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HotSpot Synchronization

A Peek Under the Hood

David Buck
Principal Member of Technical Staff
Java SE
October 26, 2015



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Program Agenda

- 1 Introduction
- 2 Java Locking Review
- 3 HotSpot's Implementation
- 4 Profiling & Tuning
- 5 Everything Else

Howdy!

David Buck

- Java SE Sustaining Engineering
- I Fix JVM Bugs
- Hobbies:
(non-Java) programming



Introduction

What We'll Cover

```
synchronized(this) {  
    c++;  
}
```

What We'll Cover

```
synchronized(this) {  
    c++;  
}
```

What We'll Cover

3: monitorenter

4: aload_0

5: dup

6: getfield #2 // Field c:l

9: iconst_1

10: iadd

11: putfield #2 // Field c:l

14: aload_1

15: monitorexit

What We'll Cover

3: **monitorenter**

4: aload_0

5: dup

6: getfield #2 // Field c:l

9: iconst_1

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11: putfield #2 // Field c:l

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15: **monitorexit**

What We Won't Cover

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- How to use locks

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- `java.util.concurrent` (JSR-166)

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- How to use locks
- `java.util.concurrent` (JSR-166)
- Java's memory model

Motivation

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- Avoiding premature optimization

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- Improve Profiling, Design, and Tuning

Motivation

- Avoiding premature optimization
- Improve Profiling, Design, and Tuning
- Fun!

Java Locking Review

Multithreading as Part of the Language



- So, what exactly **is** a Monitor?

Mutual Exclusion

Mutual Exclusion

↙ Mut ex ↘

Mutual Exclusion



condition variable



"Puffin crossing, London, UK" by secretlondon is licensed under CC BY-SA 3.0

Monitor = Mutex + Condition Variable

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- Mutex
 - synchronized keyword

Monitor = Mutex + Condition Variable

- Mutex
 - synchronized keyword
- Condition Variable
 - Object.wait()
 - Object.notify()
 - Object.notifyAll()

Java Locks are Recursive!

```
public synchronized void increment() {  
    c++;  
    printValue();  
}
```

```
public synchronized void printValue() {  
    System.out.println("My value is: " + c);  
}
```


Memory Model

Establish a “happens-before” relationship



```
public class NoSync {  
    private int c = 0;  
    public void increment() {  
        c++;  
    }  
}
```

```
public void increment();  
  flags: ACC_PUBLIC  
  Code:  
  stack=3, locals=1, args_size=1  
  0: aload_0  
  1: dup  
  2: getfield #2 // Field c:I  
  5: iconst_1  
  6: iadd  
  7: putfield #2 // Field c:I  
 10: return
```

Block Example

```
public void increment() {  
    synchronized(this) {  
        c++;  
    }  
}
```

Block Example

```
public void increment();
```

```
  flags: ACC_PUBLIC
```

```
  Code:
```

```
  stack=3, locals=3, args_size=1
```

```
  0: aload_0
```

```
  1: dup
```

```
  2: astore_1
```

```
  3: monitorenter
```

```
  4: aload_0
```

```
  5: dup
```

```
  6: getfield #2 // Field c:l
```

```
  9: iconst_1
```

```
 10: iadd
```

```
 11: putfield #2 // Field c:l
```

```
 14: aload_1
```

```
 15: monitorexit
```

```
 16: goto 24
```

```
 19: astore_2
```

```
 20: aload_1
```

```
 21: monitorexit
```

```
 22: aload_2
```

```
 23: athrow
```

```
 24: return
```

```
Exception table:
```

```
from to target type
```

```
   4 16 19 any
```

```
  19 22 19 any
```

Block Example

```
public void increment();
```

```
  flags: ACC_PUBLIC
```

```
  Code:
```

```
  stack=3, locals=3, args_size=1
```

```
  0: aload_0
```

```
  1: dup
```

```
  2: astore_1
```

```
  3: monitorenter
```

```
  4: aload_0
```

```
  5: dup
```

```
  6: getfield #2 // Field c:l
```

```
  9: iconst_1
```

```
 10: iadd
```

```
 11: putfield #2 // Field c:l
```

```
 14: aload_1
```

```
 15: monitorexit
```

```
 16: goto 24
```

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```

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 20: aload_1
```

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 21: monitorexit
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 23: athrow
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```
 24: return
```

```
Exception table:
```

```
from to target type
```

```
   4 16 19 any
```

```
  19 22 19 any
```

Method Example

```
public synchronized void increment() {  
    c++;  
}
```

Method Example

```
public synchronized void increment();  
  flags: ACC_PUBLIC, ACC_SYNCHRONIZED
```

Code:

```
stack=3, locals=1, args_size=1
```

```
0: aload_0
```

```
1: dup
```

```
2: getfield #2 // Field c:I
```

```
5: iconst_1
```

```
6: iadd
```

```
7: putfield #2 // Field c:I
```

```
10: return
```


Method Example

```
public synchronized void increment();  
  flags: ACC_PUBLIC, ACC_SYNCHRONIZED
```

Code:

```
stack=3, locals=1, args_size=1
```

```
0: aload_0
```

```
1: dup
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2: getfield #2 // Field c:I
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```
5: iconst_1
```

```
6: iadd
```

```
7: putfield #2 // Field c:I
```

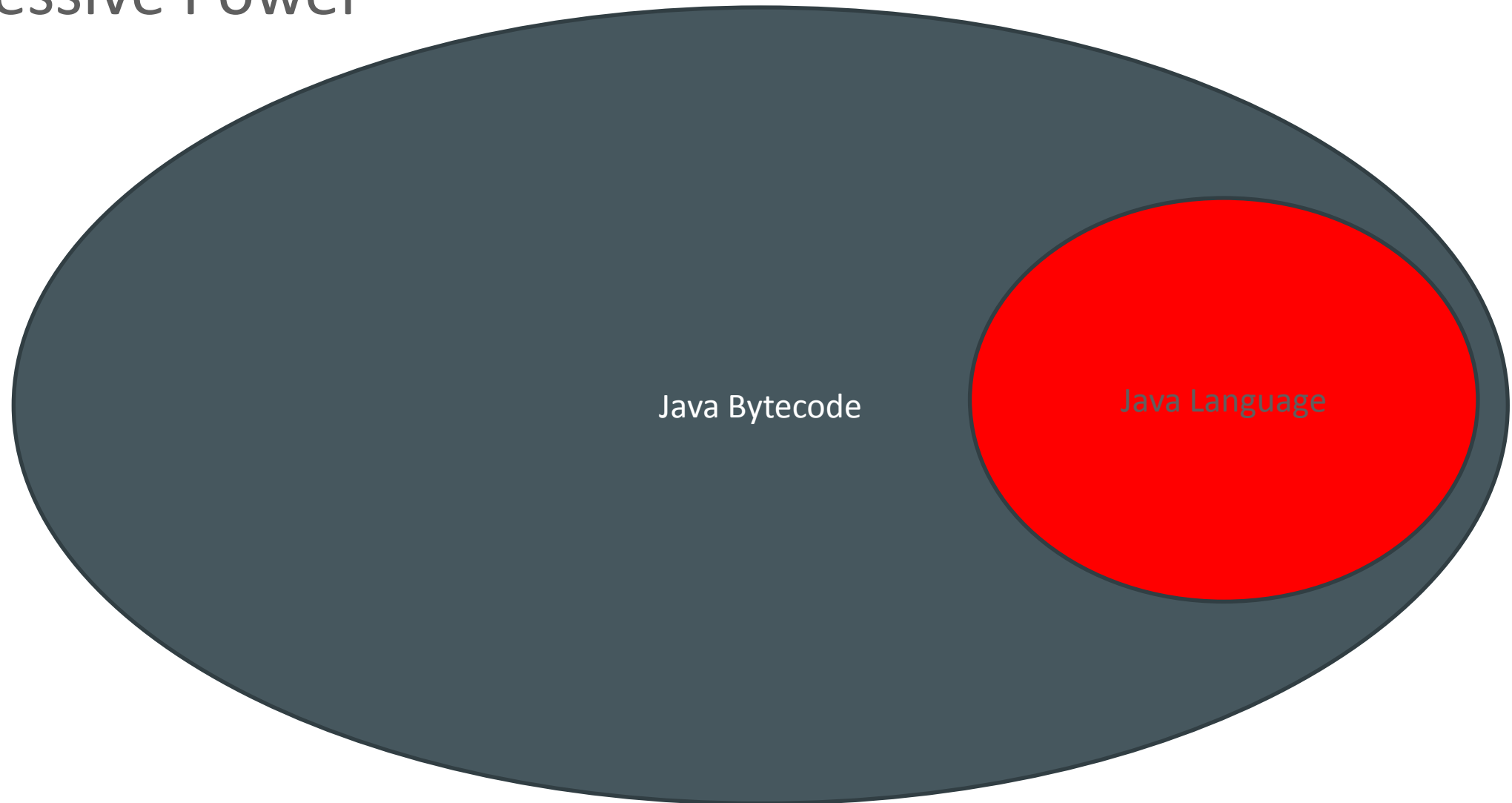
```
10: return
```

Impossible in Java Language!

```
public void lockMe();  
  flags: ACC_PUBLIC  
  Code:  
    stack=1, locals=1, args_size=1  
    0: aload_0  
    1: monitorenter  
    2: return
```

```
public void unlockMe();  
  flags: ACC_PUBLIC  
  Code:  
    stack=1, locals=1, args_size=1  
    0: aload_0  
    1: monitorexit  
    2: return
```

Expressive Power



Java Monitor Limitations

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- No way to check status of a lock

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Java Monitor Limitations

- No way to check status of a lock
- No timeout
- No way to cancel
- Must be recursive
- No reader / writer locking
- Security Issues

java.util.concurrent



HotSpot's Implementation

Design Goals

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- Every object may be used as a monitor

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- But most objects never are

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Design Goals

- Every object may be used as a monitor
- But most objects never are
- Those that are locked, are usually not used by multiple threads
- Those that are used by multiple threads, are usually not contended

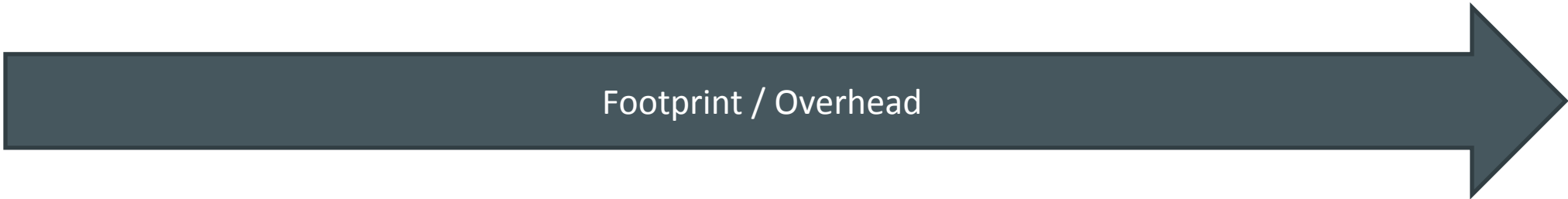
Lock Types

- Fat
- Thin
- Biased

Biased

Thin

Fat



Fat Lock

- Rely on OS scheduler
- Best use case: long wait times
- AKA: Heavyweight lock, inflated lock

Thin Lock

- Spin until lock is available
- Best use case: short pause times
- AKA: spin lock, stack lock (HS), lightweight lock

Biased Lock

- Only a single thread repeatedly locks object
- If other thread needs lock, bias needs to be revoked

BiasedLock Revocation

- Stop thread that currently holds bias (STW)
- Check if thread “really” holds lock (stack walk)

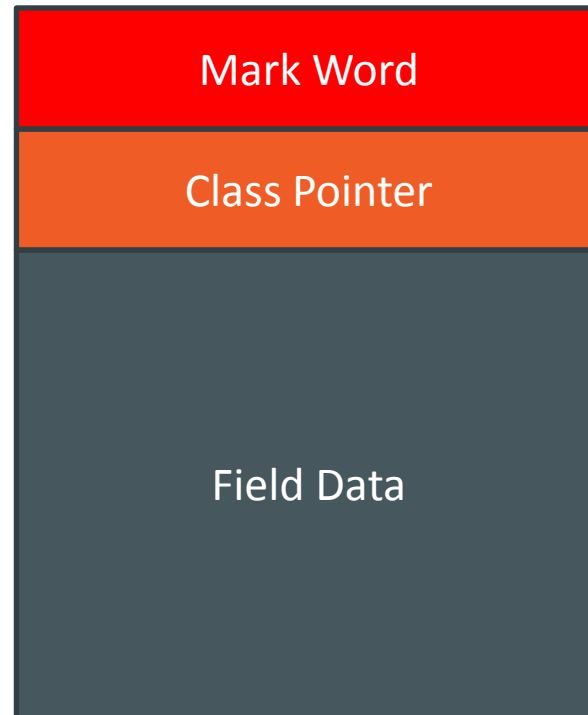
BiasedLock Banning

- Object Level
- Class Level
- Booting Phase

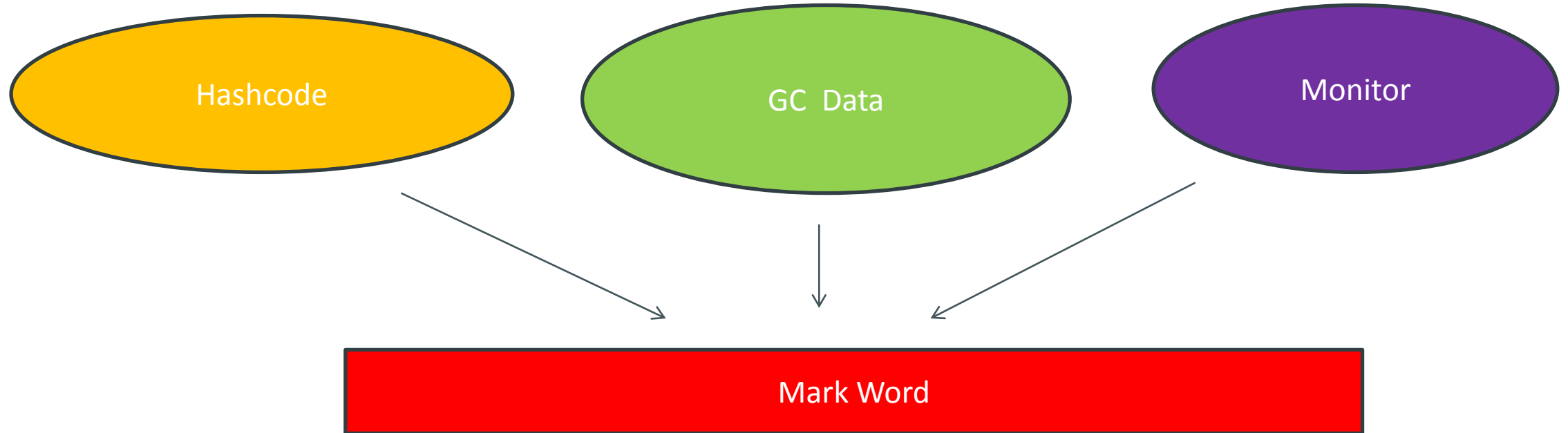
Per-Object Data

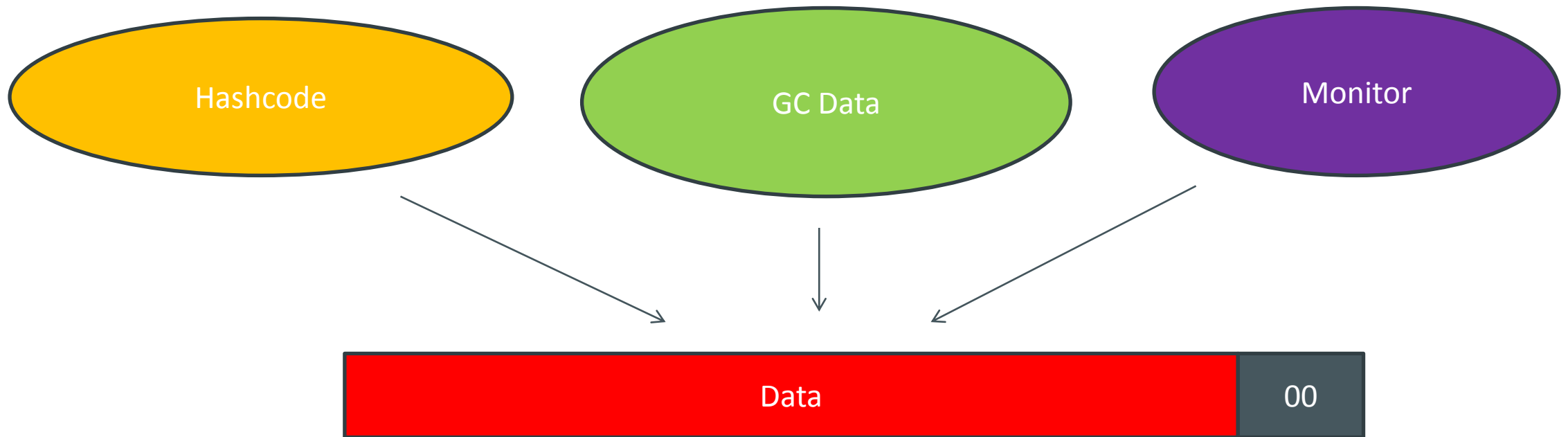
- Field data
- Metadata
 - Monitor condition
 - GC bookkeeping (e.g. age)
 - Hash code

Object Header

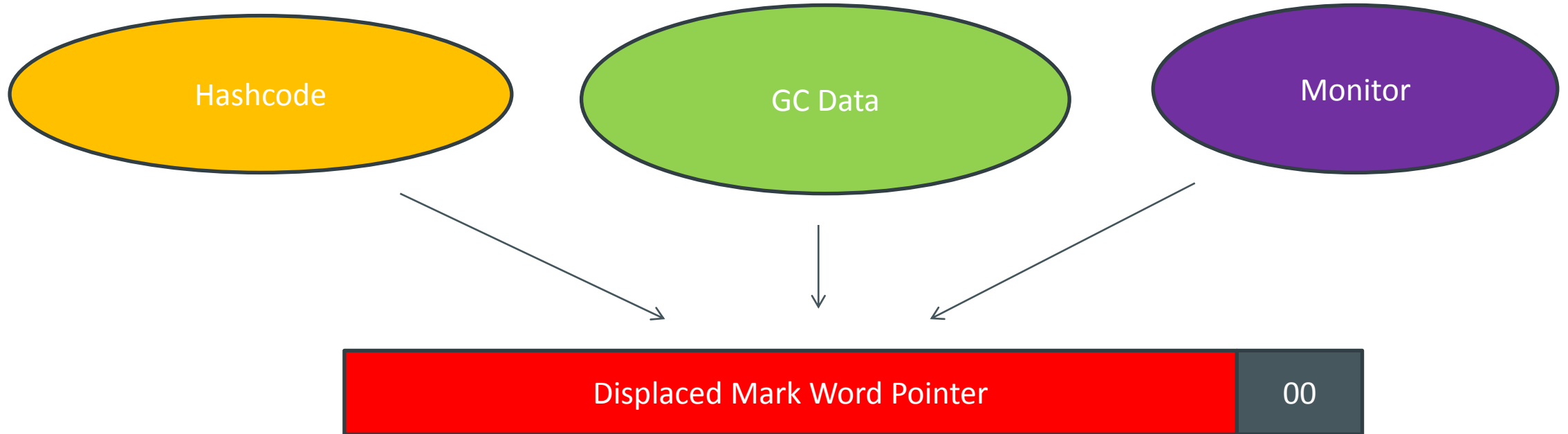


Busy Mark Word is Busy

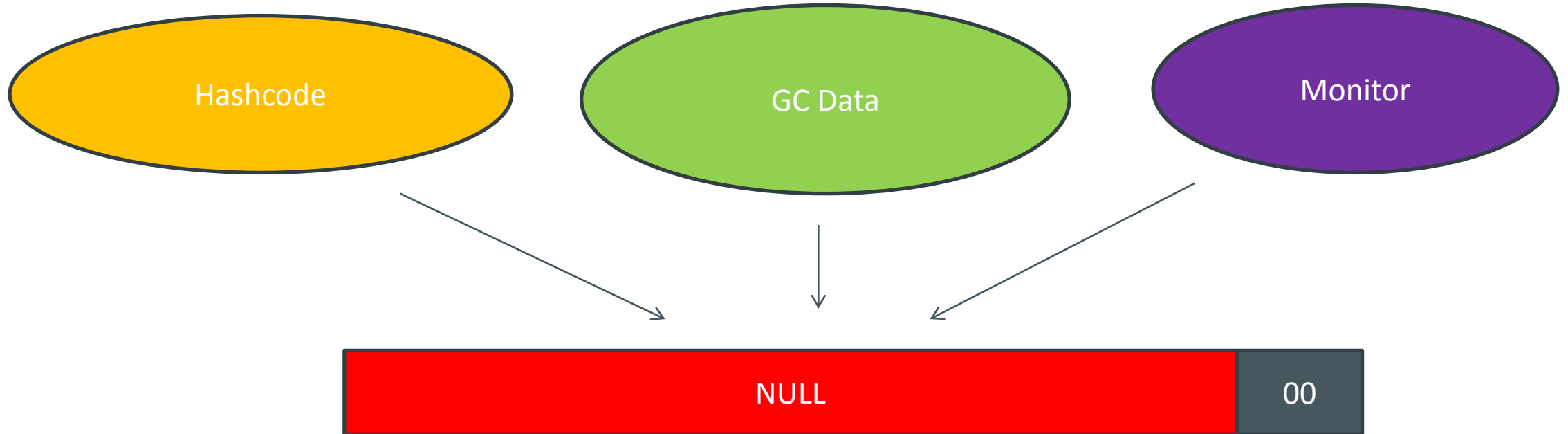




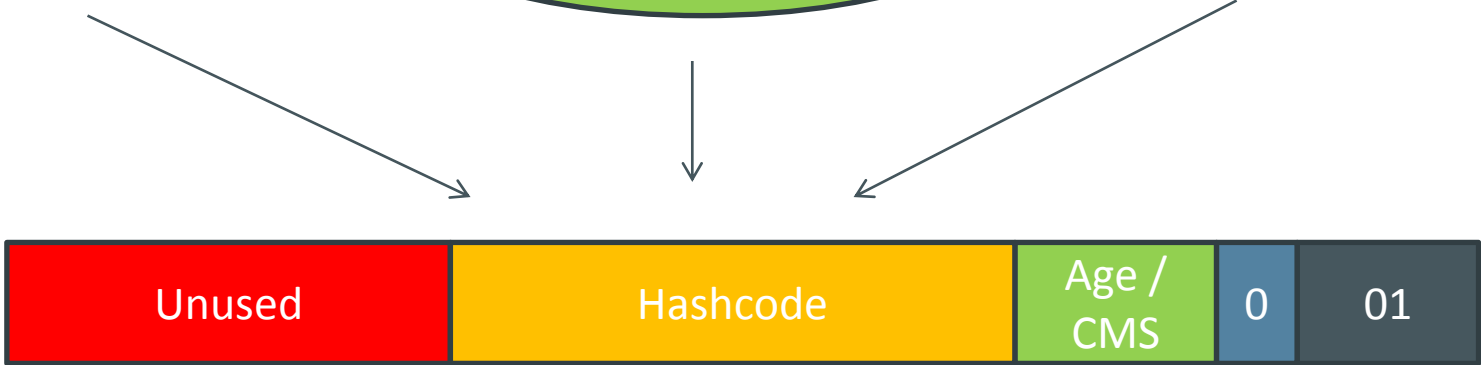
Thin Locked



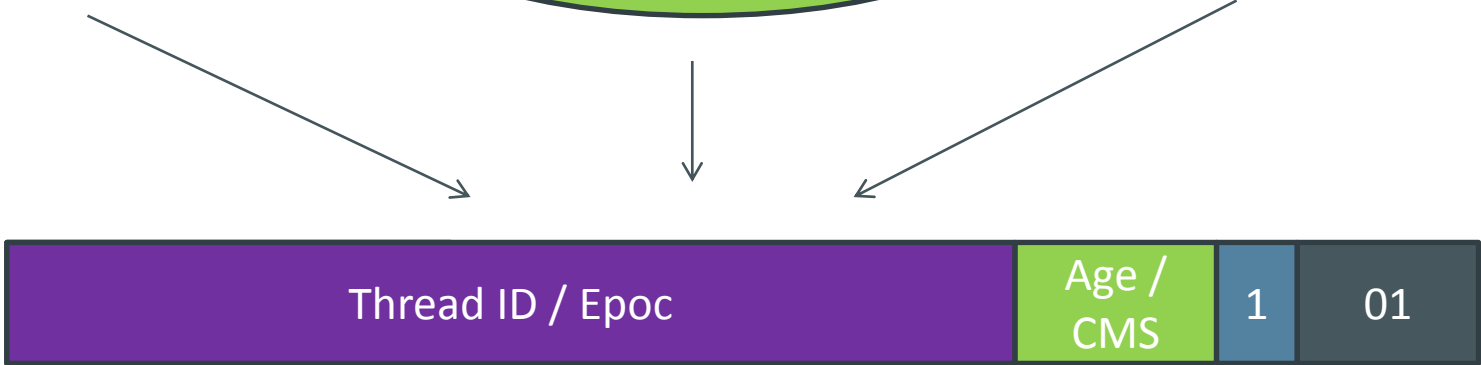
Inflating



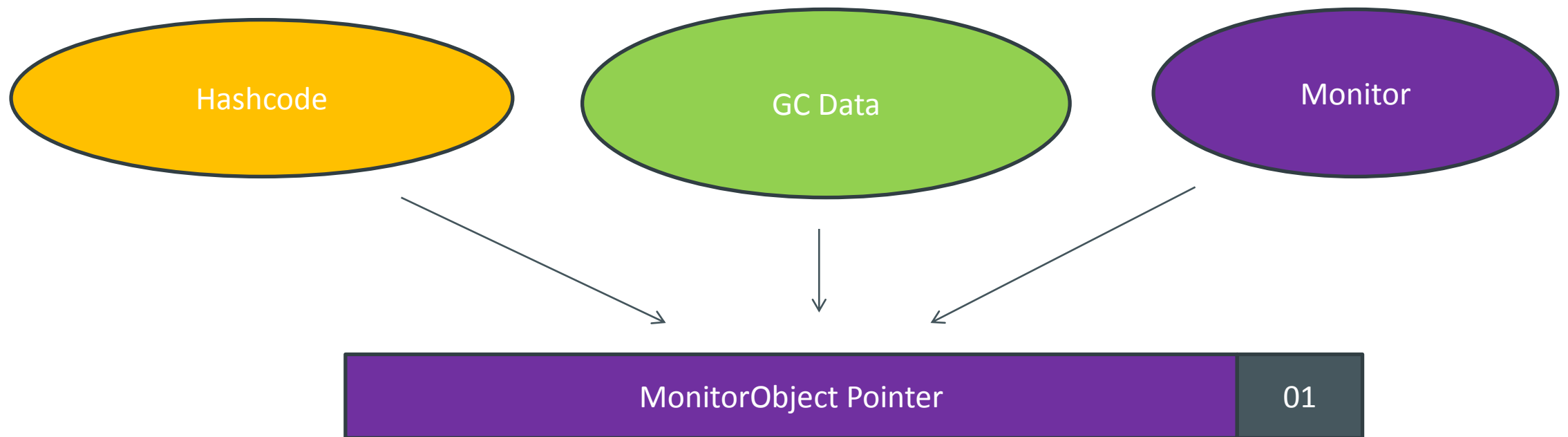
Unlocked Banned for Biased Locking



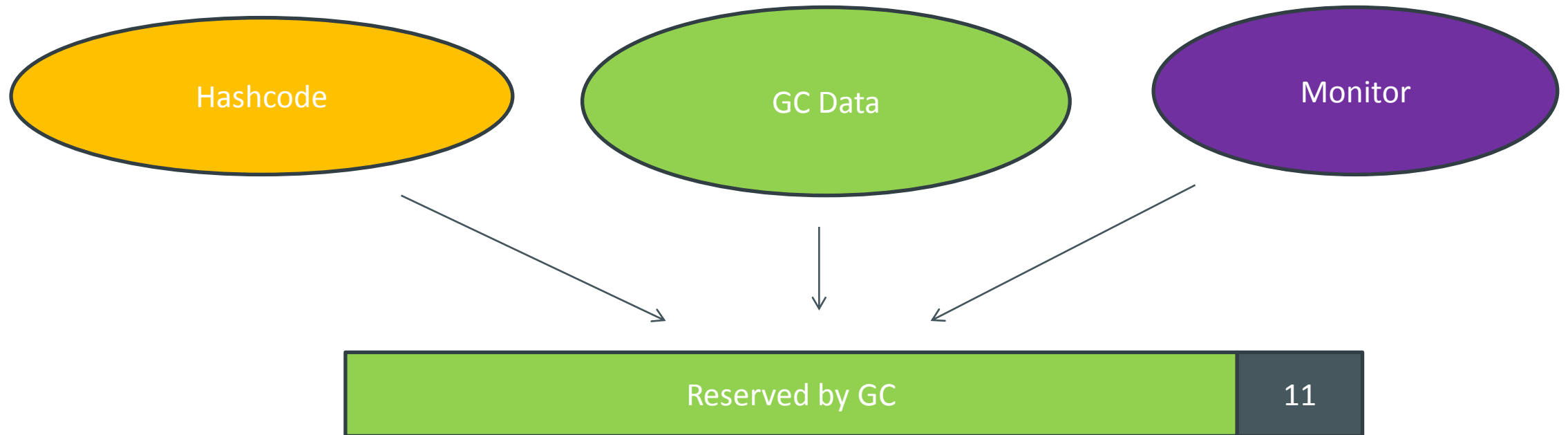
Biased



Fat Locked



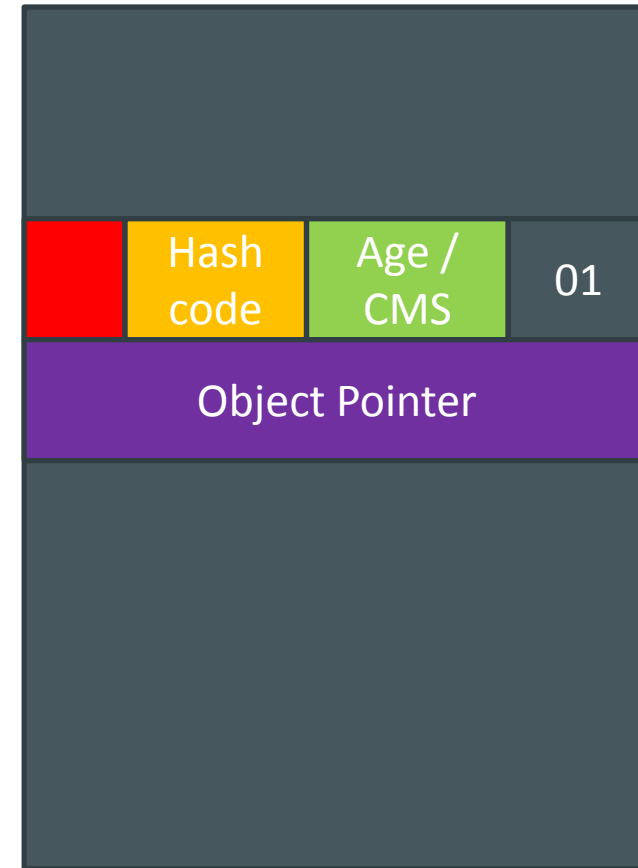
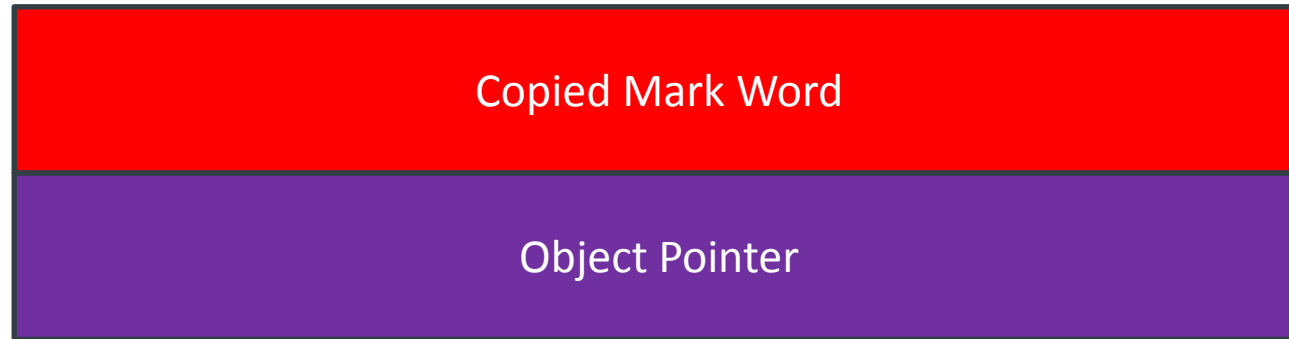
GC Running (STW)



Lock Record

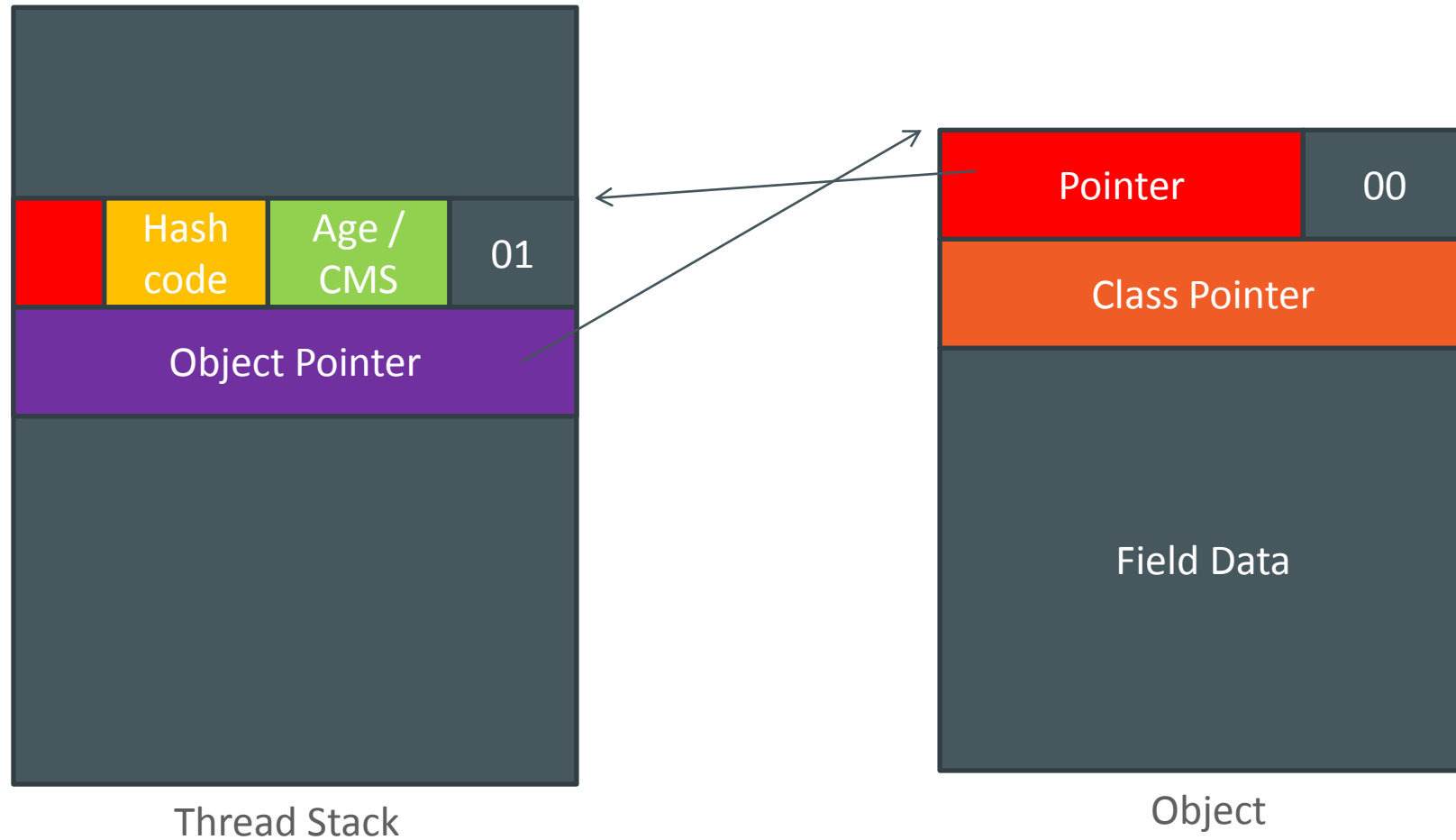


Lock Record

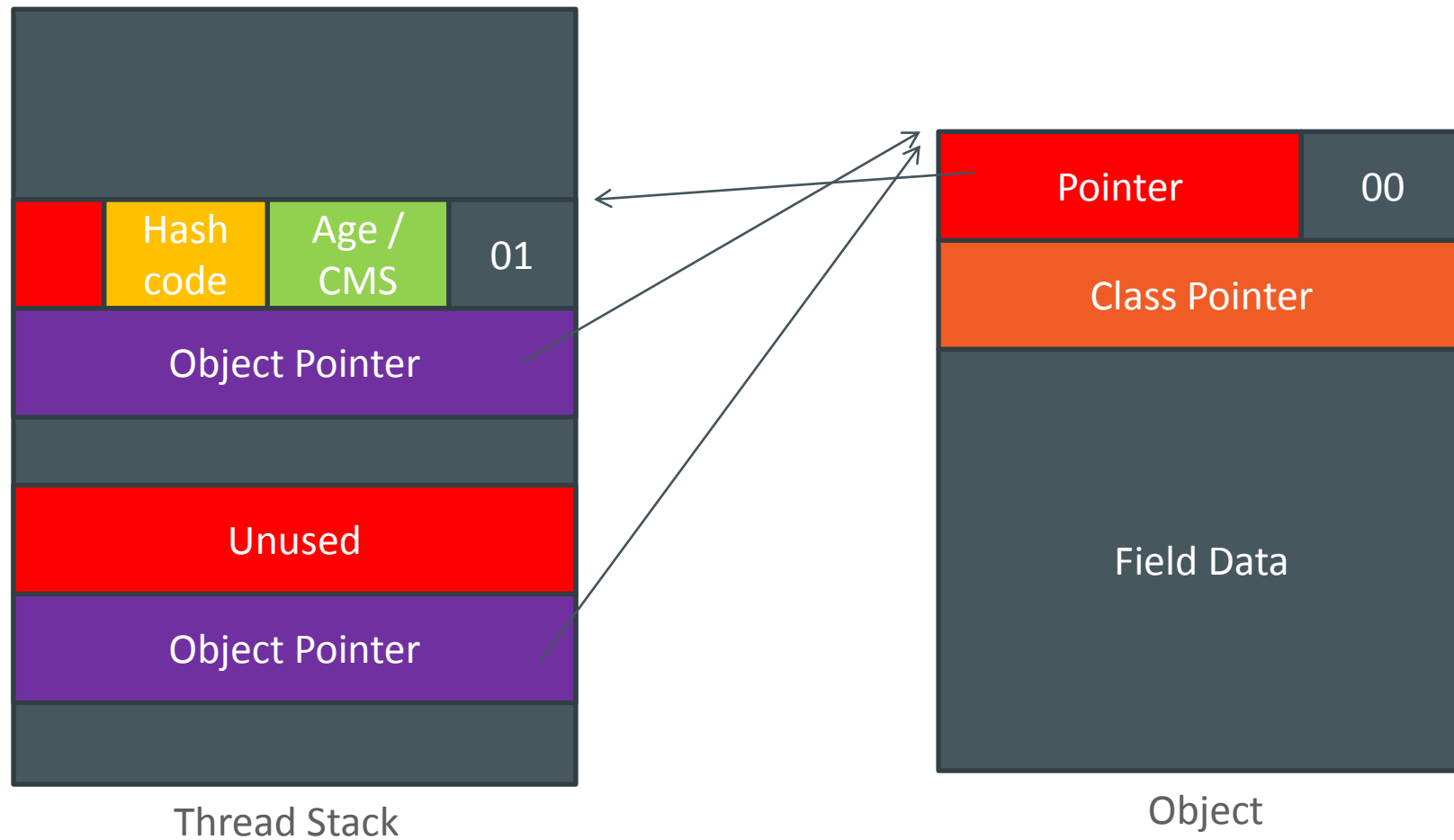


Thread Stack

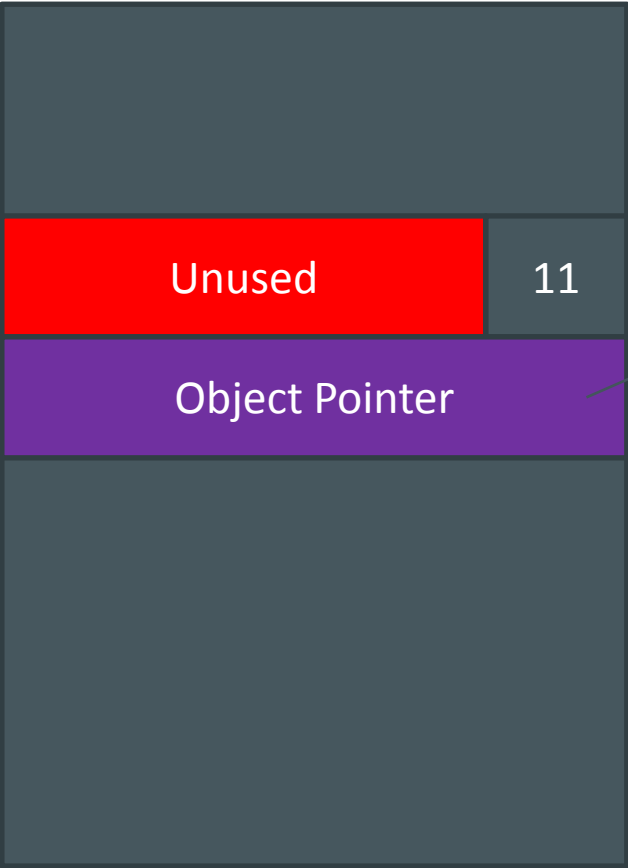
Thin Lock



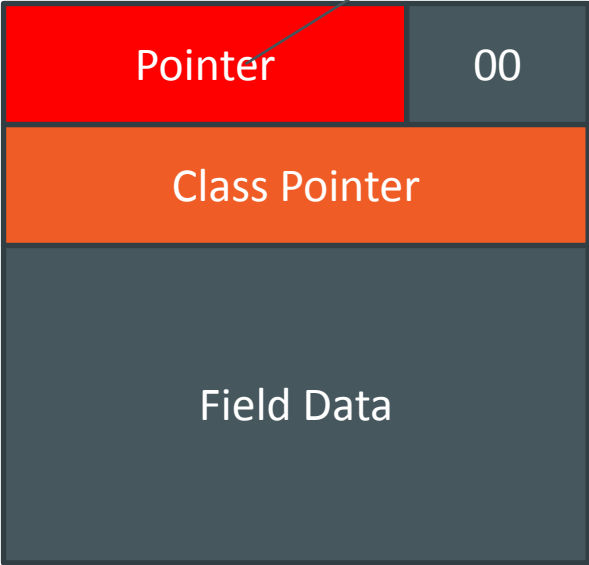
Thin Lock (Recursive)



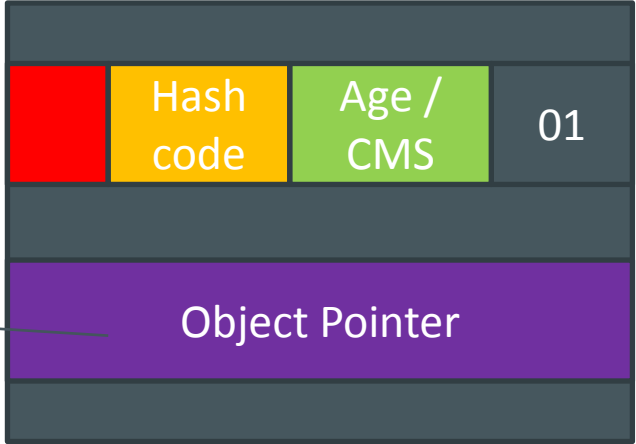
Fat Lock



Thread Stack

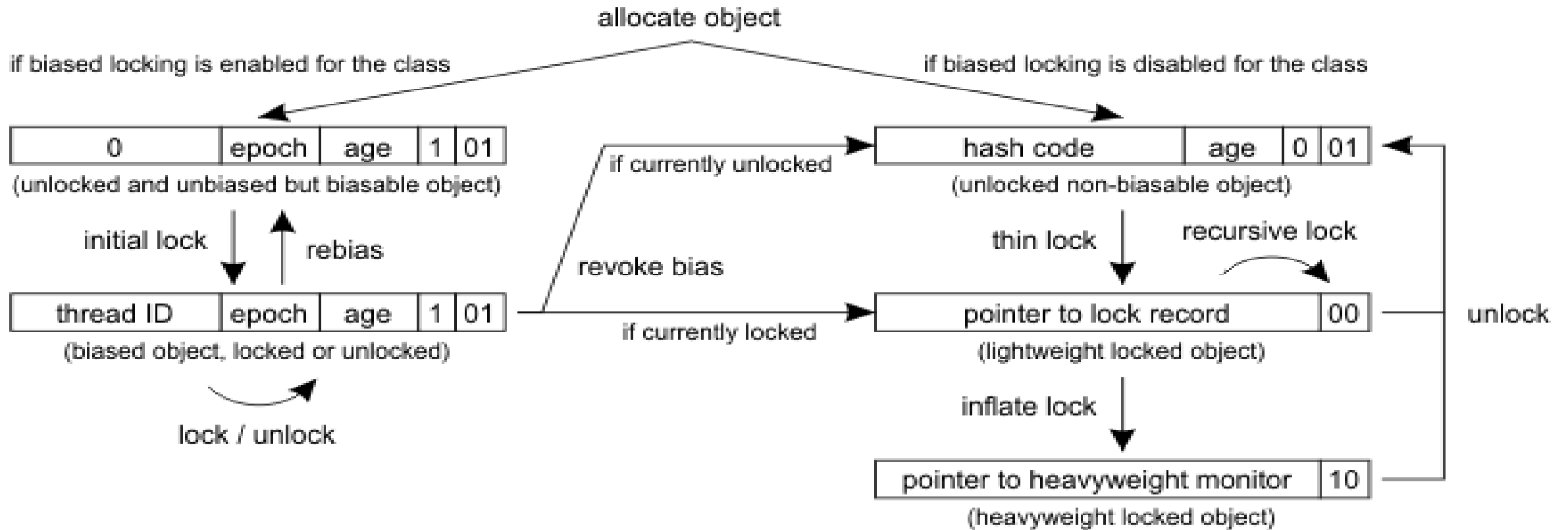


Object



ObjectMonitor

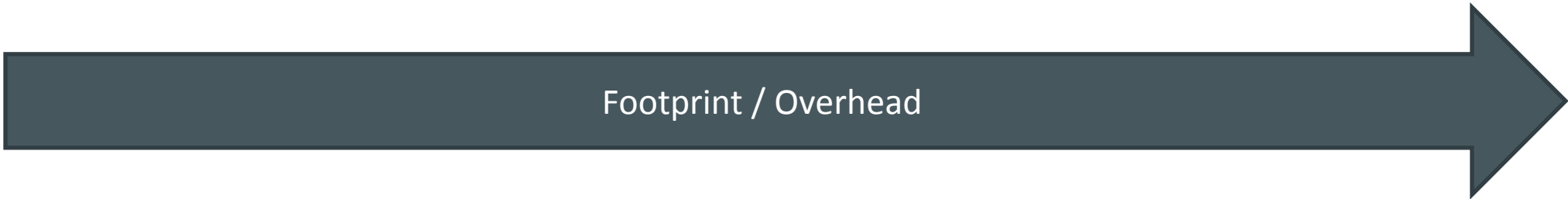
Lock Transitions



Biased

Thin

Fat



Profiling & Tuning

Profiling

DANGER:
Performance Impact Ahead!

Profiling

- Performance Counters
- DTrace
- Java Flight Recorder

Performance Counters

- No performance impact
- Not officially supported
- Intended for HotSpot troubleshooting
- Example:

```
jstat -snap -J-Djstat.showUnsupported=true <JVM_PID> |grep _sync
```

DTrace

- Most flexible
- Higher learning curve
- Supported platforms
 - Solaris
 - Oracle Linux
 - OSX
- Must use **-XX:+DTraceMonitorProbes**

DTrace

Mutex Probes

- monitor-contended-enter
- monitor-contended-entered
- monitor-contended-exit

DTrace

Condition Variable Probes

- monitor-wait
- monitor-waited
- monitor-notify
- monitor-notifyAll

Java Flight Recorder

- Free for development use
- Supported Platforms: all OracleJDK Java SE Platforms

Options

- PrintConcurrentLocks
- UseBiasedLocking
- DTraceMonitorProbes
- BiasedLockingStartupDelay
- PrintBiasedLockingStatistics
- TraceBiasedLocking
- TraceMonitorInflation
- MonitorInUseLists
- TraceMonitorMismatch
- UseHeavyMonitors
- BiasedLockingBulkRebiasThreshold
- BiasedLockingBulkRevokeThreshold
- BiasedLockingDecayTime
- SyncKnobs

Options

- `PrintConcurrentLocks`
- `UseBiasedLocking`
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- `TraceMonitorMismatch`
- `UseHeavyMonitors`
- `BiasedLockingBulkRebiasThreshold`
- `BiasedLockingBulkRevokeThreshold`
- `BiasedLockingDecayTime`
- `SyncKnobs`

PrintConcurrentLocks

- Displays `java.util.concurrent` locks in thread dumps just like normal locks!

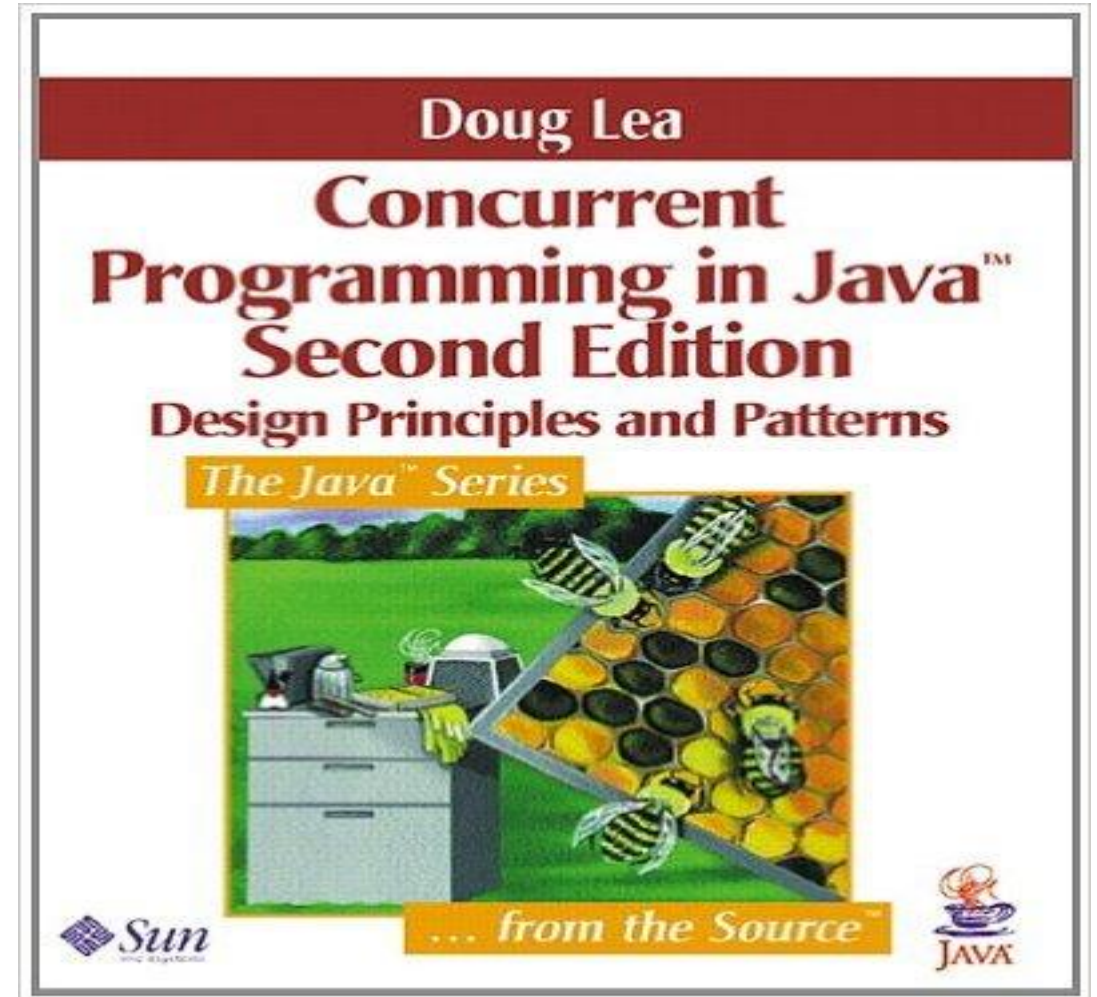
UseBiasedLocking

- Disables biased locking
- Worth trying (benchmarking) on systems with very high contention

Everything Else

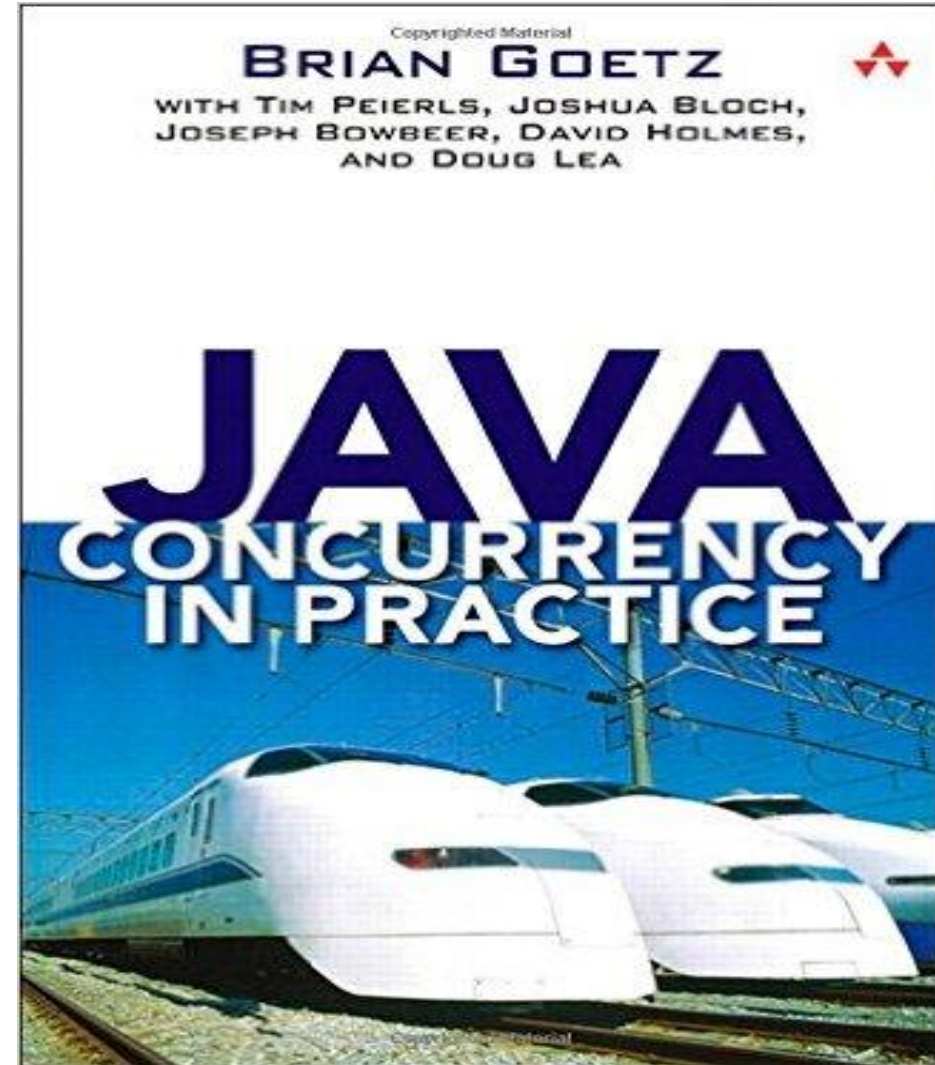
Concurrent Programming in Java™: Design Principles and Patterns

- JDK 1.2 Era
 - No modern memory model
 - The source of `java.util.concurrent`
- Focus on design
- A classic



Java Concurrency in Practice

- JDK 1.6 Era
 - New Memory Model
 - `java.util.concurrent`
- If you read only **one** book on Java concurrency...



Summary

- Leave optimization up to the JVM
- If simple monitors do not provide what you need, check out `java.util.concurrent`
- Profiling tools: JFR or DTrace
 - Watch out for performance impact
- Everyone really should read `CPIJ` and `JCiP`

Thank You!!!

References

- [jstat man page]
<https://docs.oracle.com/javase/8/docs/technotes/tools/unix/jstat.html>
- [DTrace Probes in HotSpot VM]
<http://docs.oracle.com/javase/8/docs/technotes/guides/vm/dtrace.html>
- [JMC Tutorial]
<http://hirt.se/blog/?p=611>
- [David Dice's Weblog]
<https://blogs.oracle.com/dave/>
- [HotSpot Internals]
<https://wiki.openjdk.java.net/display/HotSpot/Main>



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