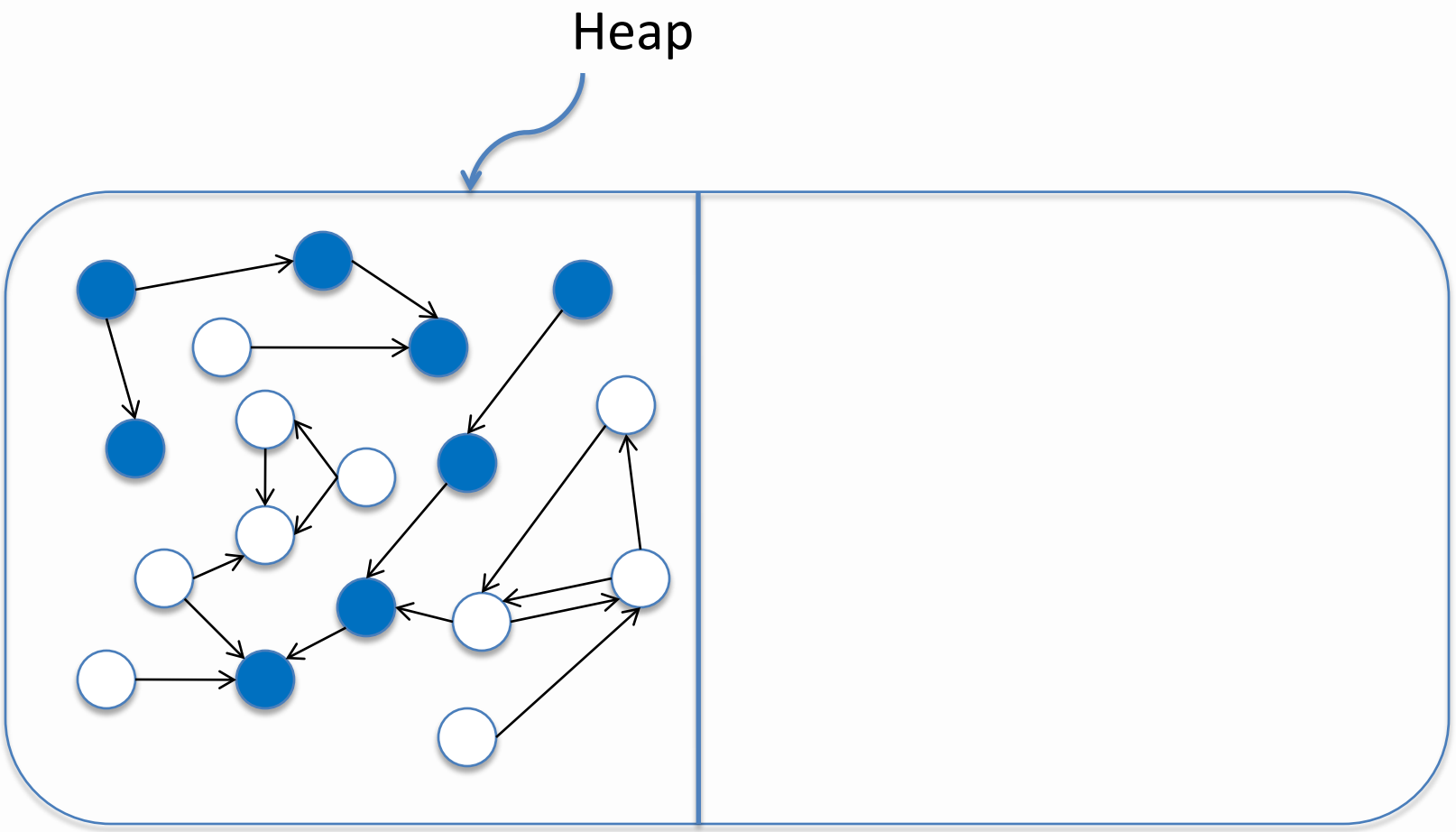

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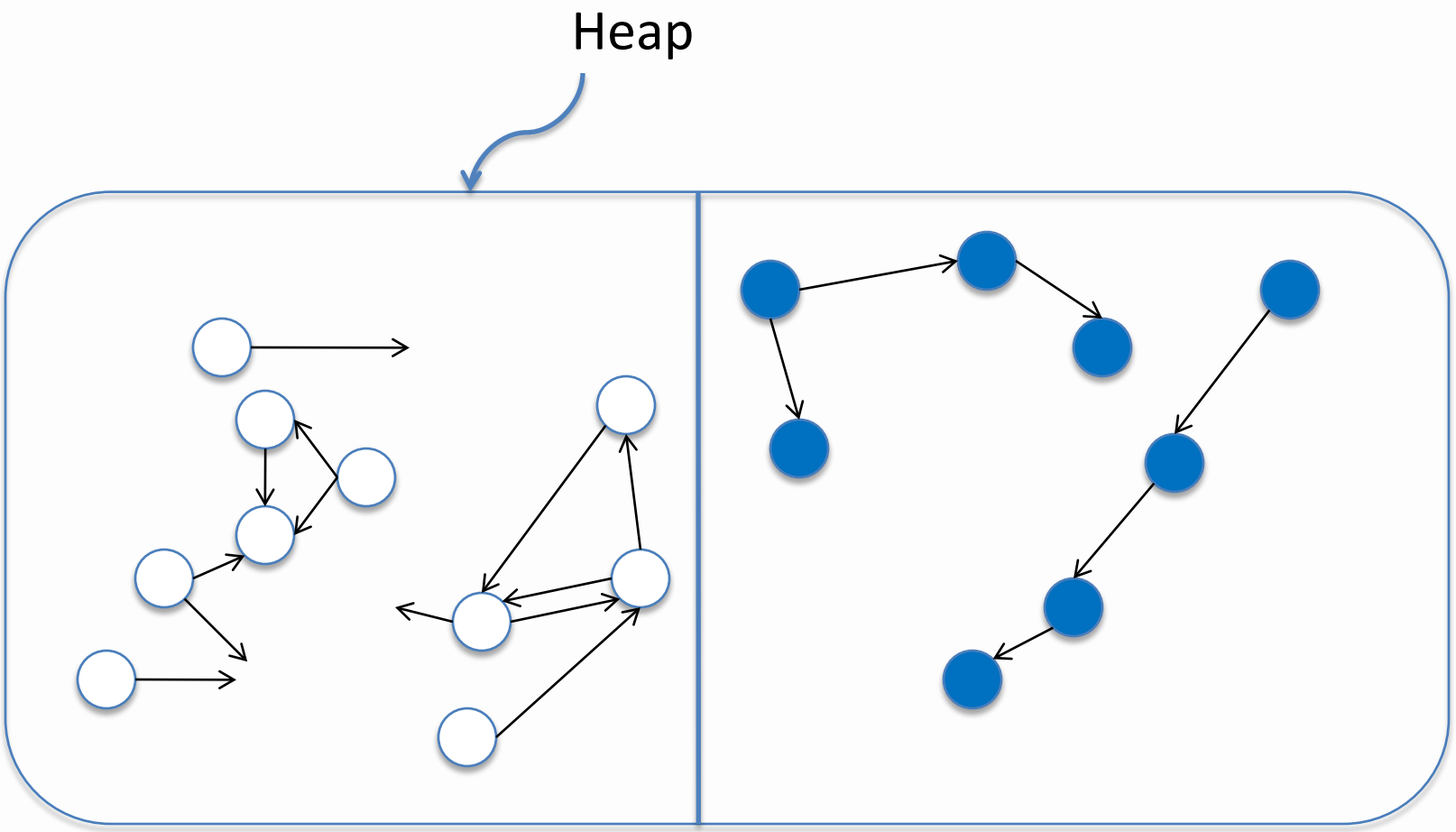

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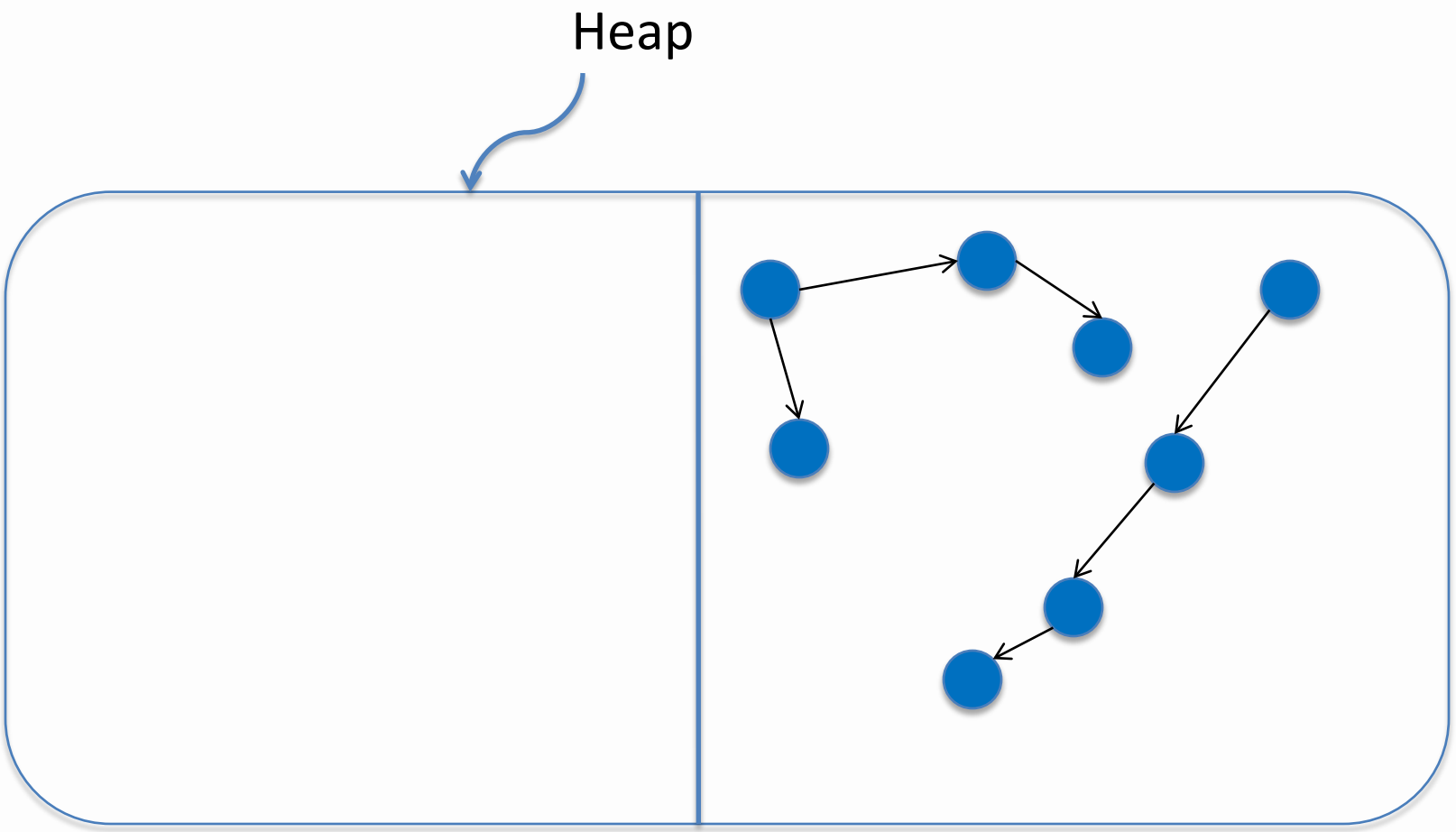


Java™


C#


Scala

Scalability

JVM crashes due to OutOfMemory error at early stage

[Fang et al., SOSP'15]

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Management cost

GC time accounts for up to **50%** of the execution time

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High cost of the managed runtime is a fundamental problem!

Two Paths, Two Hypotheses

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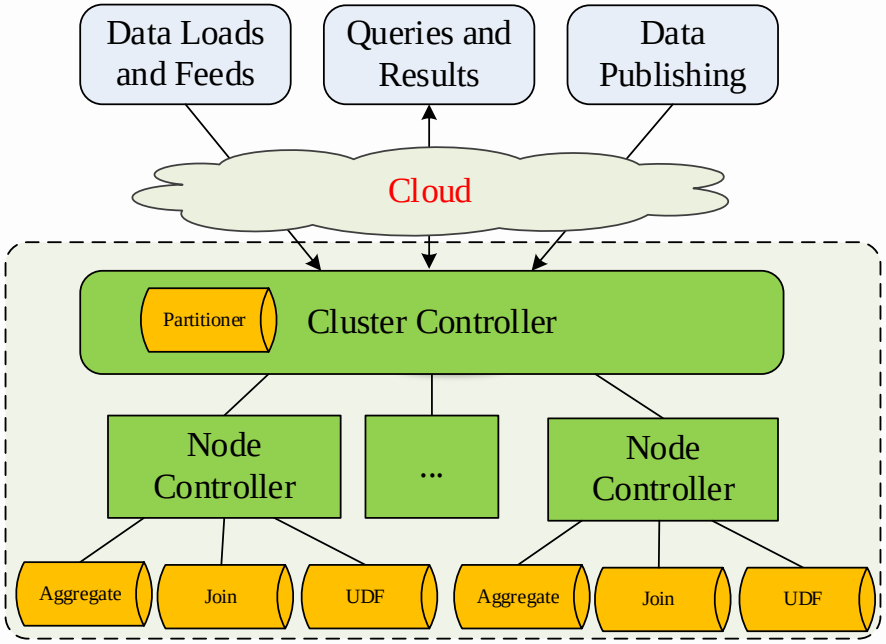

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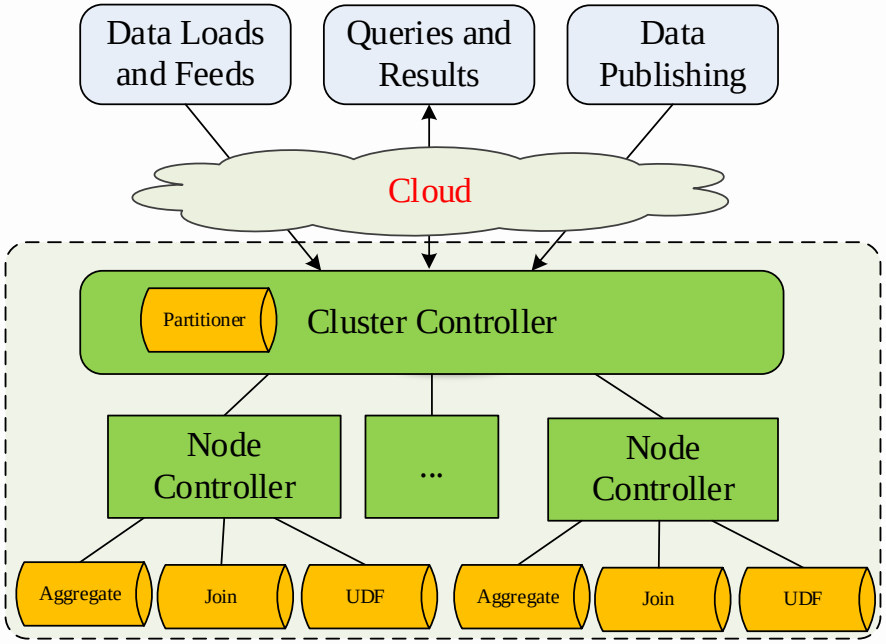
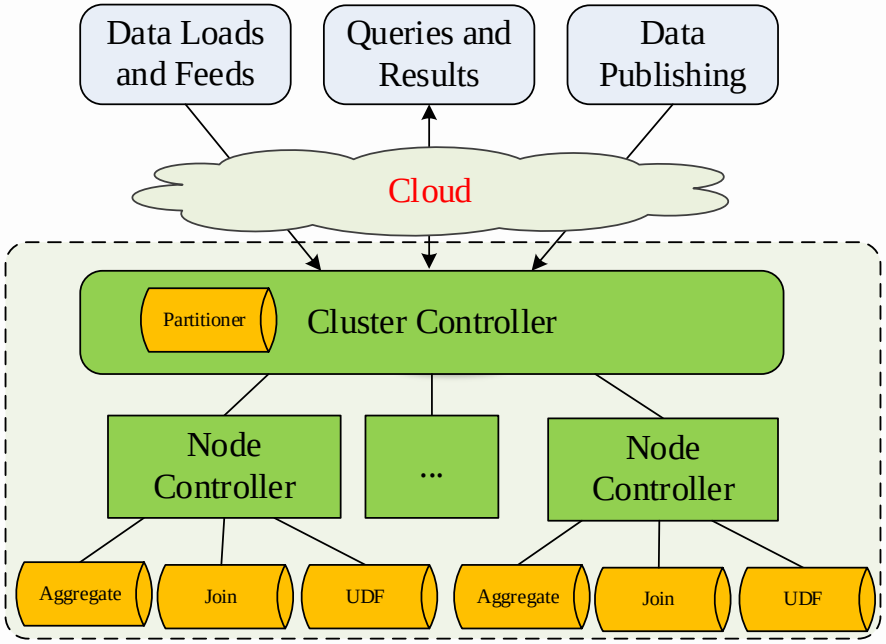


Control path

Data path

Two Paths, Two Hypotheses



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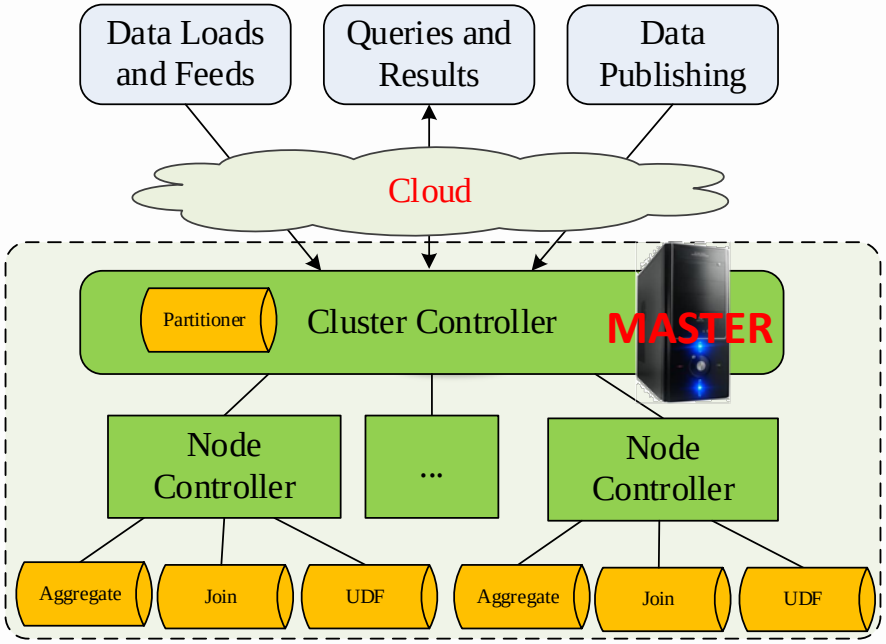

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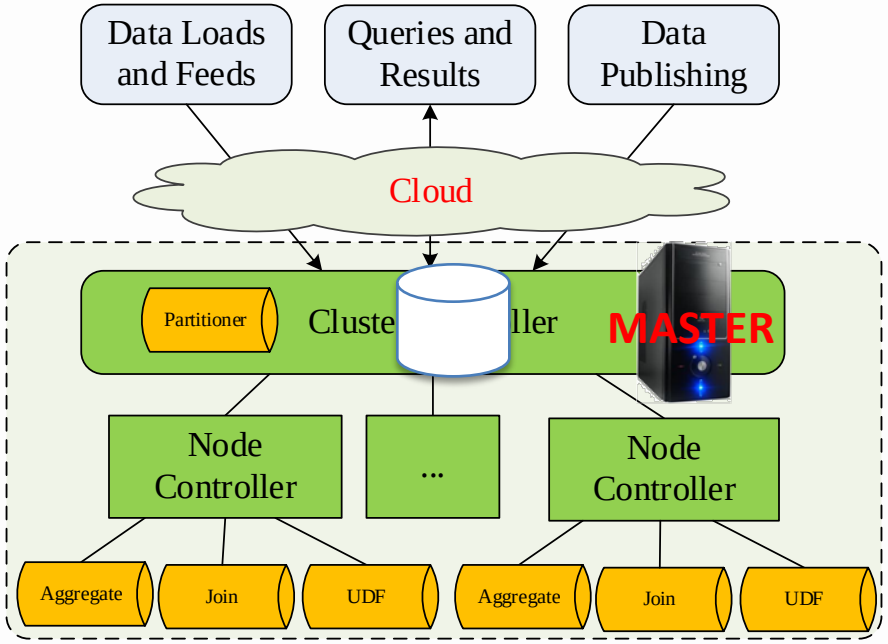

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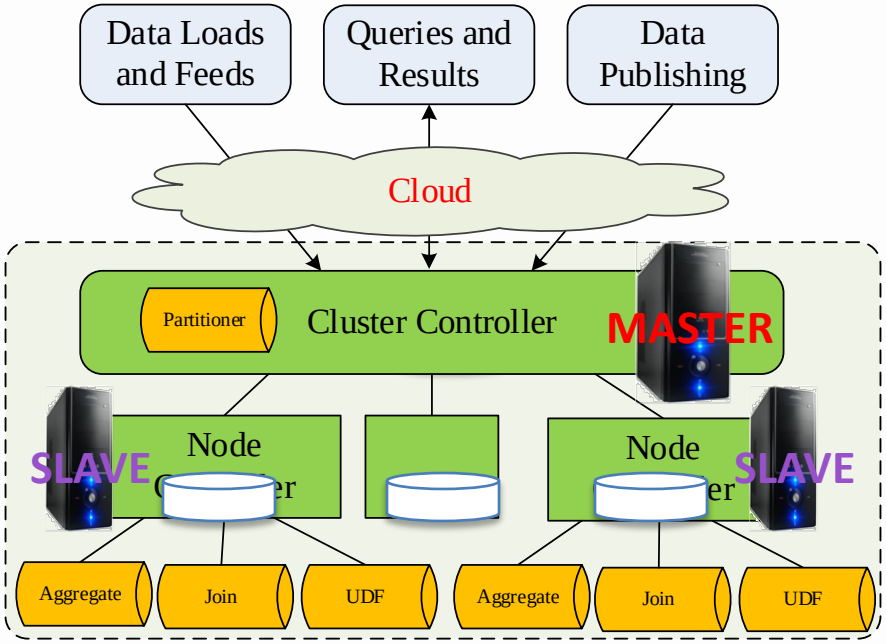

Control path

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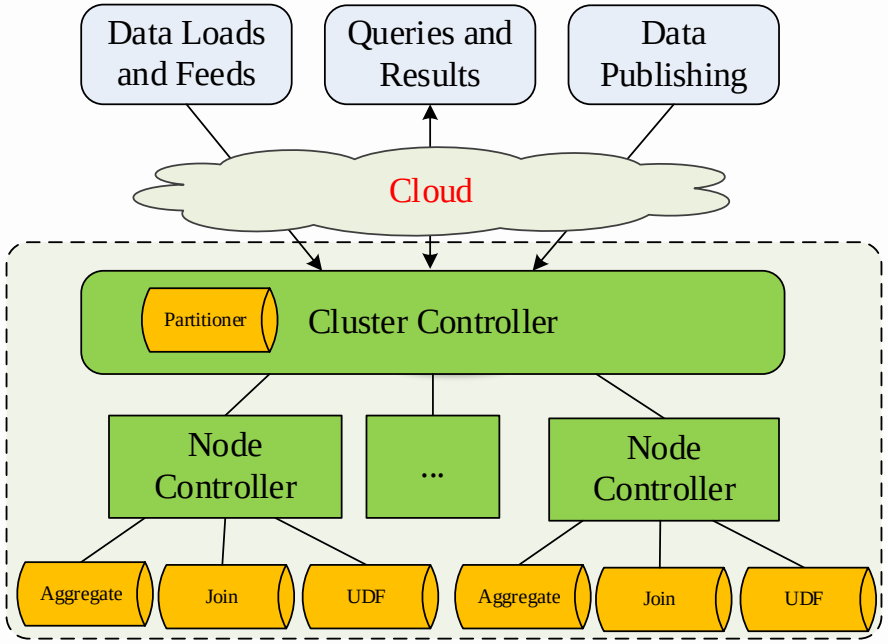

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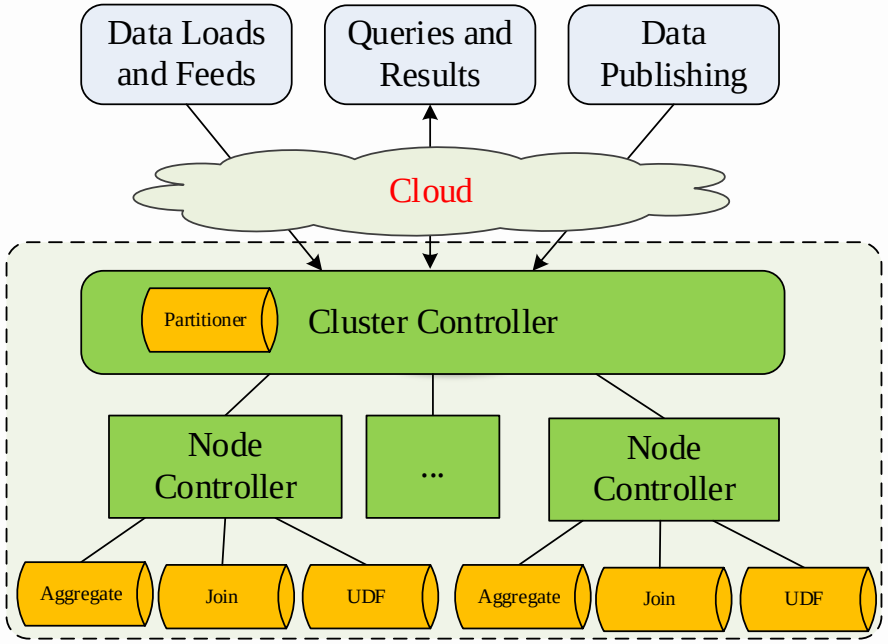
Generational Hypothesis

Two Paths, Two Hypotheses



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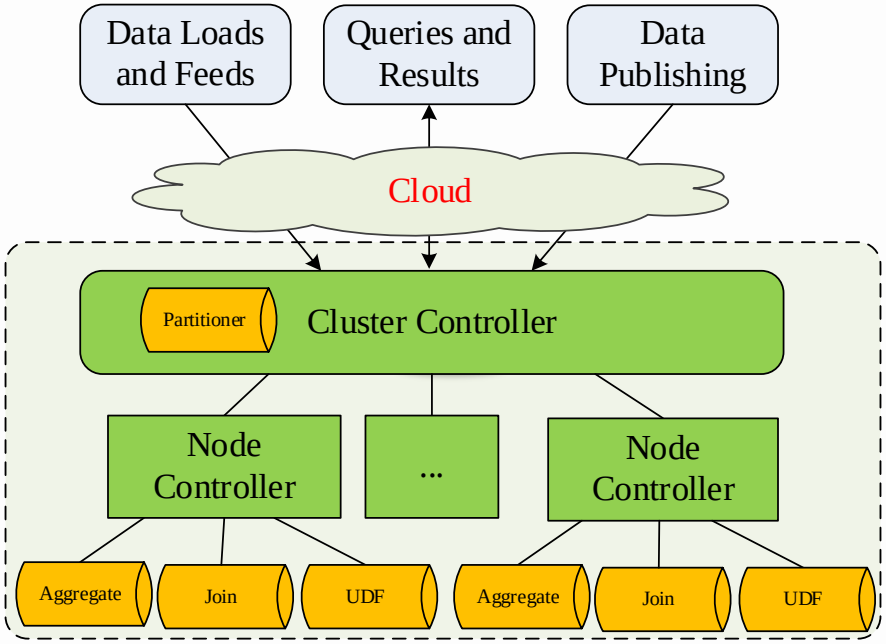


Control path

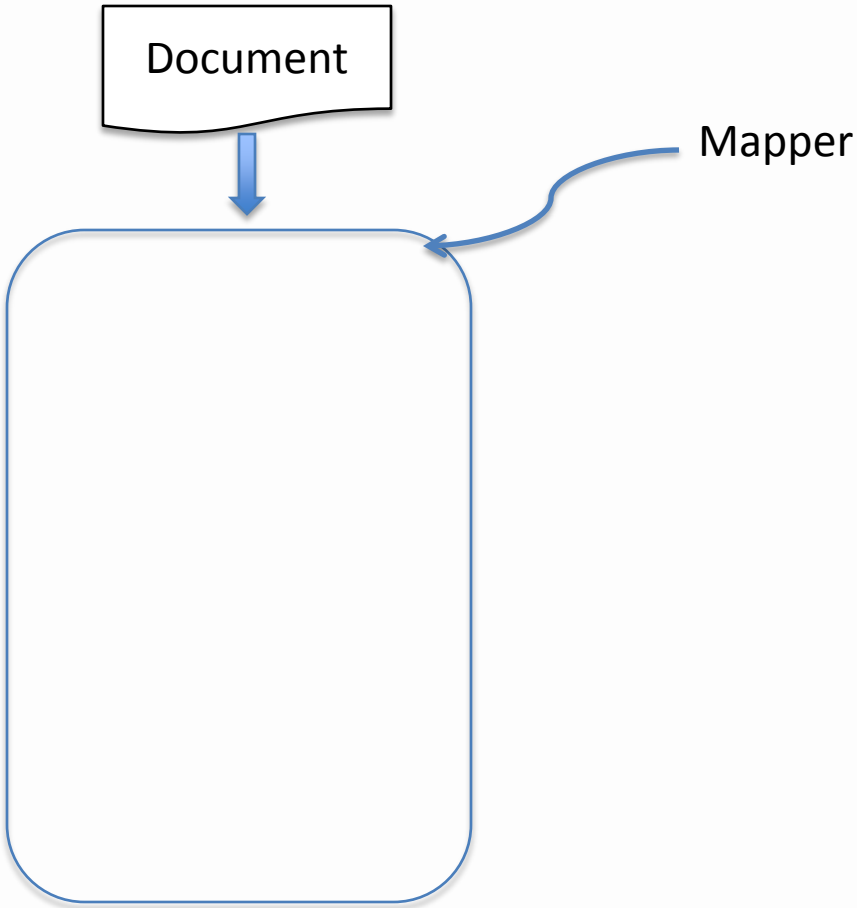
Data path

Generational Hypothesis

Epochal Hypothesis

WordCount

WordCount



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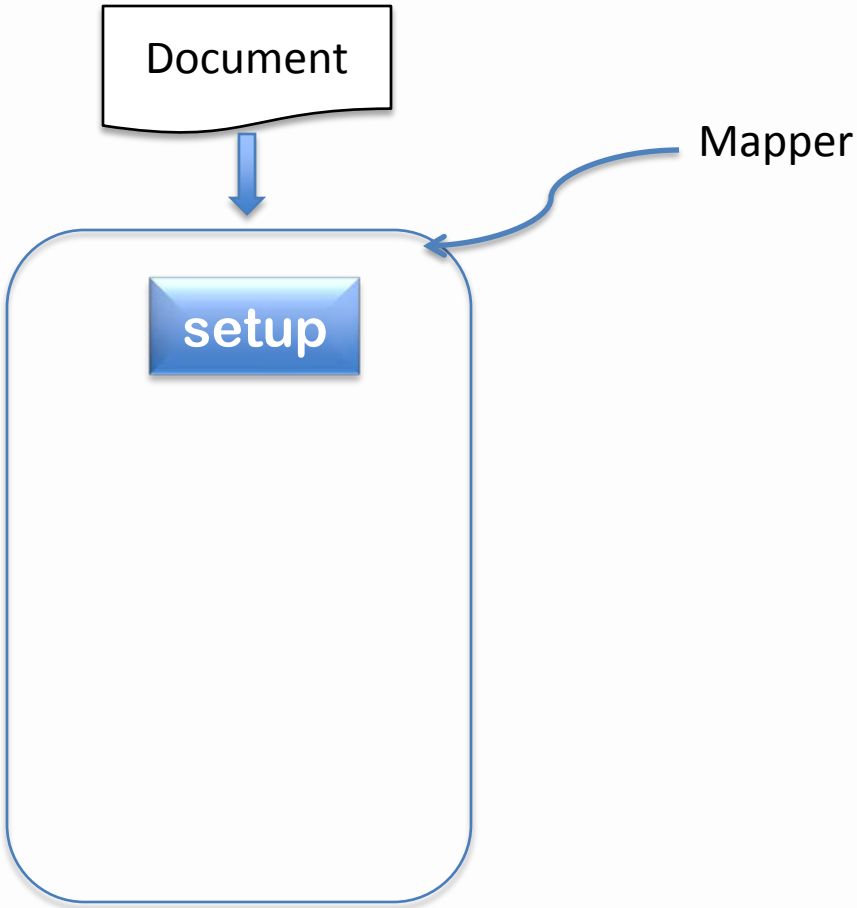

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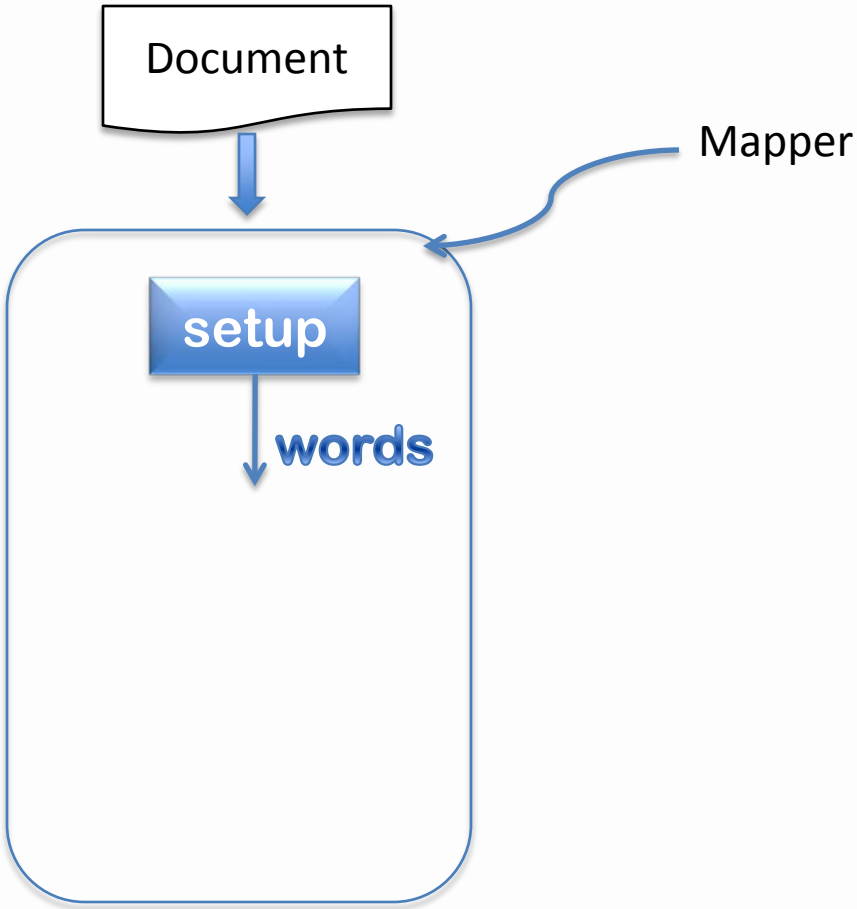

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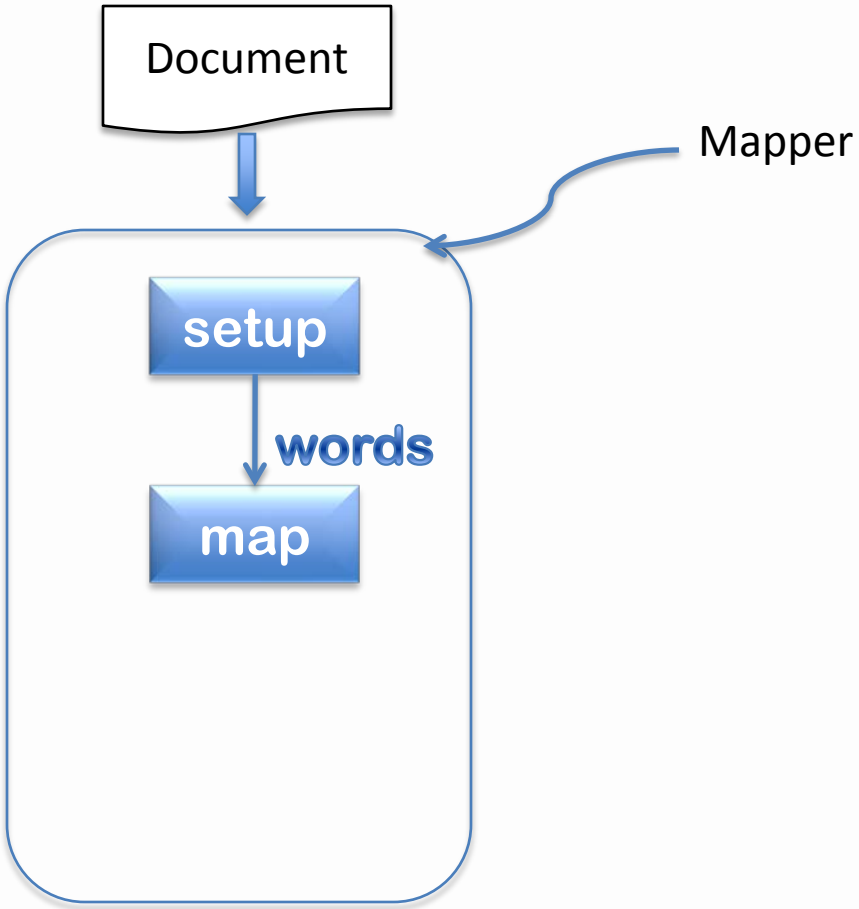

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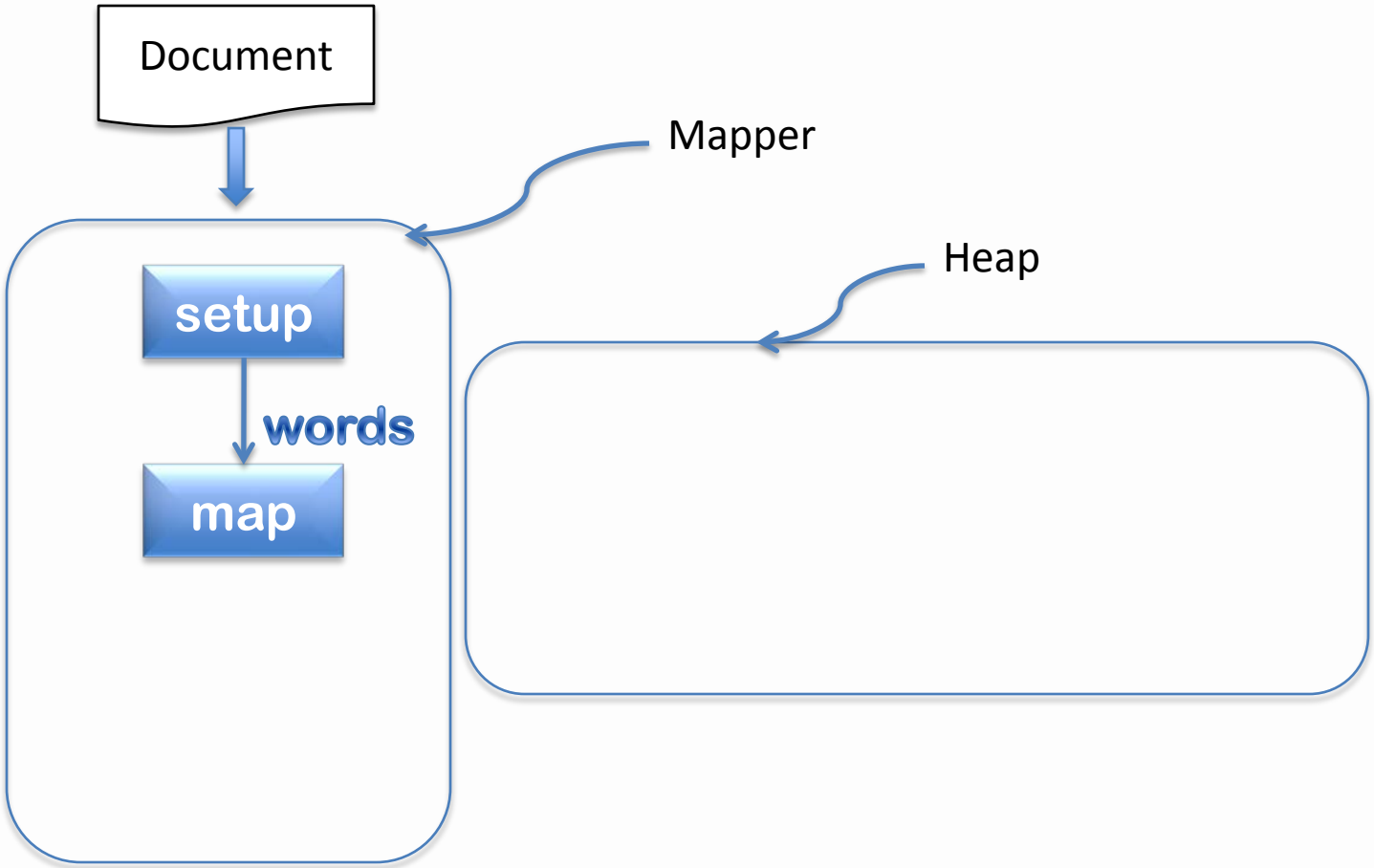

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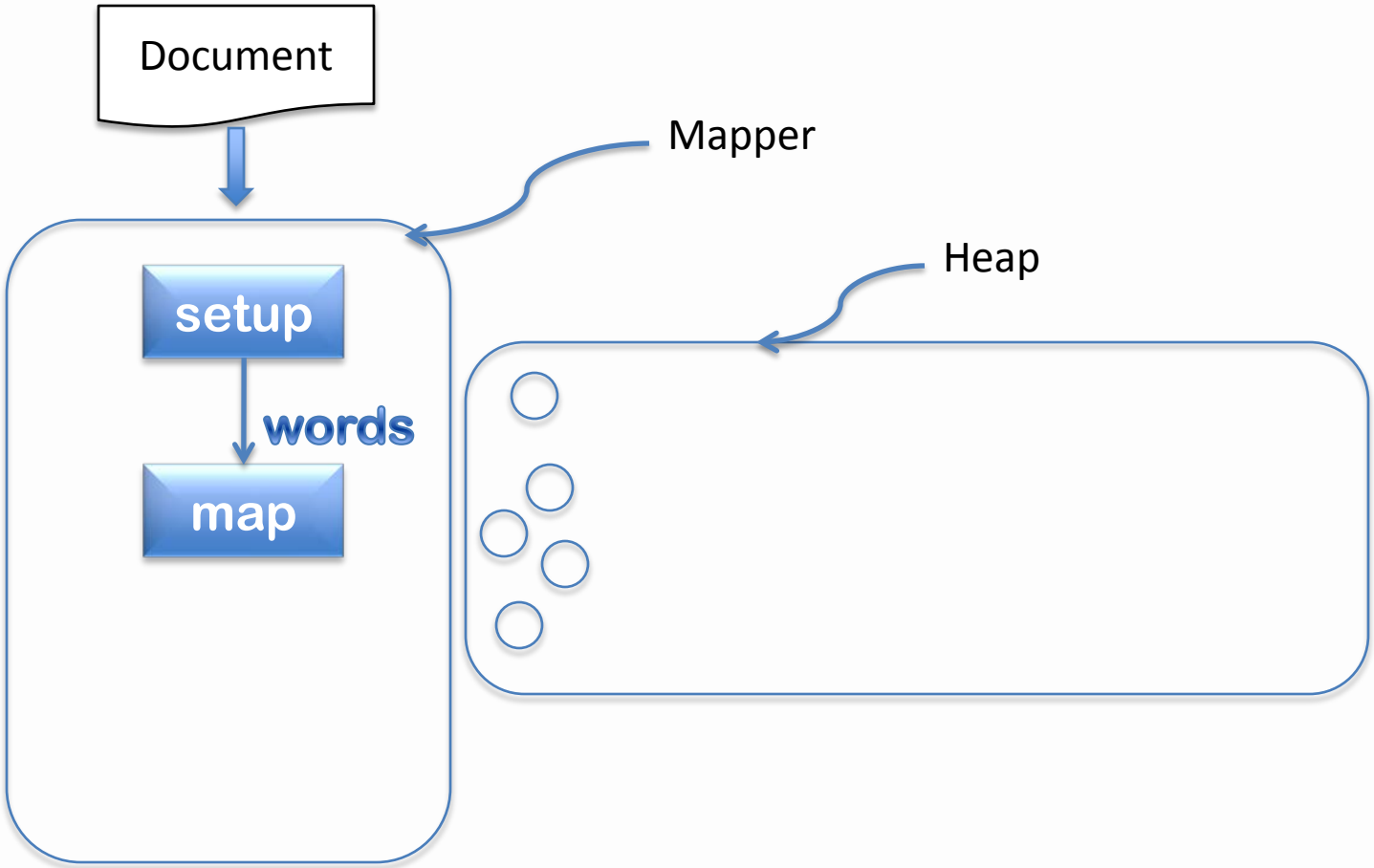

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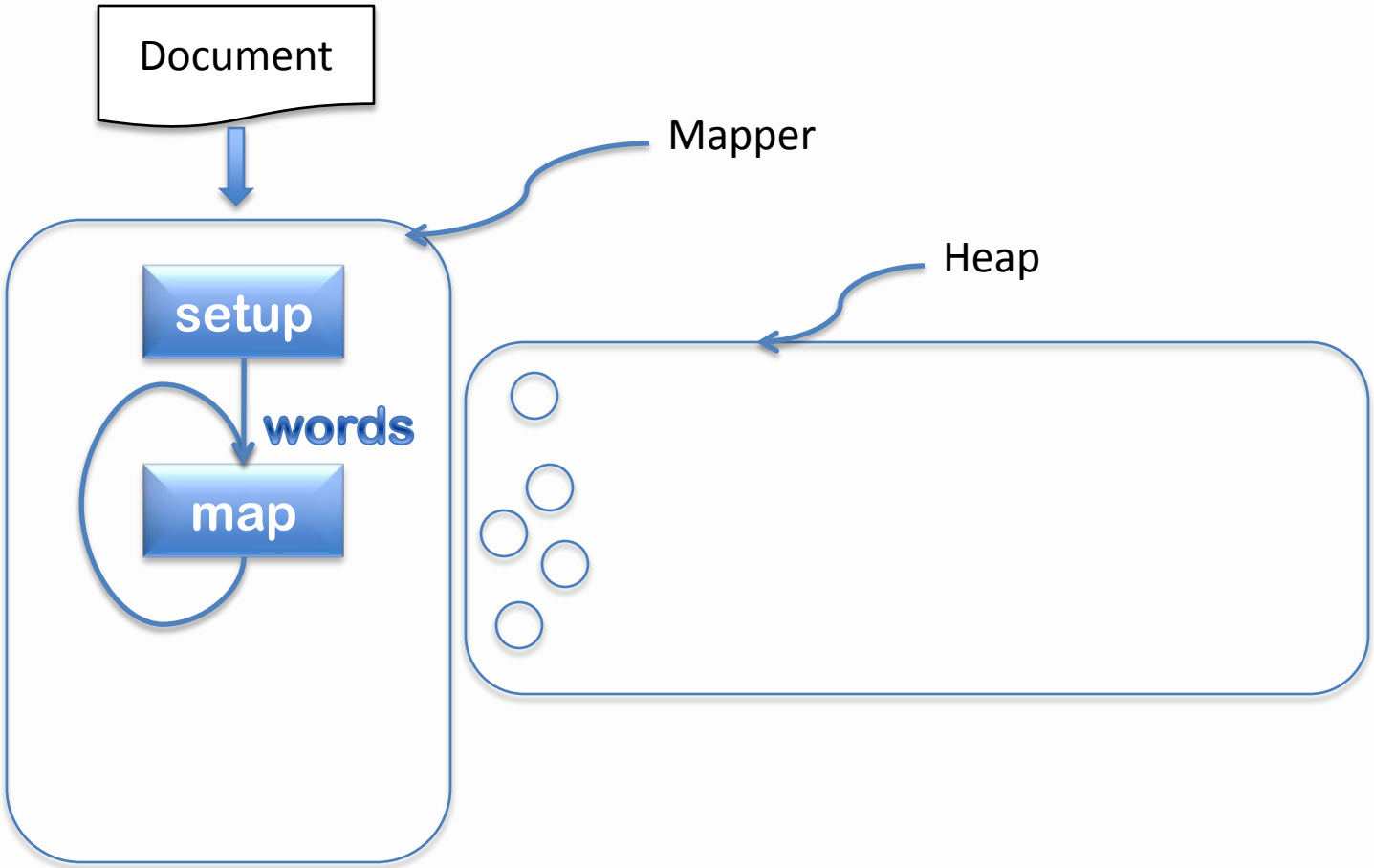

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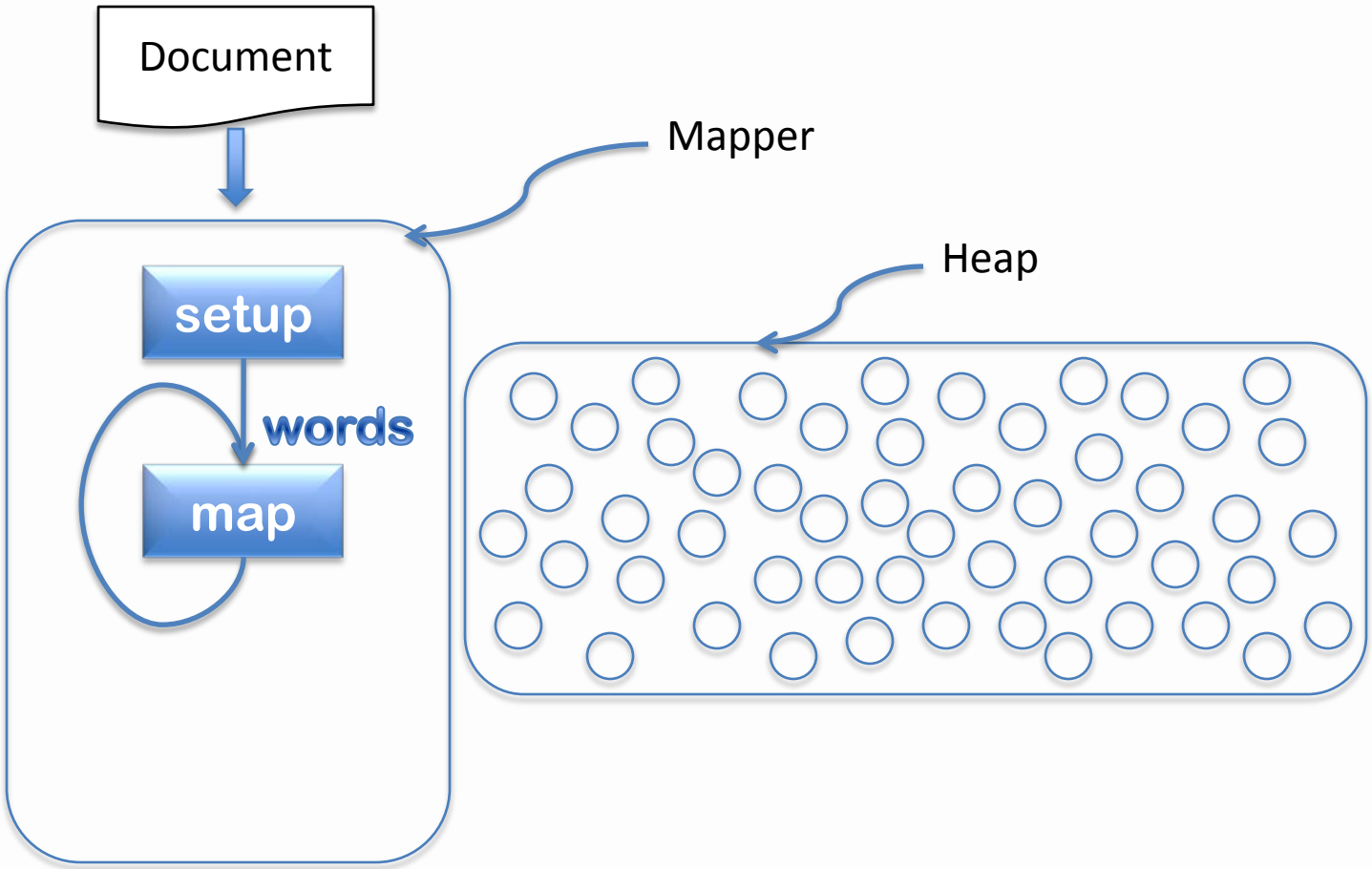

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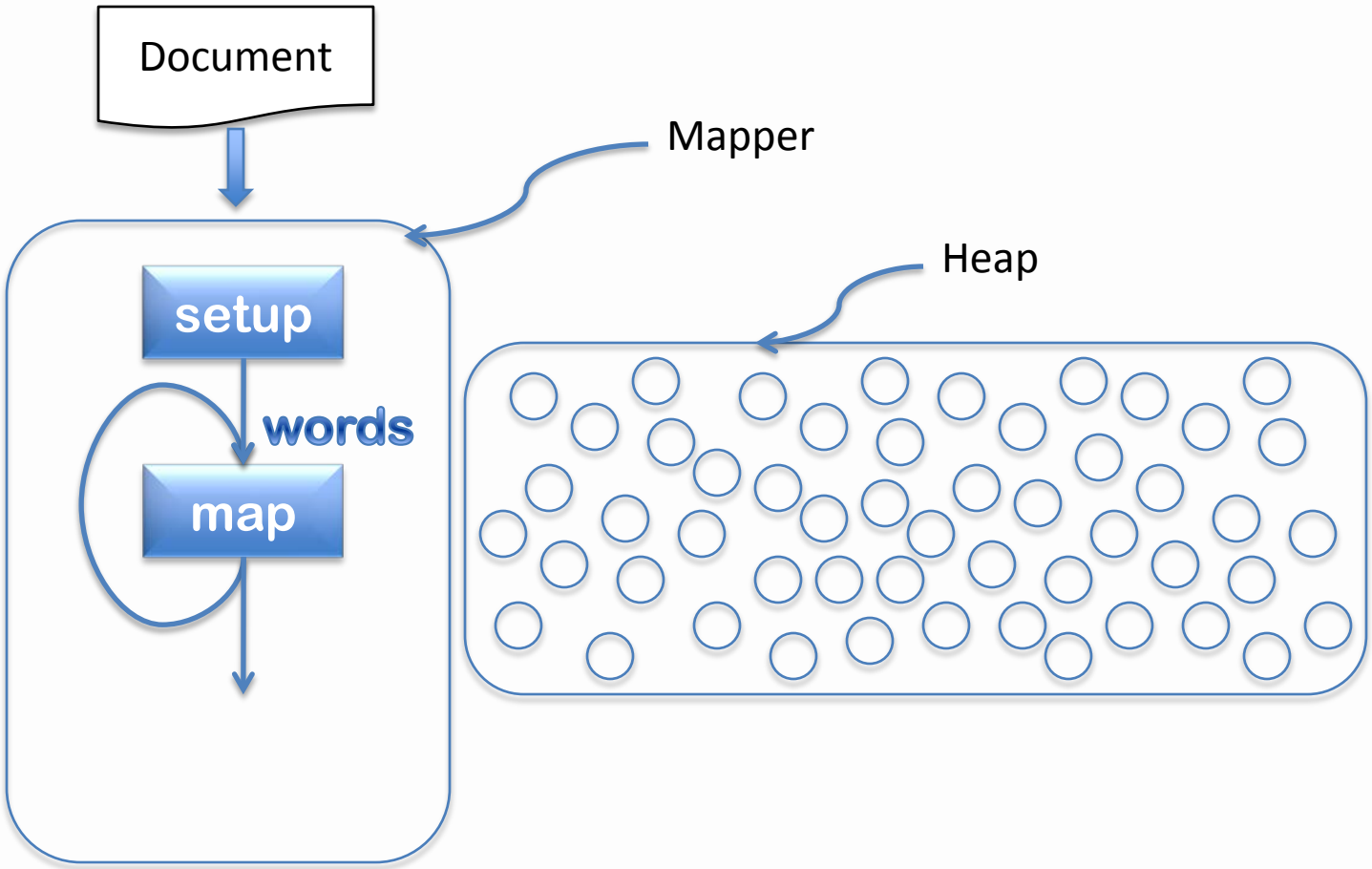

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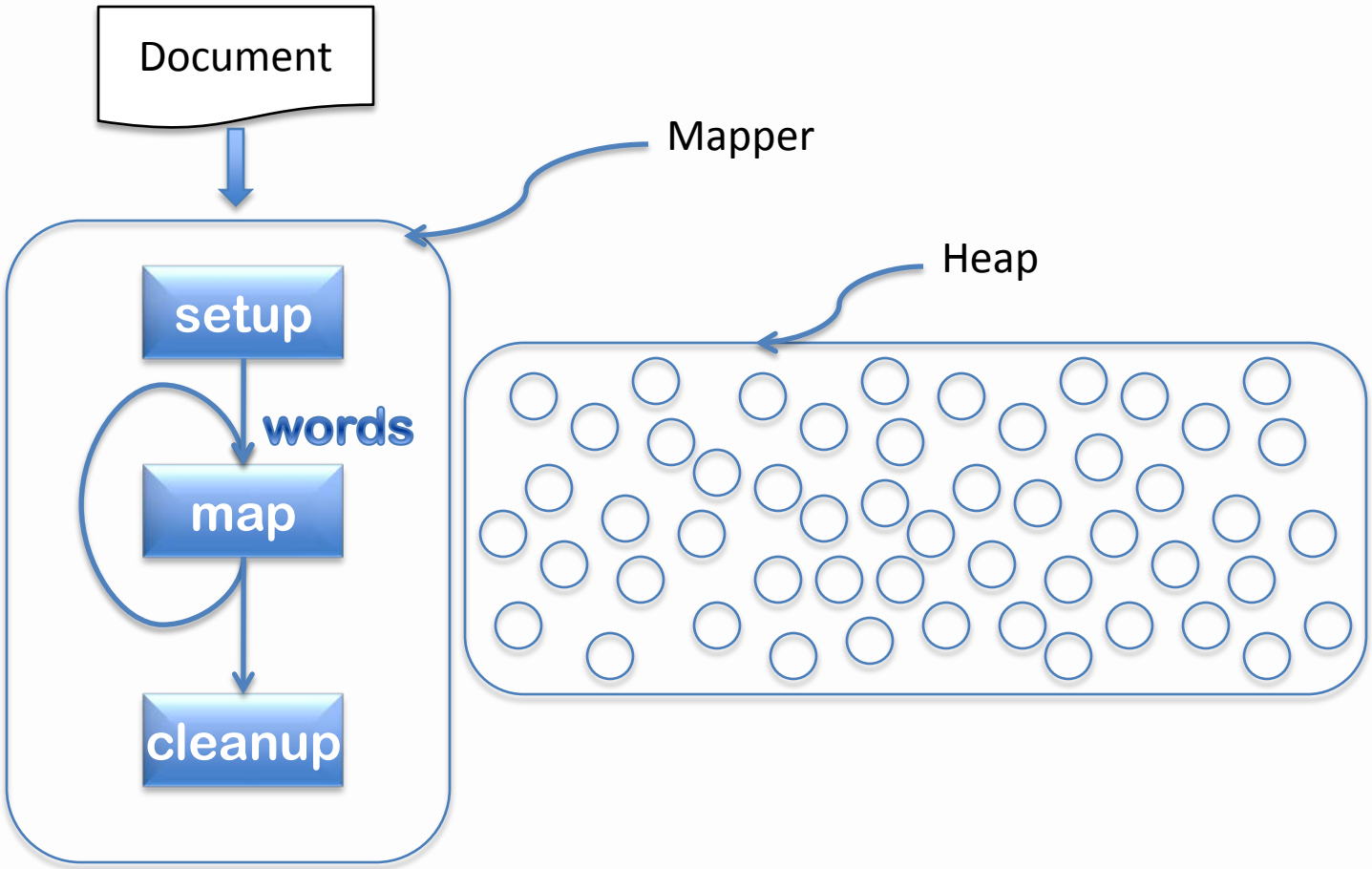

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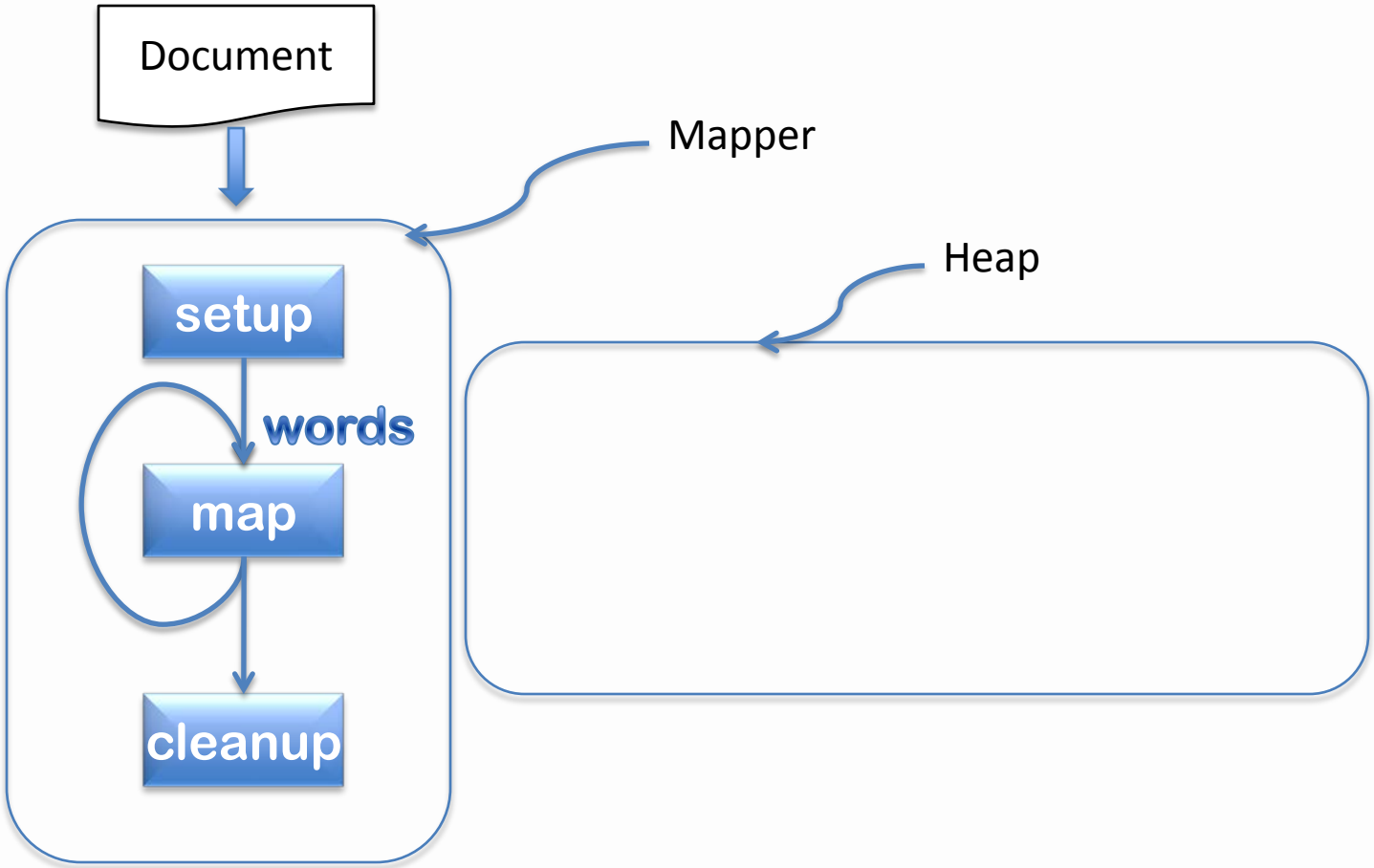

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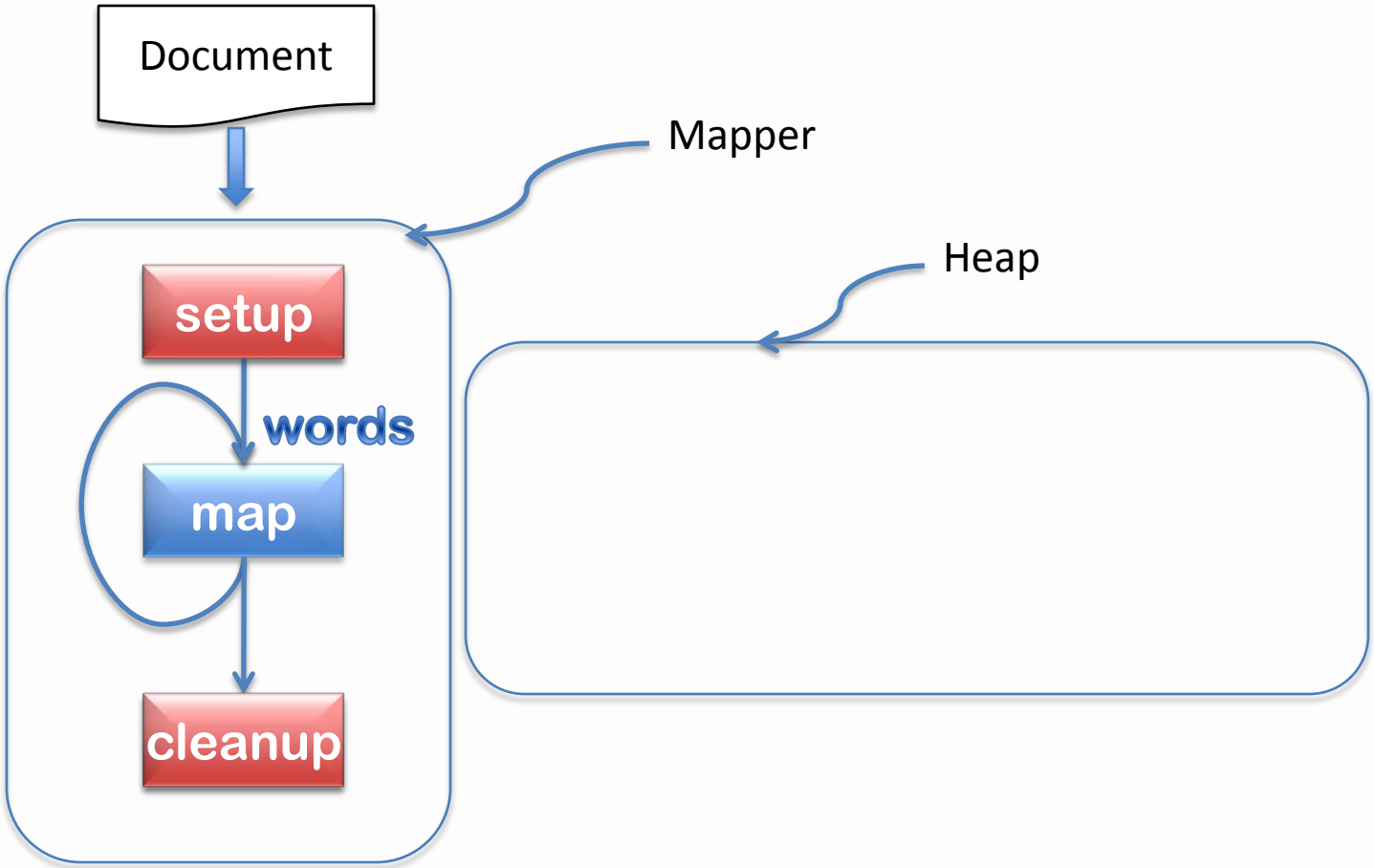

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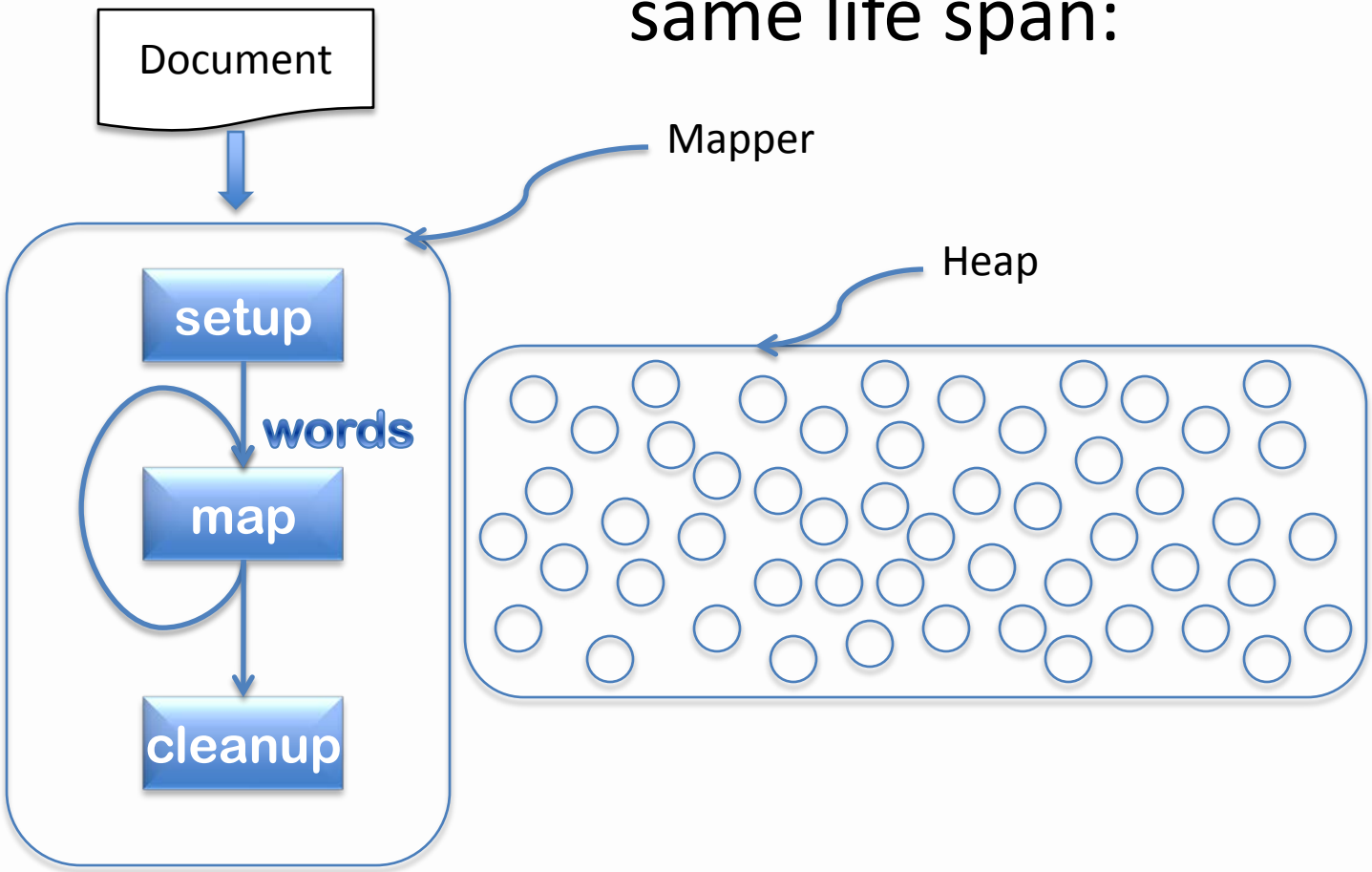
- Many data objects have the same life span:



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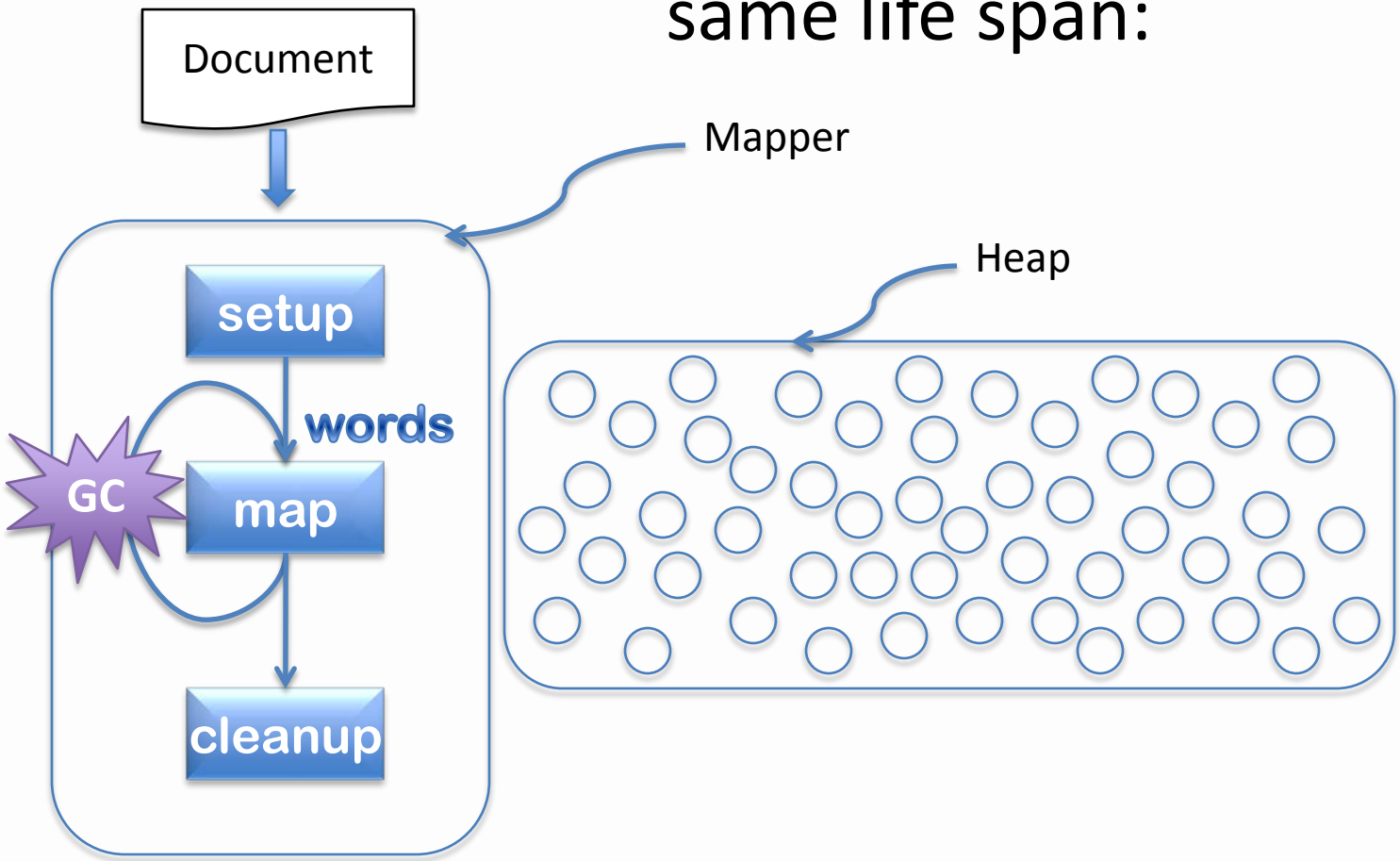

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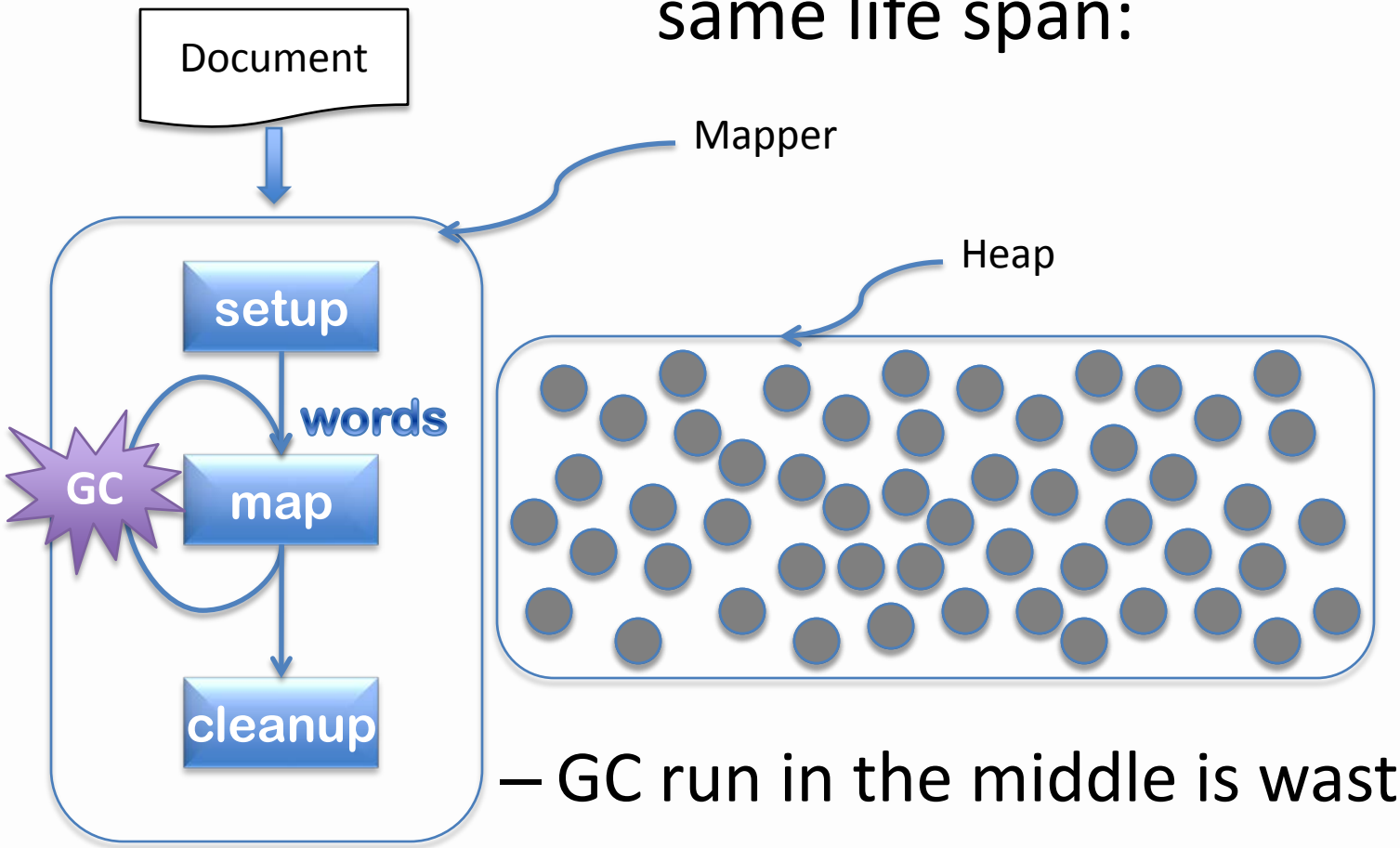

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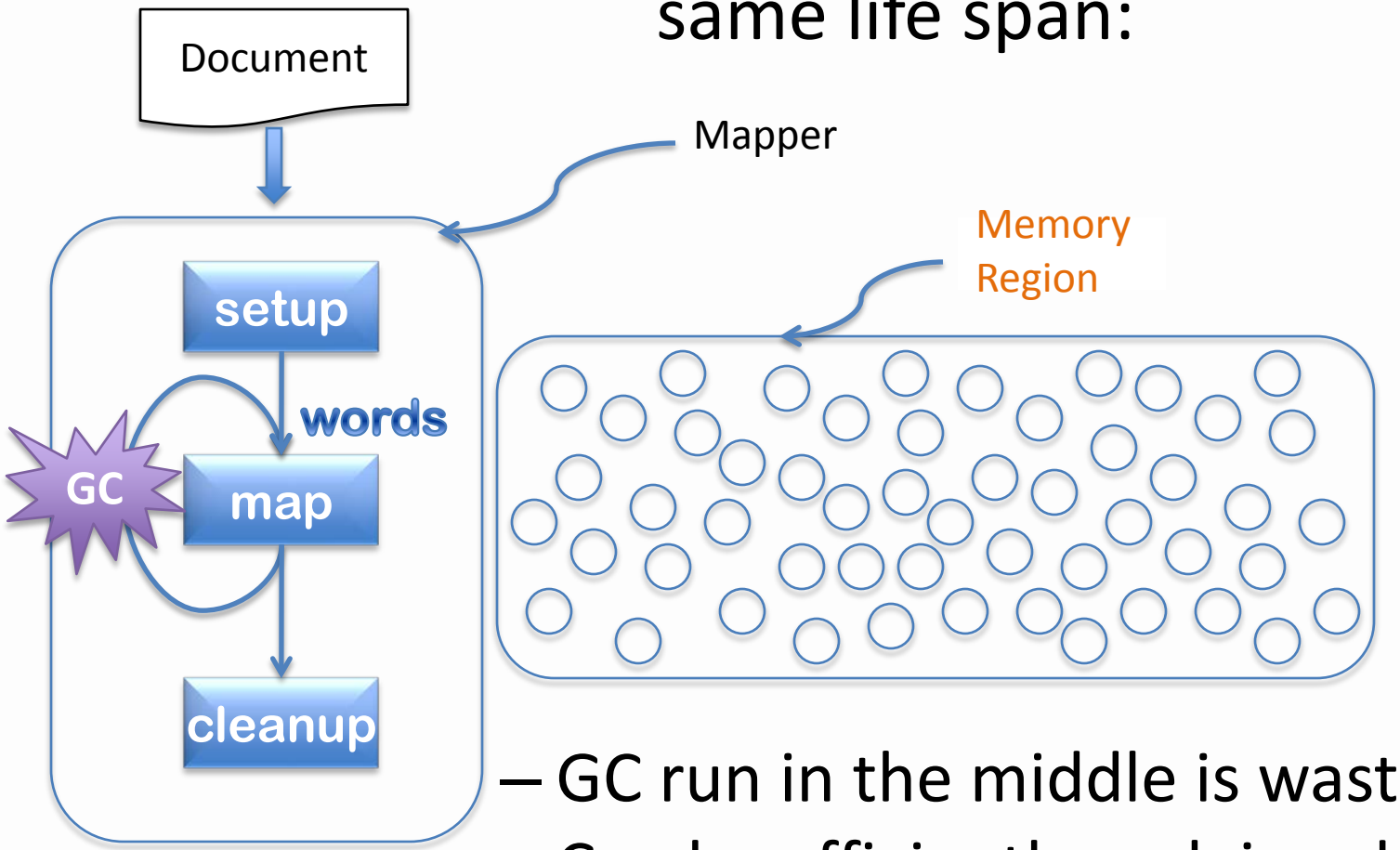

  - GC run in the middle is wasted
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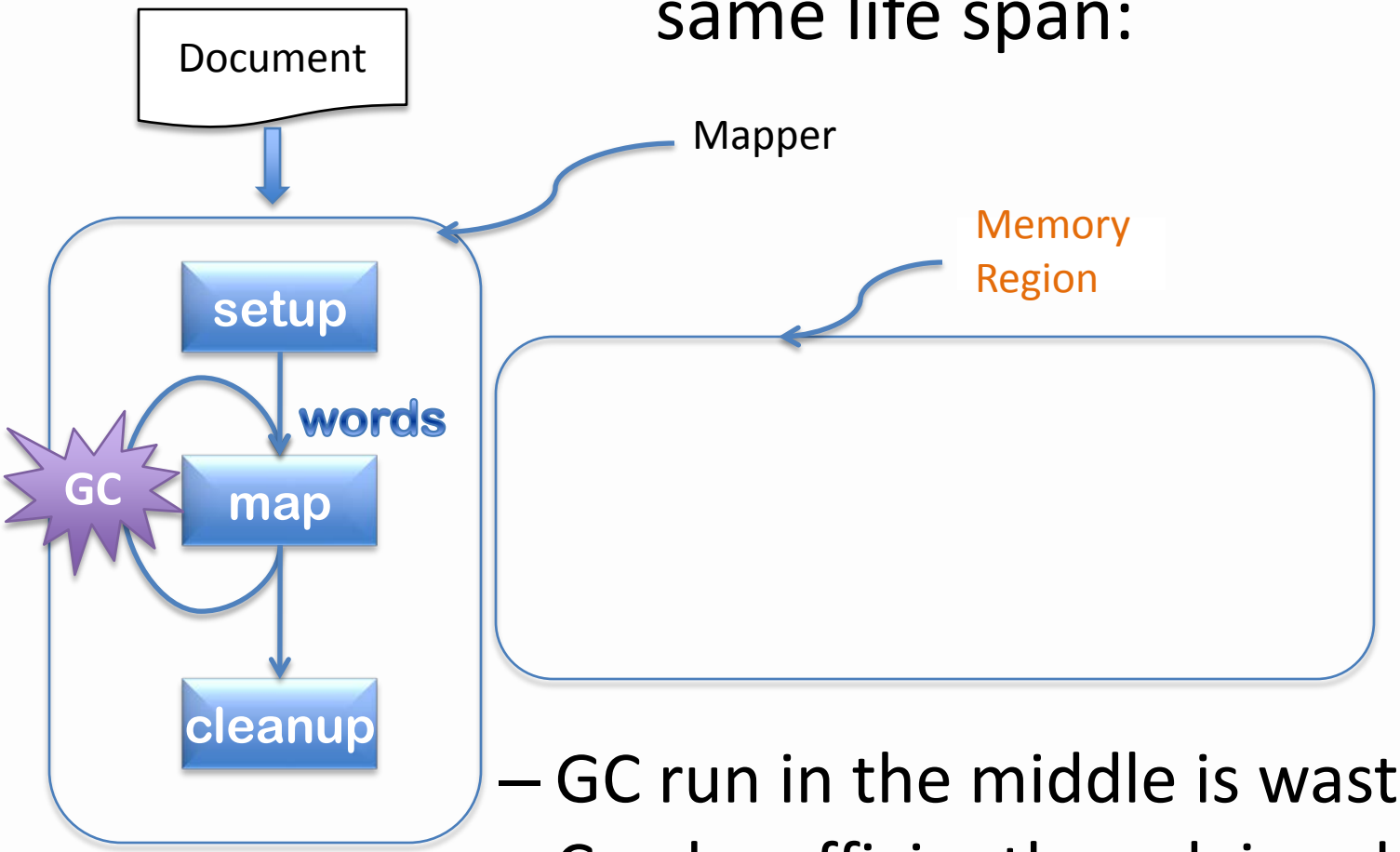

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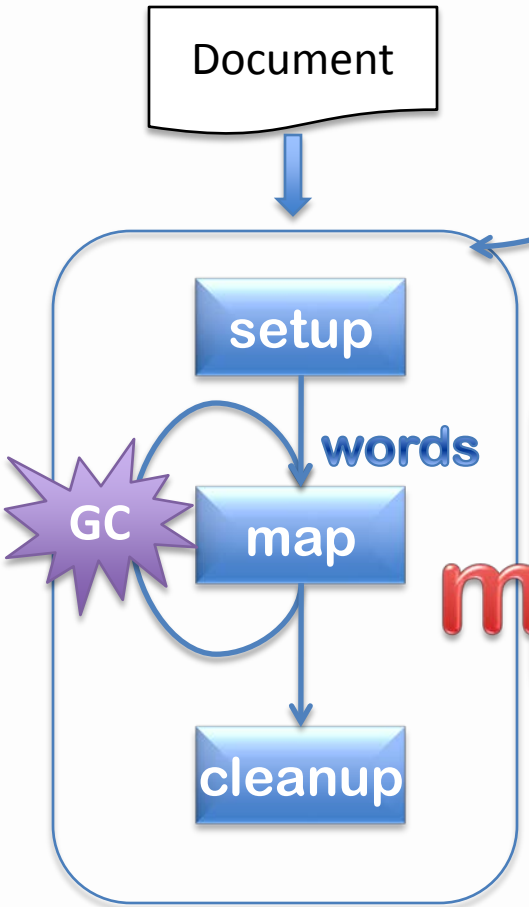

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Memory Region

Region-based memory management

  - GC run in the middle is wasted
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Region-based Memory Management

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Region-based Memory Management

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generational GC

region-based memory management

Yak Approach

Yak Approach

Yak Approach

Yak Approach

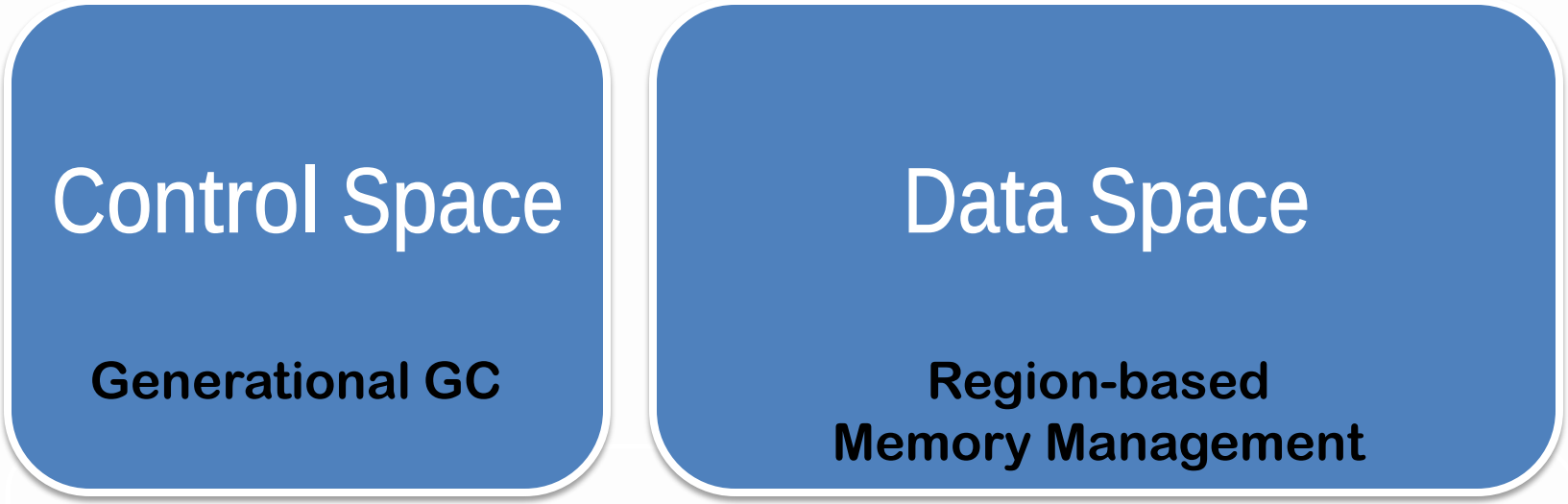
Control Space

Generational GC

Data Space

Region-based Memory Management

Yak Approach



Reduced memory management cost

Yak Approach

Control Space

Generational GC

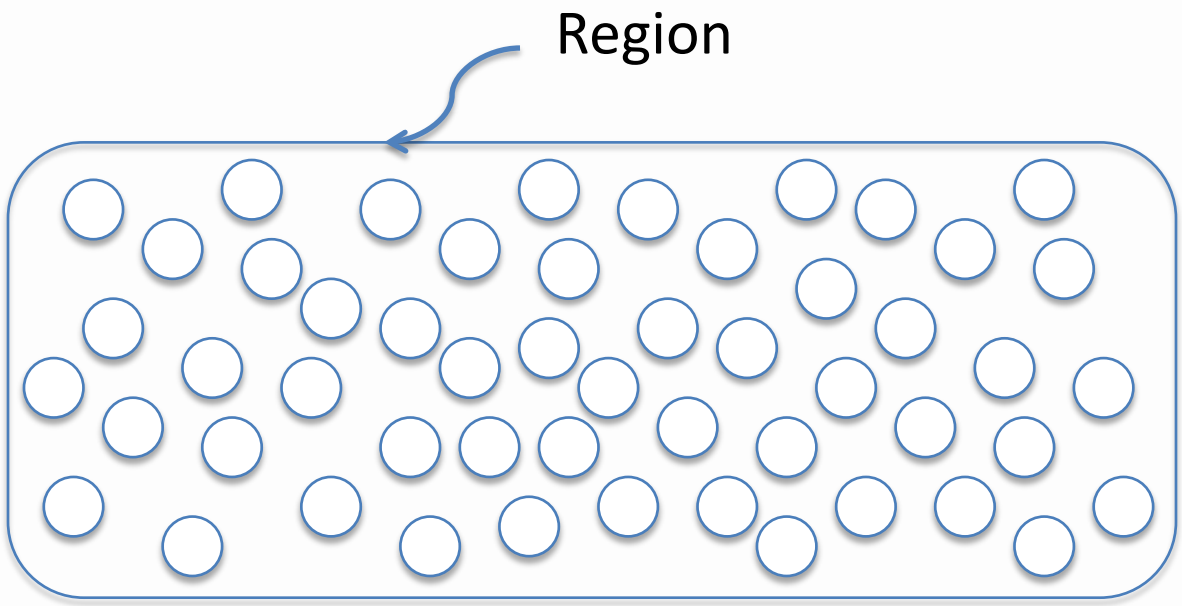
Data Space

Region-based Memory Management

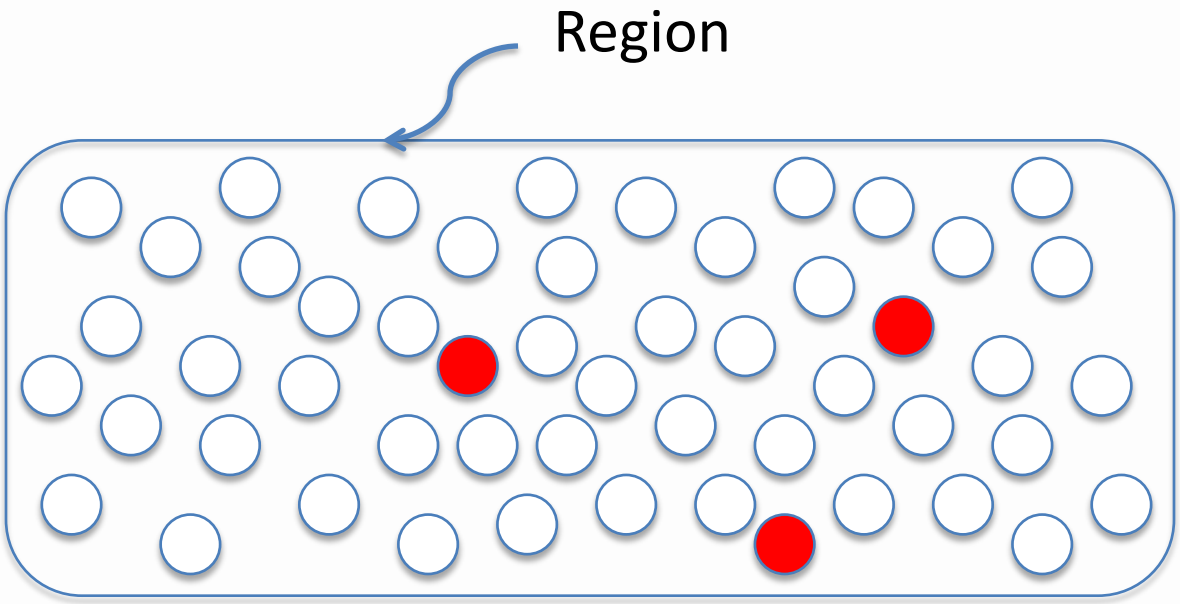
Reduced memory management cost

annotate epoch boundary:
- **epoch_start()**
- **epoch_end()**

Correctness



Correctness



Correctness

- User-based approach solution:
  - Facade [Nguyen et al., ASPLOS'15]

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annotation & refactoring

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Developers

Correctness

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Developers → Yak

Yak: An Automatic Solution

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- Yak: the first hybrid GC
  - Implemented in OpenJDK 8
    - Modified the interpreter, two JIT compilers, the heap layout, the Parallel Scavenge GC
  - NO code refactoring needed;

    correctness guaranteed by the system

Yak: An Automatic Solution

- **Yak**: the first hybrid GC
  - Implemented in OpenJDK 8
    - Modified the interpreter, two JIT compilers, the heap layout, the Parallel Scavenge GC
  - NO code refactoring needed;

    correctness guaranteed by the system
  - On average, vs. default production GC (PS):
    - Reduce **33%** execution time
    - Reduce **78%** GC time

Challenges

- How to create regions?
- How to reclaim regions correctly?

How to Create Regions?

- A region starts at a call to epoch-start and ends at a call to epoch-end
  - The location of epochs affects *performance* but not *correctness*
- Regions are thread-local
- Regions can be nested

How to Create Regions?

```
void main() {









} //end of main
```

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void main() {









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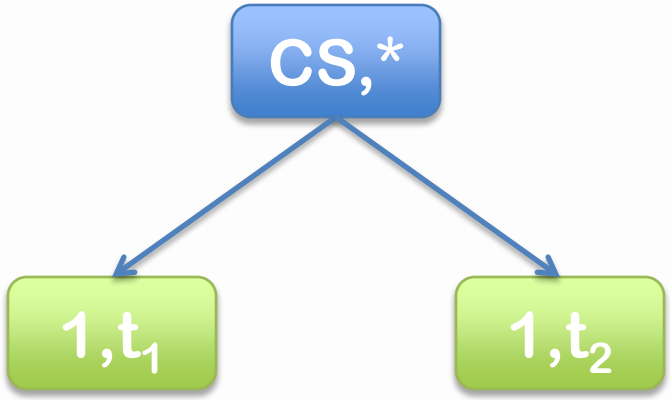
CS,*

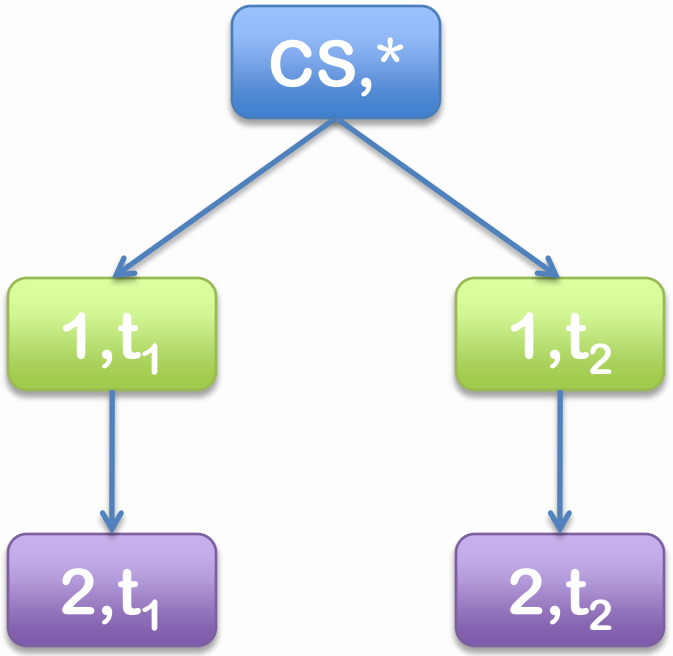
How to Create Regions?

```
void main() {

epoch_start();                    epoch #1
for(    ) {









}
epoch_end();

} //end of main
```



How to Create Regions?

```
void main() {

epoch_start();                    epoch #1
for(    ) {

   epoch_start();                 epoch #2
   for(    ) {









   }
   epoch_end();

}
epoch_end();

} //end of main
```



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   for(    ) {

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      for(    ) {

      }
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   }
   epoch_end();

}
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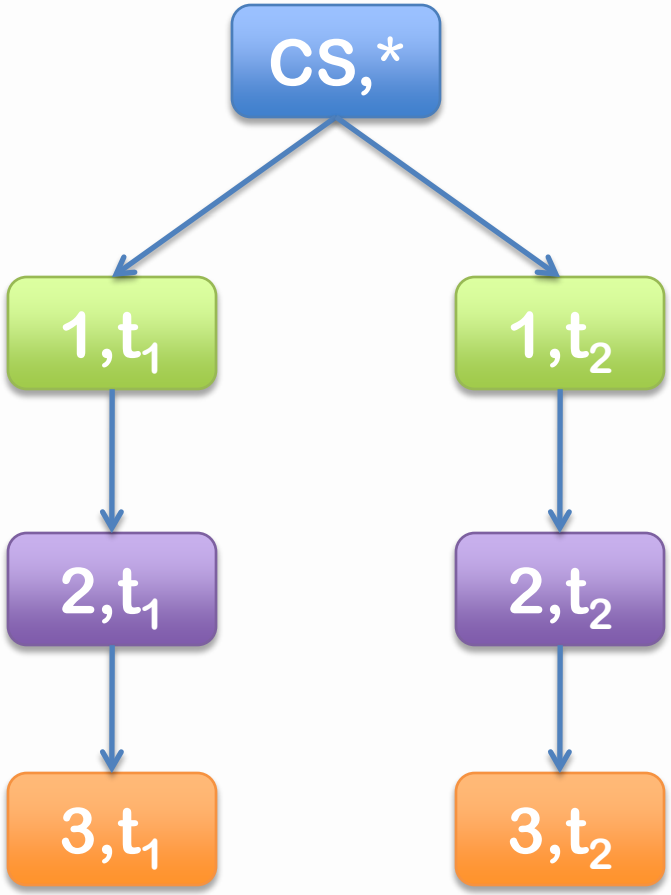

Region Semilattice

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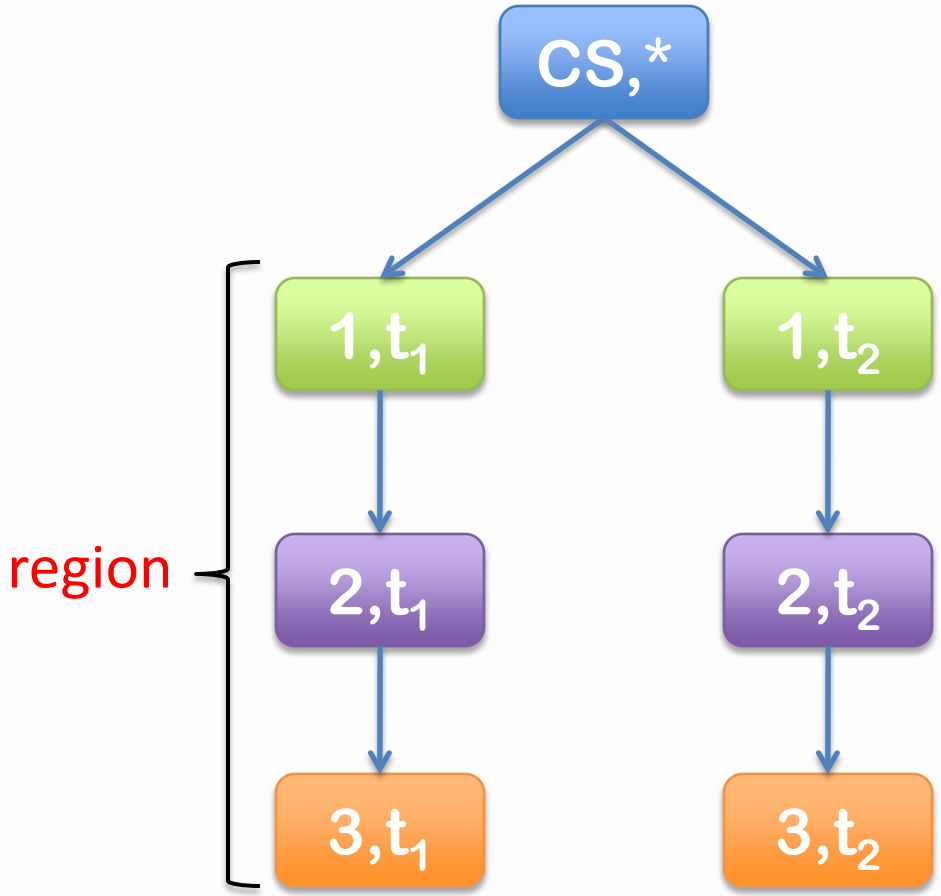

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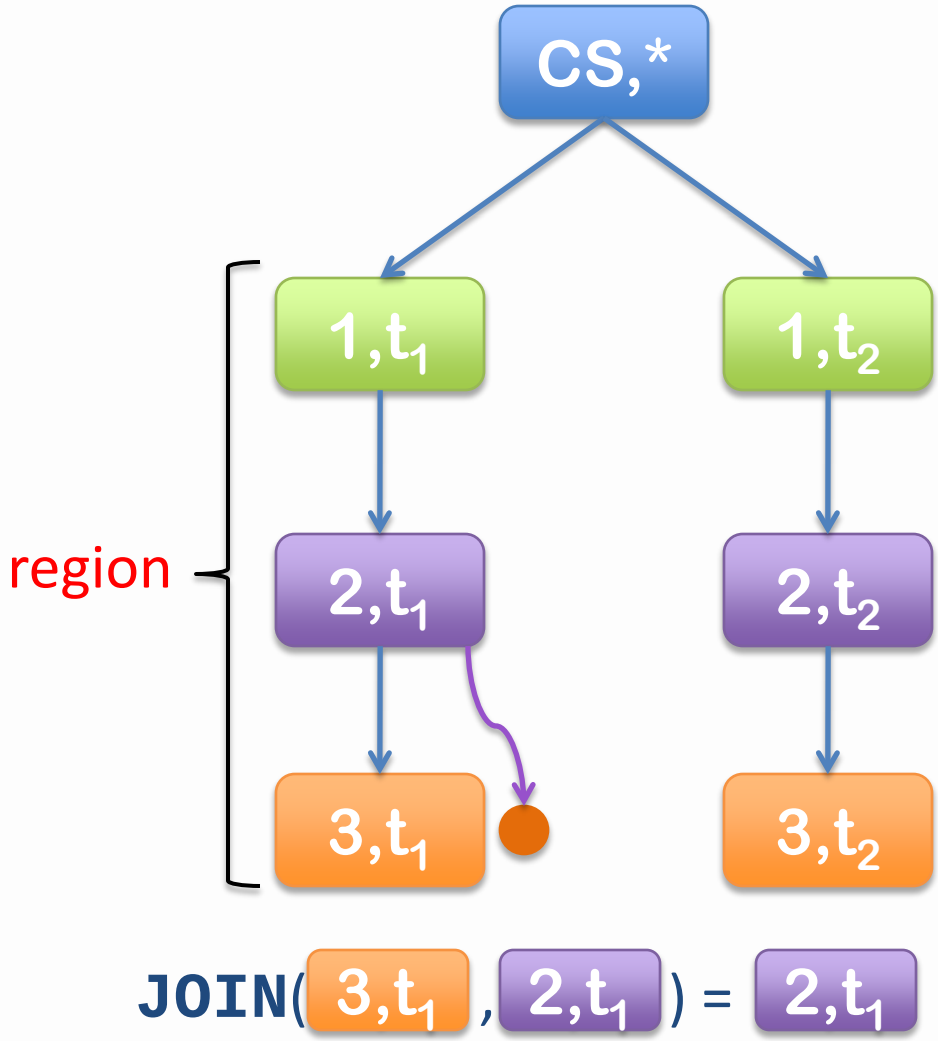

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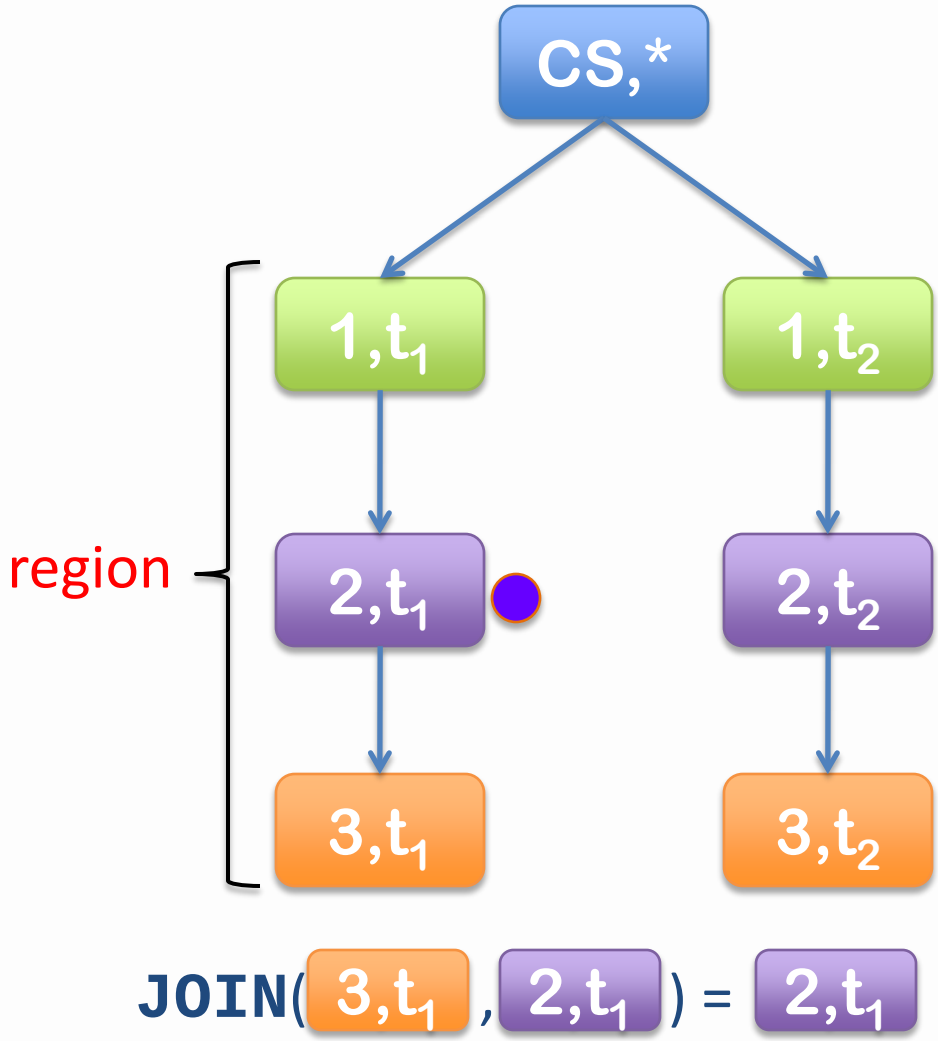

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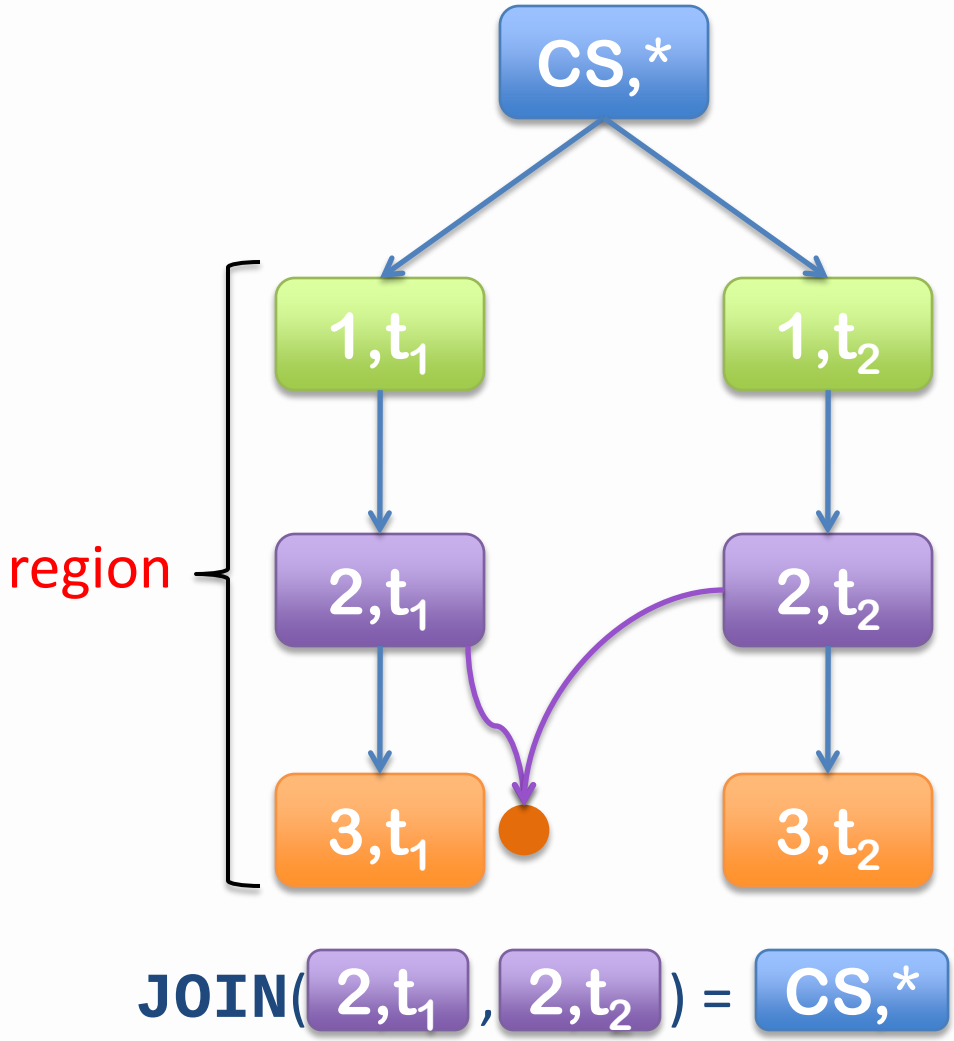

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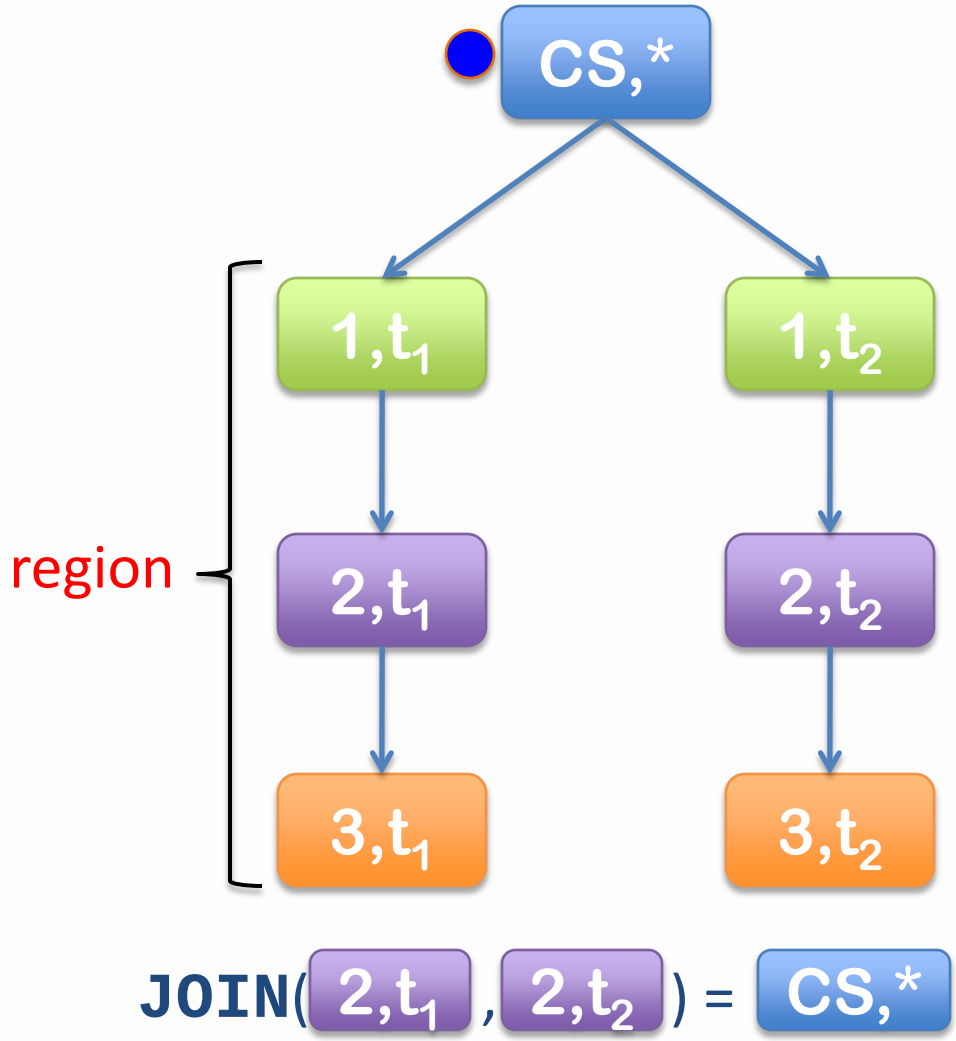

How to Reclaim Regions Correctly?

Object Promotion Algorithm

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Two key tasks:

- What: Identify escaping objects:

How to Reclaim Regions Correctly?

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  Tracking of cross-region/space references in write barrier

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  - Inter-region references are recorded in the remember sets of their destination regions

How to Reclaim Regions Correctly?

Object Promotion Algorithm

Two key tasks:

- What: Identify escaping objects:

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  - A fast path for intra-region references
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- Where: Decide the relocation destination:

How to Reclaim Regions Correctly?

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  Tracking of cross-region/space references in write barrier

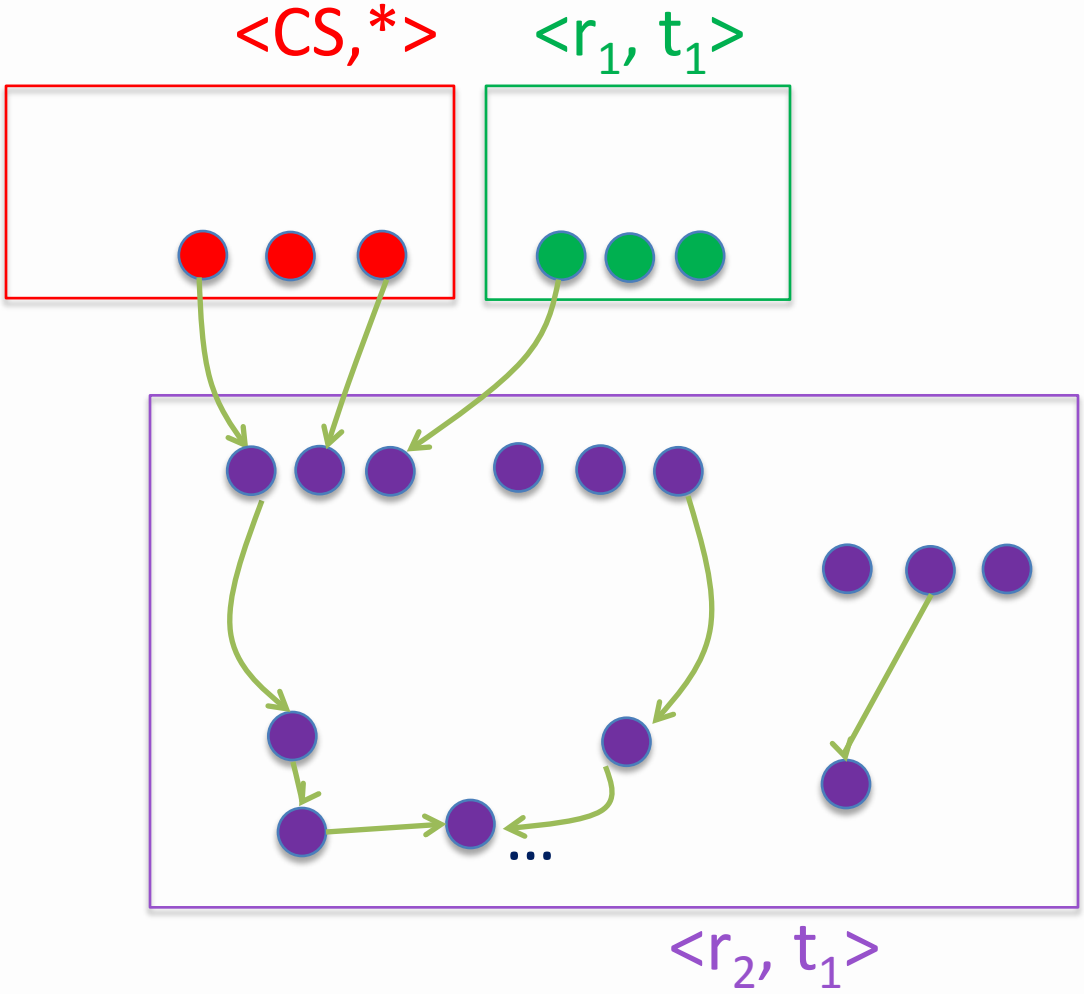
  - A fast path for intra-region references
  - Inter-region references are recorded in the remember sets of their destination regions

- Where: Decide the relocation destination:

  Query region semilattice

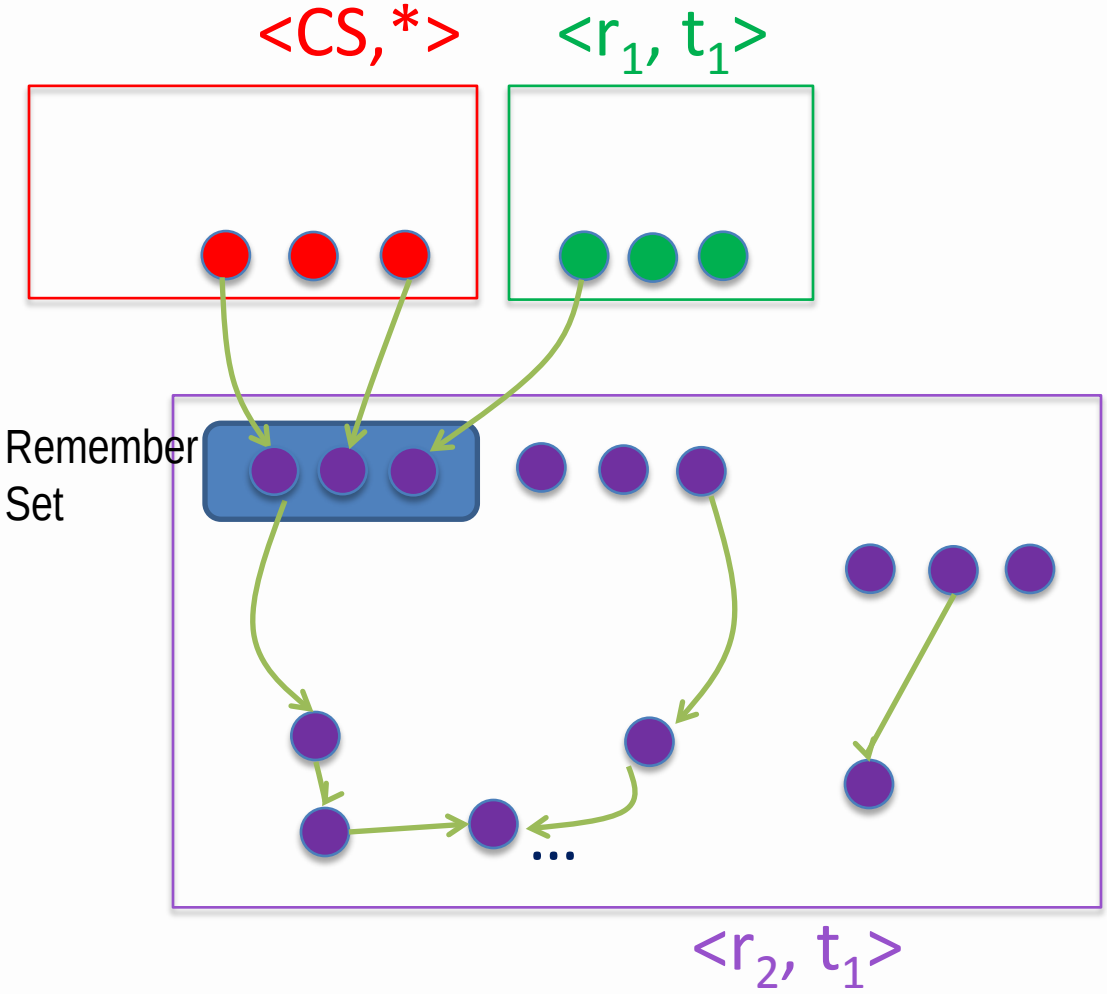
Region Deallocation

epoch_end()



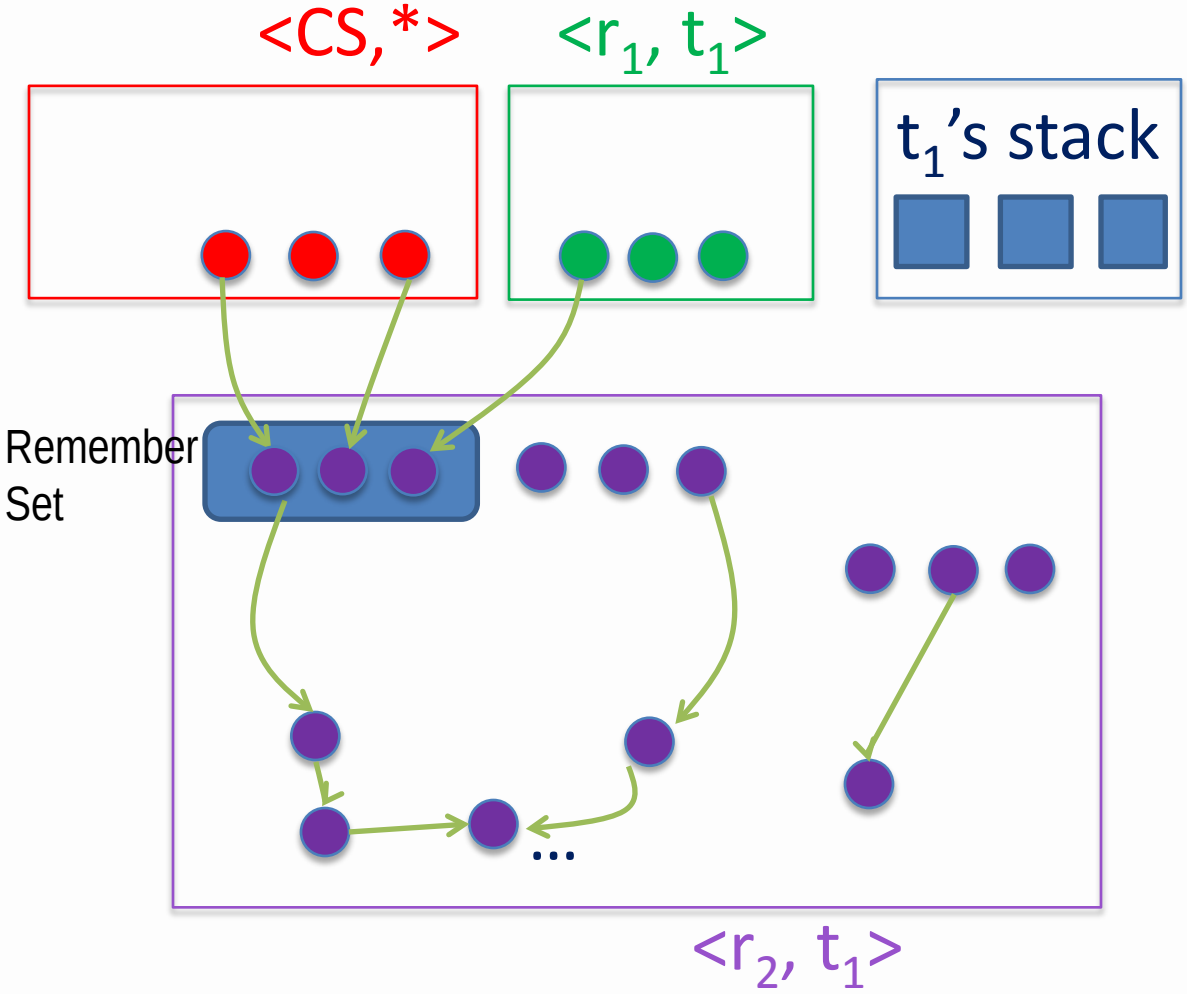
Region Deallocation

epoch_end()



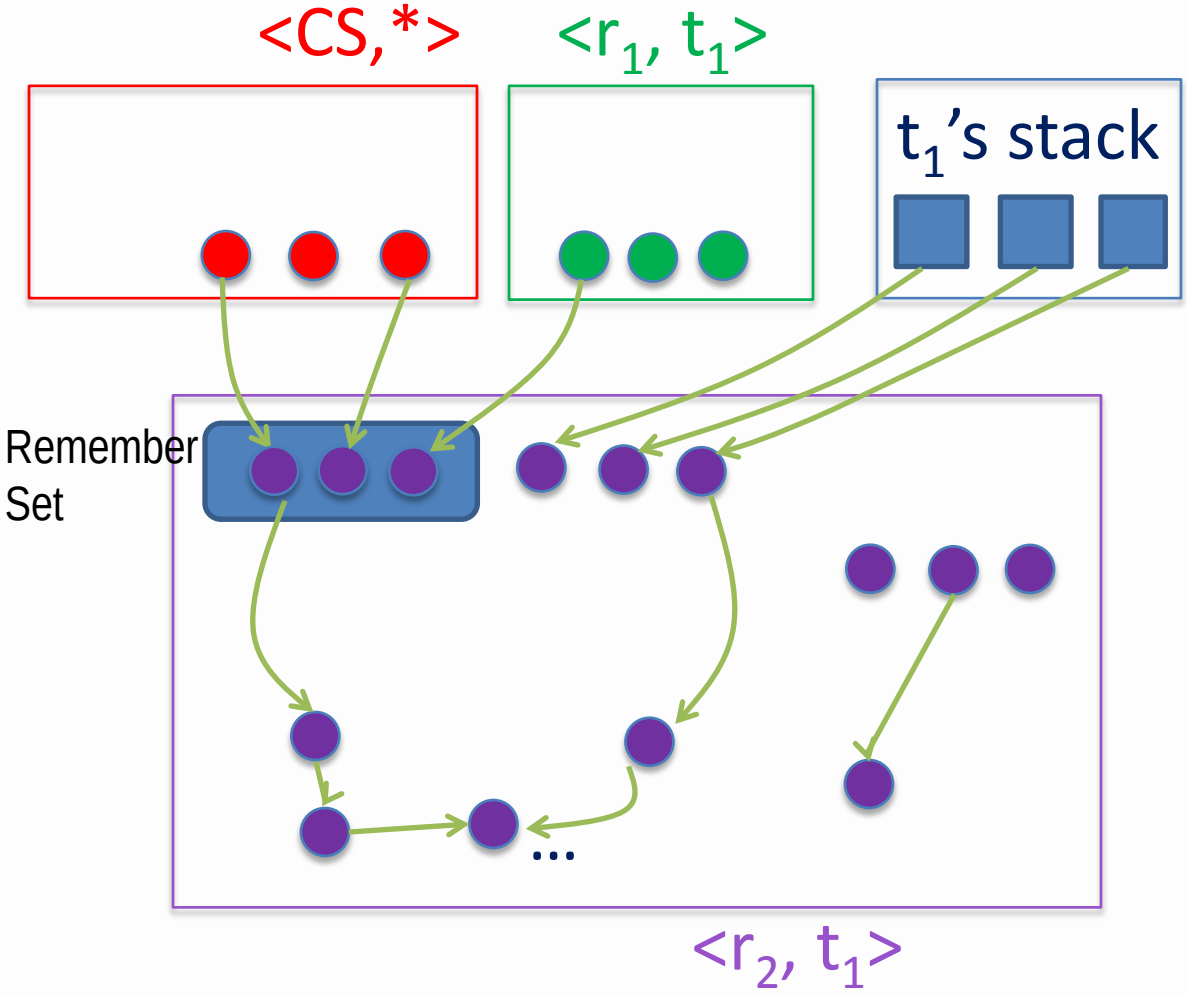
Region Deallocation

epoch_end()



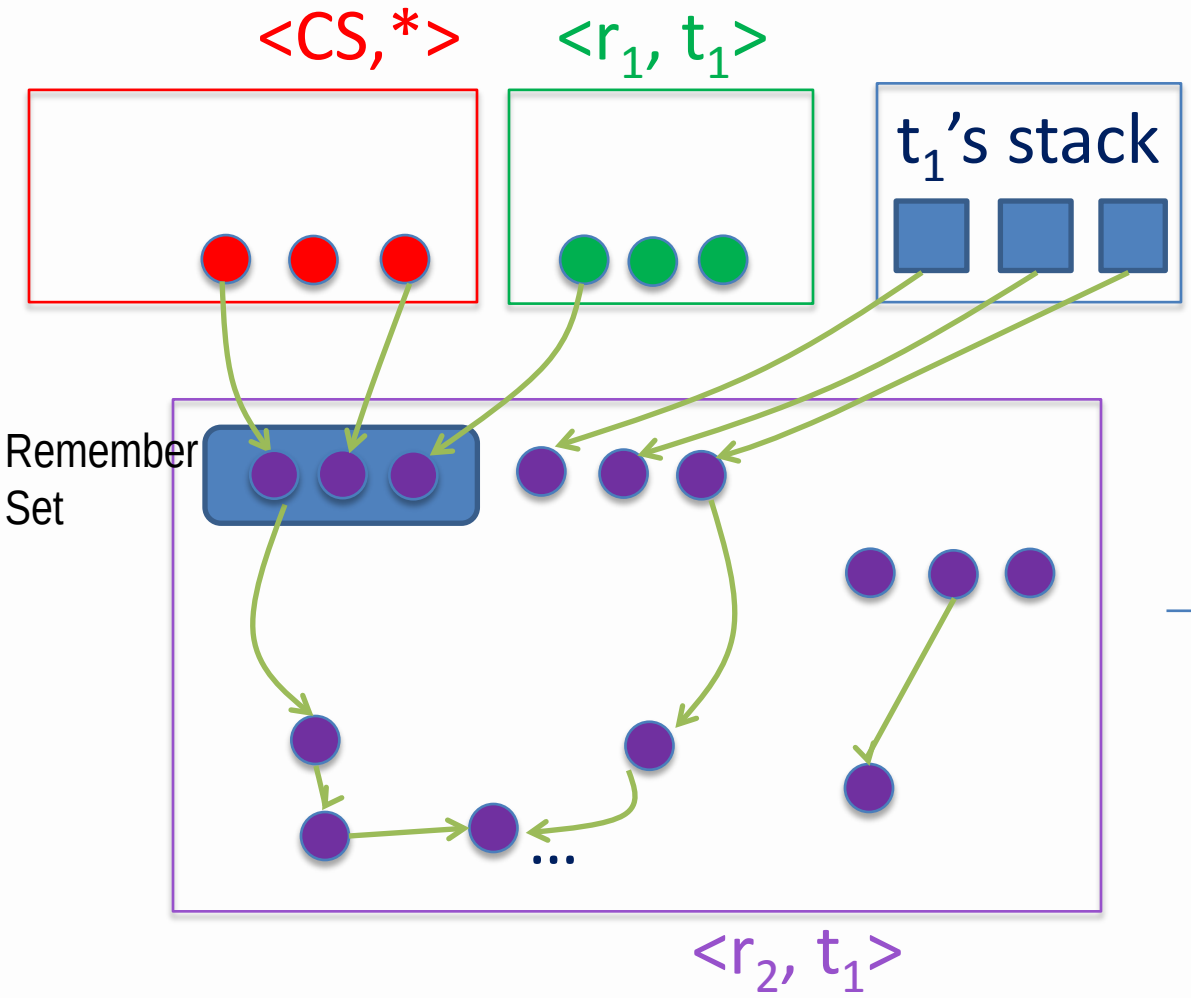
Region Deallocation

epoch_end()



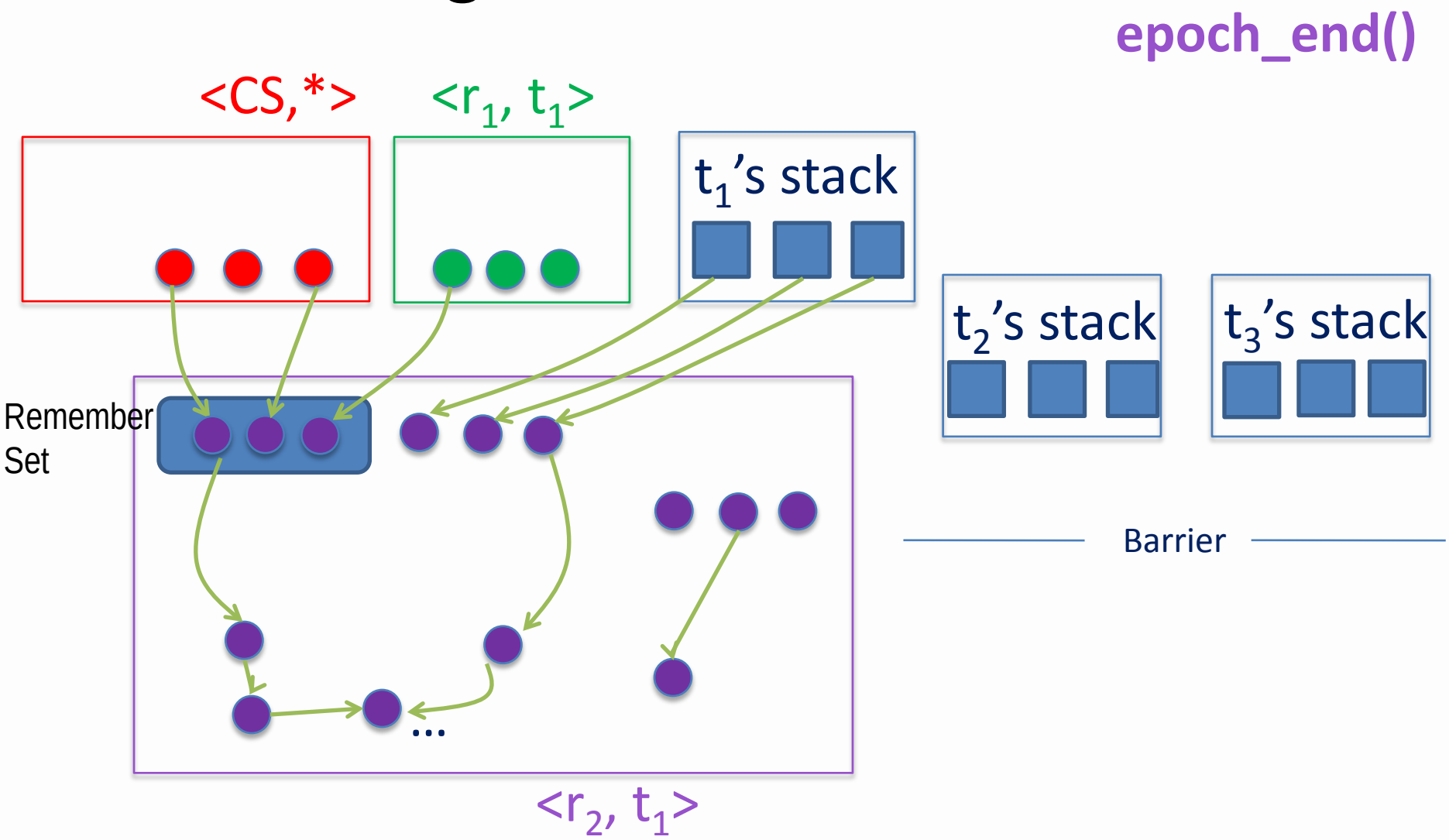
Region Deallocation

epoch_end()

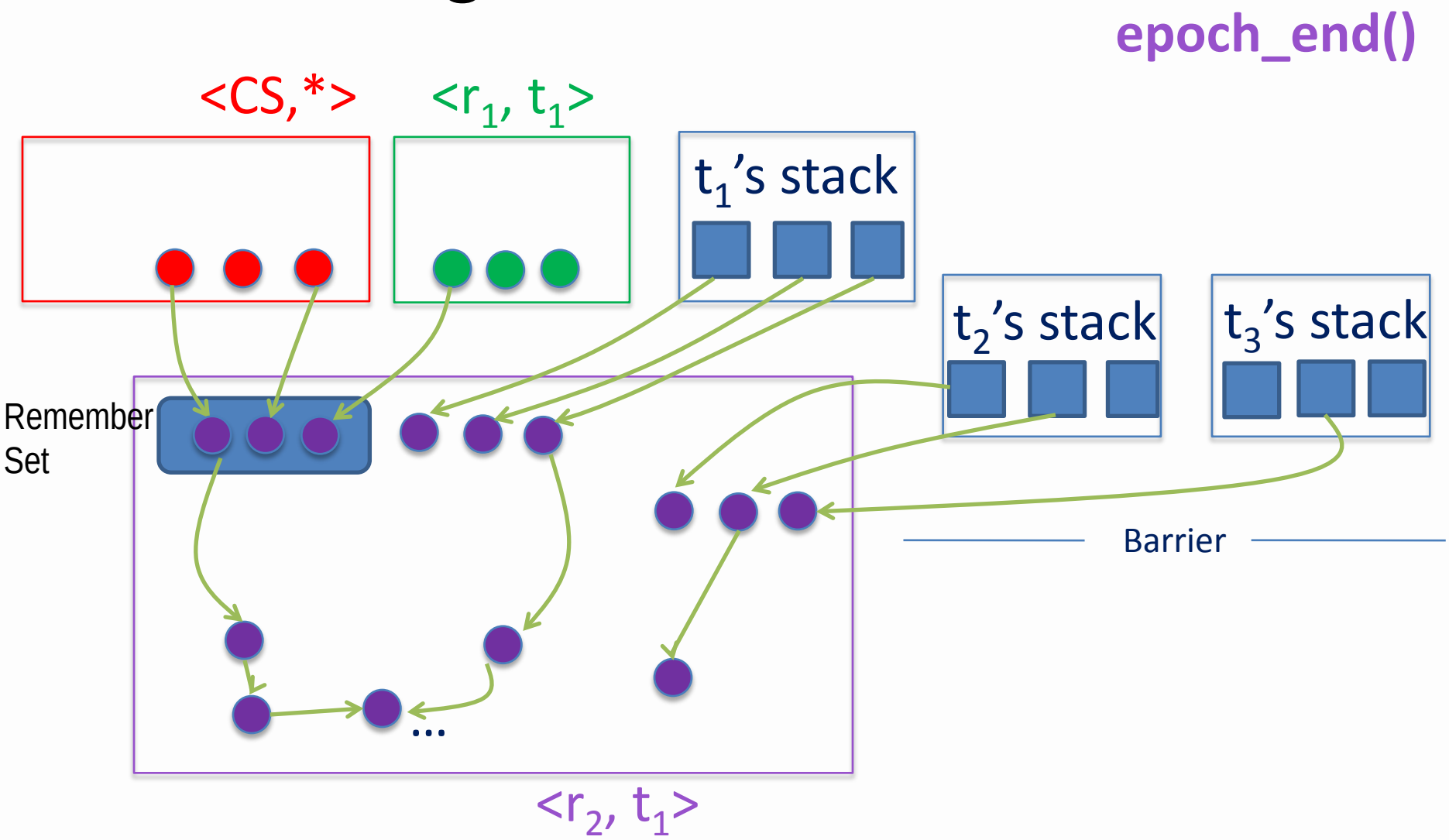


Barrier

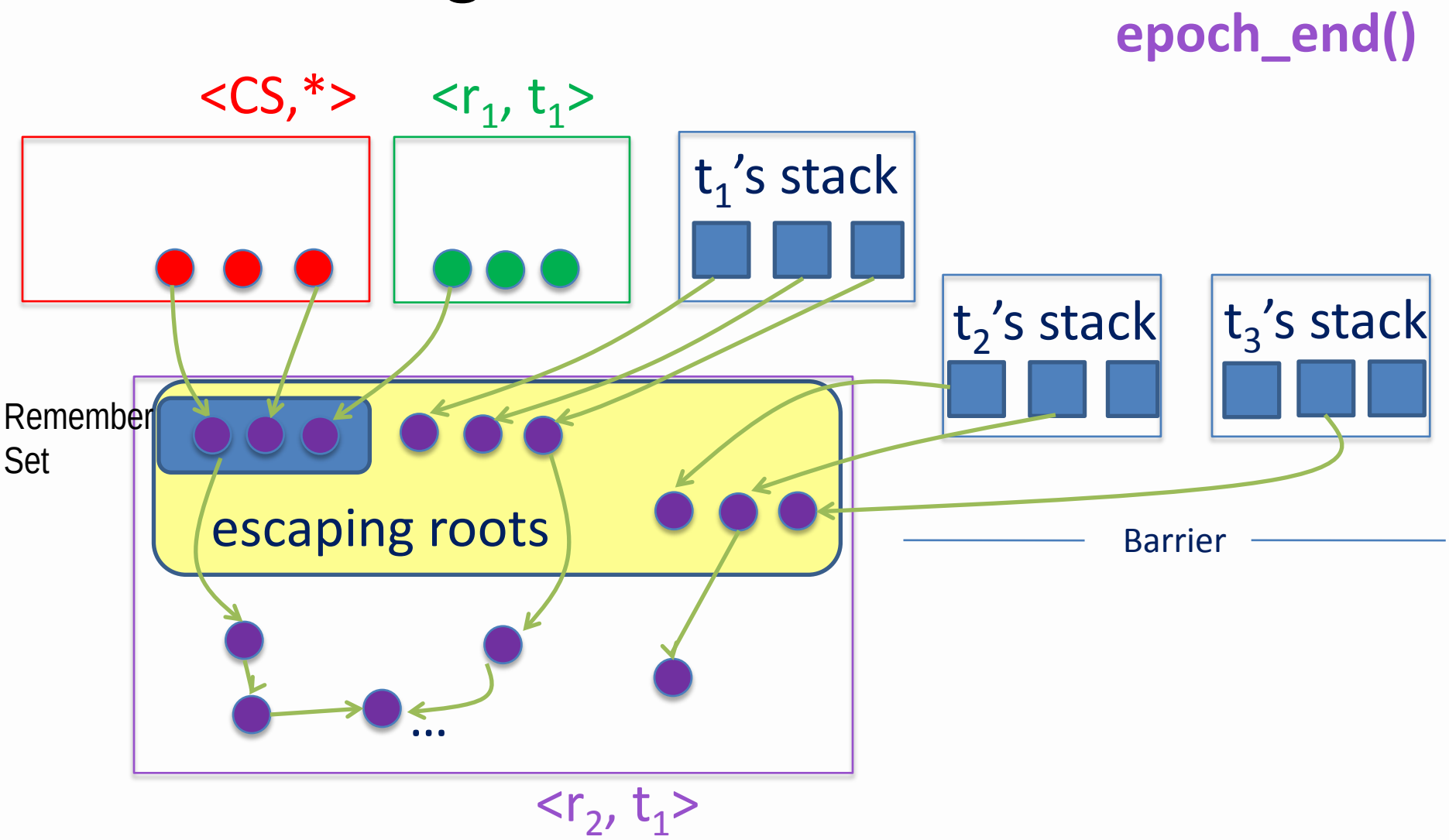
Region Deallocation



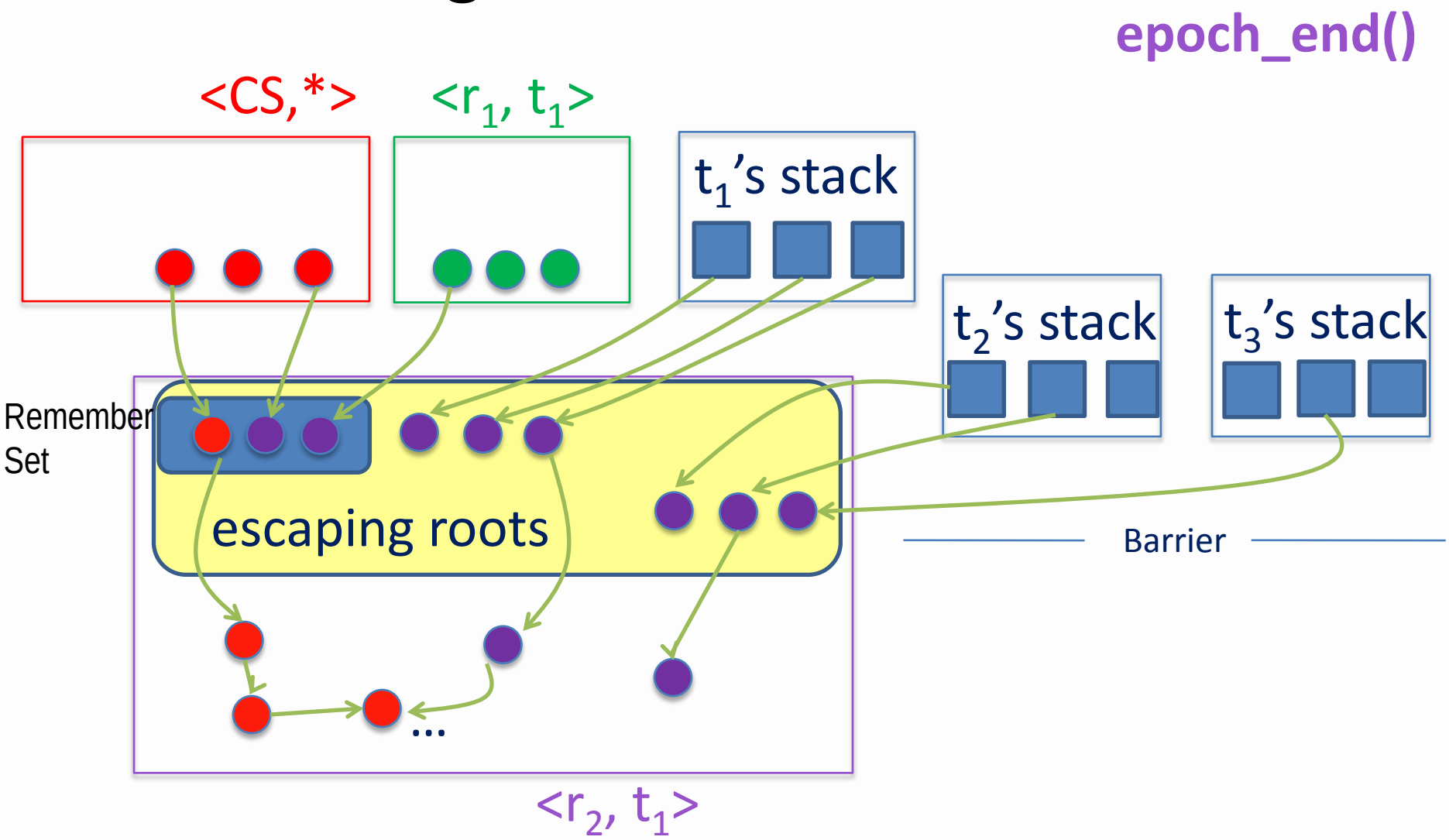
Region Deallocation



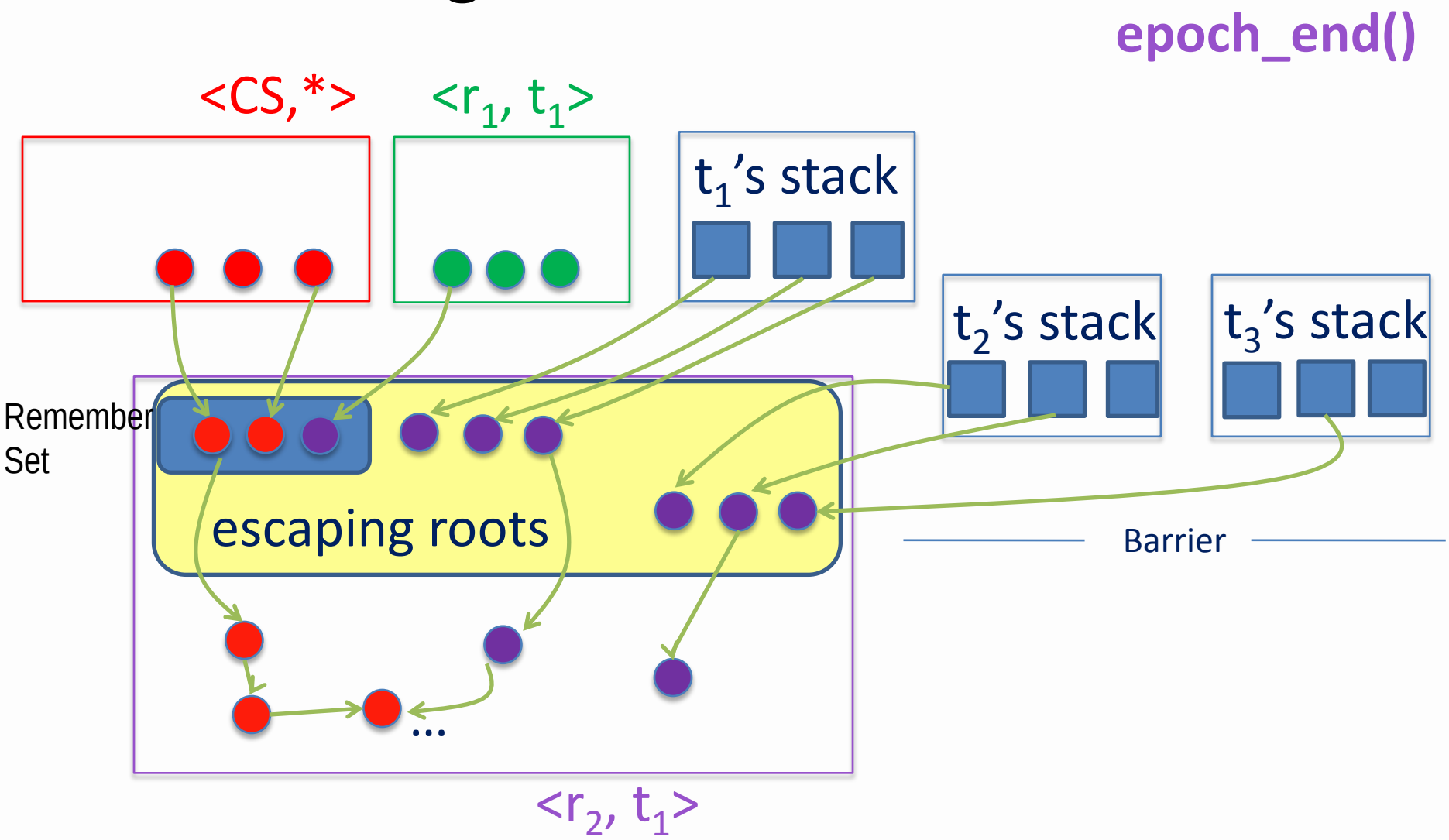
Region Deallocation



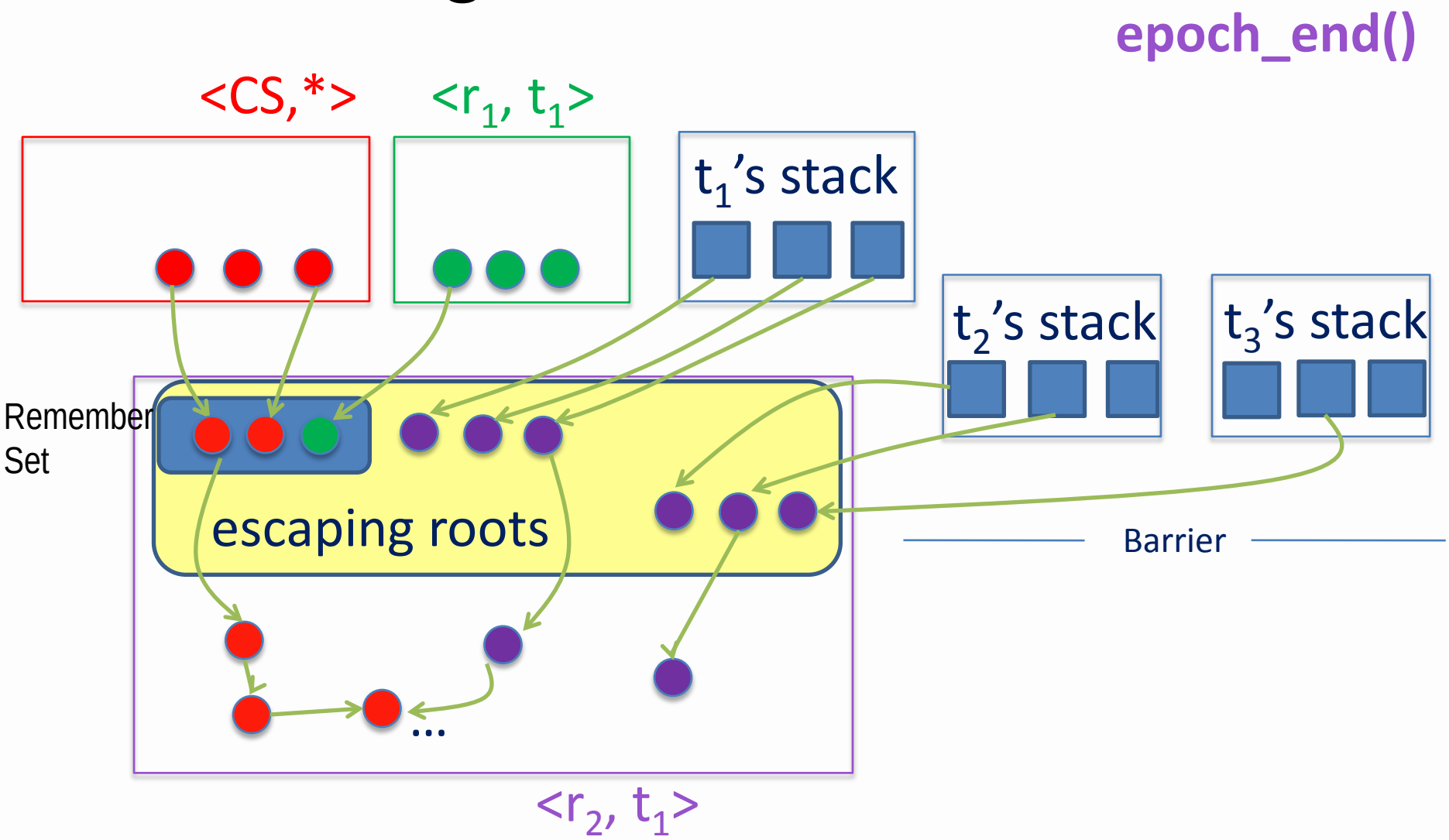
Region Deallocation



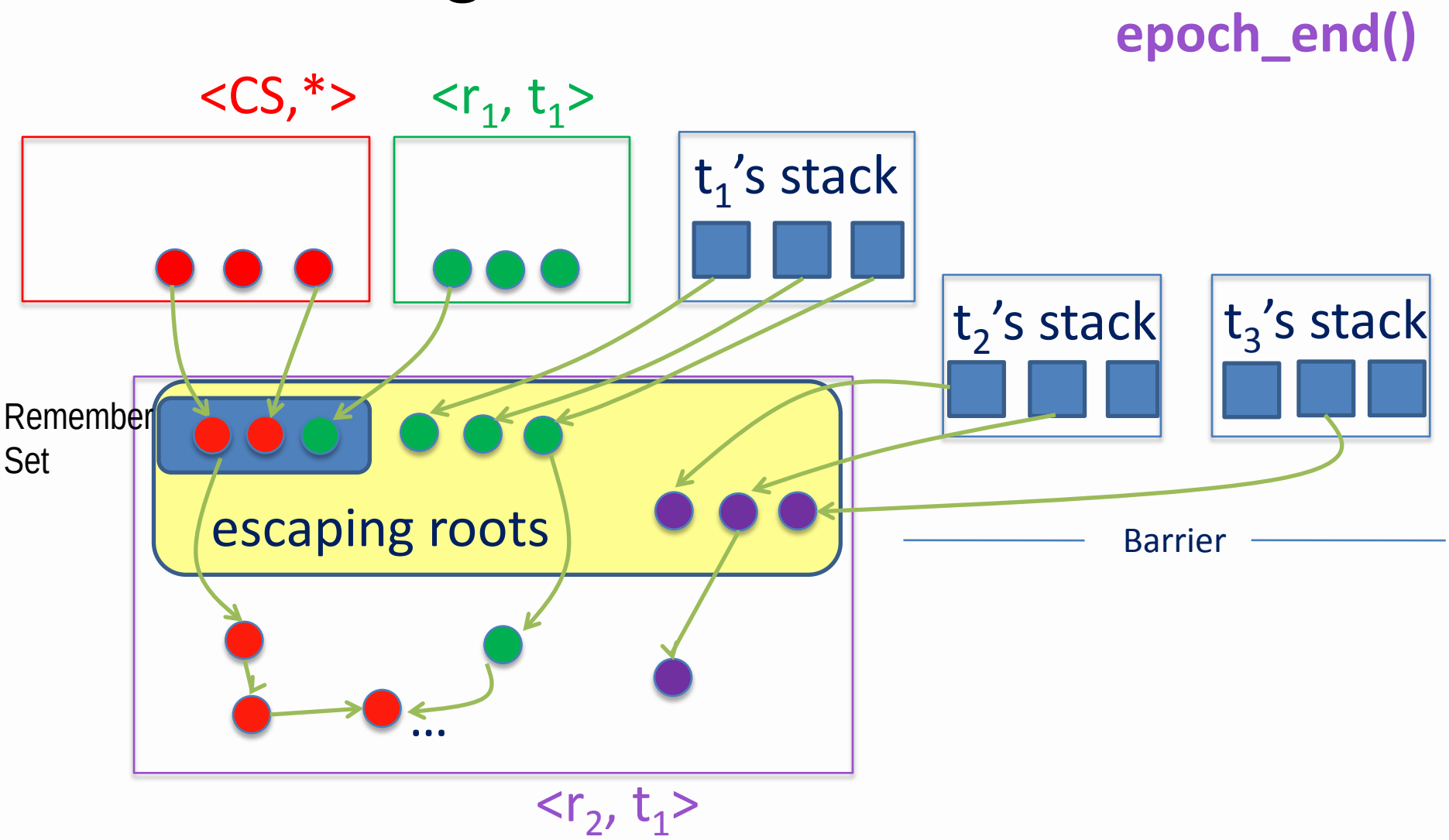
Region Deallocation



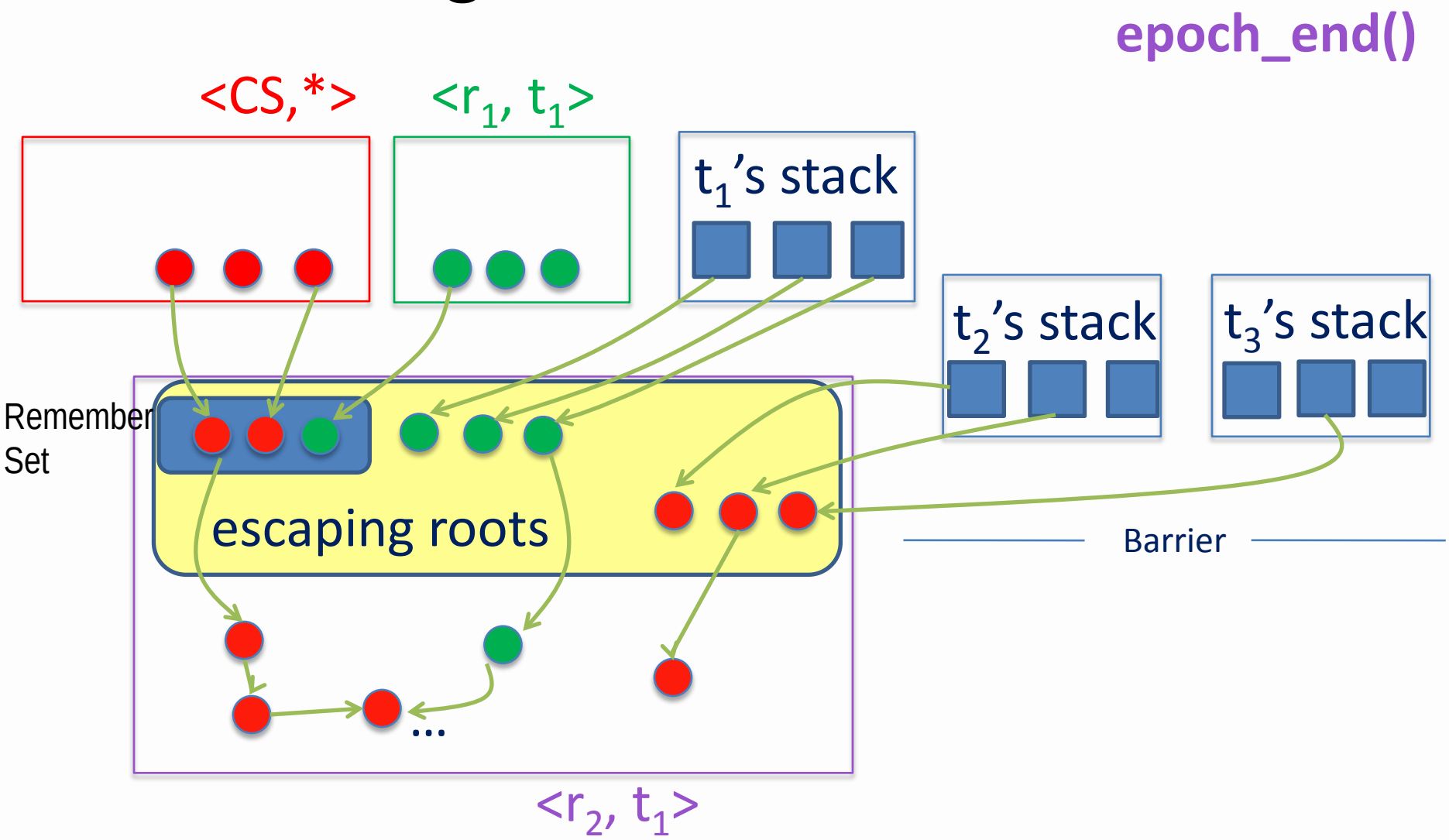
Region Deallocation



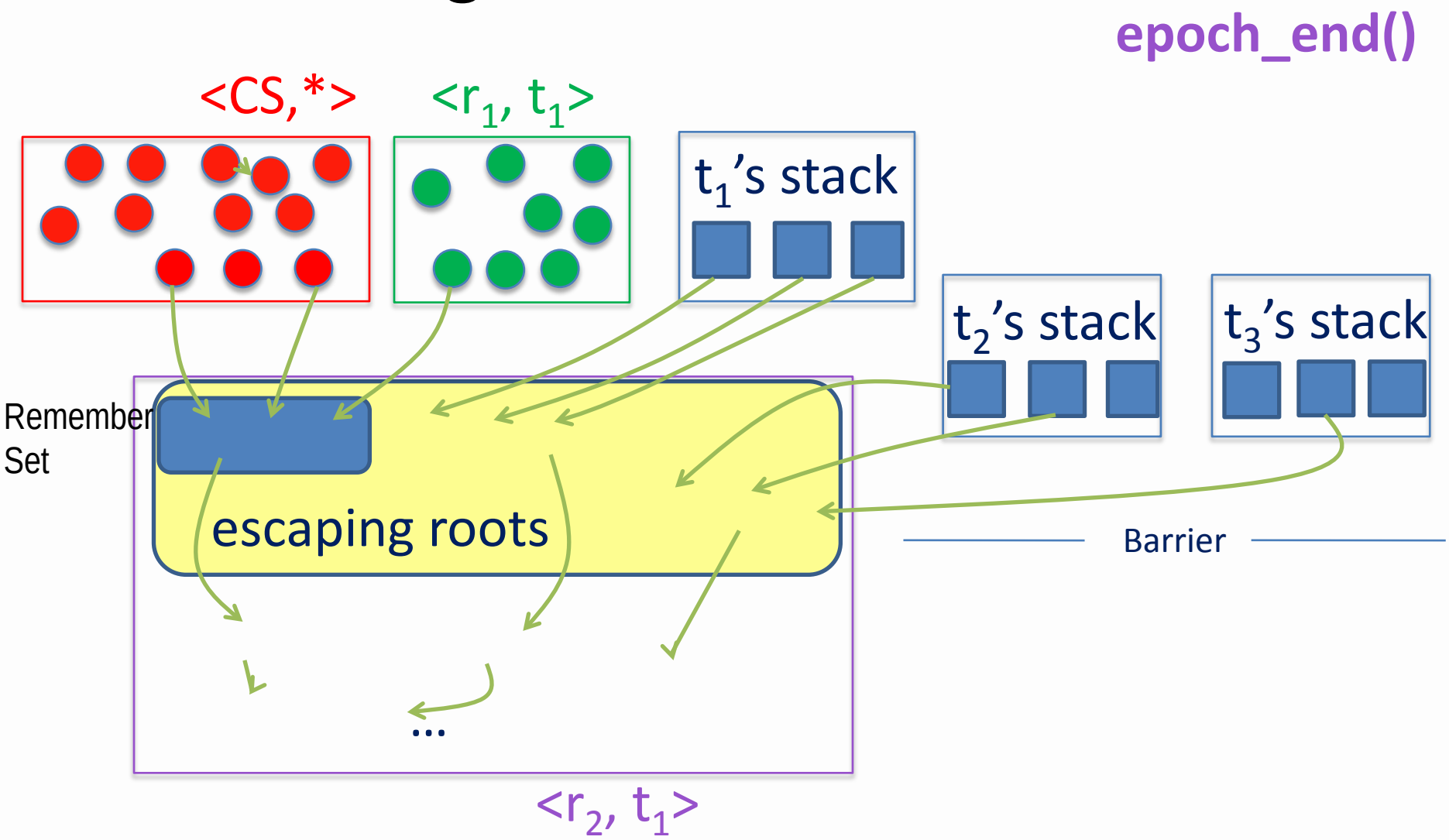
Region Deallocation



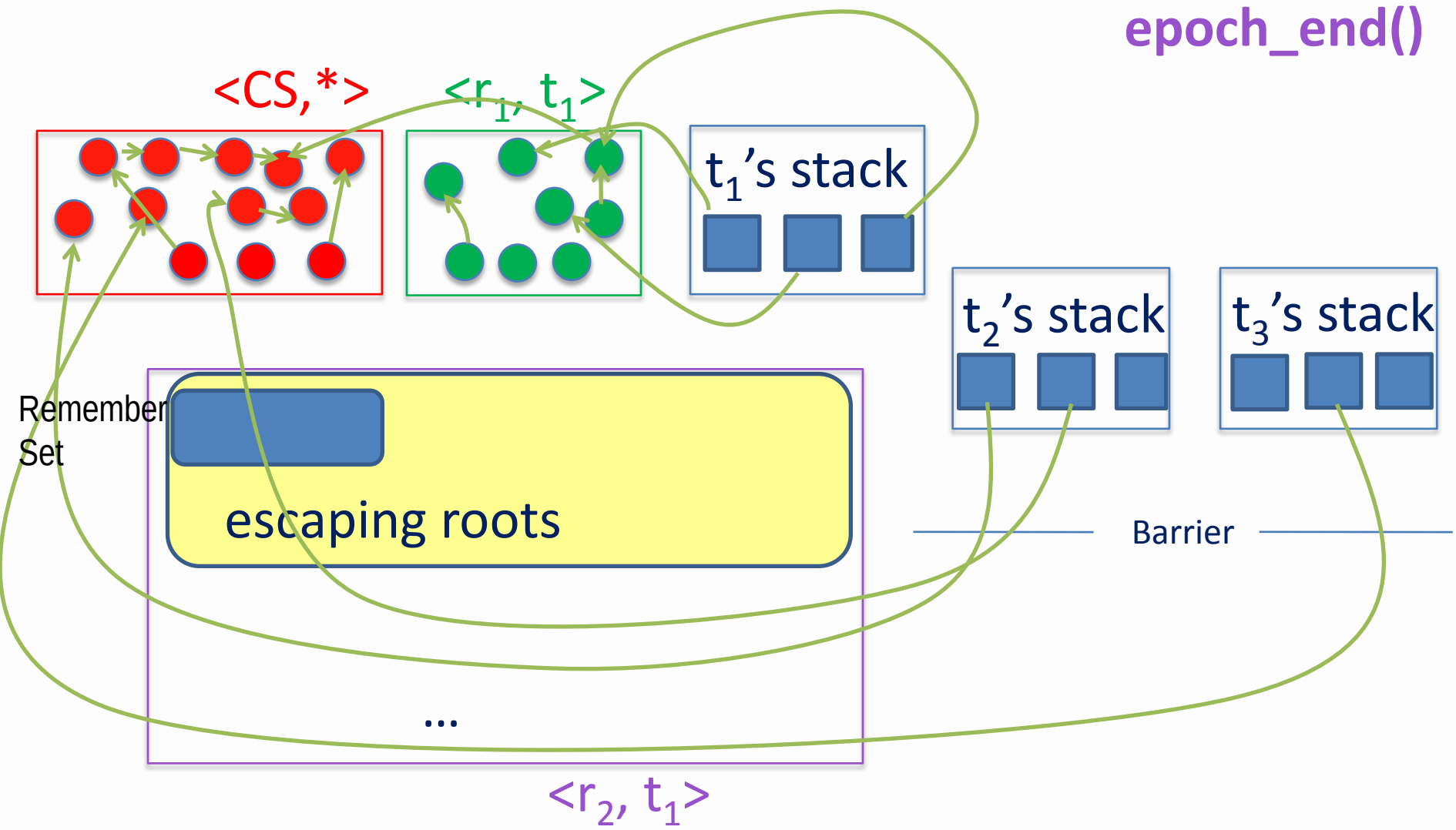
Region Deallocation



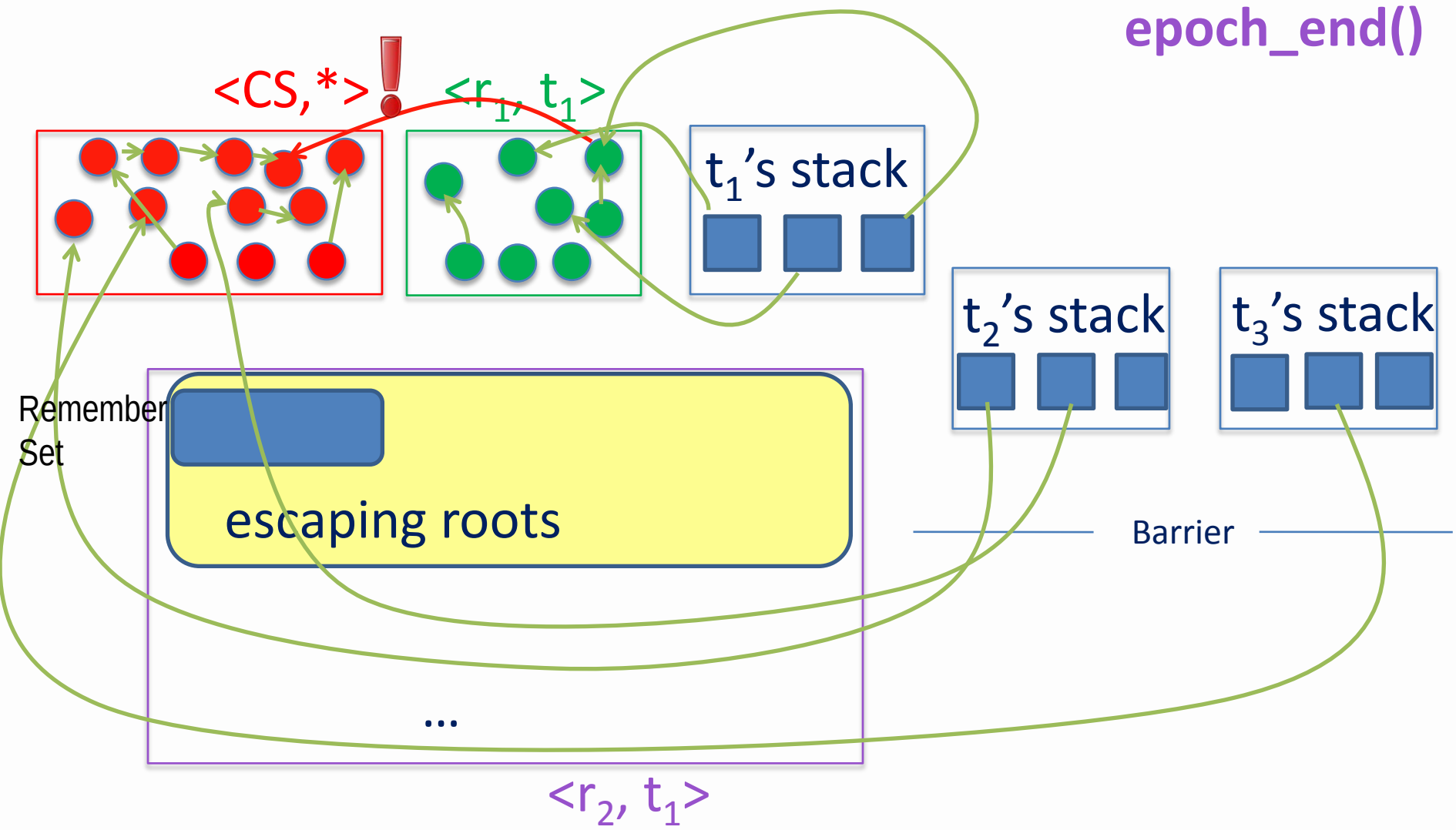
Region Deallocation



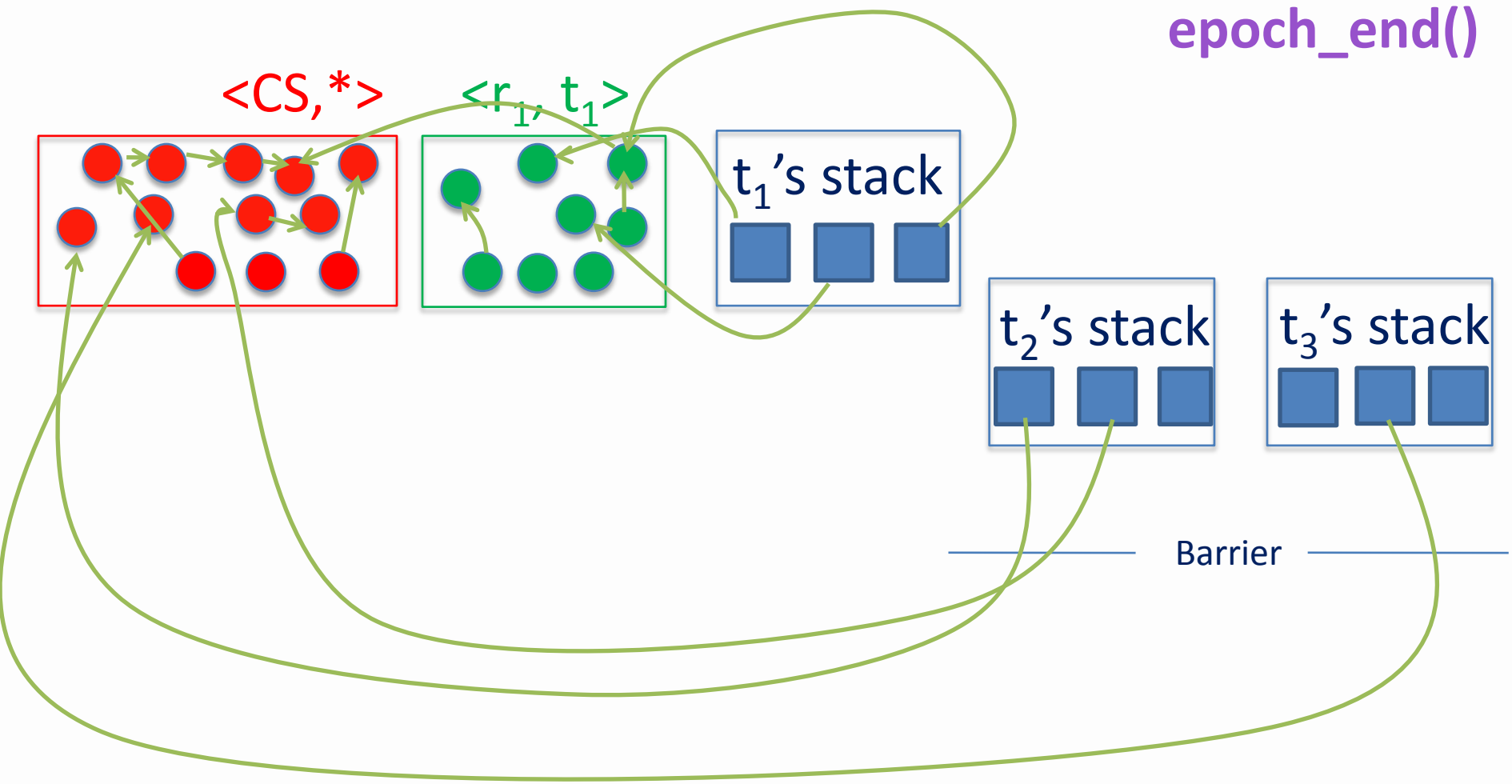
Region Deallocation



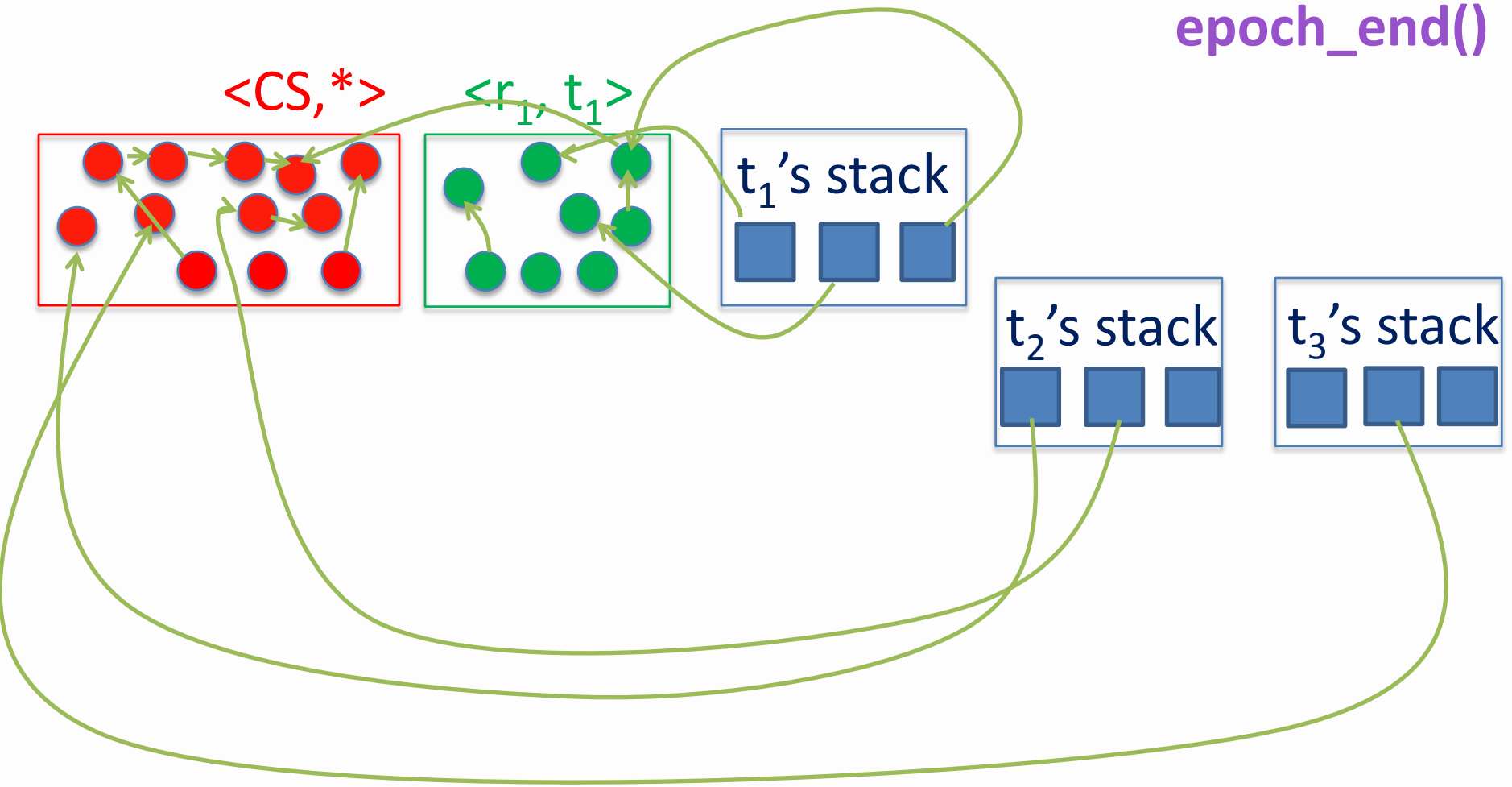
Region Deallocation



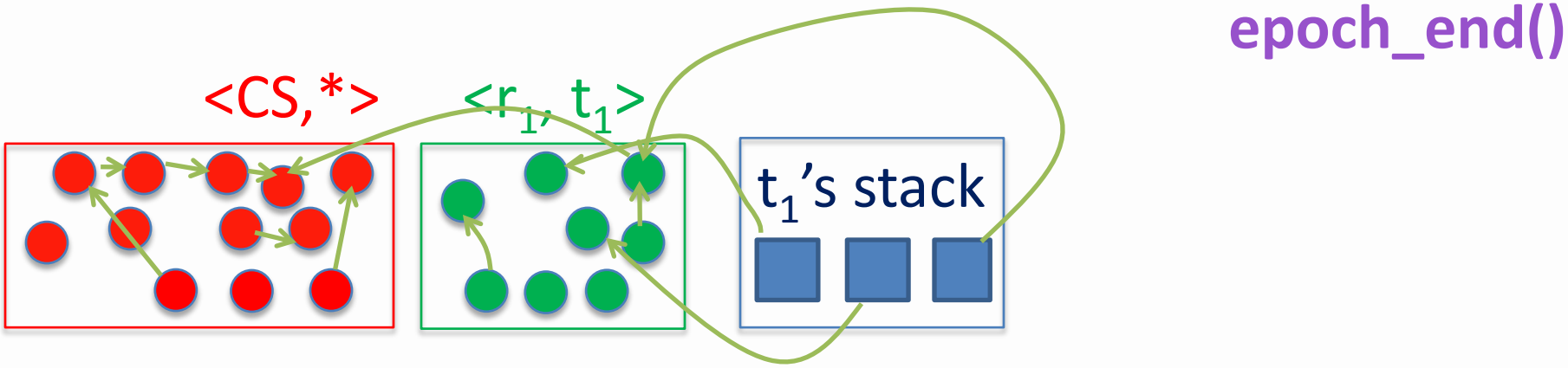
Region Deallocation



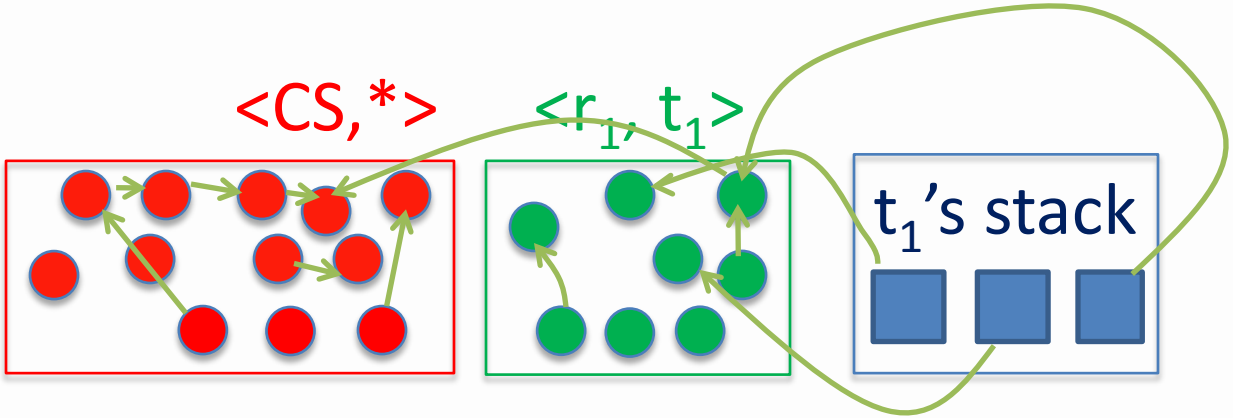
Region Deallocation



Region Deallocation



Region Deallocation

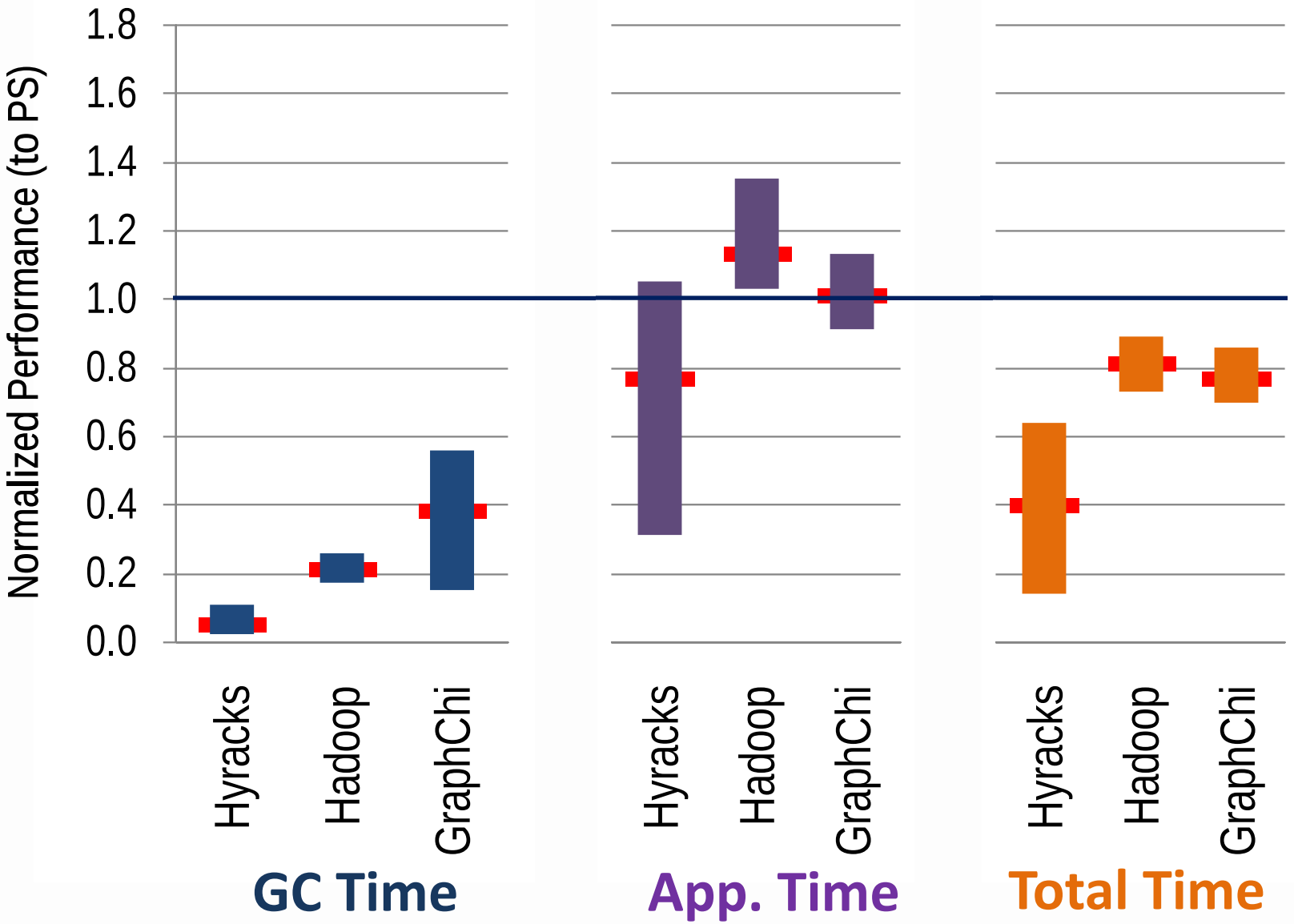


Evaluations

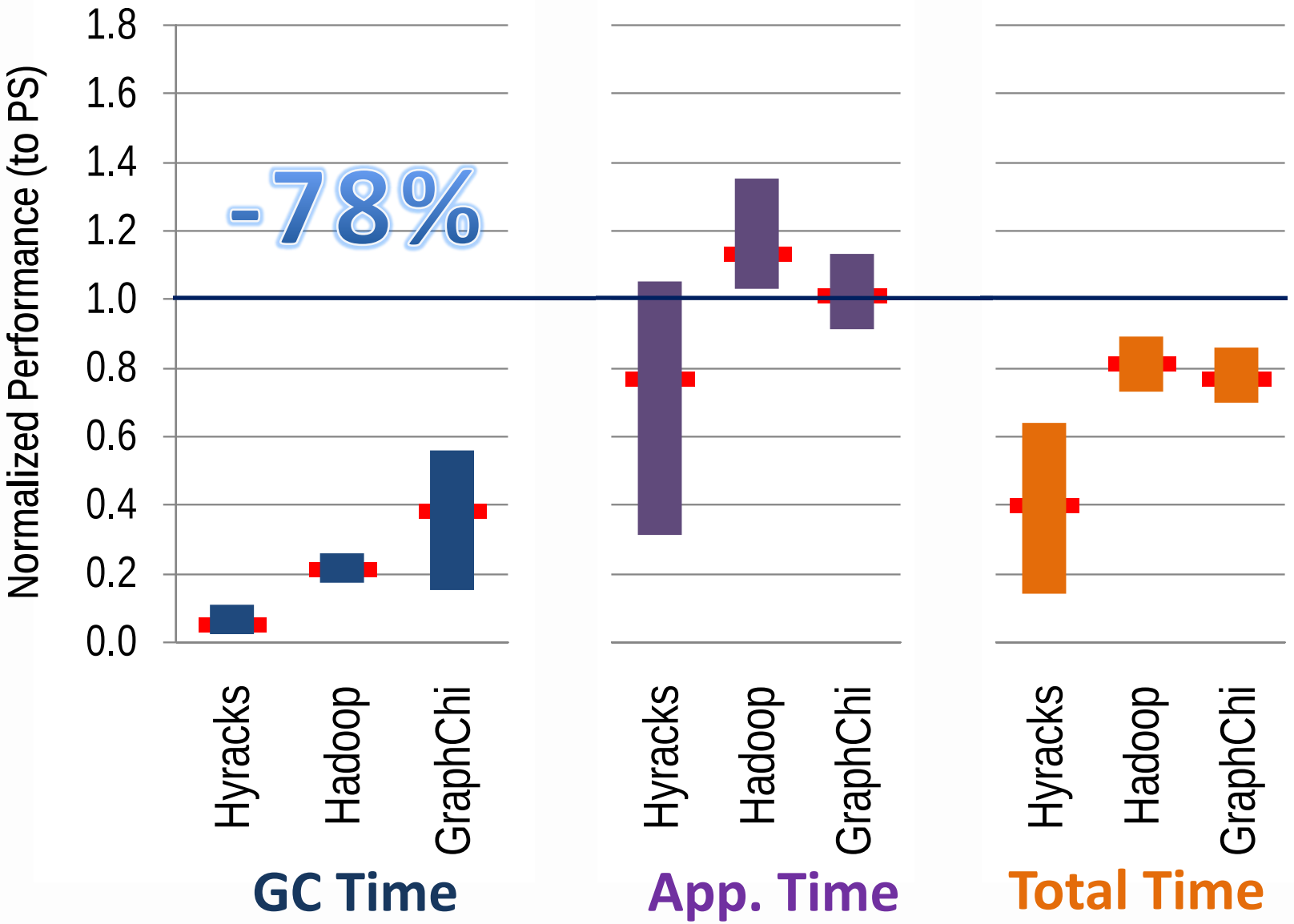
3 real-world systems, 9 applications:

- Hadoop
  - Popular distributed MapReduce implementation
- Hyracks [Borkar et al., ICDE'11]
  - Data-parallel platform to run data-intensive jobs on a cluster of shared-nothing machines
- GraphChi [Kyrola et al., OSDI'12]
  - High-performance graph analytical framework for a single machine

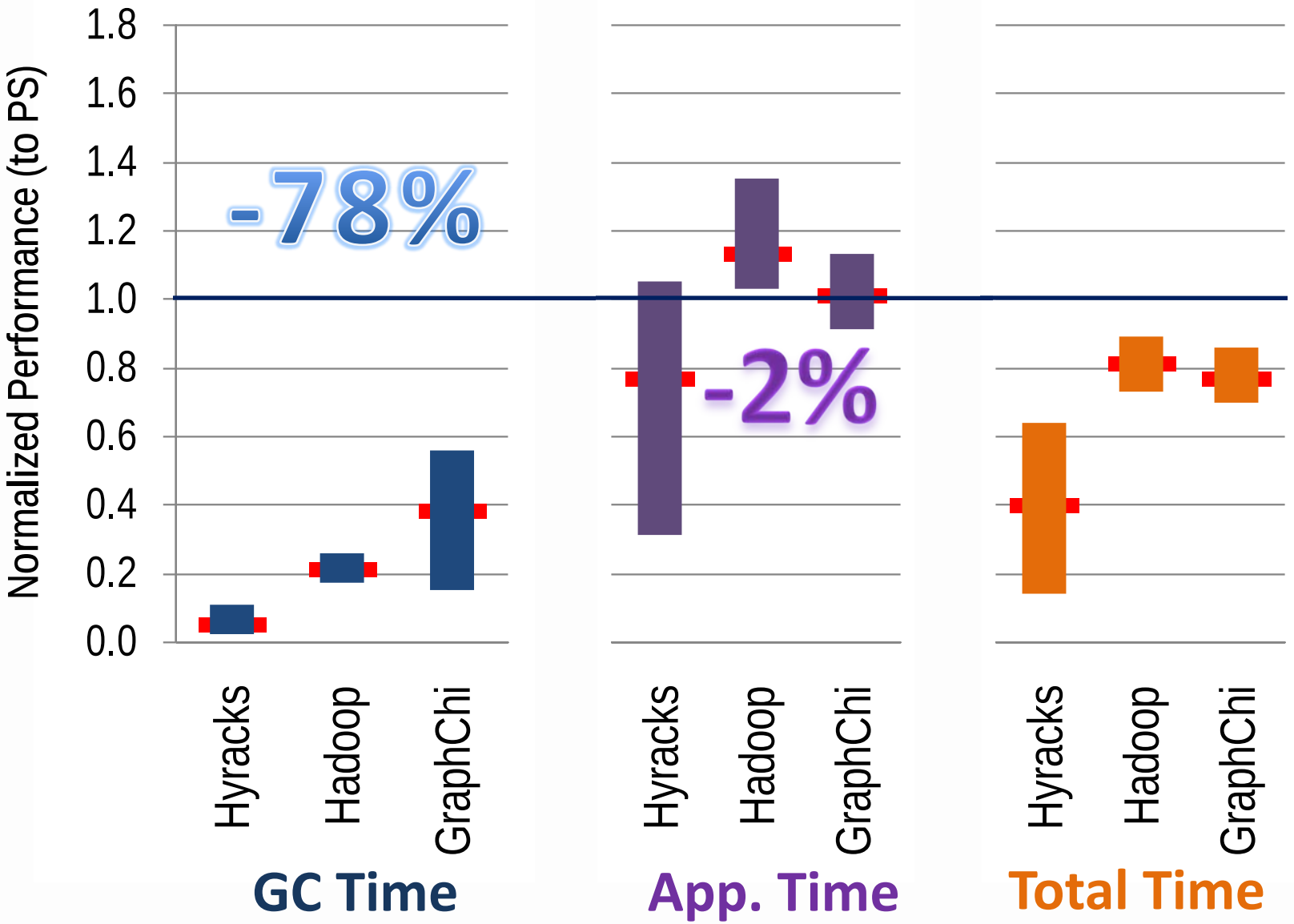
Improvement Summary



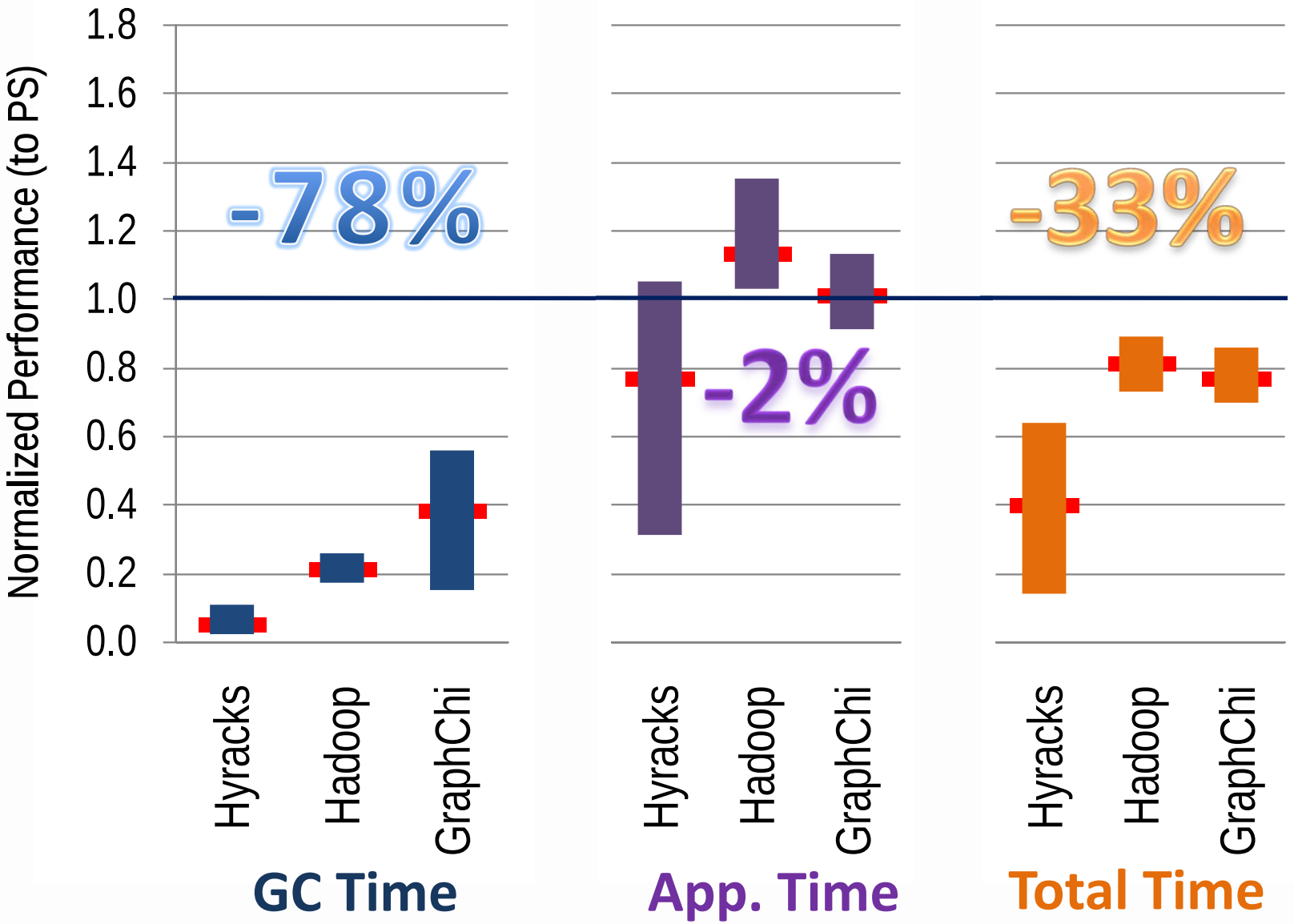
Improvement Summary



Improvement Summary



Improvement Summary



More Data in the Paper

- Statistics on Yak's heap
- Overhead breakdown
  - Write barrier cost
  - Extra space cost

Conclusion

- *Goal:* Reduce memory management cost in Big Data systems

- *Solution:* **Yak**, the first hybrid GC
  - **33%** execution time savings

    78% GC time reduction
  - Requires almost *zero* user effort

Thank You!