UCI University of California, Irvine

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

OSDI '16

Khanh Nguyen, Lu Fang, Guoqing Xu, Brian Demsky, Sanazsadat Alamian
University of California, Irvine

Shan Lu
University of Chicago

Onur Mutlu
ETH Zürich

BIG DATA

cloudera IMPALA

APACHE GIRAPH

hadoop MapReduce

Apache Hama

BIG DATA

HIVE

Hortonworks

Naiad

mahout

FLUME

Spark

AsterixDB

Dryad

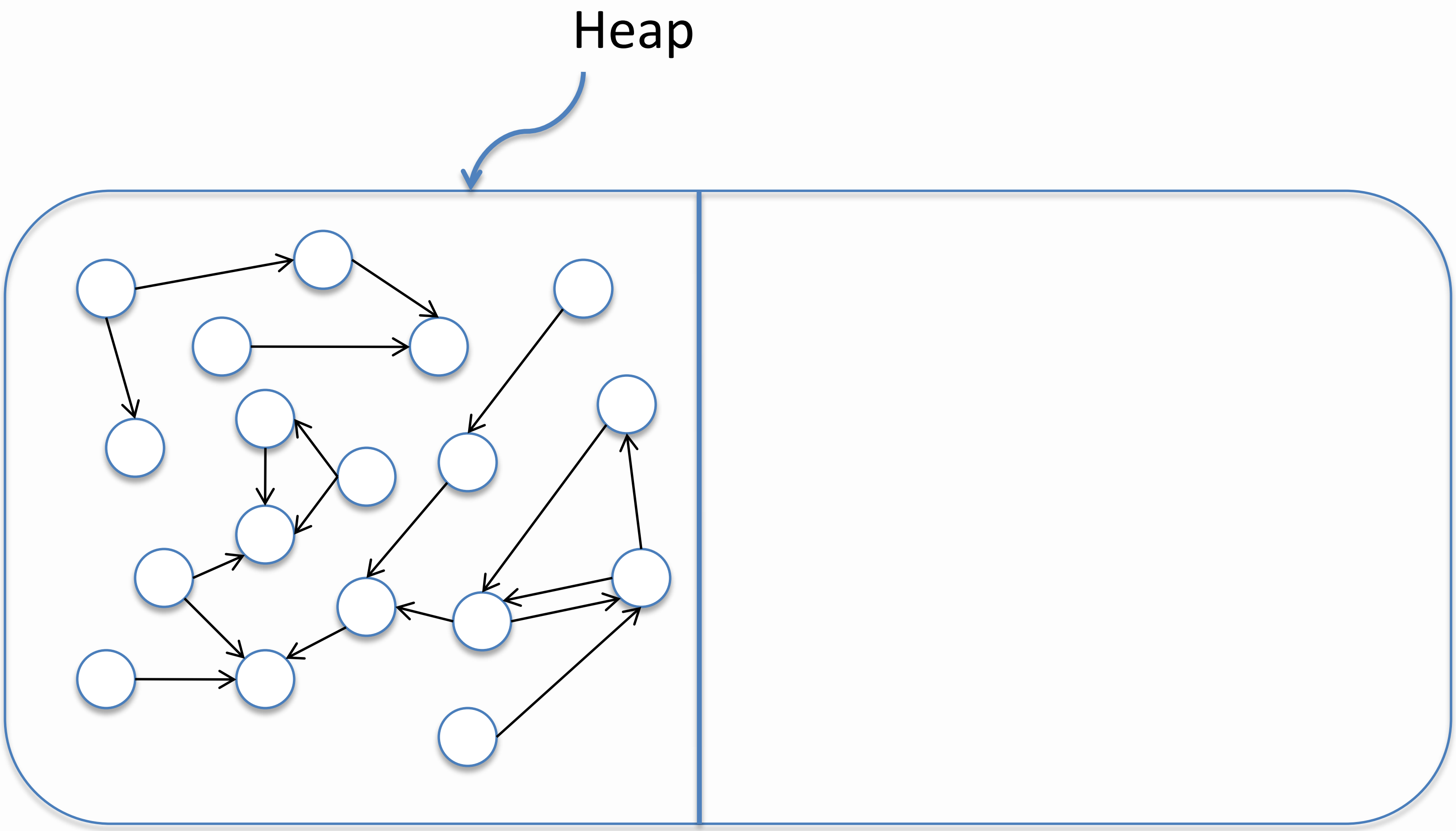
APACHE STORM™

Java™

C#

Scala

Background: GC



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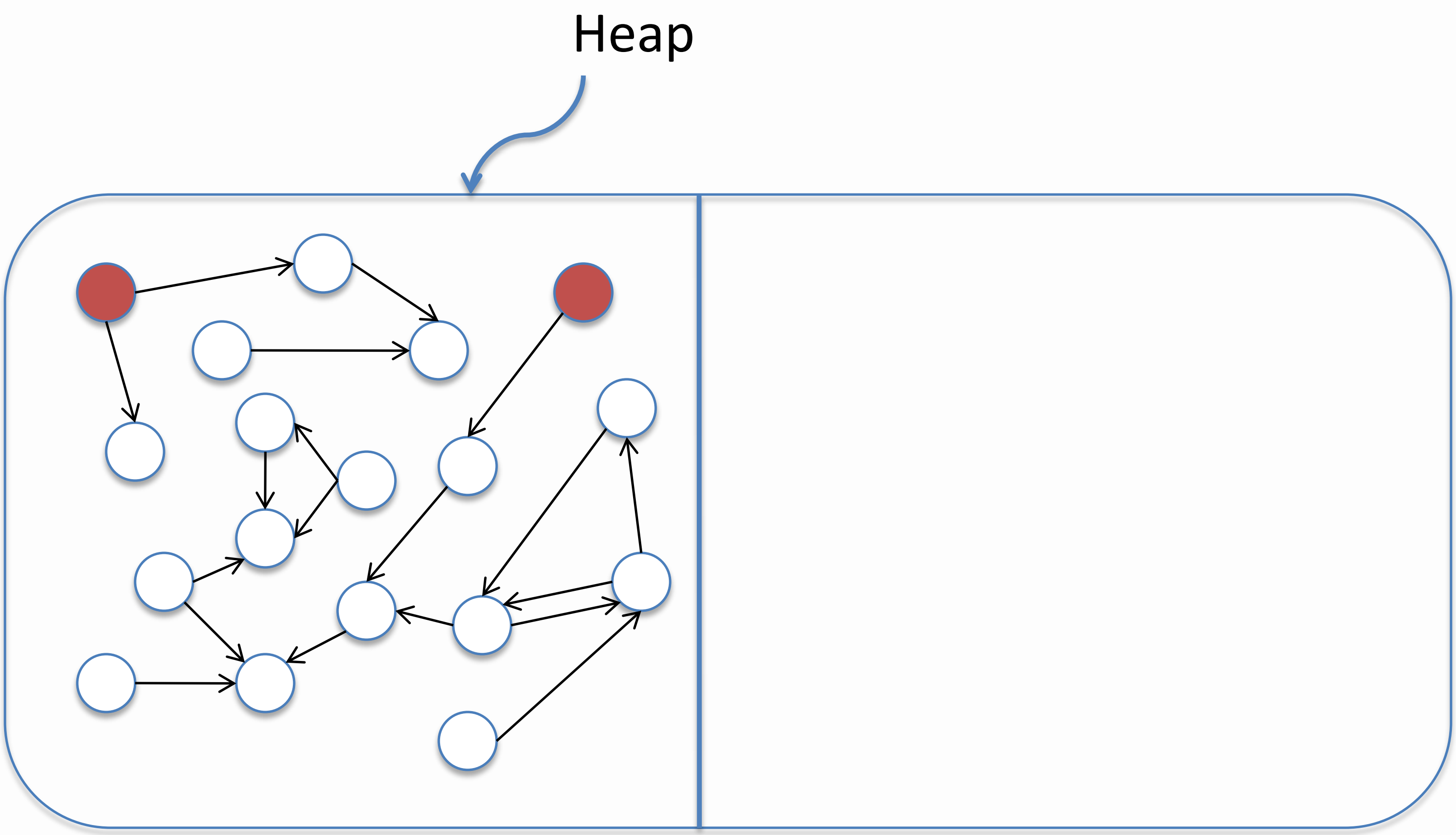

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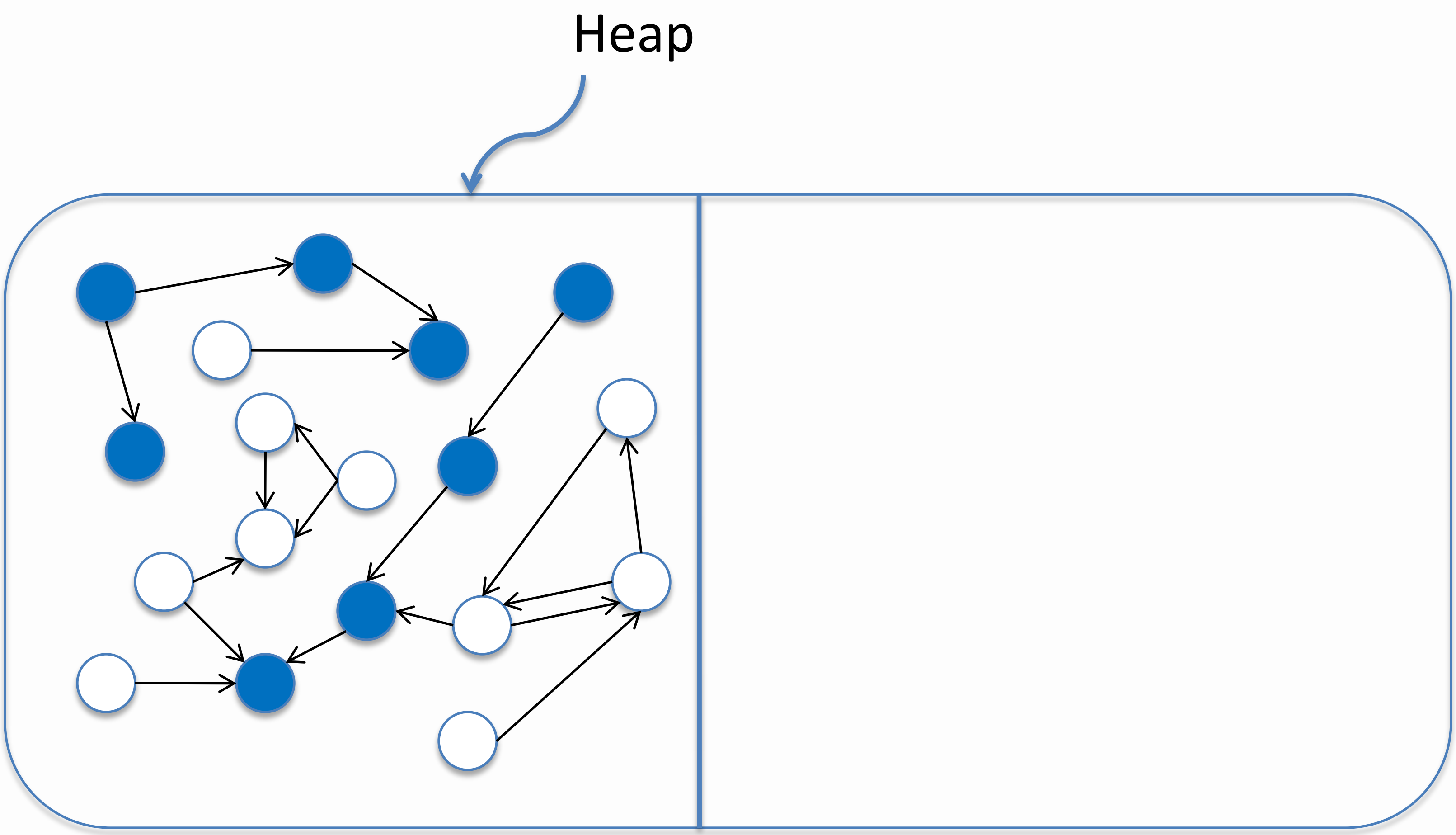

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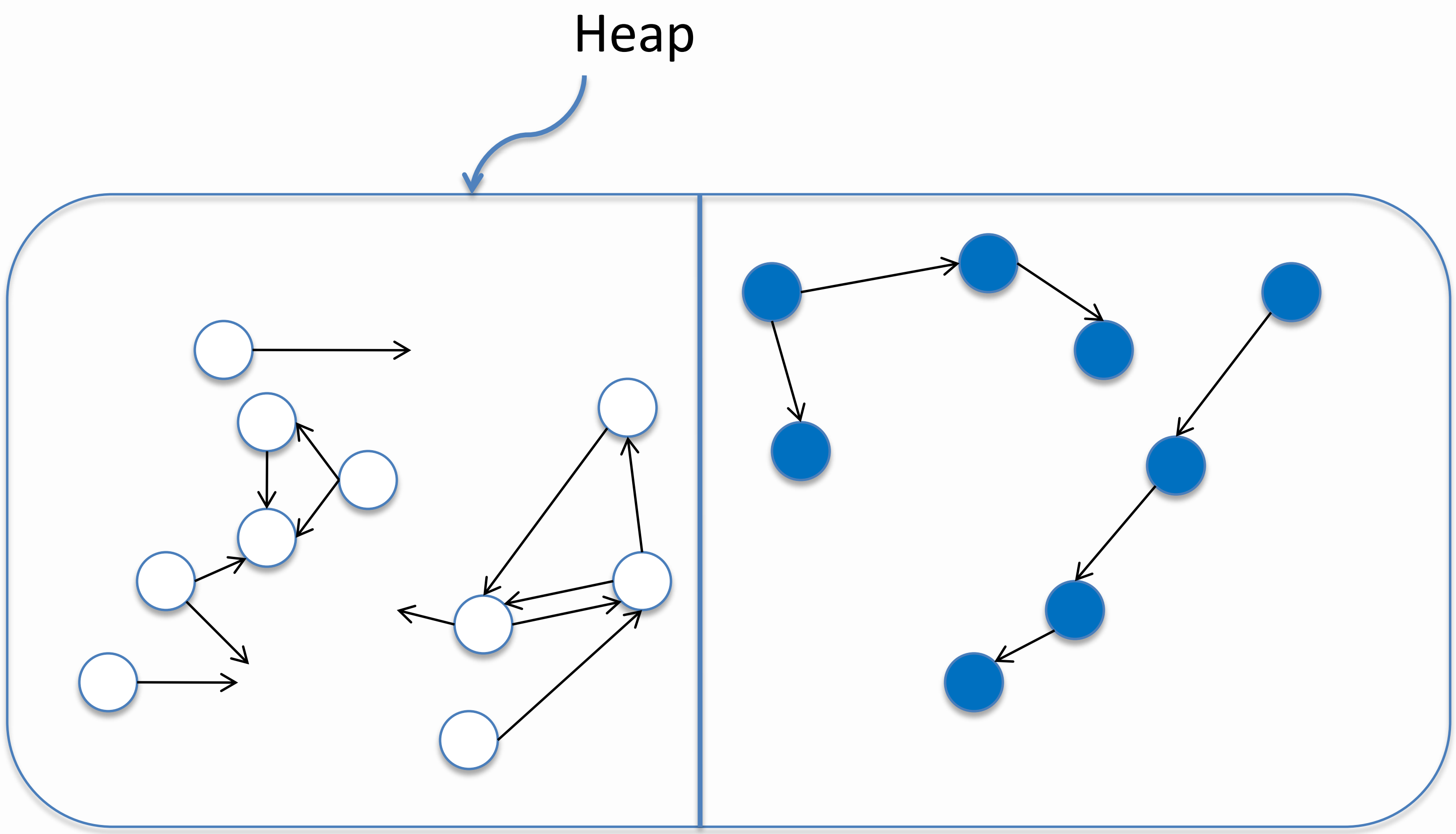

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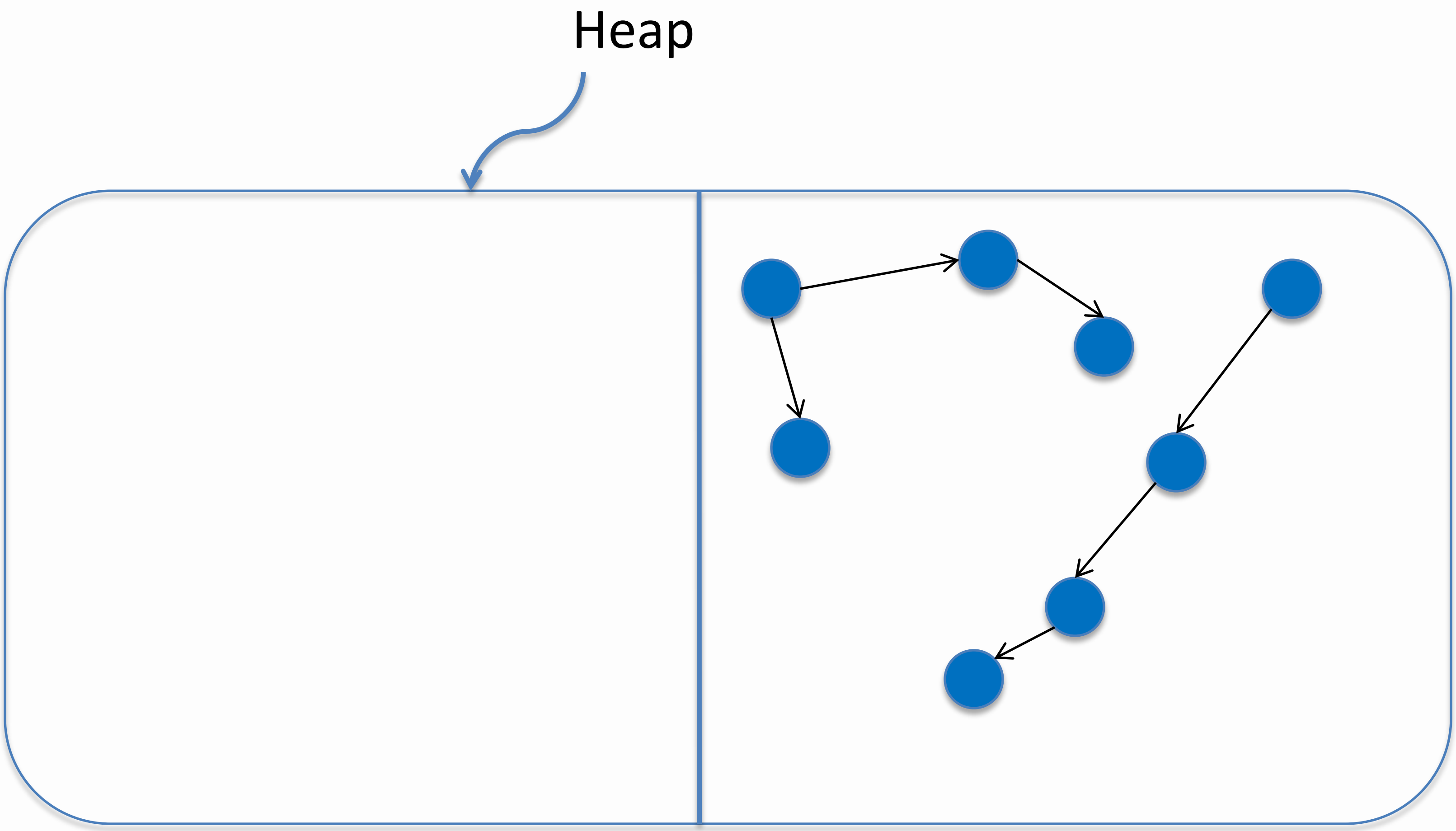

Java™

C#

Scala

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

[Bu et al., ISMM'13]

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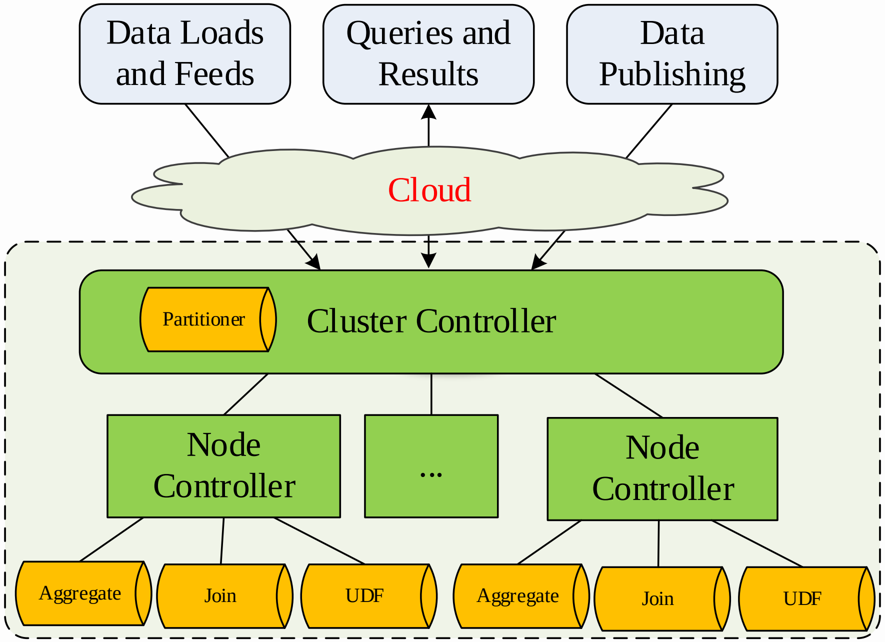
[Bu et al., ISMM'13]

High cost of the managed runtime is a fundamental problem!

Two Paths, Two Hypotheses

Two Paths, Two Hypotheses



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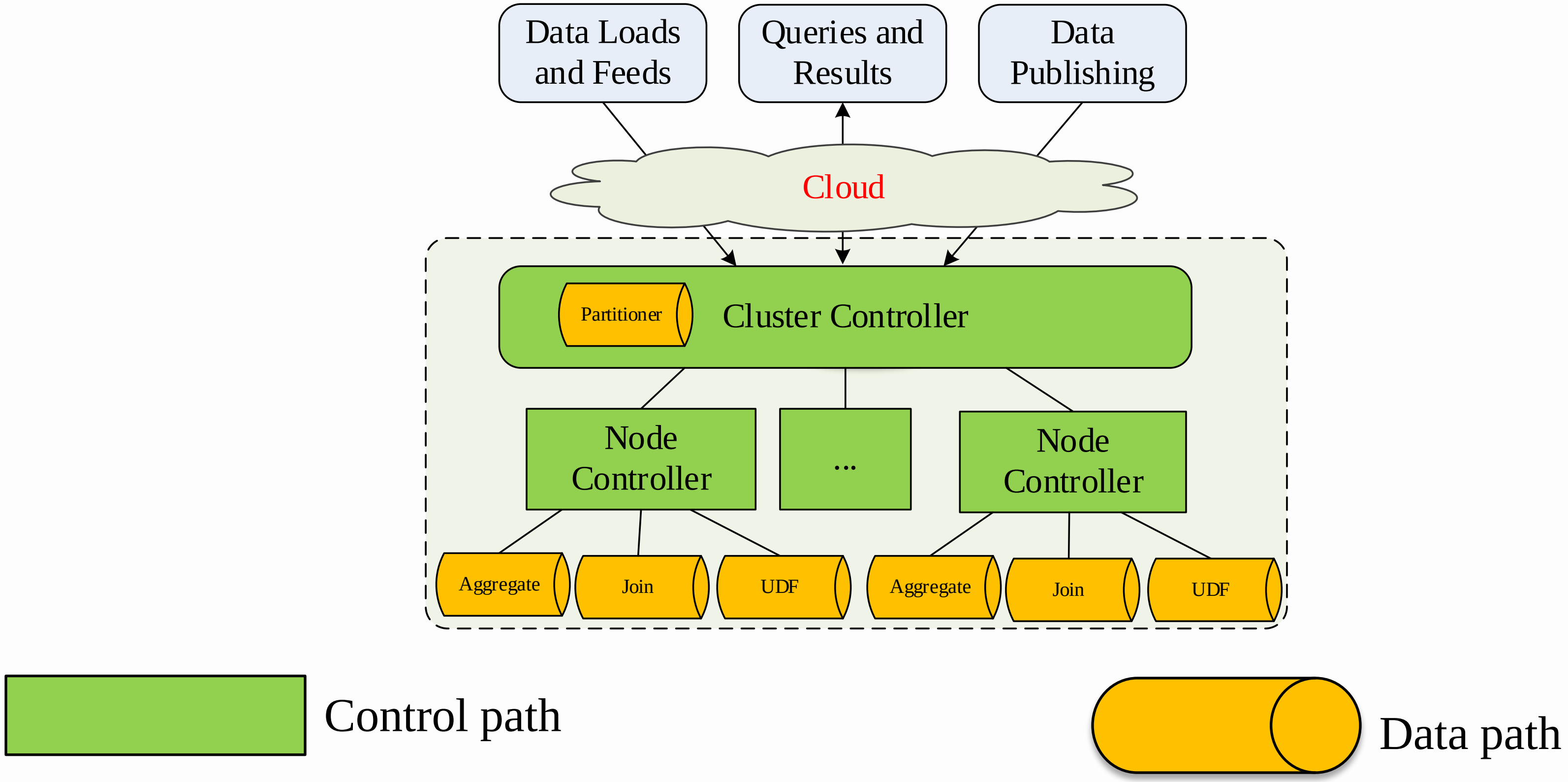

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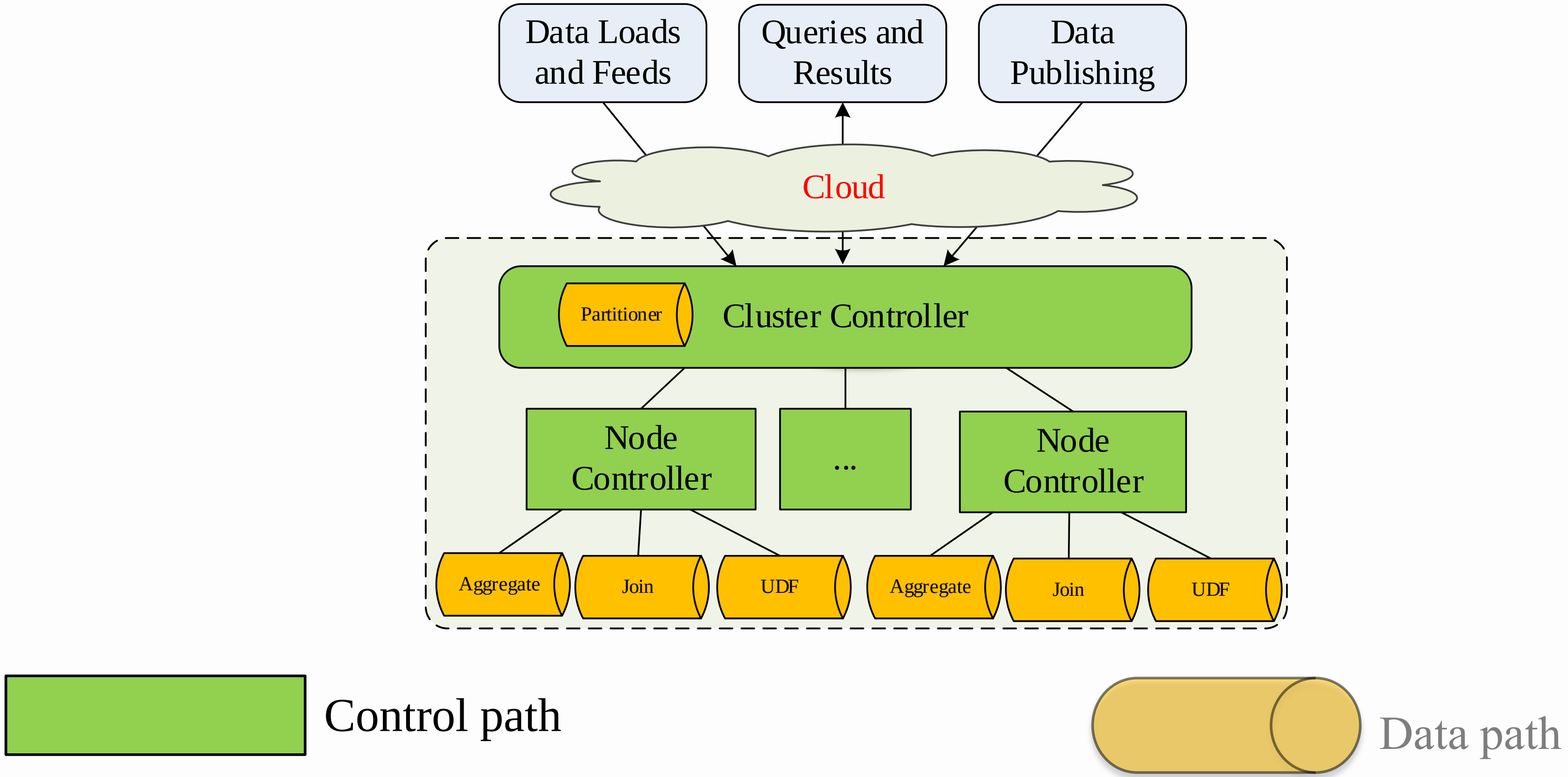

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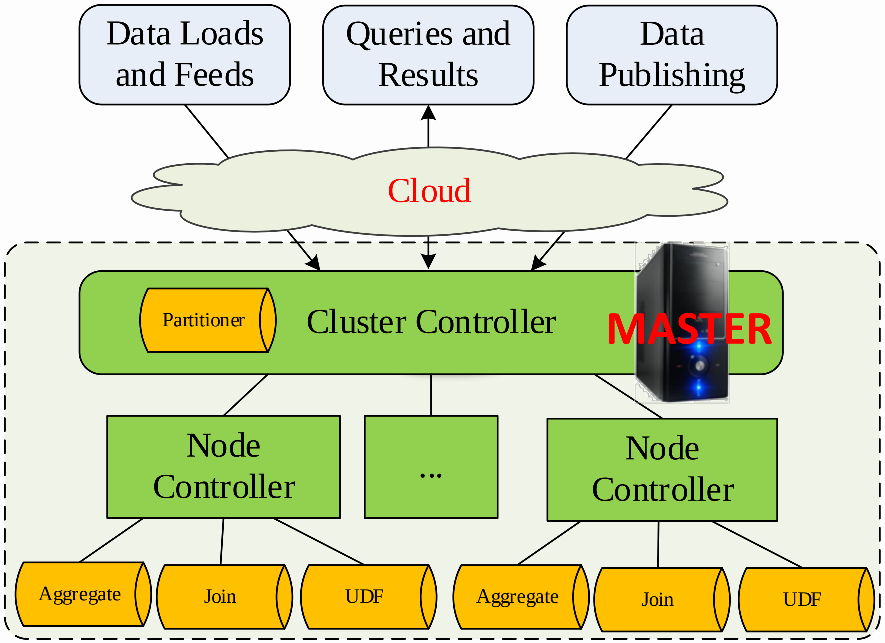

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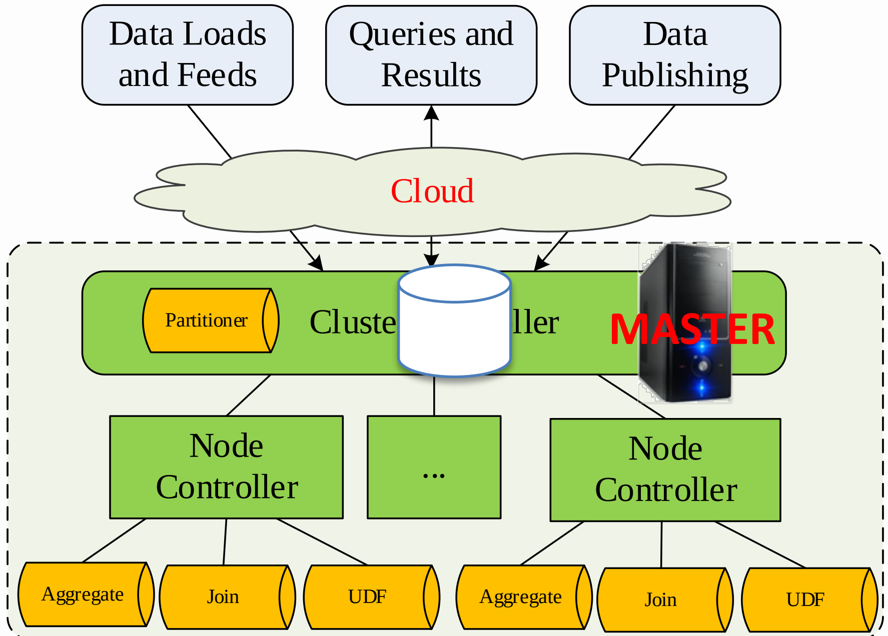
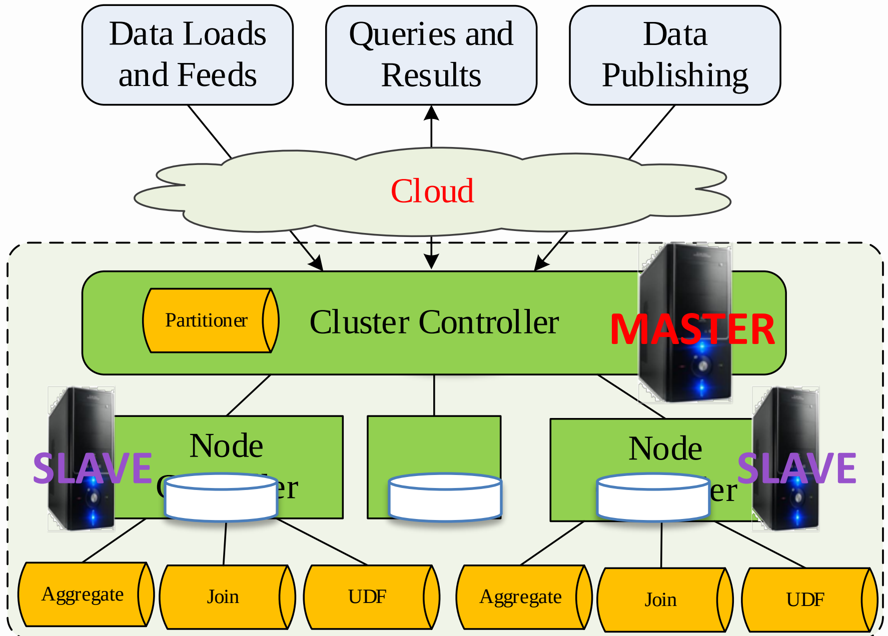


Control path

Data path

Two Paths, Two Hypotheses



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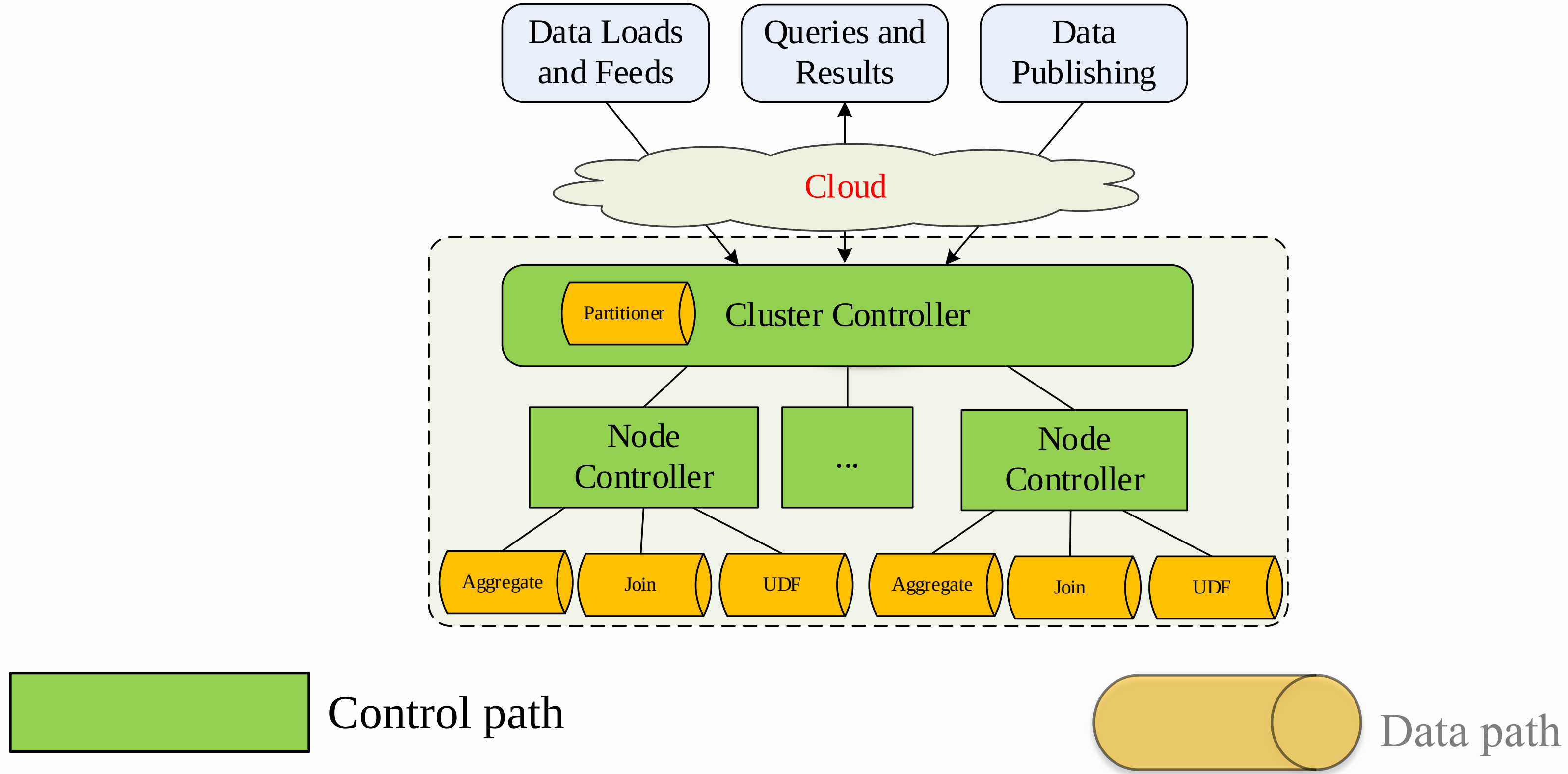
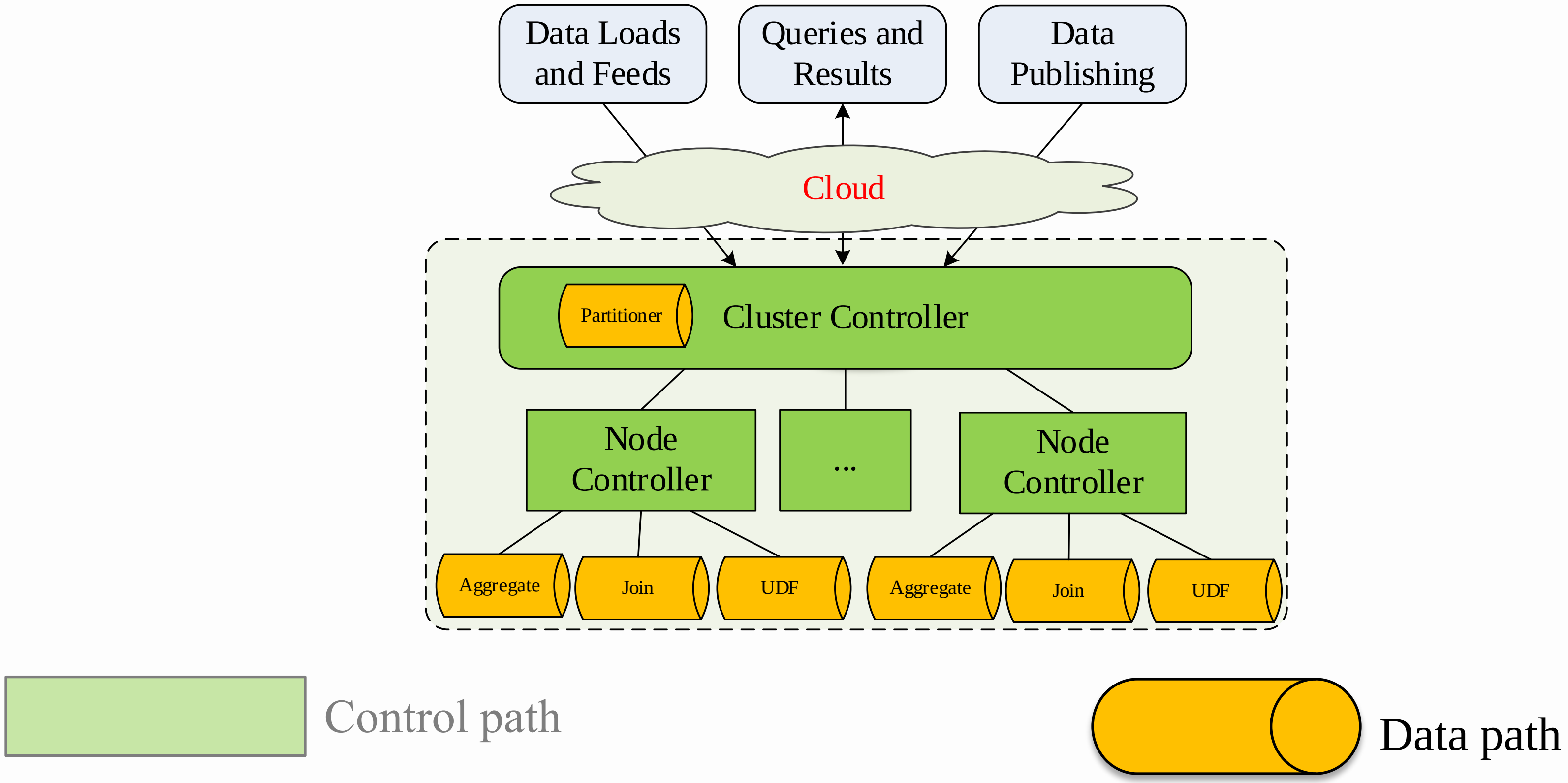


Generational Hypothesis

Two Paths, Two Hypotheses



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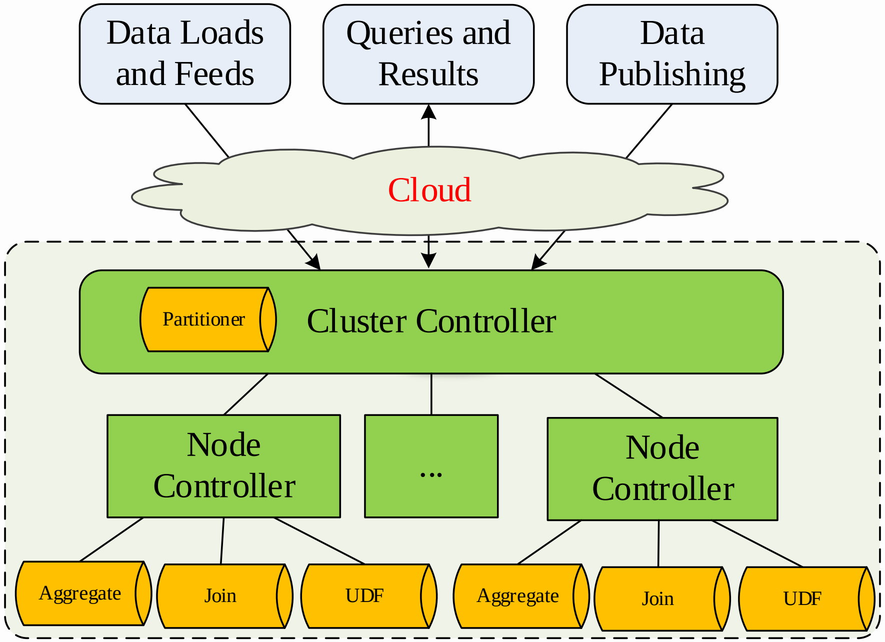
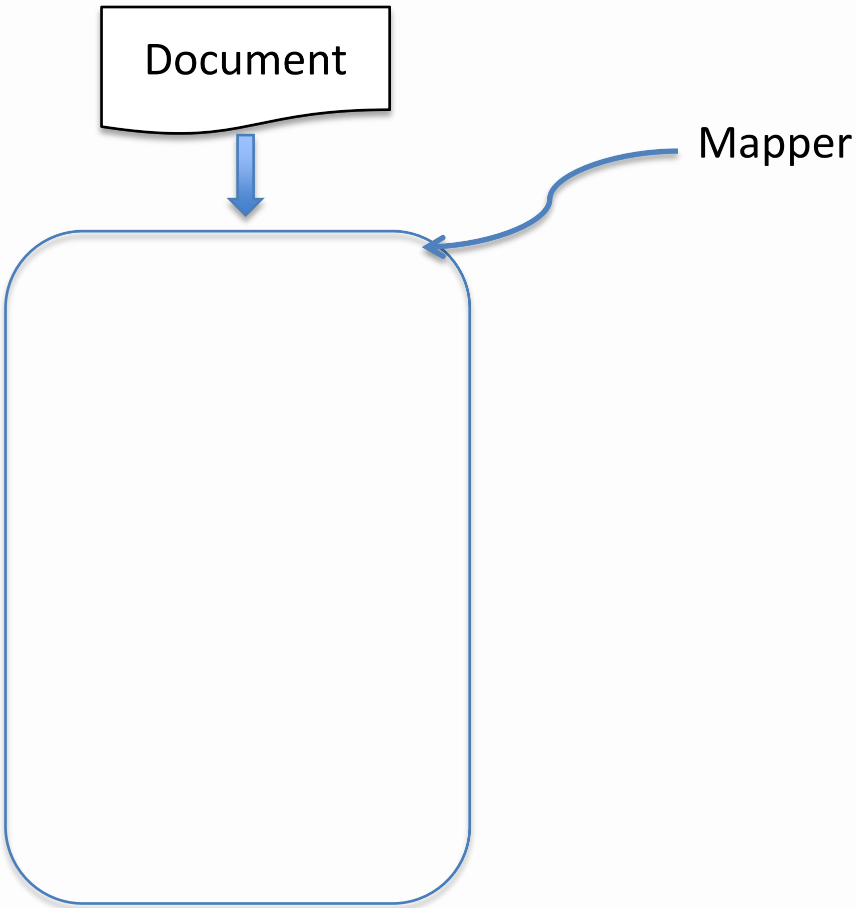


Generational Hypothesis

Epochal Hypothesis

WordCount

WordCount



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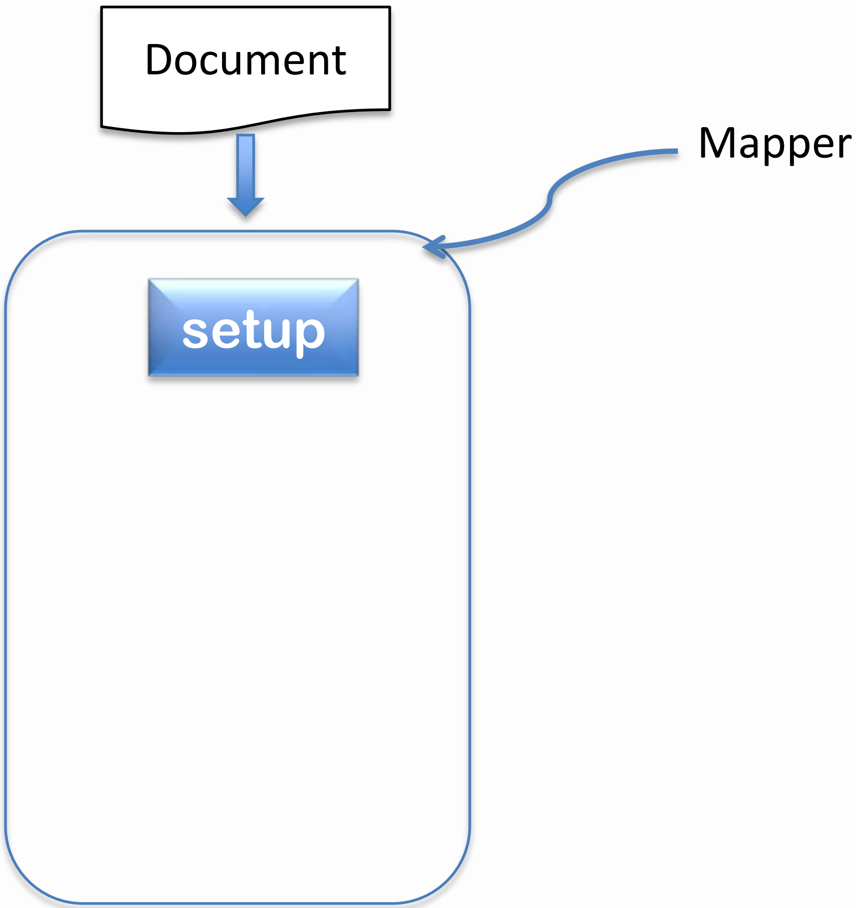

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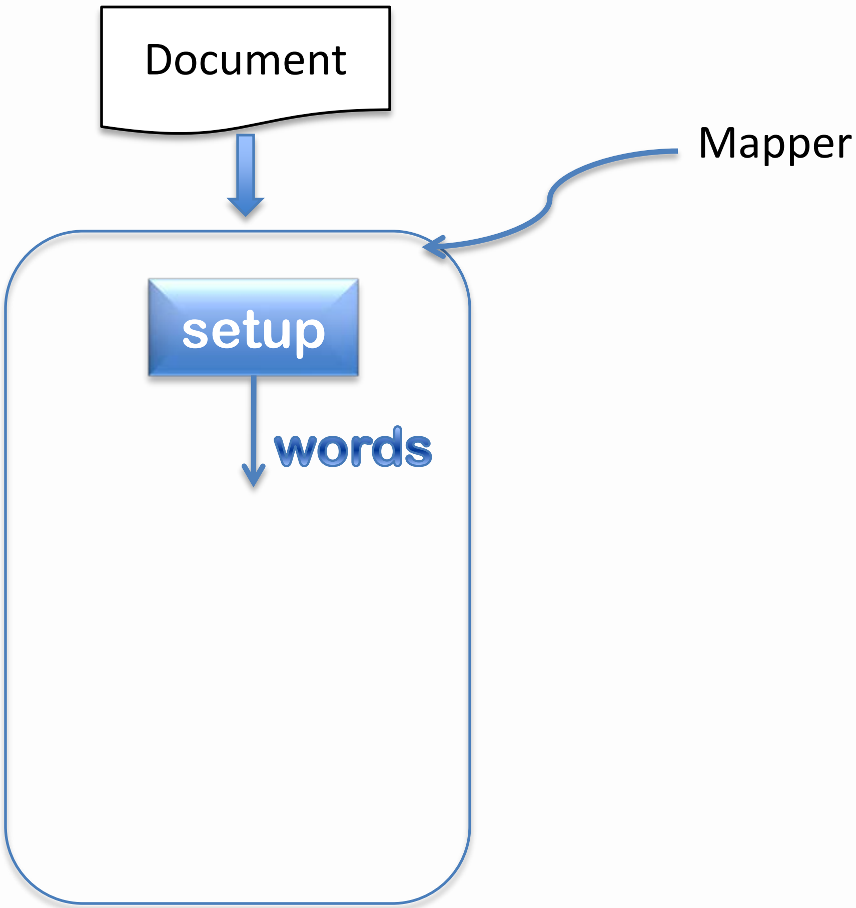

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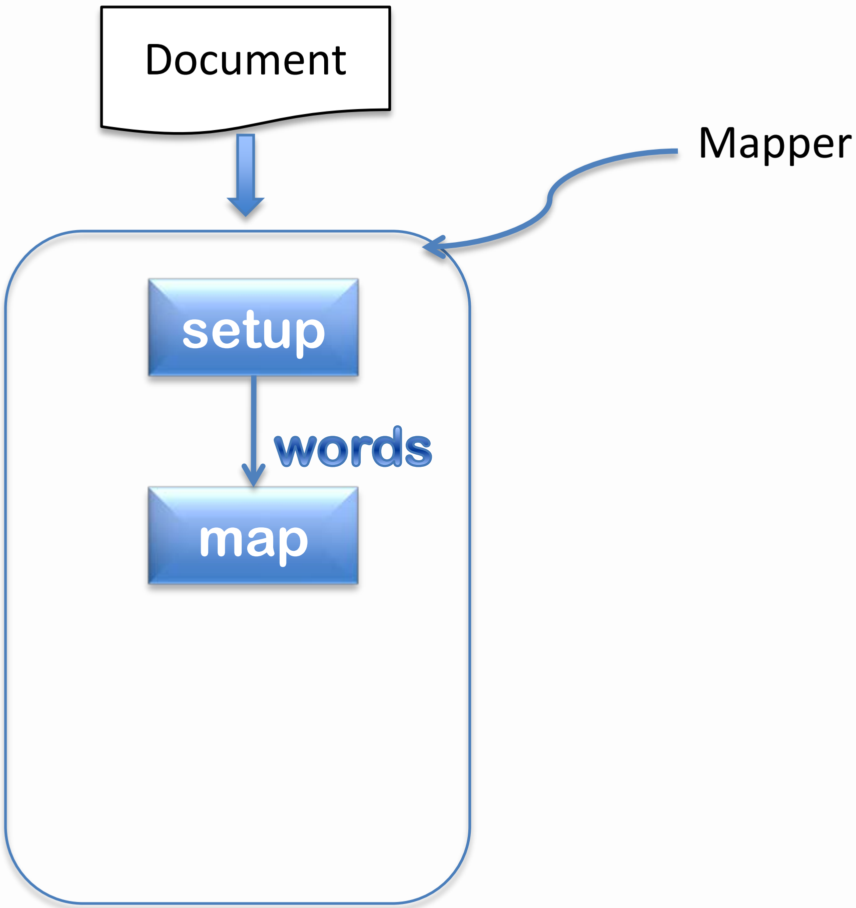

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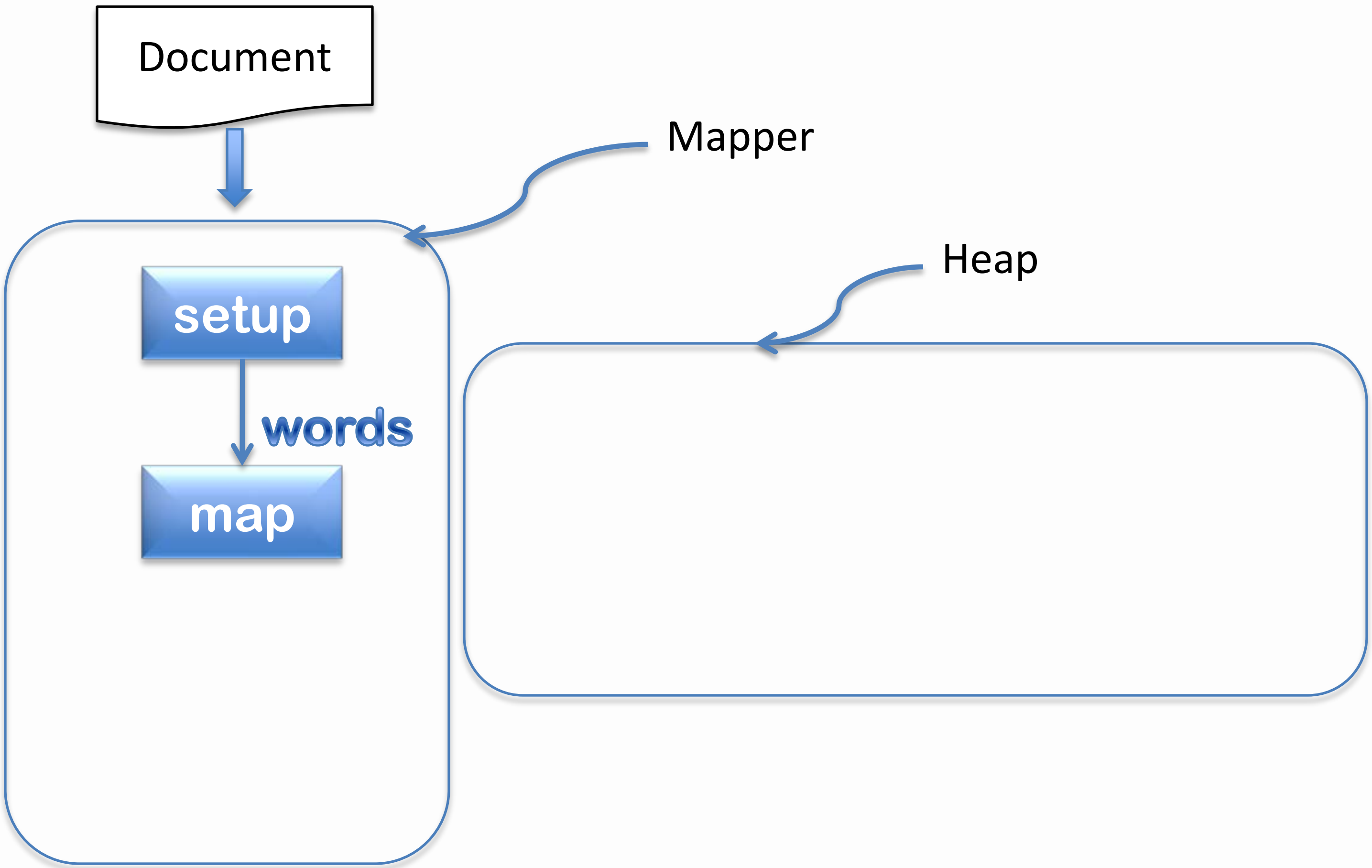

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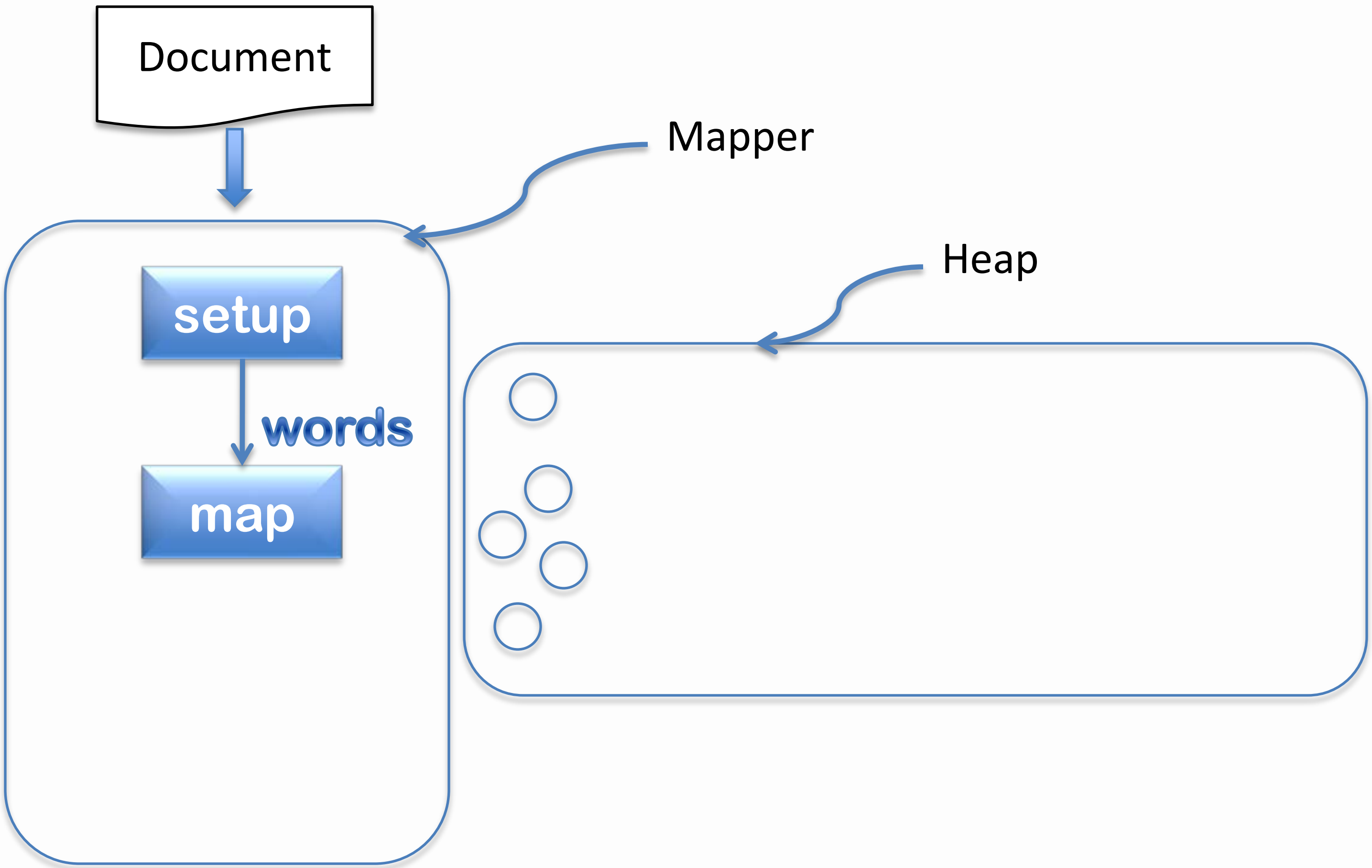

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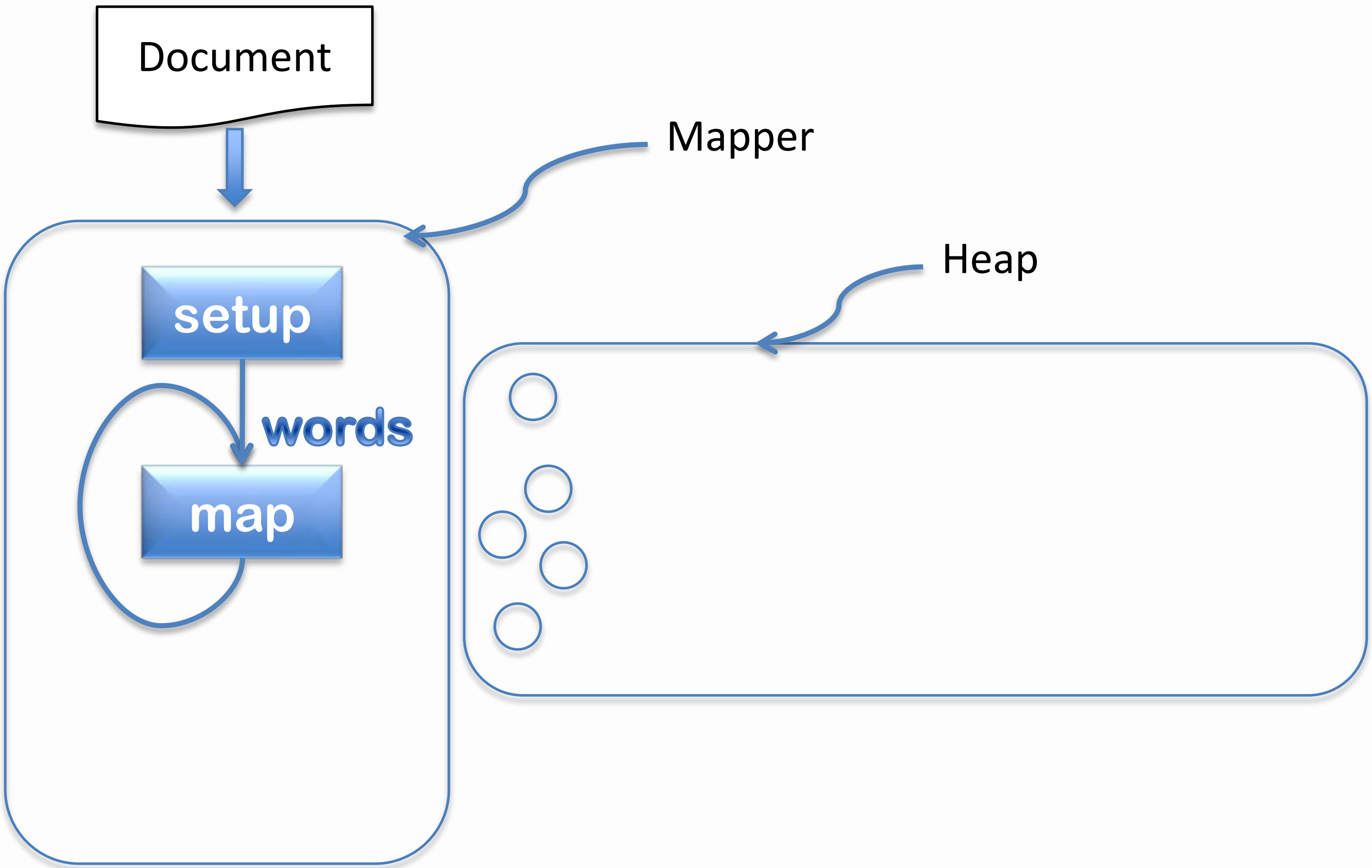

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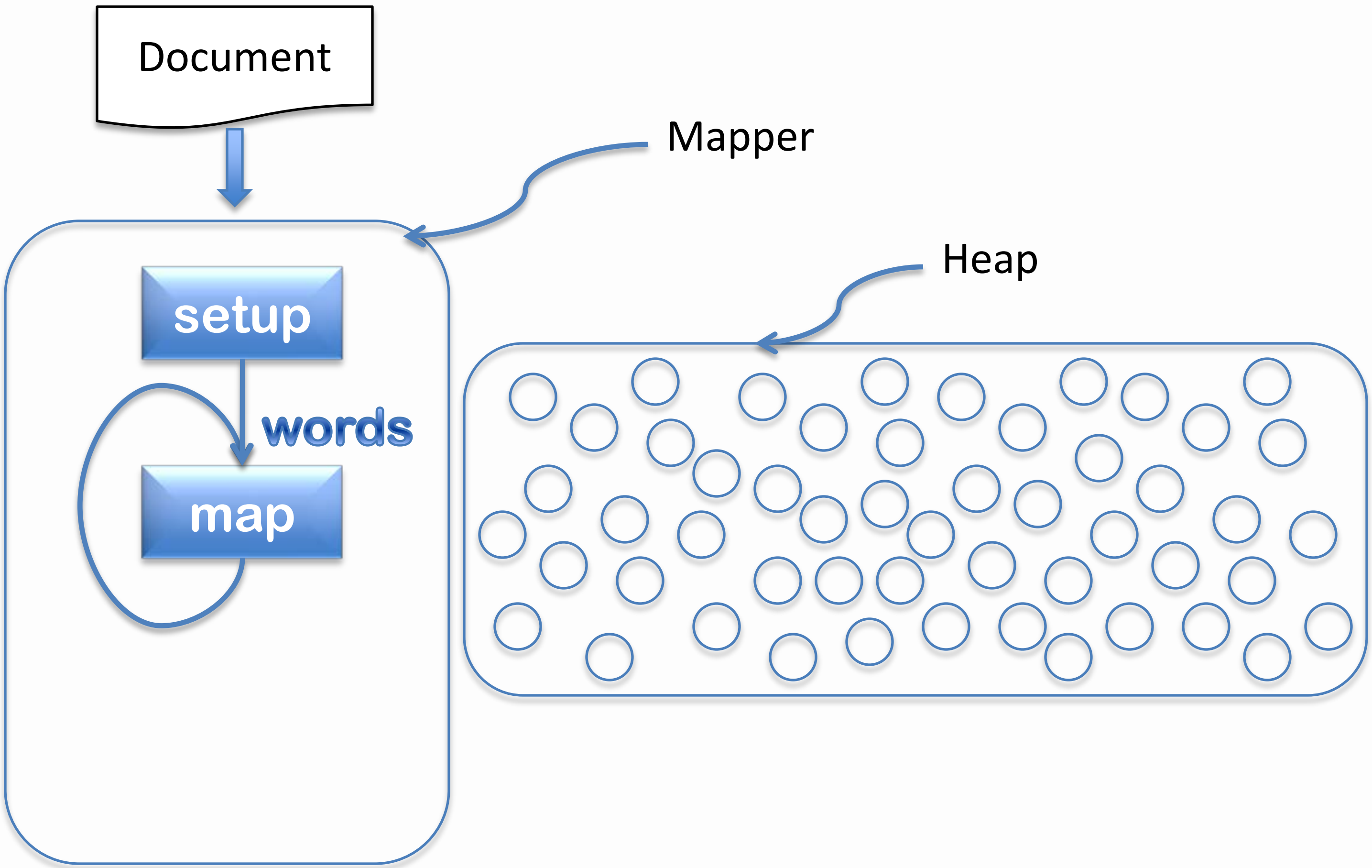

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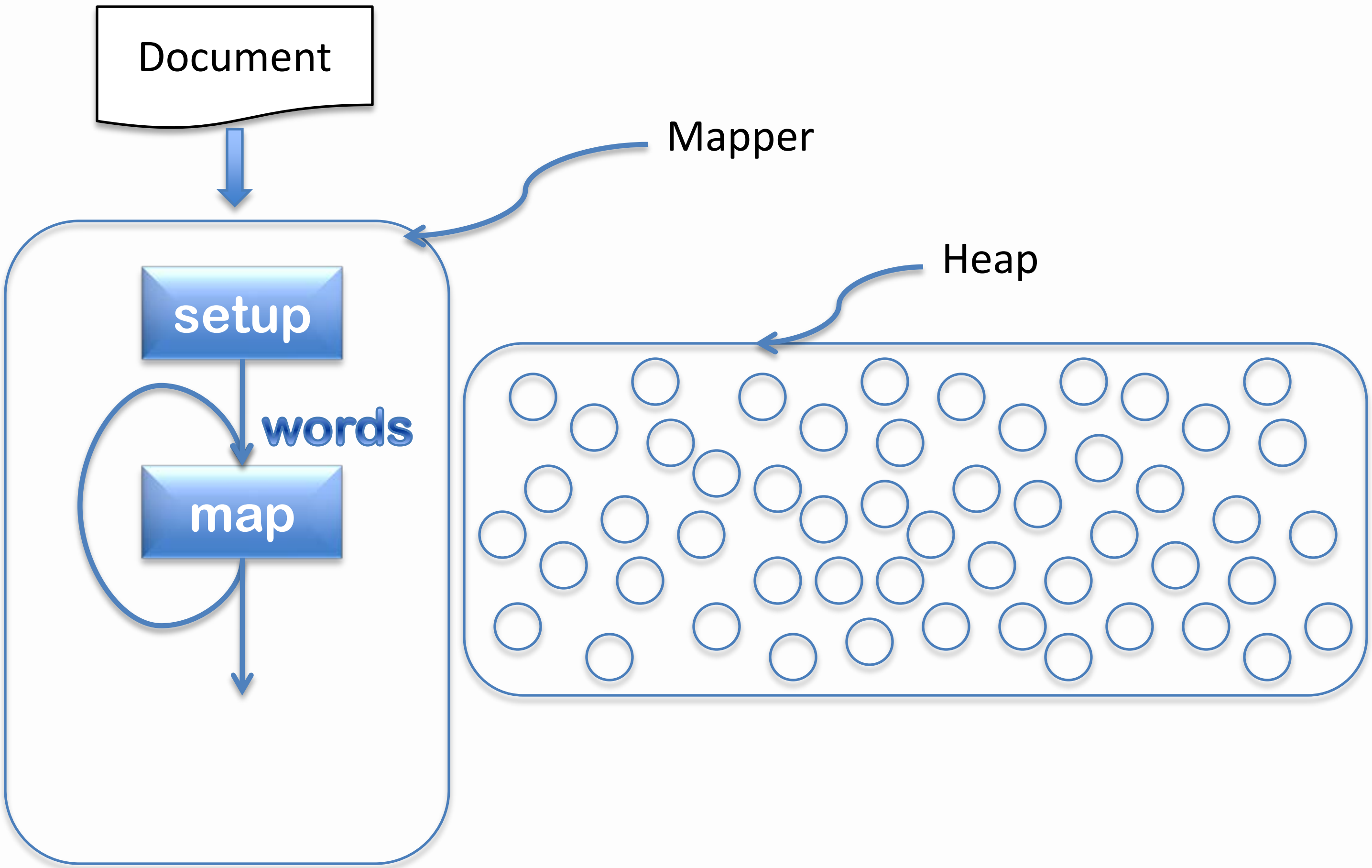

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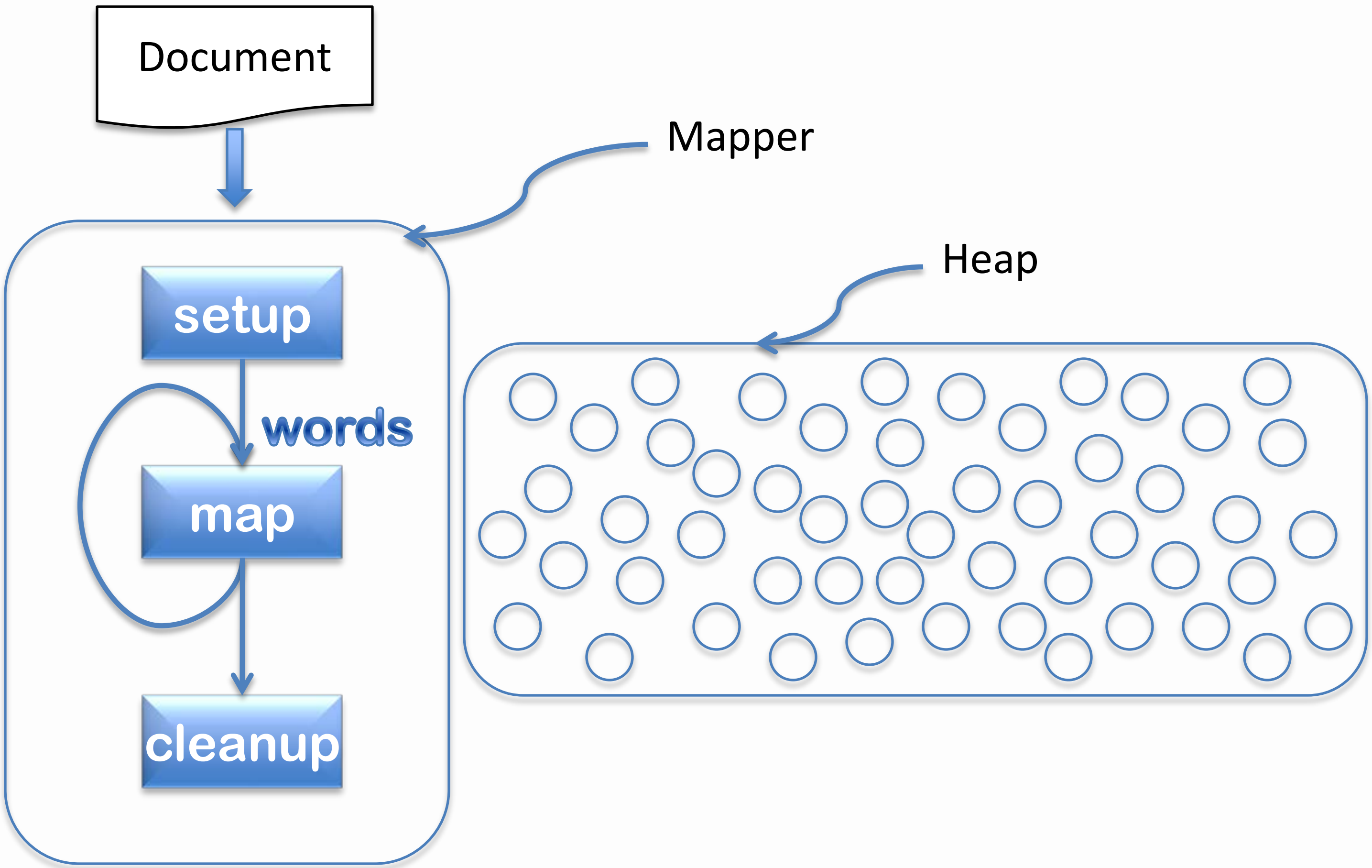
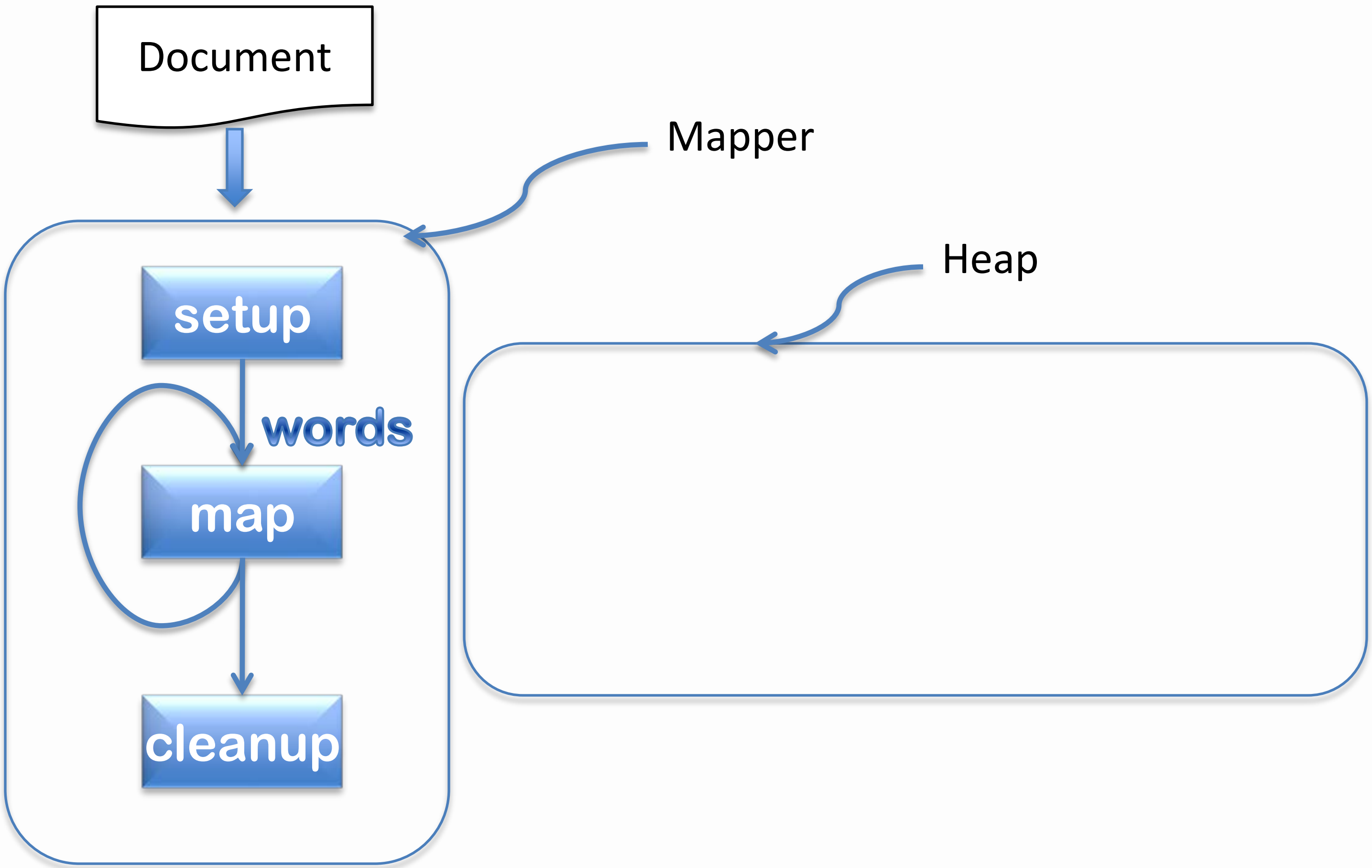


WordCount



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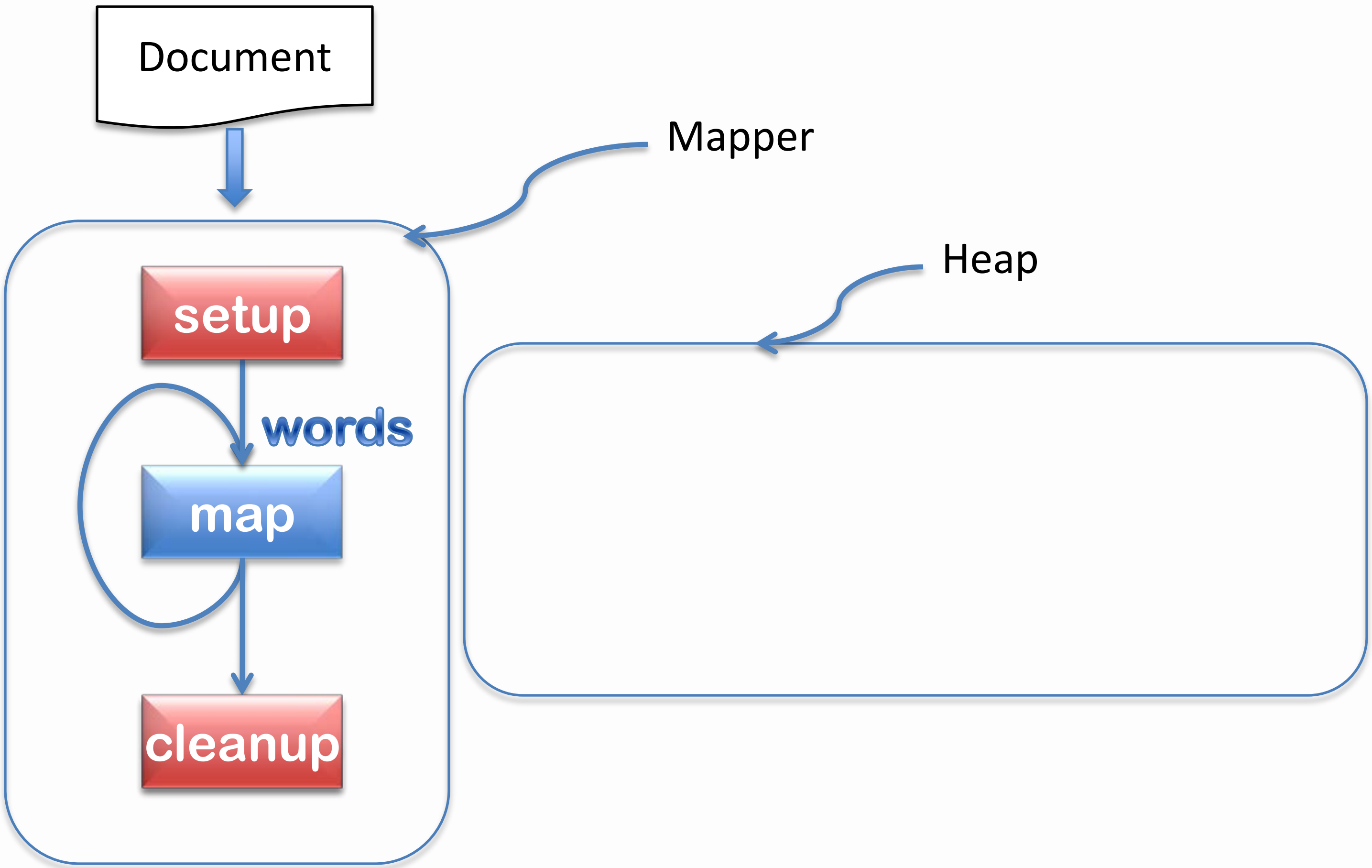

WordCount

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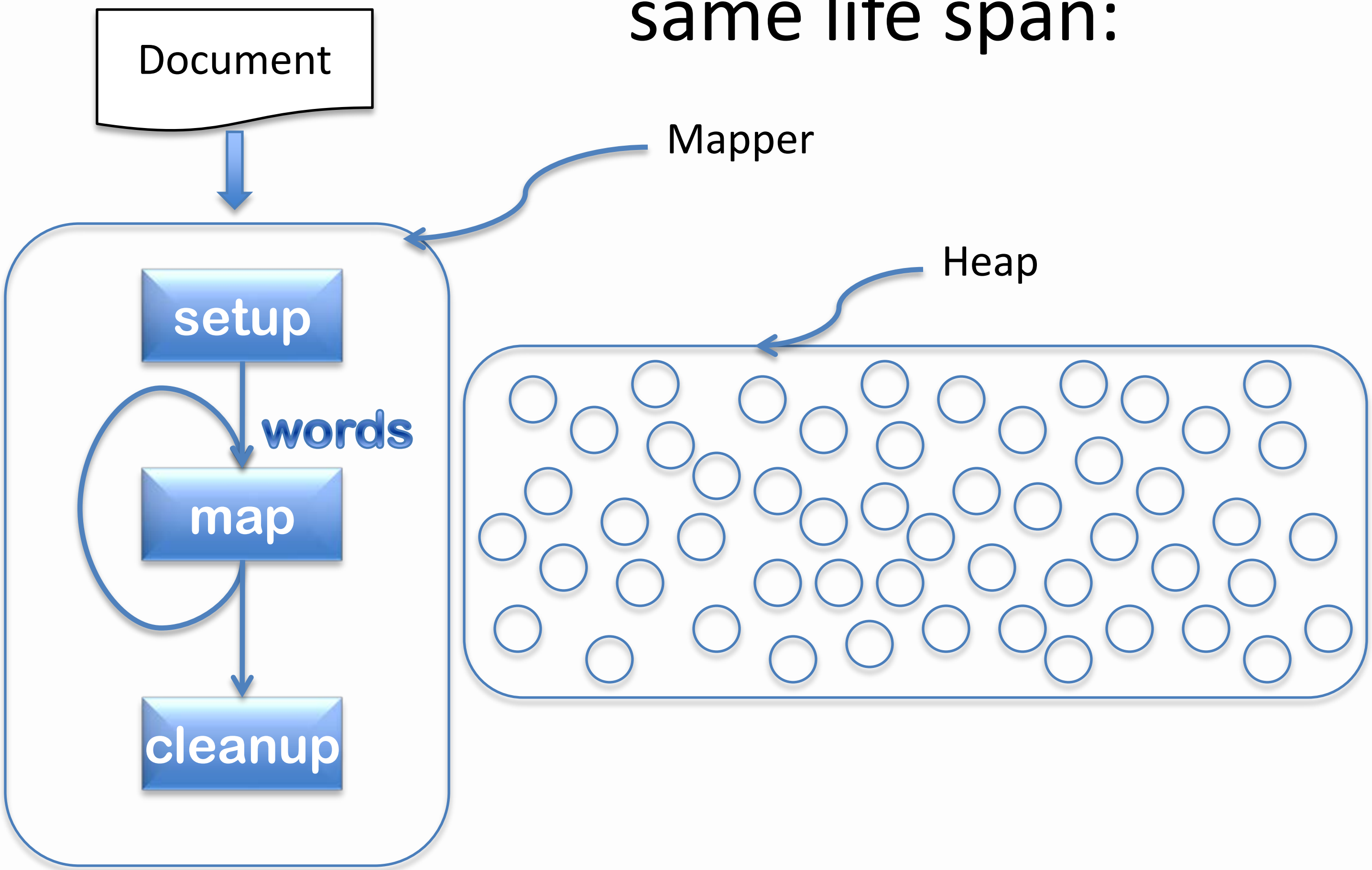

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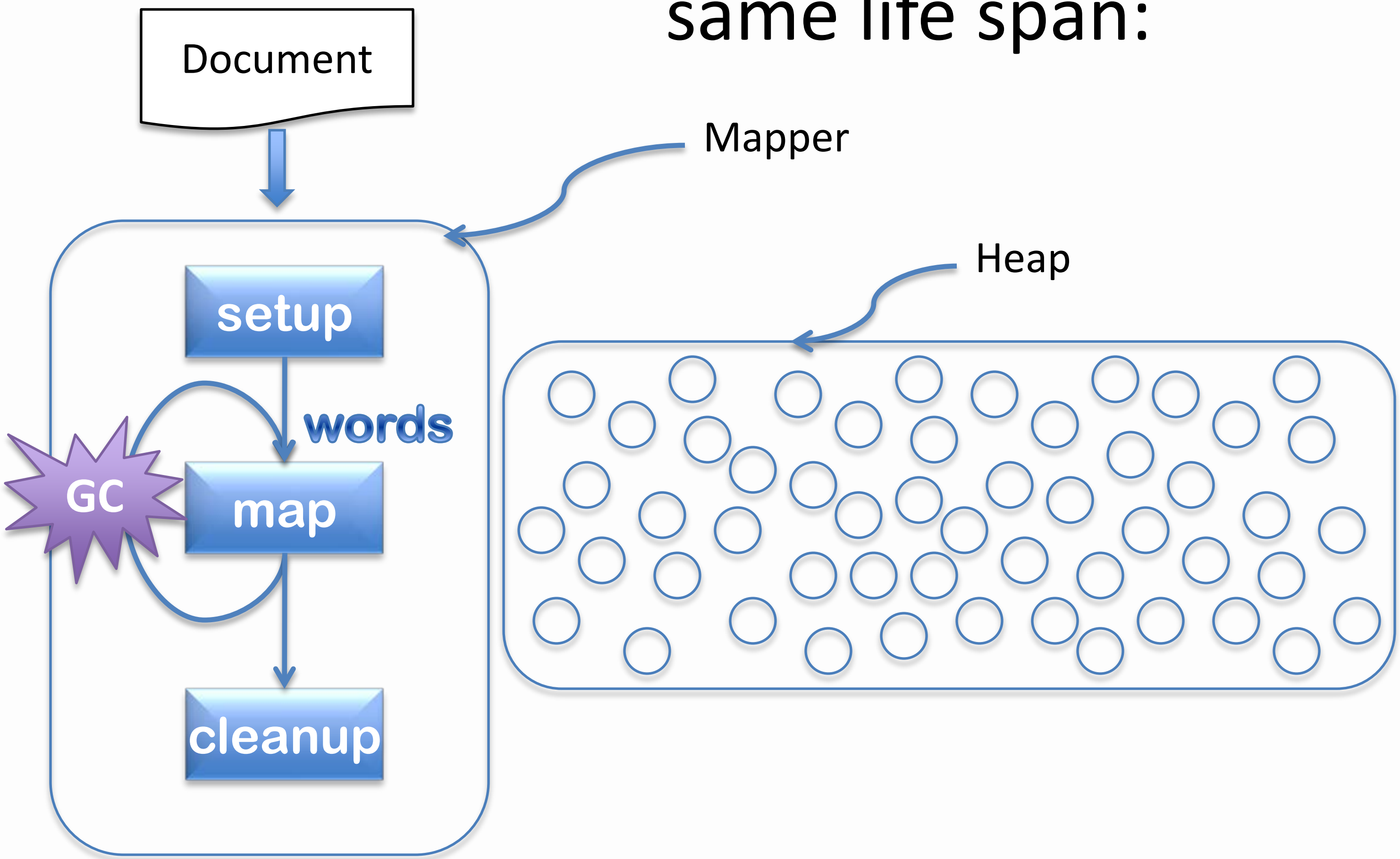

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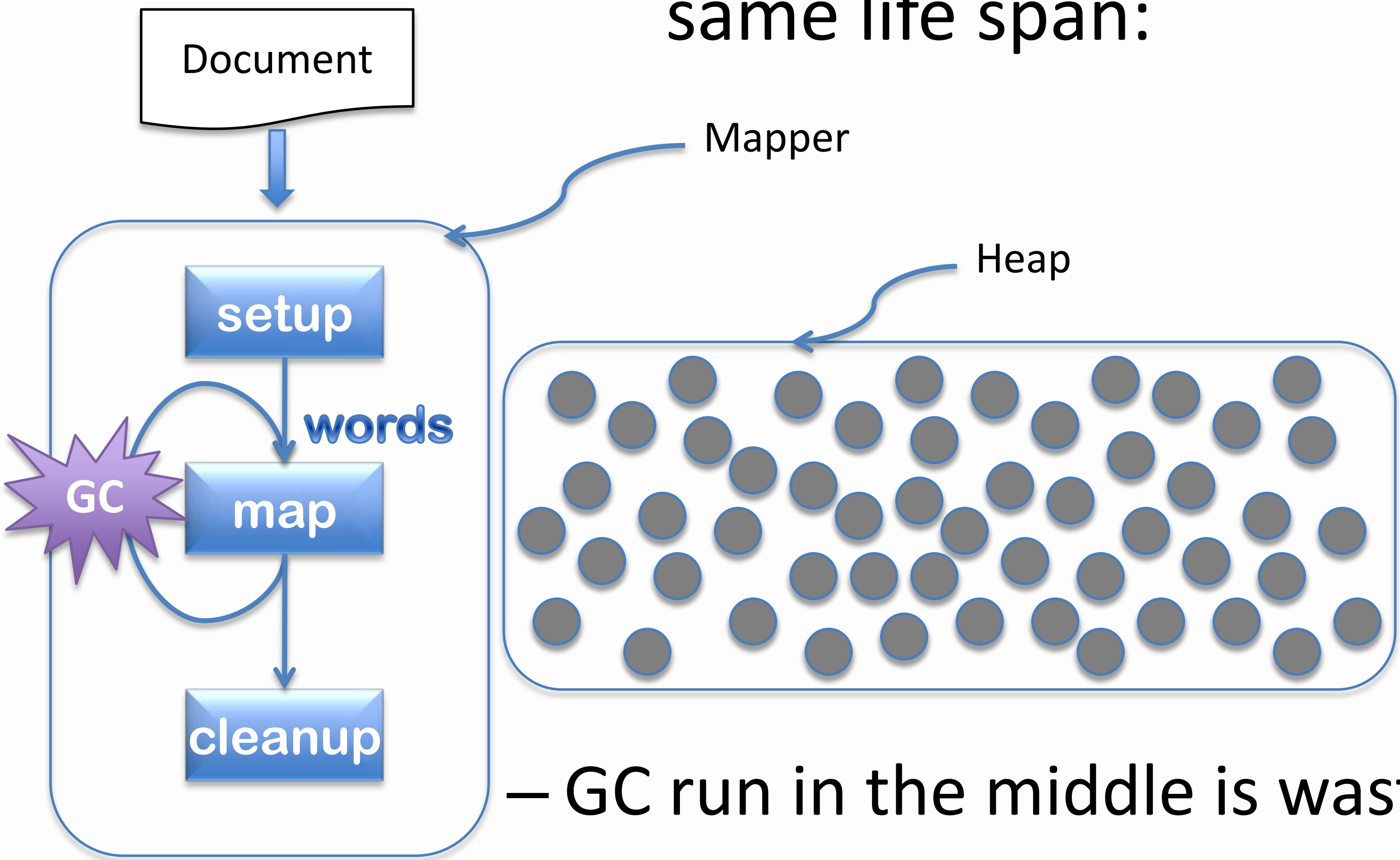

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WordCount

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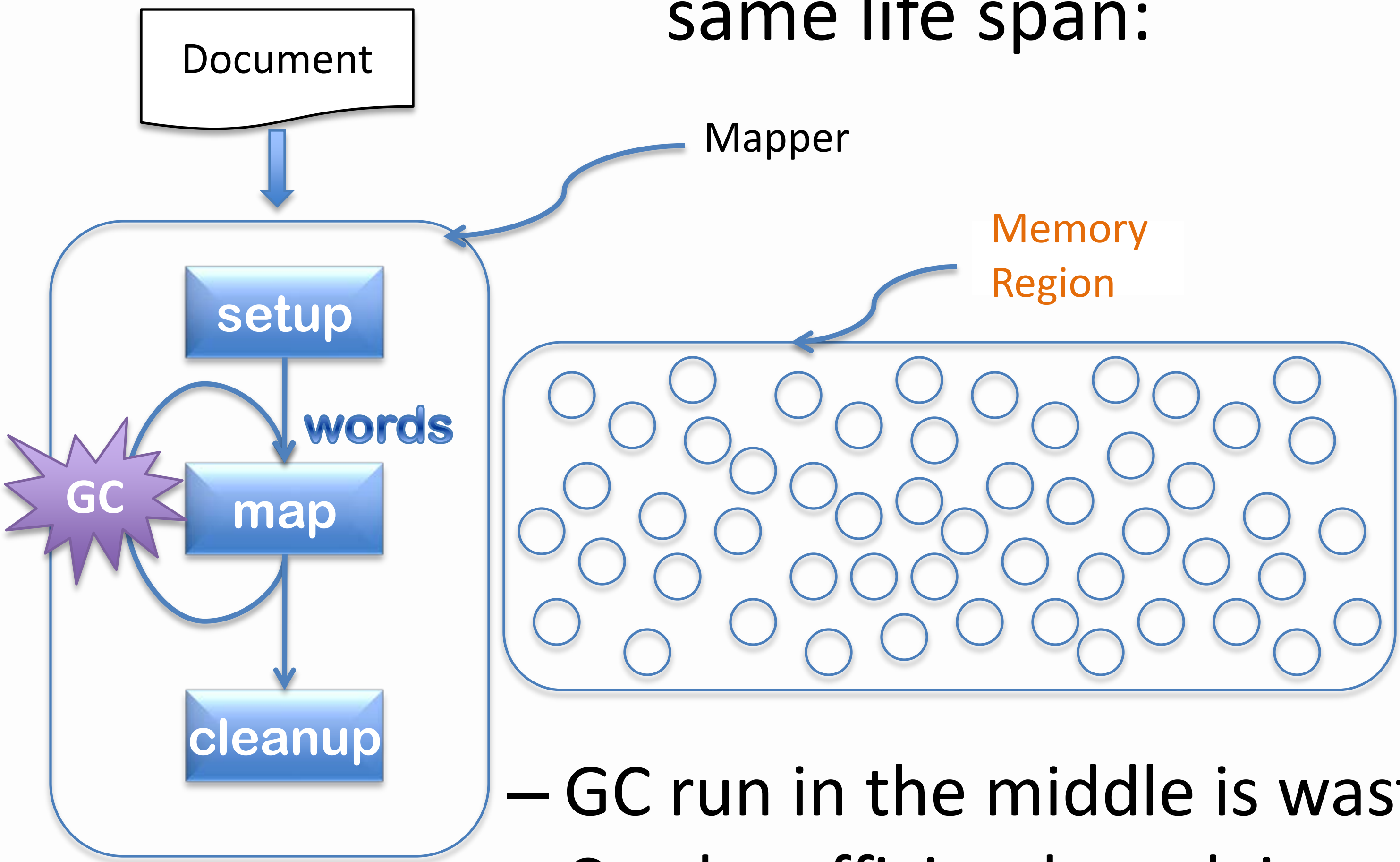

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  - Can be efficiently reclaimed together

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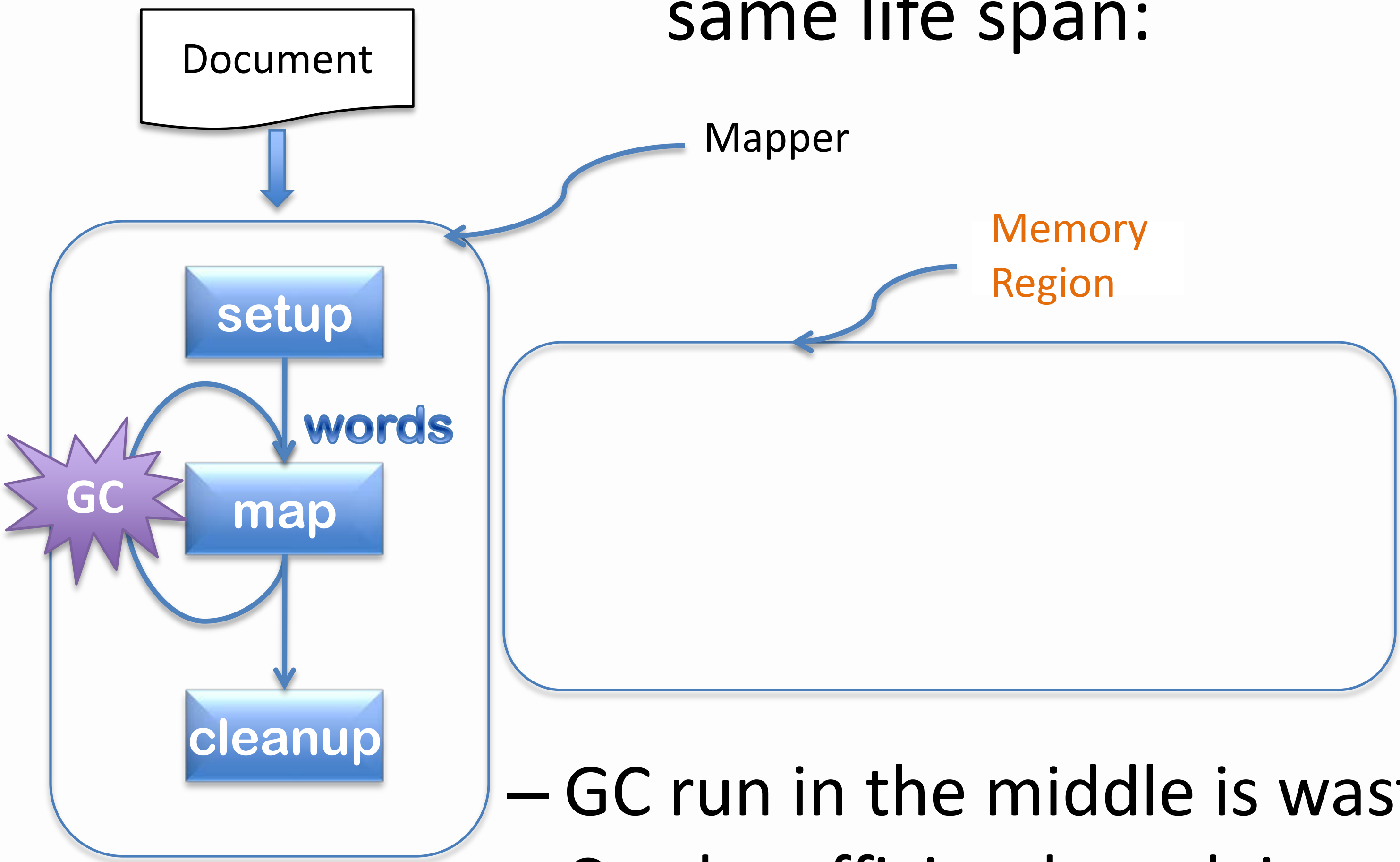

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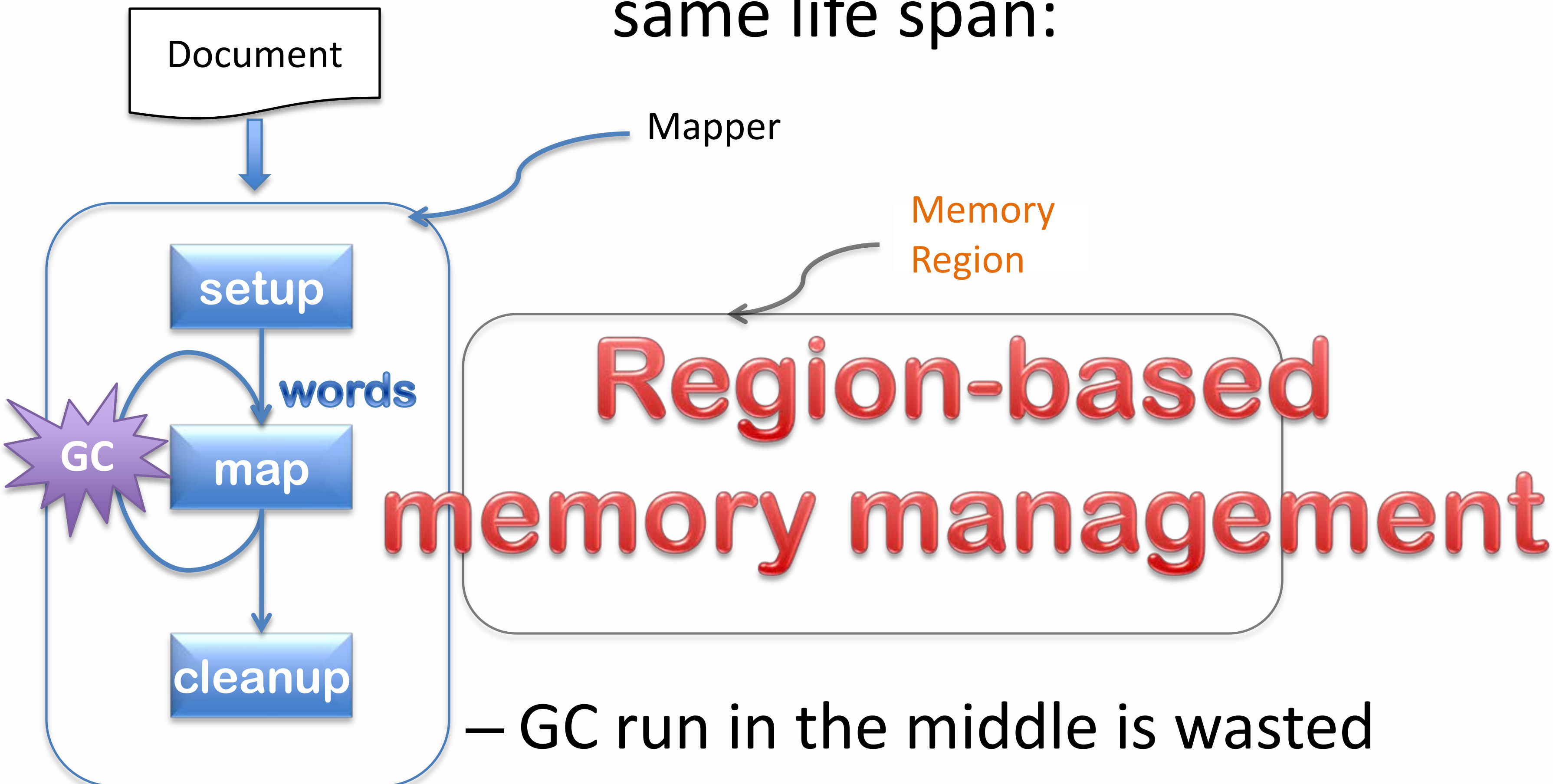

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Region-based Memory Management

- Sophisticated static analysis won't work for data-intensive systems

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Region-based Memory Management

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- What about control path?

generational GC ➕ region-based memory management

Yak Approach

Heap

Yak Approach

Control Space

Data Space

Yak Approach

Control Space

Generational GC

Data Space

Yak Approach

Control Space

Generational GC

Data Space

Region-based
Memory Management

Yak Approach

Control Space

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Data Space

Region-based Memory Management

Reduced memory management cost

Yak Approach

Control Space

Generational GC

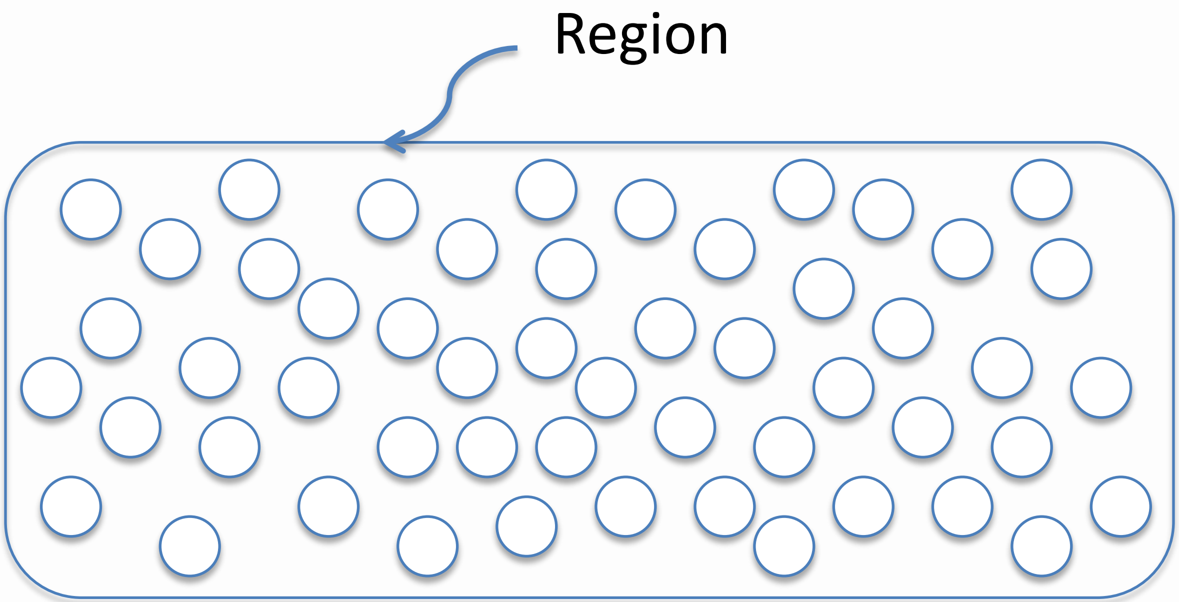
Data Space

Region-based
Memory Management

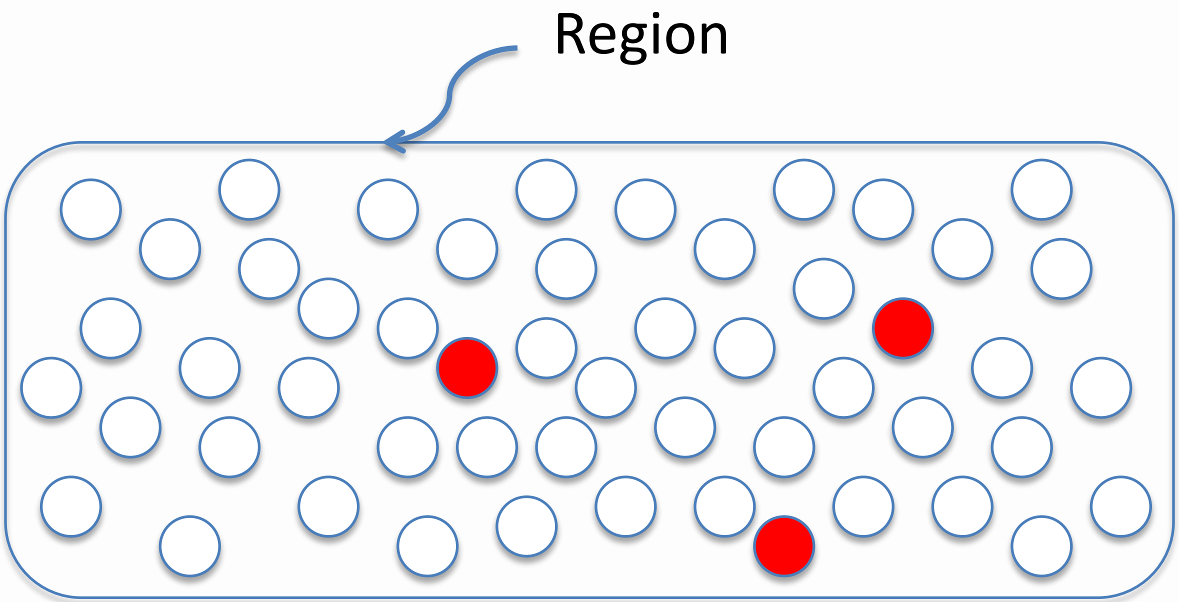
Reduced memory management cost

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

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Developers → Yak

Yak: An Automatic Solution

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  - Implemented in OpenJDK 8
    - Modified the interpreter, two JIT compilers, the heap layout, the Parallel Scavenge GC
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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
  - 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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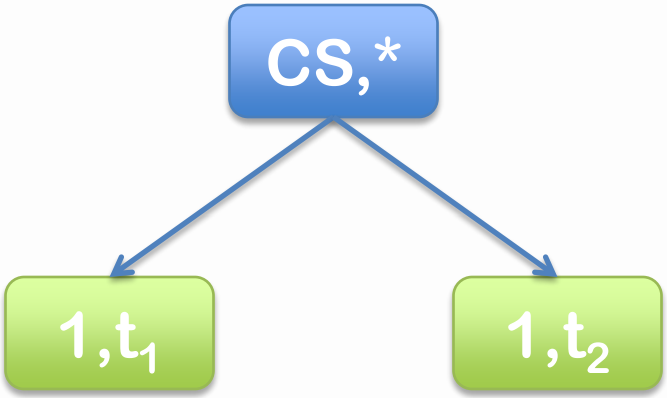
```
void main() {

} //end of main
```

CS,*

How to Create Regions?

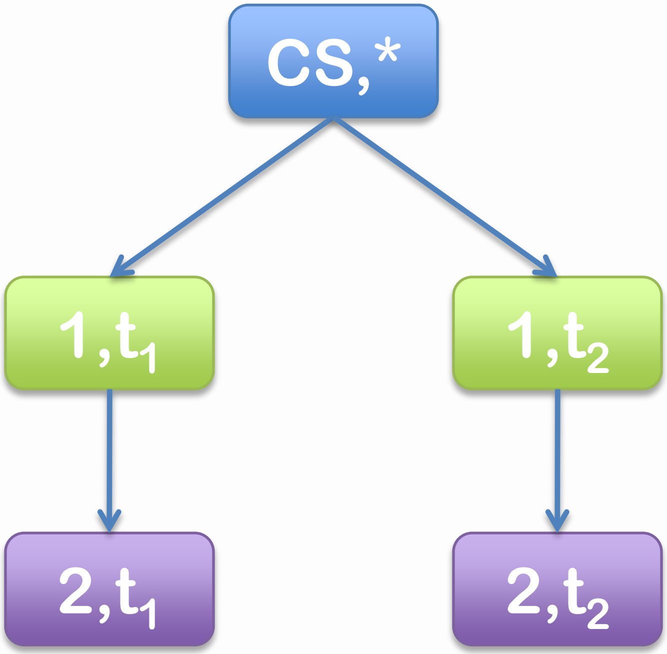
```
void main() {

epoch_start();
for(    ) {



}
epoch_end();

} //end of main
```

epoch #1



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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void main() {

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    epoch_start();          epoch #2
    for(    ) {
        epoch_start();      epoch #3
        for(    ) {

        }
        epoch_end();

    }
    epoch_end();
}
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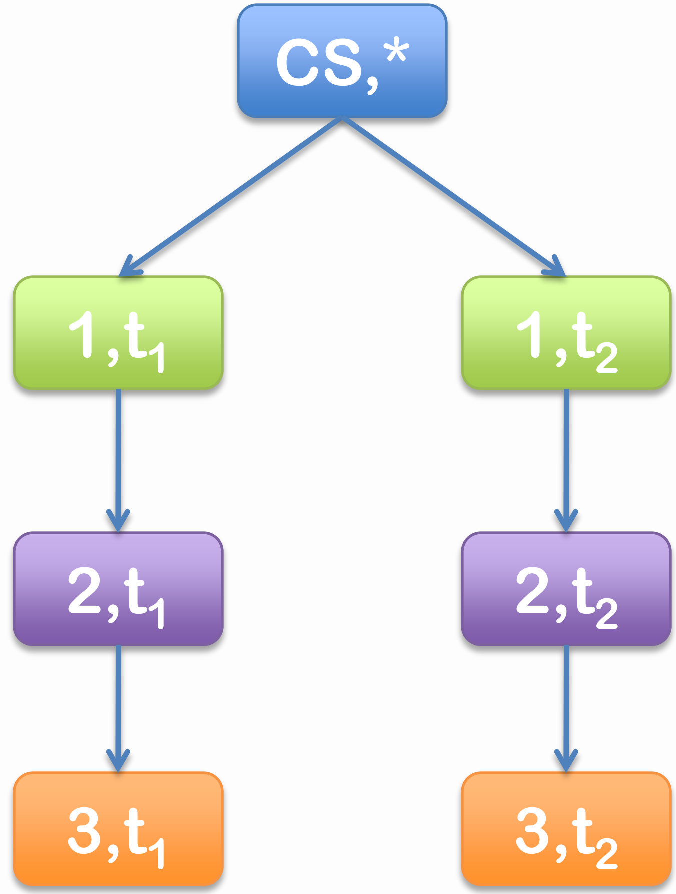

Region Semilattice

```
void main() {

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    for(    ) {
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      for(    ) {

      }
      epoch_end();

    }
    epoch_end();

  }
  epoch_end();

} //end of main
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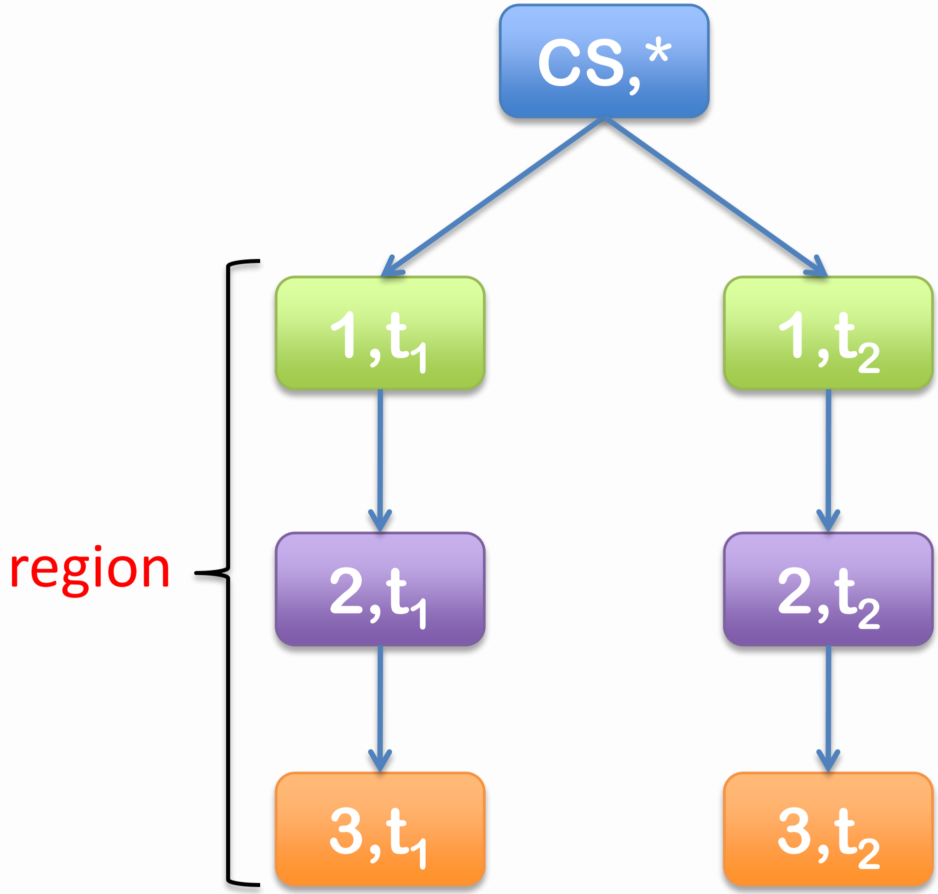

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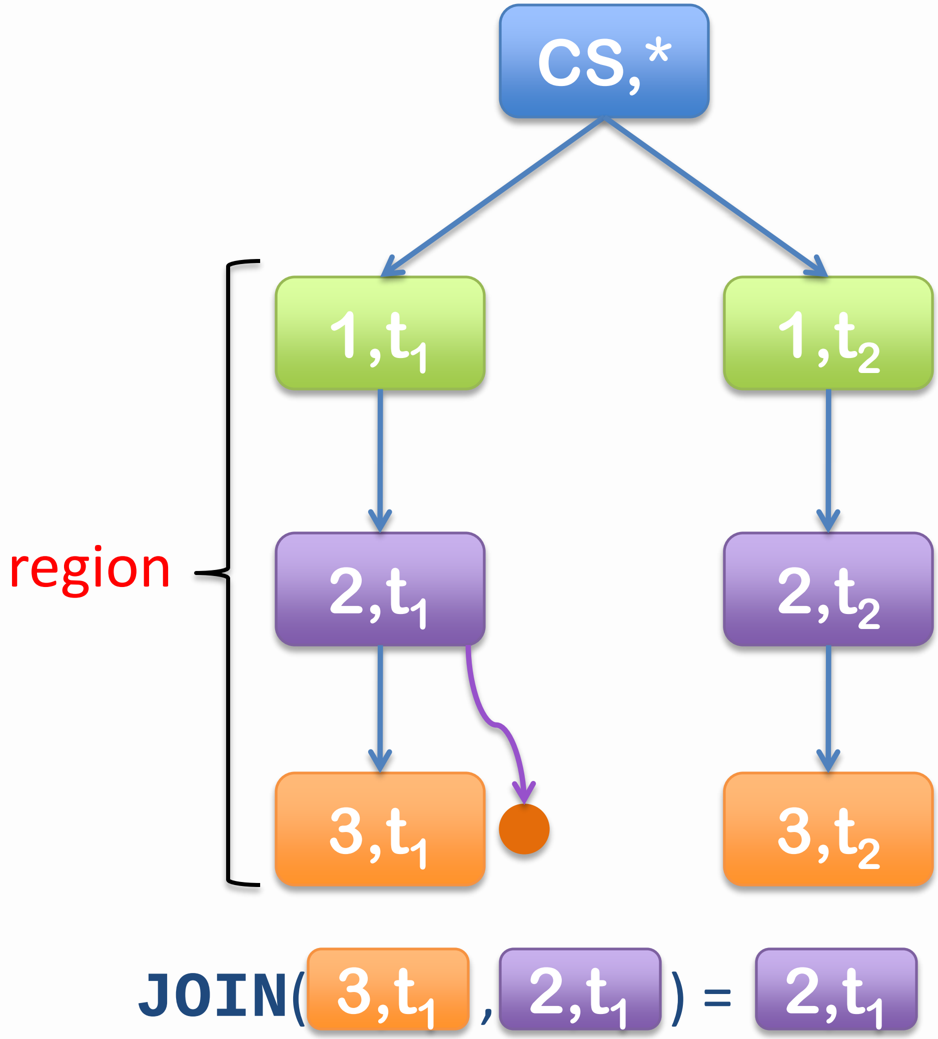

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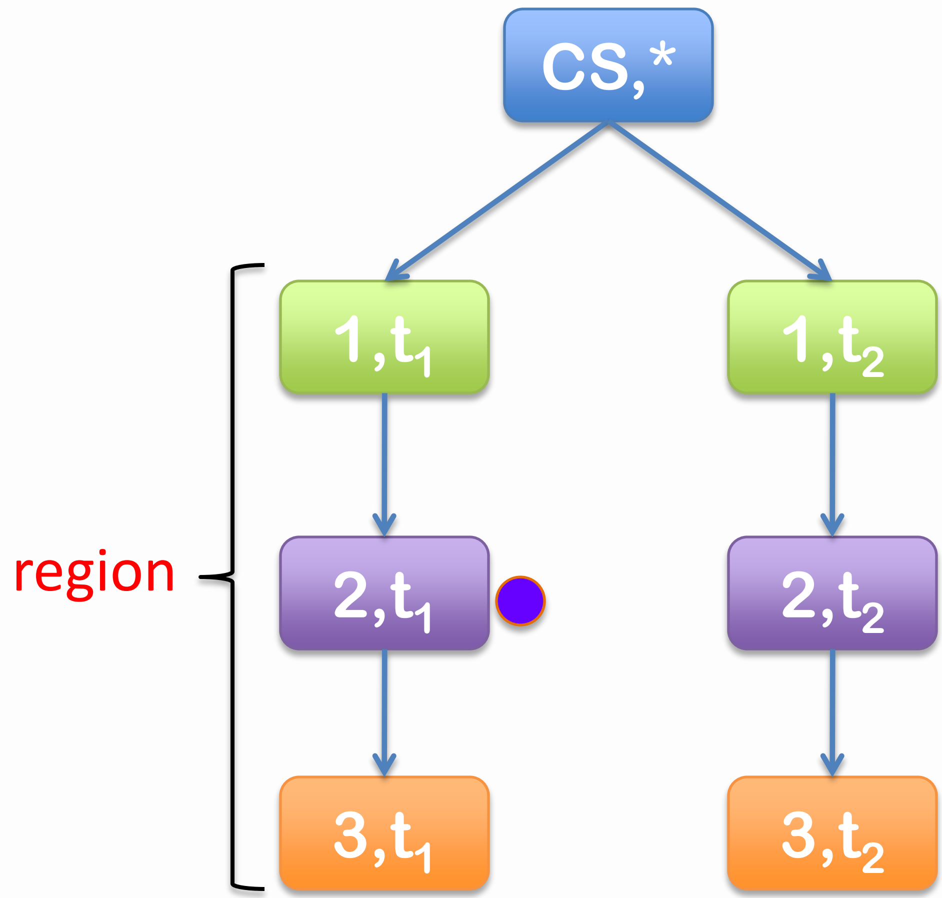

$\mathrm{JOIN}(3,t_1\,,\ 2,t_1) = 2,t_1$

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        }
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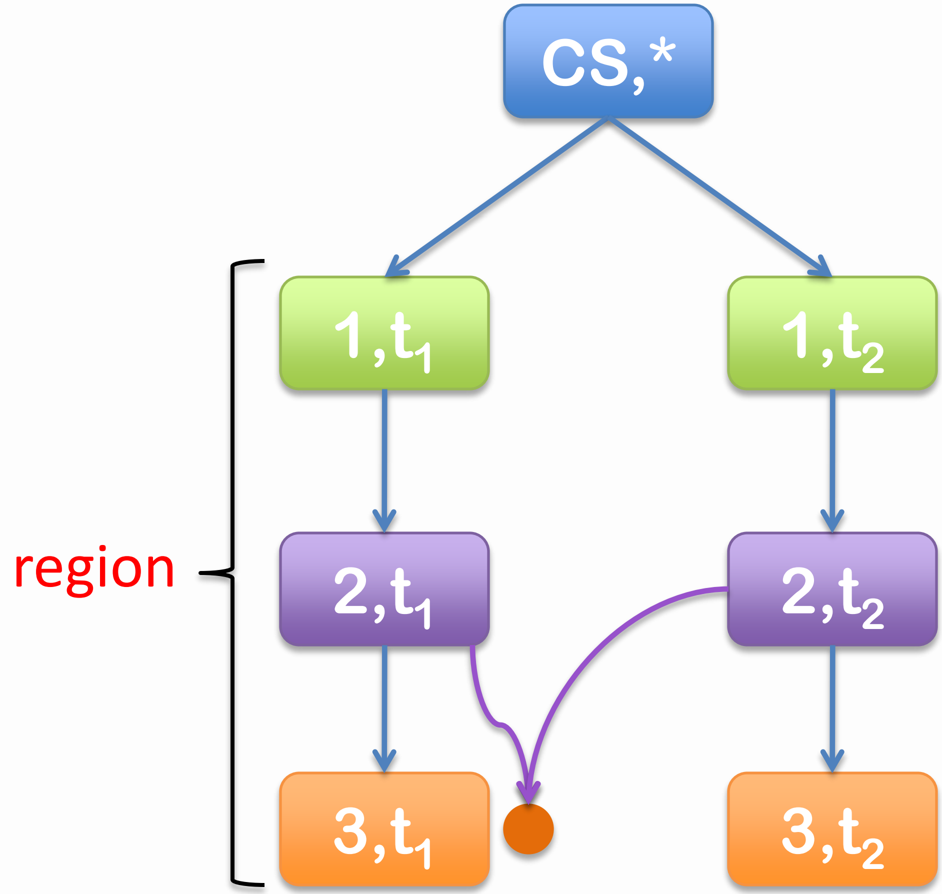

JOIN(2,t_1 , 2,t_2) = CS,*

Region Semilattice

```
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    epoch_start();            epoch #2
    for(    ) {
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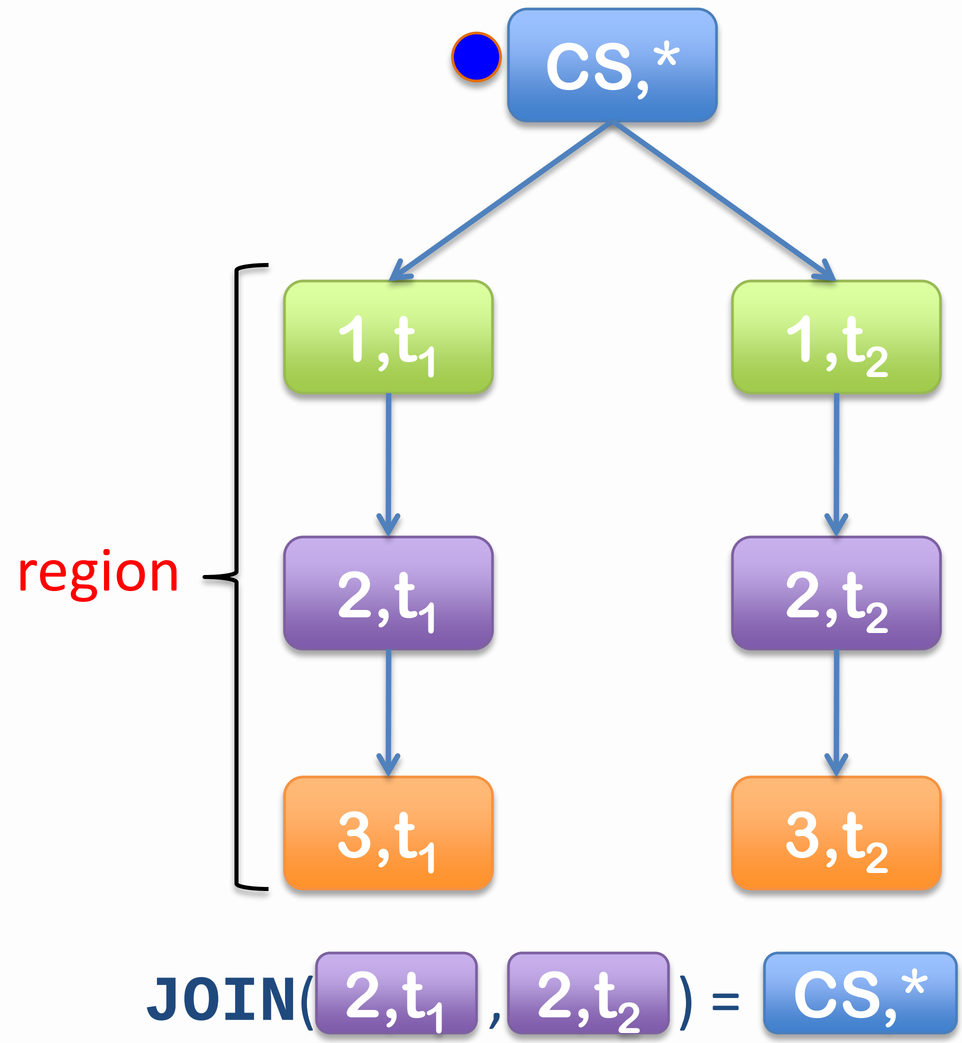

How to Reclaim Regions Correctly?

Object Promotion Algorithm

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Two key tasks:

- What: Identify escaping objects:

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  Tracking of cross-region/space references in write barrier

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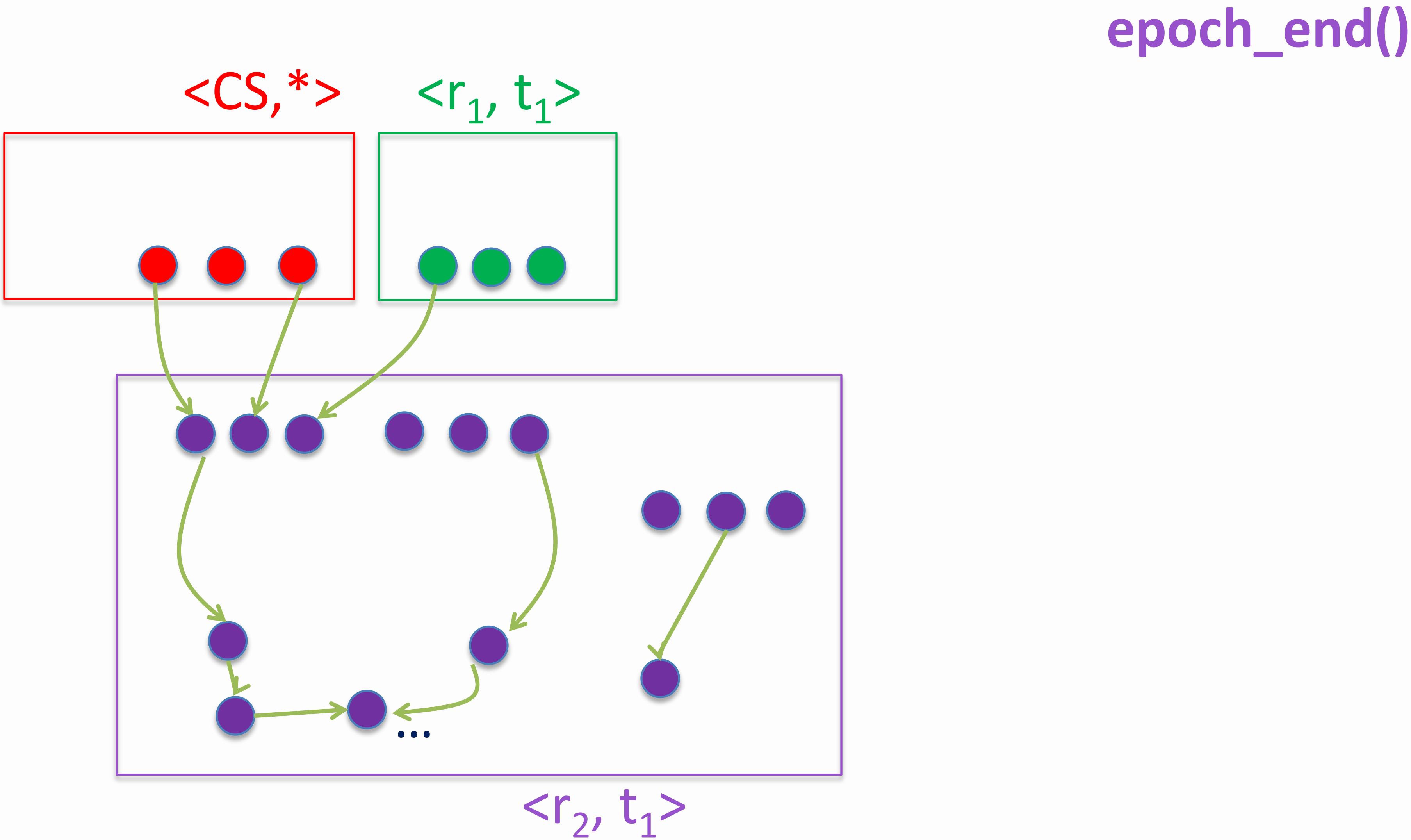
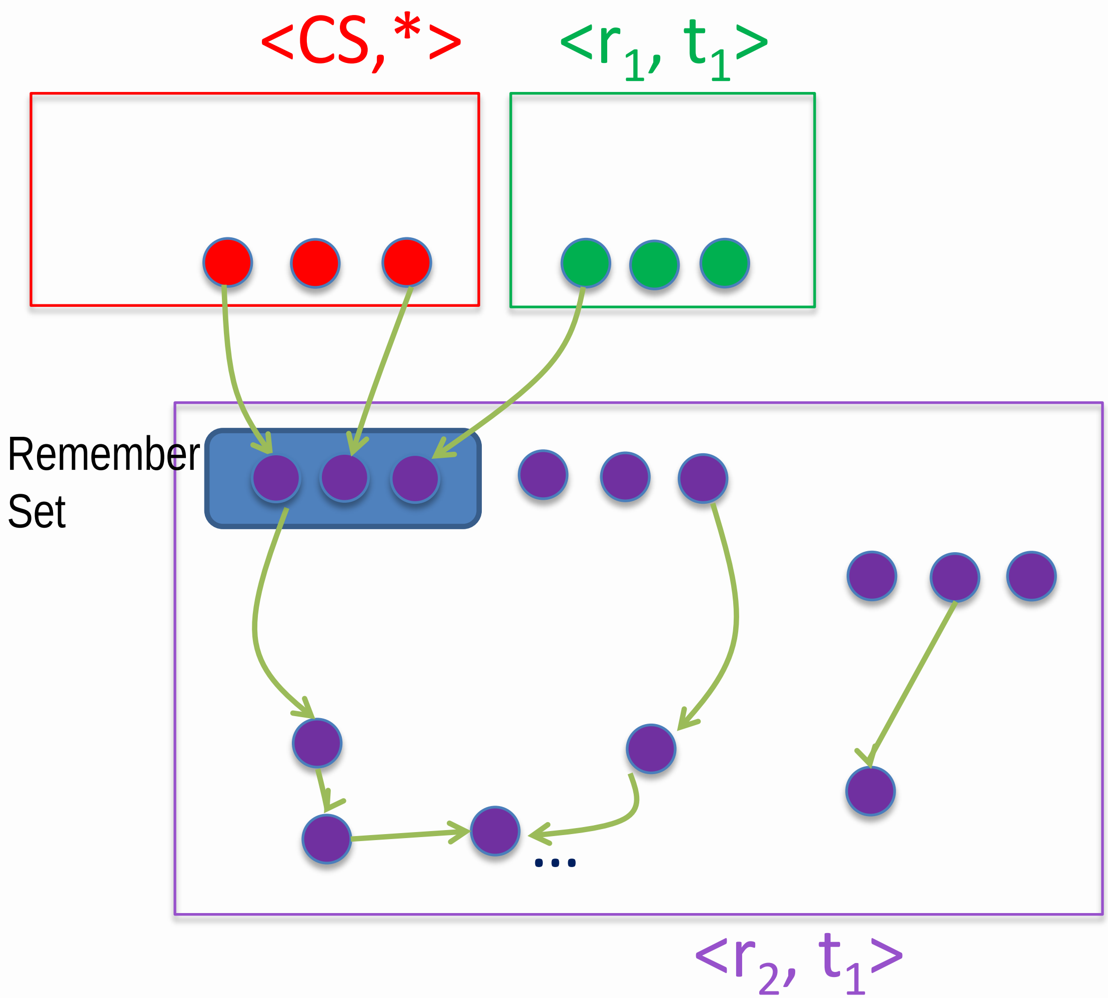
  Query region semilattice

Region Deallocation



Region Deallocation

epoch_end()



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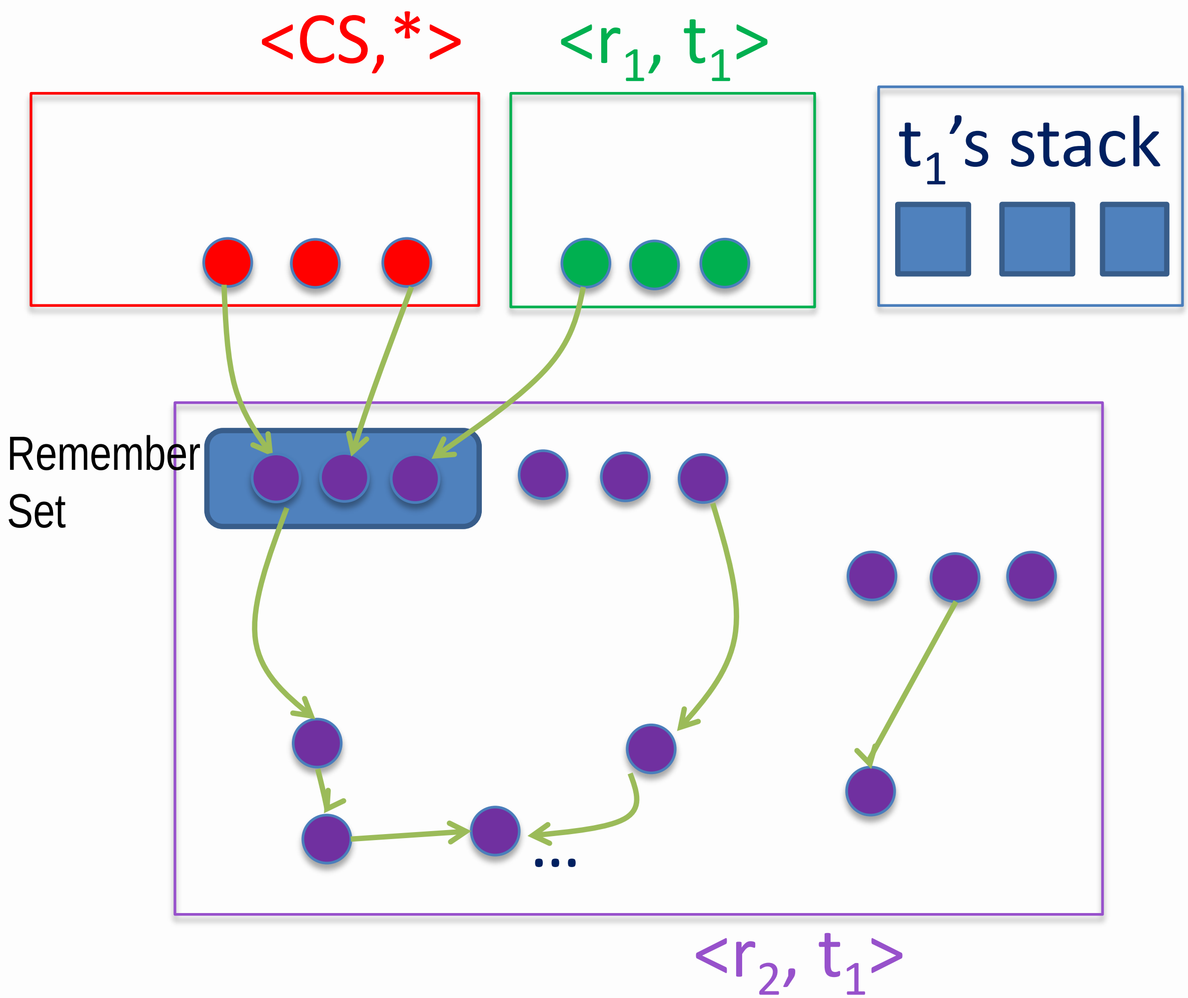

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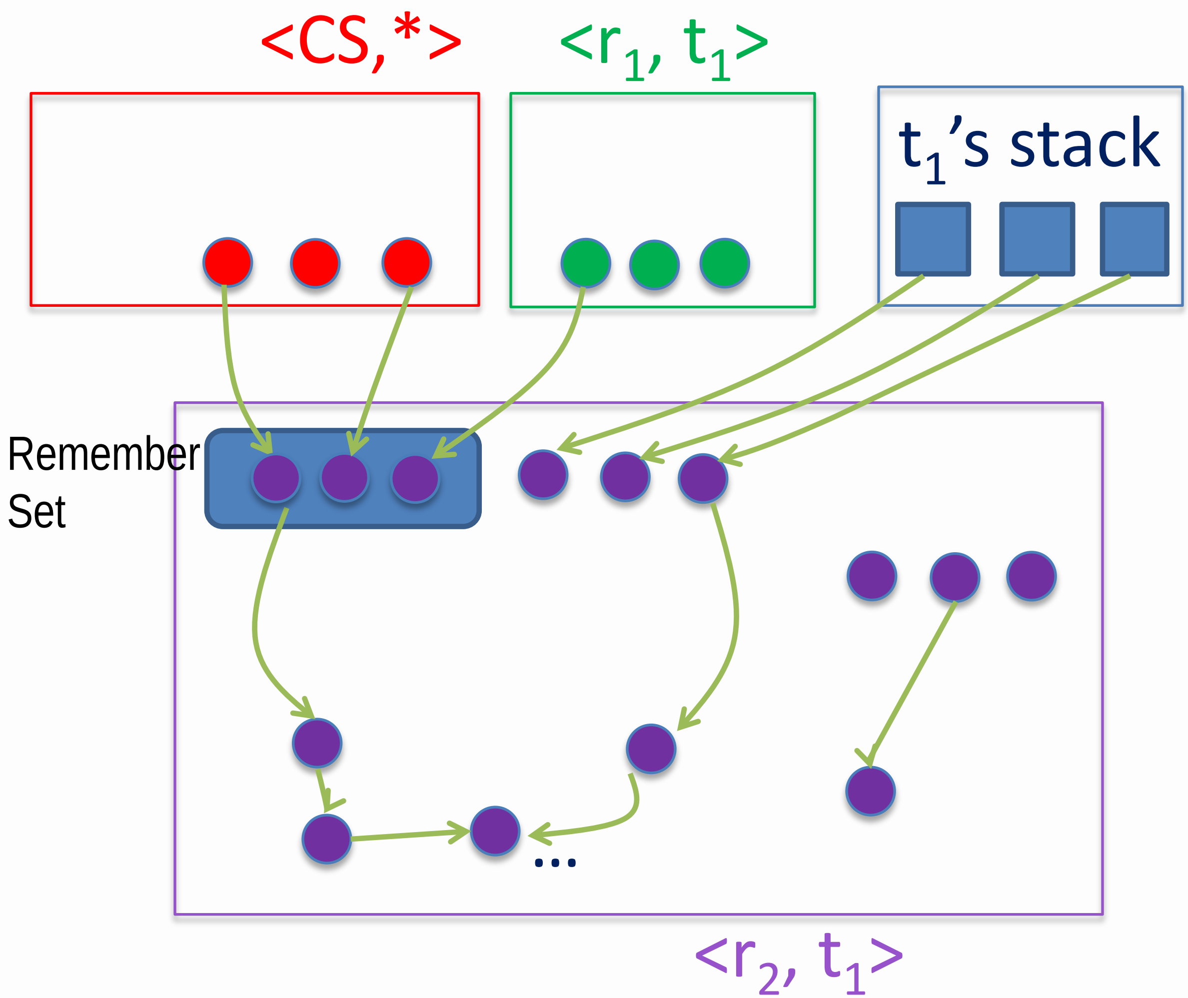

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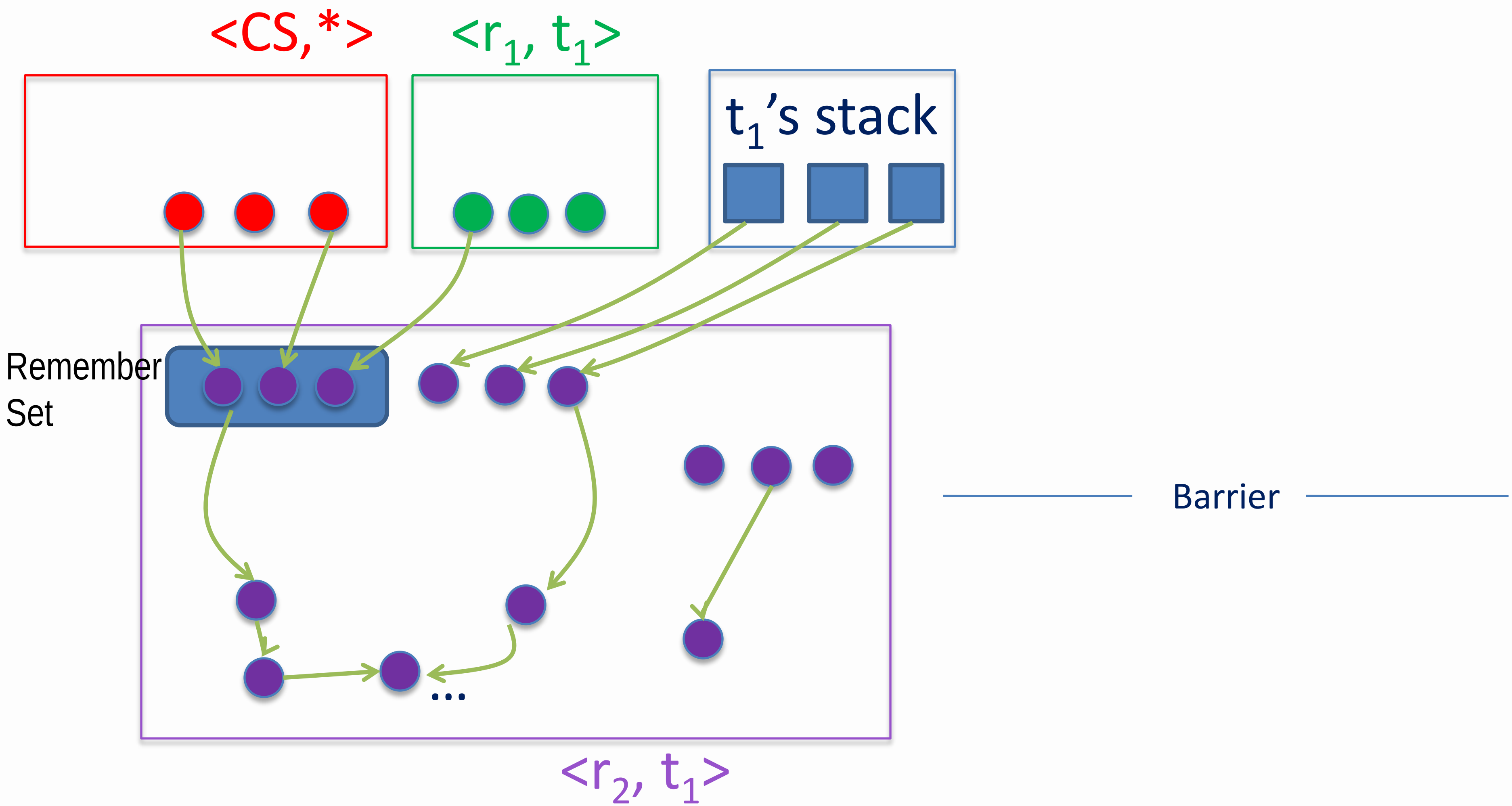

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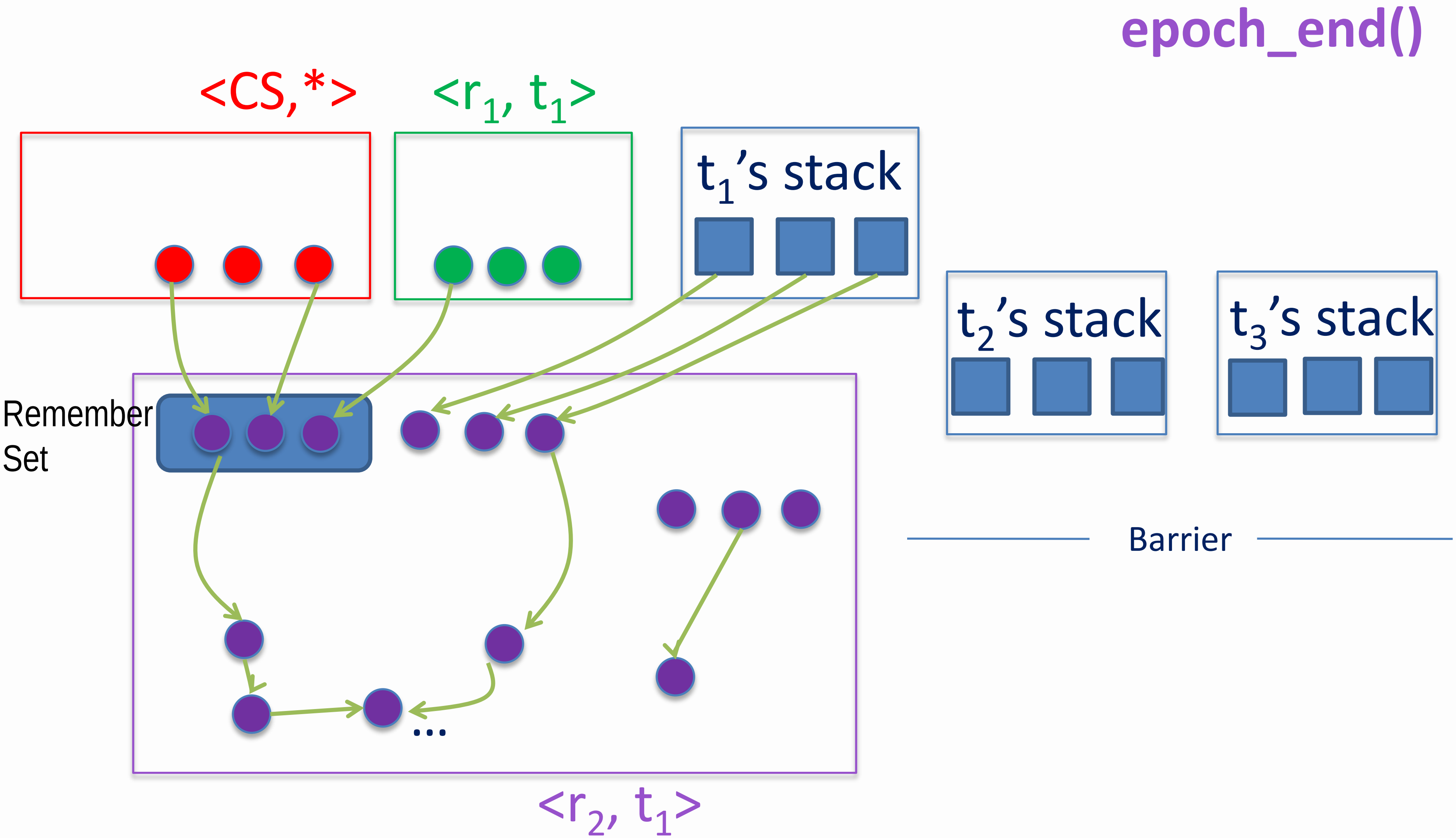

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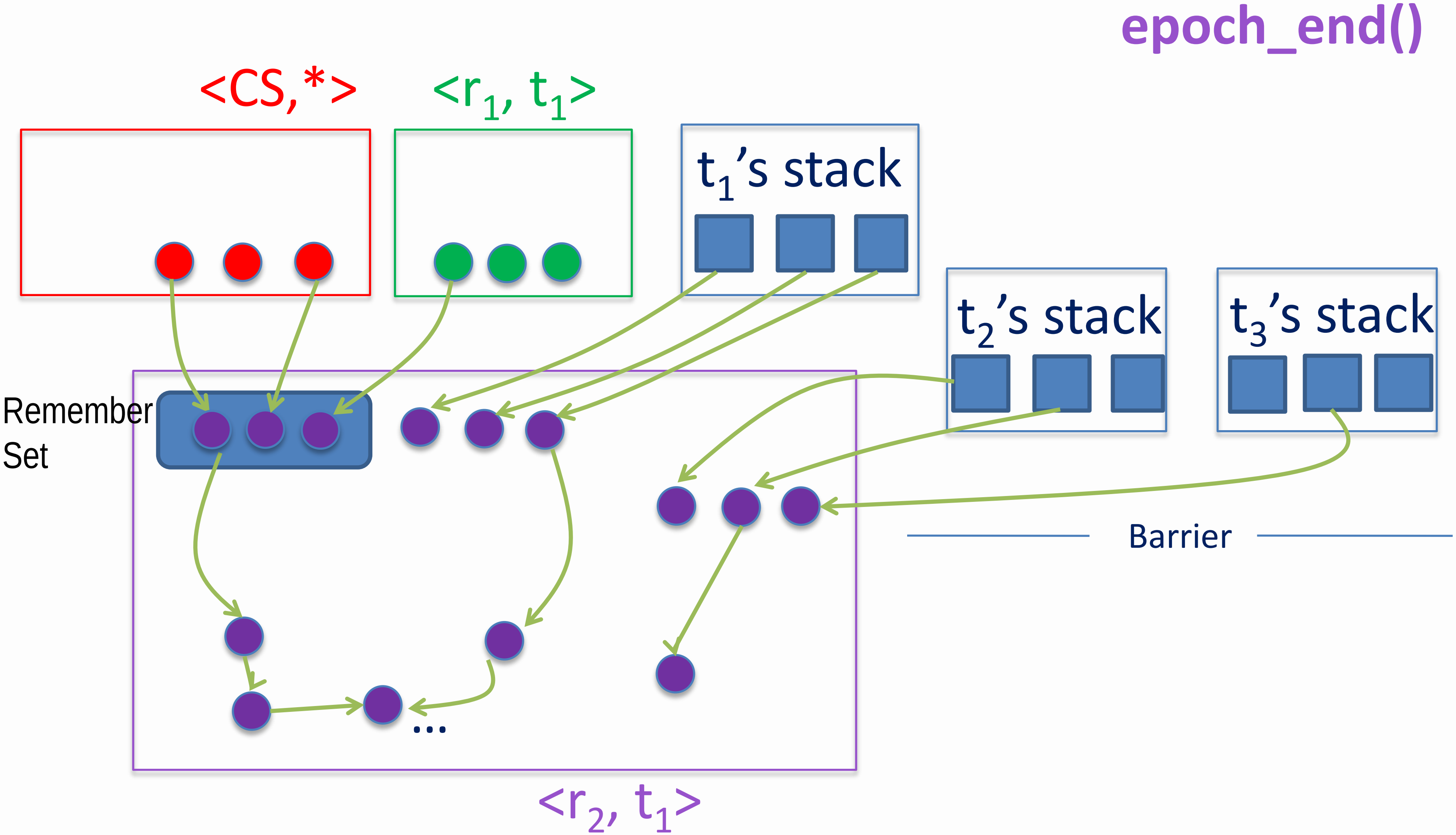

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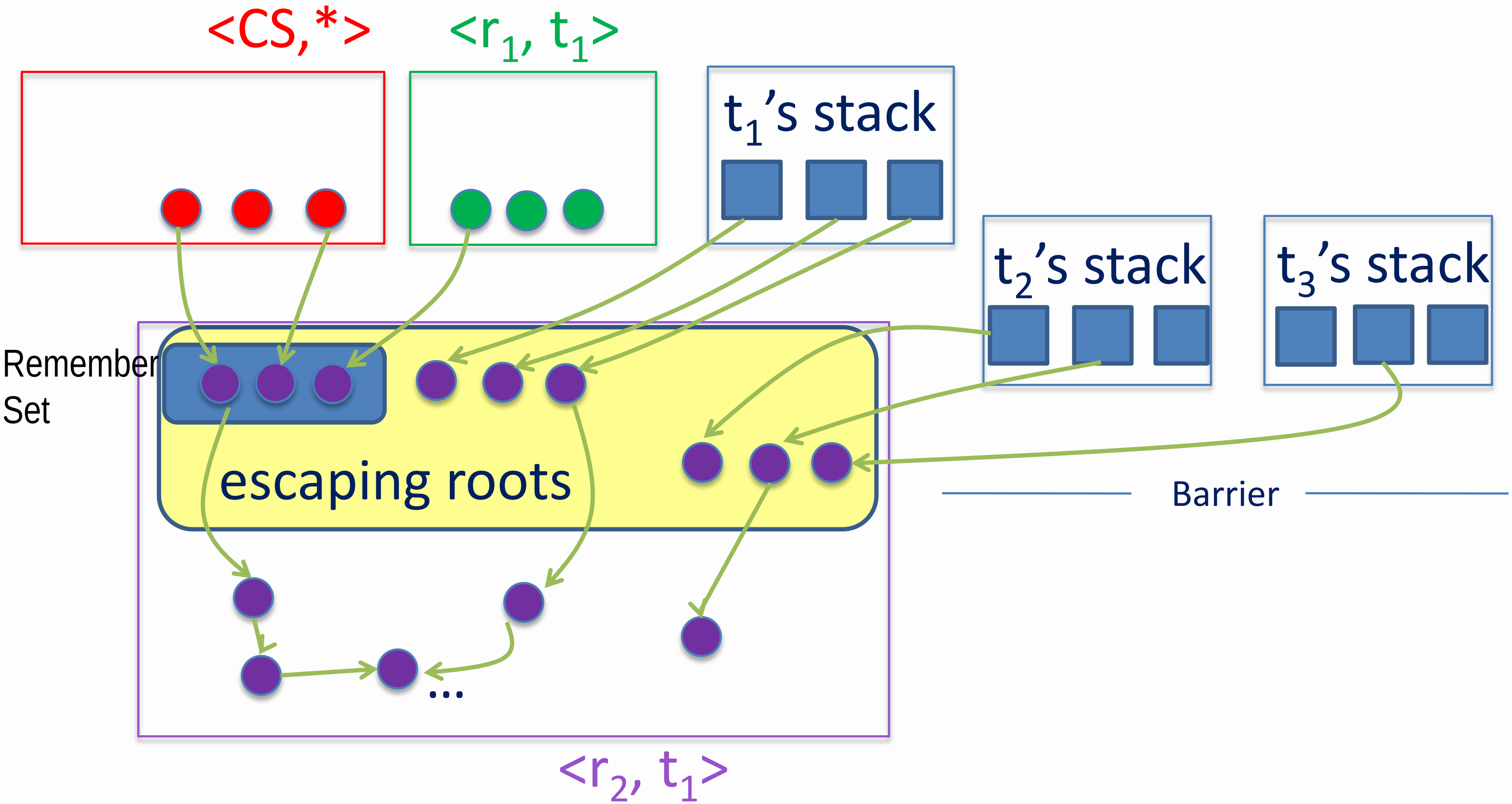

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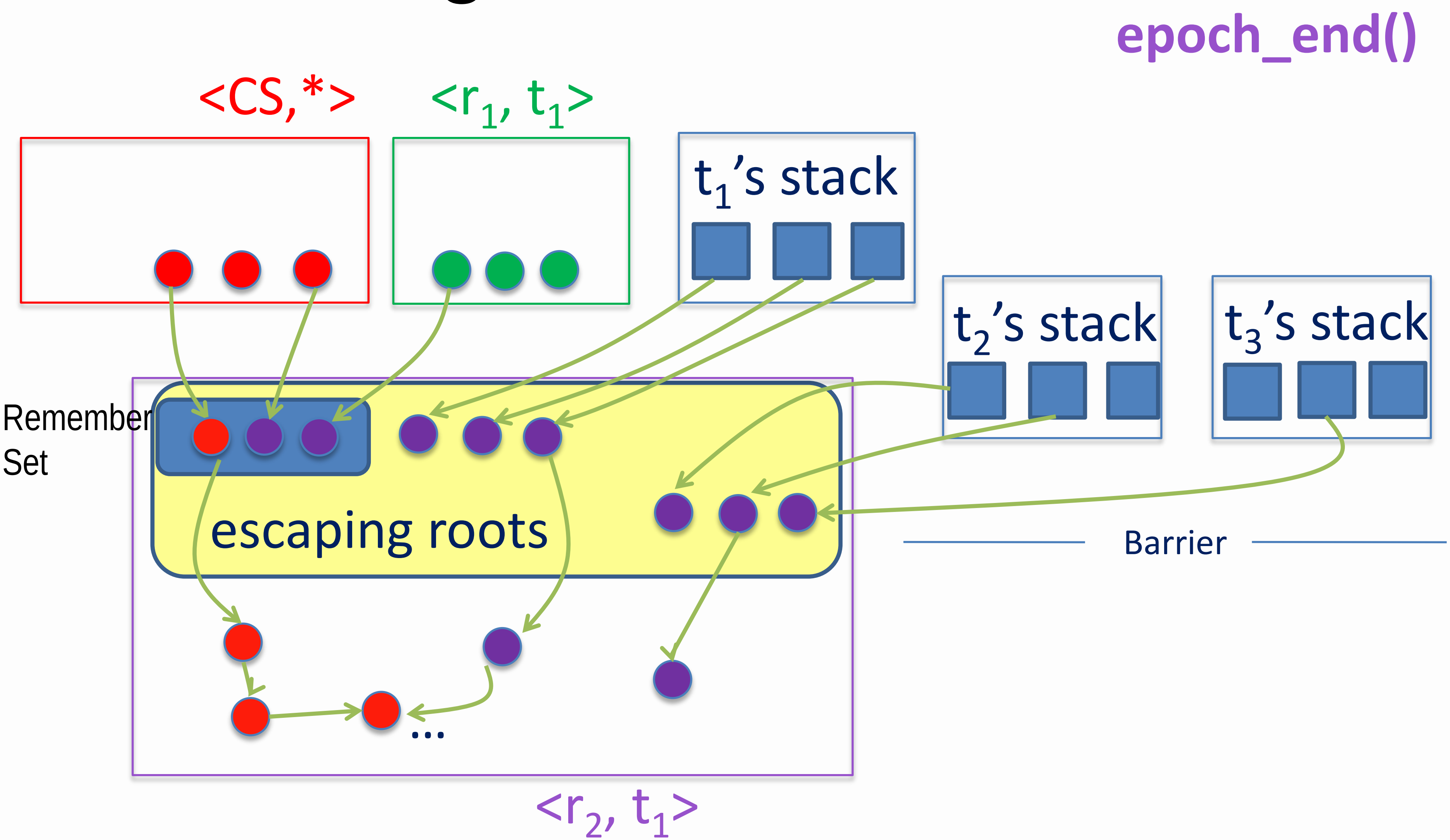
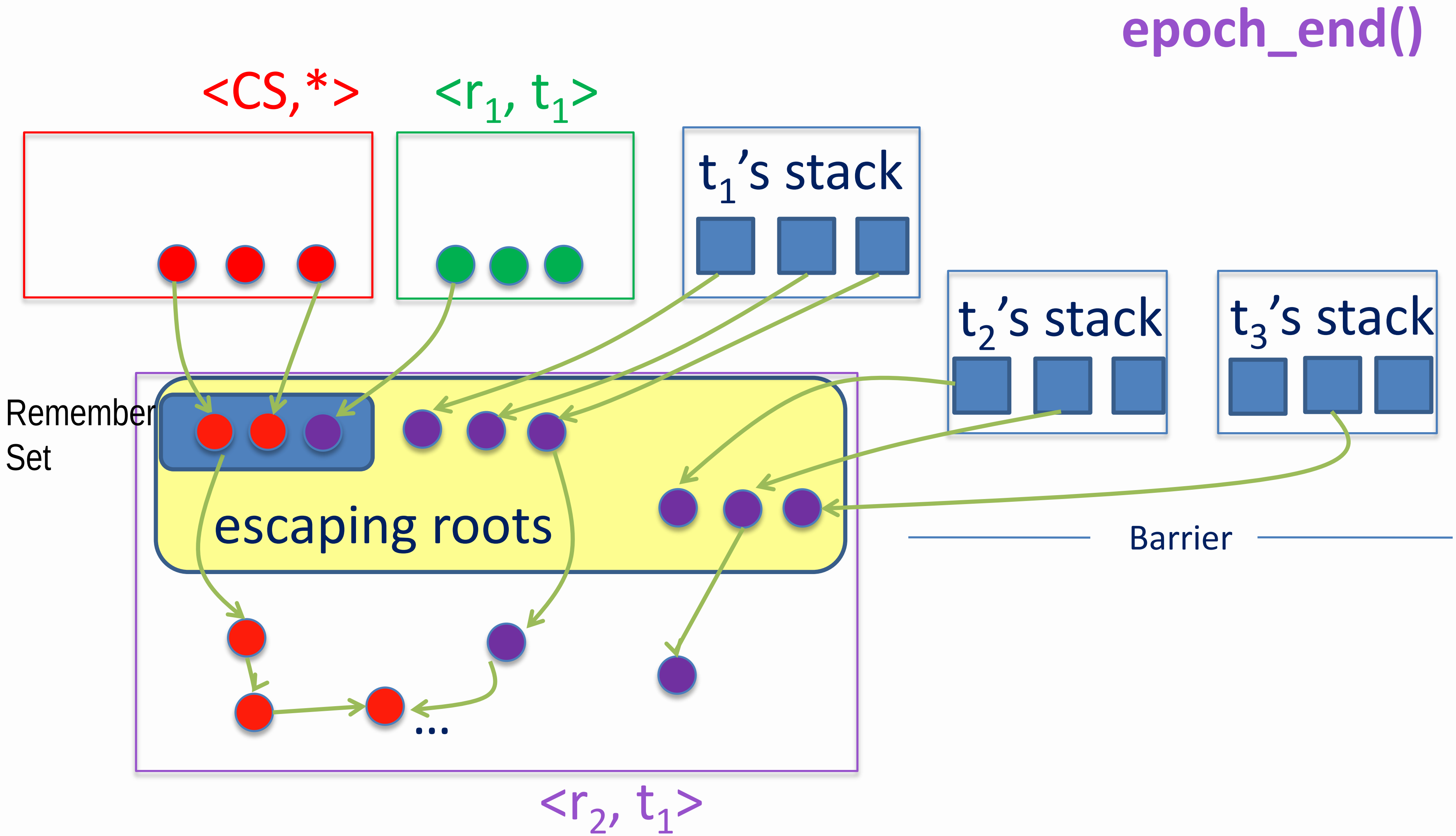


Region Deallocation



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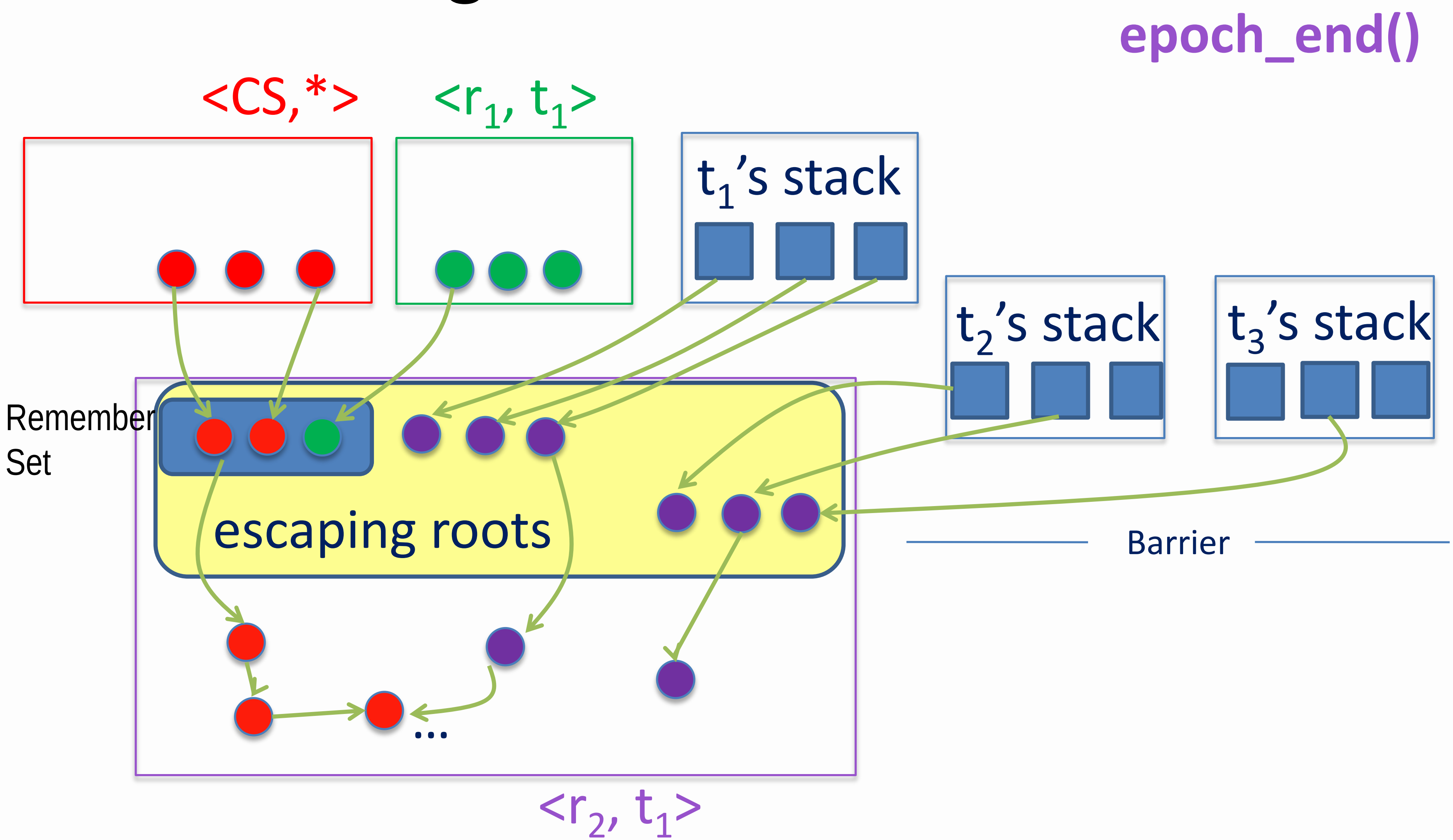

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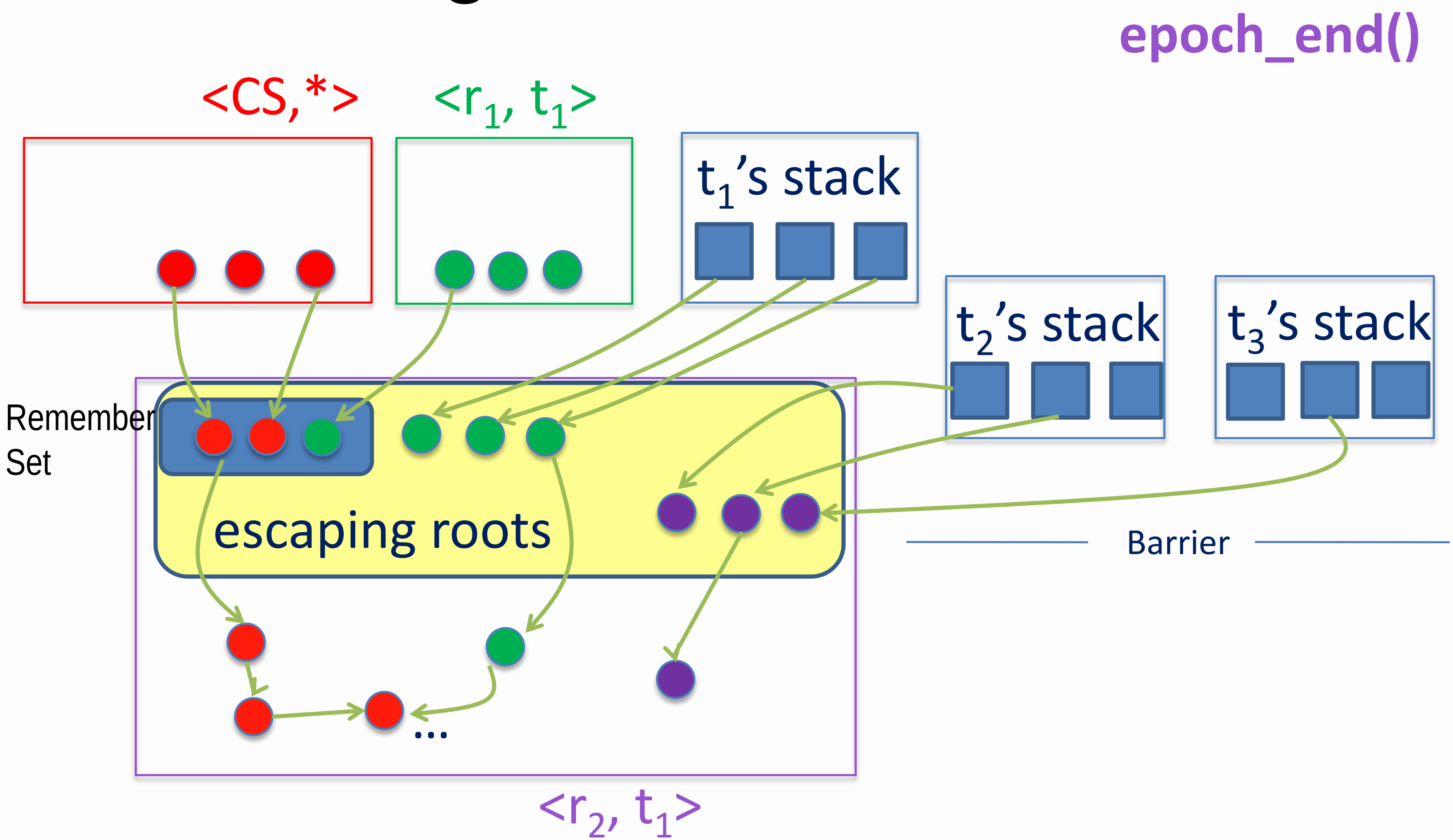

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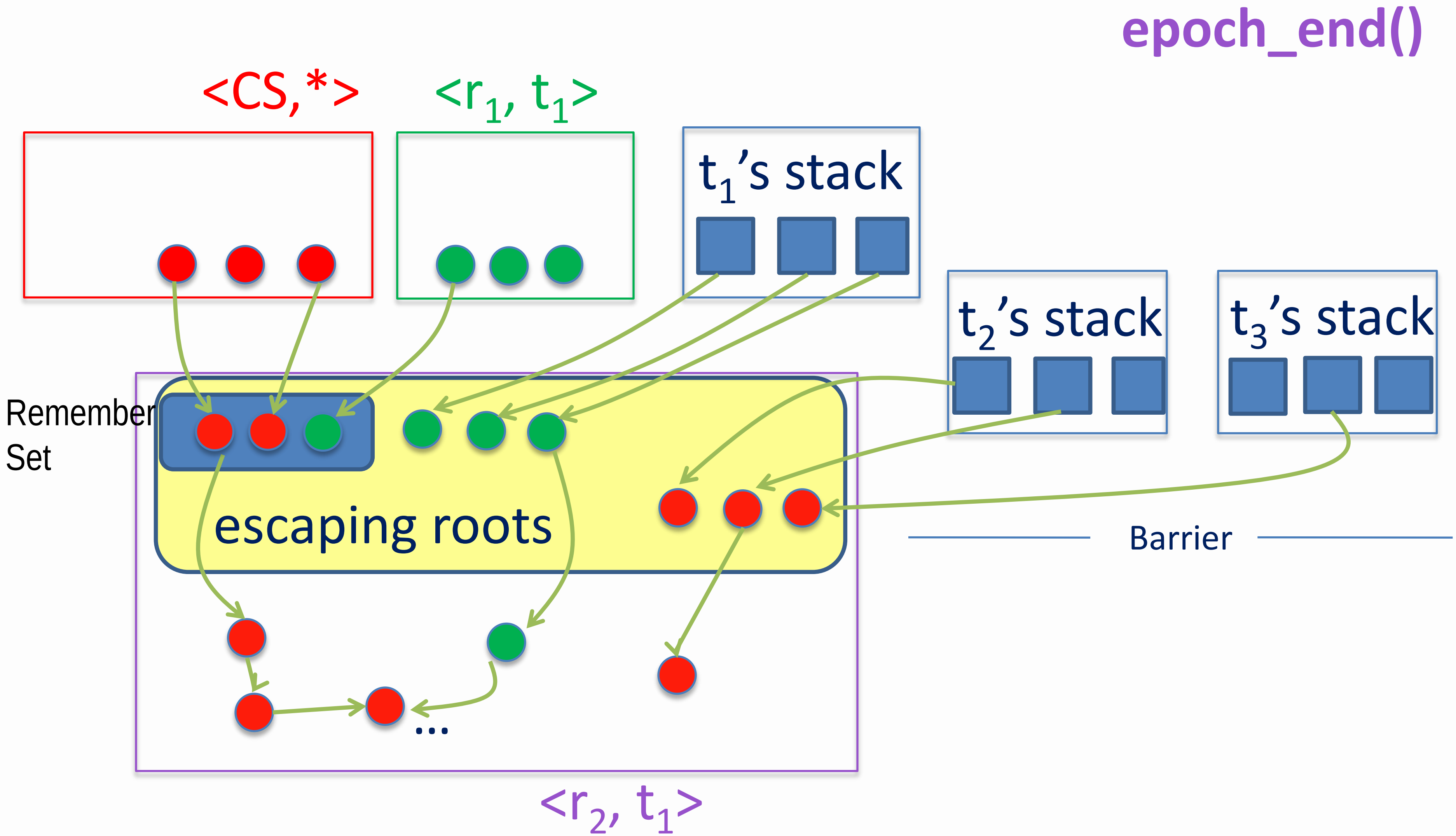

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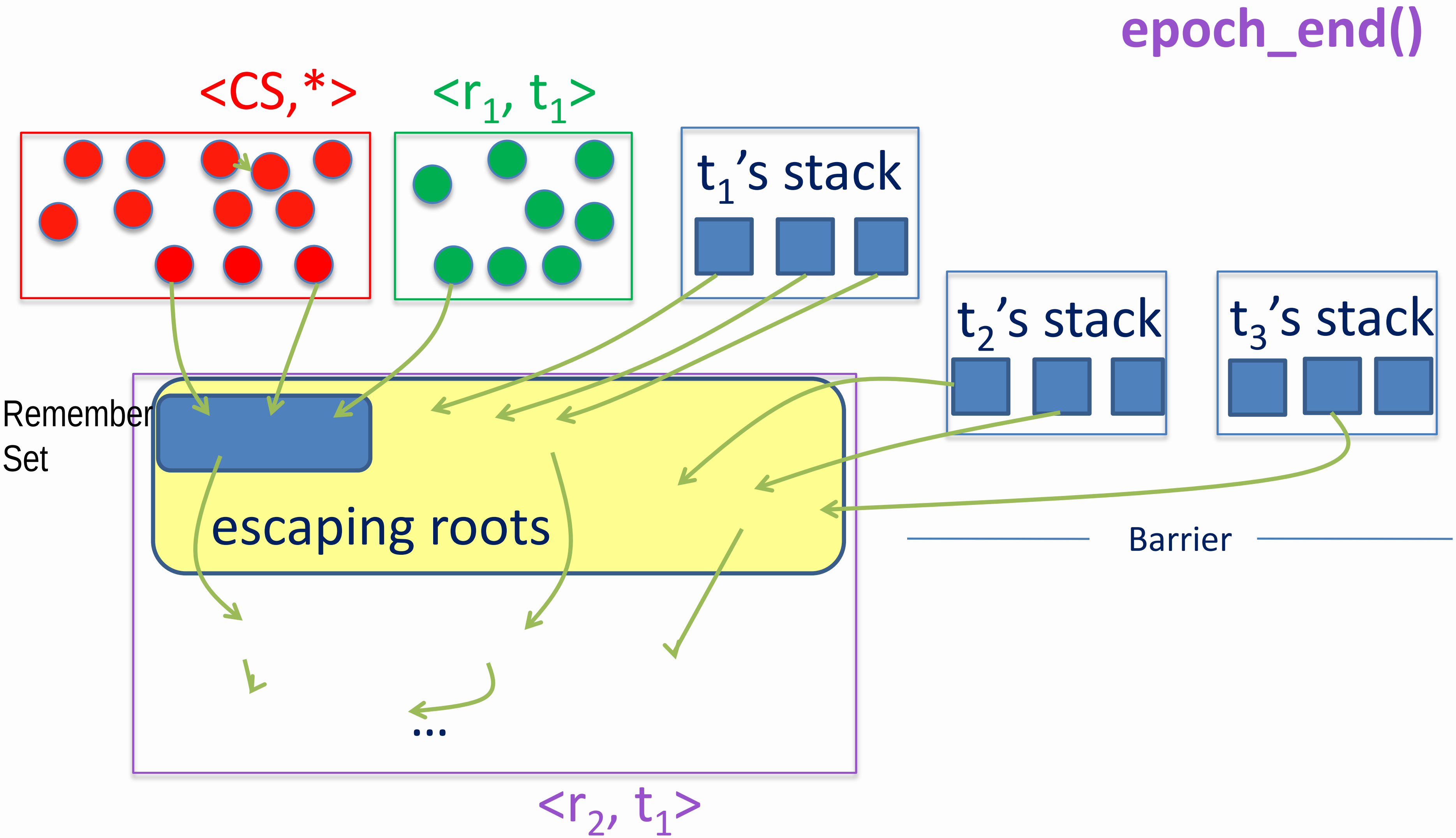

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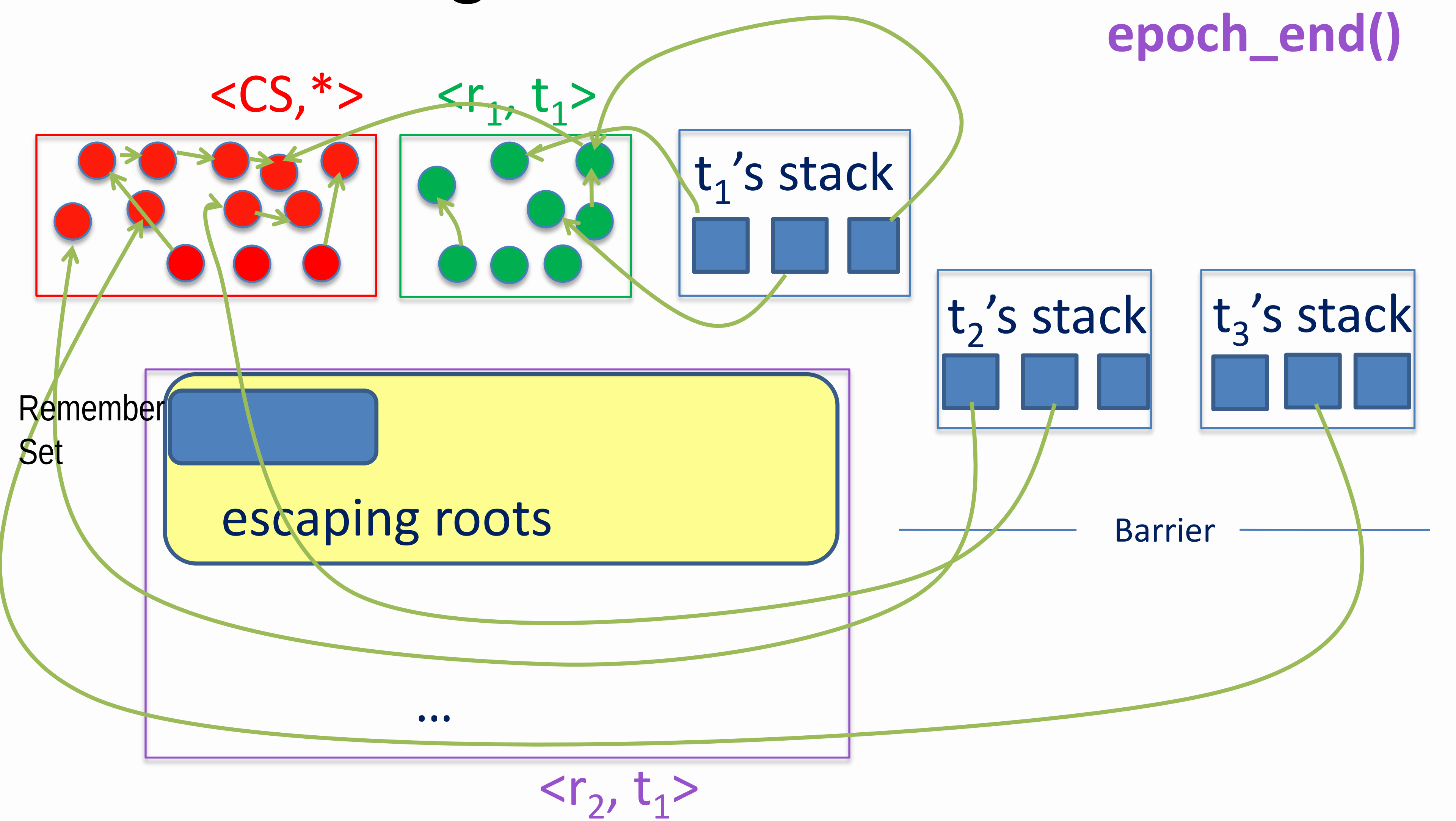
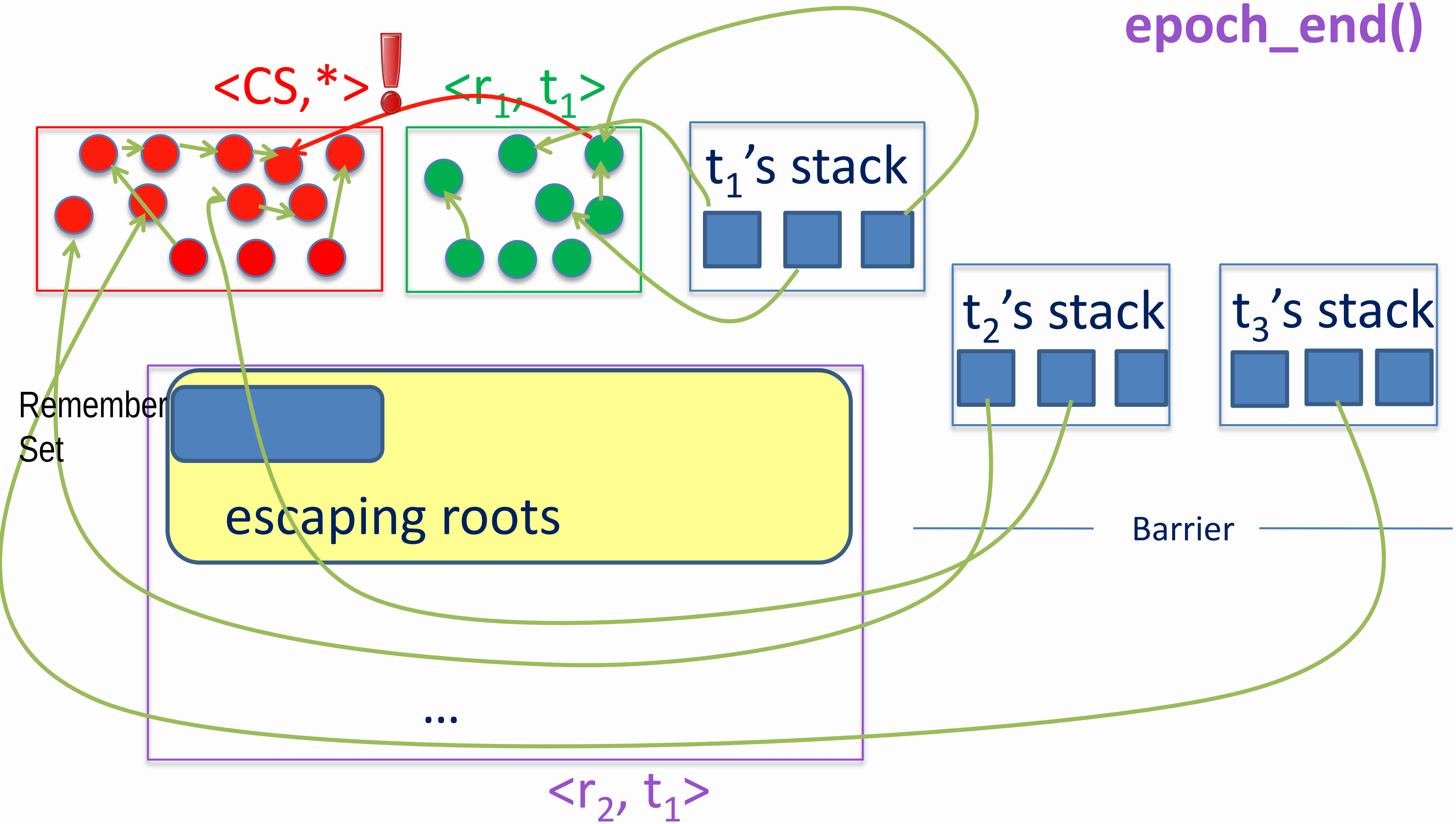
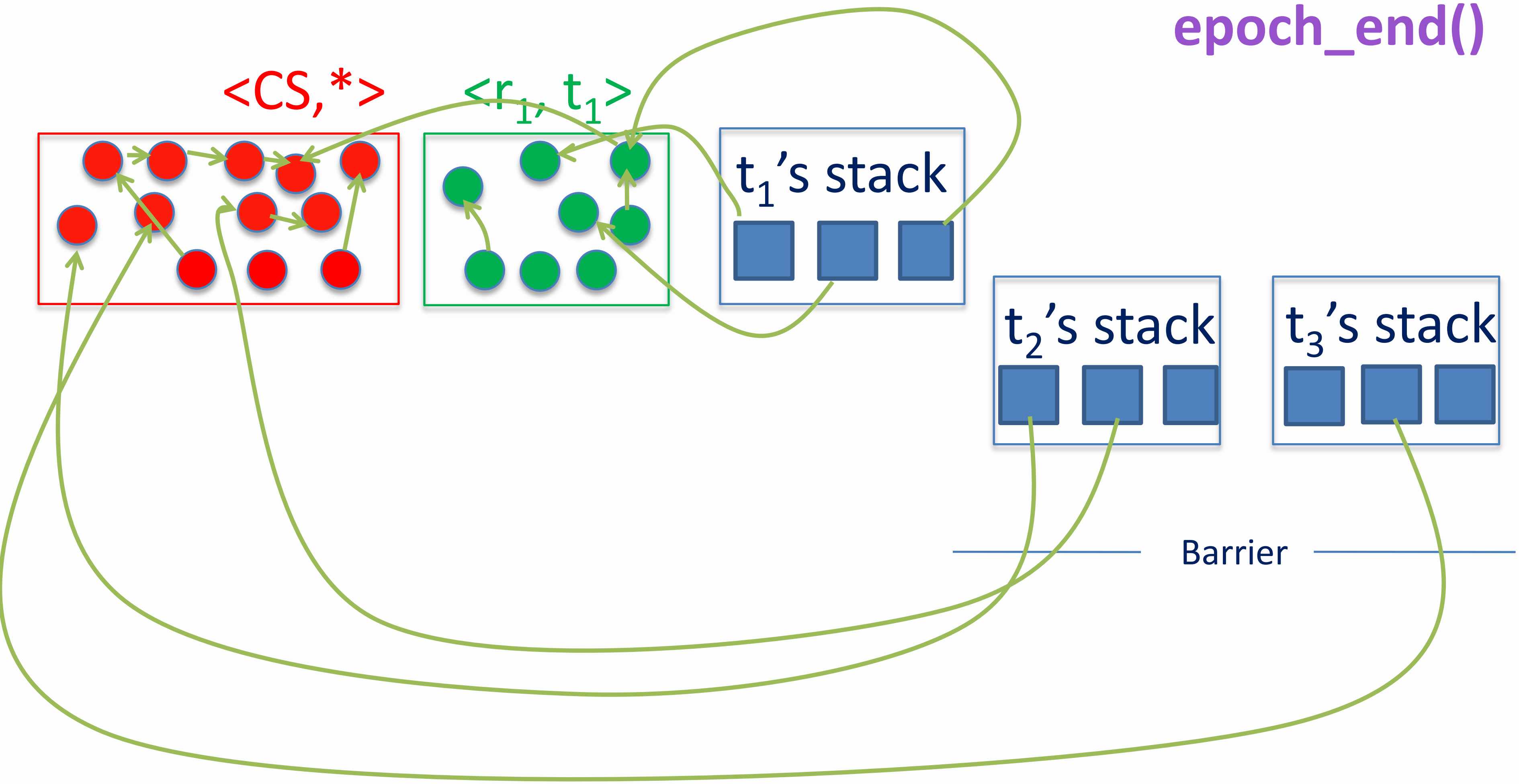


Region Deallocation

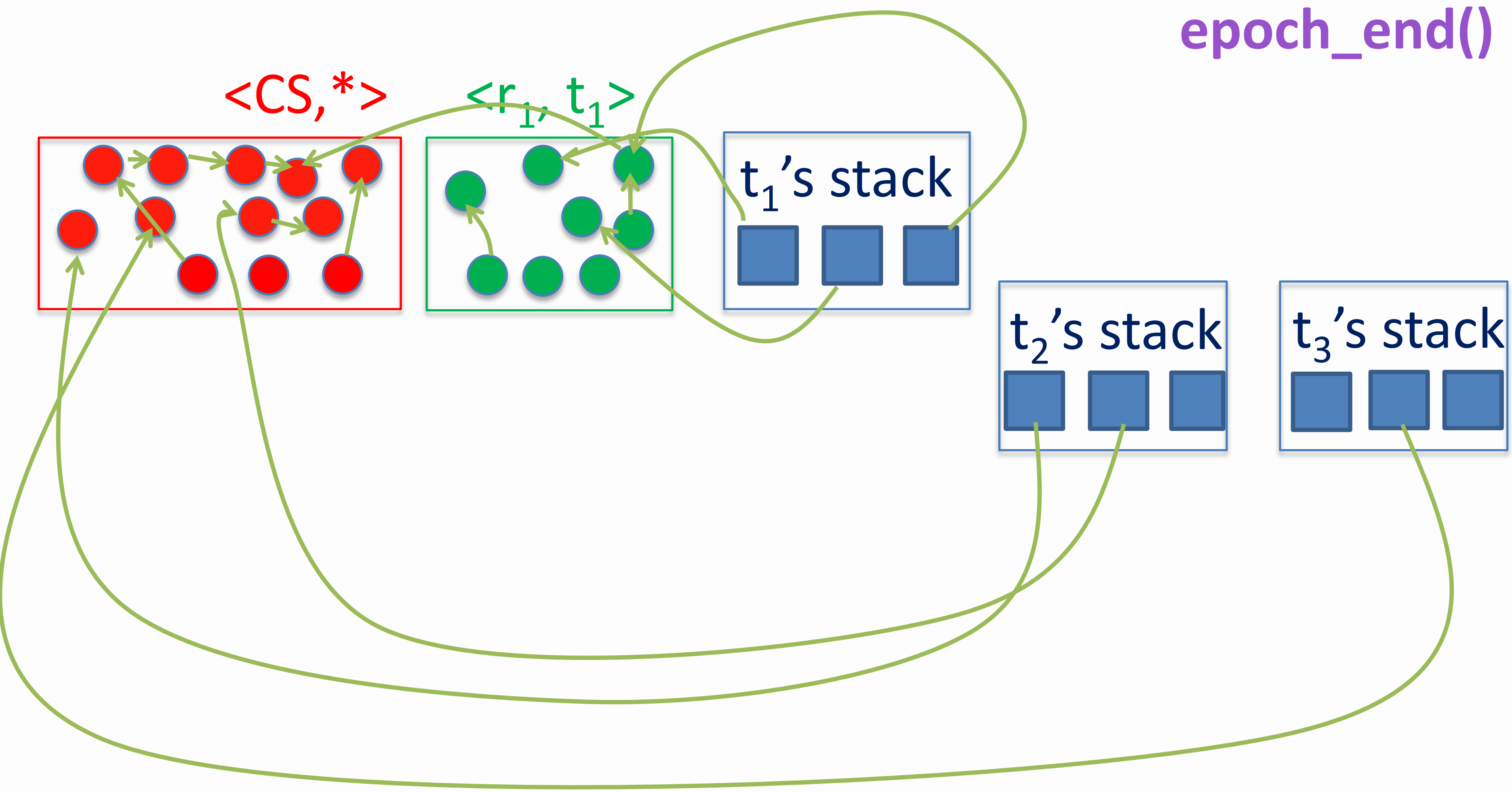
epoch_end()



Region Deallocation

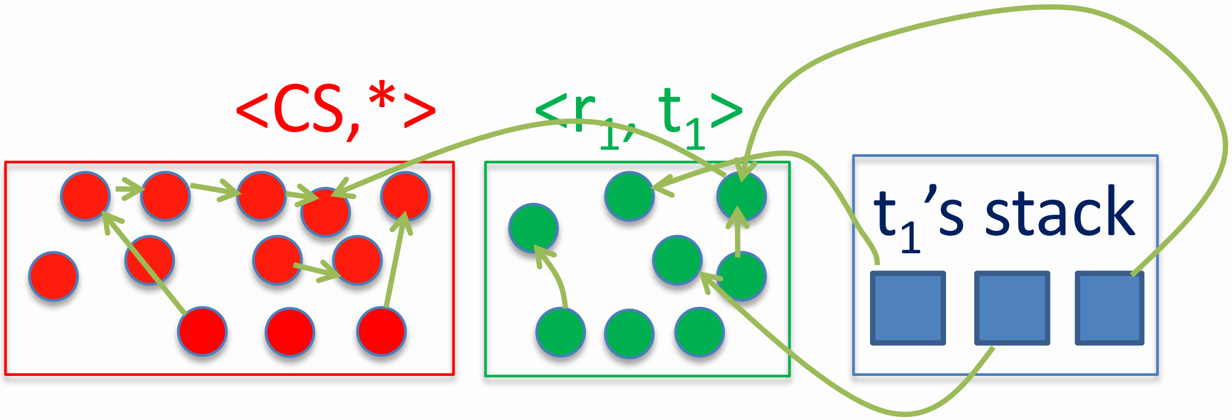


Region Deallocation

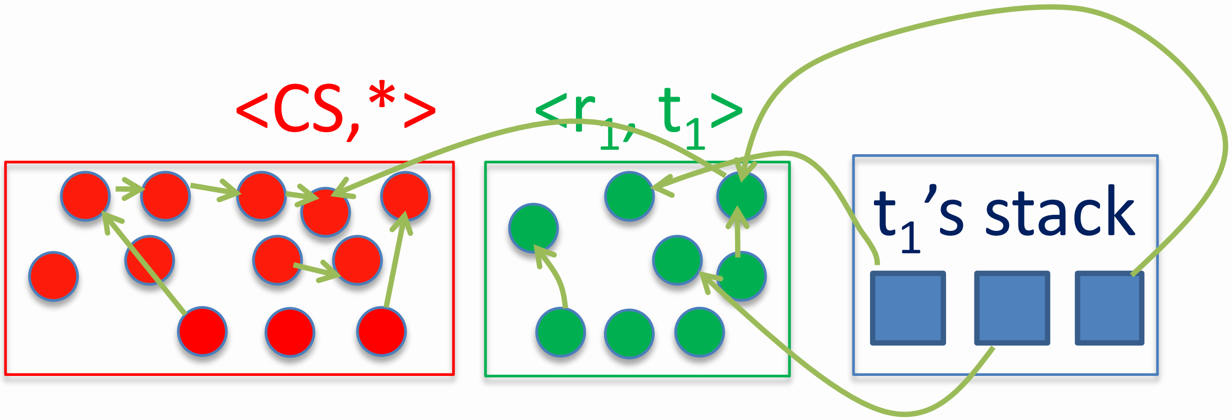


Region Deallocation

epoch_end()



Region Deallocation

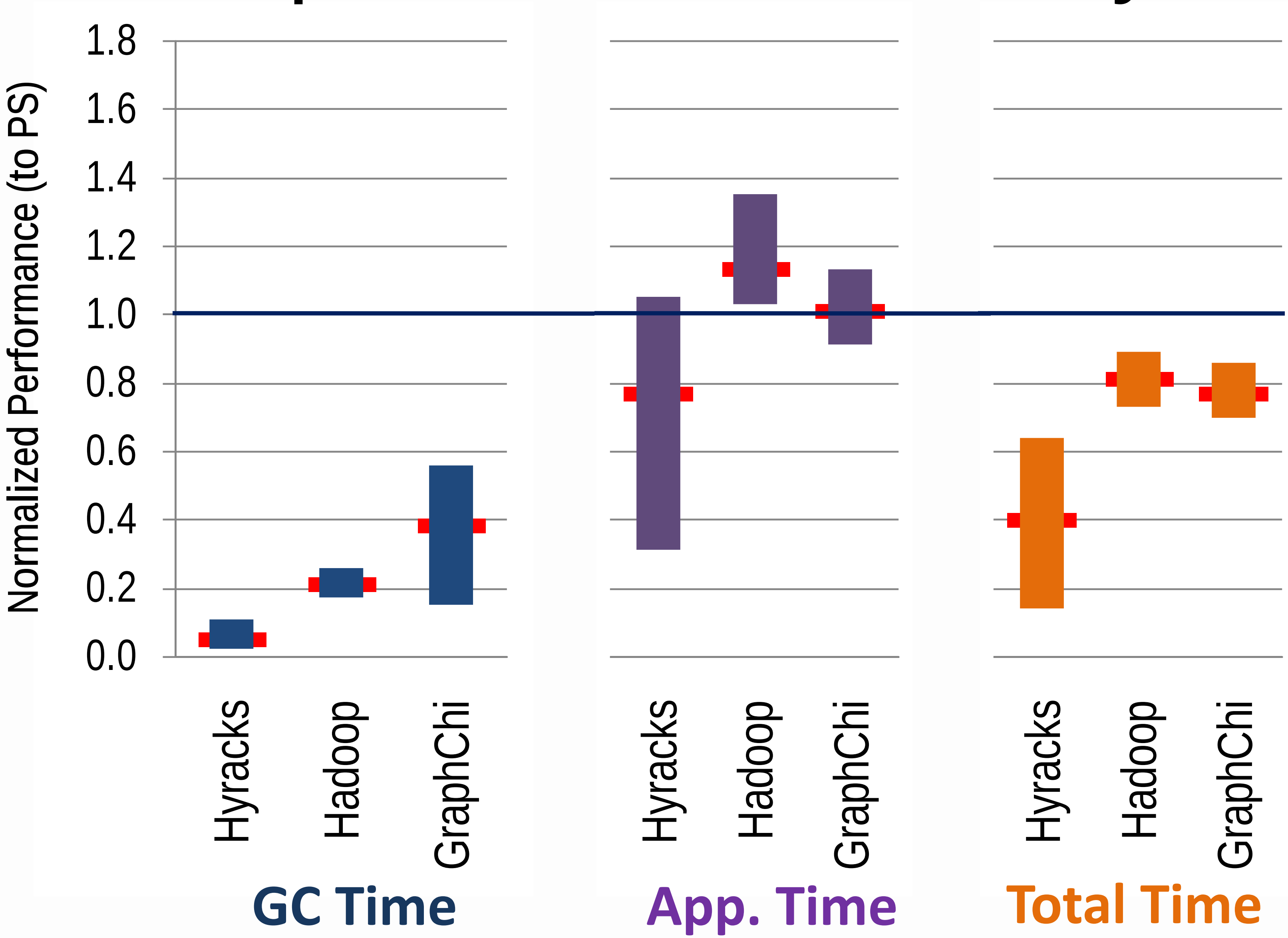


Evaluations

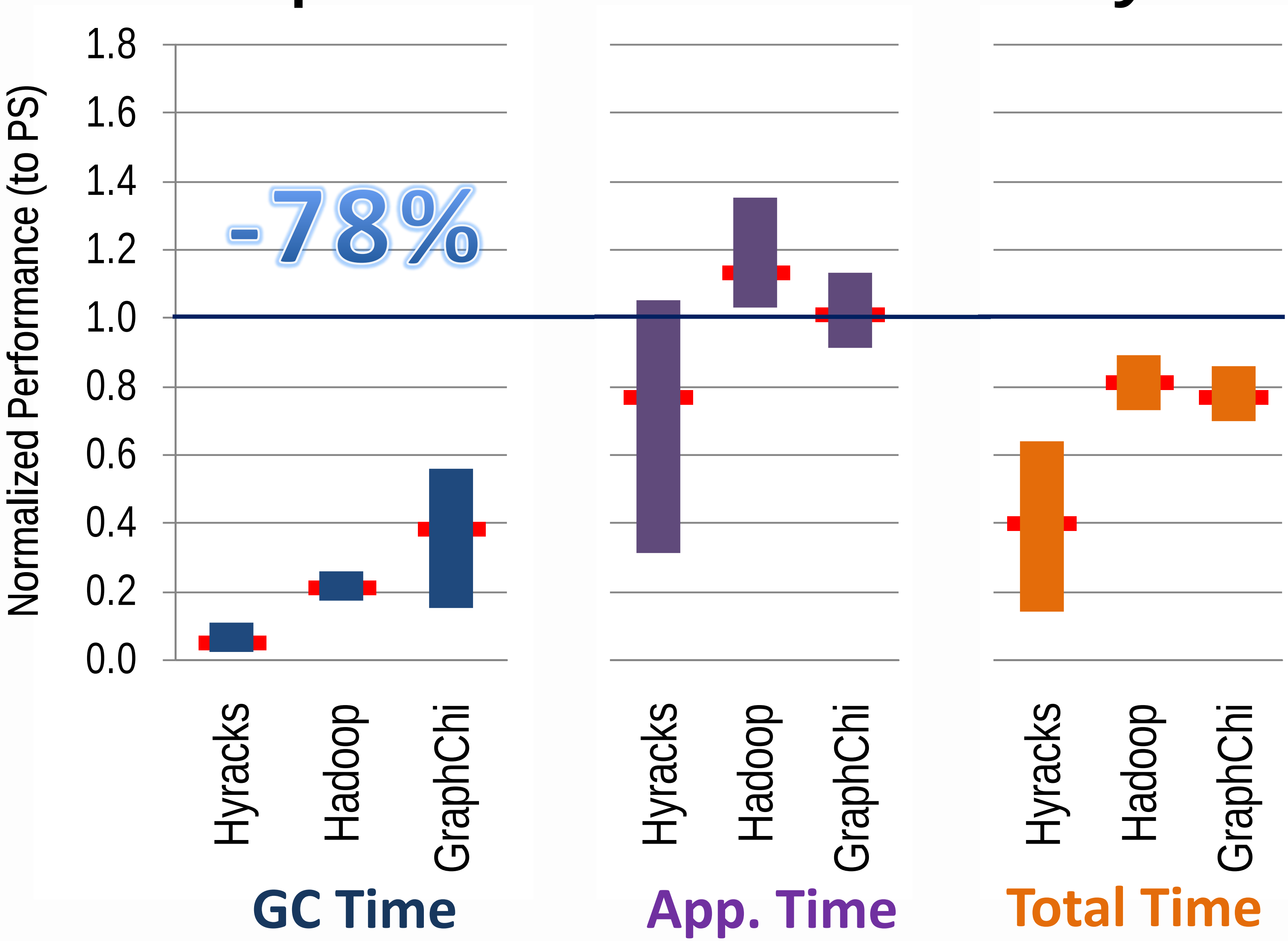
3 real-world systems, 9 applications:

- 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

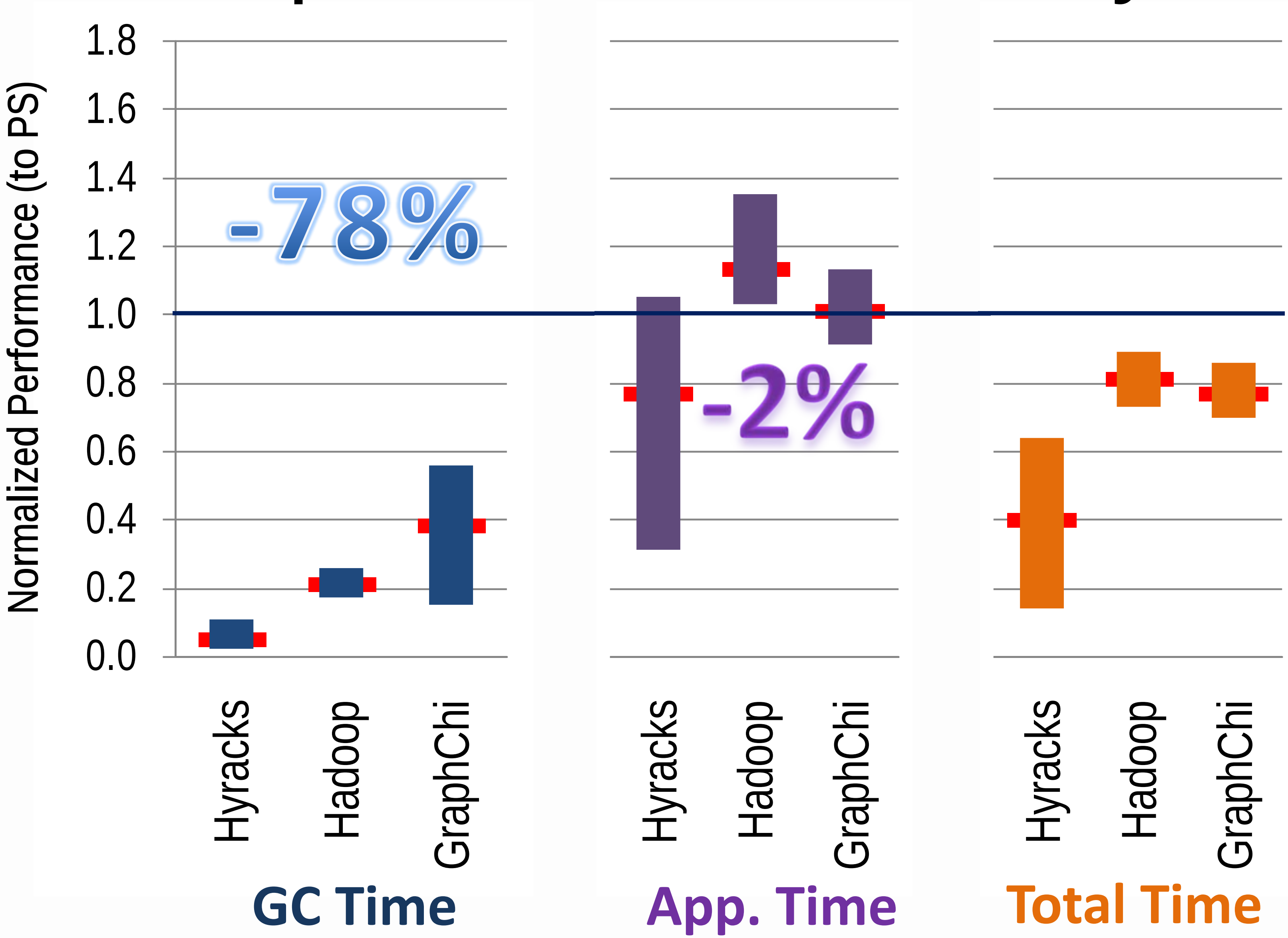
Improvement Summary



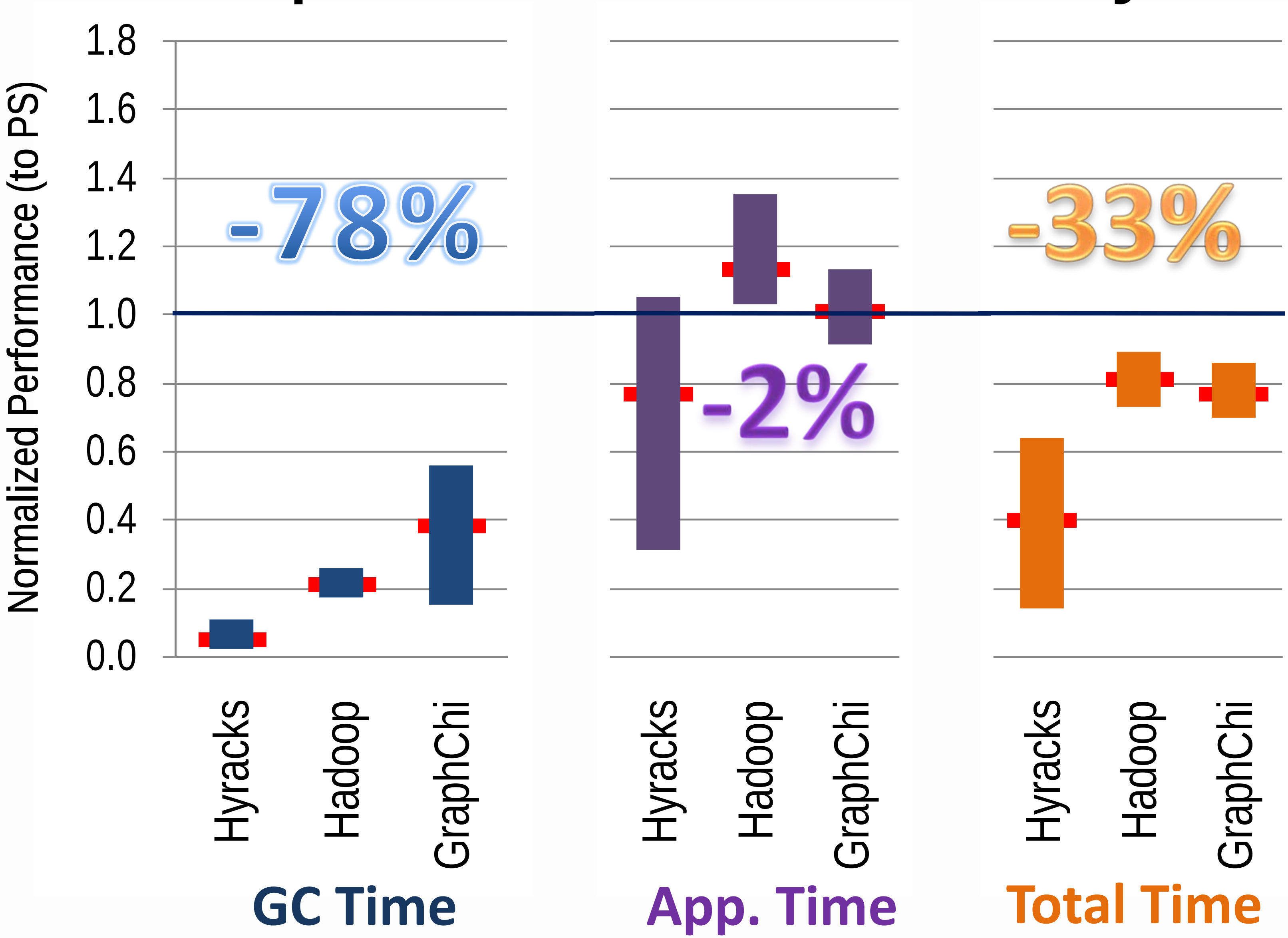
Improvement Summary



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!