Java Memory Management

Märt Bakhoff

Java Fundamentals

01.11.2016

Agenda

- JVM memory
- Reference objects
- Monitoring
- Garbage collectors
  - ParallelGC
  - G1GC

JVM memory

- Heap (user objects)
- Non-heap
  - Stack (per thread: call stack, local variables)
  - Metaspace (class metadata)
  - Direct Byte Buffers
  - Native stuff (JNI, Java internals)

Method call	Locals
printSubstring	s -> 0x1 ss -> 0x33 offset = 6
main	args -> 0x27 info -> 0x1

Address	Value
0x1	“luke ...”
0x27	String[0]
0x33	“i’m your ...”

```java
public class Example {

  public static void main(String[] args) {
    String info = new String("luke, i'm your father");
    printSubstring(info, 6);
  }

  private static void printSubstring(String s, int offset) {
    String ss = s.substring(offset);
    System.out.println(ss);
  }
}
```

Tuning options

- Ergonomics!
- -Xms512M (initial heap size)
- -Xmx2G (max heap size)
- -Xss2M (max stack size, per thread)
- java [options] classname [args]
- All options at
  https://docs.oracle.com/javase/8/docs/technotes/tools/unix/java.html
  https://docs.oracle.com/javase/8/docs/technotes/guides/vm/gctuning/

PermGen

- Java 8+: class metadata lives in Metaspace
- -XX:MaxMetaspaceSize=size (default: unlimited)
- Older versions: classes live in PermGen, PermGen is a special part of the heap
- OutOfMemoryError: PermGen space
- -XX:MaxPermSize=size (default: limited)

Generating garbage

- Primitives in the stack, objects in the heap
- Using *new* allocates objects in the heap
- When and how are objects “deleted” and heap space freed up?

Garbage collection (GC)

- Sort garbage / live objects
- Reclaims heap space
- Fully automatic, no manual deallocation
  Java GC vs C++ new/delete
- Different GC algorithms exist

GC advantages

- Avoid bugs
  - forgetting to free the memory
  - double freeing memory
  - using already freed memory
- Java specific
  - No direct memory access
  - Can't accidentally overwrite unrelated memory

GC disadvantages

- Consumes resources
- Automatic, no manual control
- Unpredictable stalls
- Harder to understand

How does it work?

- Basic principle
  - Find referenced objects
  - Everything else is garbage
- Reachability (GC roots)
  - Classes loaded by system classloader (static fields!)
  - Stack locals (local variables, parameters)
  - Active threads
  - JNI References

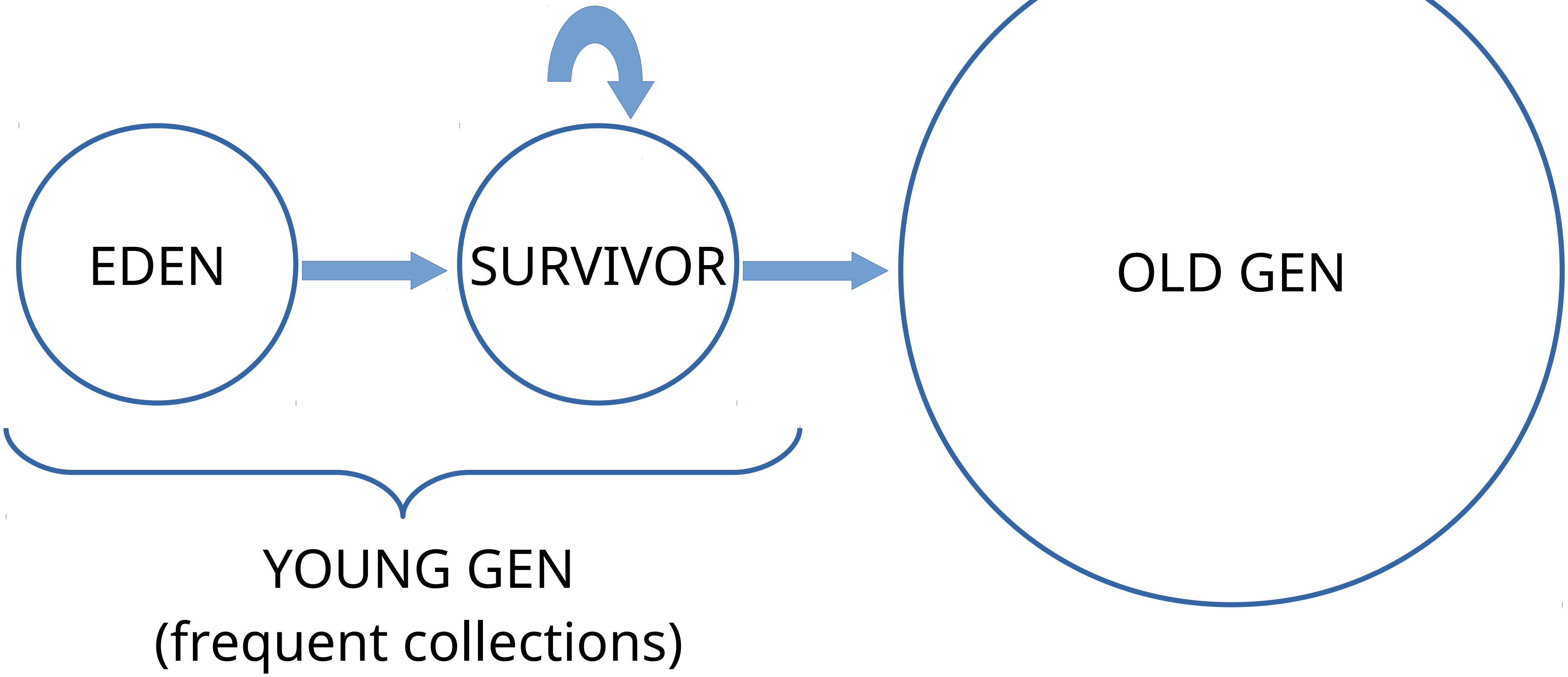
Consumes resources?

- Extra memory + CPU for bookkeeping
- Stop The World pauses all threads
- Some applications need to tune GC: pause duration vs pause frequency

Generational GC

- Most objects die young
- Generations: memory pools holding objects of different ages
  - Young generation: eden, survivors
  - Old/tenured generation
- Young-Old default size ratio 1:2

Young/Old



GC algoritms

- Serial
- **Parallel**
- Concurrent Mark-Sweep
- **Garbage first (G1)**
- IBM, Azul special stuff

Agenda

- JVM memory
- Reference objects
- Monitoring
- Garbage collectors
  - ParallelGC
  - G1GC

Reference objects

- java.lang.ref package docs are useful
- WeakReference<T>
- PhantomReference<T>
- ReferenceQueue<T>

Detour: memory leaks

```java
interface Passenger {
  void trainArrived();
}

class TrainStation {
  private final List<Passenger> passengers = new...
  public void startWaiting(Passenger passenger) {
    passengers.add(passenger);
  }
  public void leave(Passenger passenger) {
    passengers.remove(passenger);
  }
  public void onTrainArrived() {
    passengers.forEach(Passenger::trainArrived);
  }
}
```

Detour: memory leaks

```
interface Passenger {
  void trainArrived();
}

class TrainStation {
  private final List<Passenger> passengers = new...
  public void startWaiting(Passenger passenger) {
    passengers.add(passenger);
  }
  public void leave(Passenger passenger) {
    passengers.remove(passenger);
  }
  public void onTrainArrived() {
    passengers.forEach(Passenger::trainArrived);
  }
}
```

WeakReference<T>

Keep a reference without preventing GC

```java
private final WeakReference<SomethingBig> weakRef;

public Example(SomethingBig sb) {
  this.weakRef = new WeakReference<>(sb);
}

private void tryPrint() {
  SomethingBig strongRef = weakRef.get();
  System.out.println(strongRef != null
    ? strongRef
    : "collected");
}
```

Make it foolproof

```
interface Passenger {
  void trainArrived();
}

class TrainStation {
  private final List<Passenger> passengers = new...
  public void startWaiting(Passenger passenger) {
    passengers.add(passenger);
  }
  public void leave(Passenger passenger) {
    passengers.remove(passenger);
  }
  public void onTrainArrived() {
    passengers.forEach(Passenger::trainArrived);
  }
}
```

Weaker TrainStation

```
class TrainStation {
  private List<WeakReference<Passenger>> passengers;

  public void startWaiting(Passenger passenger) {
    passengers.add(new WeakReference<>(passenger));
  }

  public void onTrainArrived() {
    for (WeakReference<Passenger> ref : passengers) {
      Passenger passenger = ref.get();
      if (passenger != null)
        passenger.trainArrived();
    }
  }
}
```

Detour: finalizers

From java.lang.Object JavaDoc

- protected void finalize()

  Called by the garbage collector on an object when garbage collection determines that there are no more references to the object.

- Safety net for file streams, network sockets, JDBC connections, etc.

Detour: finalizers

From “Effective Java” by Joshua Bloch

- Finalizers are unpredictable, often dangerous, and generally unnecessary.
- Not only does the language specification provide no guarantee that finalizers will get executed promptly; it provides no guarantee that they’ll get executed at all.

Detour: finalizers

Trolling the garbage collector:

```
public class Test {
  static Test t;
  @Override
  public void finalize() {
    t = this; // I refuse to die
  }
}
```

PhantomReference<T>

- Not a reference, but a GC token
- Only usable with a ReferenceQueue
- Enqueued by the garbage collector, only after referent is collected
- get() -> null always!

PhantomReference<T>

```java
Example e = new Example();
ReferenceQueue<Example> queue =
    new ReferenceQueue<>();
PhantomReference<Example> phantom =
    new PhantomReference<>(e, queue);
e = null;


// generate garbage, cause a GC
Reference<?> collected = queue.remove();
if (collected == phantom) {
  // our e has been collected
}
```

Agenda

- JVM memory
- Reference objects
- Monitoring
- Garbage collectors
  - ParallelGC
  - G1GC

GC logging

- -XX:+PrintGCTimeStamps
- -XX:+PrintGCDetails
- -Xloggc:filename
- Output depends heavily on GC algo
- Read the fine manual:
  plumbr.eu/java-garbage-collection-handbook
  “GC Algorithms: Implementations”

ParallelGC minor

```
2015-05-26T14:27:40.915-0200: 116.115:
[GC (Allocation Failure)
  [PSYoungGen: 2 694 440K -> 1 305 132K (2 796 544K)]
  9 556 775K -> 8 438 926K (11 185 152K), 0.24066 secs
]
[Times: user=1.77 sys=0.01, real=0.24 secs]
```

ParallelGC full

```
2015-05-26T14:27:41.155-0200: 116.356:
[Full GC (Ergonomics)
  [PSYoungGen: 1 305 132K -> 0K(2 796 544K)]
  [ParOldGen: 7 133 794K -> 6 597 672K (8 388 608K)]
  8 438 926K -> 6 597 672K (11 185 152K),
  [Metaspace: 6 745K -> 6 745K (1 056 768K)] ,
  0.91588 secs
]
[Times: user=4.49 sys=0.64, real=0.92 secs]
```

G1 minor

```
0.134: [GC pause (G1 Evacuation Pause)
(young), 0.0144119 secs] ... [
  Eden: 24.0M (24.0M) -> 0.0B (13.0M)
  Survivors: 0.0B -> 3072.0K
  Heap: 24.0M (256.0M) -> 21.9M (256.0M)
]
[Times: user=0.04 sys=0.04, real=0.02 secs]
```

GC overhead

```
116.356: [Full GC …
117.331: [Full GC …
118.378: [Full GC …
119.316: [Full GC …
```

```
java.lang.OutOfMemoryError:
  GC overhead limit exceeded
```

Frequent+quick minor collections expected

Heap dumps

- JVisualVM
- Eclipse memory analyzer (MAT)
- jmap -heap / -histo / -dump:... <pid>
- -XX:+HeapDumpOnOutOfMemory

  -XX:HeapDumpPath=path

jmap

```
$ jmap -heap 1244
Heap Usage:
PS Young Generation
   capacity = (930.0MB)
   used     = (595.2MB)
   free     = (334.7MB)
   64.0% used
```

```
PS Old Generation
   capacity = (167.0MB)
   used     = (2.9MB)
   free     = (164.0MB)
   1.7% used
```

jmap

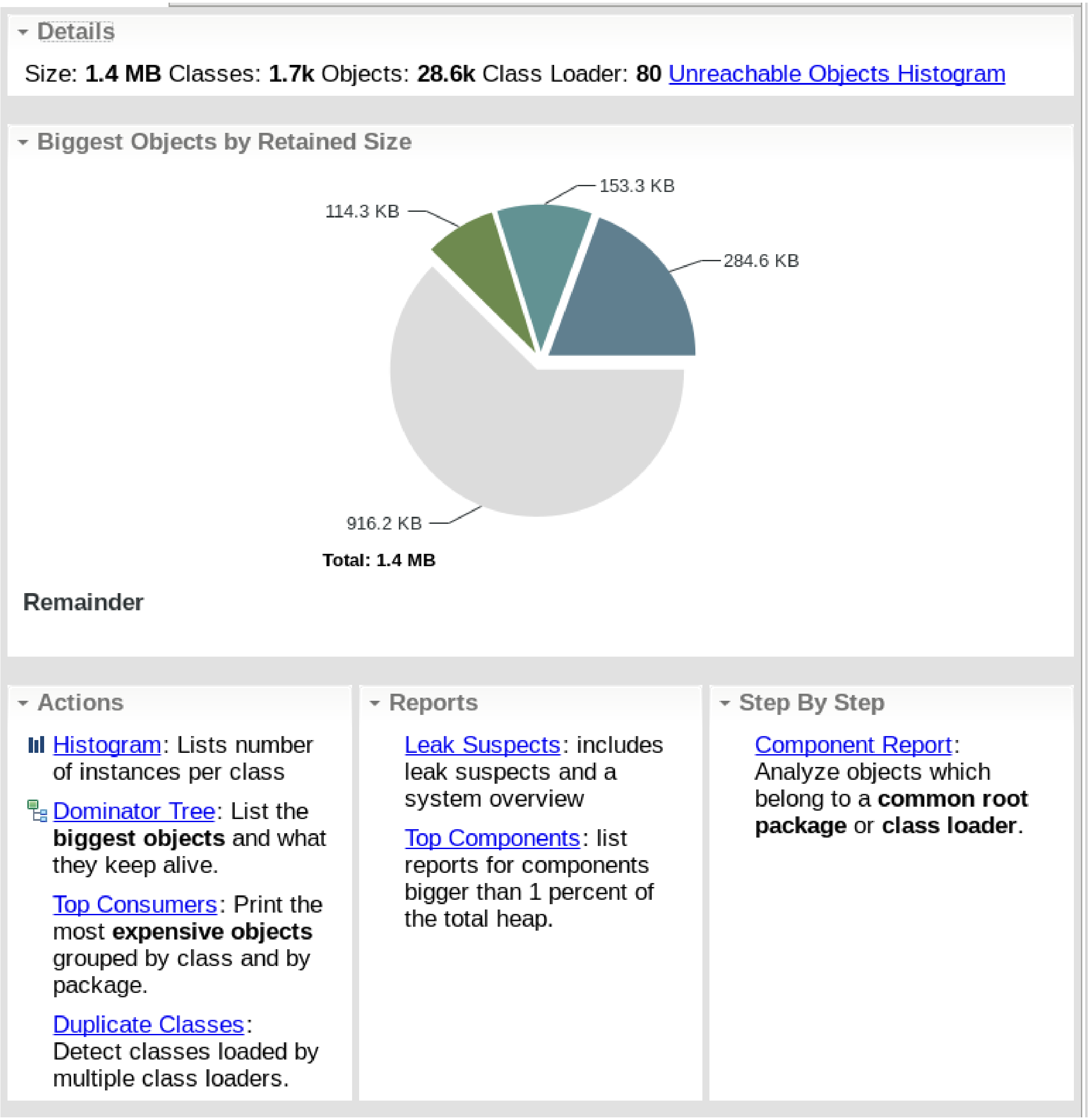
```
$ jmap -histo 1244
 num     #instances         #bytes  class name
----------------------------------------------
   1:        250080      217038824  [C
   2:           874       11646608  [I
   3:        250040        6000960  java.lang.String
   4:           577          85968  [Ljava.lang.Object;
   5:           582          66144  java.lang.Class
   6:            22          25312  [B
   7:           109           7848  j.l.r.Field
```

jps + jmap

```
$ jps -lv
30086 com.intellij.idea.Main ...
1738 sun.tools.jps.Jps ...
1659 org.jetbrains.jps.cmdline.Launcher ...
1660 com.intellij.rt.execution.application.AppMain ...

$ jmap -dump:format=b,file=dump.bin 1660
Dumping heap to /tmp/dump.bin ...
Heap dump file created
```

Eclipse memory analyzer



Size: **1.4 MB** Classes: **1.7k** Objects: **28.6k** Class Loader: **80** Unreachable Objects Histogram

Histogram: Lists number of instances per class

Dominator Tree: List the **biggest objects** and what they keep alive.

Top Consumers: Print the most **expensive objects** grouped by class and by package.

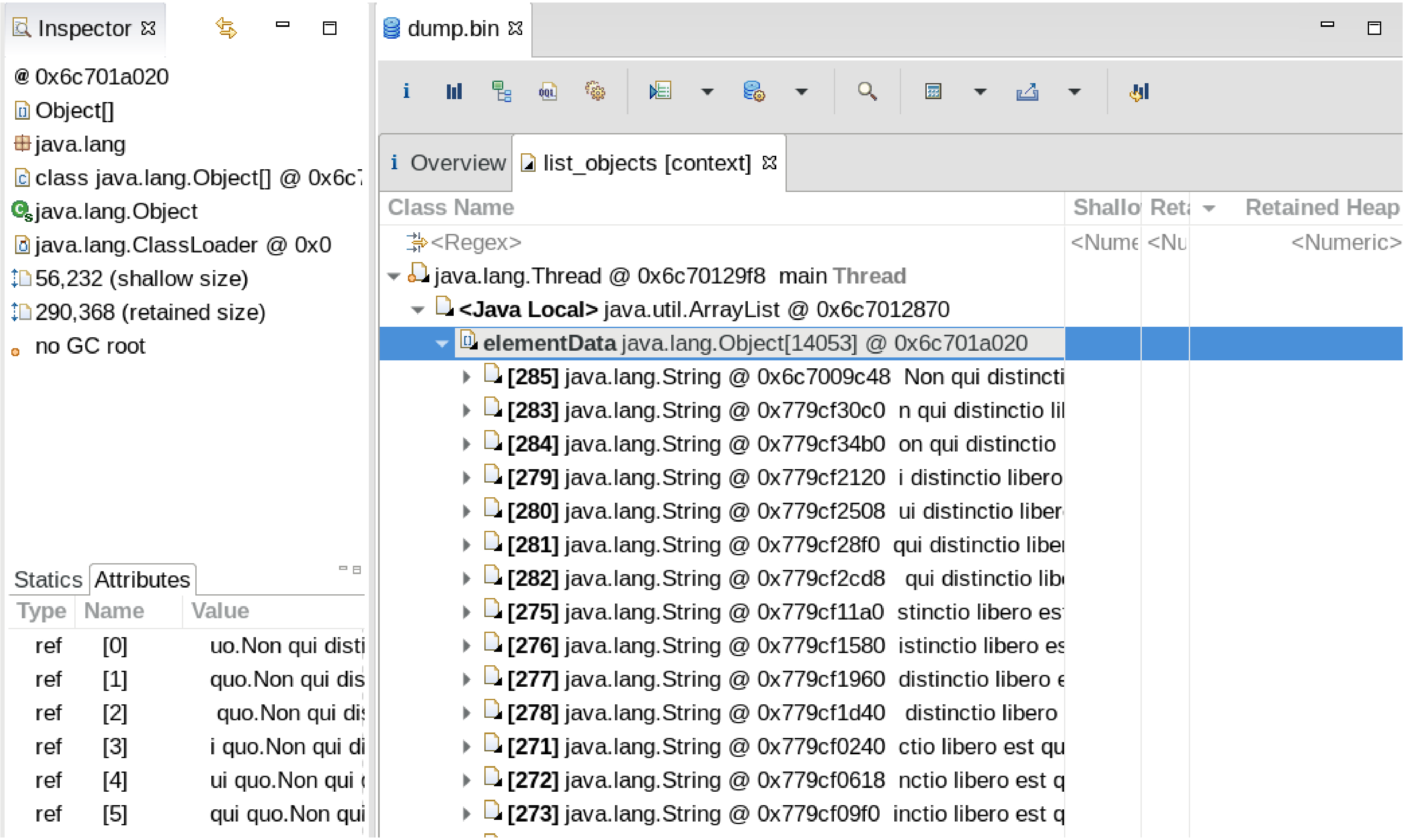
Duplicate Classes: Detect classes loaded by multiple class loaders.

Leak Suspects: includes leak suspects and a system overview

Top Components: list reports for components bigger than 1 percent of the total heap.

Component Report: Analyze objects which belong to a **common root package** or **class loader**.

Eclipse memory analyzer

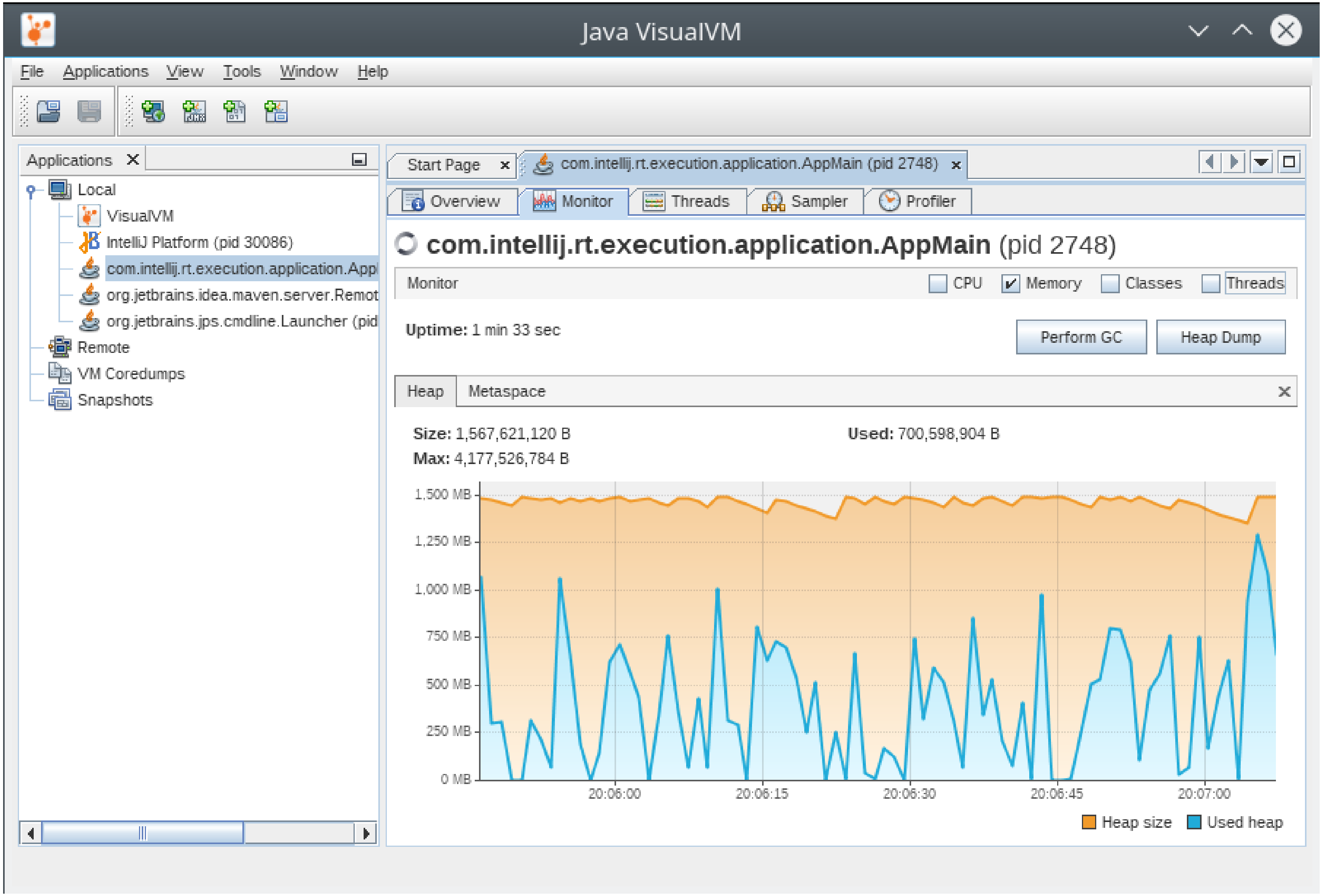


```
@ 0x6c701a020
Object[]
java.lang
class java.lang.Object[] @ 0x6c7
java.lang.Object
java.lang.ClassLoader @ 0x0
56,232 (shallow size)
290,368 (retained size)
no GC root
```

Type	Name	Value
ref	[0]	uo.Non qui disti
ref	[1]	quo.Non qui dis
ref	[2]	quo.Non qui di
ref	[3]	i quo.Non qui di
ref	[4]	ui quo.Non qui
ref	[5]	qui quo.Non qui

Class Name	Shallo	Reta	Retained Heap
<Regex>	<Nume	<Nu	<Numeric>
java.lang.Thread @ 0x6c70129f8 main Thread			
<Java Local> java.util.ArrayList @ 0x6c7012870			
elementData java.lang.Object[14053] @ 0x6c701a020			
[285] java.lang.String @ 0x6c7009c48 Non qui distincti			
[283] java.lang.String @ 0x779cf30c0 n qui distinctio lil			
[284] java.lang.String @ 0x779cf34b0 on qui distinctio			
[279] java.lang.String @ 0x779cf2120 i distinctio libero			
[280] java.lang.String @ 0x779cf2508 ui distinctio liber			
[281] java.lang.String @ 0x779cf28f0 qui distinctio liber			
[282] java.lang.String @ 0x779cf2cd8 qui distinctio lib			
[275] java.lang.String @ 0x779cf11a0 stinctio libero es			
[276] java.lang.String @ 0x779cf1580 istinctio libero es			
[277] java.lang.String @ 0x779cf1960 distinctio libero e			
[278] java.lang.String @ 0x779cf1d40 distinctio libero			
[271] java.lang.String @ 0x779cf0240 ctio libero est qu			
[272] java.lang.String @ 0x779cf0618 nctio libero est q			
[273] java.lang.String @ 0x779cf09f0 inctio libero est q			

JVisualVM



com.intellij.rt.execution.application.AppMain (pid 2748)

Monitor ☐ CPU ☑ Memory ☐ Classes ☐ Threads

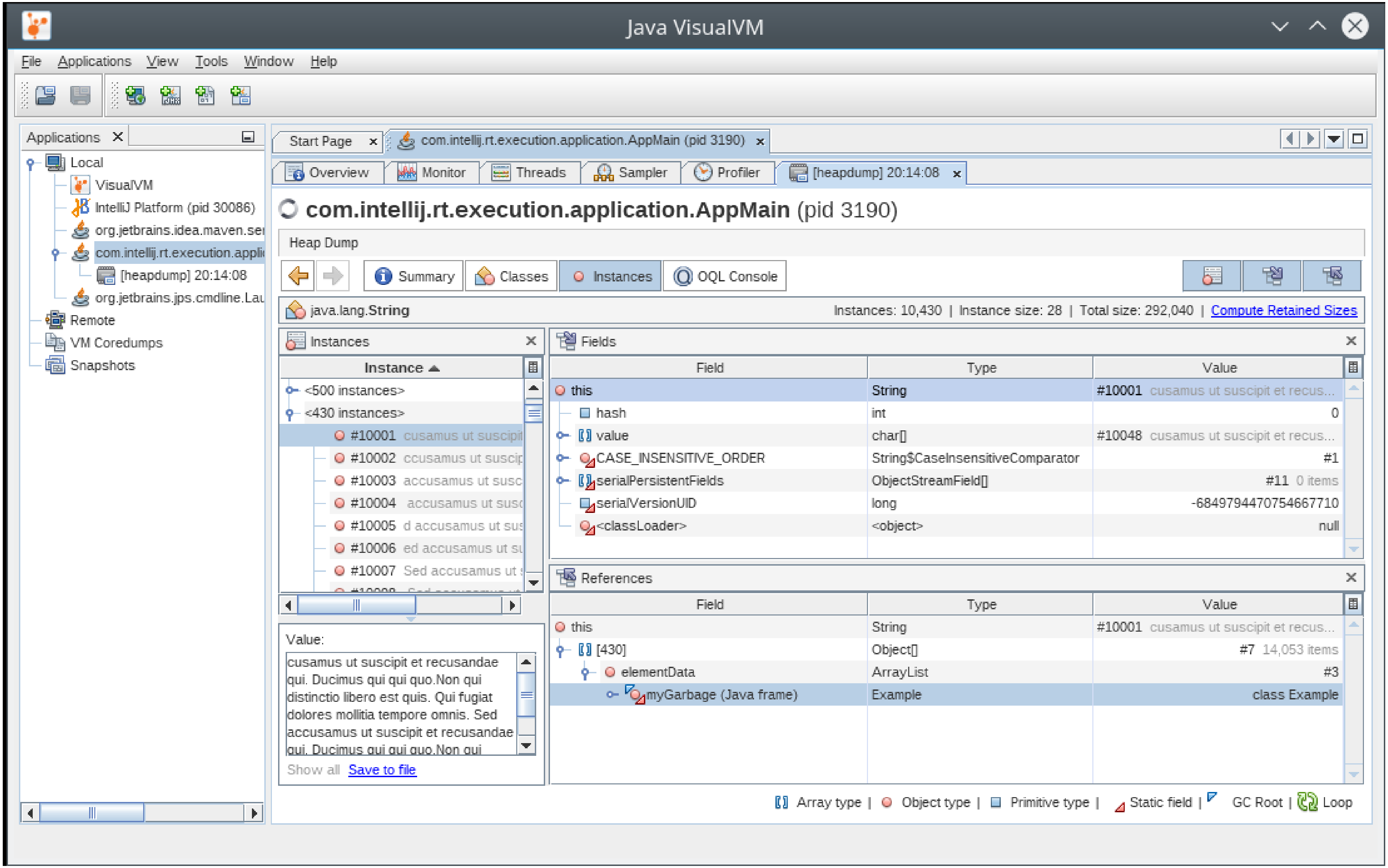
Uptime: 1 min 33 sec

Size: 1,567,621,120 B

Used: 700,598,904 B

Max: 4,177,526,784 B

JVisualVM



com.intellij.rt.execution.application.AppMain (pid 3190)

java.lang.String — Instances: 10,430 | Instance size: 28 | Total size: 292,040 | Compute Retained Sizes

Instance ▲
<500 instances>
<430 instances>
#10001 cusamus ut suscipit
#10002 ccusamus ut suscip
#10003 accusamus ut susc
#10004 accusamus ut susc
#10005 d accusamus ut sus
#10006 ed accusamus ut su
#10007 Sed accusamus ut

Fields

Field	Type	Value
this	String	#10001 cusamus ut suscipit et recus...
hash	int	0
value	char[]	#10048 cusamus ut suscipit et recus...
CASE_INSENSITIVE_ORDER	String$CaseInsensitiveComparator	#1
serialPersistentFields	ObjectStreamField[]	#11 0 items
serialVersionUID	long	-6849794470754667710
<classLoader>	<object>	null

References

Field	Type	Value
this	String	#10001 cusamus ut suscipit et recus...
[430]	Object[]	#7 14,053 items
elementData	ArrayList	#3
myGarbage (Java frame)	Example	class Example

Value:

cusamus ut suscipit et recusandae qui. Ducimus qui qui quo.Non qui distinctio libero est quis. Qui fugiat dolores mollitia tempore omnis. Sed accusamus ut suscipit et recusandae qui. Ducimus qui qui quo.Non qui

[] Array type | ● Object type | □ Primitive type | Static field | GC Root | Loop

JVisualVM

- Bundled with JDK
- Windows:
  C:\Program Files\Java\jdk1.8.x\bin\jvisualvm.exe
- Linux:
  jvisualvm or visualvm
  (apt-get install visualvm)
- Compile & Run: https://goo.gl/L3dhos

5min break

Agenda

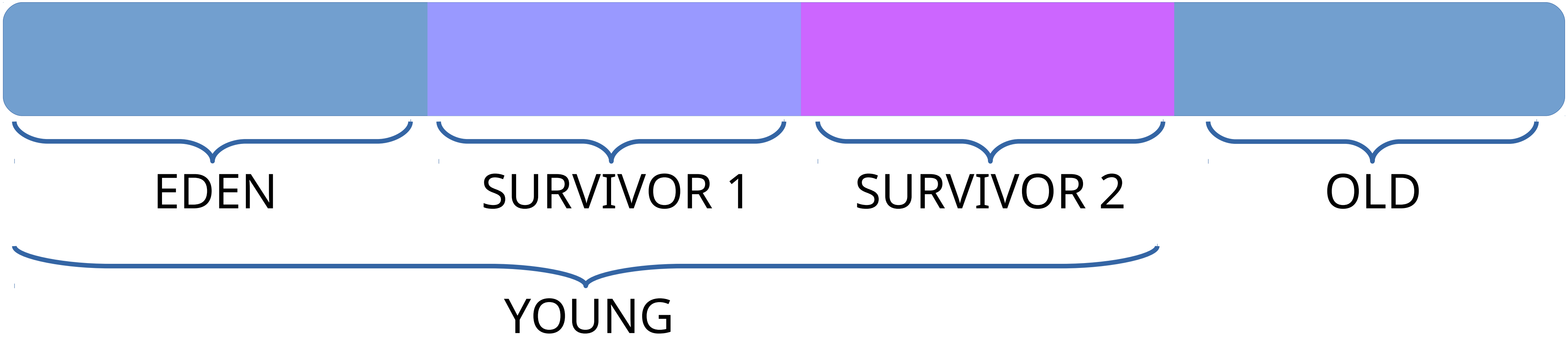
- JVM memory
- Reference objects
- Monitoring
- Garbage collectors
  - ParallelGC
  - G1GC

ParallelGC

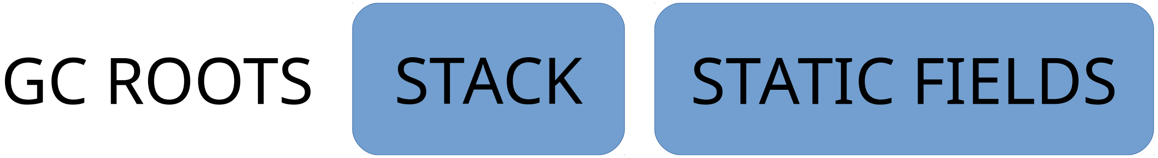
- GC roots
  - static fields
  - stack locals
  - threads
- Young gen: eden, survivor to/from
- Old gen
- Stop The World pauses

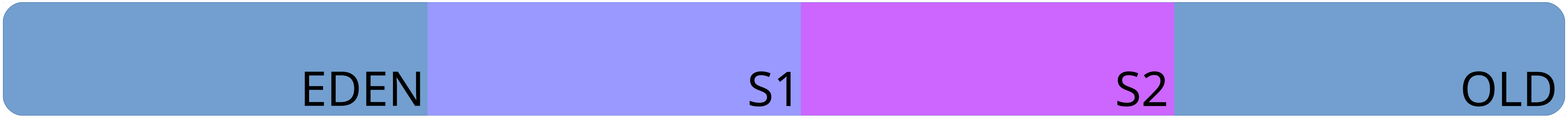
GC ROOTS STACK STATIC FIELDS

RUNNING/
STOP THE WORLD

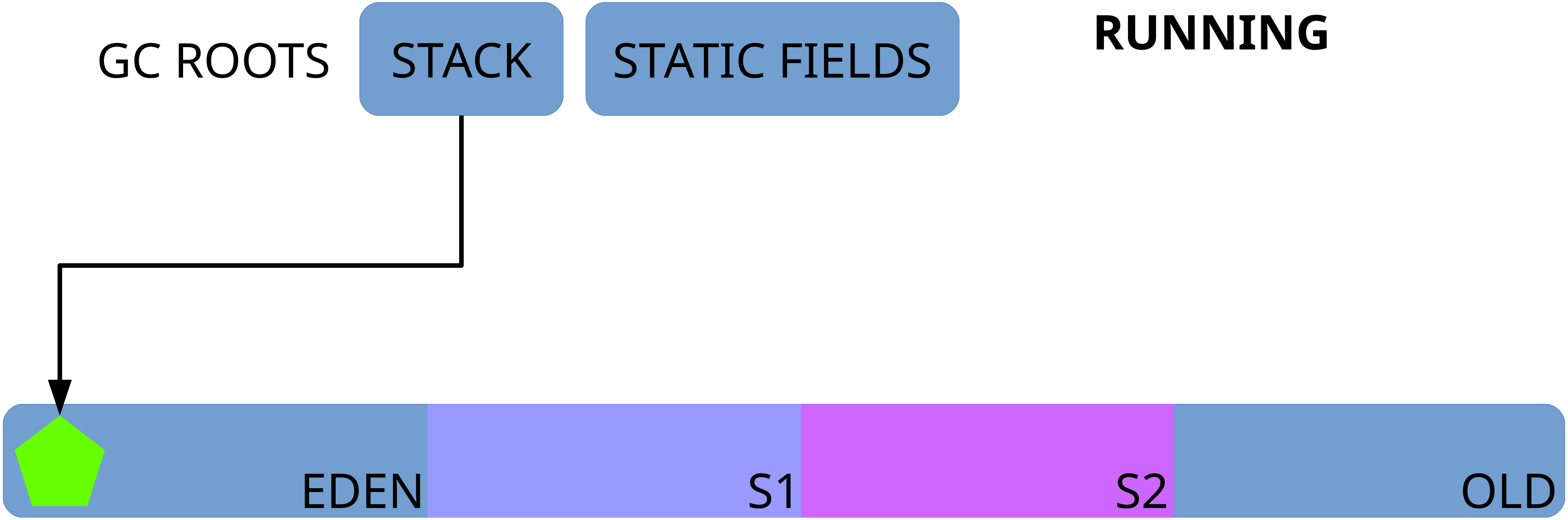


RUNNING





RUNNING



GC ROOTS

STACK

STATIC FIELDS

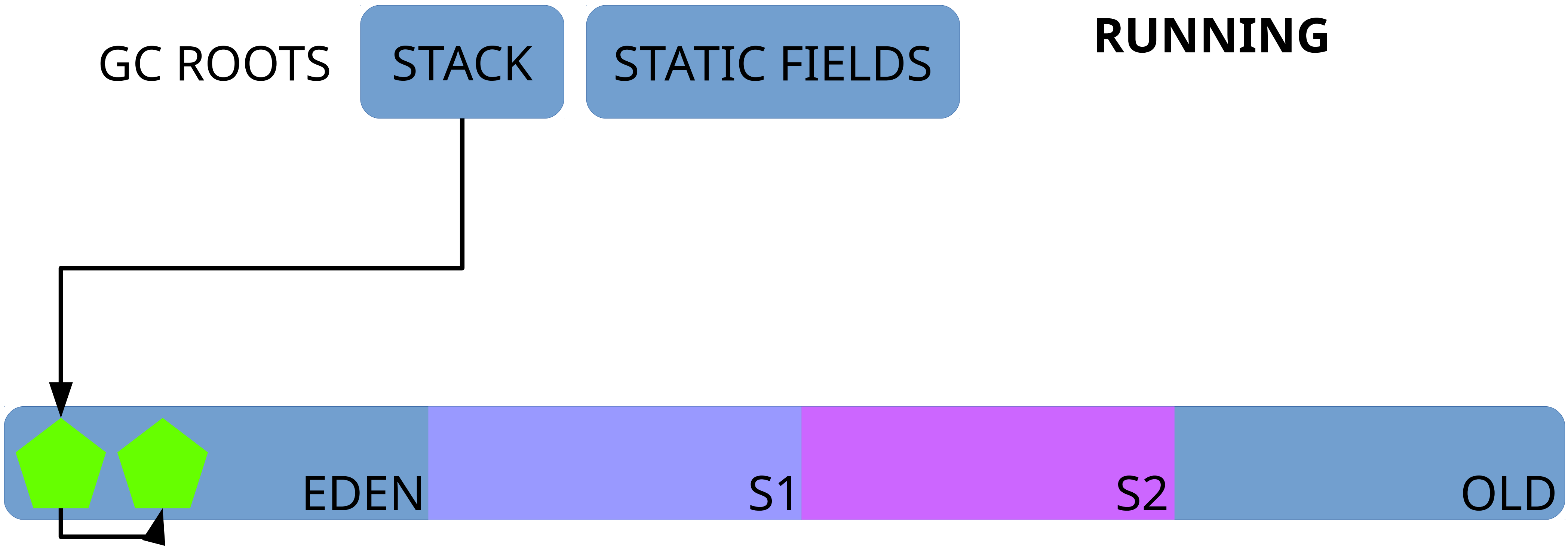
EDEN

S1

S2

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

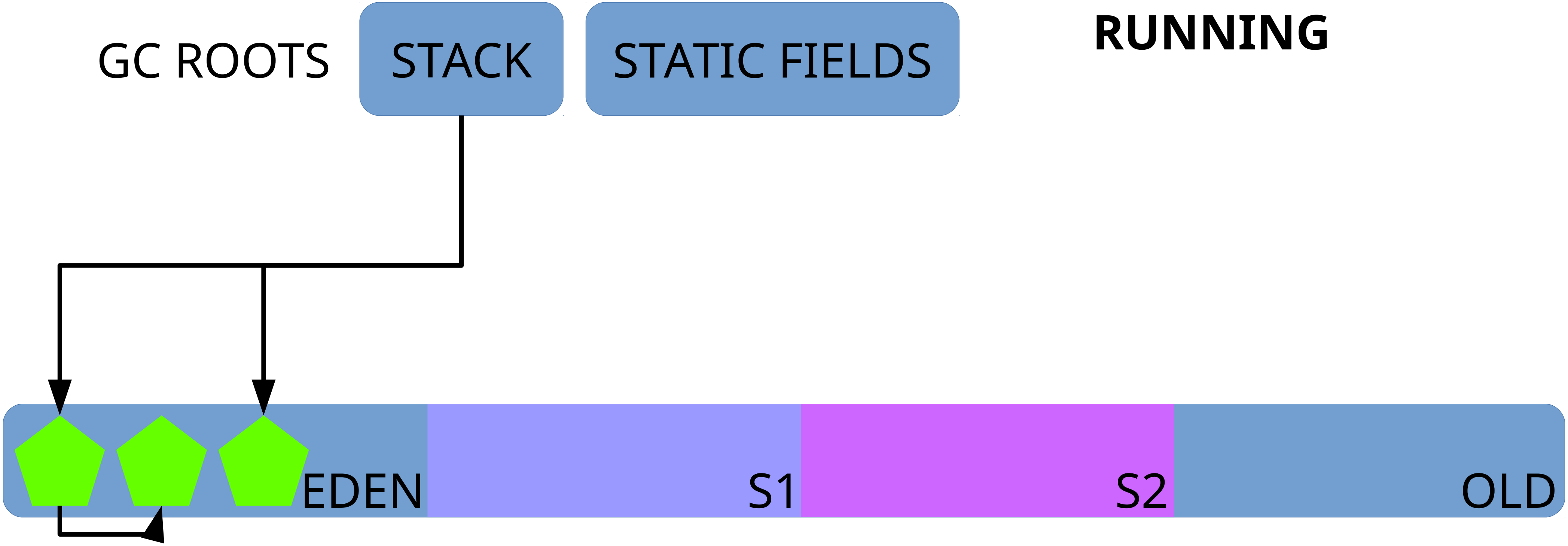
EDEN

S1

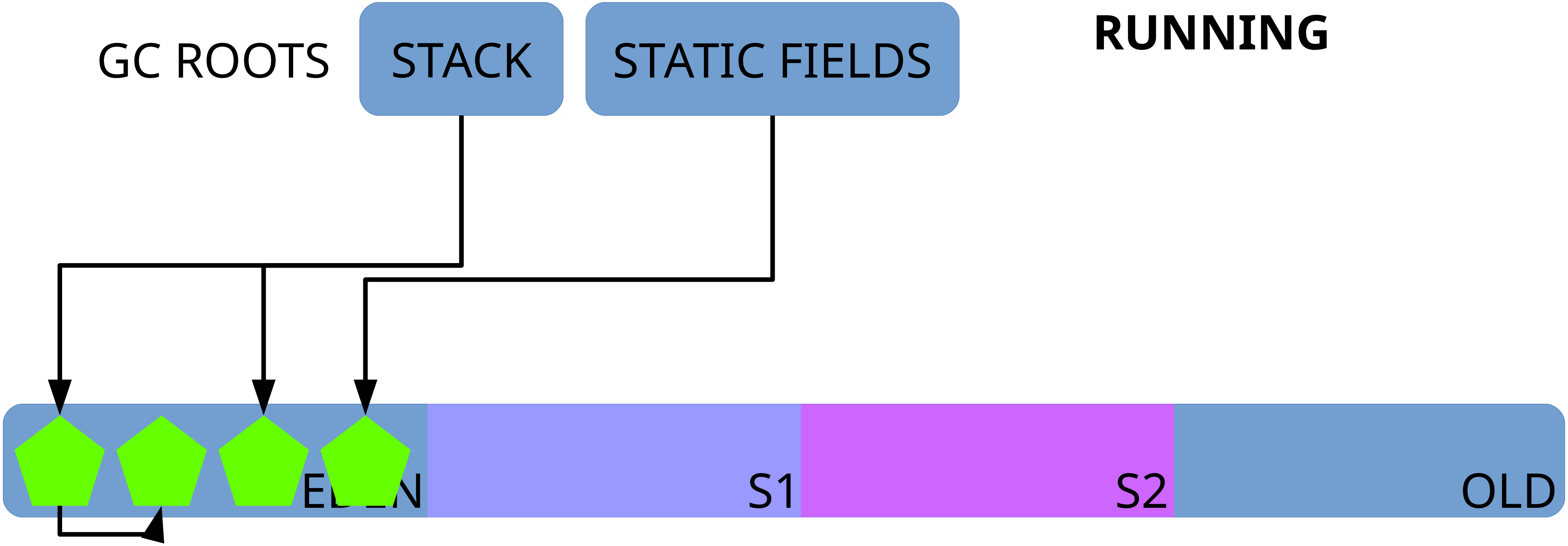
S2

OLD

RUNNING



RUNNING



GC ROOTS

STACK

STATIC FIELDS

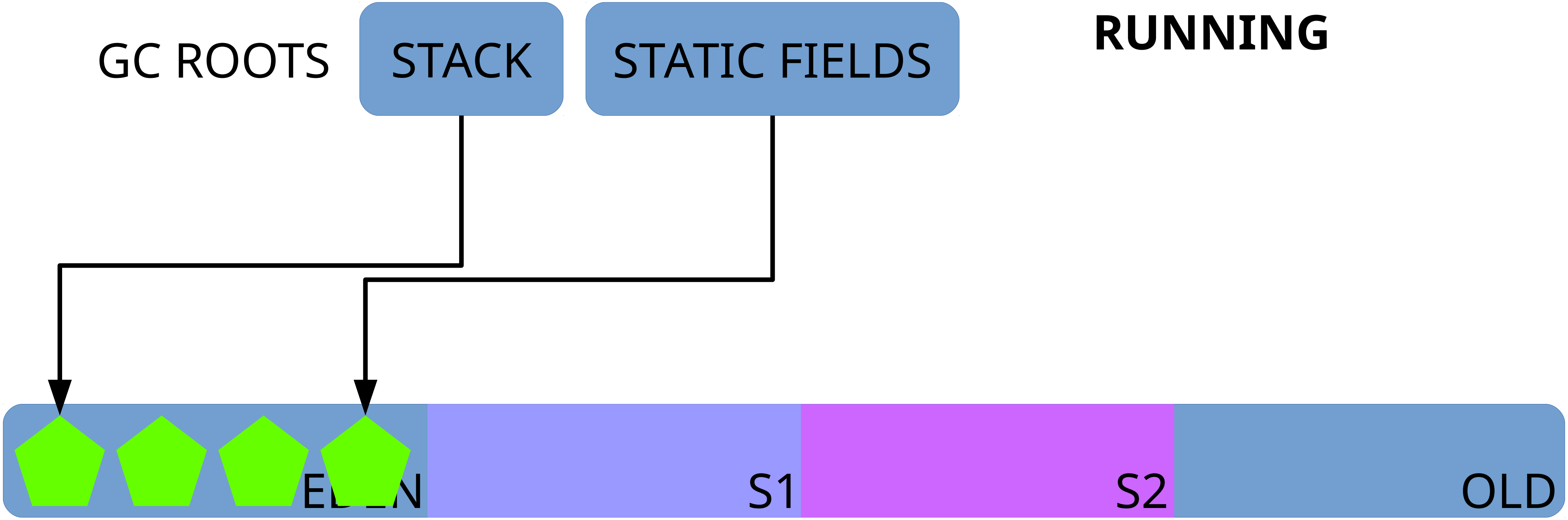
EDEN

S1

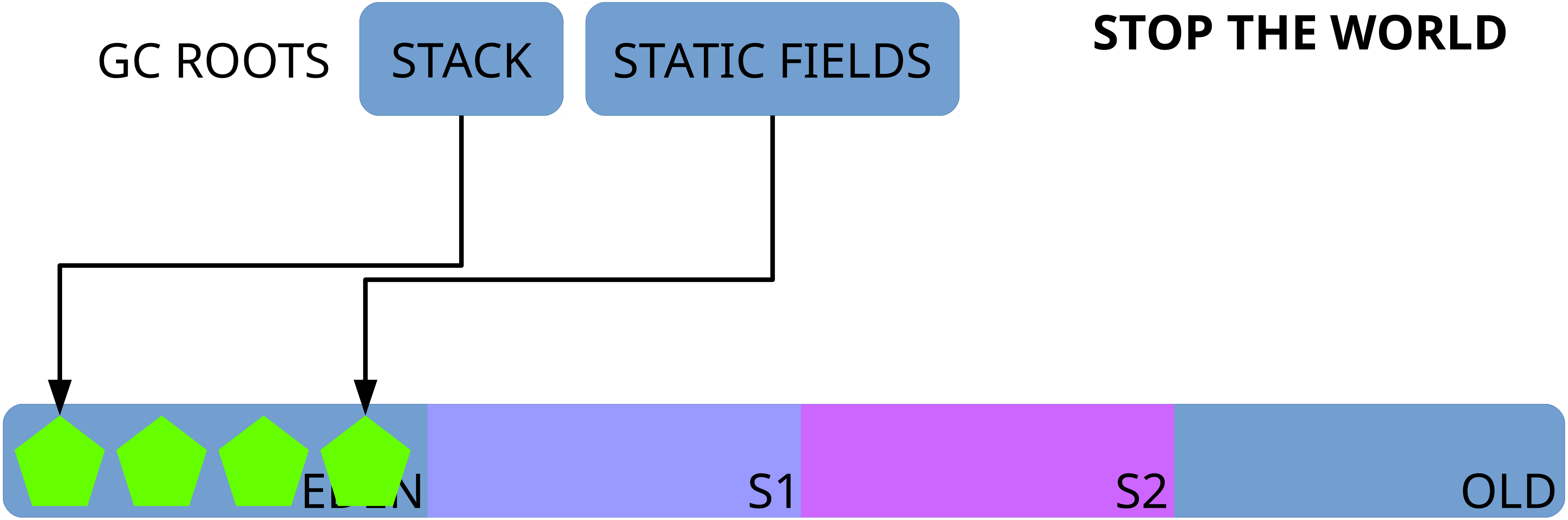
S2

OLD

RUNNING



STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

EDEN

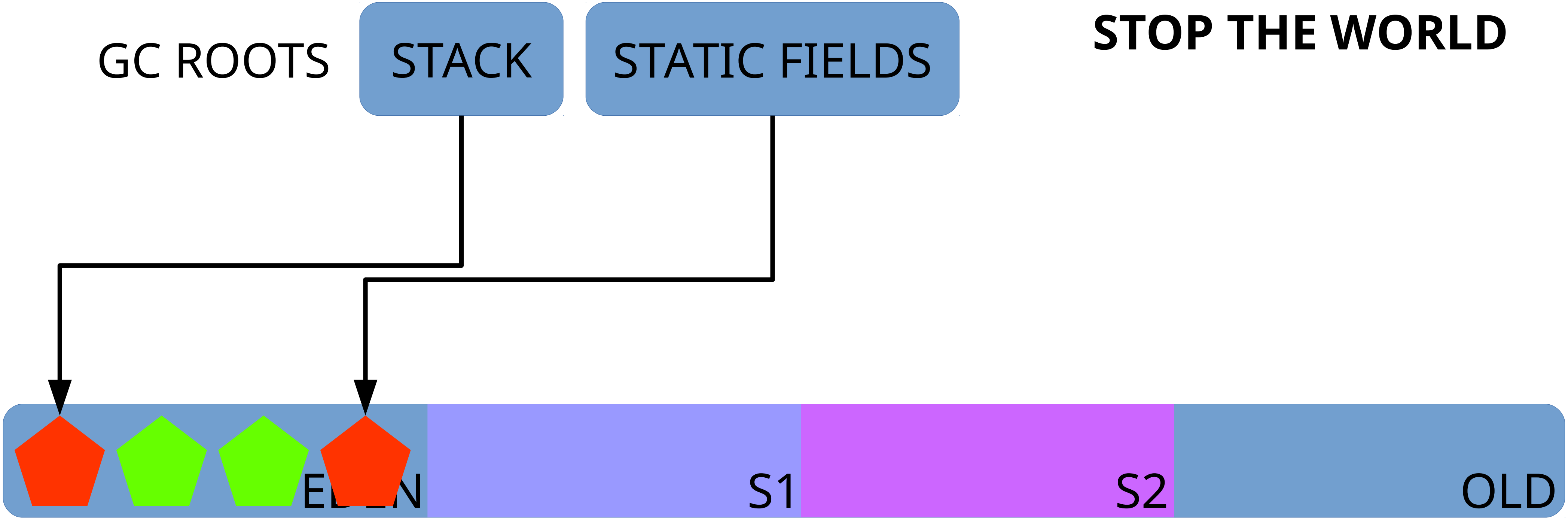
S1

S2

OLD

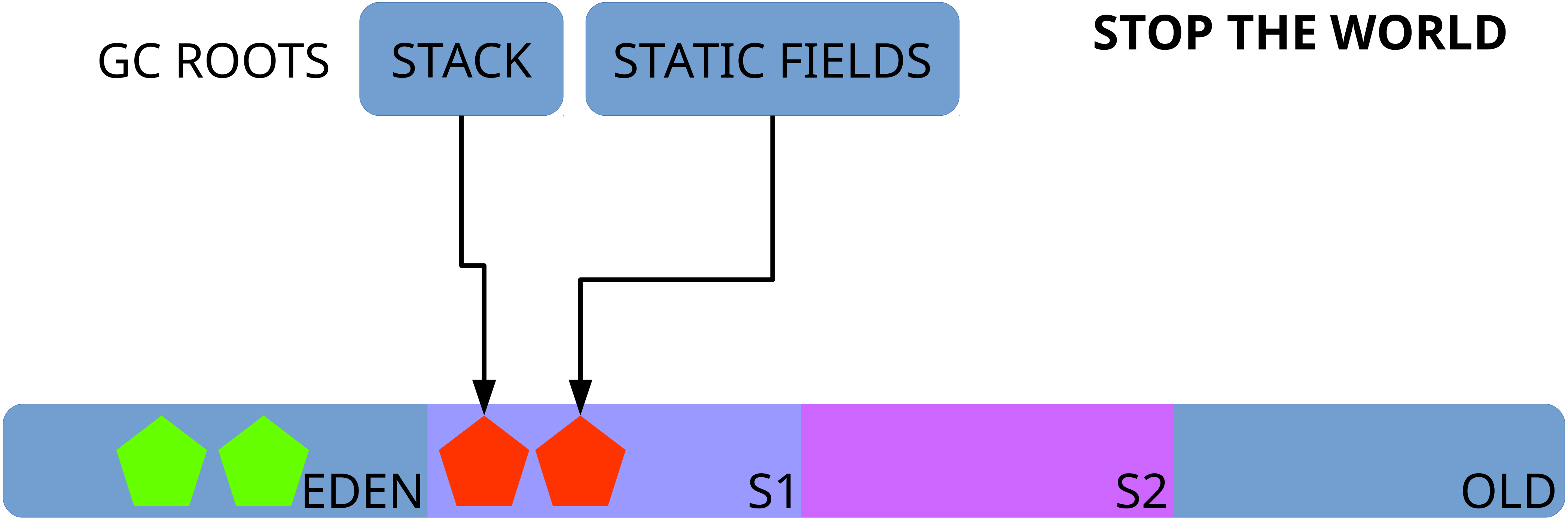
```
2015-05-26T14:27:40.915-0200: 116.115:
[GC (Allocation Failure) ... ]
```

STOP THE WORLD



Find live objects, starting from GC roots (mark)

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

EDEN

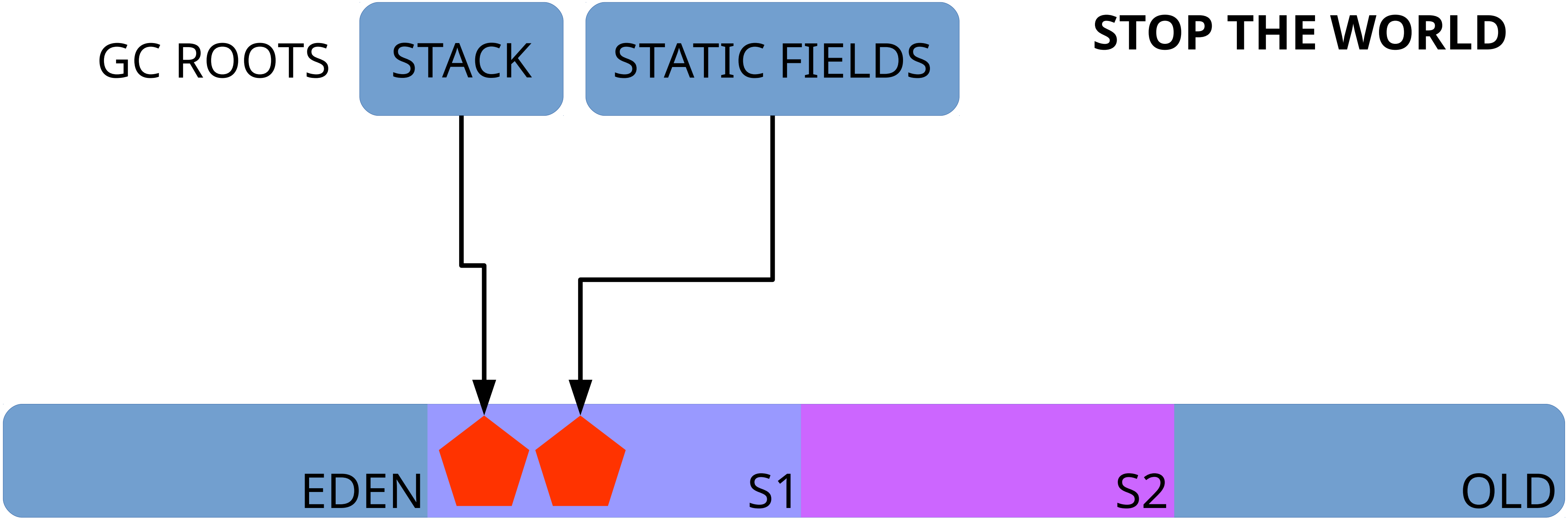
S1

S2

OLD

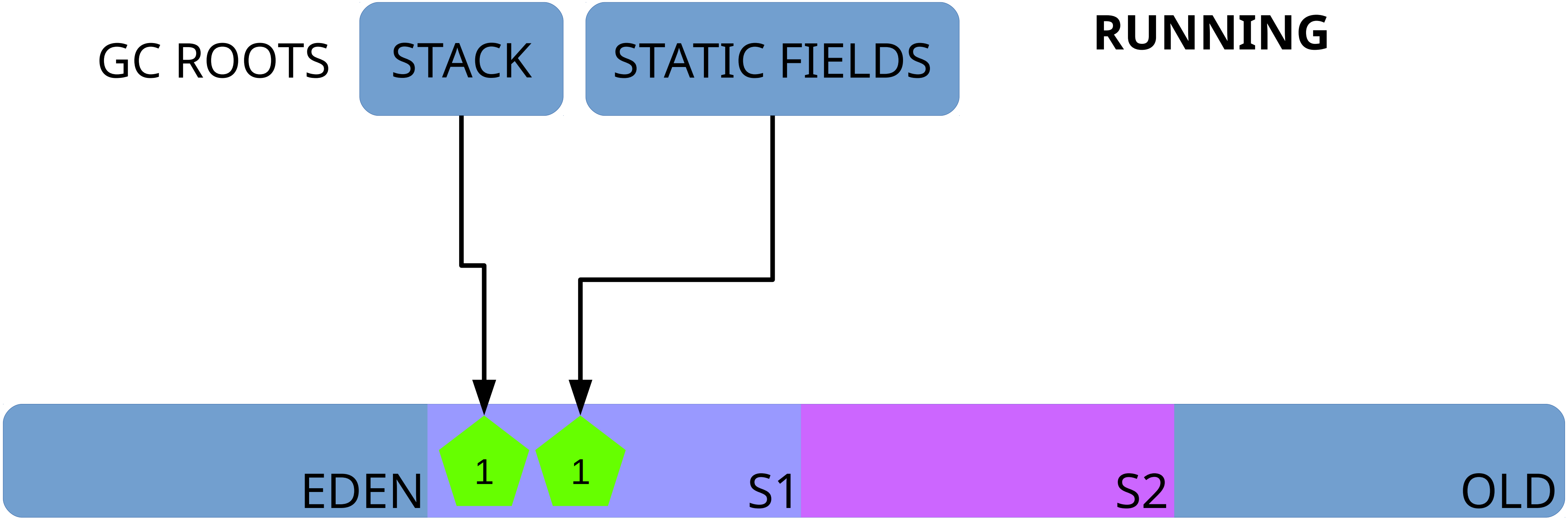
Move live objects to survivors (compacting)

STOP THE WORLD



Mark EDEN as clean

RUNNING



GC ROOTS

STACK

STATIC FIELDS

EDEN

1

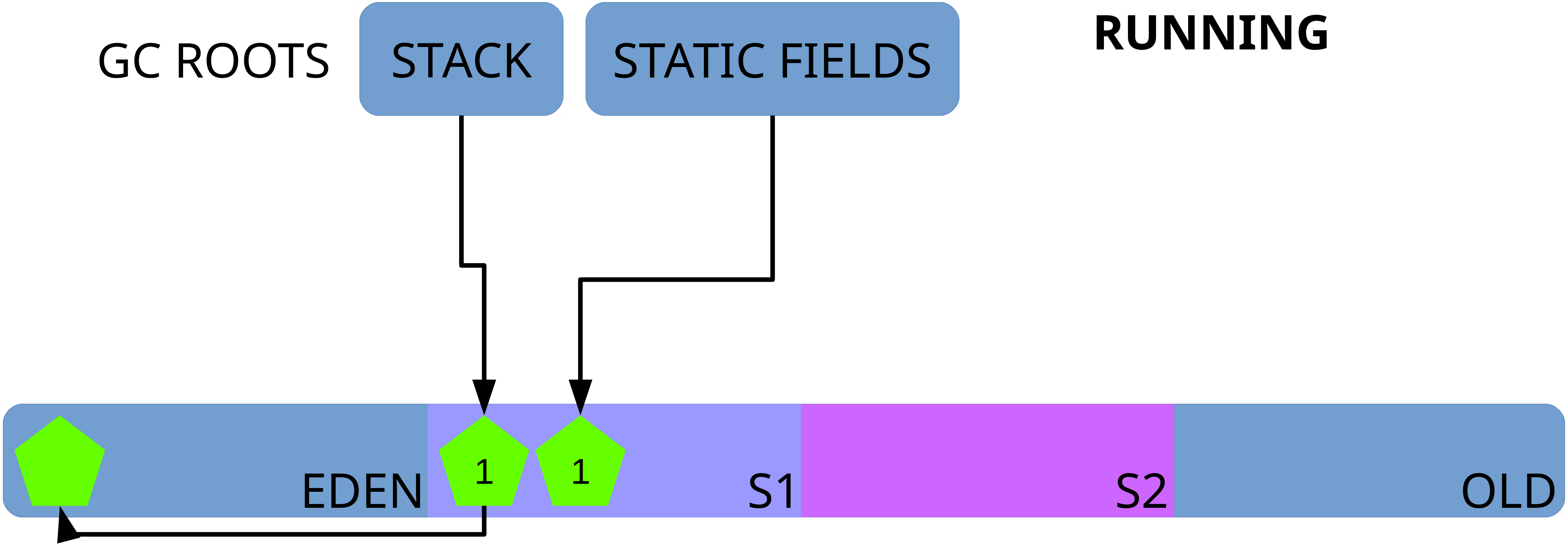
1

S1

S2

OLD

RUNNING

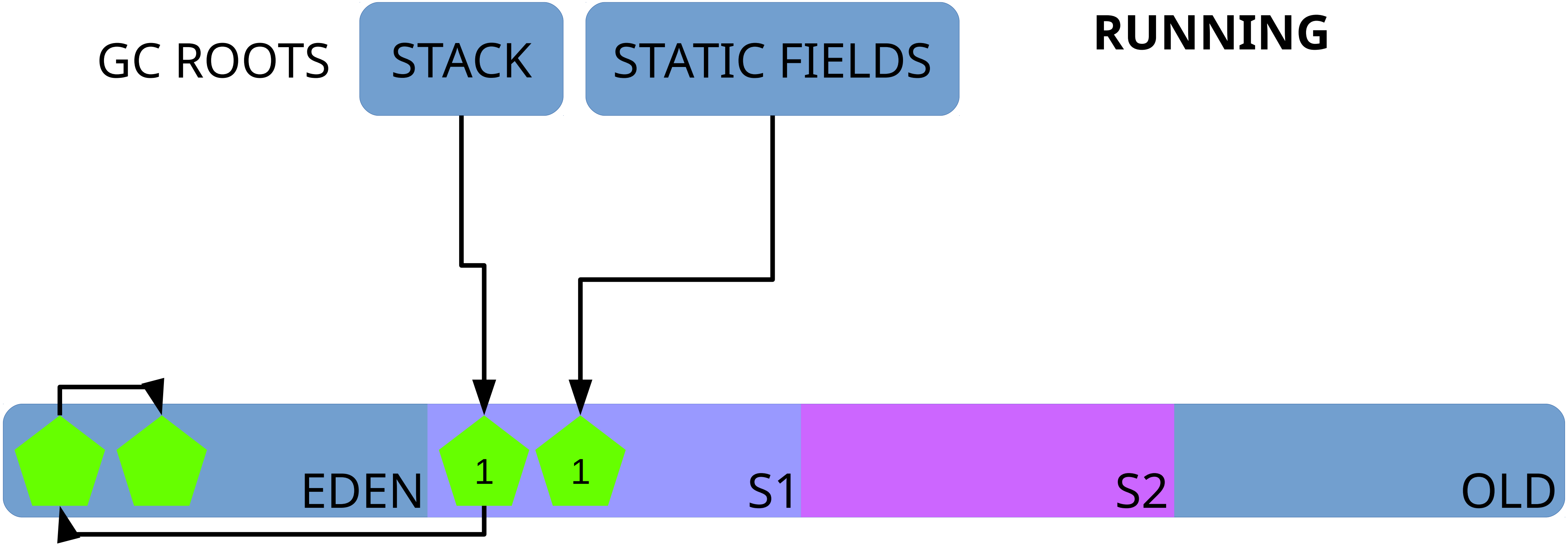


GC ROOTS

STACK

STATIC FIELDS

RUNNING



GC ROOTS

STACK

STATIC FIELDS

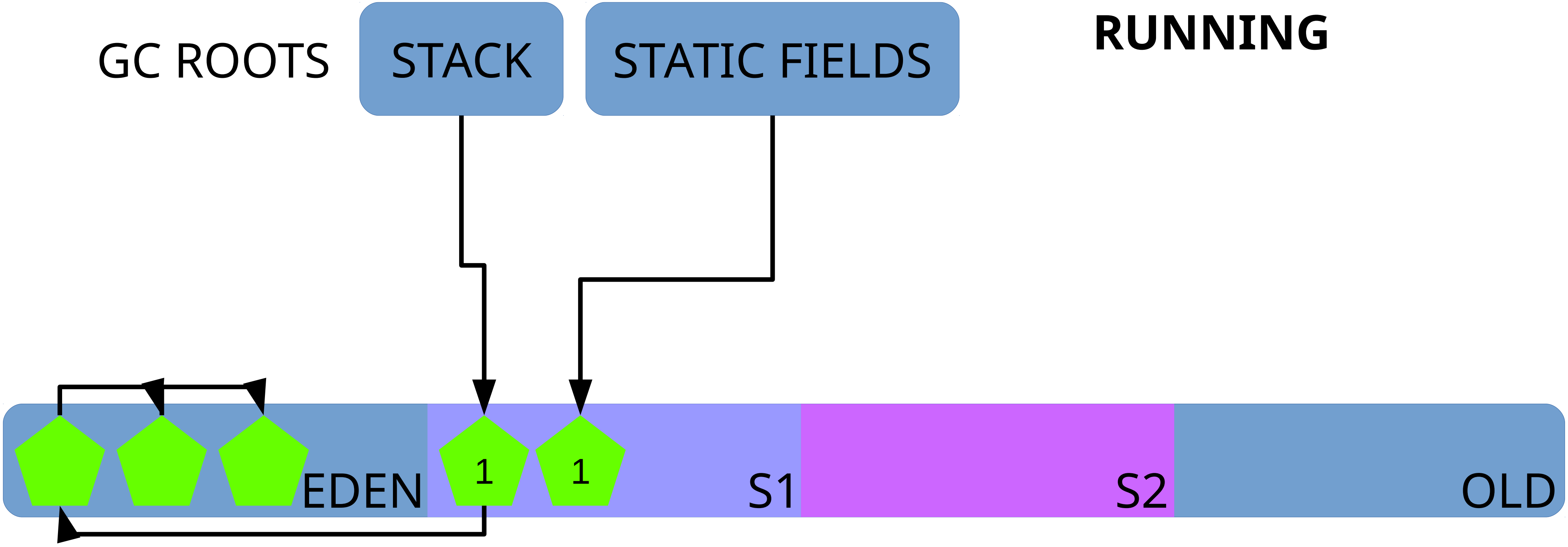
EDEN

S1

S2

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

EDEN

1

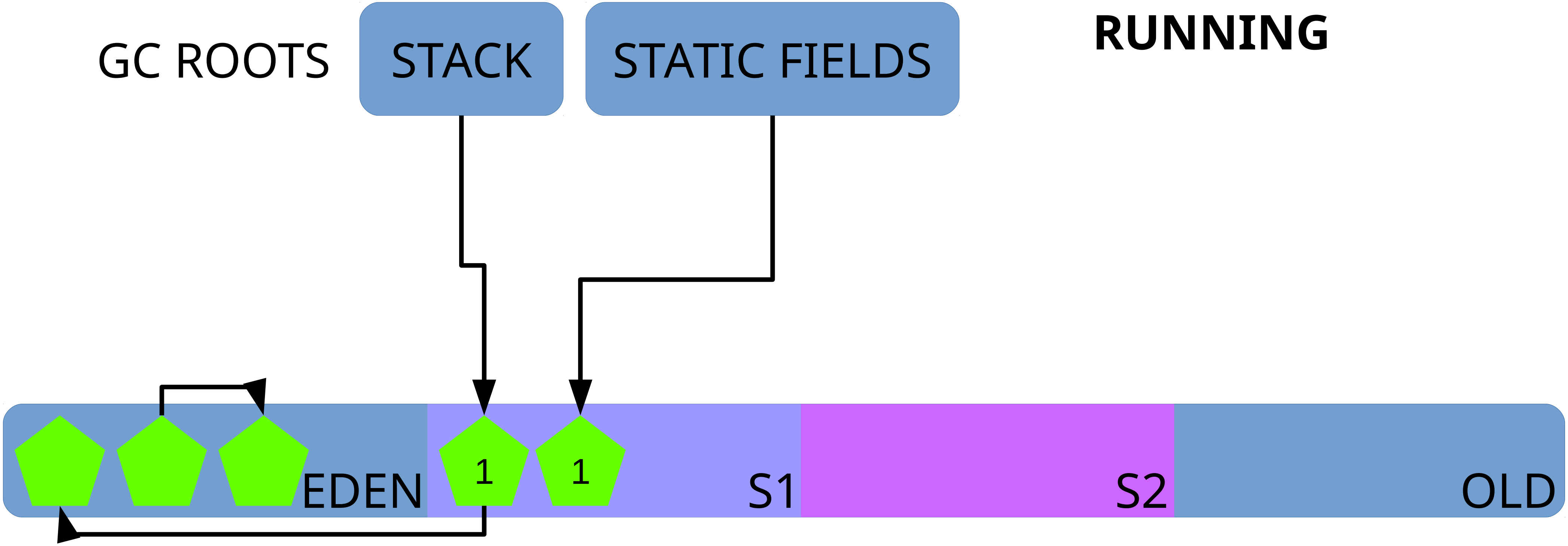
1

S1

S2

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

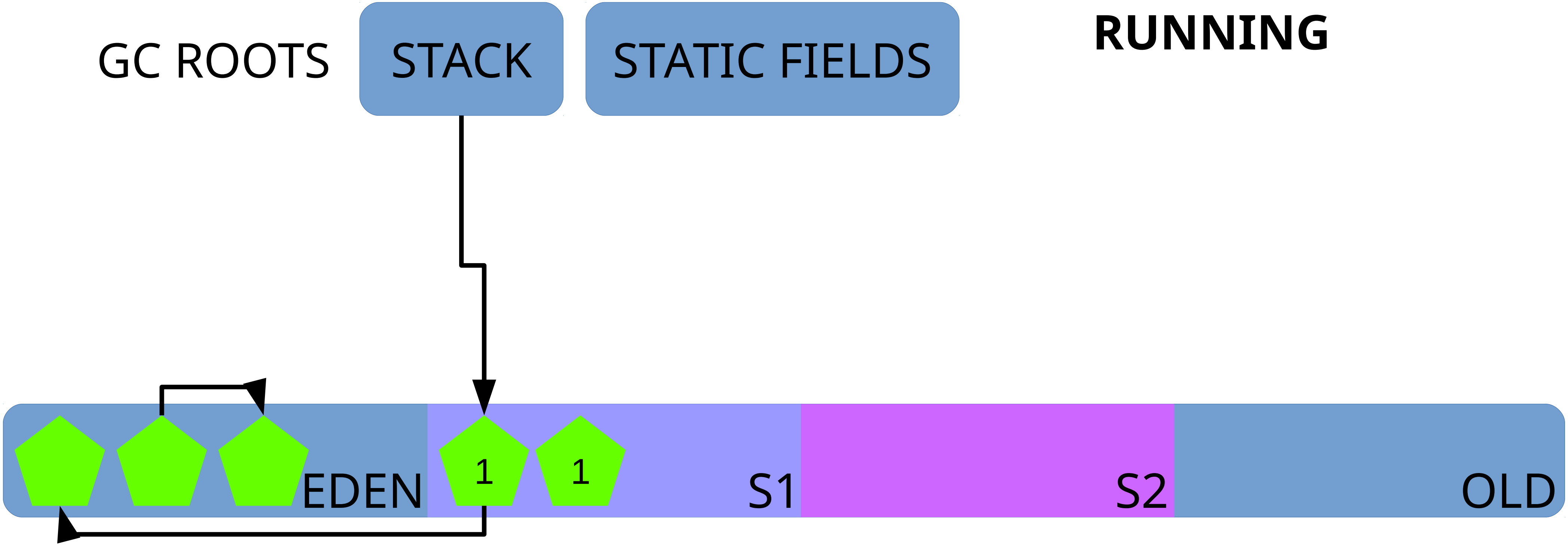
EDEN

S1

S2

OLD

RUNNING

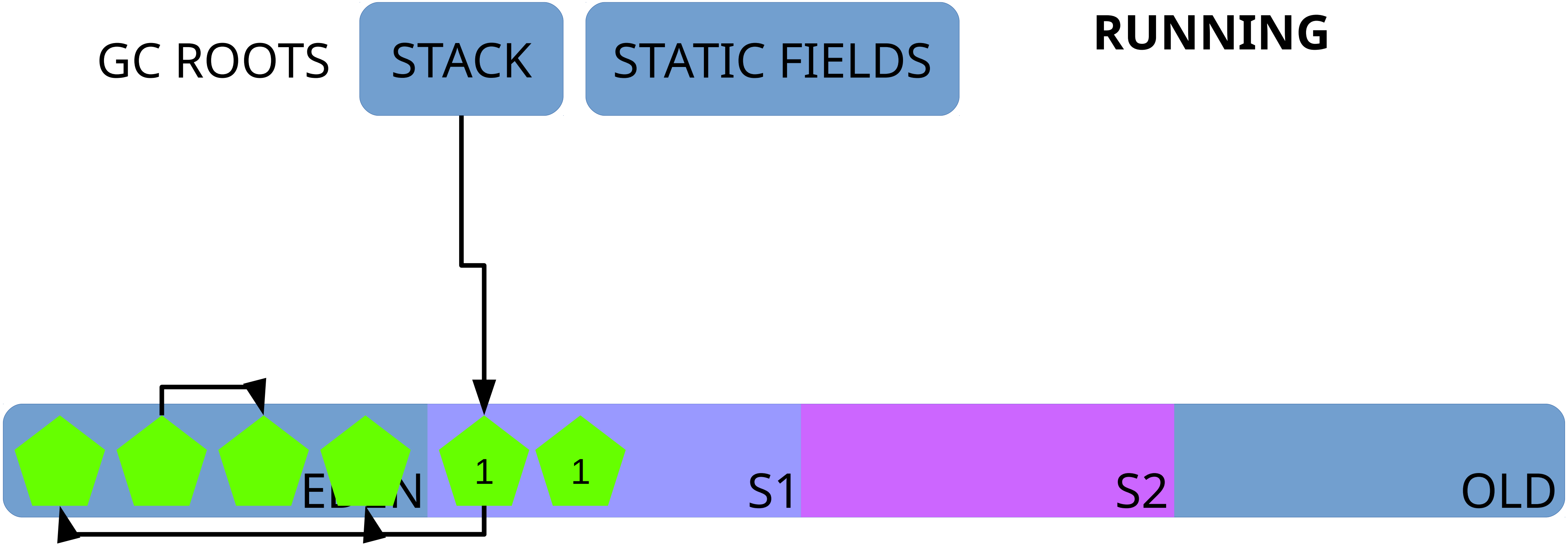


GC ROOTS

STACK

STATIC FIELDS

RUNNING

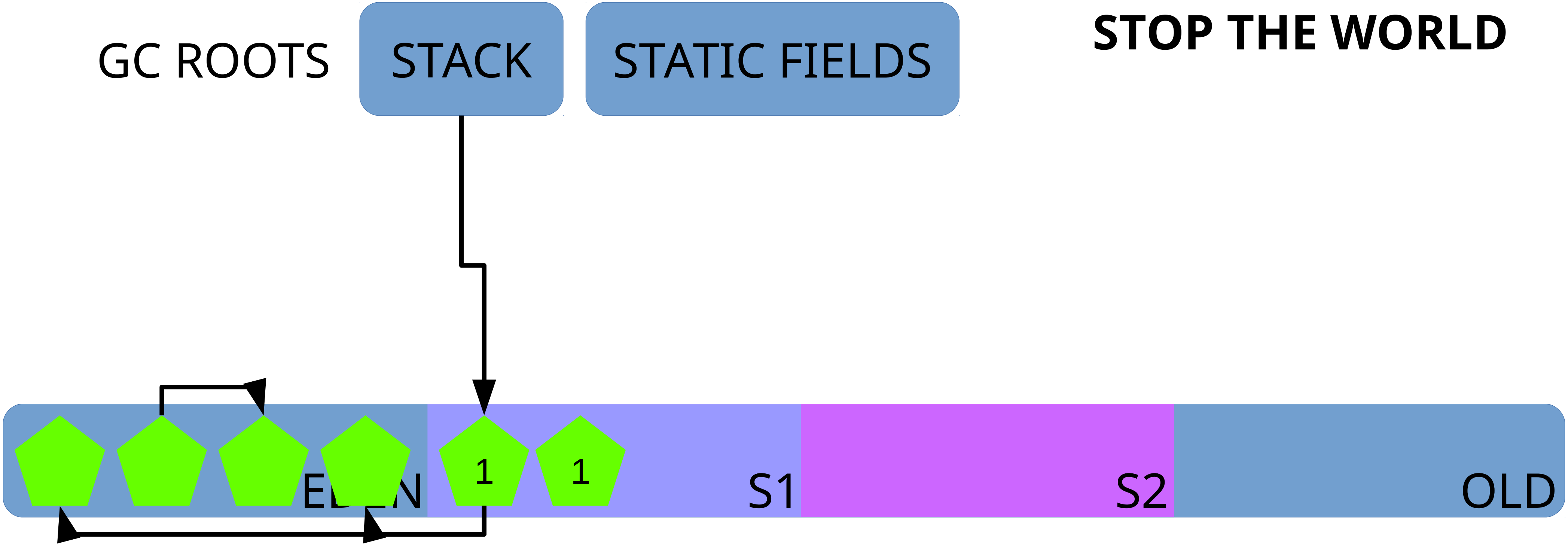


GC ROOTS

STACK

STATIC FIELDS

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

1

1

EDEN

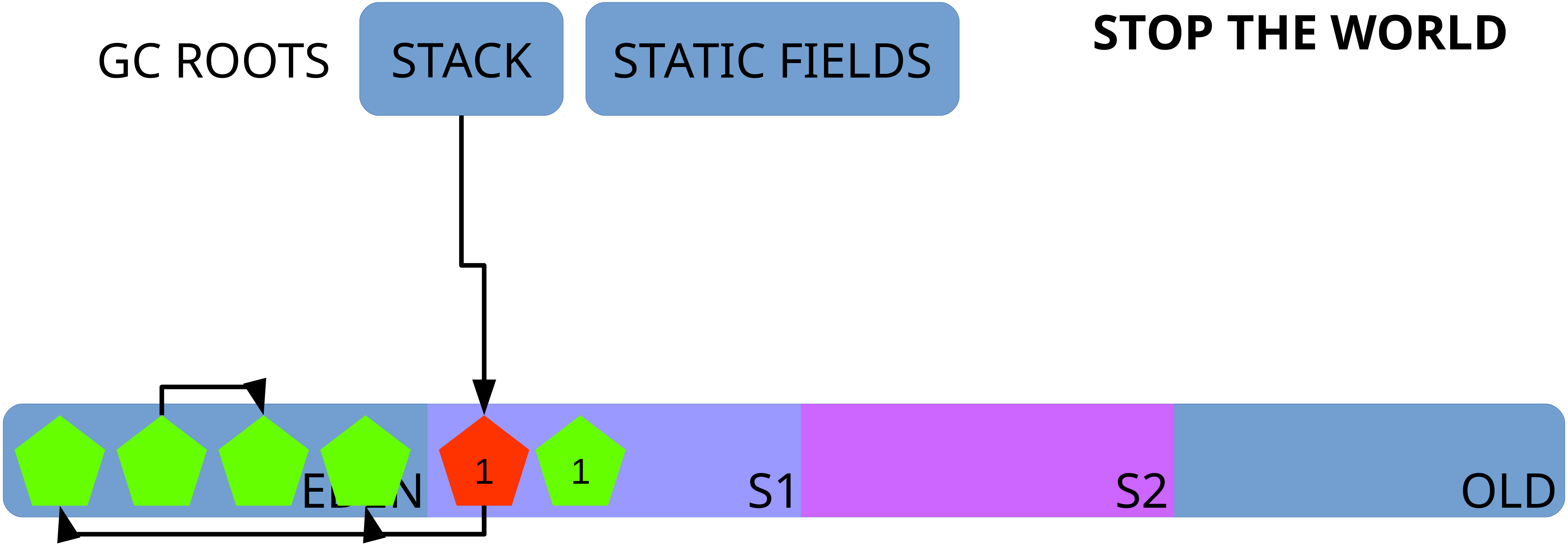
S1

S2

OLD

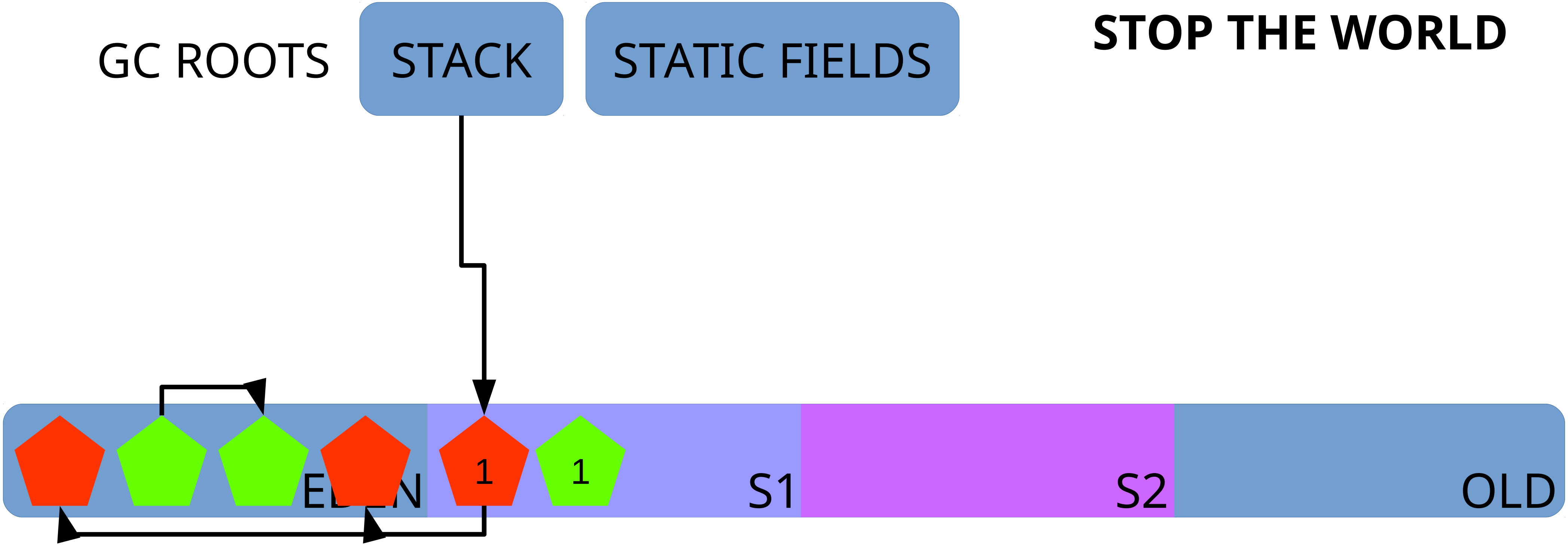
2015-05-26T14:27:41.915-0200: 117.115:
[GC (Allocation Failure) ...]

STOP THE WORLD



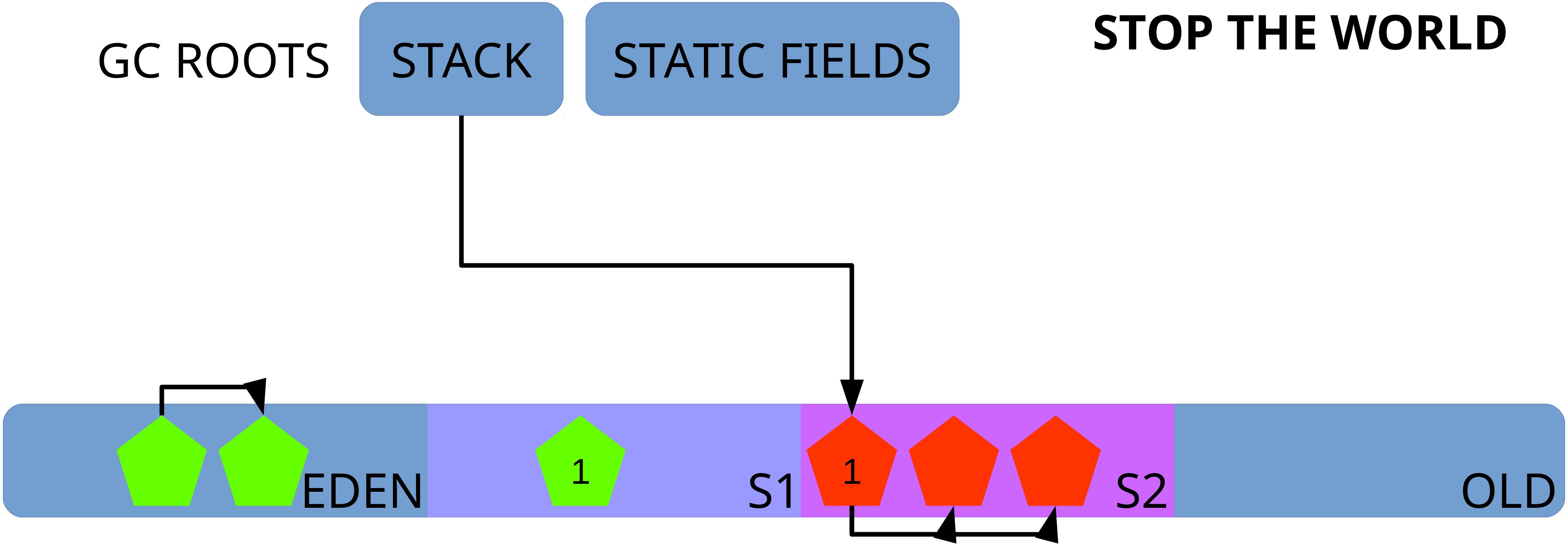
Find live objects, starting from GC roots (mark)

STOP THE WORLD



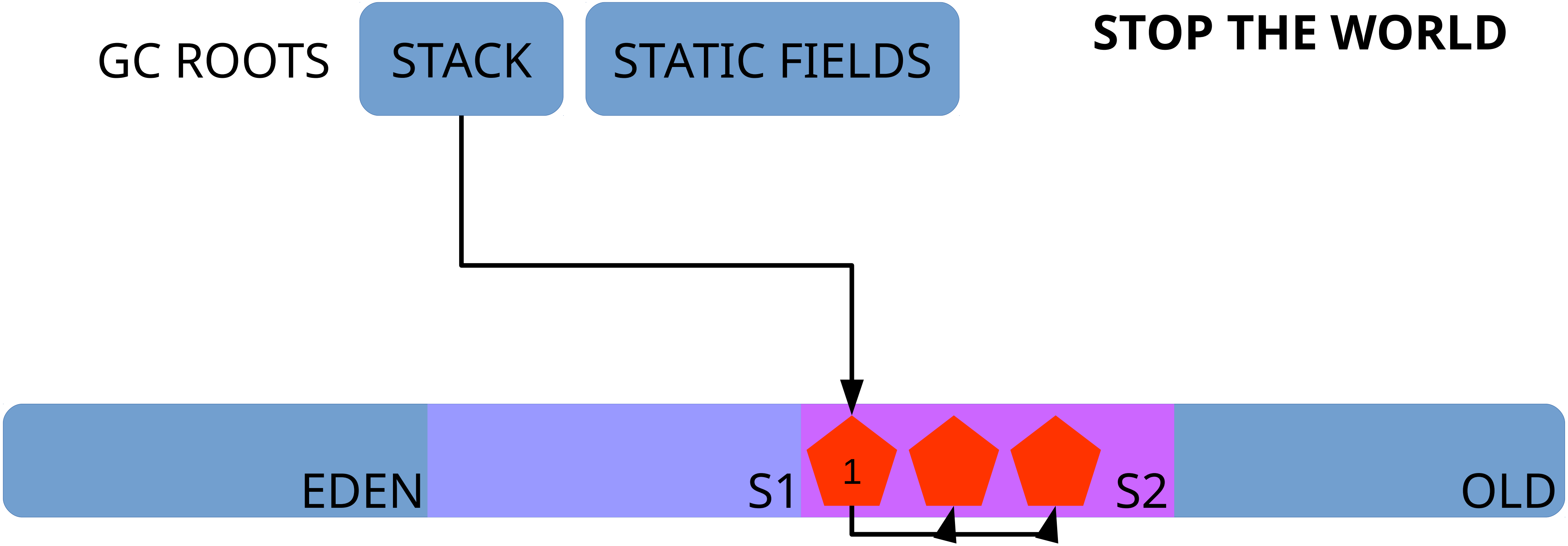
Find live objects, starting from GC roots (mark)

STOP THE WORLD



Move live objects to survivors (compacting)

STOP THE WORLD


GC ROOTS

STACK

STATIC FIELDS

1

EDEN

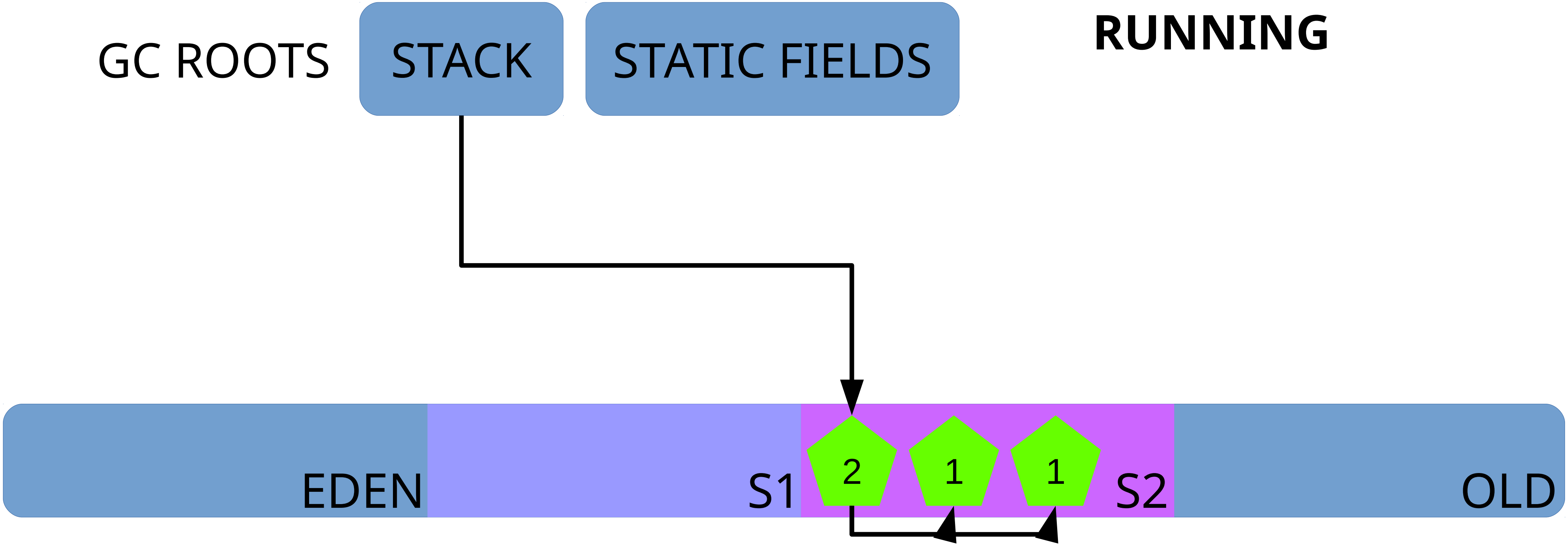
S1

S2

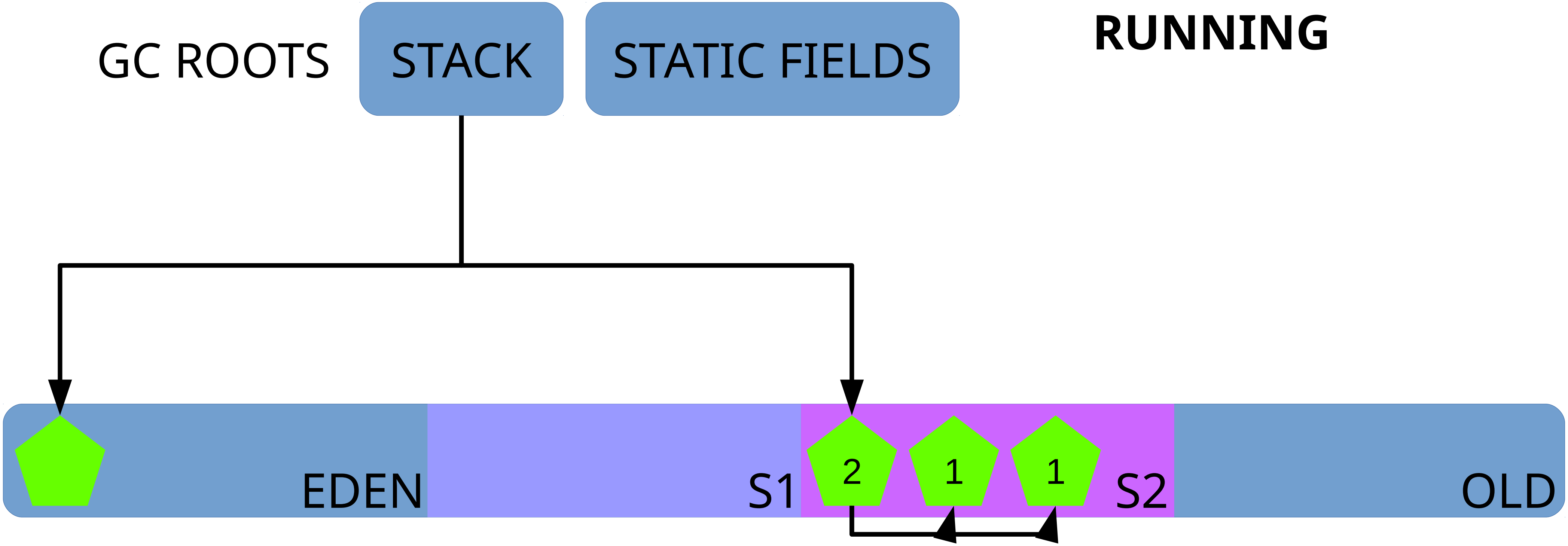
OLD

Mark EDEN+S1 as clean
S1/S2 compaction

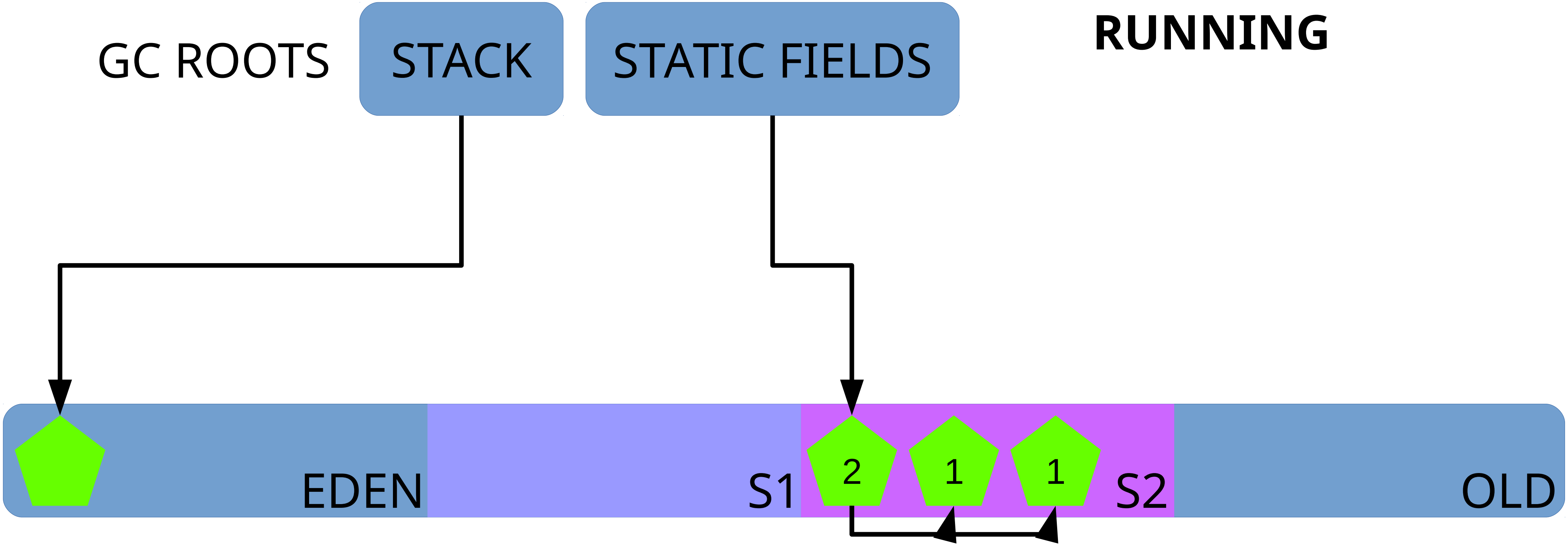
RUNNING



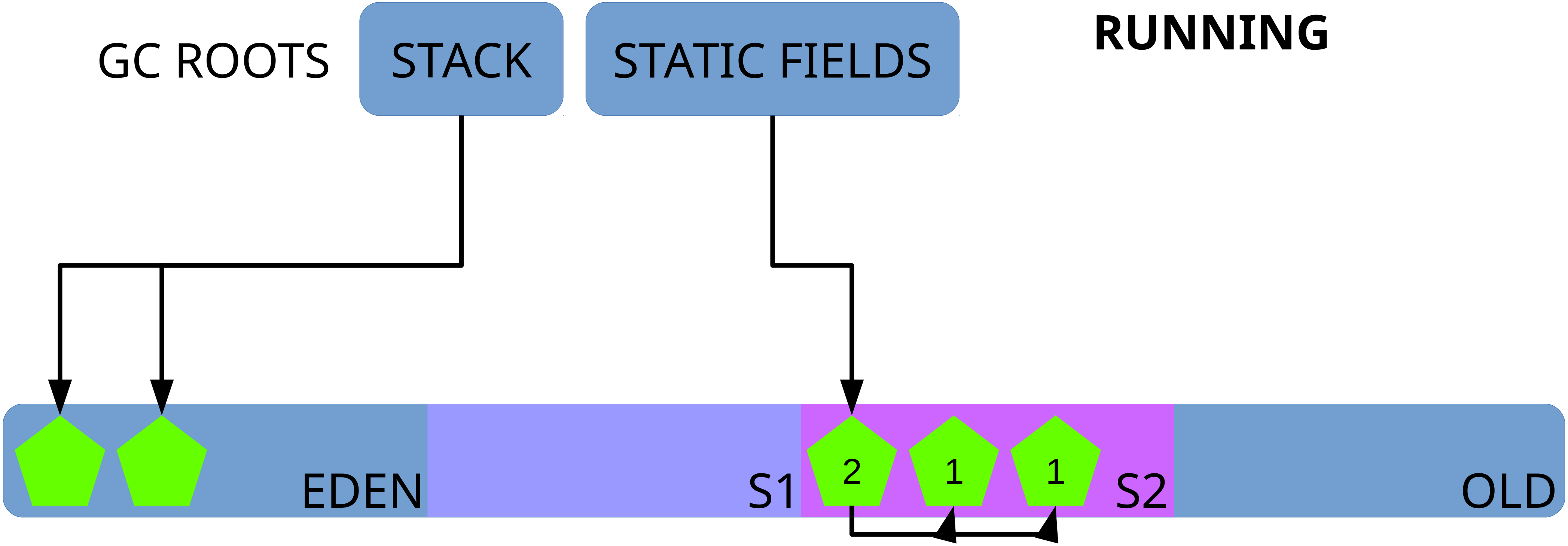
RUNNING



RUNNING



RUNNING



GC ROOTS

STACK

STATIC FIELDS

EDEN

S1

2

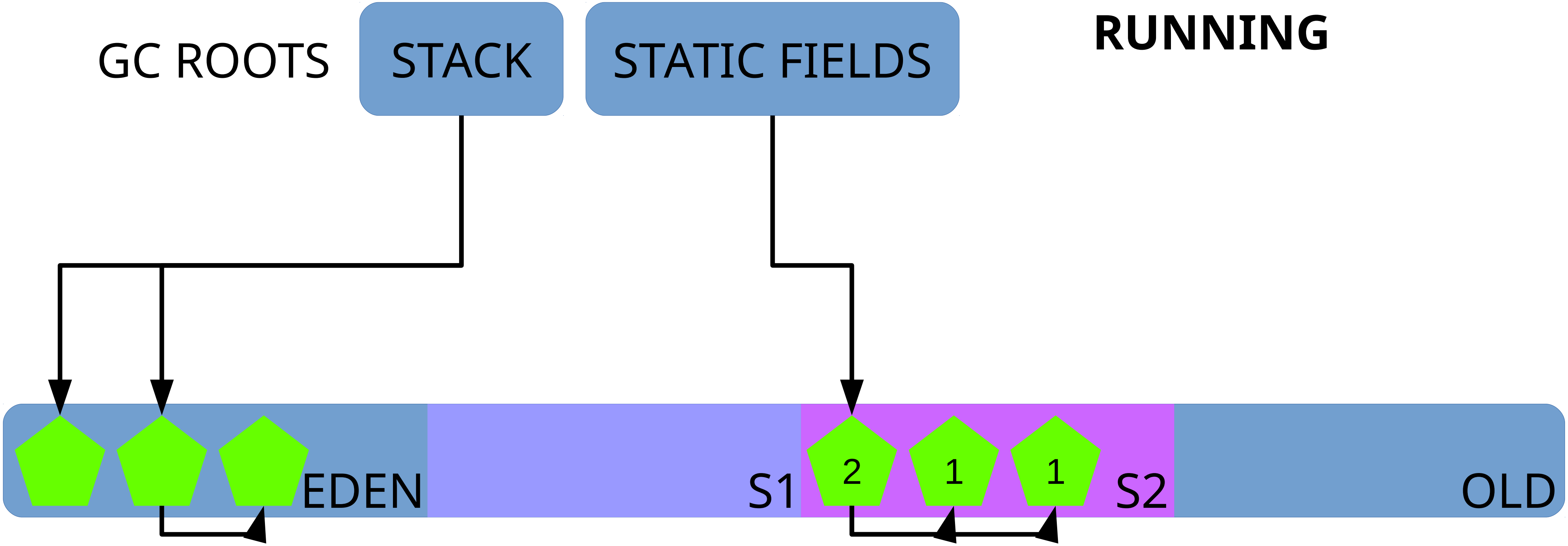
1

1

S2

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

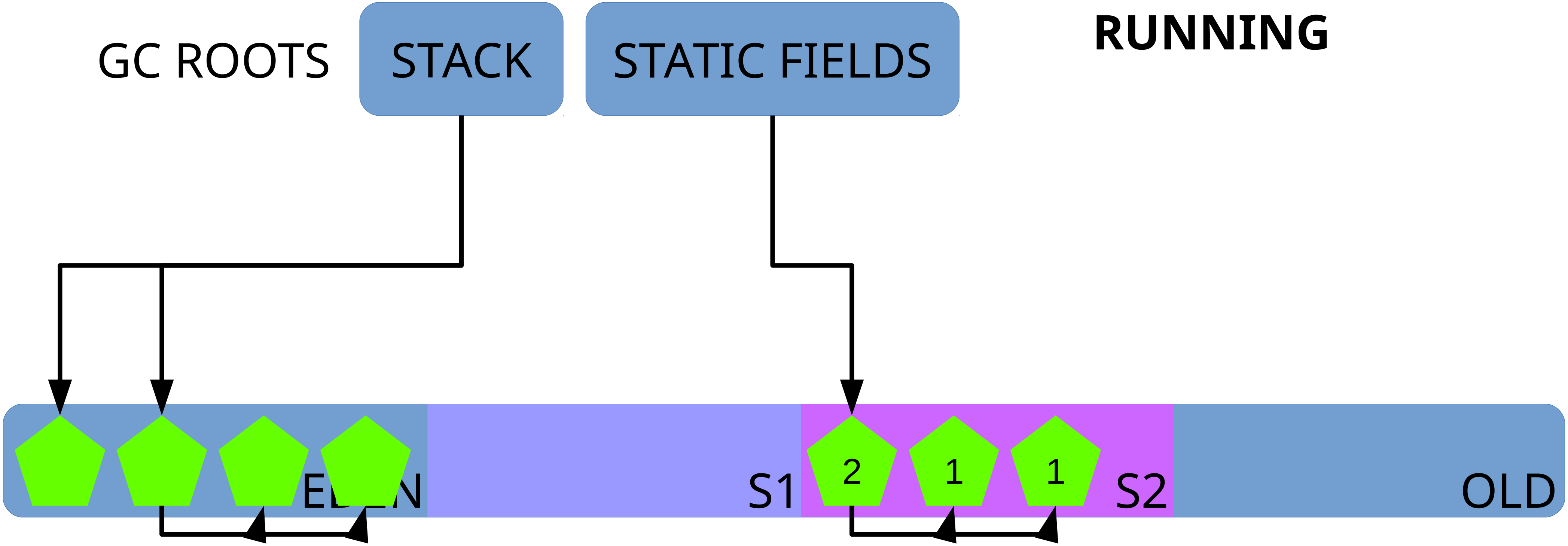
EDEN

S1

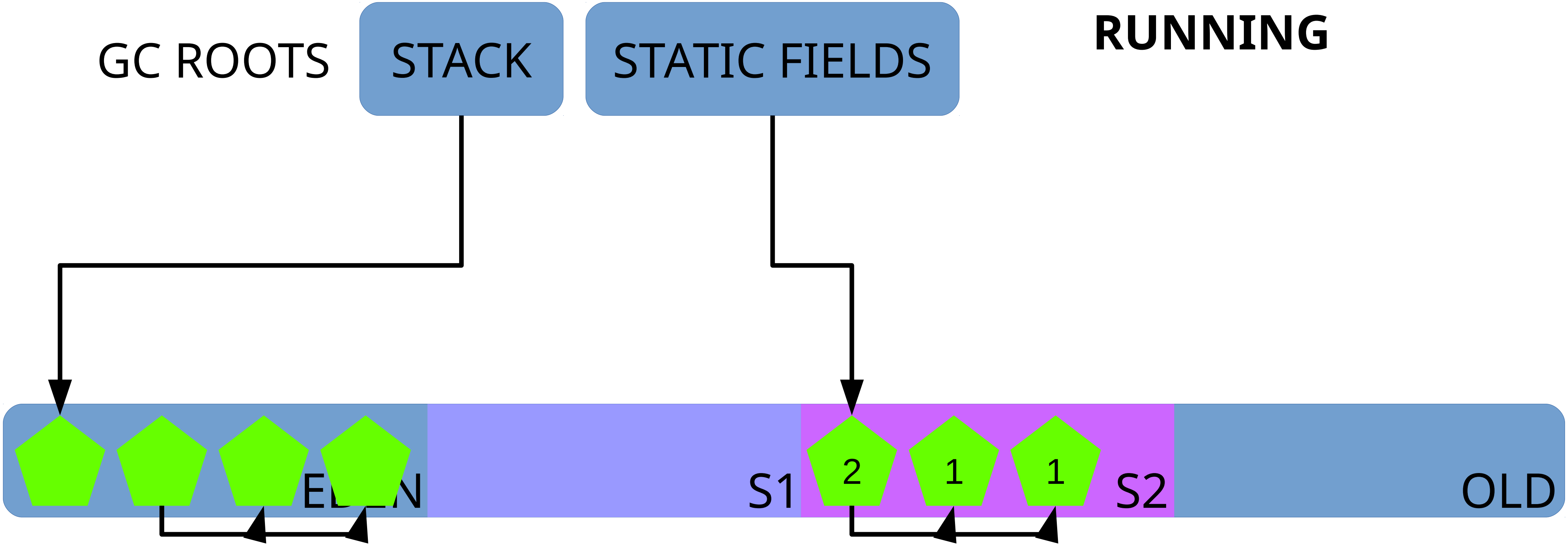
S2

OLD

RUNNING



RUNNING



GC ROOTS

STACK

STATIC FIELDS

EDEN

S1

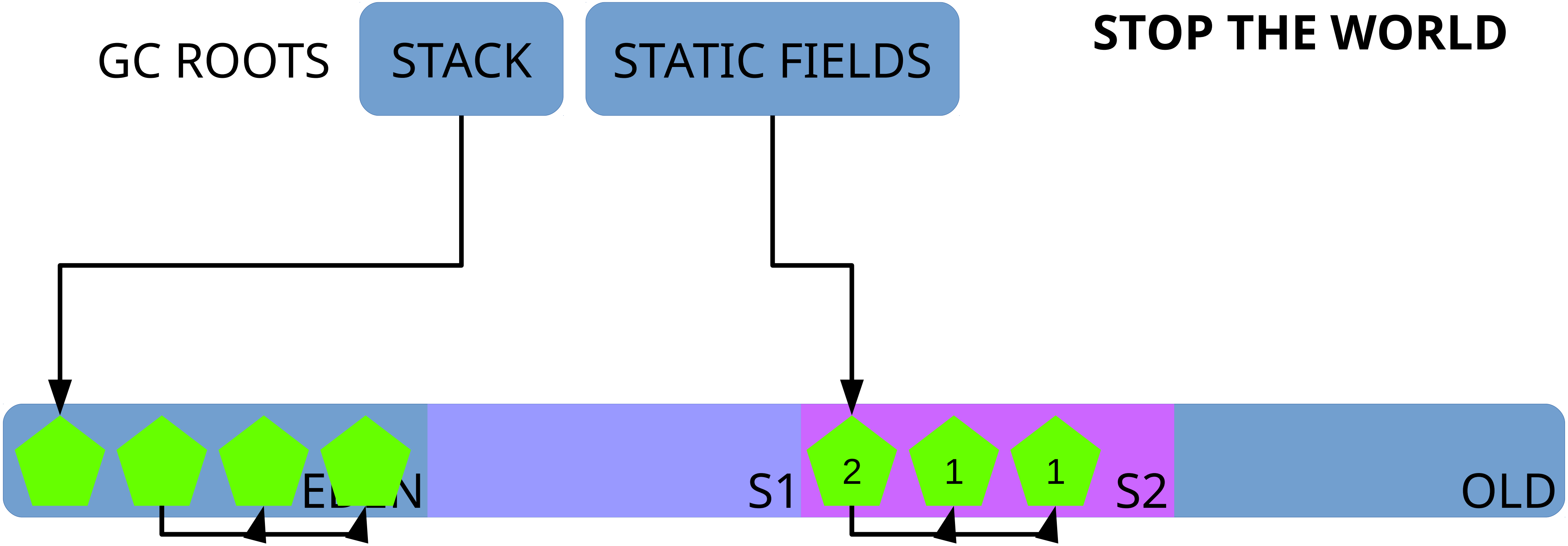
2

1

1

S2

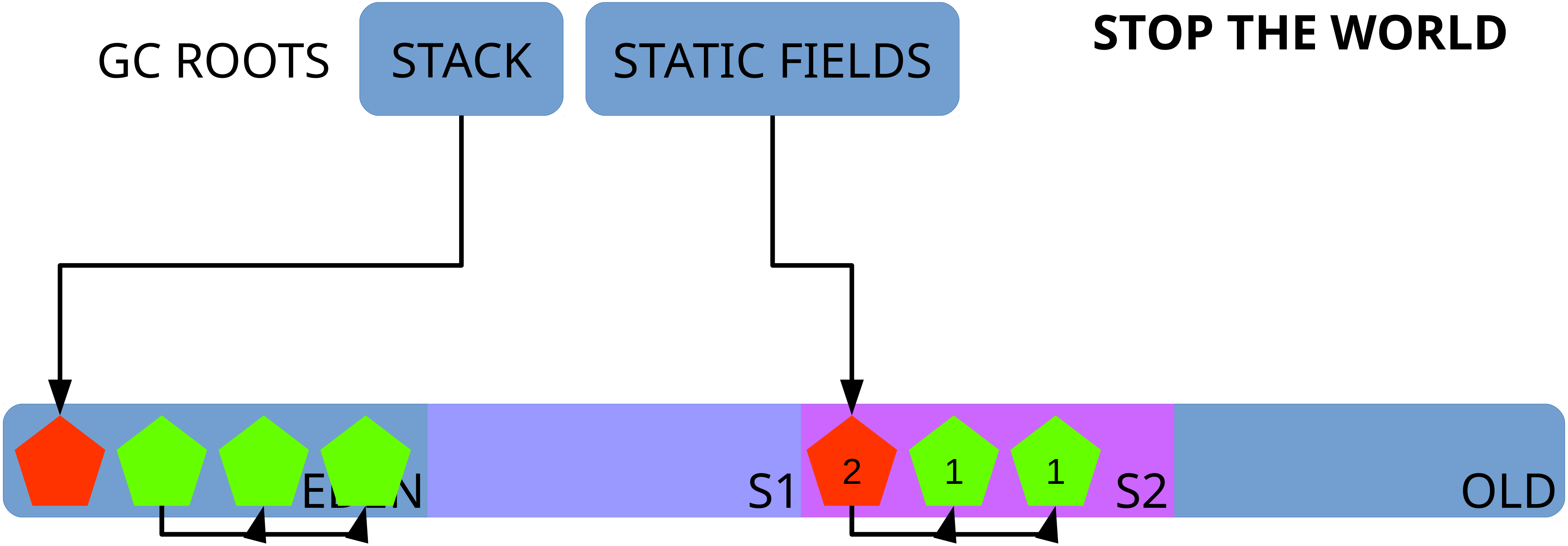
OLD



STOP THE WORLD

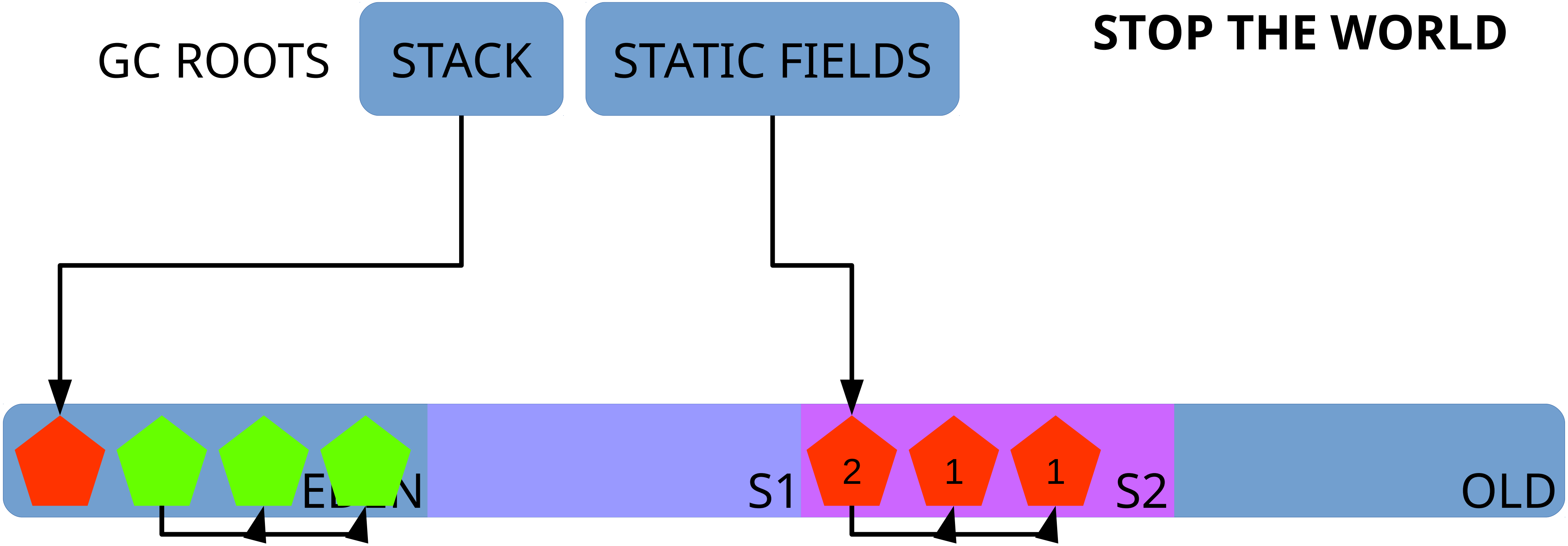
2015-05-26T14:27:43.915-0200: 119.115:
[GC (Allocation Failure) ...]

STOP THE WORLD



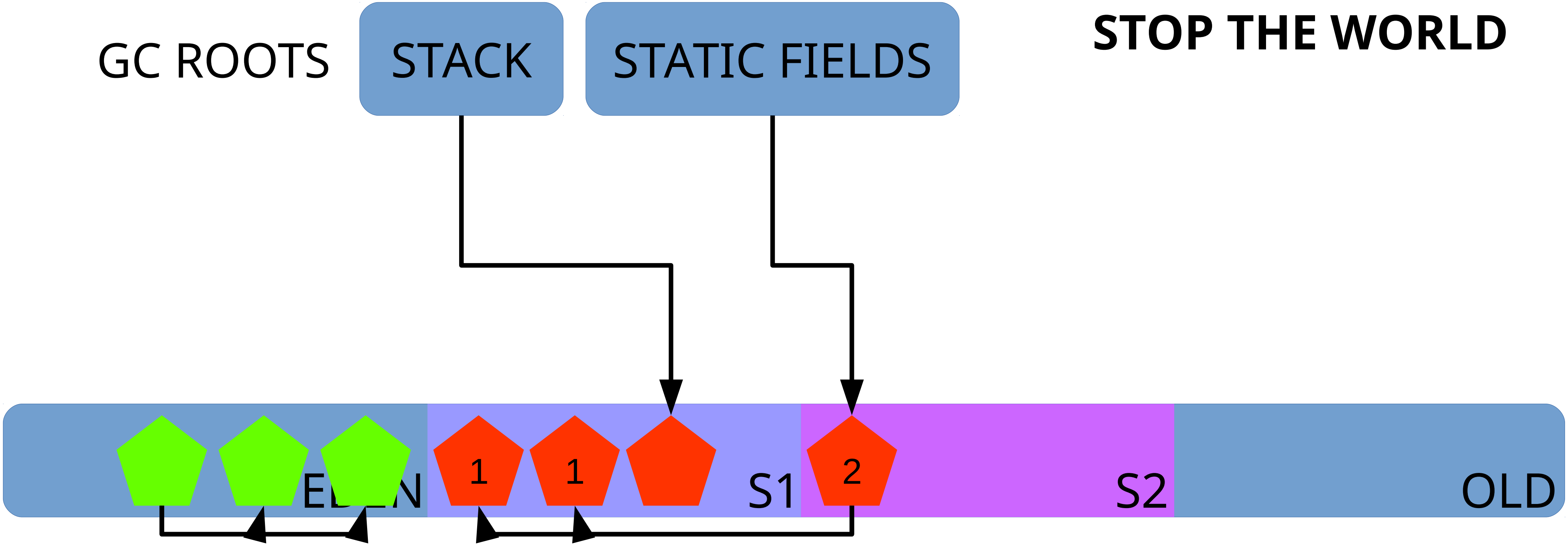
Find live objects, starting from GC roots (mark)

STOP THE WORLD

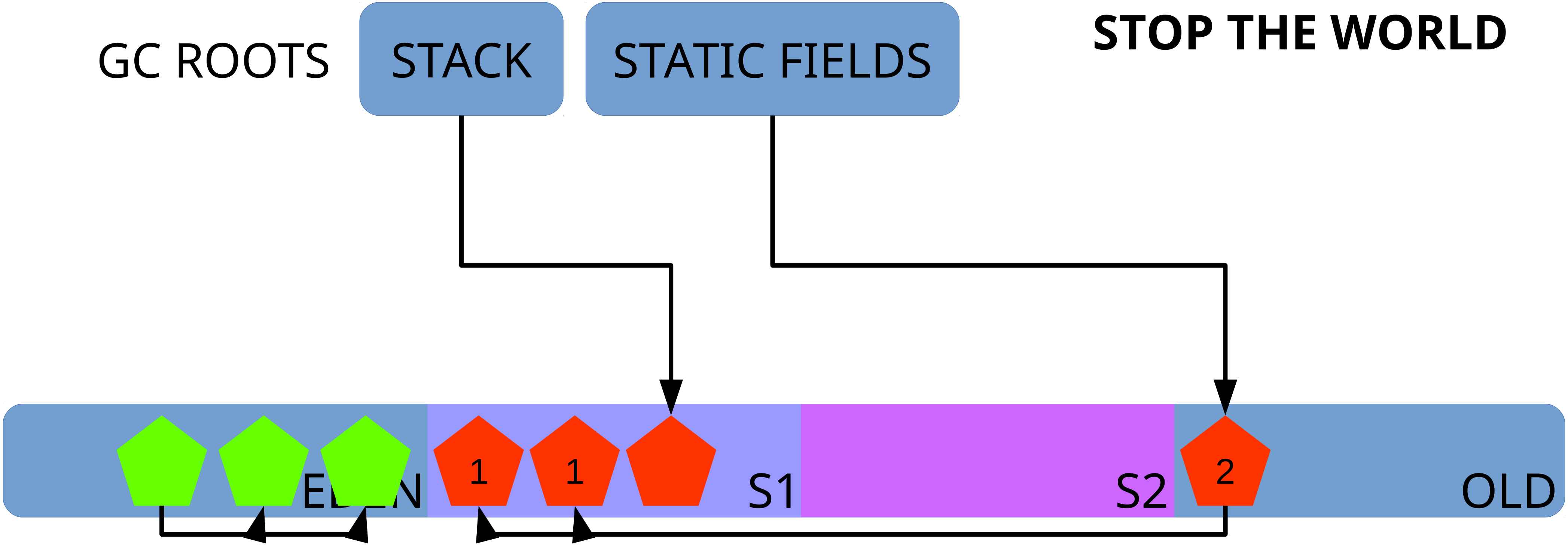


Find live objects, starting from GC roots (mark)

STOP THE WORLD

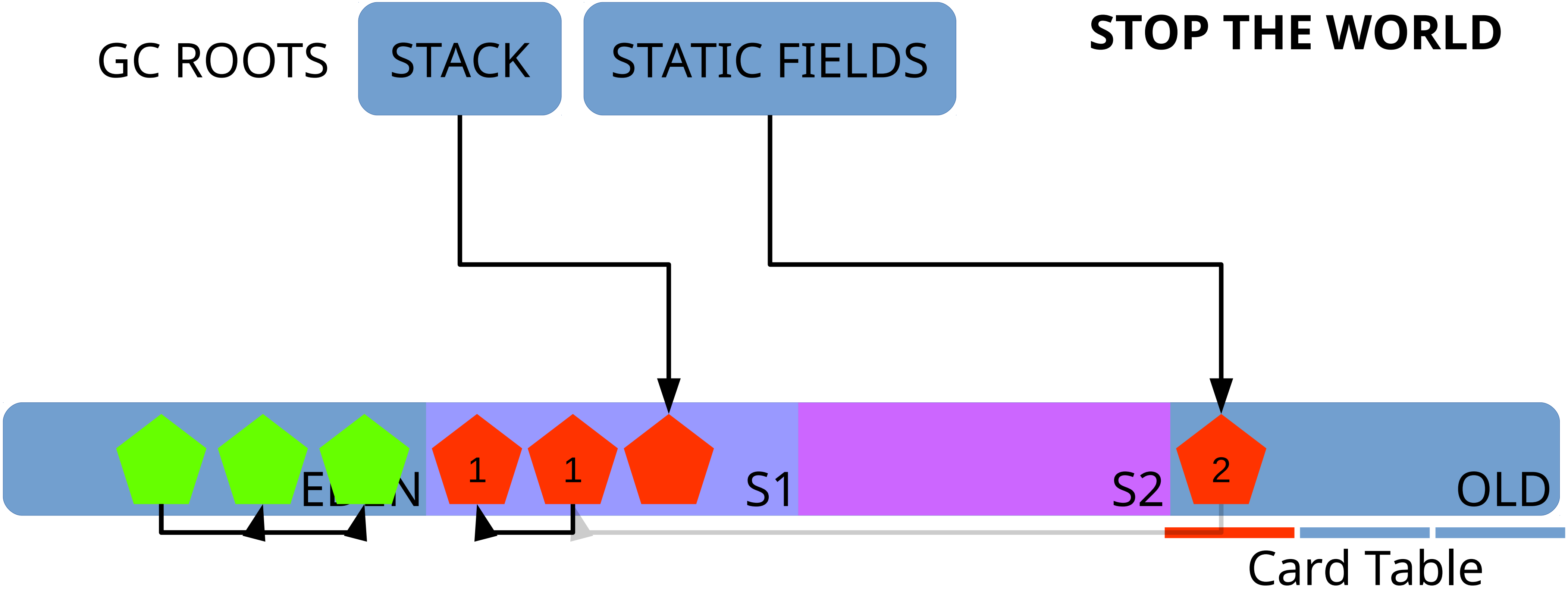


Move live objects to survivors (compacting)



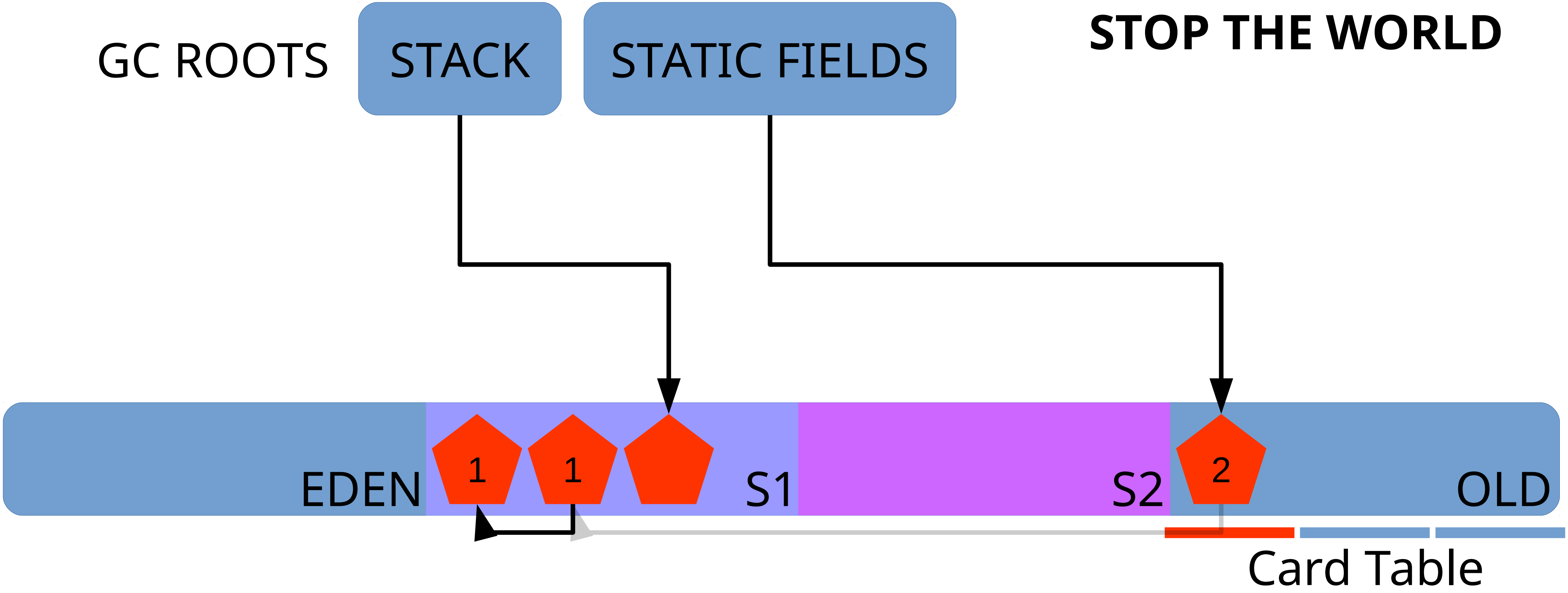
Move live objects to survivors or old (compacting)

STOP THE WORLD



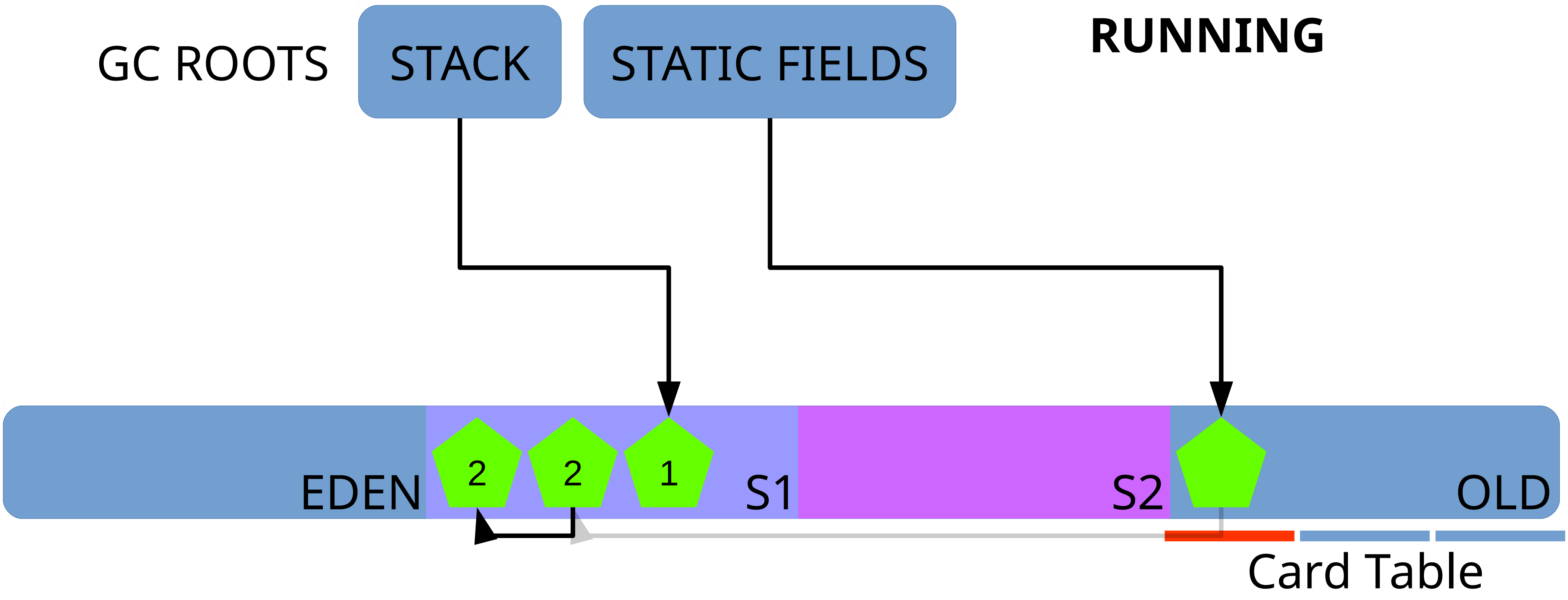
Old Gen has a “Card Table” (card region ~2M)
Identifies regions that reference Young Gen

STOP THE WORLD

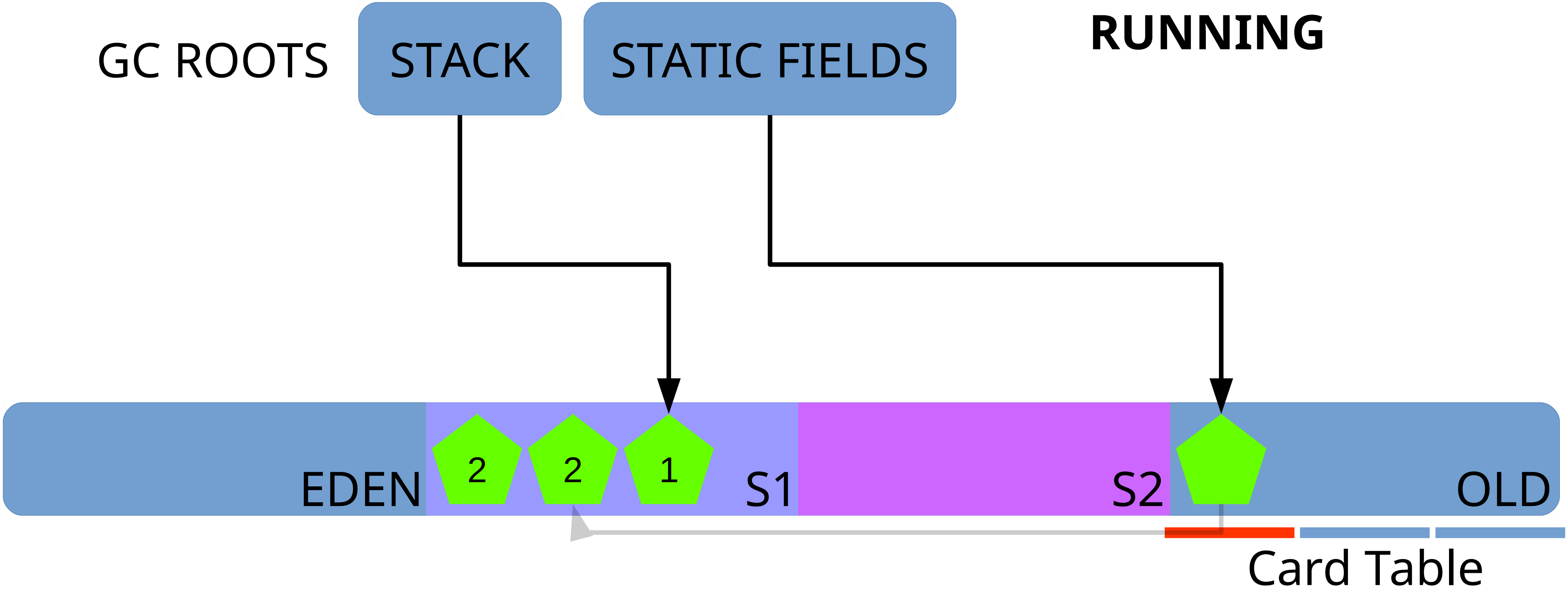


Mark EDEN+S2 as clean

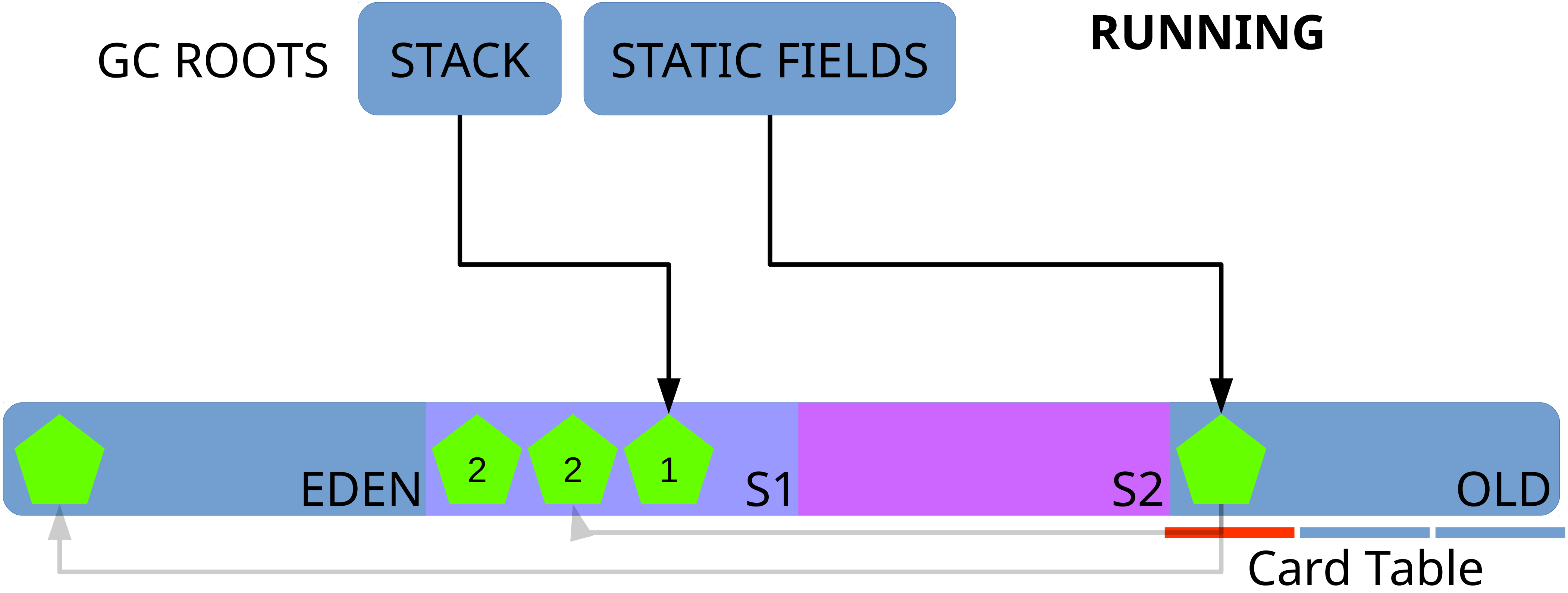
RUNNING



RUNNING



RUNNING



GC ROOTS

STACK

STATIC FIELDS

EDEN

2

2

1

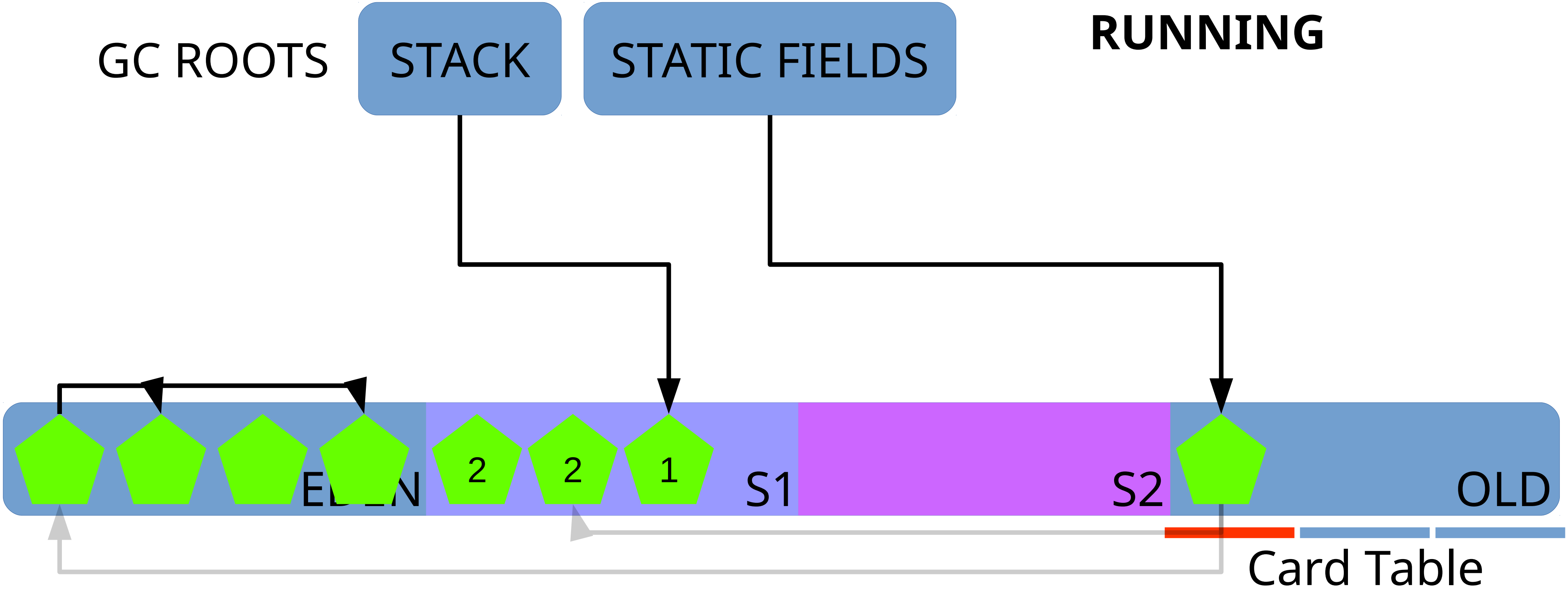
S1

S2

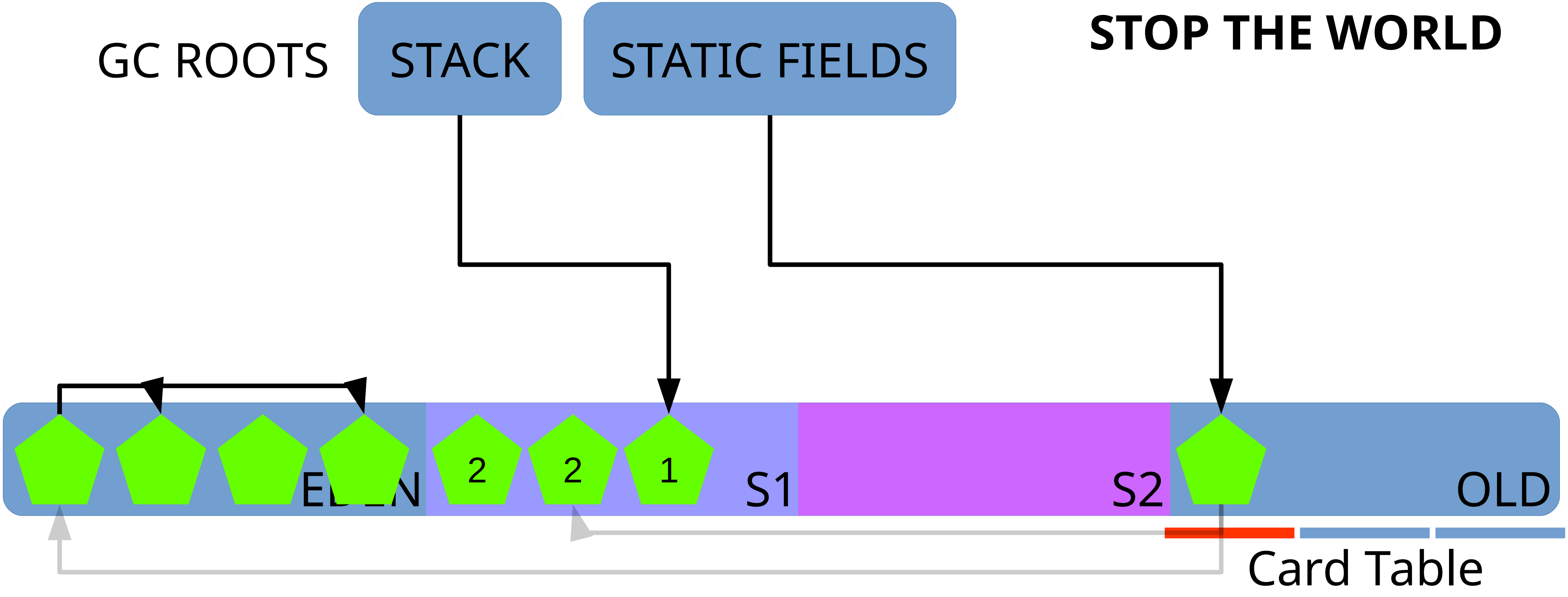
OLD

Card Table

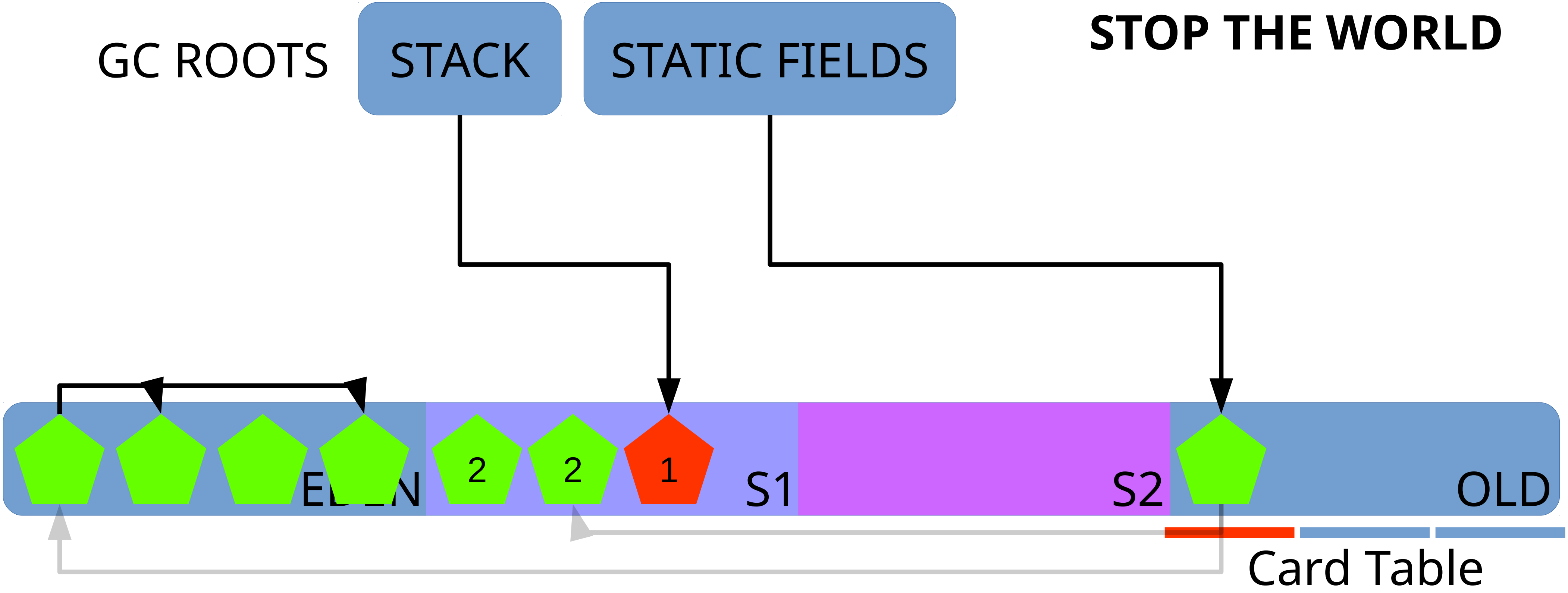
RUNNING



STOP THE WORLD

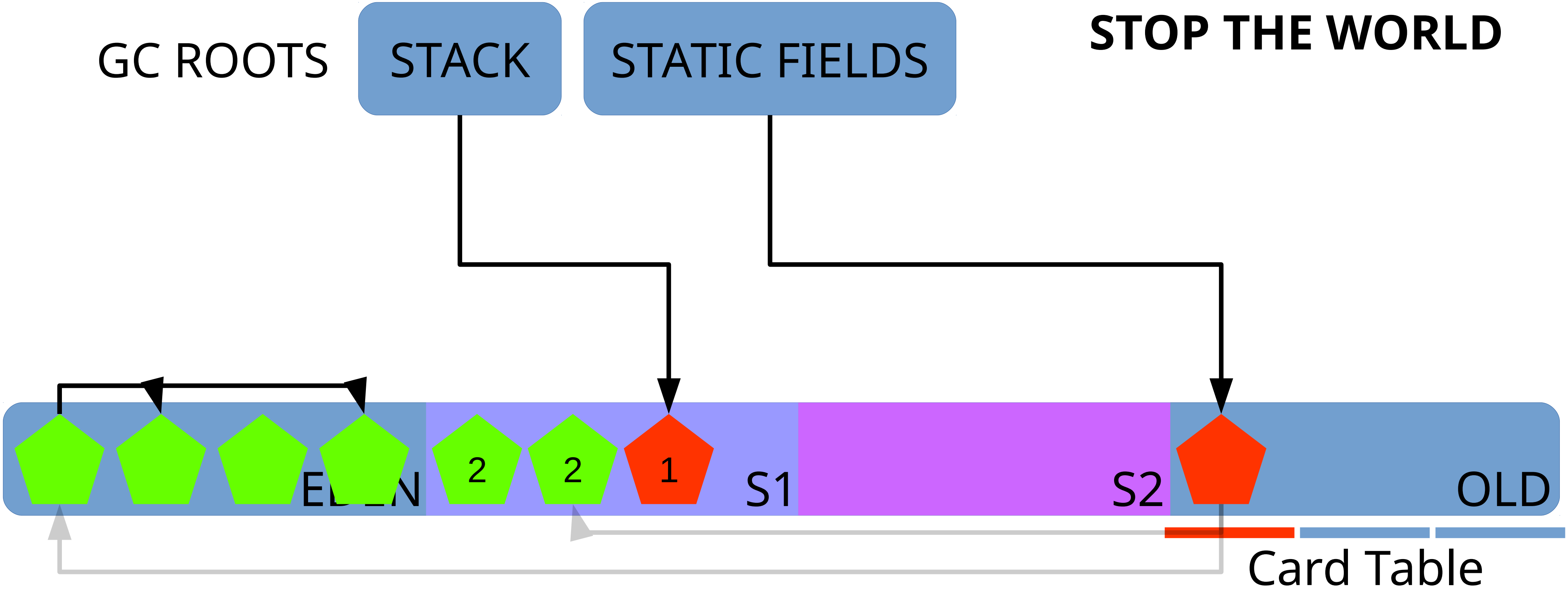


```
2015-05-26T14:27:44.915-0200: 120.115:
[GC (Allocation Failure) ... ]
```



Find live objects, starting from GC roots (mark)
* Don’t look for live objects in Old Gen

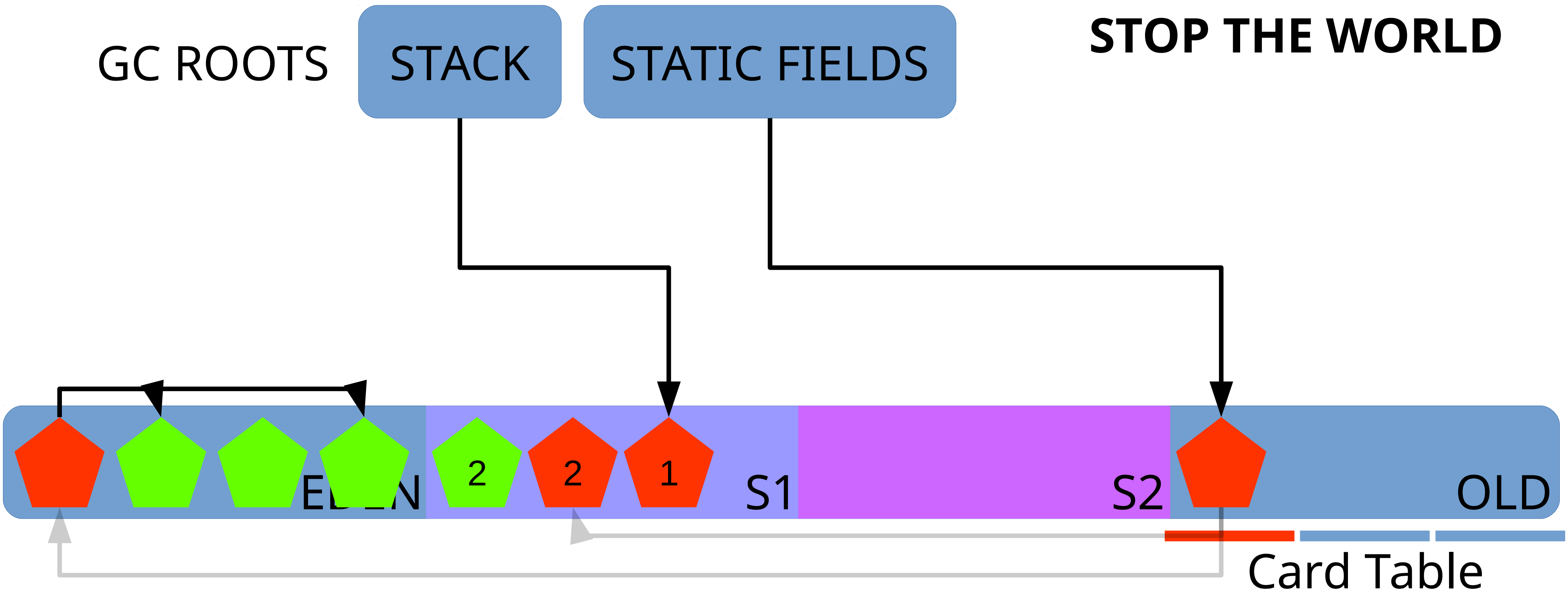
STOP THE WORLD



Find live objects, starting from GC roots (mark)

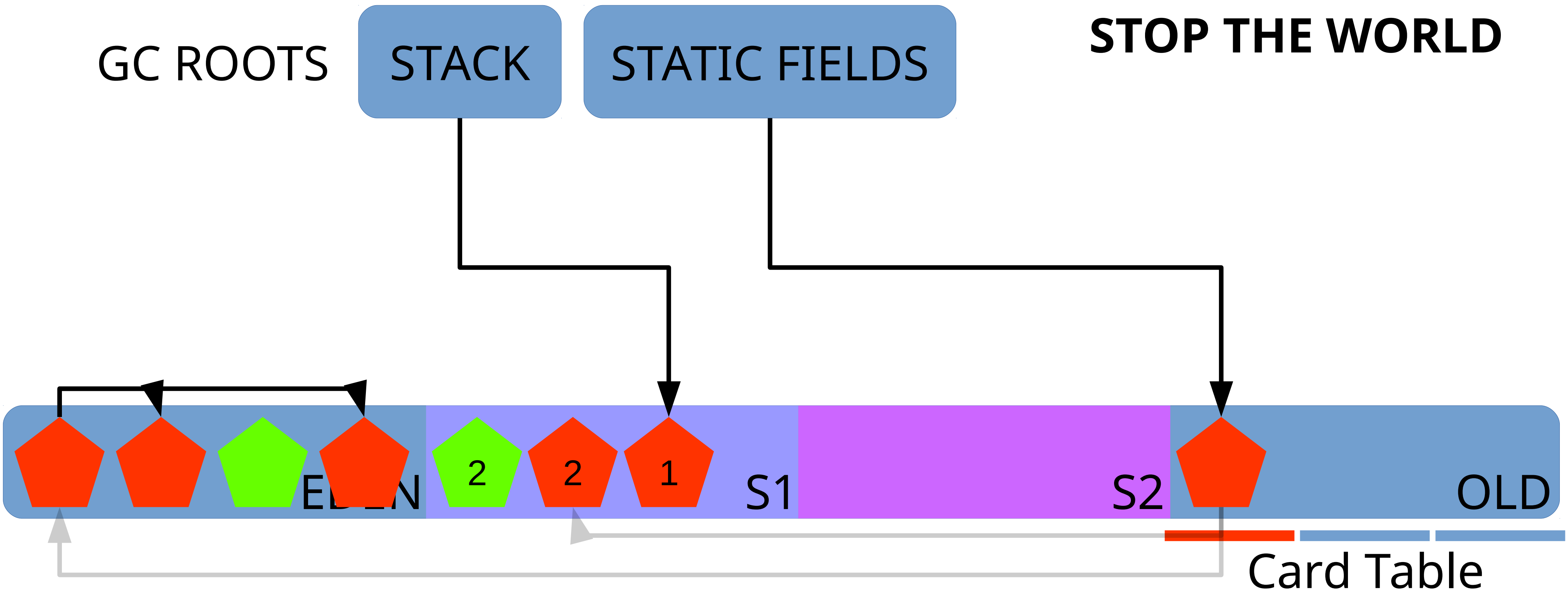
* Don’t look for live objects in Old Gen

* Scan Card Table regions for extra references



Find live objects, starting from GC roots (mark)
* Don’t look for live objects in Old Gen
* Scan Card Table regions for extra references

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

EDEN

2

2

1

S1

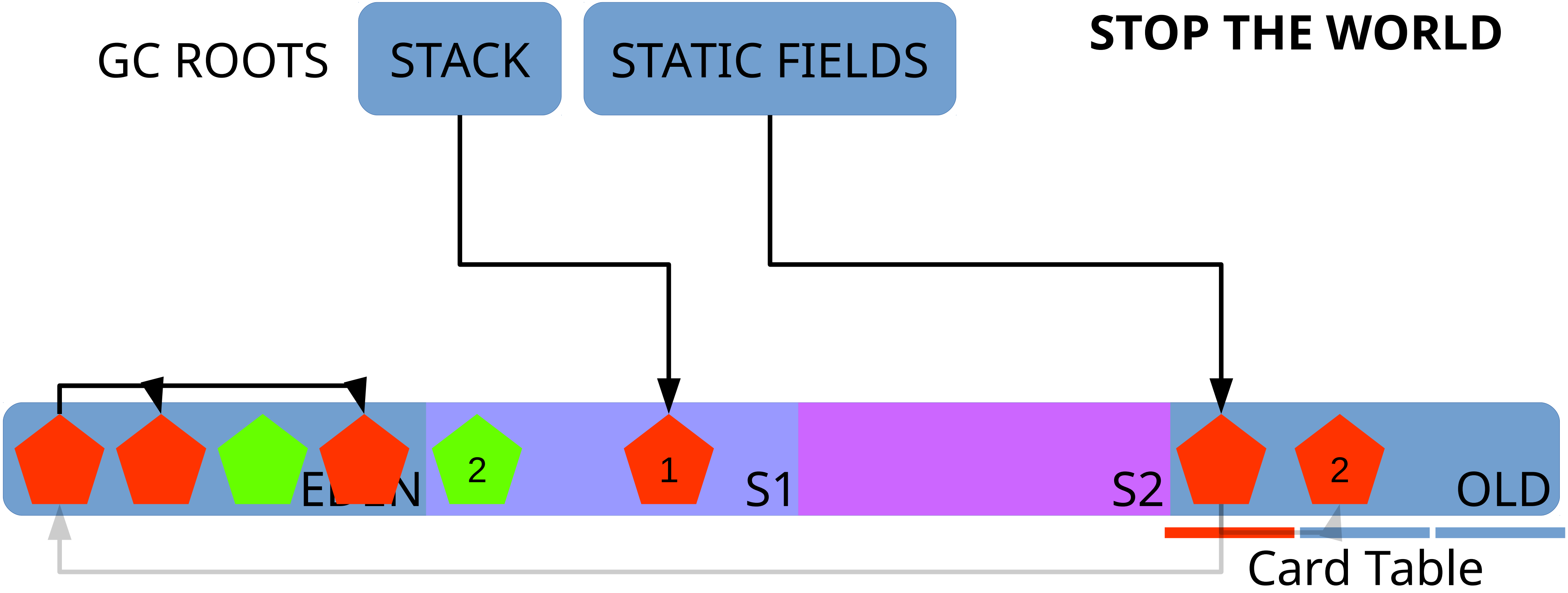
S2

OLD

Card Table

Find live objects, starting from GC roots (mark)
* Don’t look for live objects in Old Gen
* Scan Card Table regions for extra references

STOP THE WORLD


GC ROOTS

STACK

STATIC FIELDS

EDEN

S1

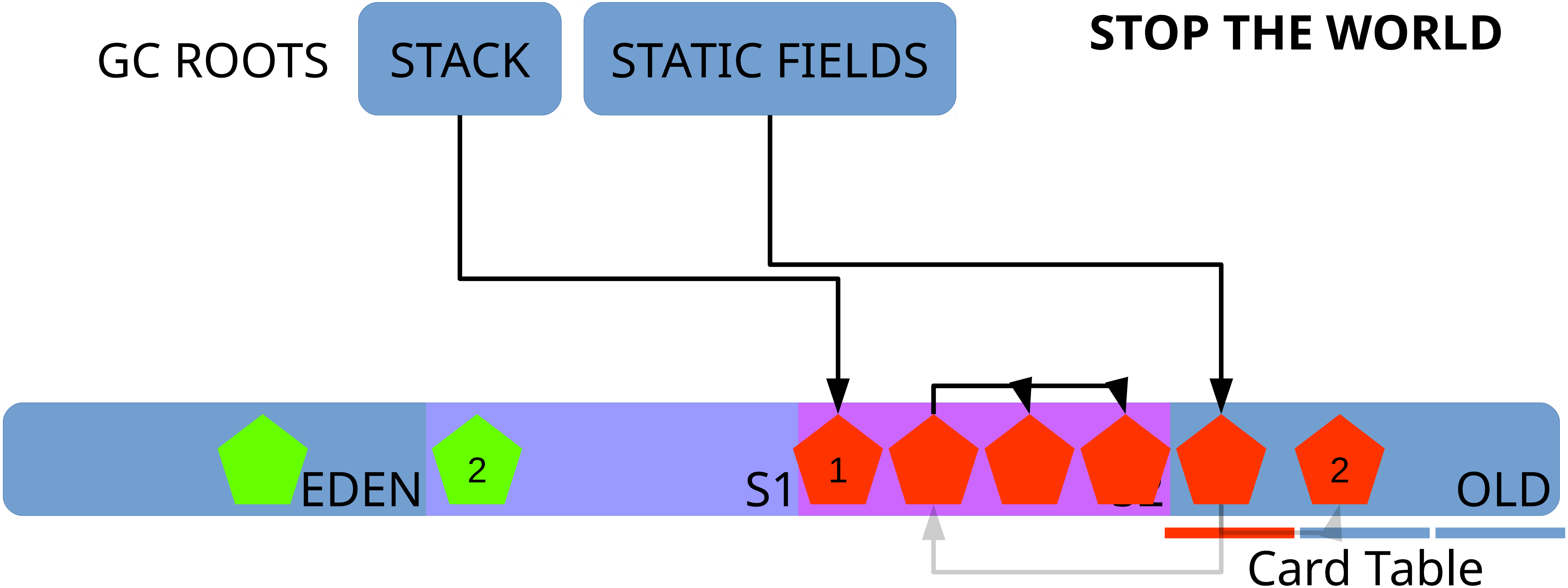
S2

OLD

Card Table

Move live objects to survivors or old (compacting)

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

EDEN

S1

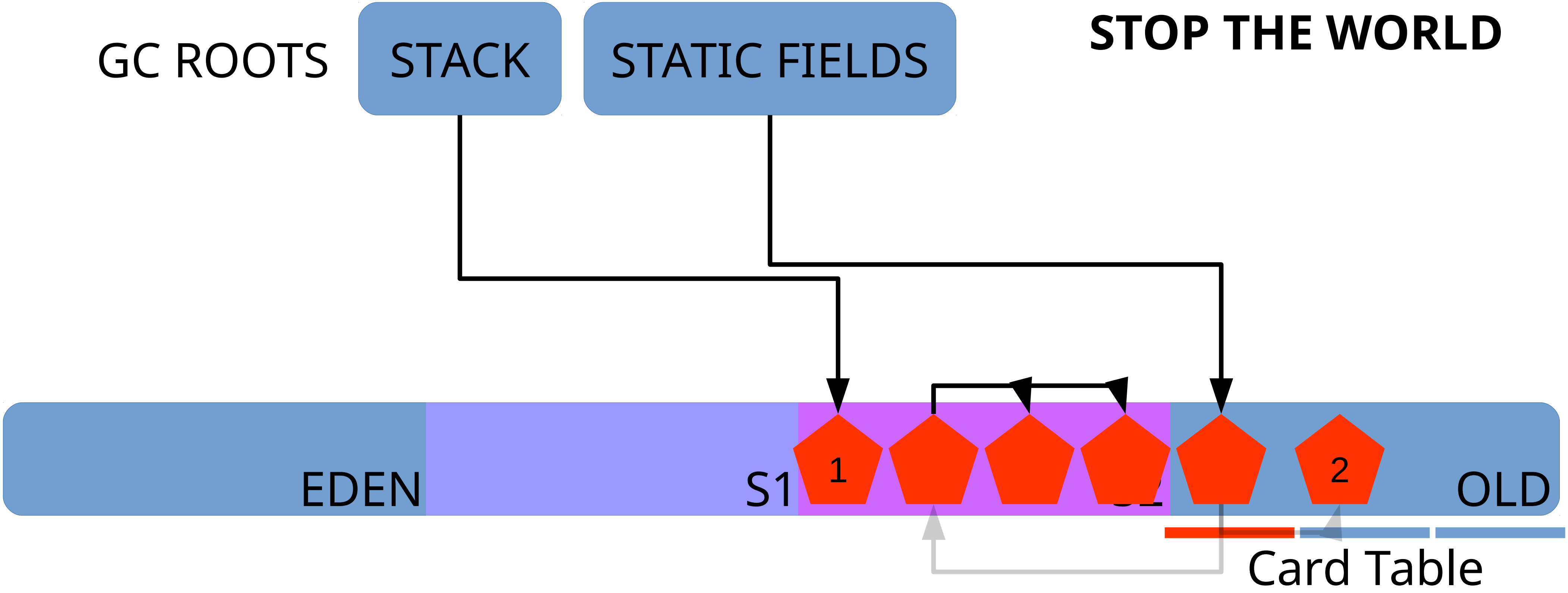
S2

OLD

Card Table

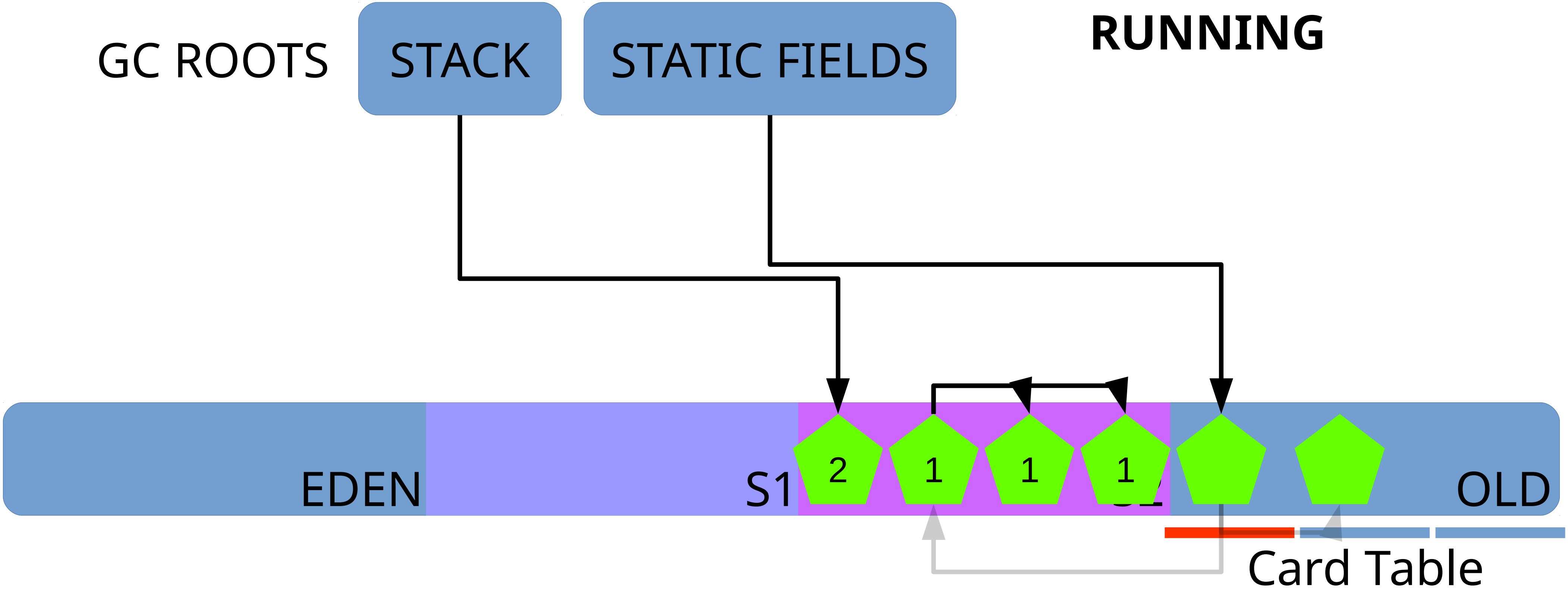
Move live objects to survivors or old (compacting)

STOP THE WORLD



Mark EDEN+S1 as clean

RUNNING



GC ROOTS

STACK

STATIC FIELDS

2

1

1

1

EDEN

S1

OLD

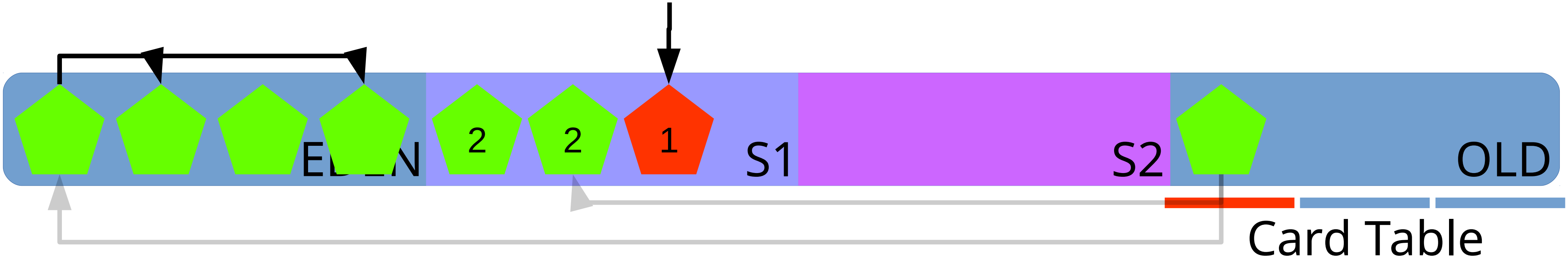
Card Table

Recap: ParallelGC

- Allocate to eden
- Copy live objects to survivors or old
- Clear entire eden + cleared survivor space
- Promote repeat-survivors to Old gen
- Use Card Tables to avoid scanning Old gen
- Use Old objects as GC roots in minor collection
- Full GC when everything is full

ParallelGC insights (1)

- Reference scanning expensive
- size(Old) > size(Young)
- Card Table -> avoid most scanning



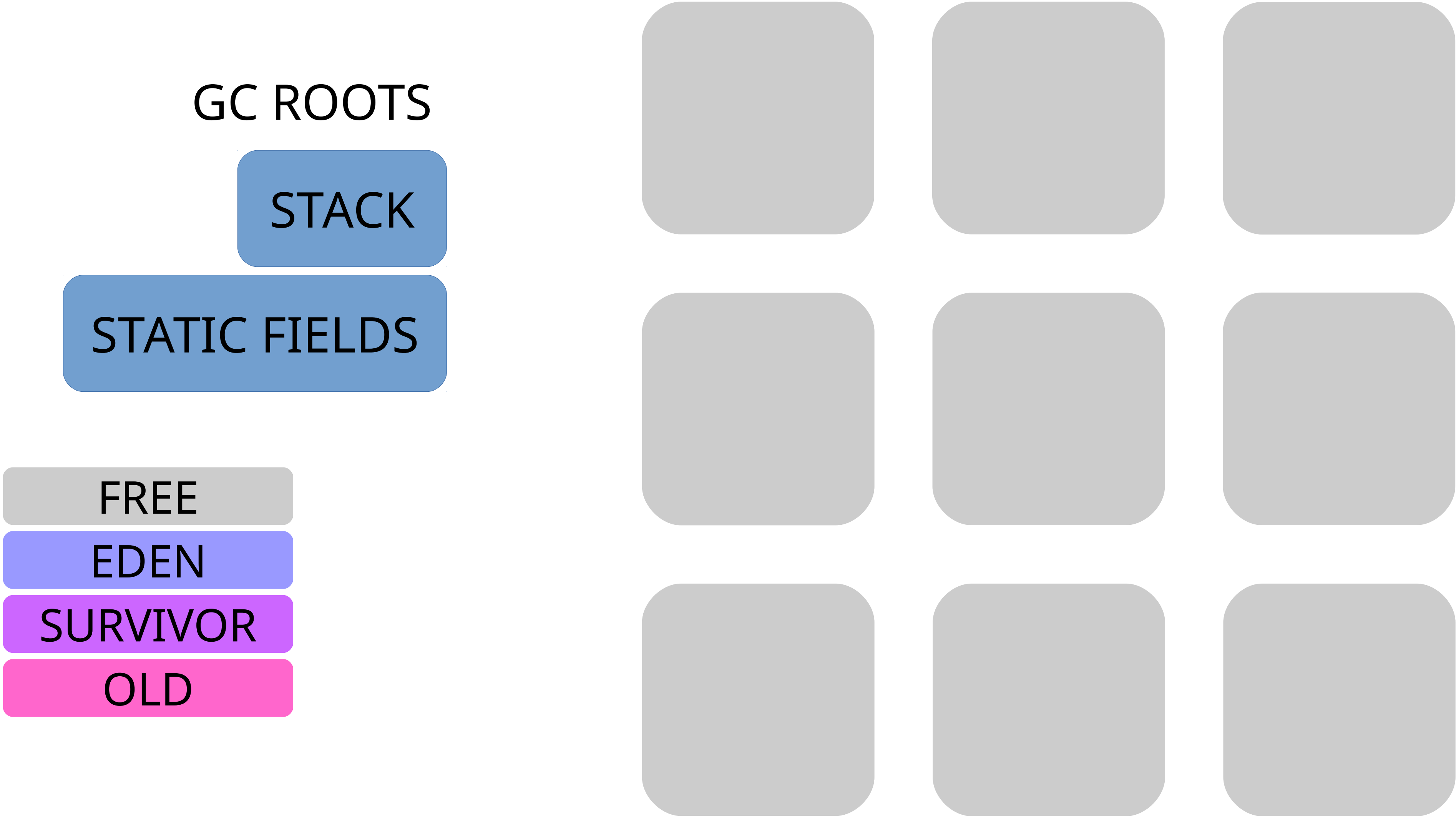
ParallelGC insights (2)

- Objects die young
- Copy only live objects
- Don’t touch Old Gen until Full GC

G1

- Generational: young (eden, survivor), old
- Aims for short Stop The World pauses
- Thousands of non-contiguous regions
- Concurrent marking

RUNNING/ STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

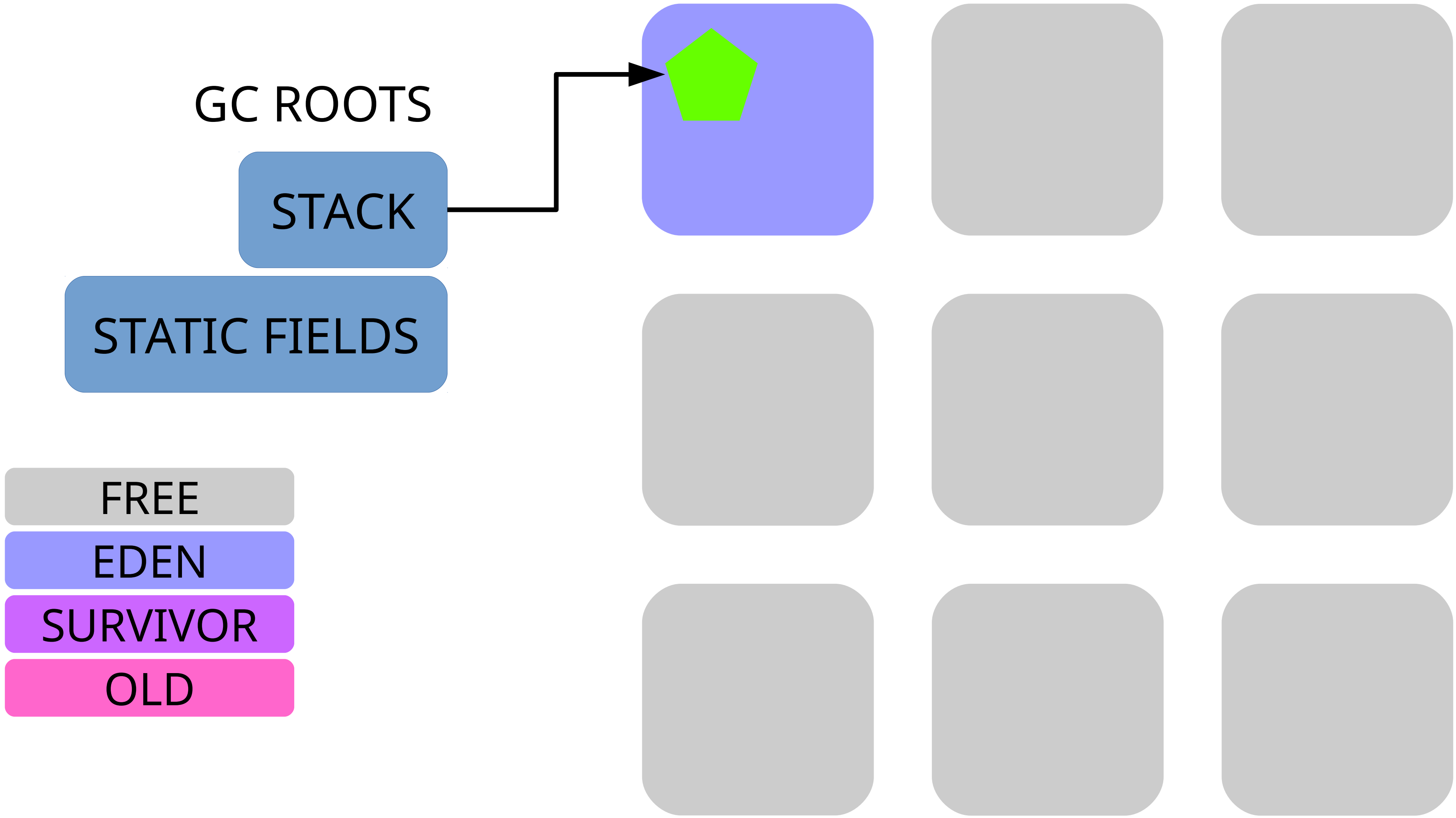
FREE

EDEN

SURVIVOR

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

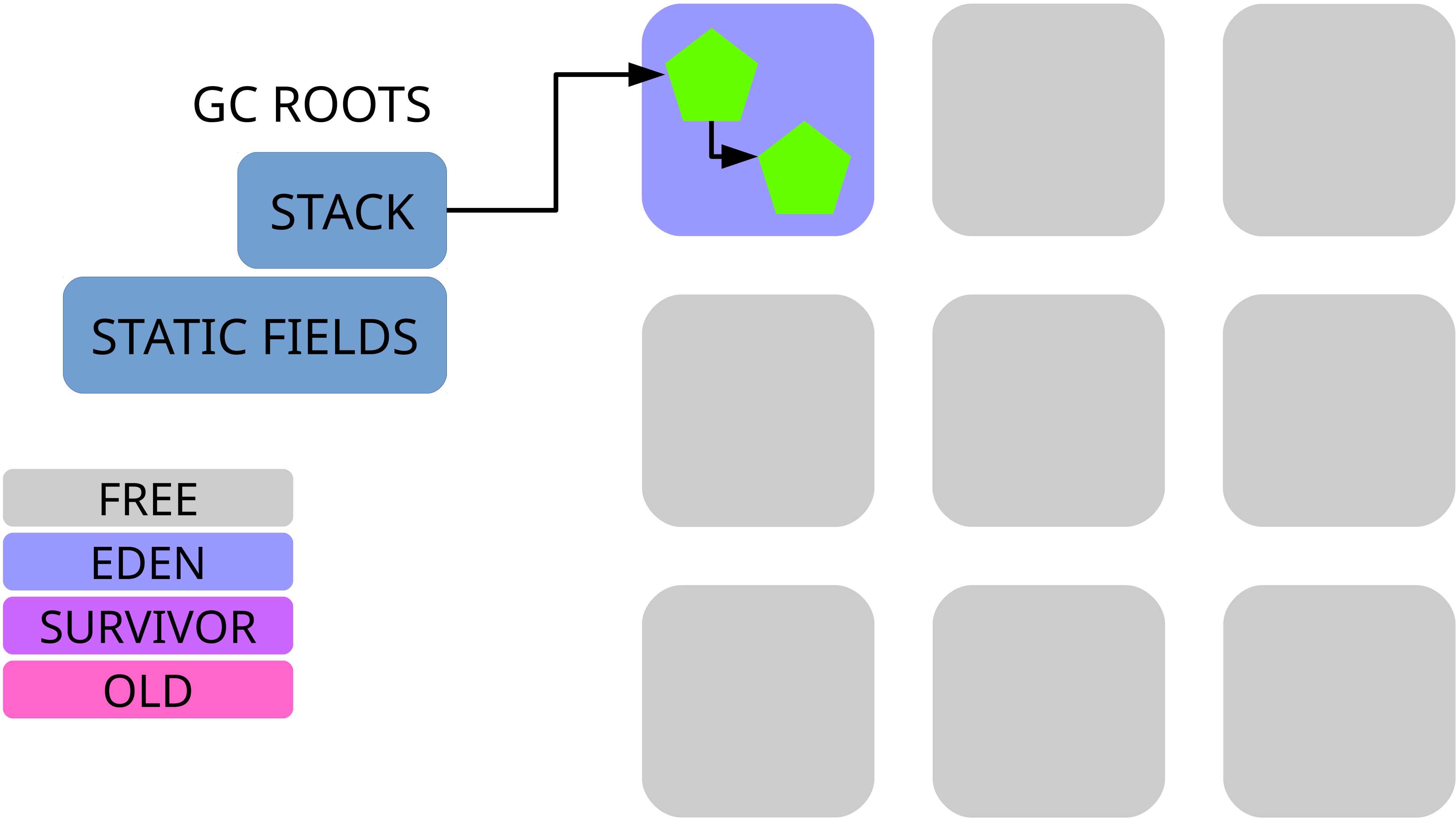
FREE

EDEN

SURVIVOR

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

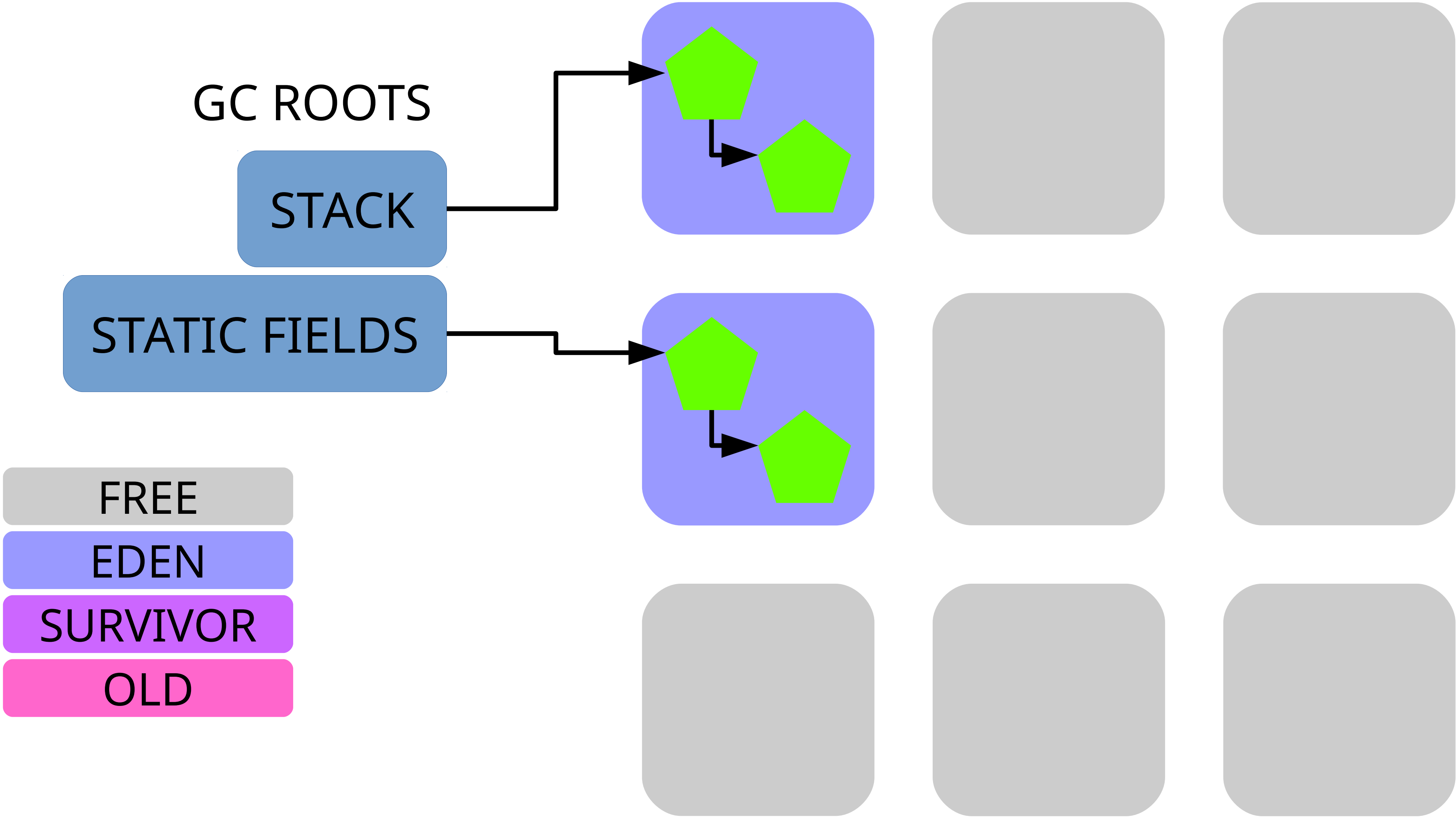
FREE

EDEN

SURVIVOR

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

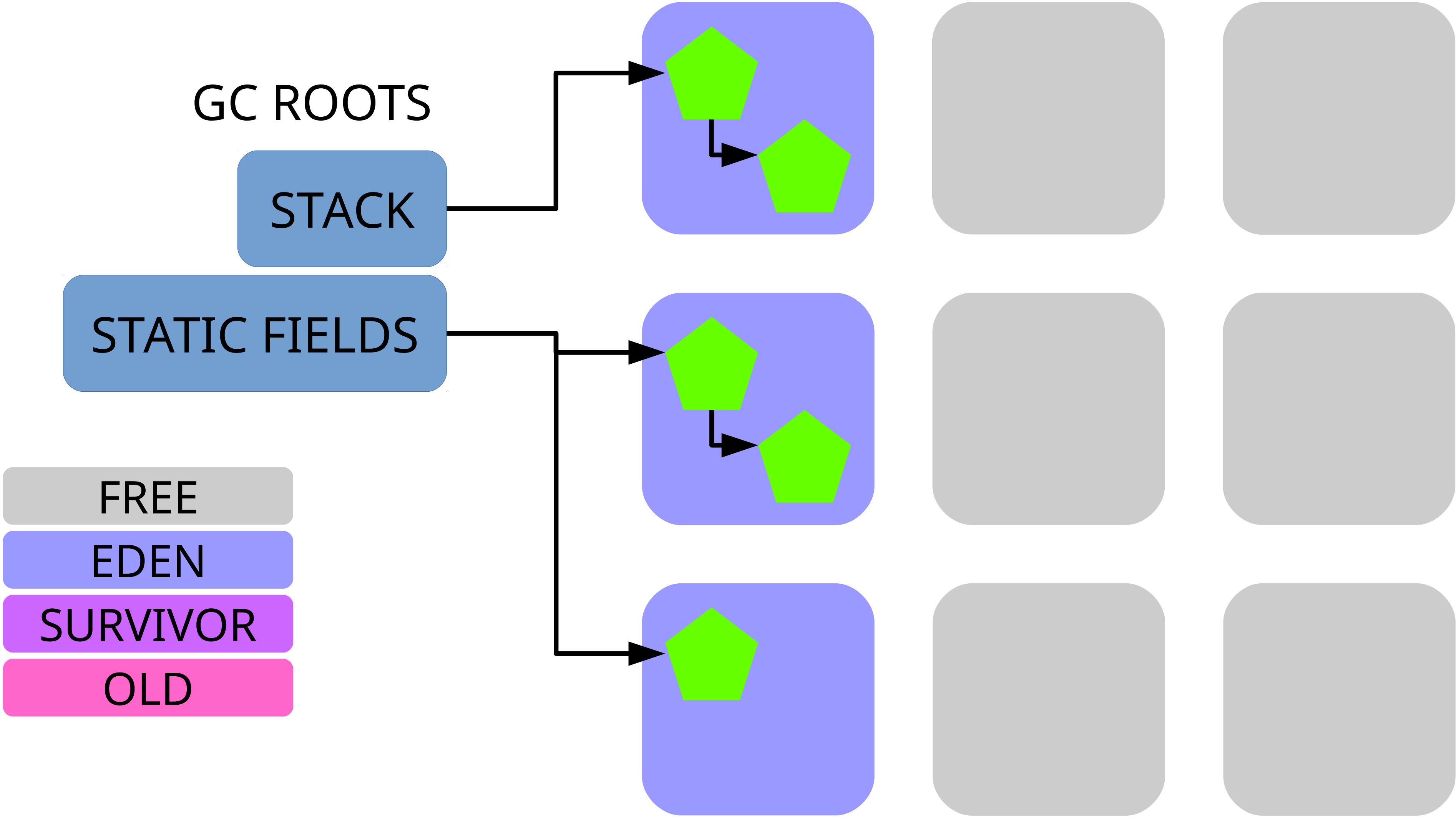
FREE

EDEN

SURVIVOR

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

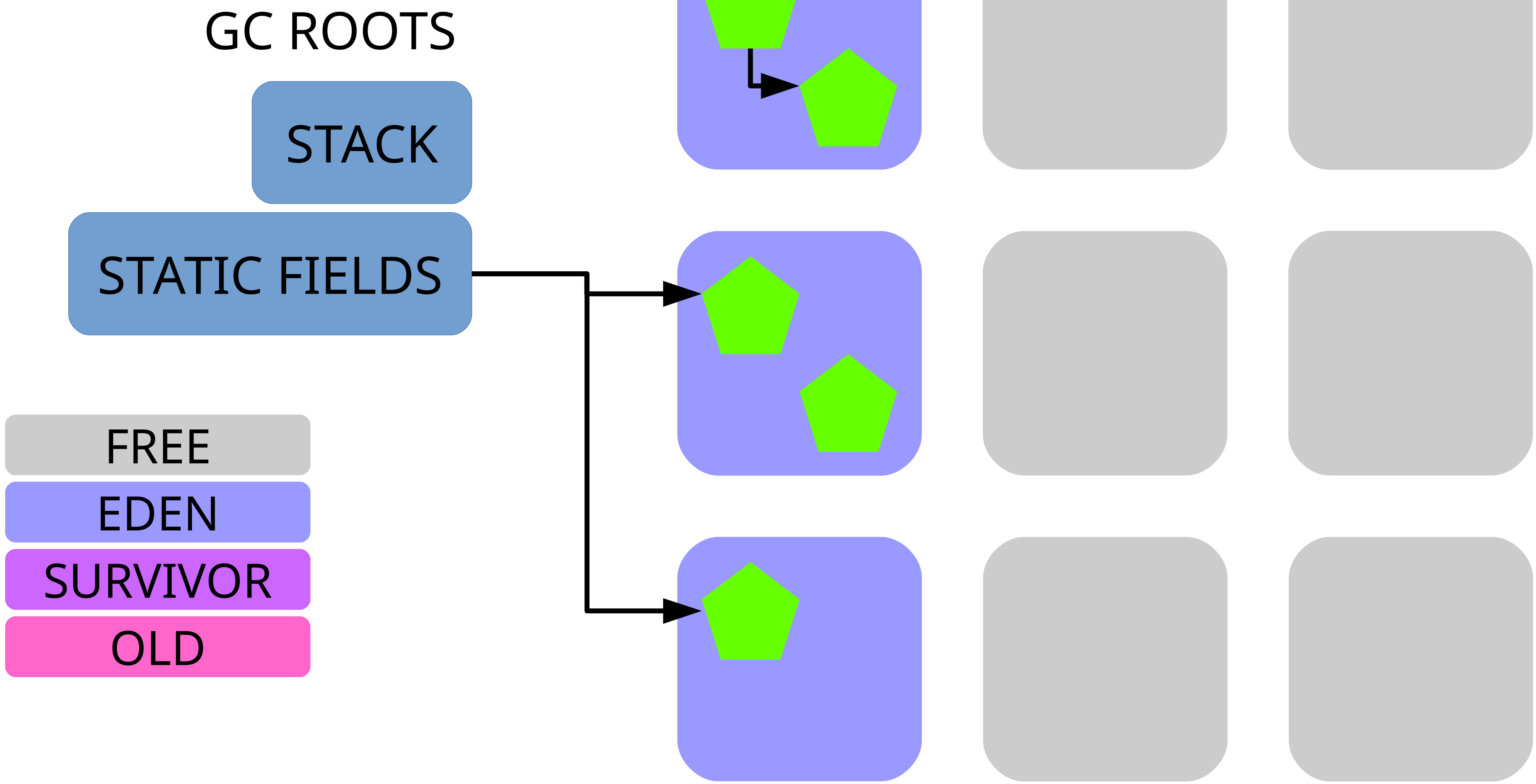
FREE

EDEN

SURVIVOR

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

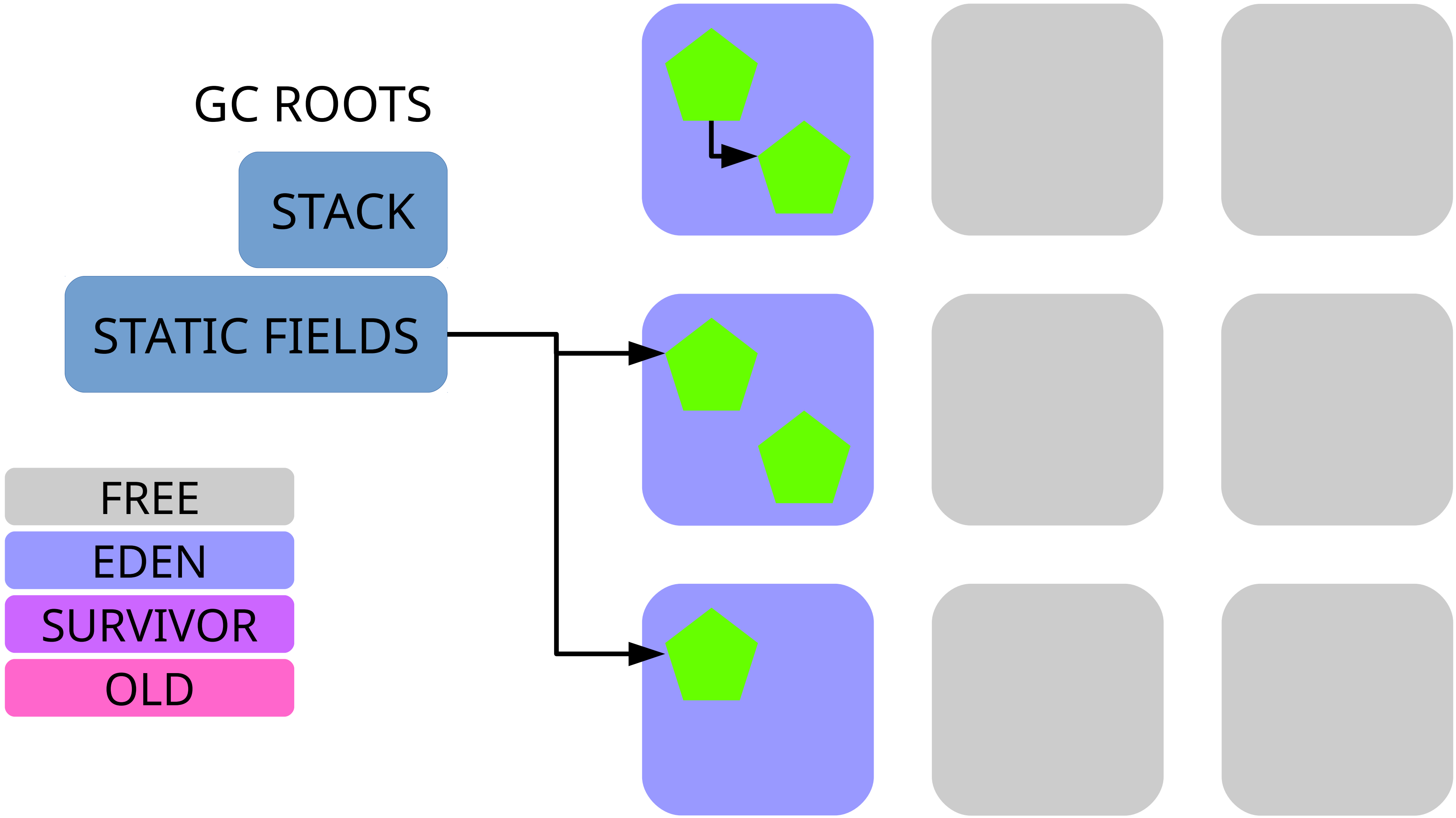
FREE

EDEN

SURVIVOR

OLD

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

EDEN

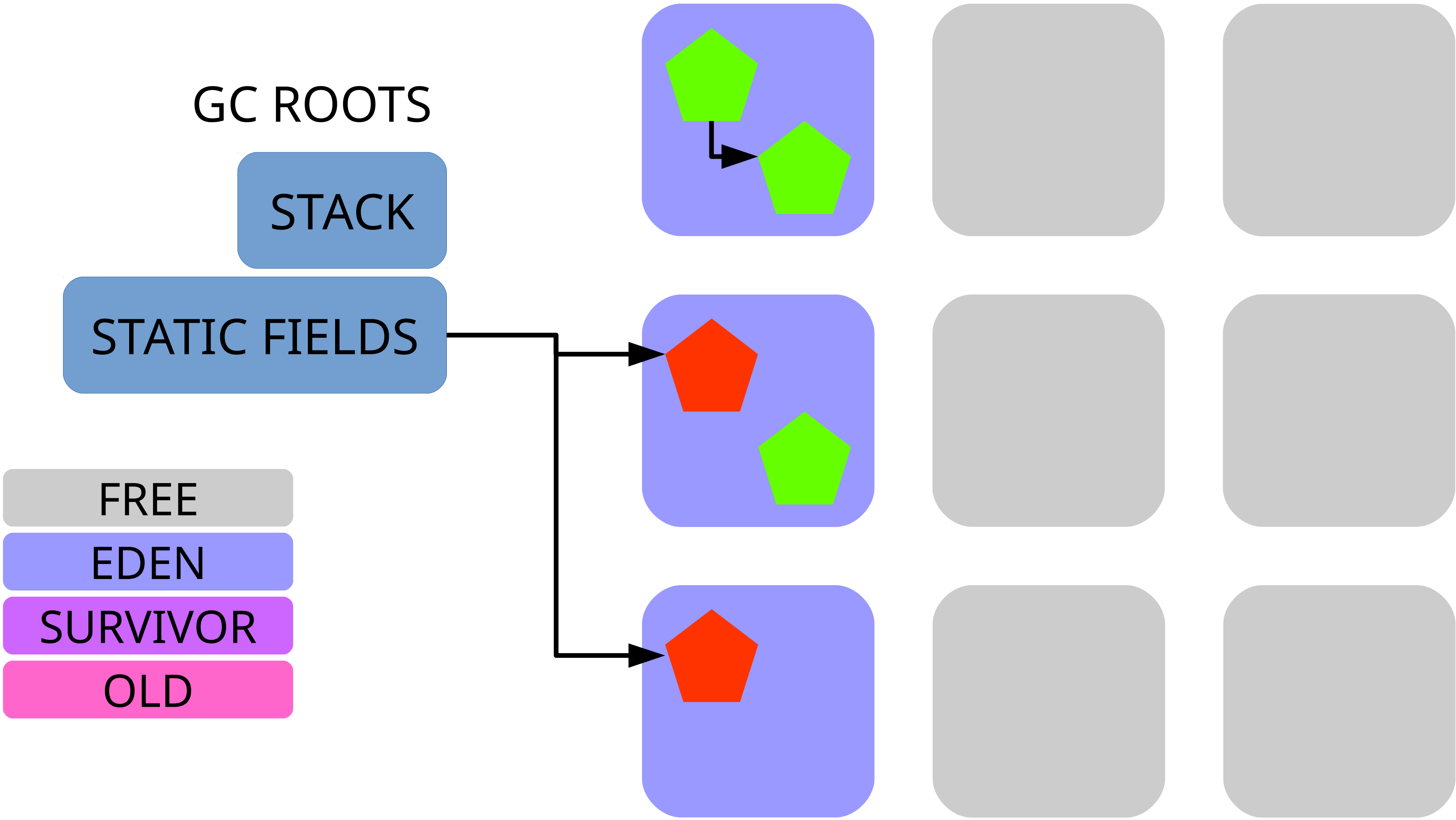
SURVIVOR

OLD

[GC pause (G1 Evacuation Pause) (young) ..]

Collection Set: all young

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

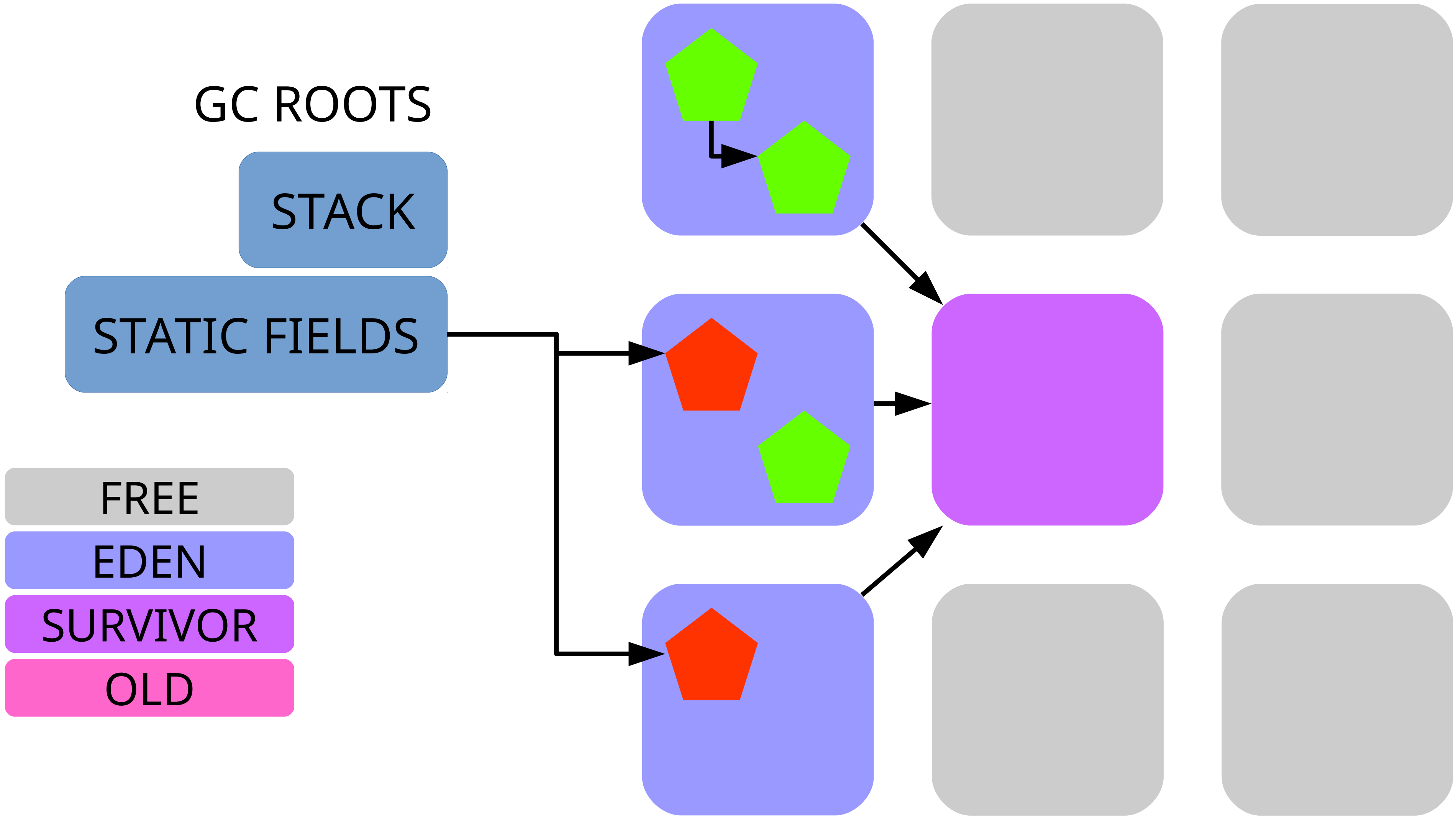
EDEN

SURVIVOR

OLD

Mark objects reachable from roots

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

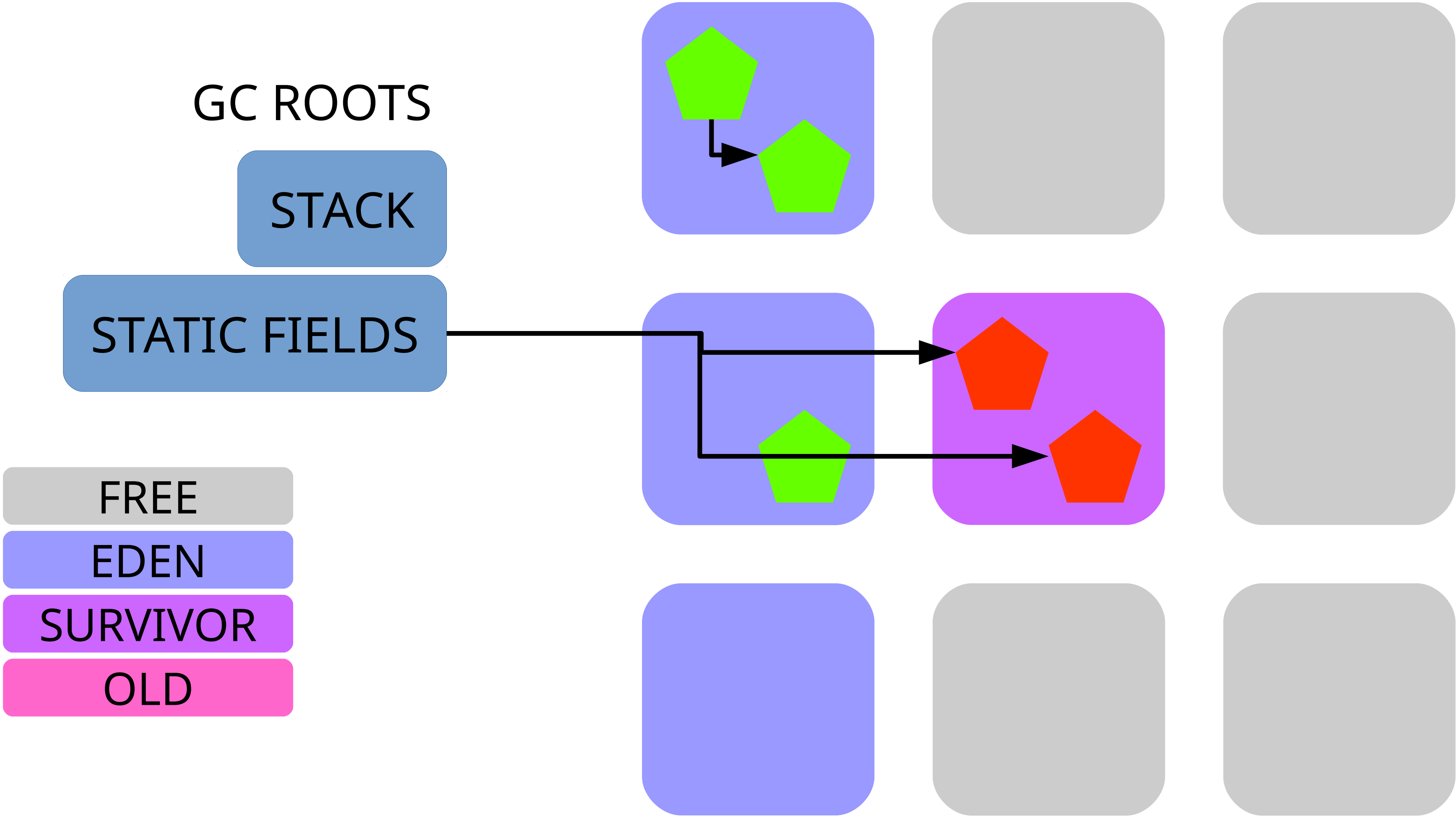
FREE

EDEN

SURVIVOR

OLD

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

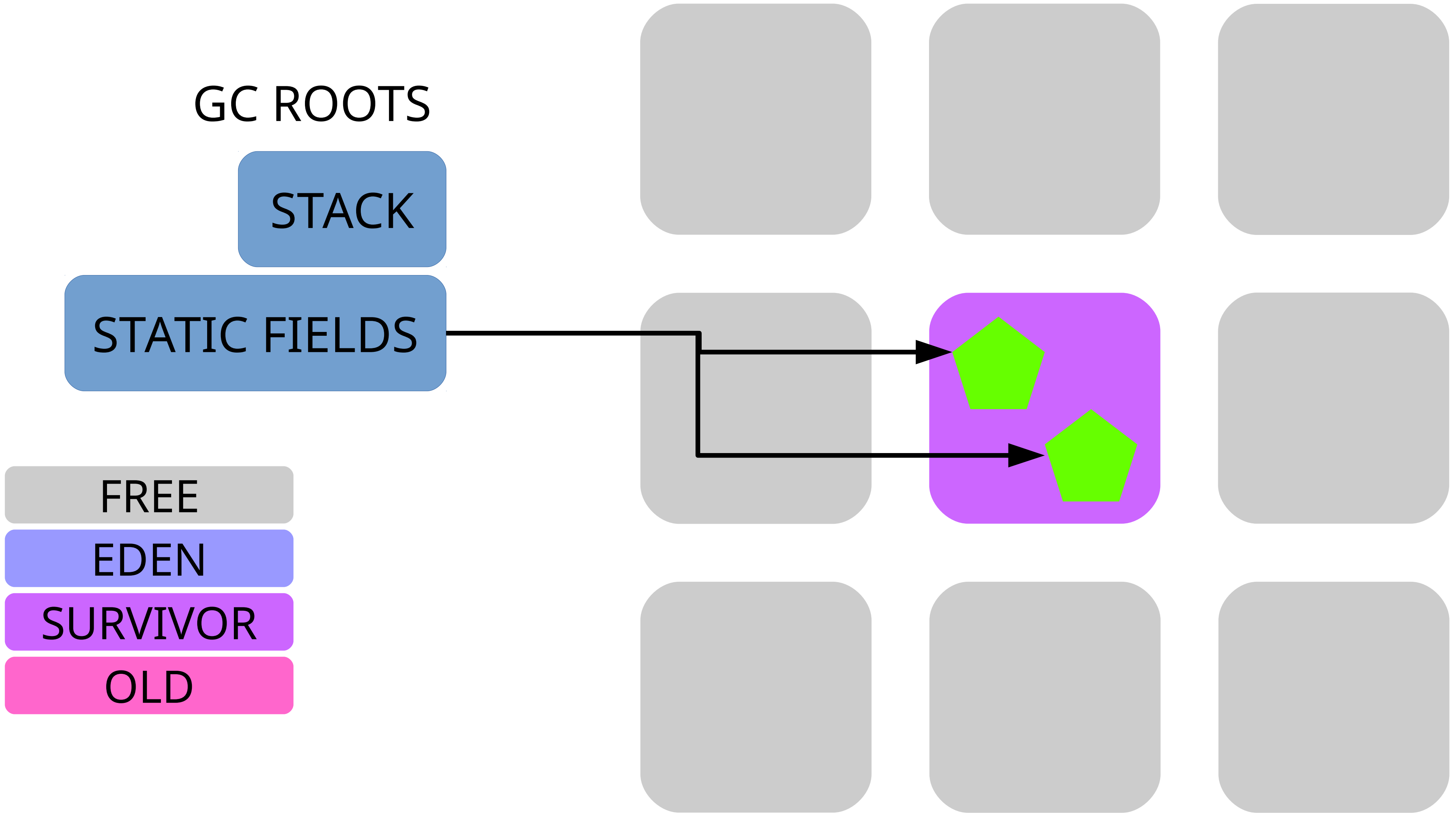
EDEN

SURVIVOR

OLD

Move to new survivor region

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

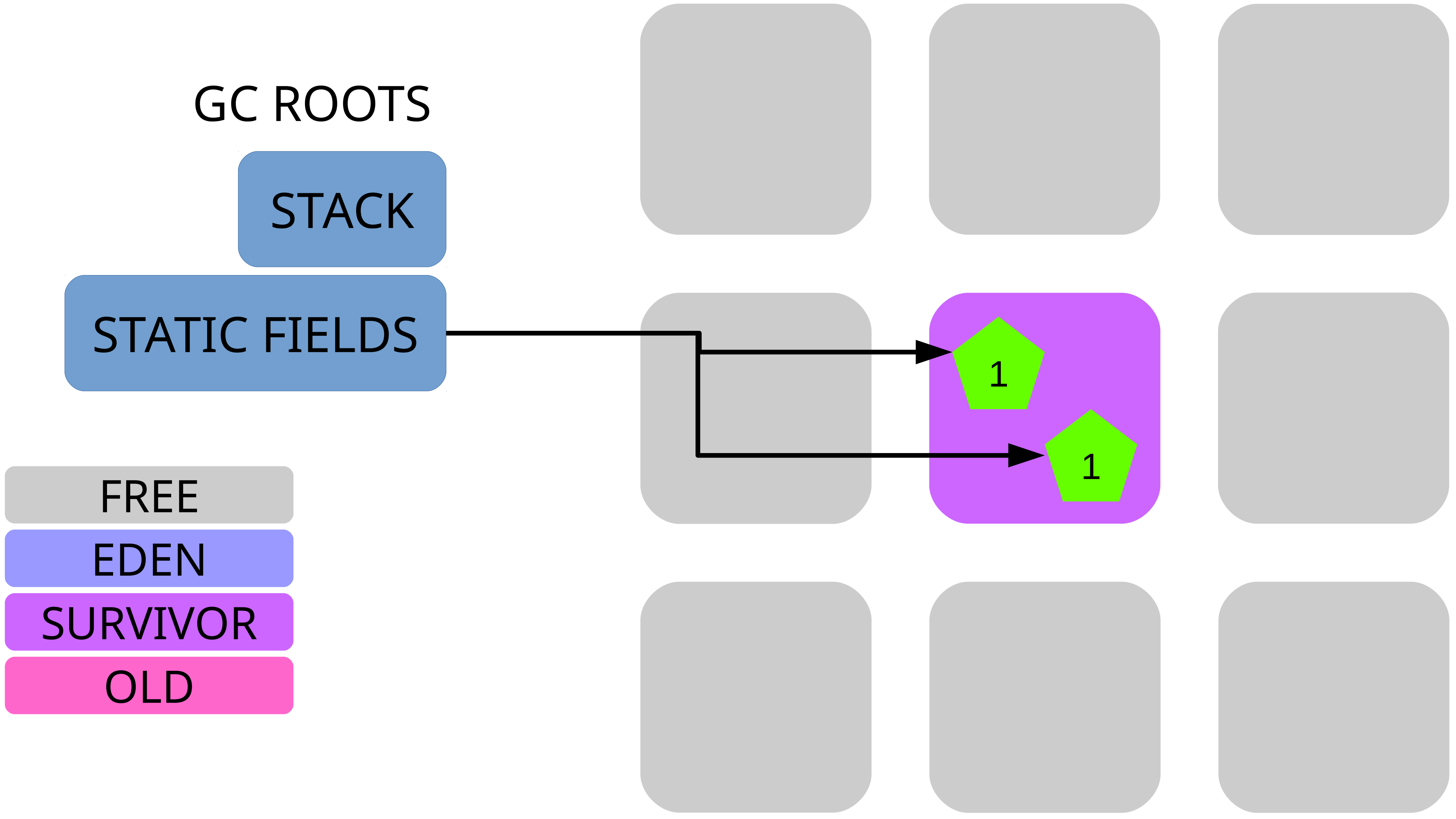
EDEN

SURVIVOR

OLD

Free evacuated regions

RUNNING



GC ROOTS

STACK

STATIC FIELDS

1

1

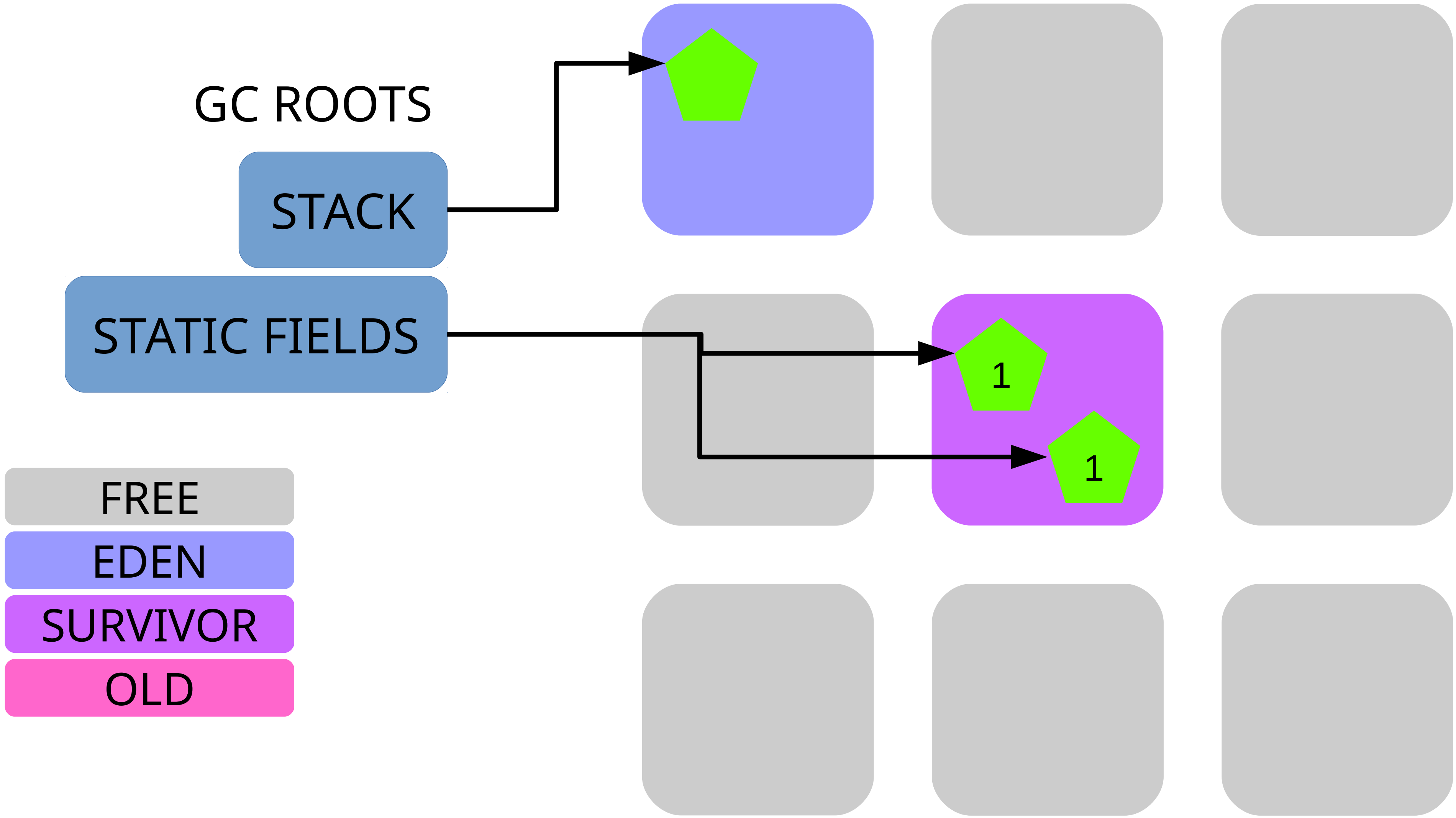
FREE

EDEN

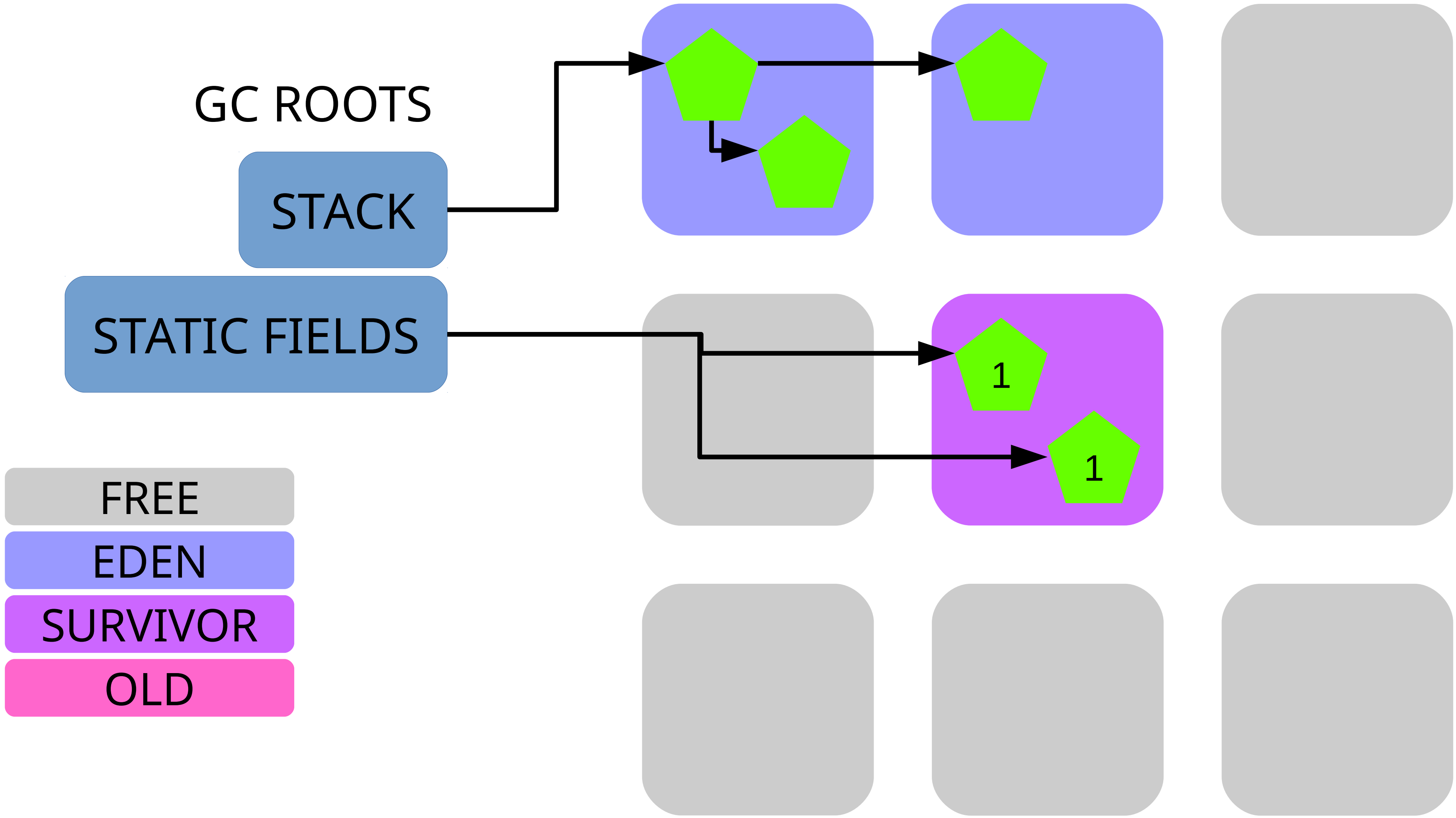
SURVIVOR

OLD

RUNNING



RUNNING



GC ROOTS

STACK

STATIC FIELDS

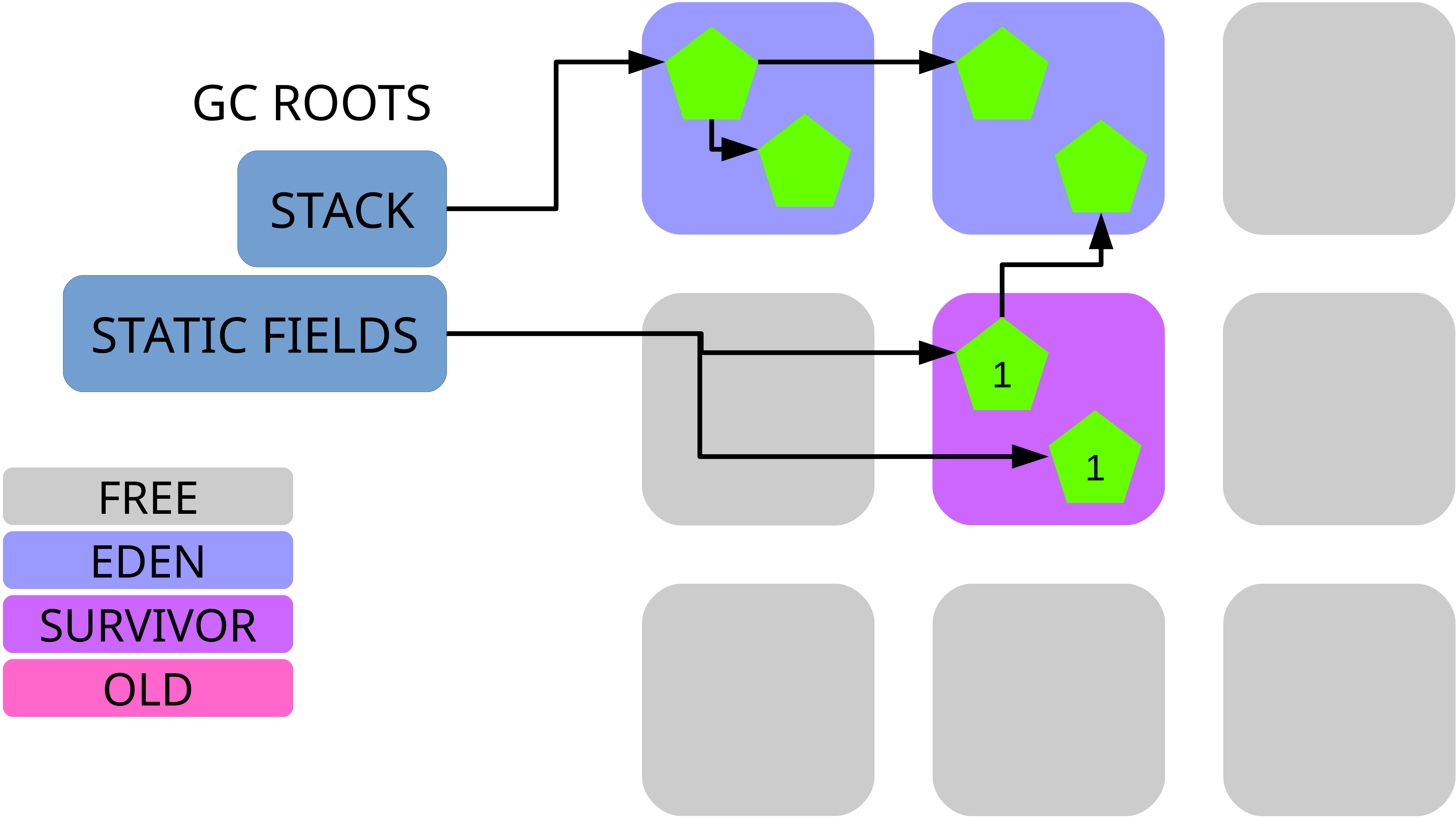
FREE

EDEN

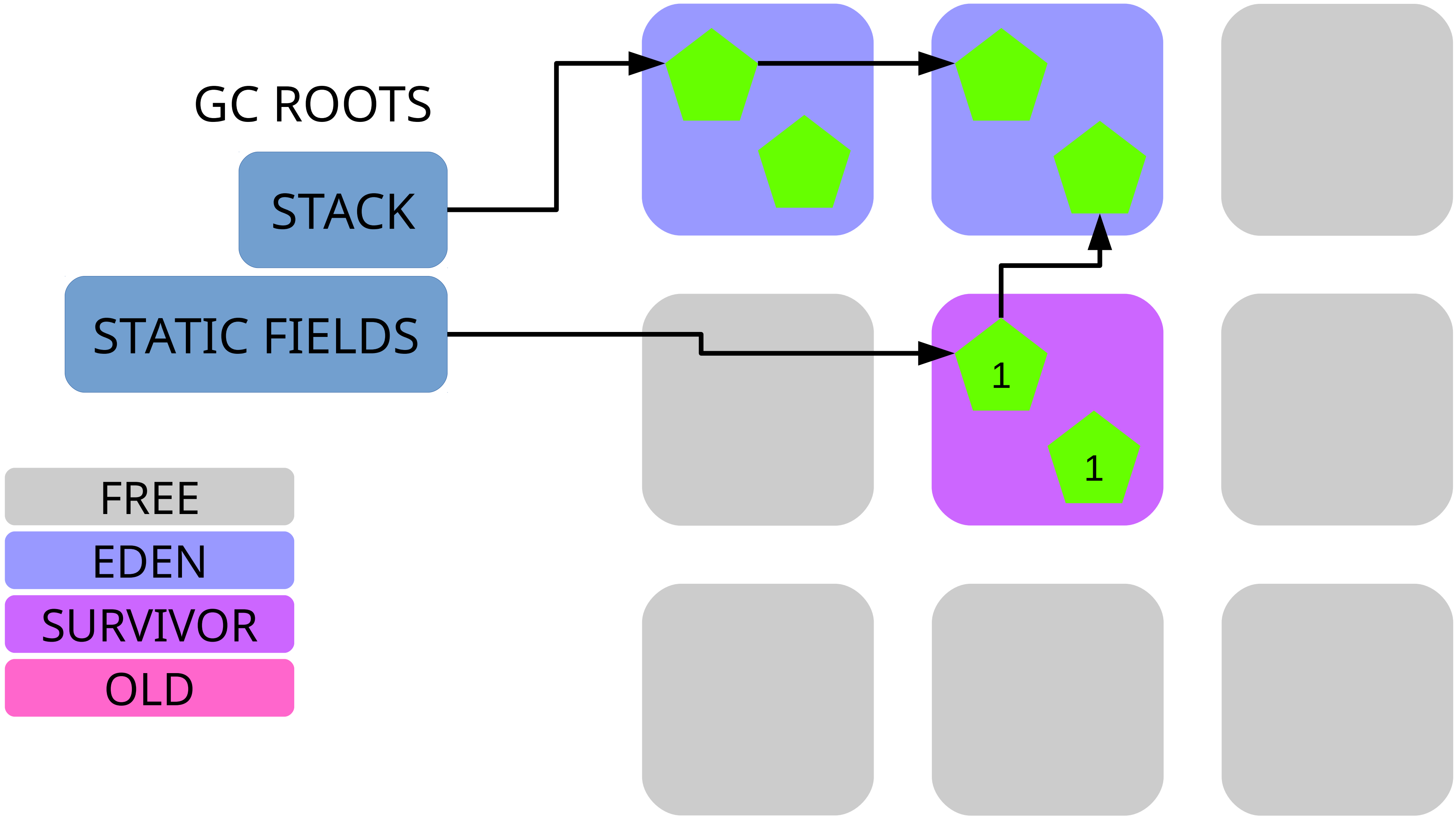
SURVIVOR

OLD

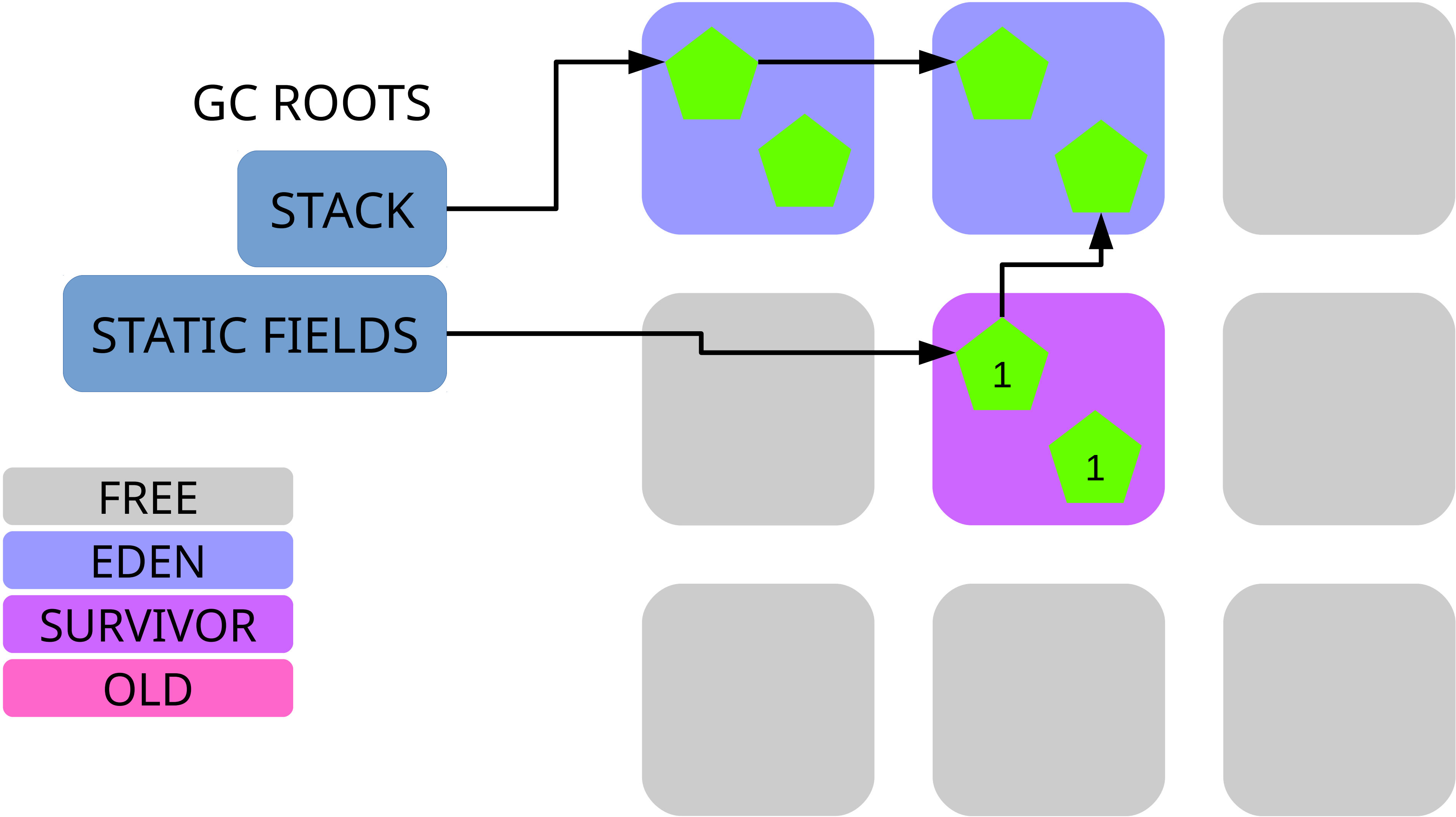
RUNNING



RUNNING



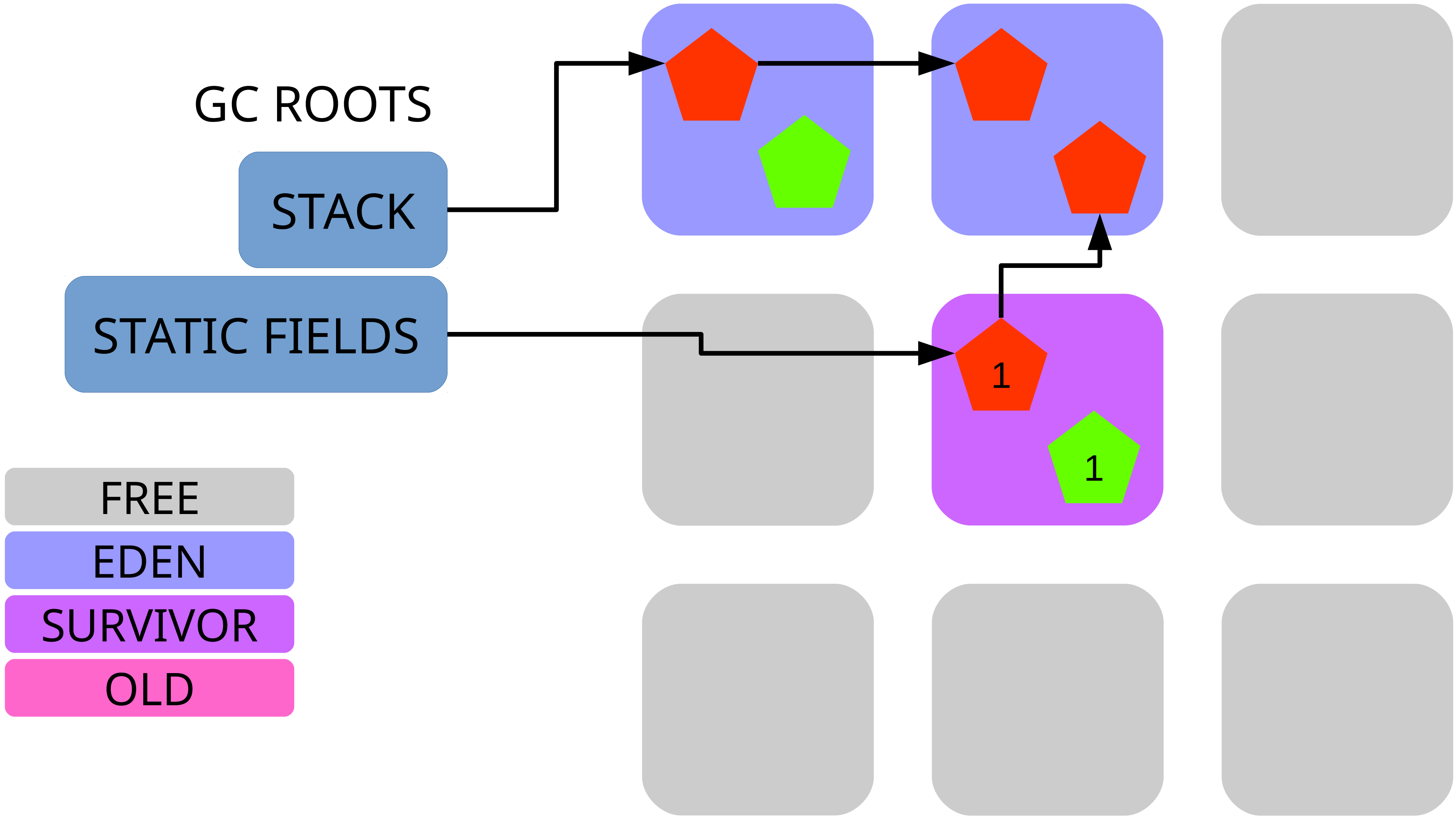
STOP THE WORLD



[GC pause (G1 Evacuation Pause) (young) ..]

Collection Set: all young

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

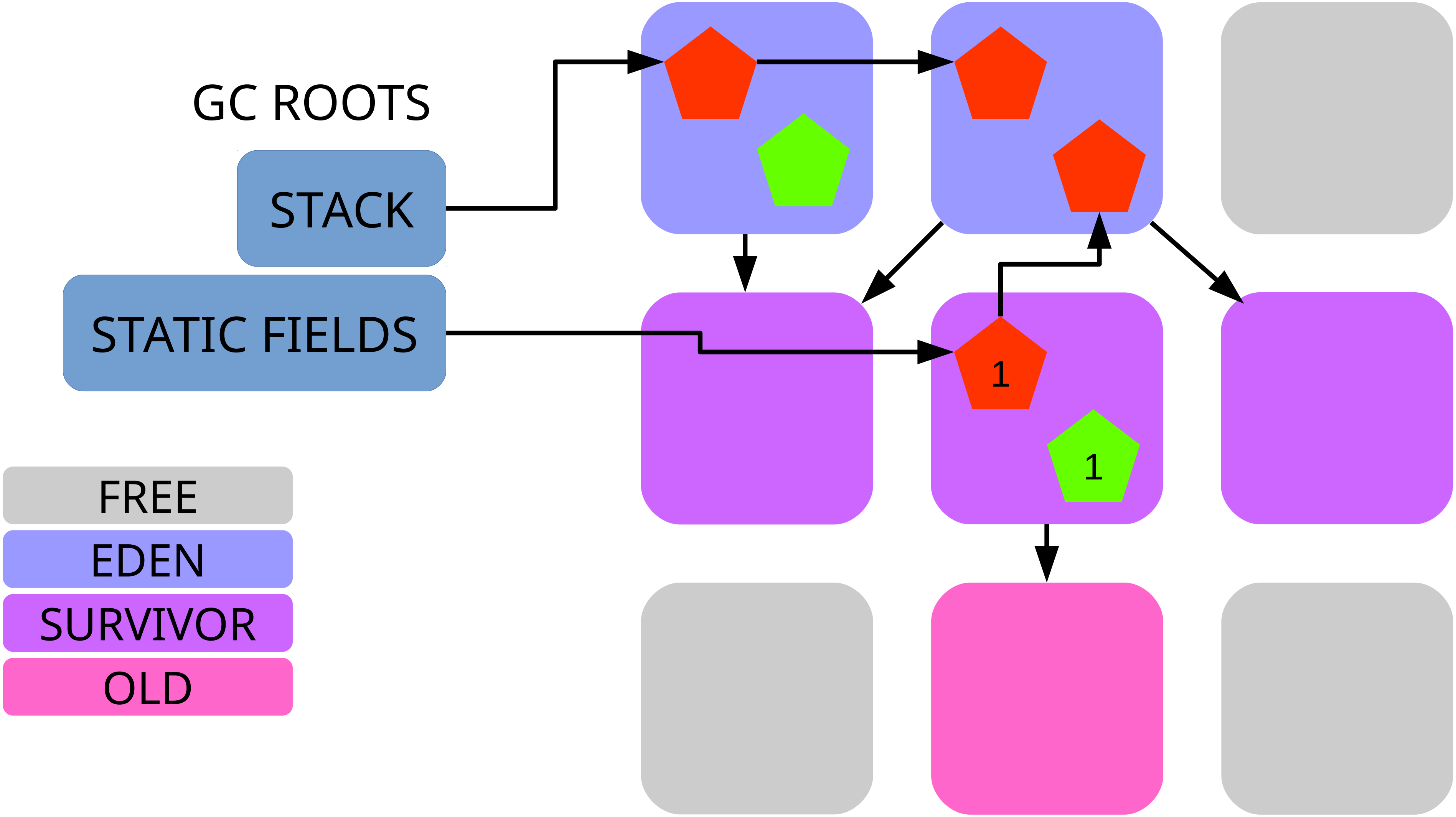
EDEN

SURVIVOR

OLD

Mark objects reachable from roots

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

1

1

FREE

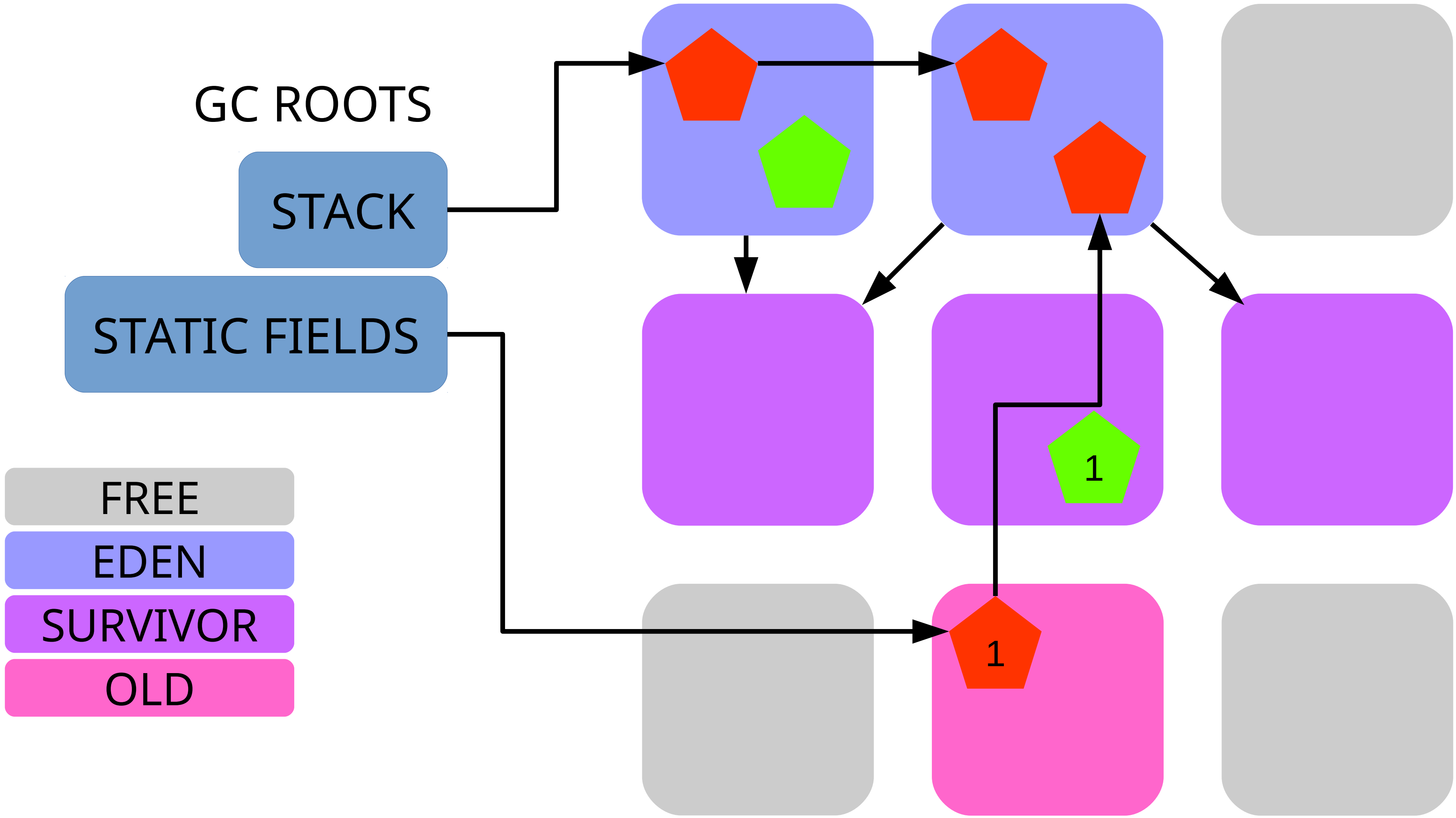
EDEN

SURVIVOR

OLD

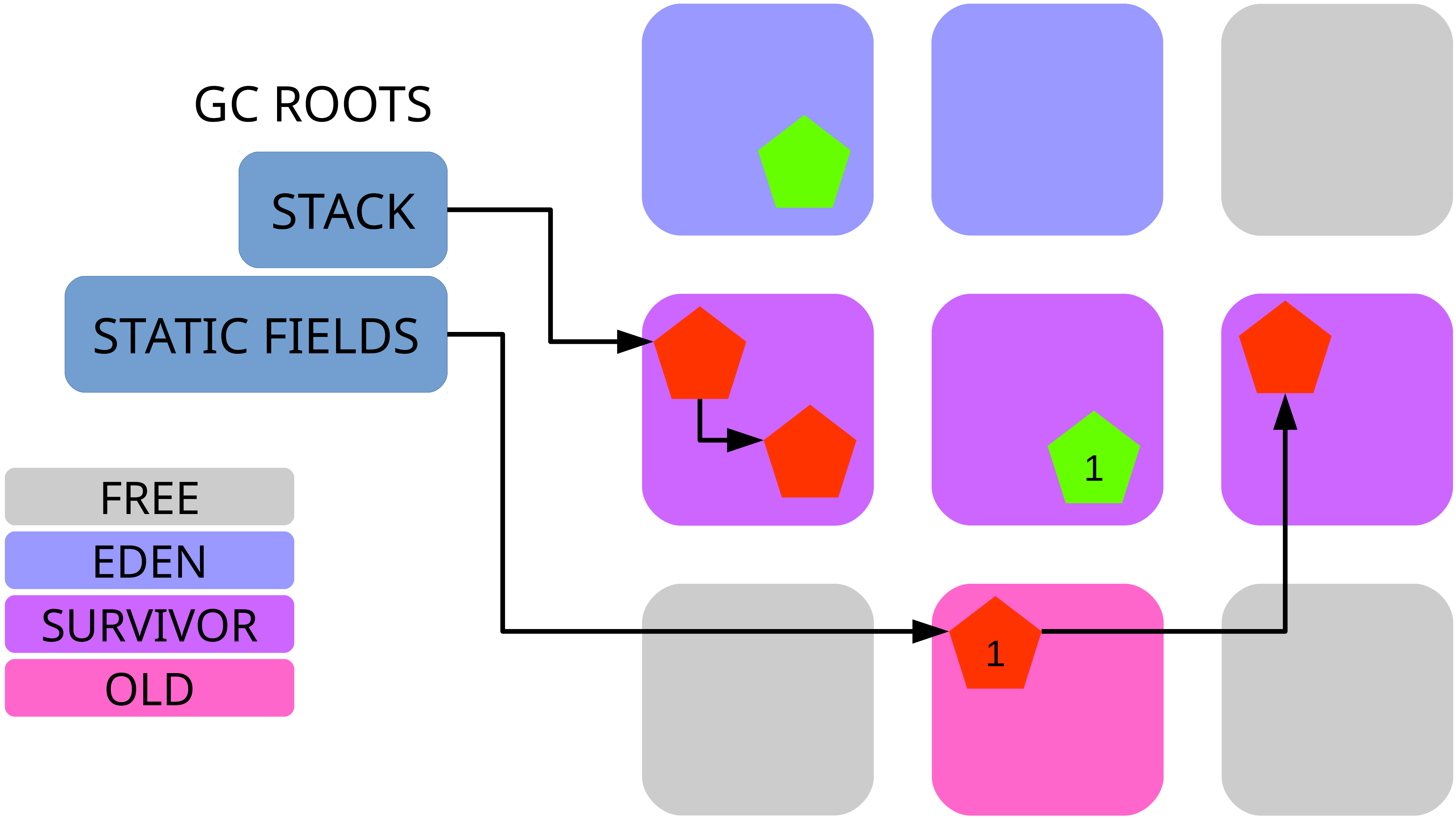
Move to new survivor region / old

STOP THE WORLD



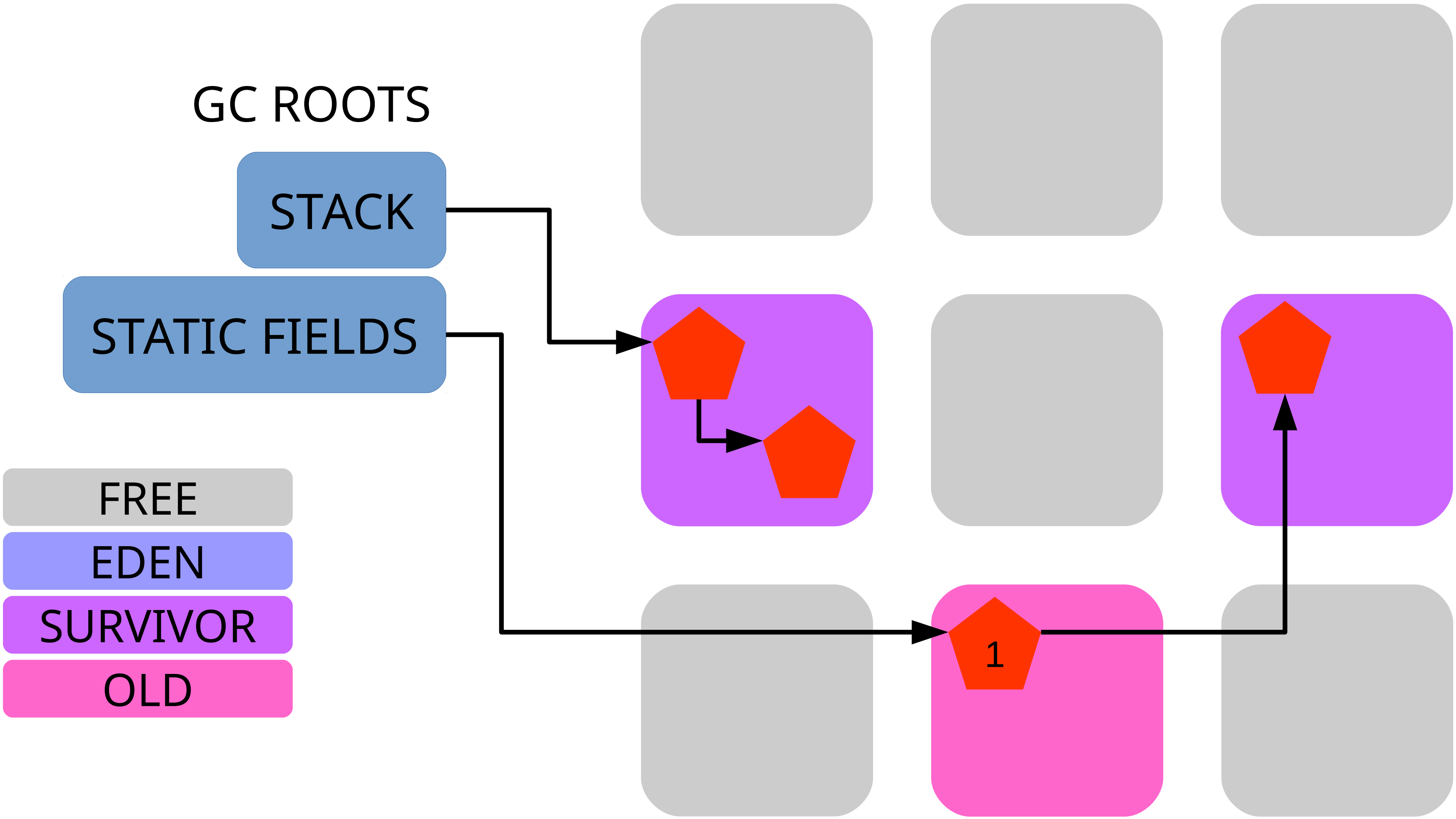
Move to new survivor region / old

STOP THE WORLD



Move to new survivor region / old

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

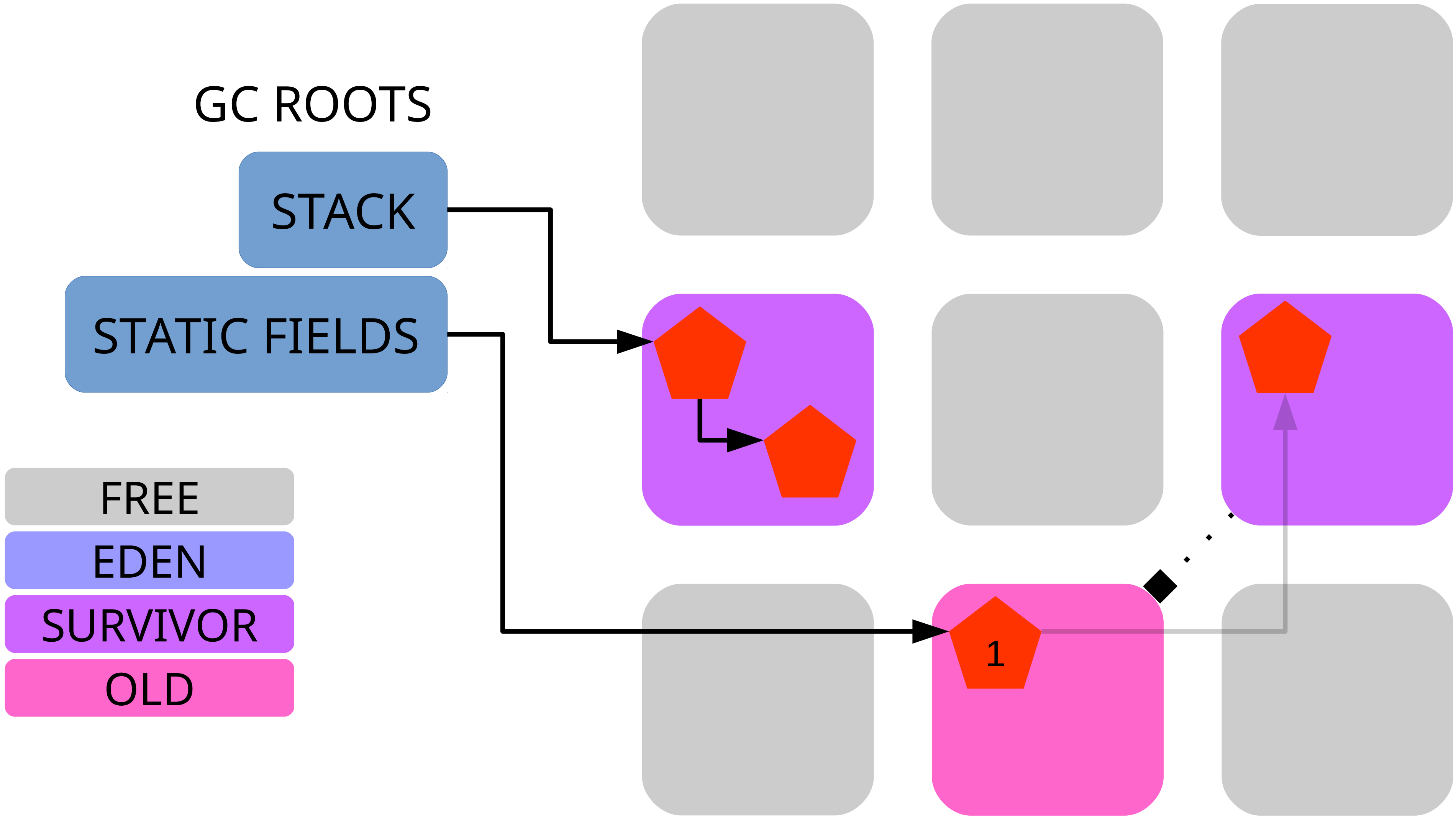
EDEN

SURVIVOR

OLD

Free evacuated regions

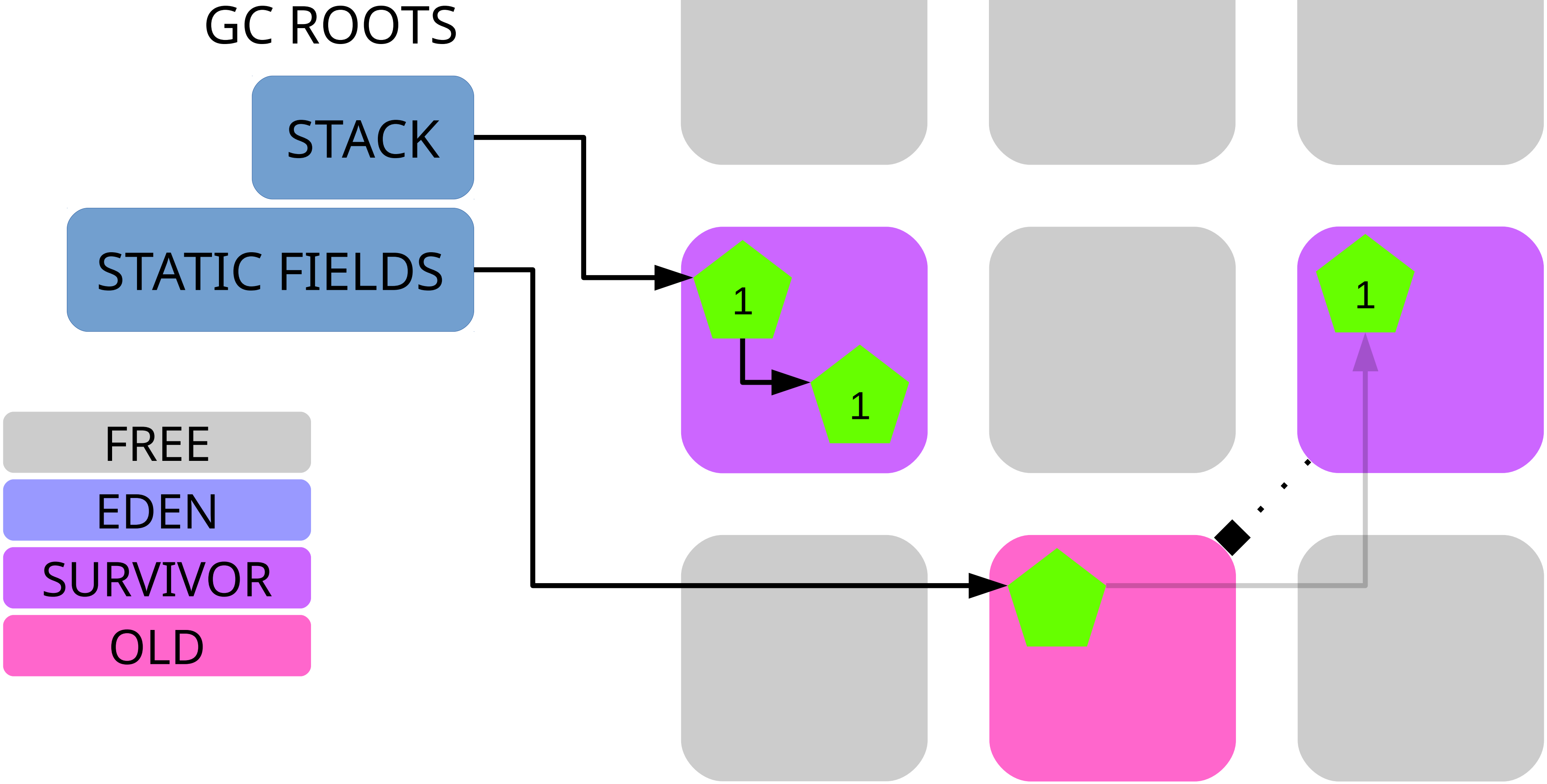
STOP THE WORLD



Update RSets (Per region Card Table on steroids)

old->old, old->young

RUNNING



GC ROOTS

STACK

STATIC FIELDS

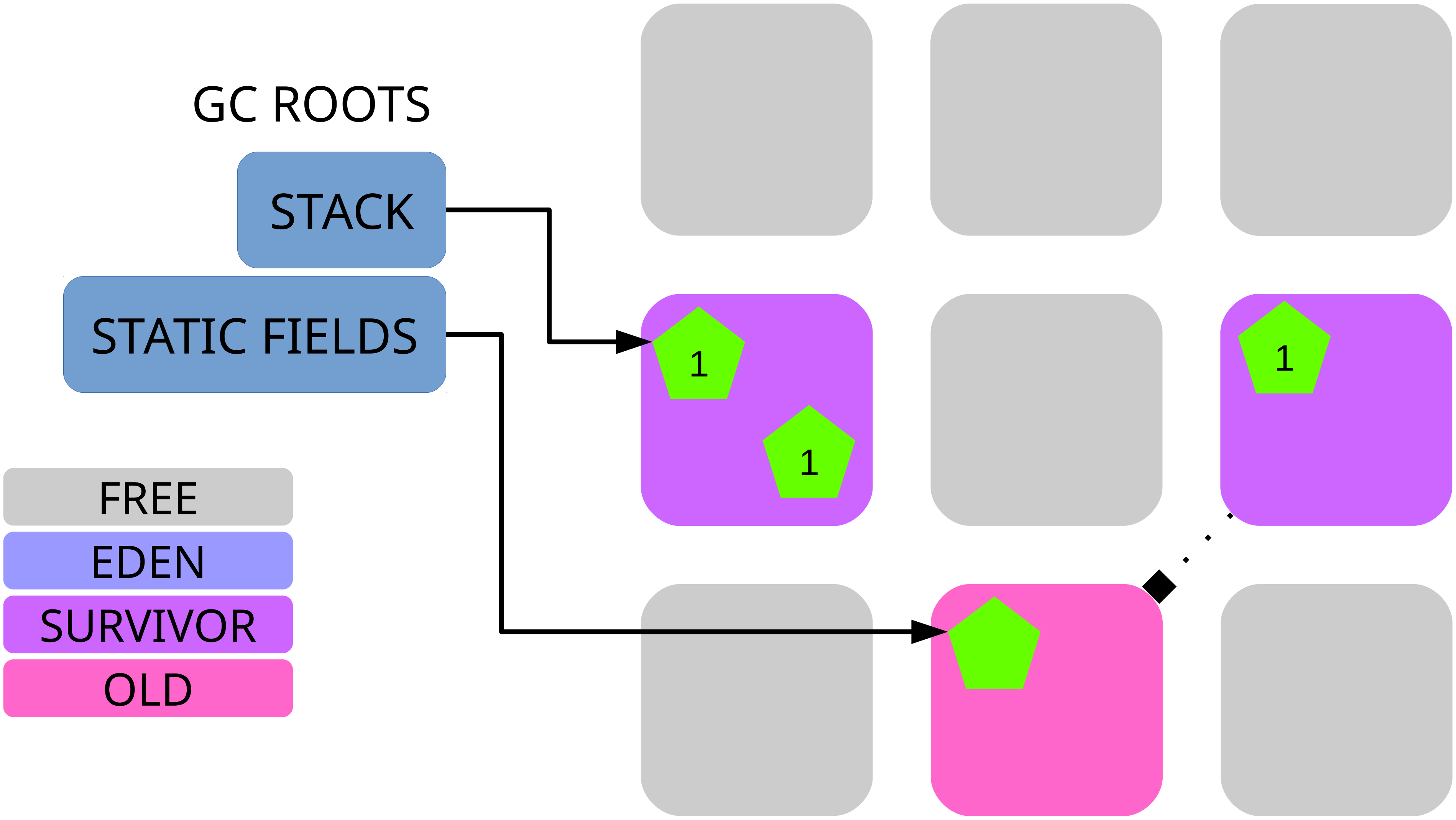
FREE

EDEN

SURVIVOR

OLD

RUNNING



GC ROOTS

STACK

STATIC FIELDS

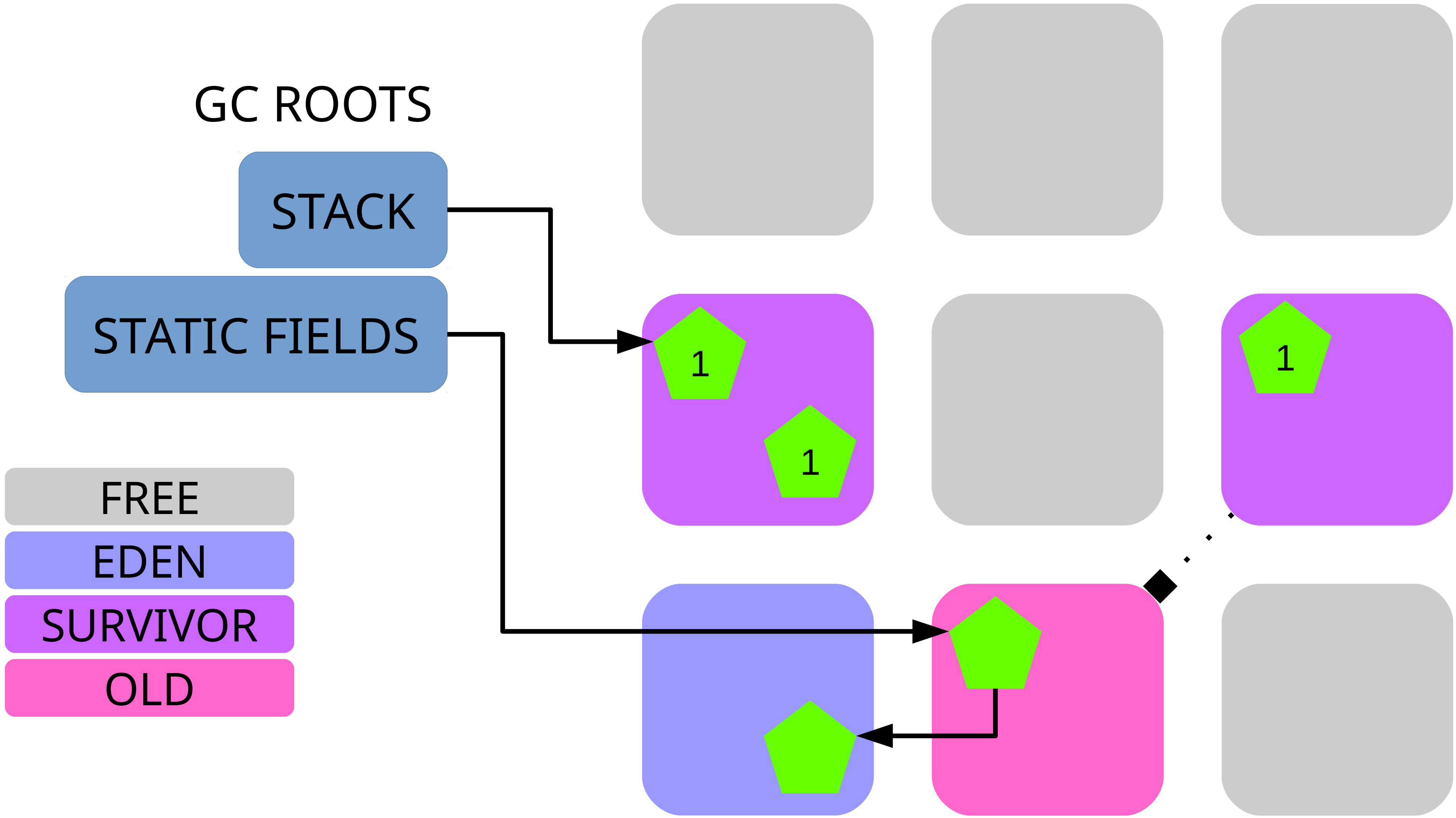
FREE

EDEN

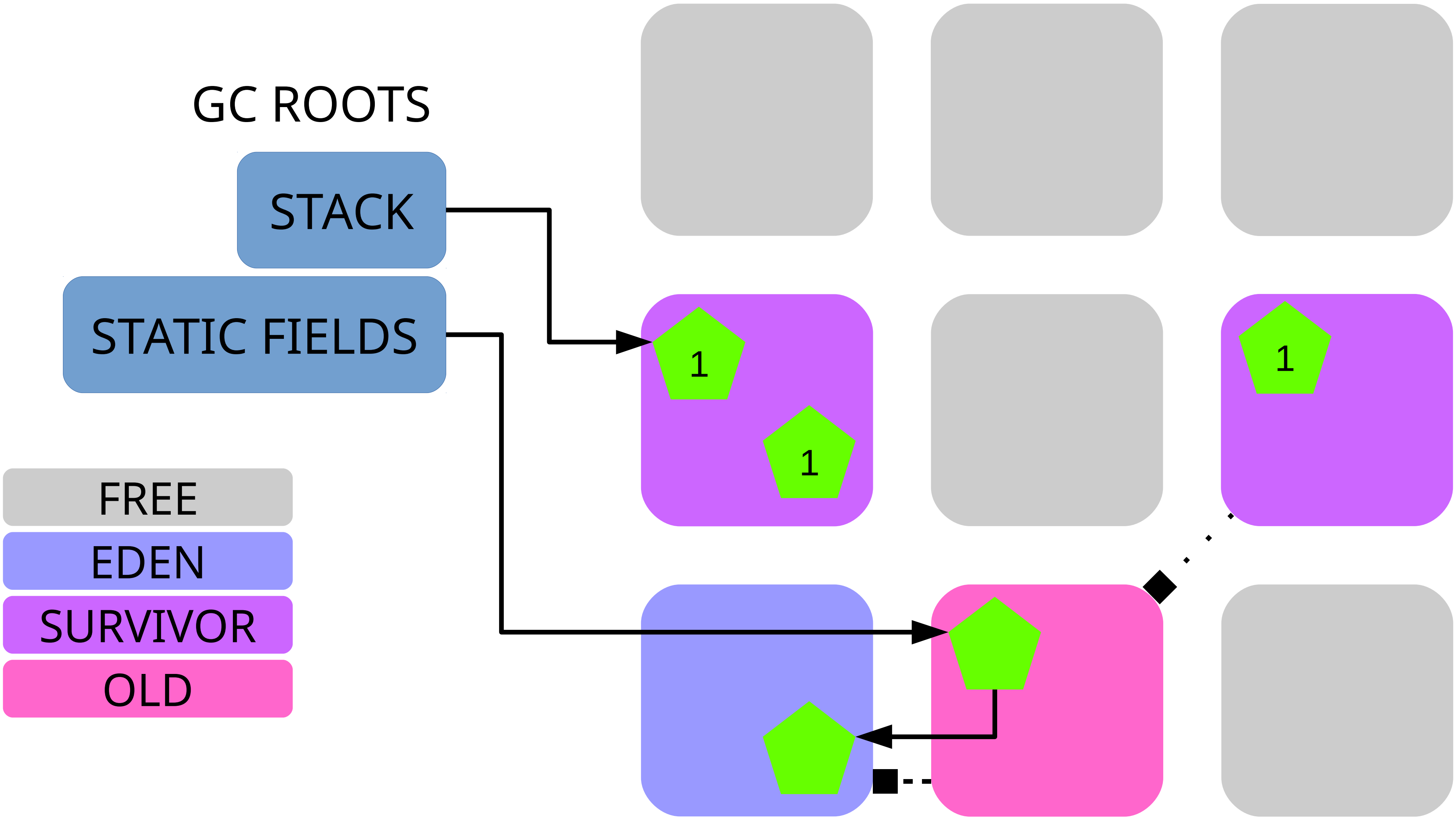
SURVIVOR

OLD

RUNNING



RUNNING



GC ROOTS

STACK

STATIC FIELDS

FREE

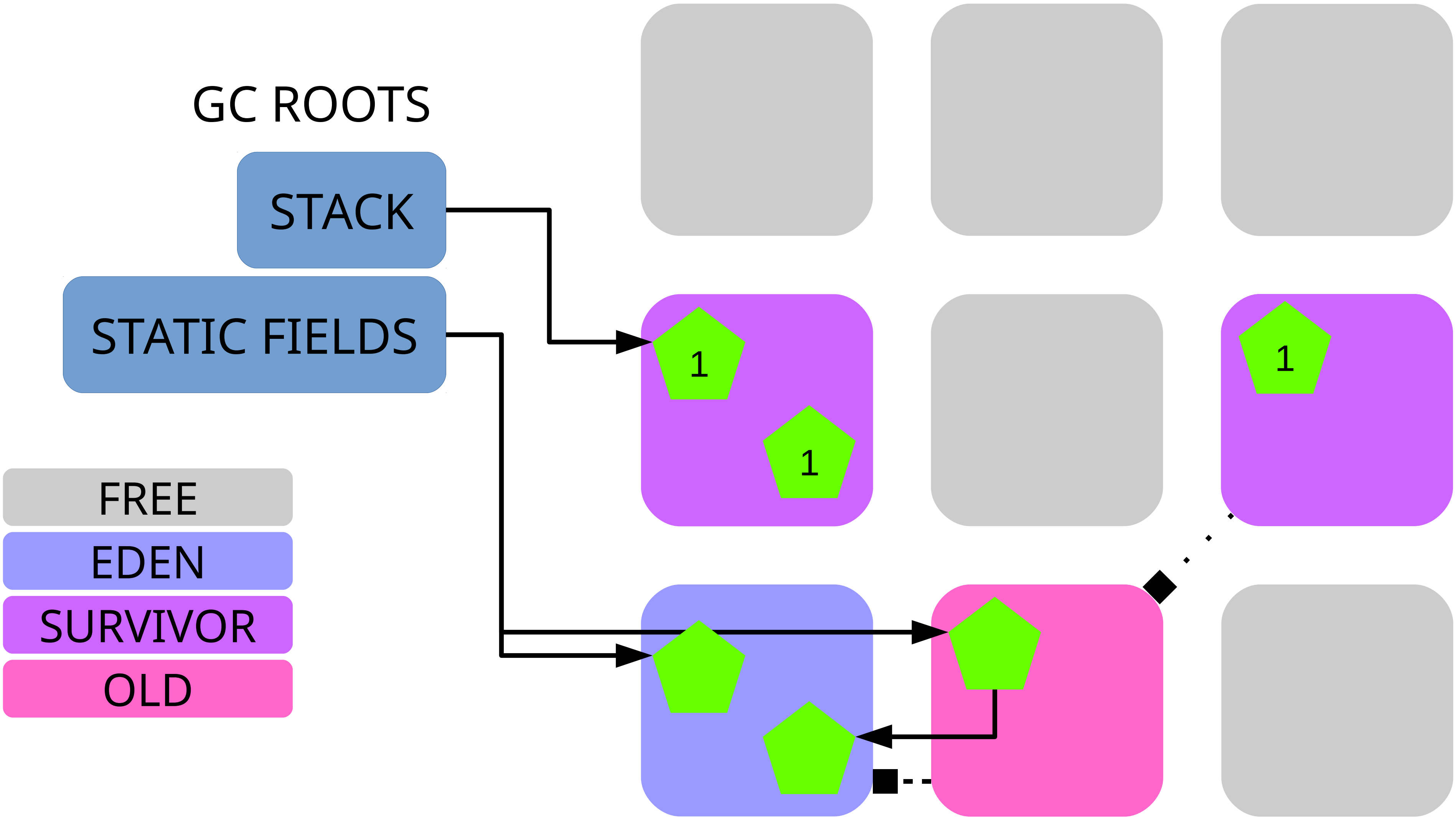
EDEN

SURVIVOR

OLD

Update RSet: old->young

RUNNING



GC ROOTS

STACK

STATIC FIELDS

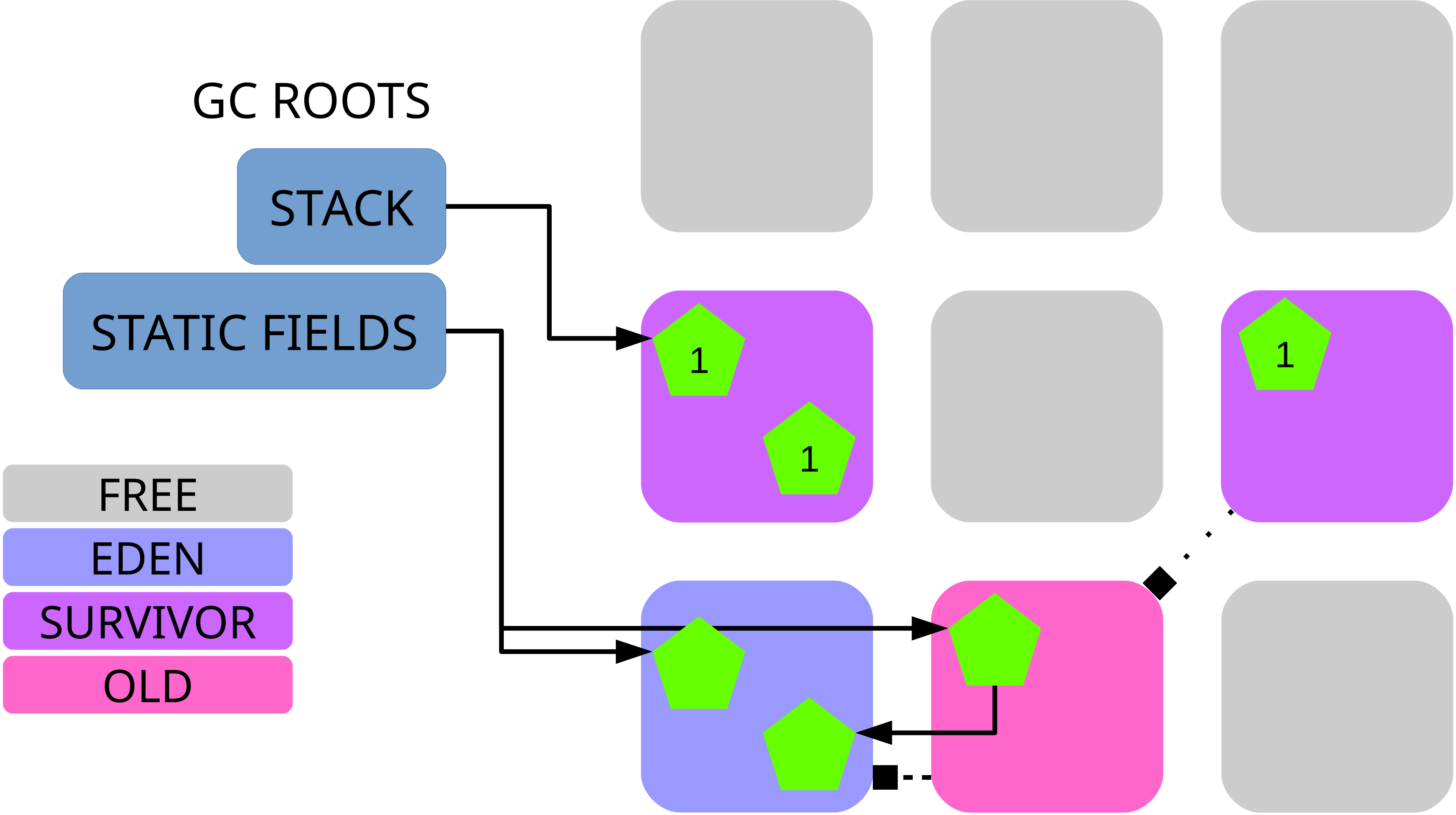
FREE

EDEN

SURVIVOR

OLD

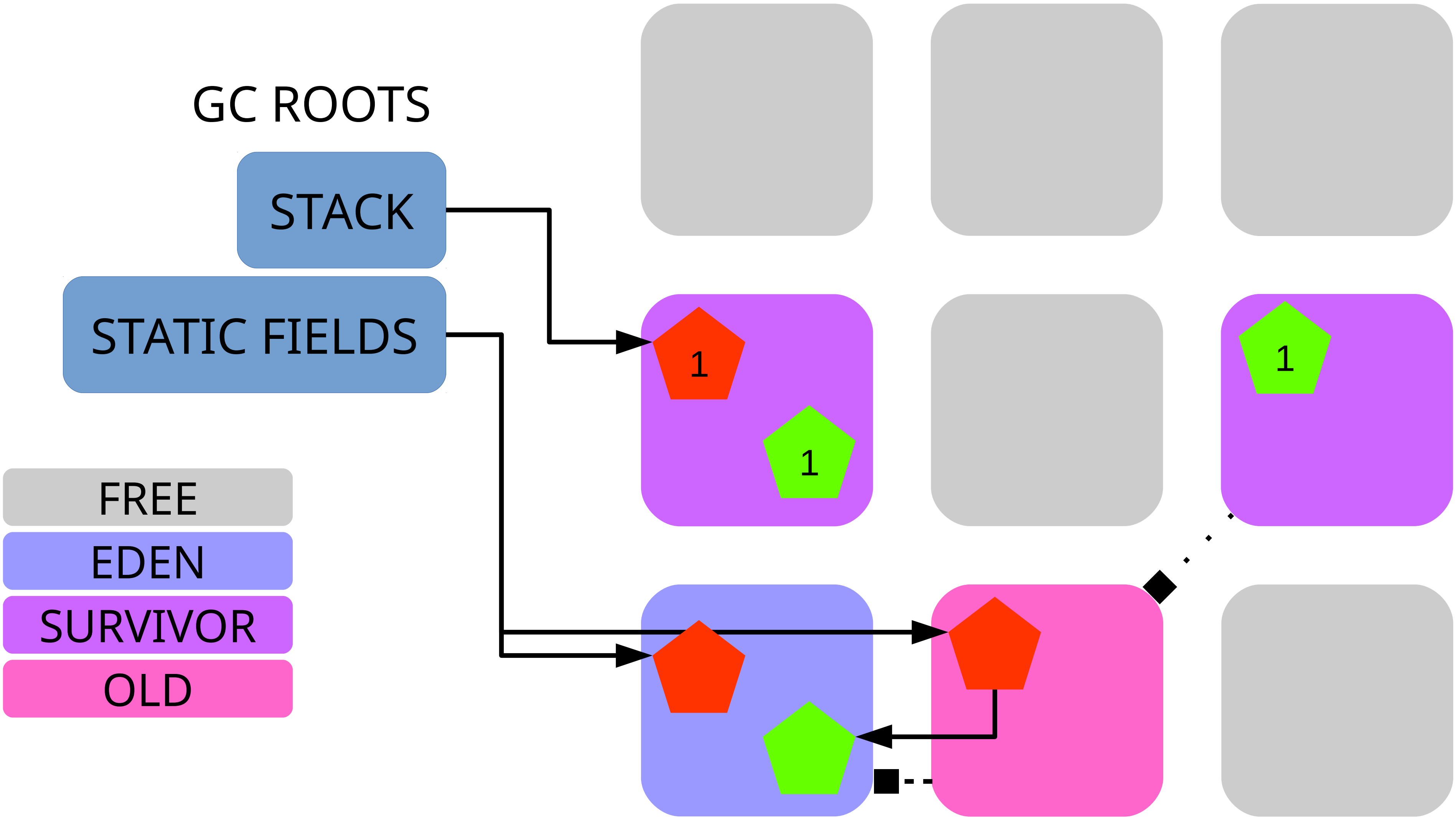
STOP THE WORLD



[GC pause (G1 Evacuation Pause) (young) ..]

Collection Set: all young

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

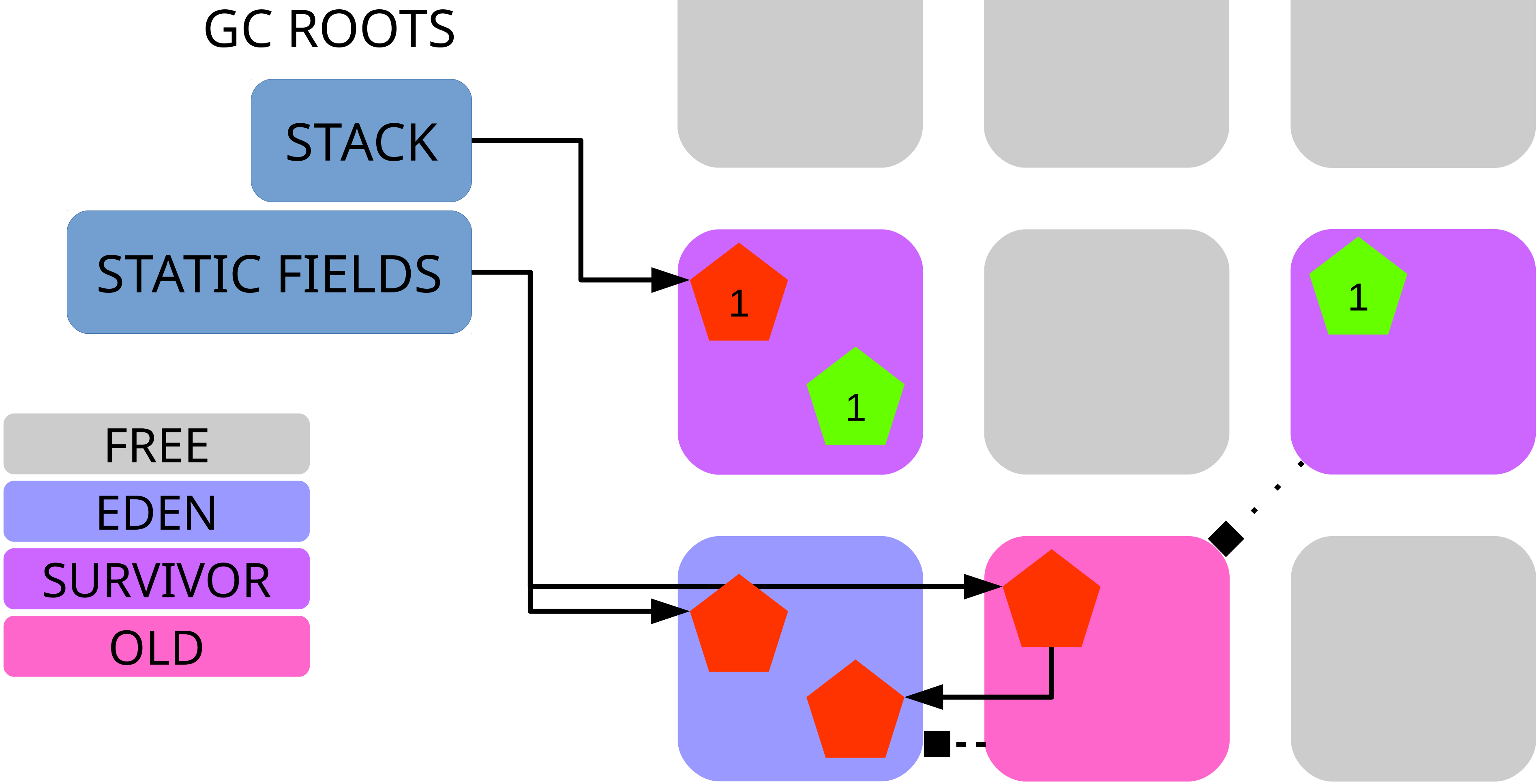
EDEN

SURVIVOR

OLD

Mark objects reachable from roots

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

EDEN

SURVIVOR

OLD

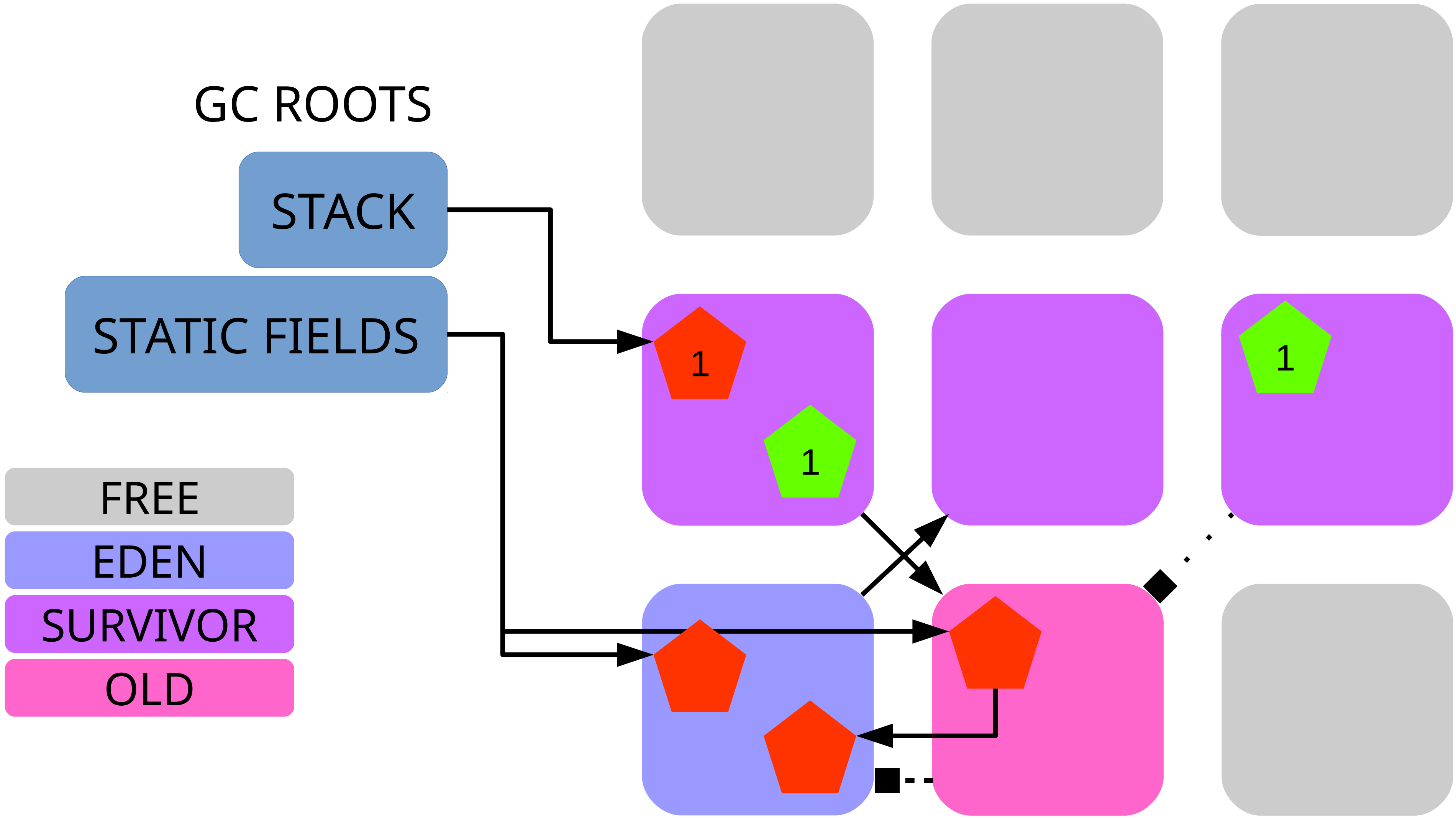
1

1

1

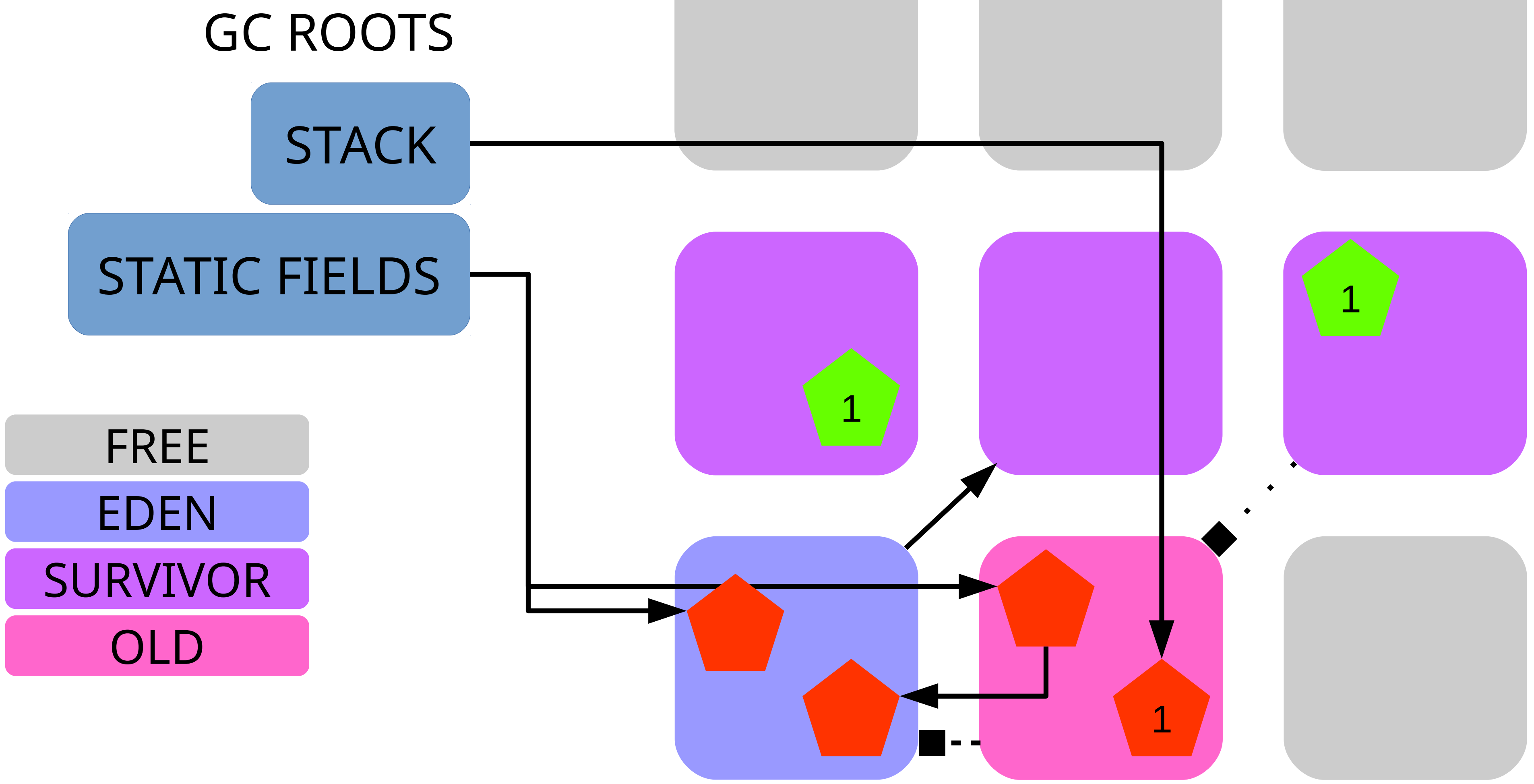
Mark objects reachable from roots and RSets

STOP THE WORLD



Move to new survivor region / old

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

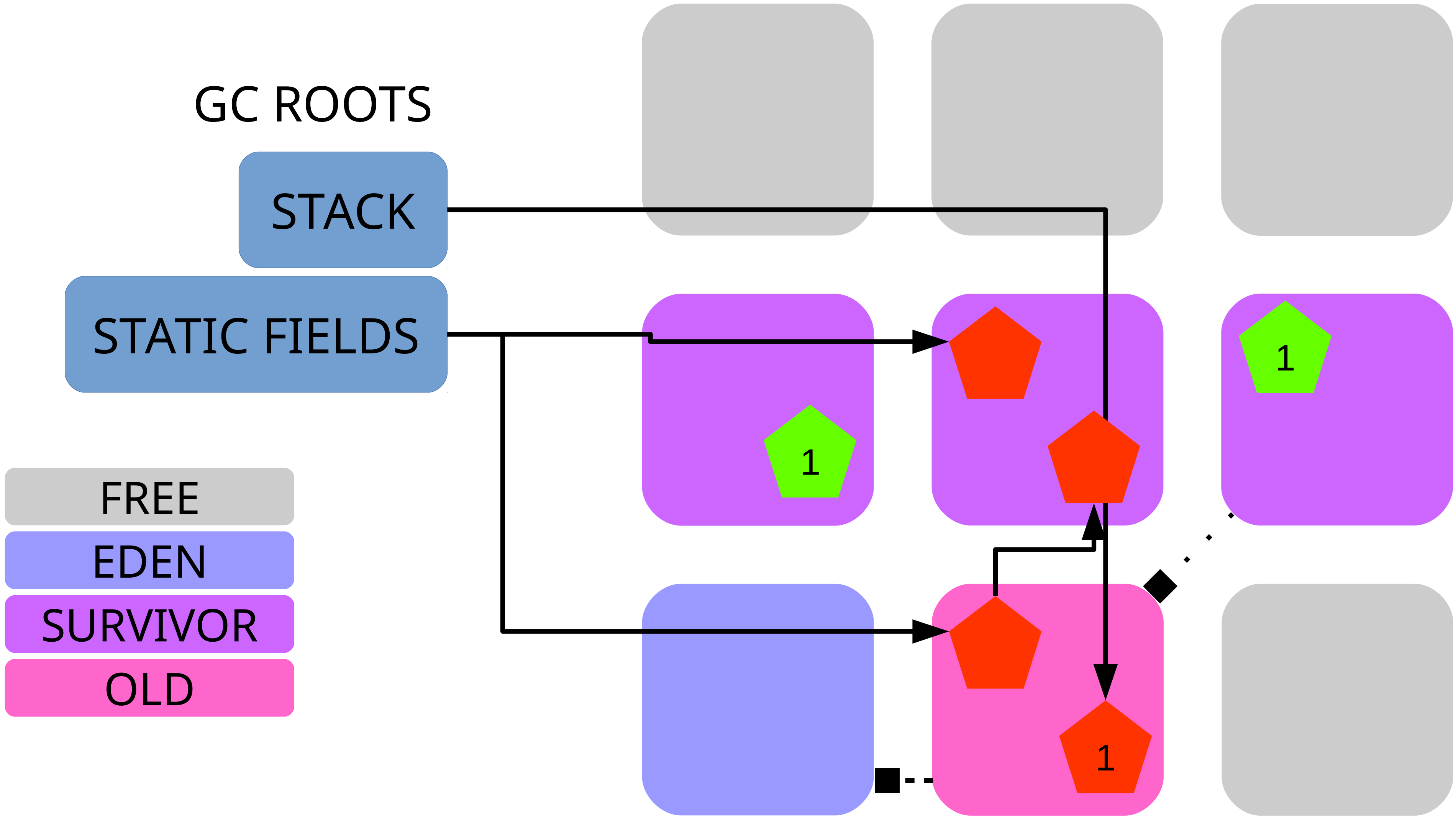
EDEN

SURVIVOR

OLD

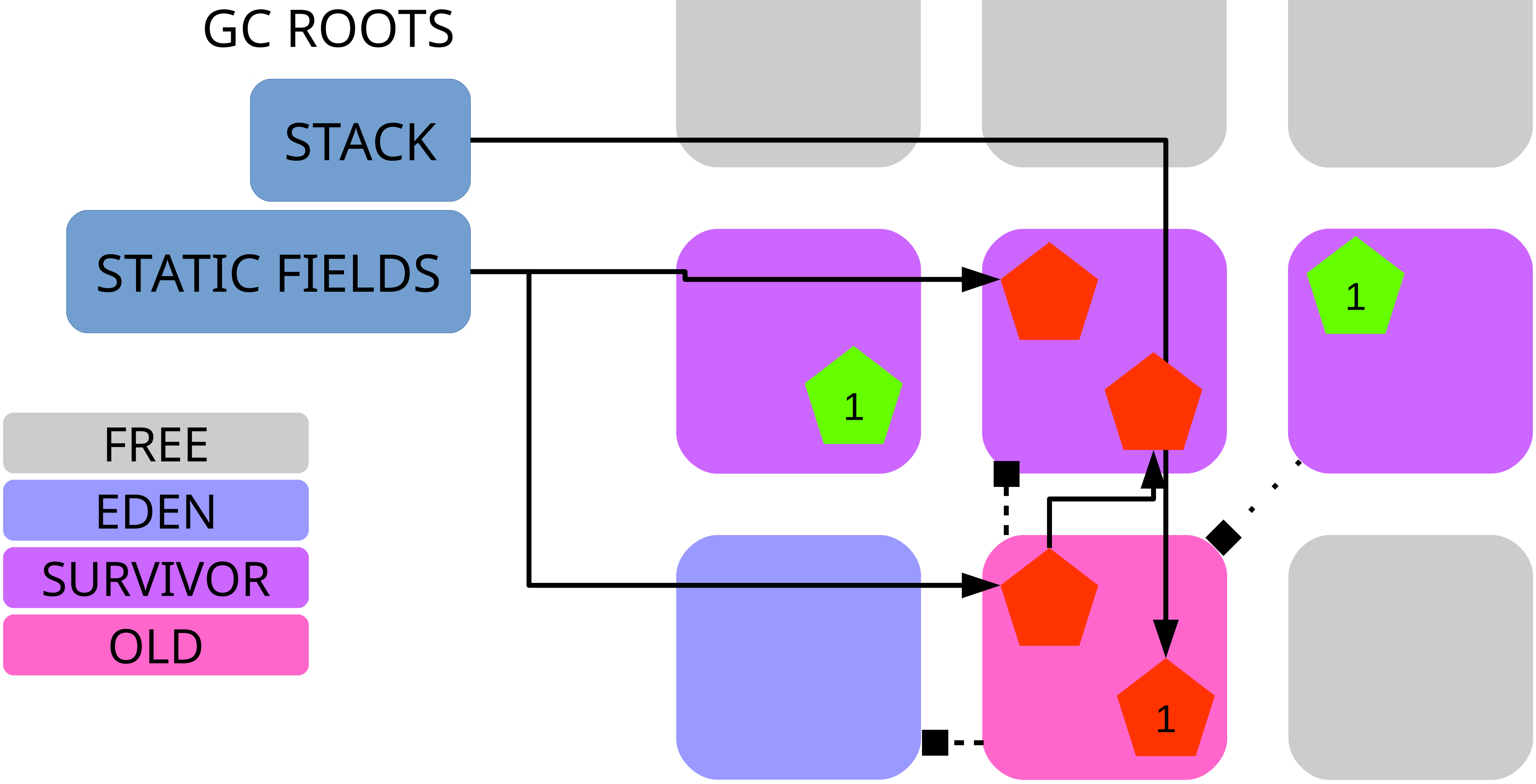
Move to new survivor region / old

STOP THE WORLD



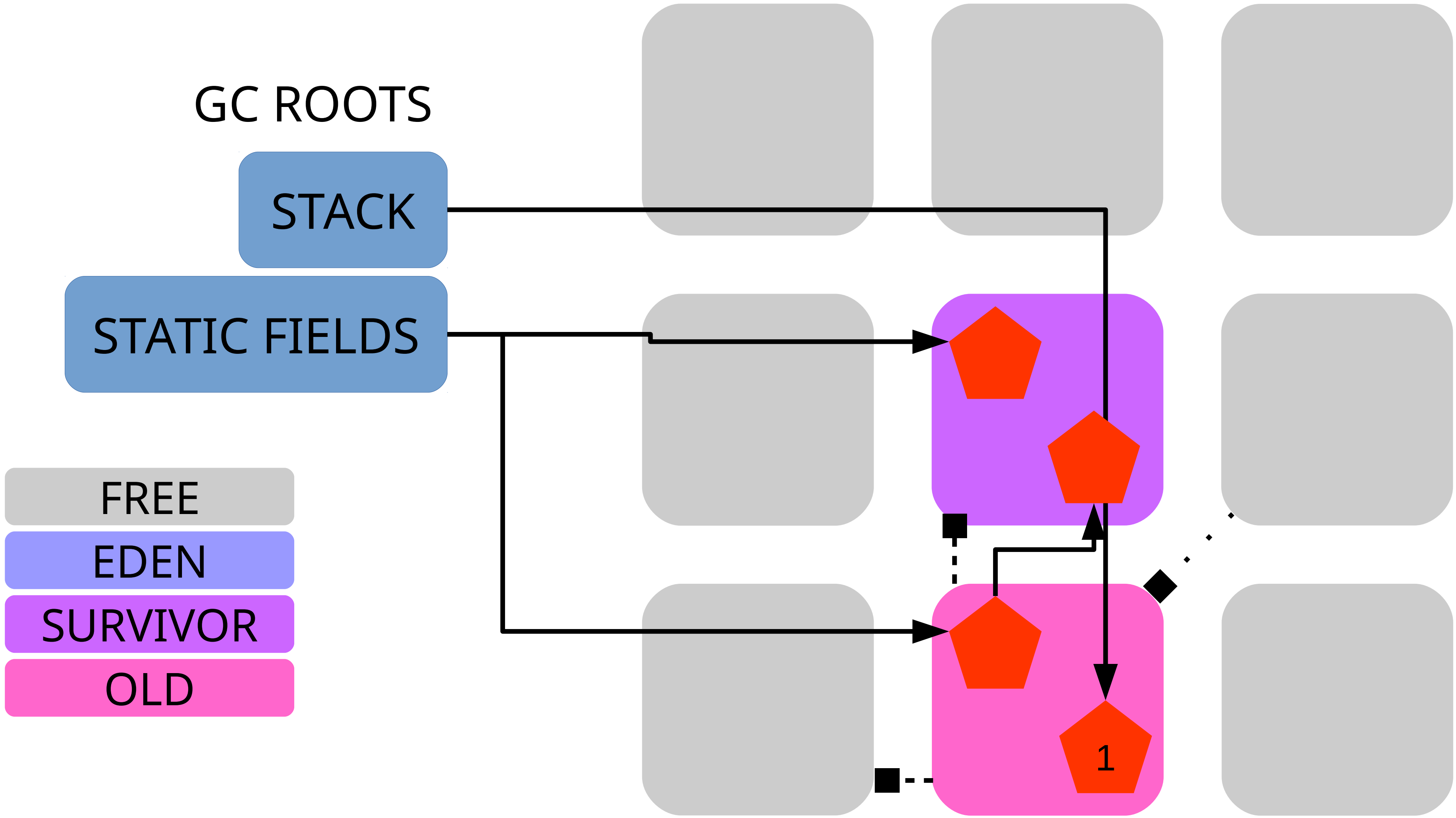
Move to new survivor region / old

STOP THE WORLD



Update RSet: old->young

STOP THE WORLD



GC ROOTS

STACK

STATIC FIELDS

FREE

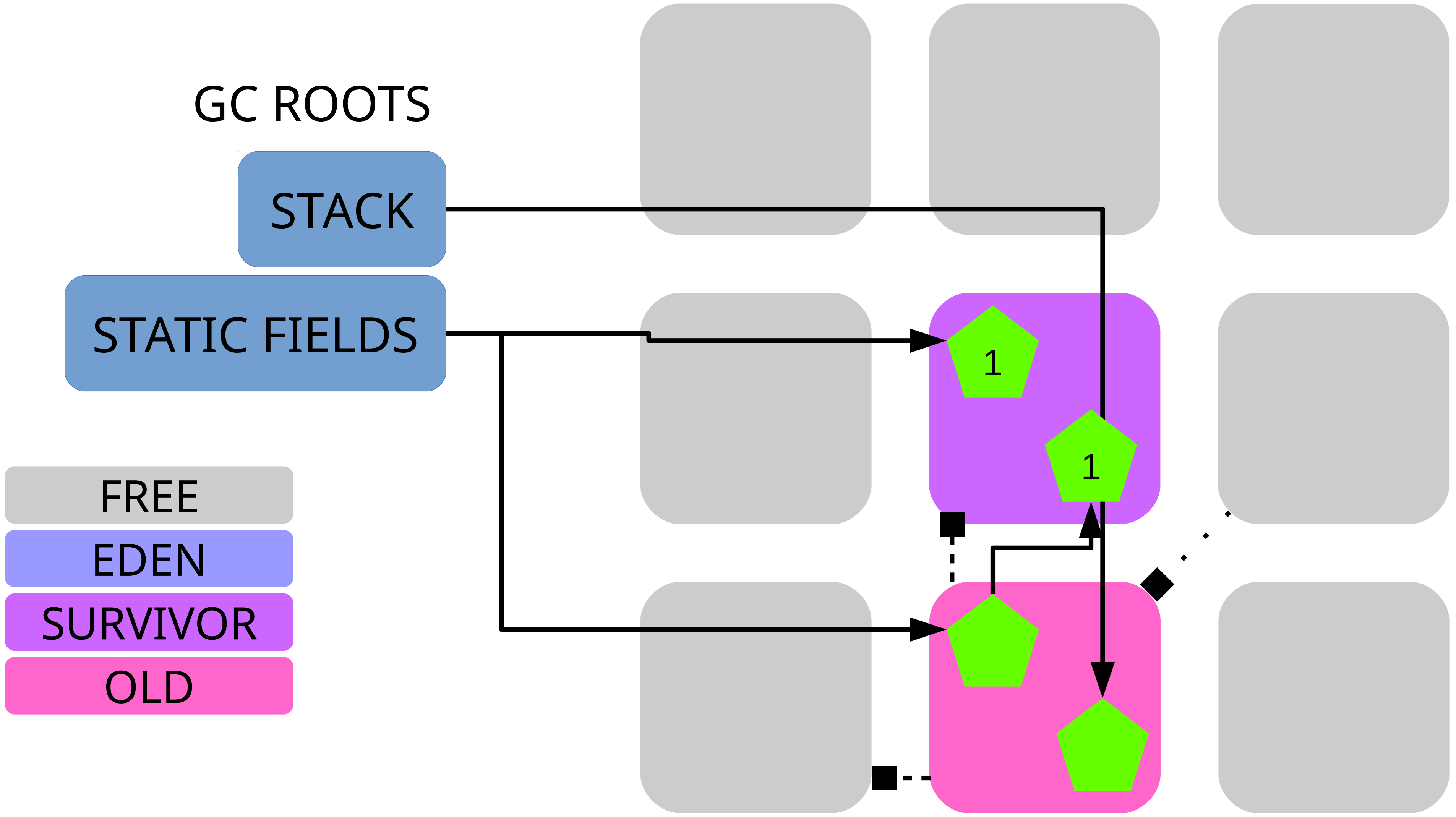
EDEN

SURVIVOR

OLD

Free evacuated regions

RUNNING



GC ROOTS

STACK

STATIC FIELDS

FREE

EDEN

SURVIVOR

OLD

Meanwhile..

- Concurrent marking
- Start from GC roots
- Find all live objects
- Sort regions by “liveness”

After concurrent marking

- Stop The World
- Scrub RSets
- Collection set: all young
  + Old with least live objects
- 1.269: [GC pause (**mixed**) ...]
- Amount of old regions selected ~ pause time

Recap: G1

- Use concurrent marking
- Collection set: all young
  + hand picked old (most garbage)
- Find live objects from GC roots + RSets
- Compact to new survivors / old regions
- Free entire evacuated regions

G1 insights

- Avoid reference scanning with RSets
- Avoid long pauses with mixed collection: never clean entire Old Gen
- Only collect Old regions with most garbage
  - -> don’t touch live Old objects
  - -> more time to become garbage
  - Less live objects -> less copying

Homework (1)

- Use PhantomReferences to write a finalize() replacement
- User can register several cleanup tasks for any object
- PostCollectionTaskRunner starts a thread that runs cleanup tasks in the background

```
interface PostCollectionTaskRunner {
  void register(Object o, Runnable task);
  void shutdown() throws Exception;
}
```

Homework (2)

- Run with ParallelGC (Java8 default).
  Enable detailed GC logging. Cause a Full GC.
- Submit the GC log + following comments:
  - for one minor collection: time since last collection and bytes freed for young gen
  - for one Full GC: bytes freed for young gen, old gen, total heap size
- Use max heap size 64M
- Also submit code for triggering Full GC

Homework (3)

- Phantoms expensive -> use 1 per managed object
- Don’t keep stuff for dead objects
- Reasonably efficient code: no Thread#sleep, crazy list iterations, etc.
- shutdown() -> stop thread, clear data
- Deadline: 07 Nov 23:59 local time

Read more..

- https://docs.oracle.com/javase/8/docs/technotes/guides/vm/gctuning/
- https://plumbr.eu/handbook/garbage-collection-algorithms-implementations
- https://vimeo.com/181948157
- https://stackoverflow.com/q/19154607
- http://insightfullogic.com/2013/Mar/06/garbage-collection-java-2/