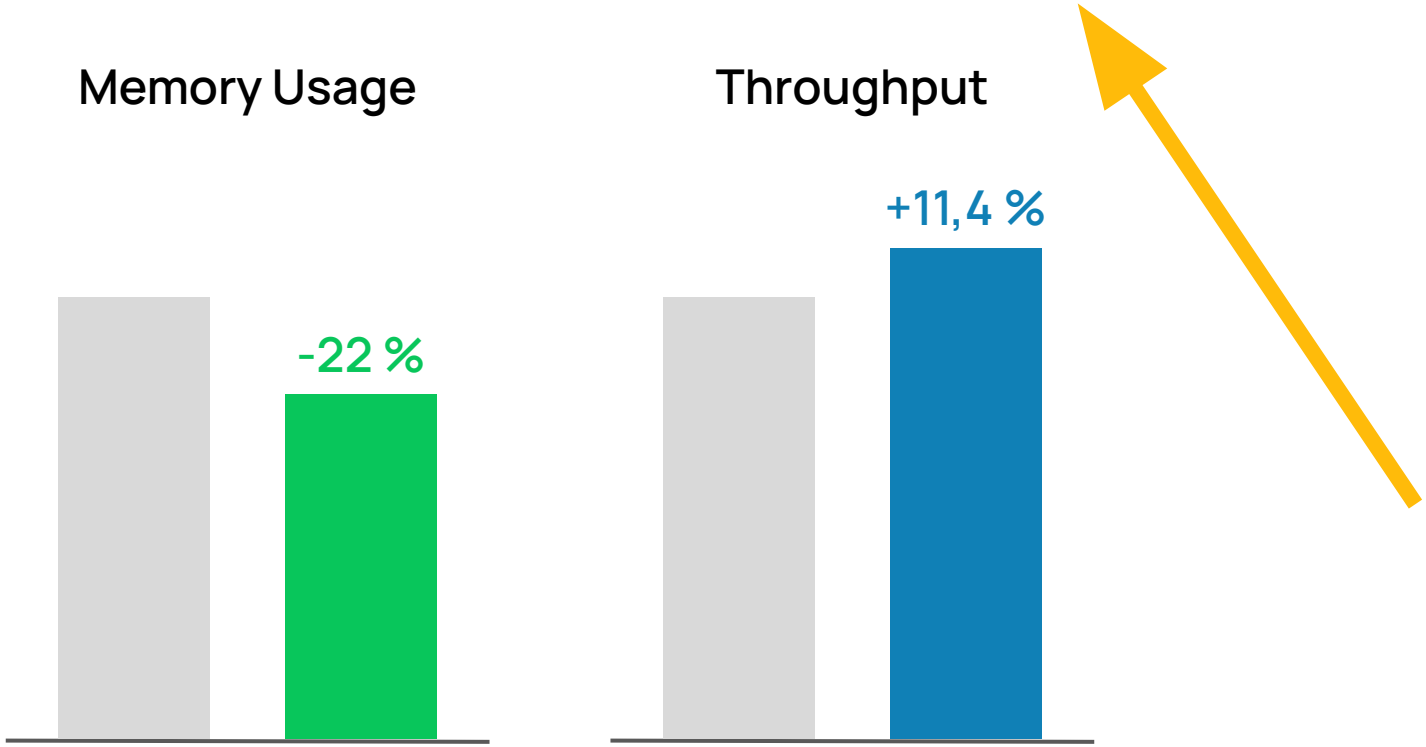
Von Compressed OOPs bis Compact Headers:

JVM-Interna verständlich erklärt

Sven Woltmann

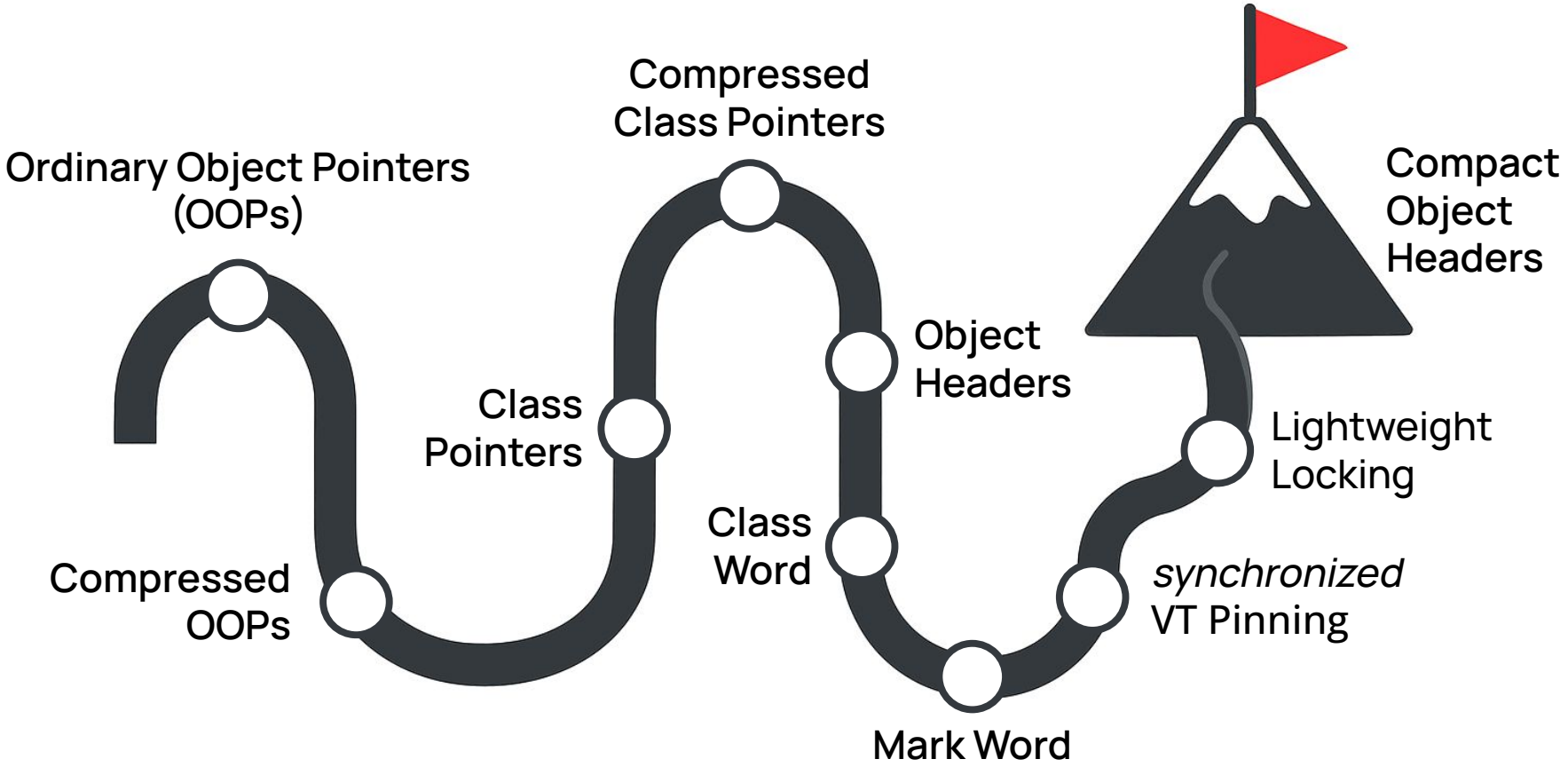
Java Consultant, Speaker, Trainer

Java 25 with `-XX:+UseCompactObjectHeaders`

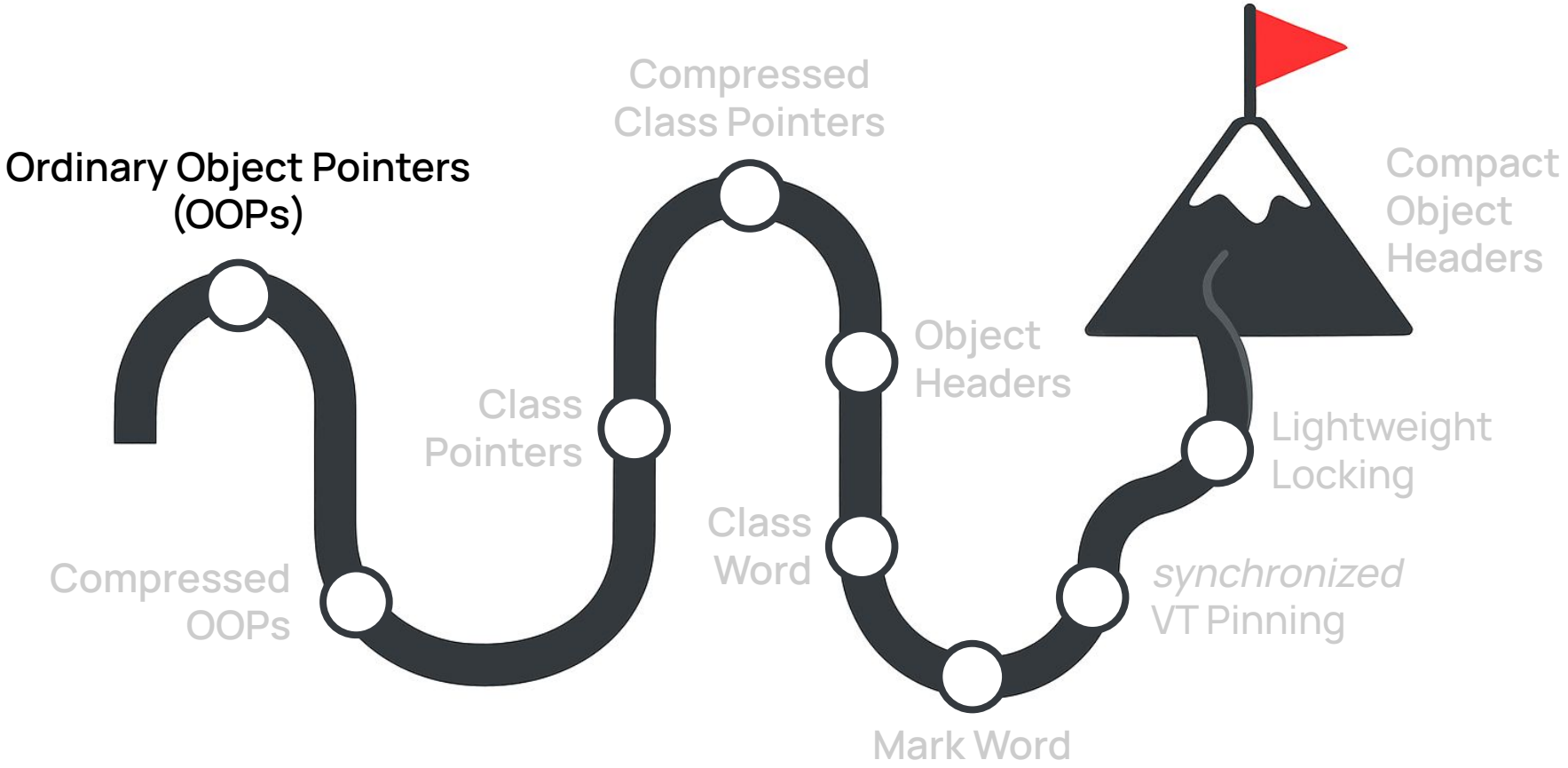


Source: https://github.com/rkennke/talks/blob/master/Lilliput-FOSDEM-2025.pdf

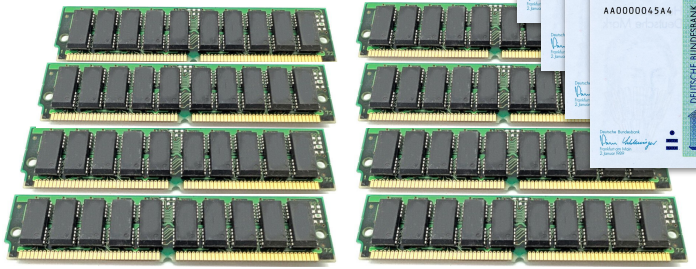
Journey into the JVM



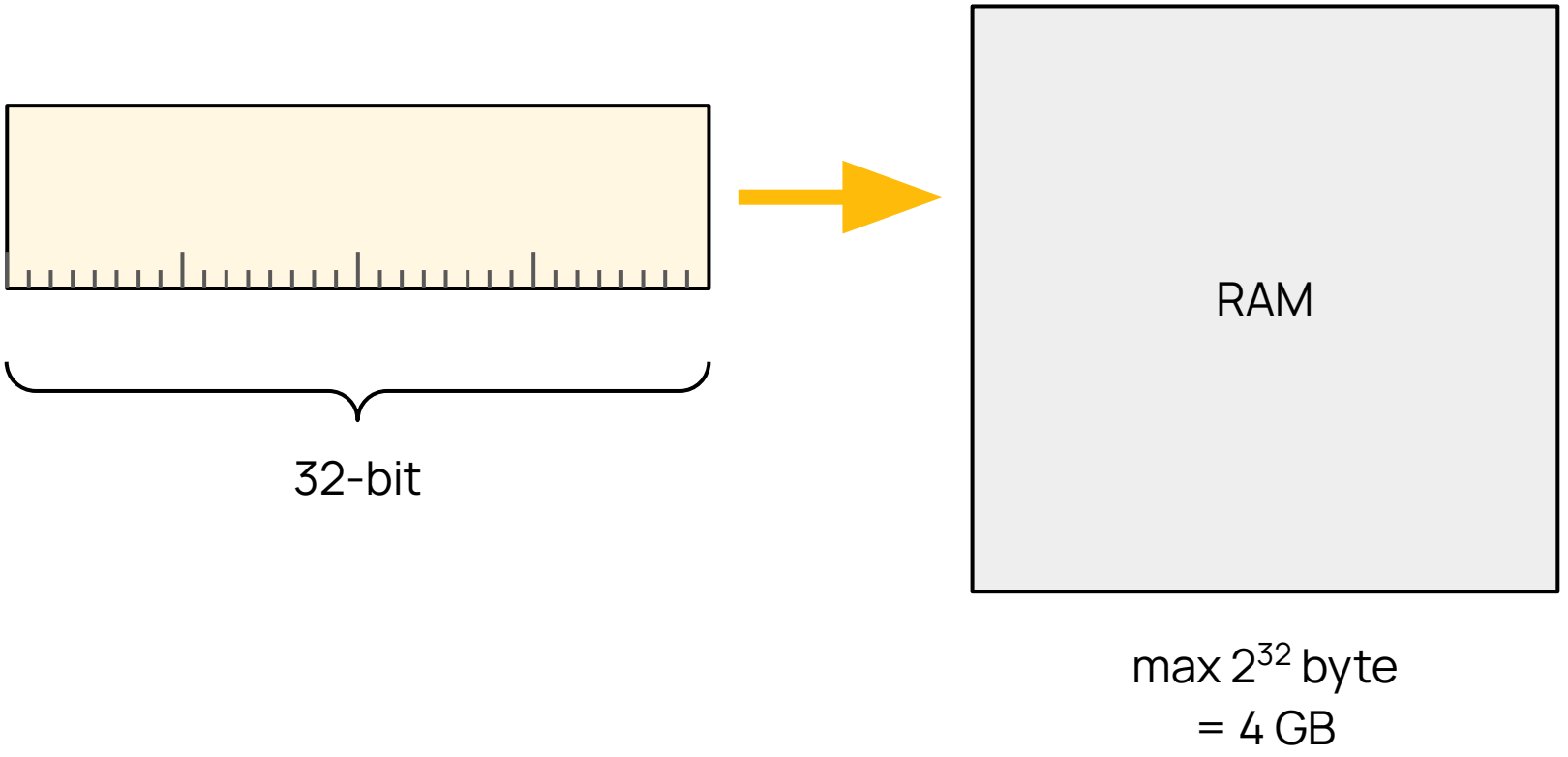
Journey into the JVM



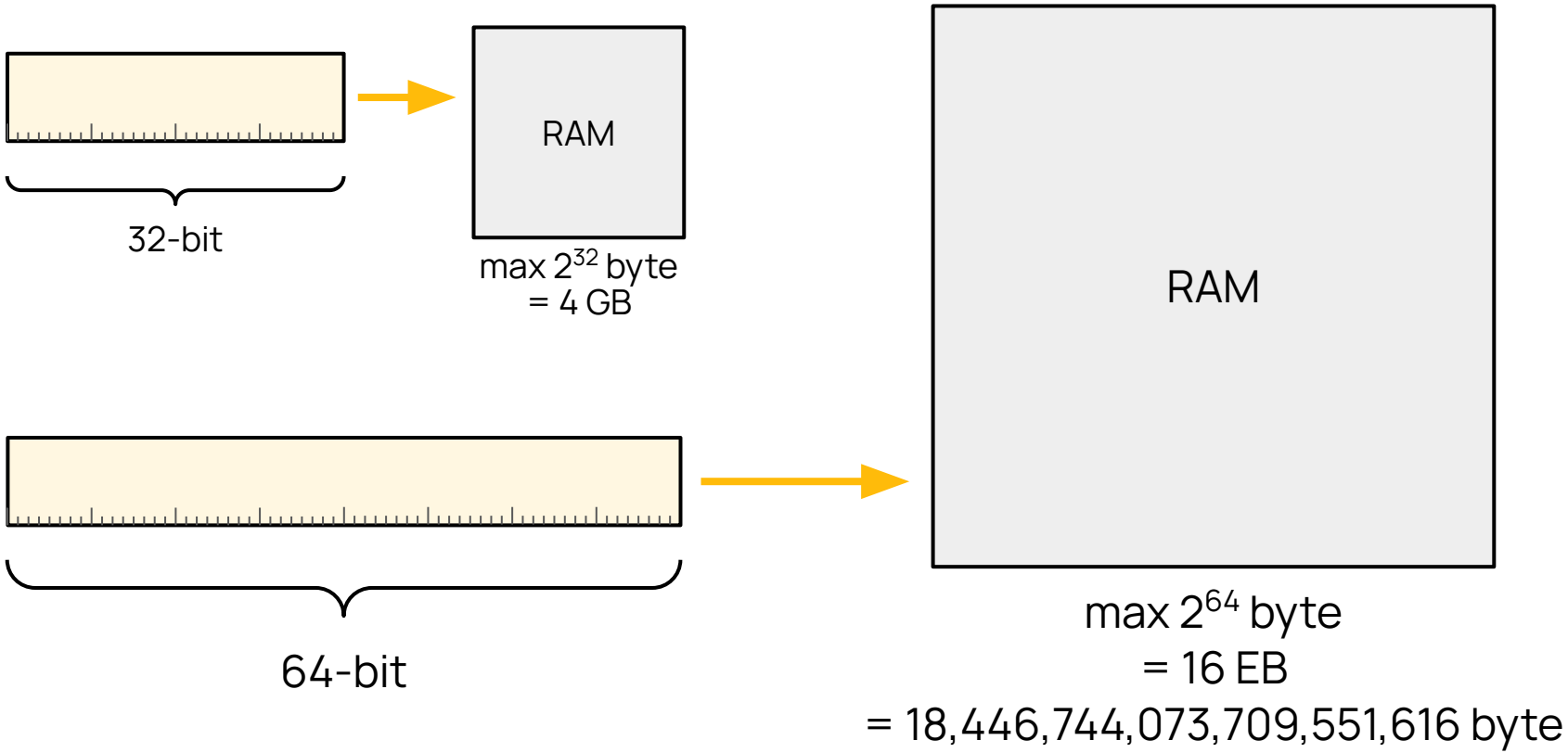
Ordinary Object Pointers



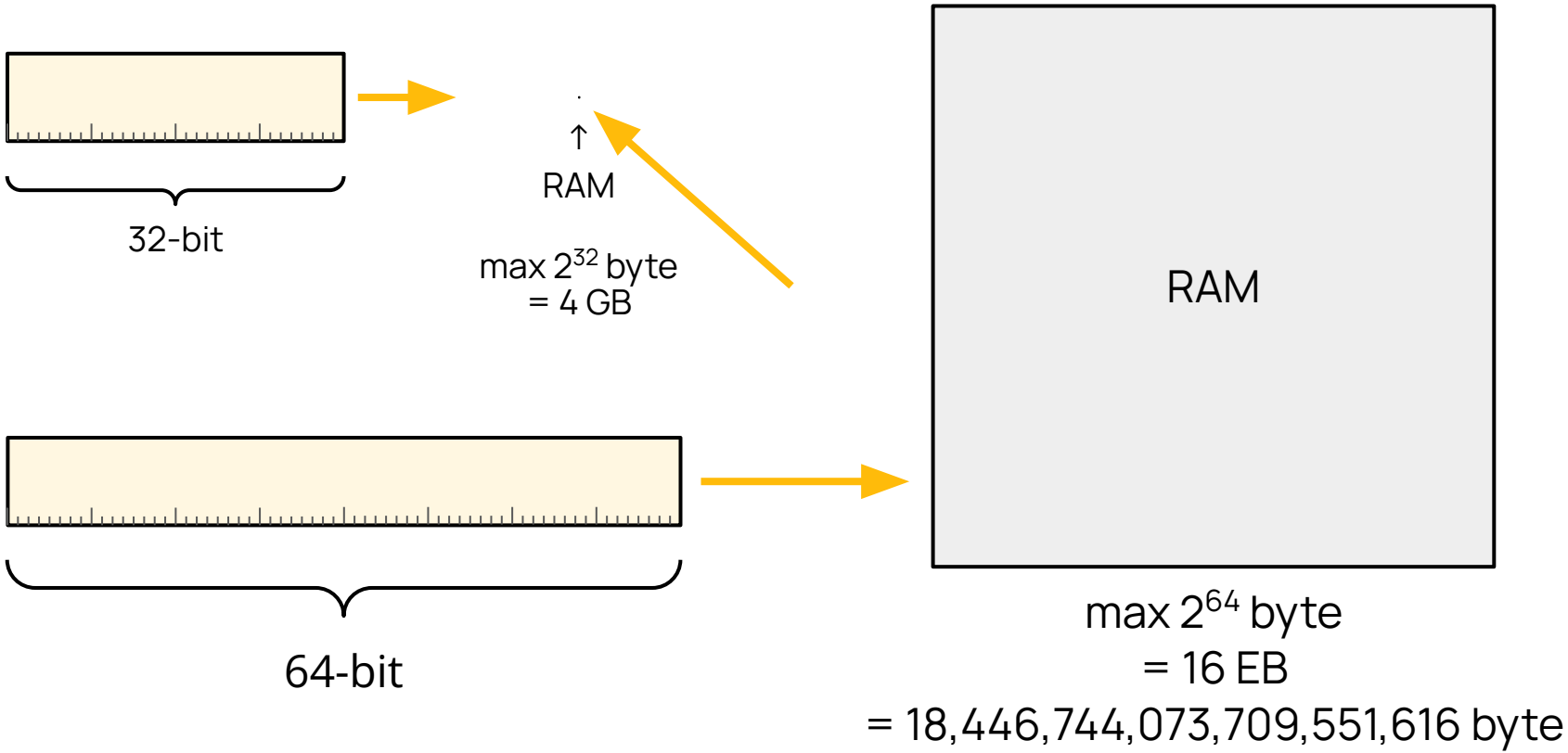
Ordinary Object Pointers



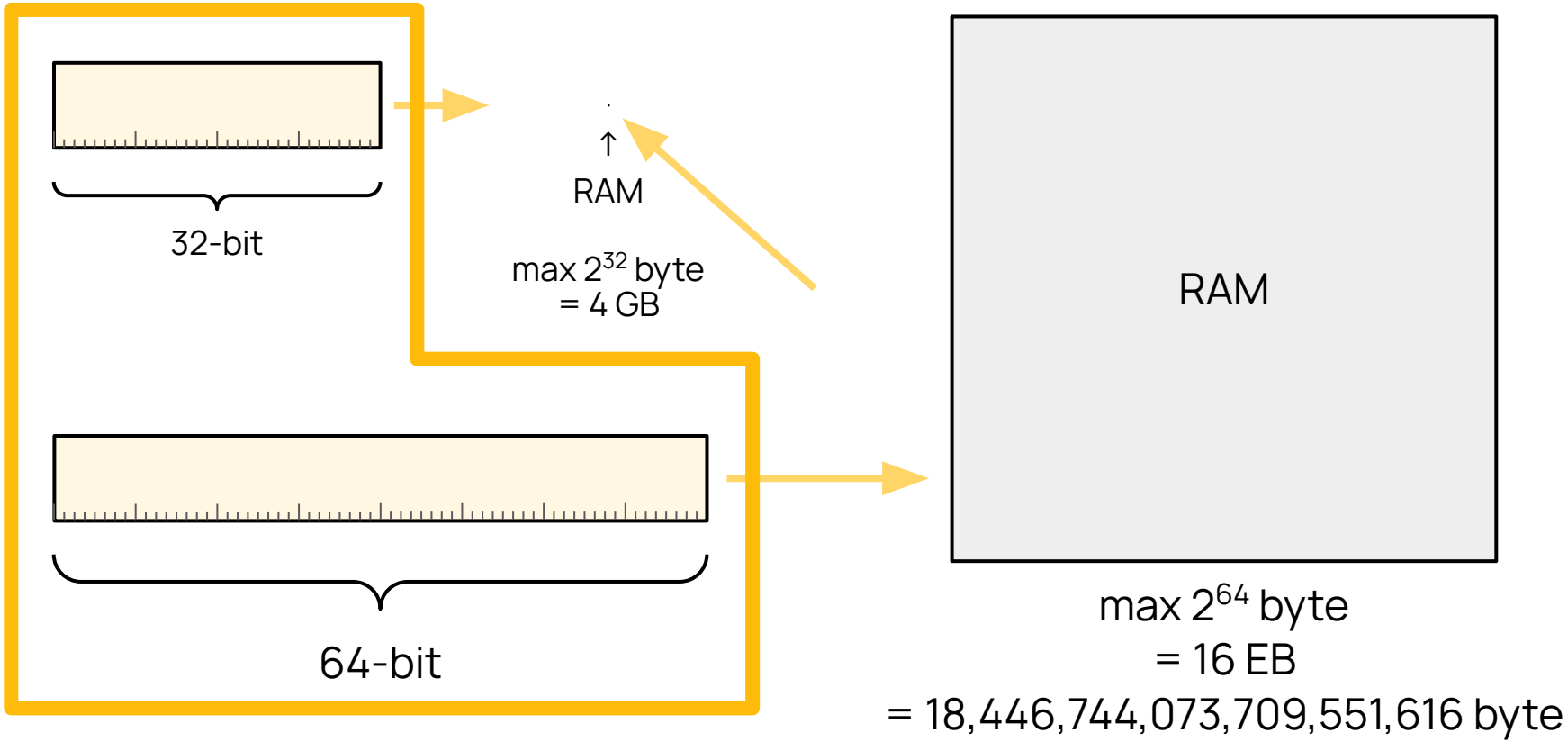
Ordinary Object Pointers



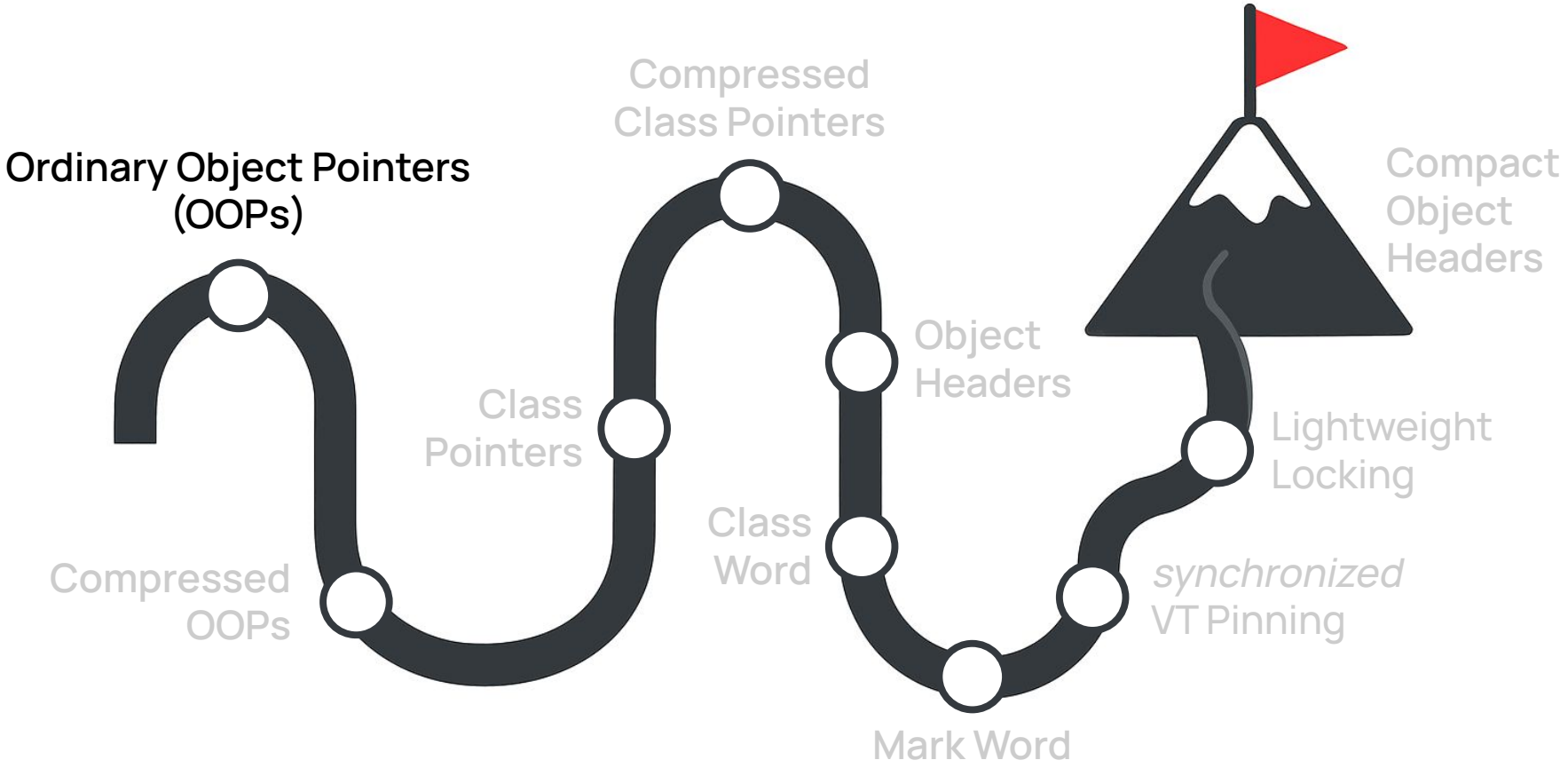
Ordinary Object Pointers



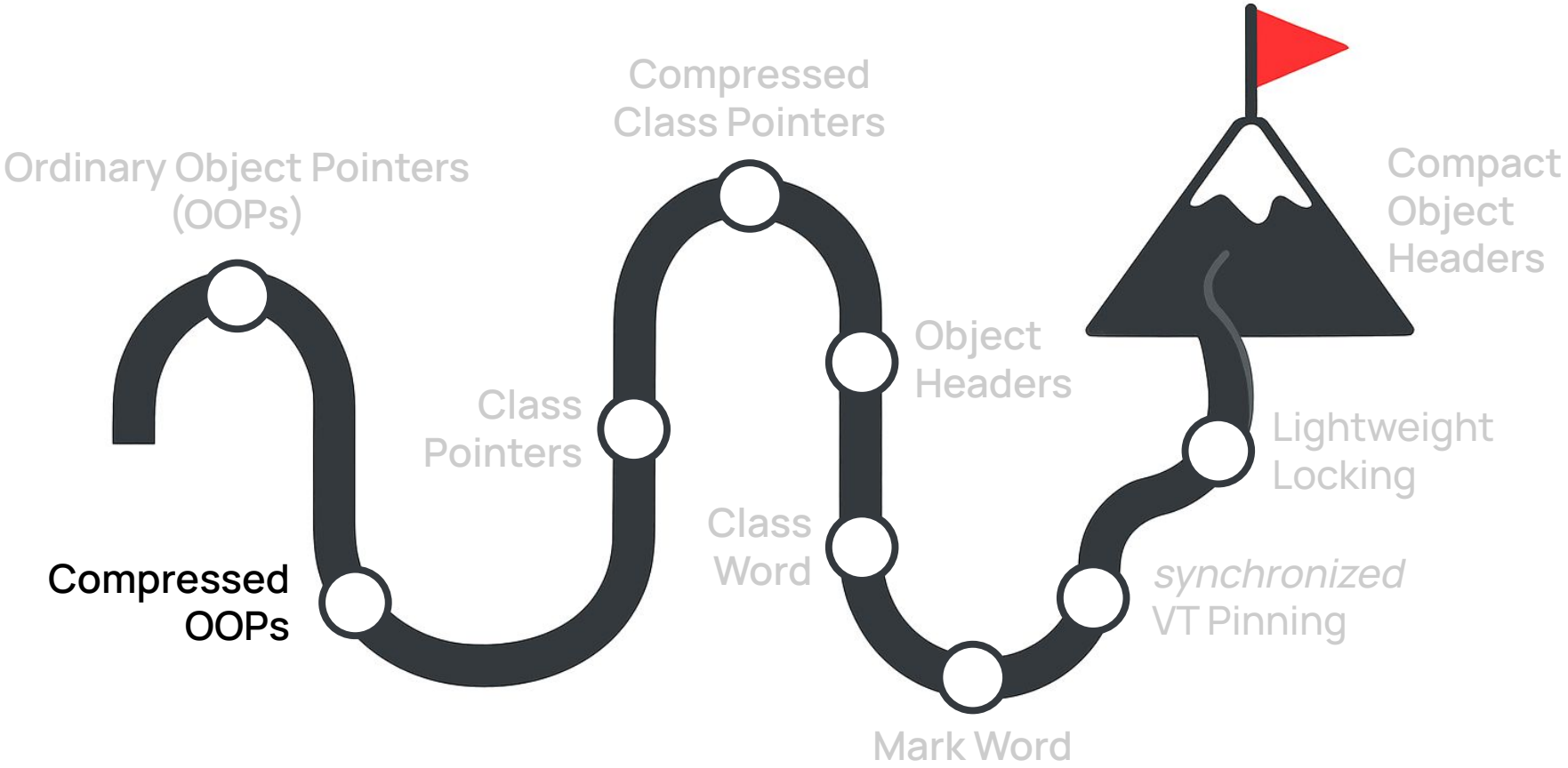
Ordinary Object Pointers



Journey into the JVM

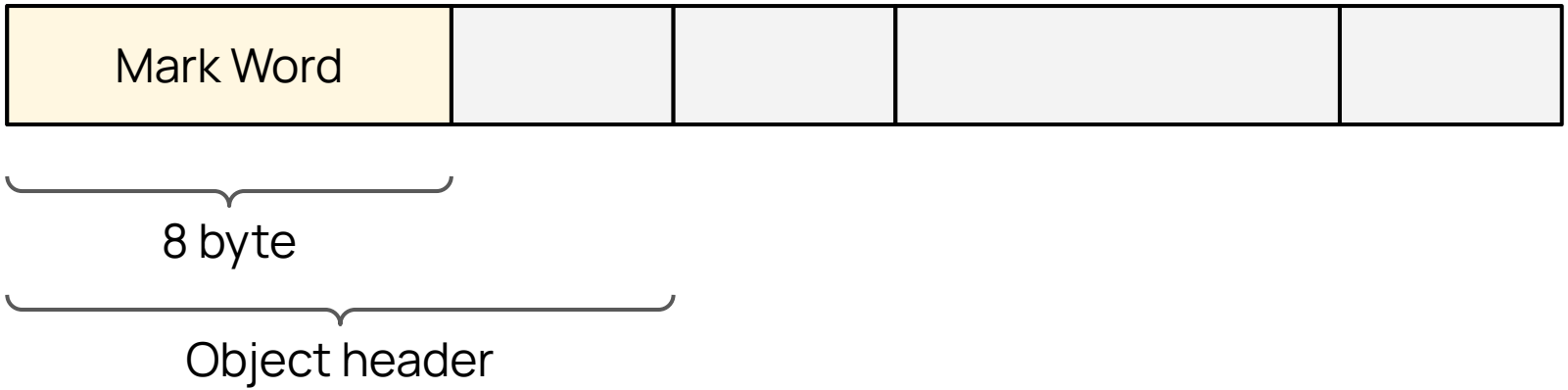


Journey into the JVM

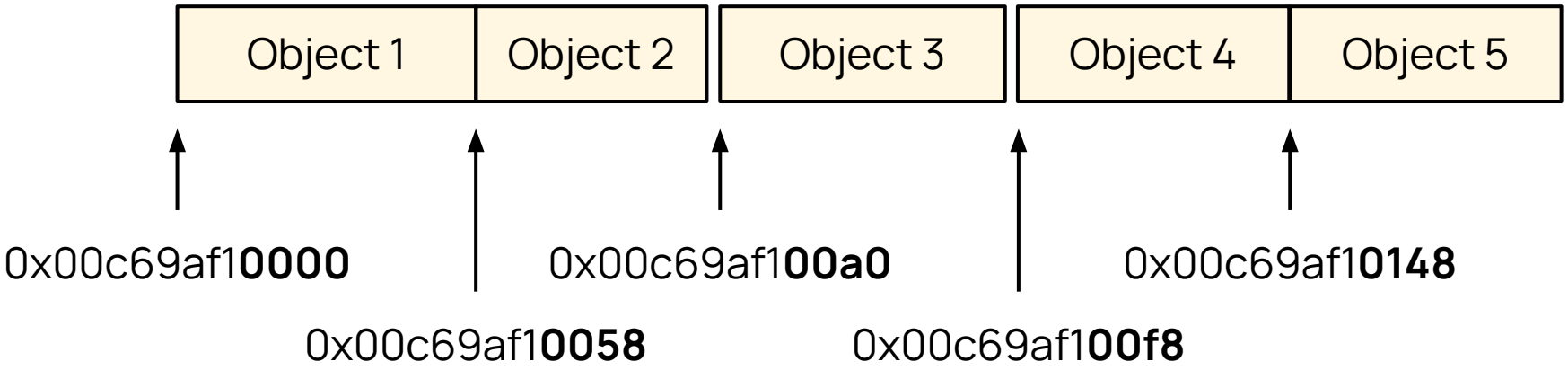


Compressed OOPs

Compressed OOPs



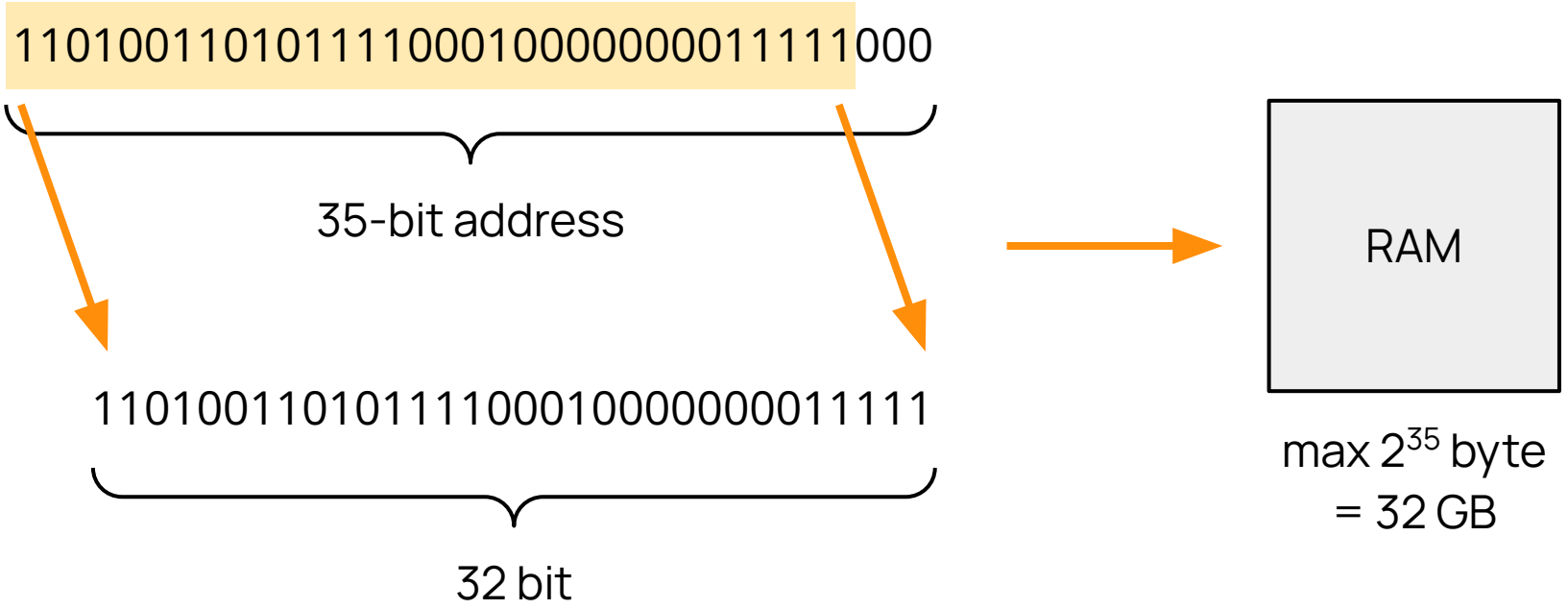
Compressed OOPs



Compressed OOPs

0x00c69af1**0000**	0b00000000110001101001101011110001**000000000000**000
0x00c69af1**0058**	0b00000000110001101001101011110001**000000000101**000
0x00c69af1**00a0**	0b00000000110001101001101011110001**000000001010**000
0x00c69af1**00f8**	0b00000000110001101001101011110001**000000001111**000
0x00c69af1**0148**	0b00000000110001101001101011110001**000000010100**000

Compressed OOPs



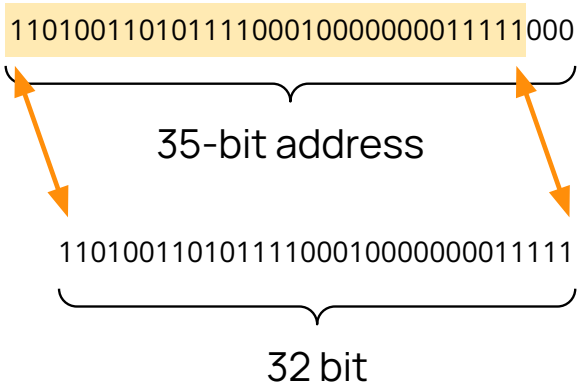
Compressed OOPs

Disable Compressed OOPs and use 64-bit pointers:

```
-XX:-UseCompressedOops
```

Compressed OOPs

Max 32 GB Heap

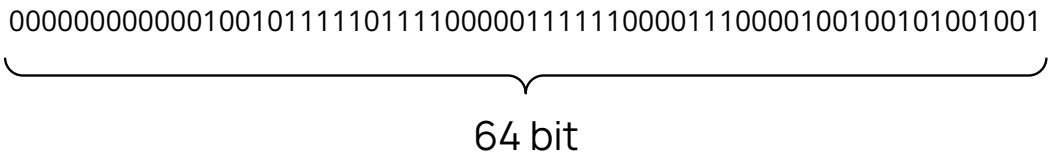


> 32 GB Heap
or
`-XX:-UseCompressedOops`

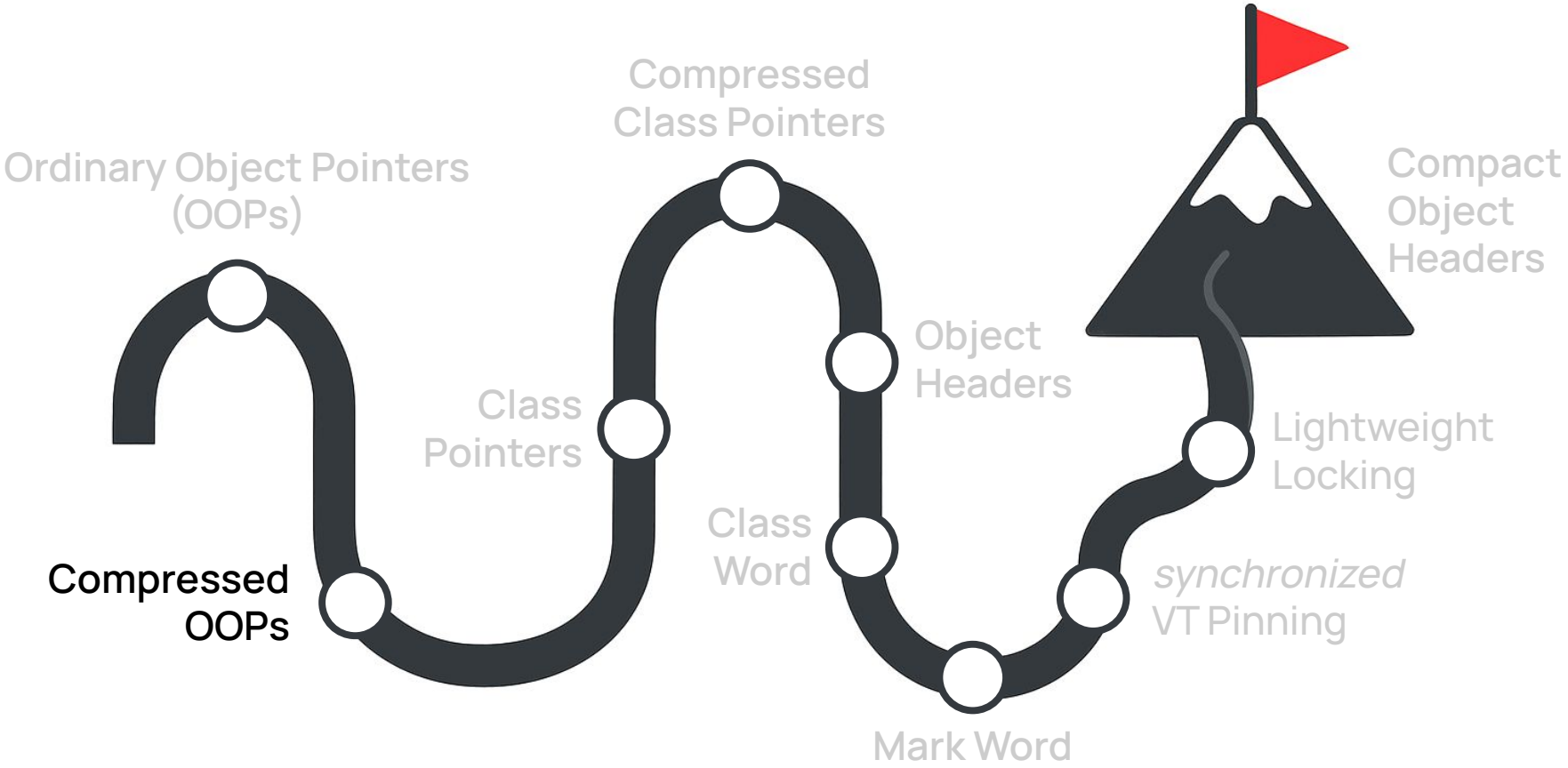
Compressed OOPs

Max 32 GB Heap

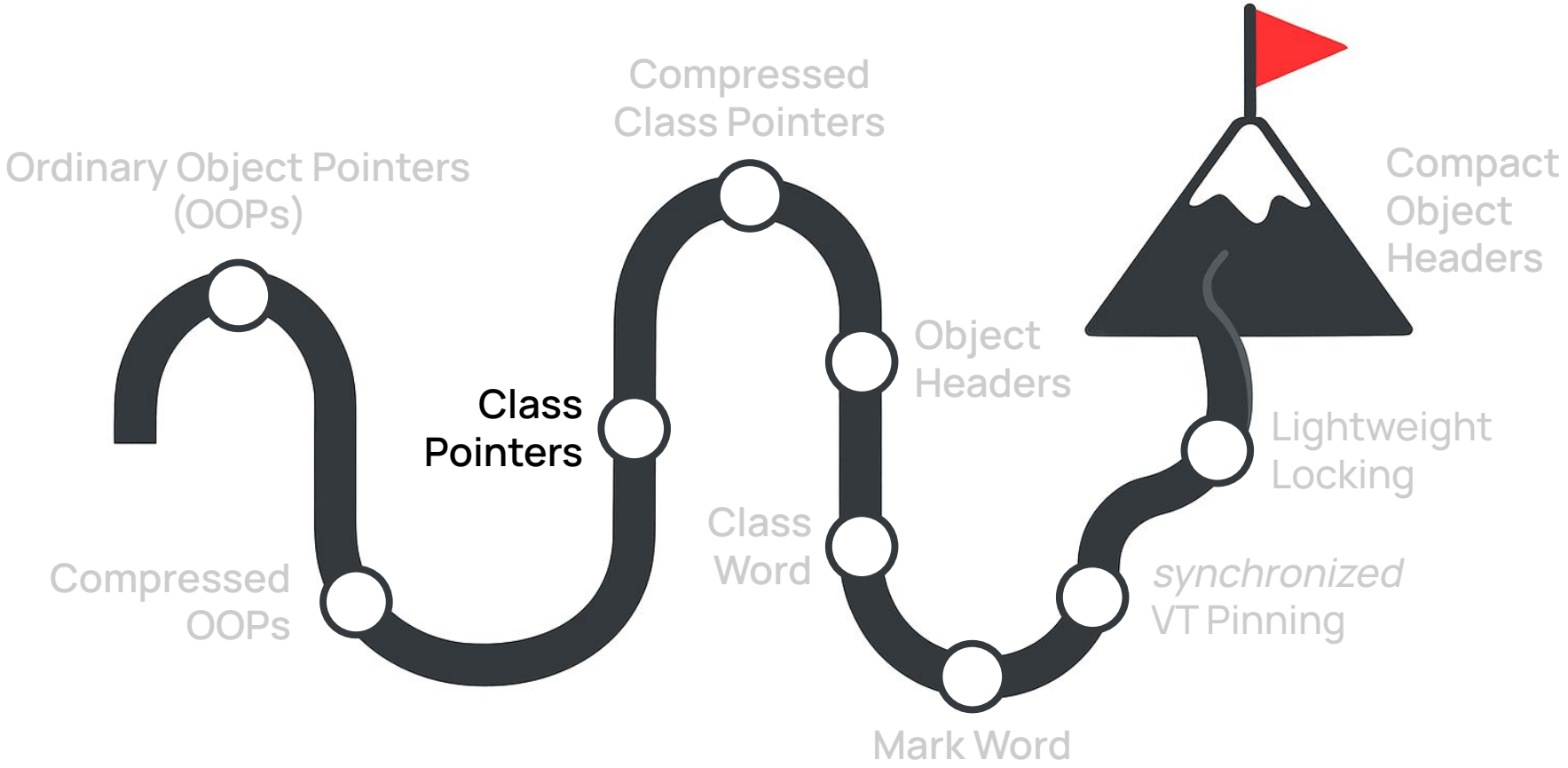
> 32 GB Heap
or
`-XX:-UseCompressedOops`



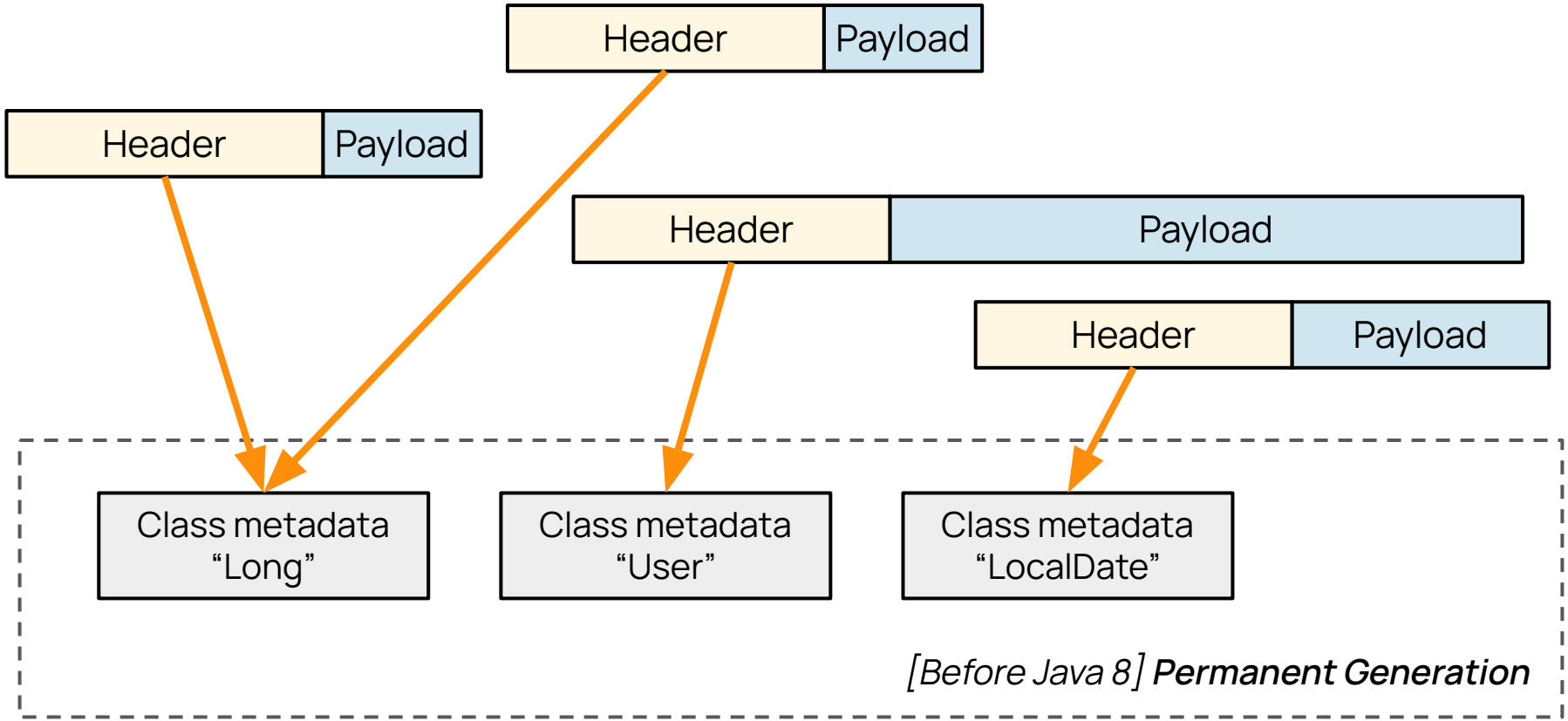
Journey into the JVM



Journey into the JVM



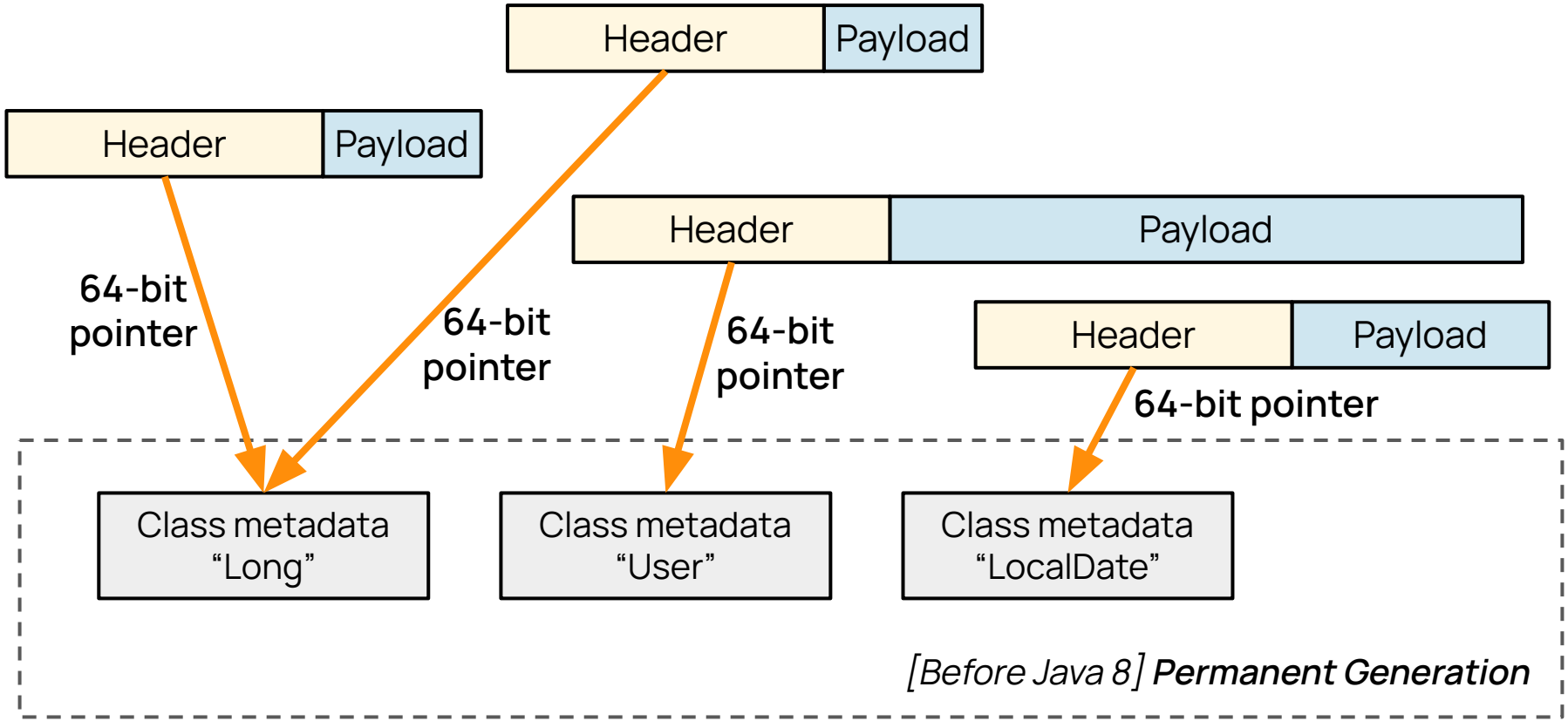
Class Pointers



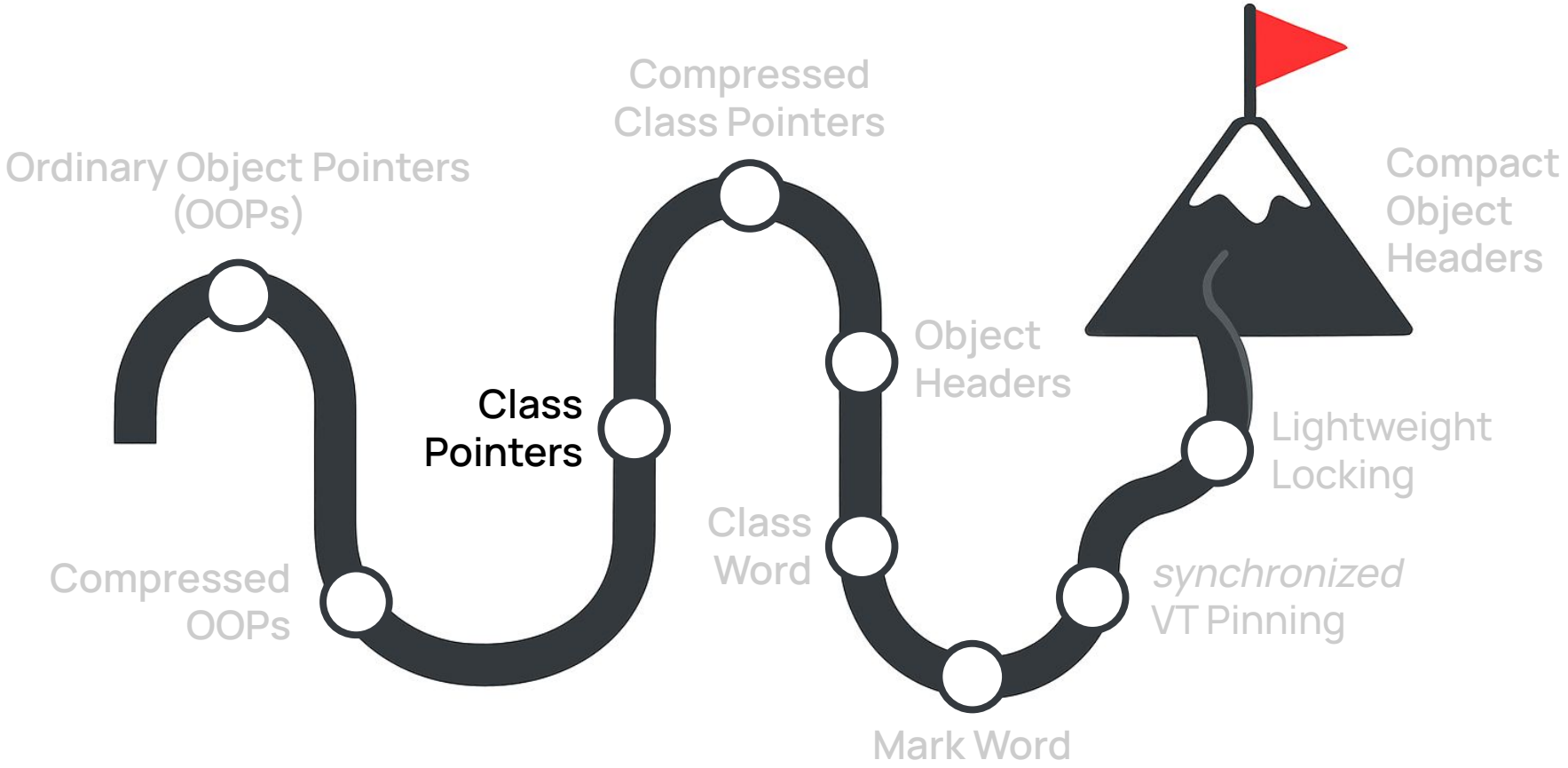
Class Pointers

OutOfMemoryError:
PermGen space

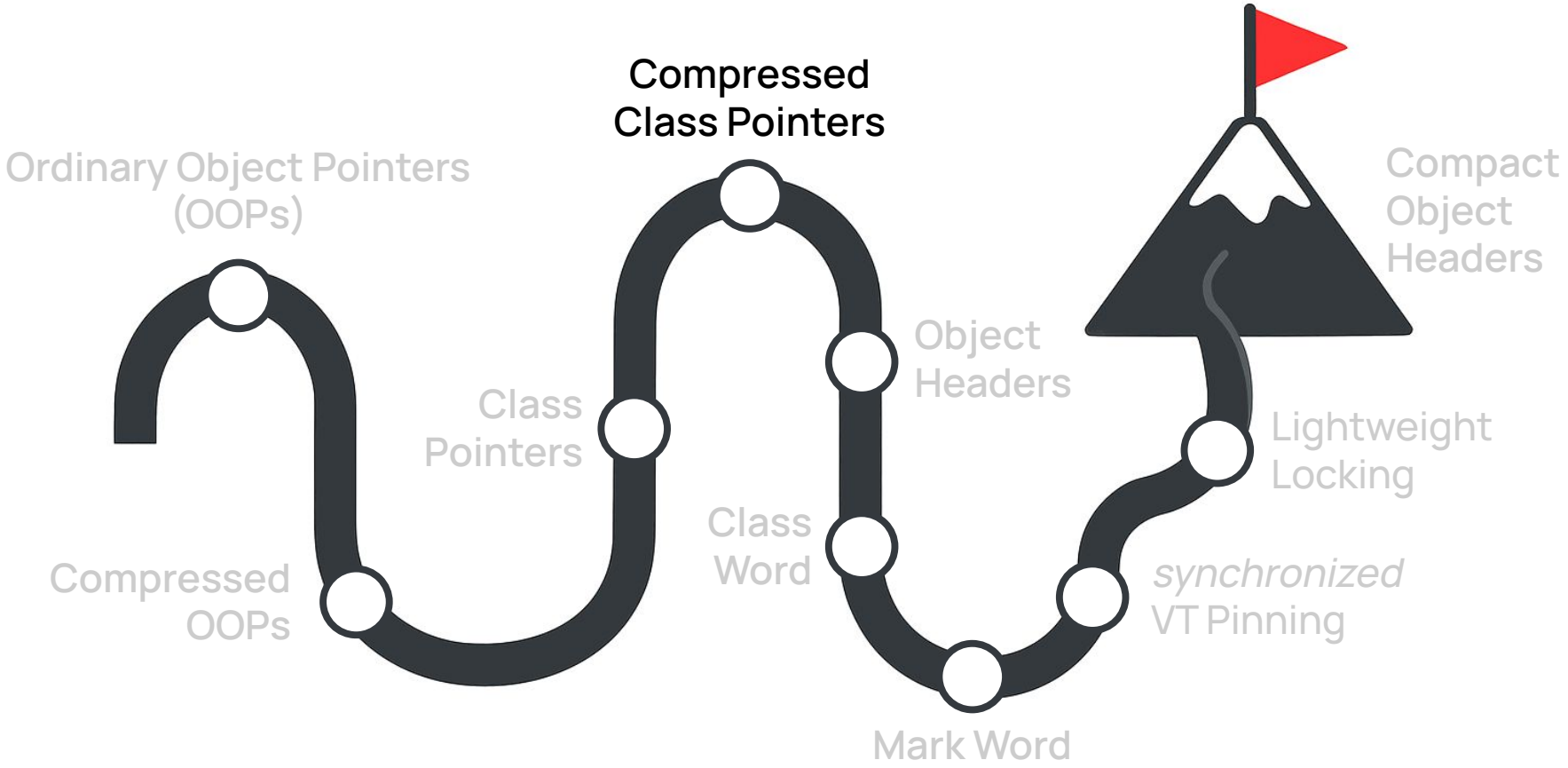
Class Pointers



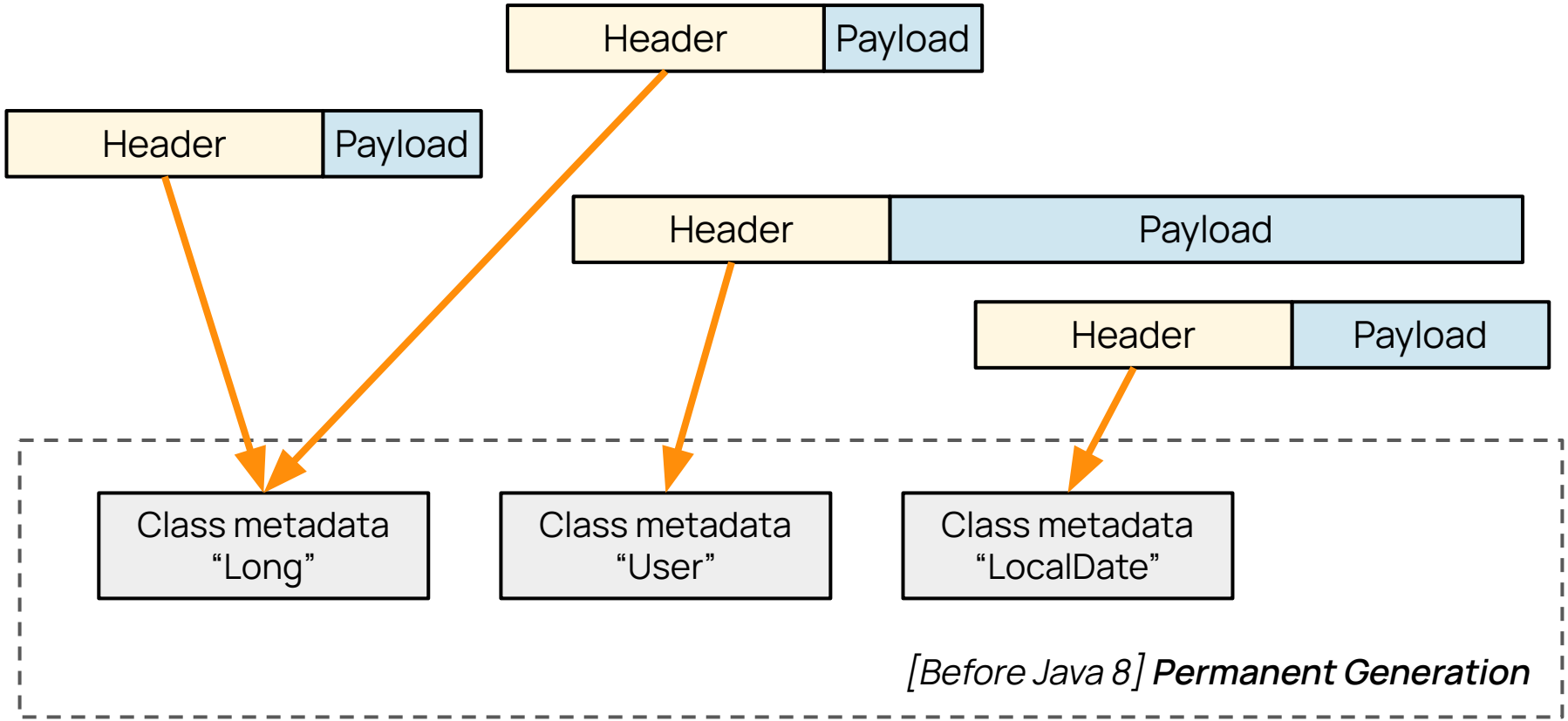
Journey into the JVM



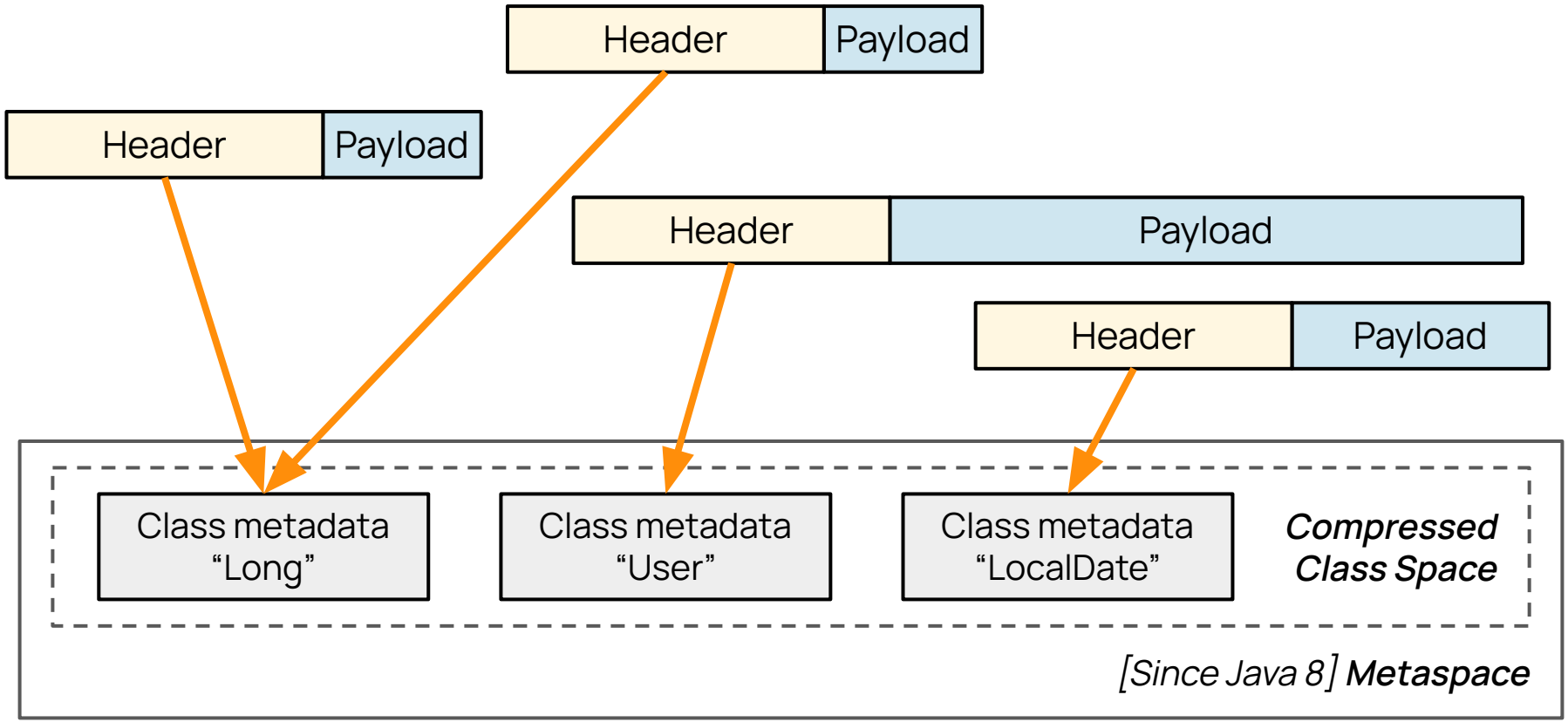
Journey into the JVM



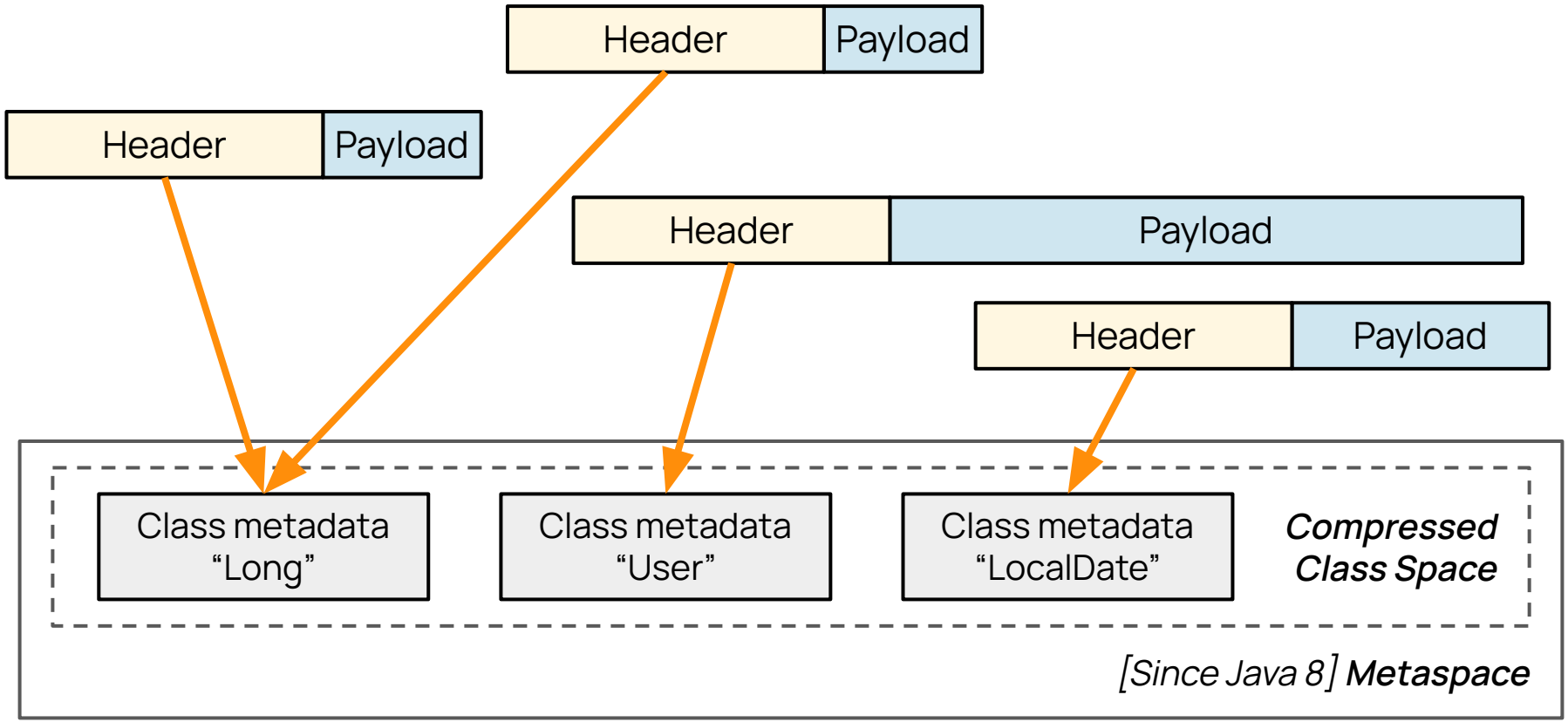
Compressed Class Pointers



Compressed Class Pointers



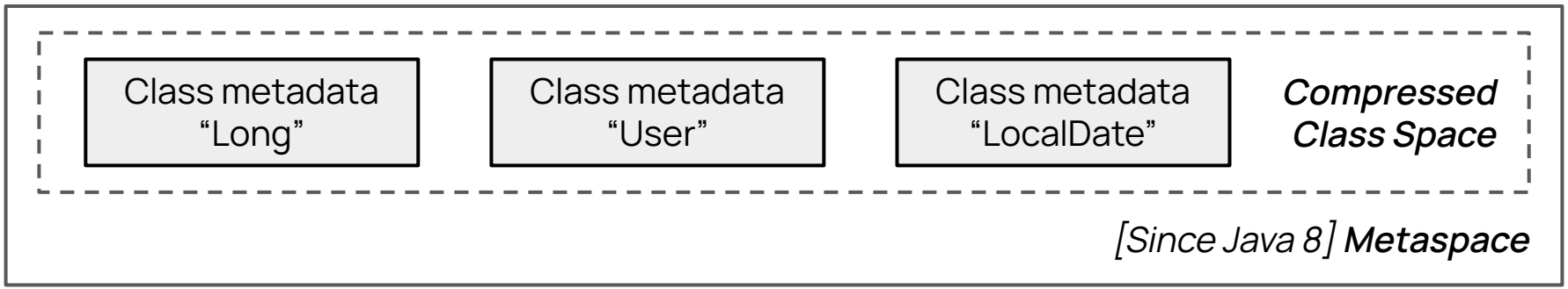
Compressed Class Pointers



Compressed Class Pointers

Class metadata size: 512~1024 bytes

Addressable with 64 bit: 2^{64} bytes / 768 bytes
≈ 24,000,000,000,000,000

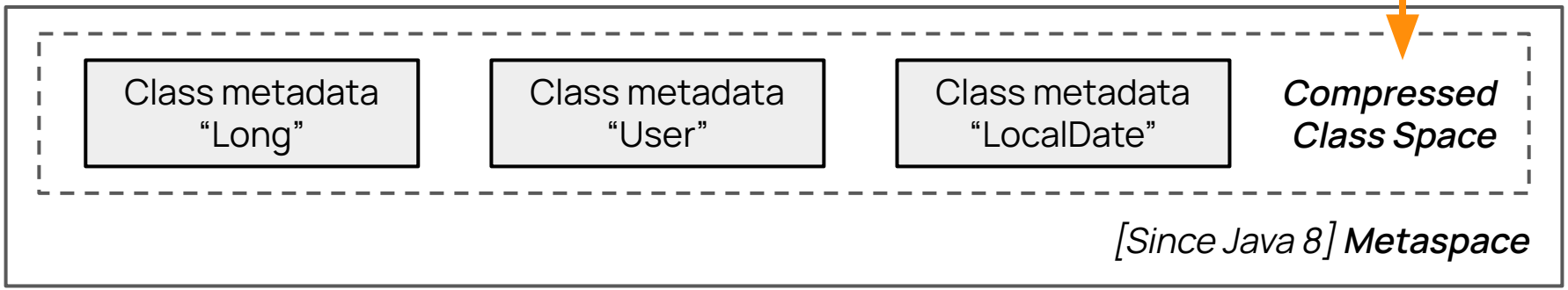


Compressed Class Pointers

Class metadata size: 512~1024 bytes

Addressable with 64 bit: 2^{64} bytes / 768 bytes
≈ 24,000,000,000,000,000

`-XX:CompressedClassSpaceSize` → 1 GB by default
4 GB maximum



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Addressable with 64 bit: 2^{64} bytes / 768 bytes
≈ 24,000,000,000,000,000

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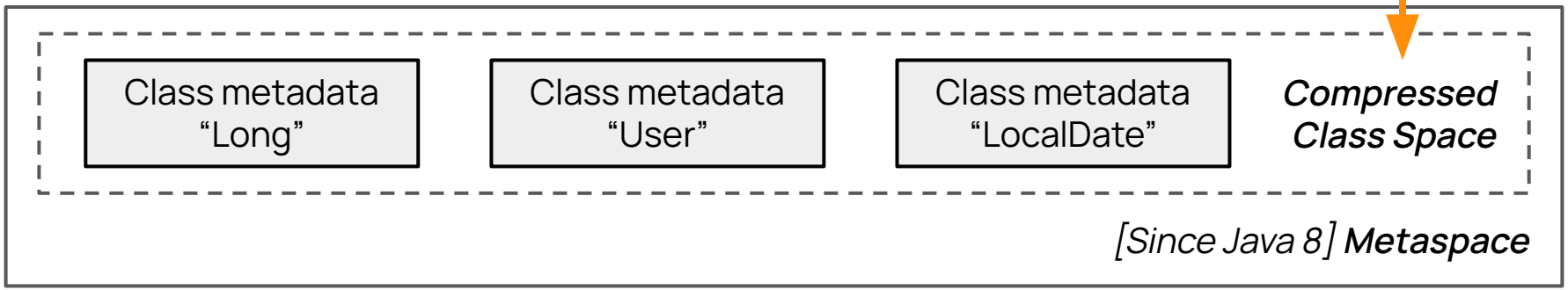


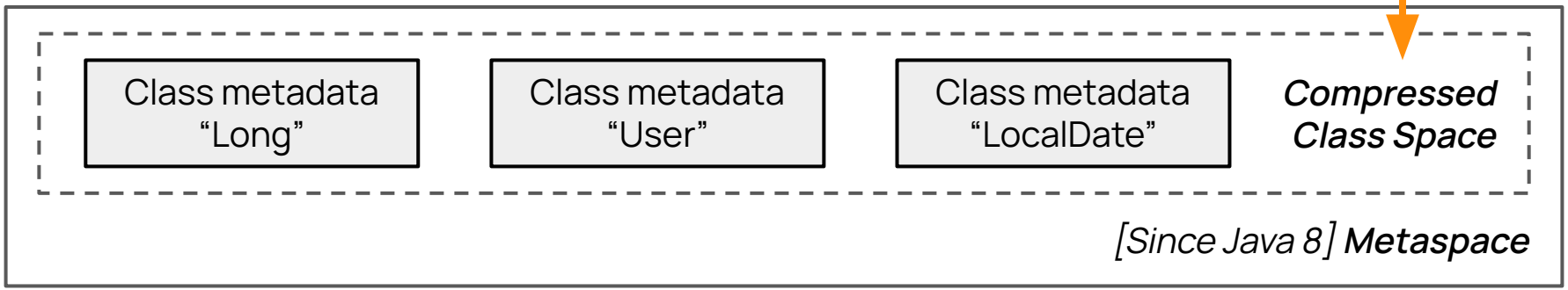
Compressed Class Pointers

Class metadata size: 512~1024 bytes

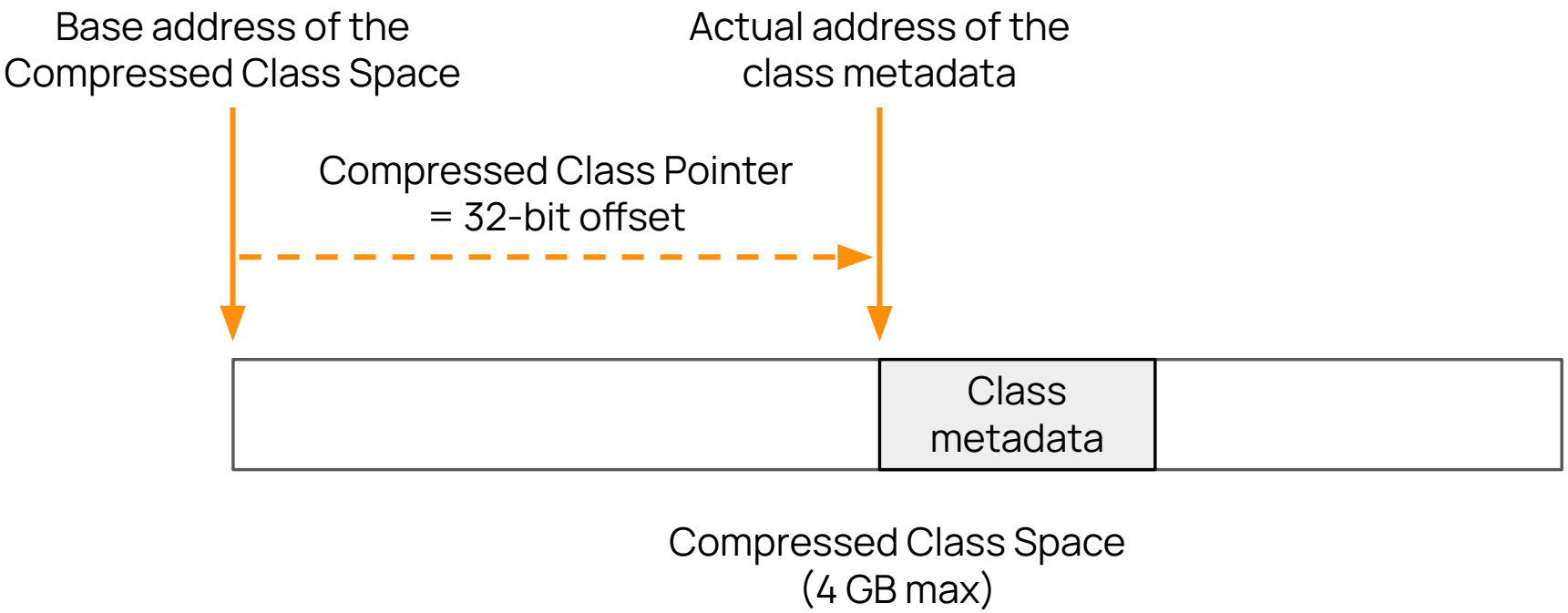
Addressable with 32 bit: 2^{32} bytes = 4 GB

1 GB by default

`-XX:CompressedClassSpaceSize` → 4 GB maximum



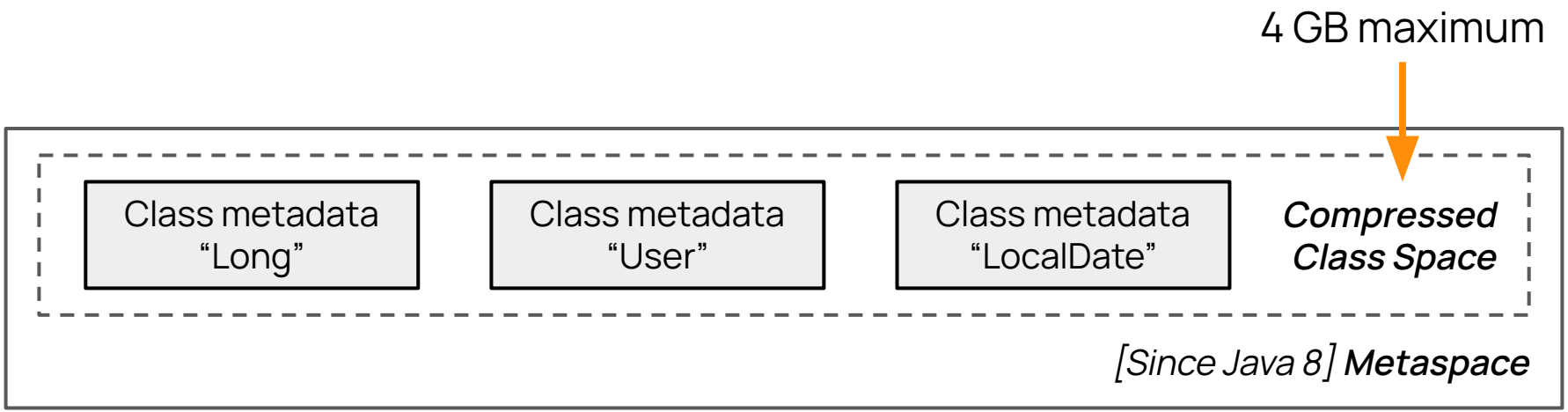
Compressed Class Pointers



Compressed Class Pointers

Class metadata size: 512~1024 bytes

Addressable with 32 bit: 4 GB / 768 bytes
≈ 5,600,000



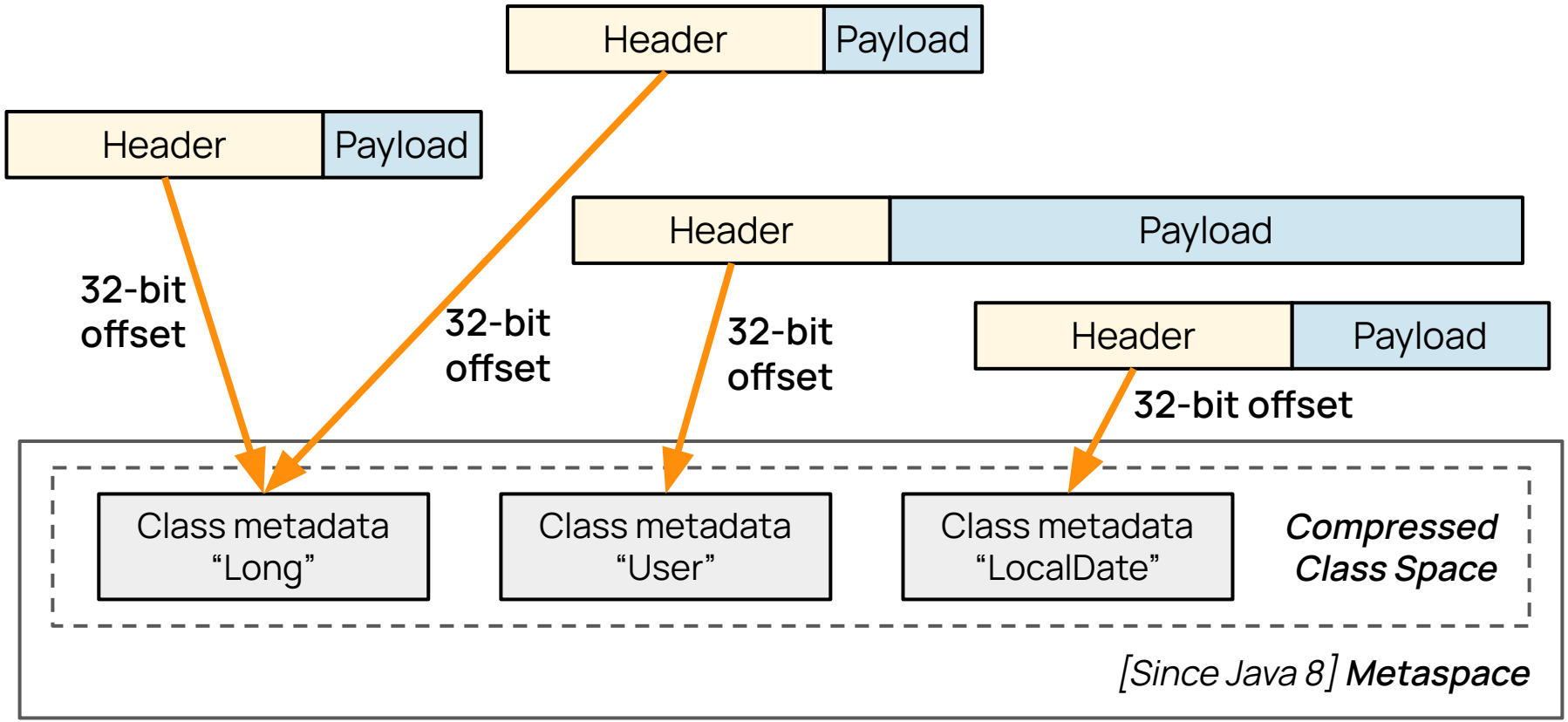
Compressed Class Pointers

Disable Compressed Class Pointers:

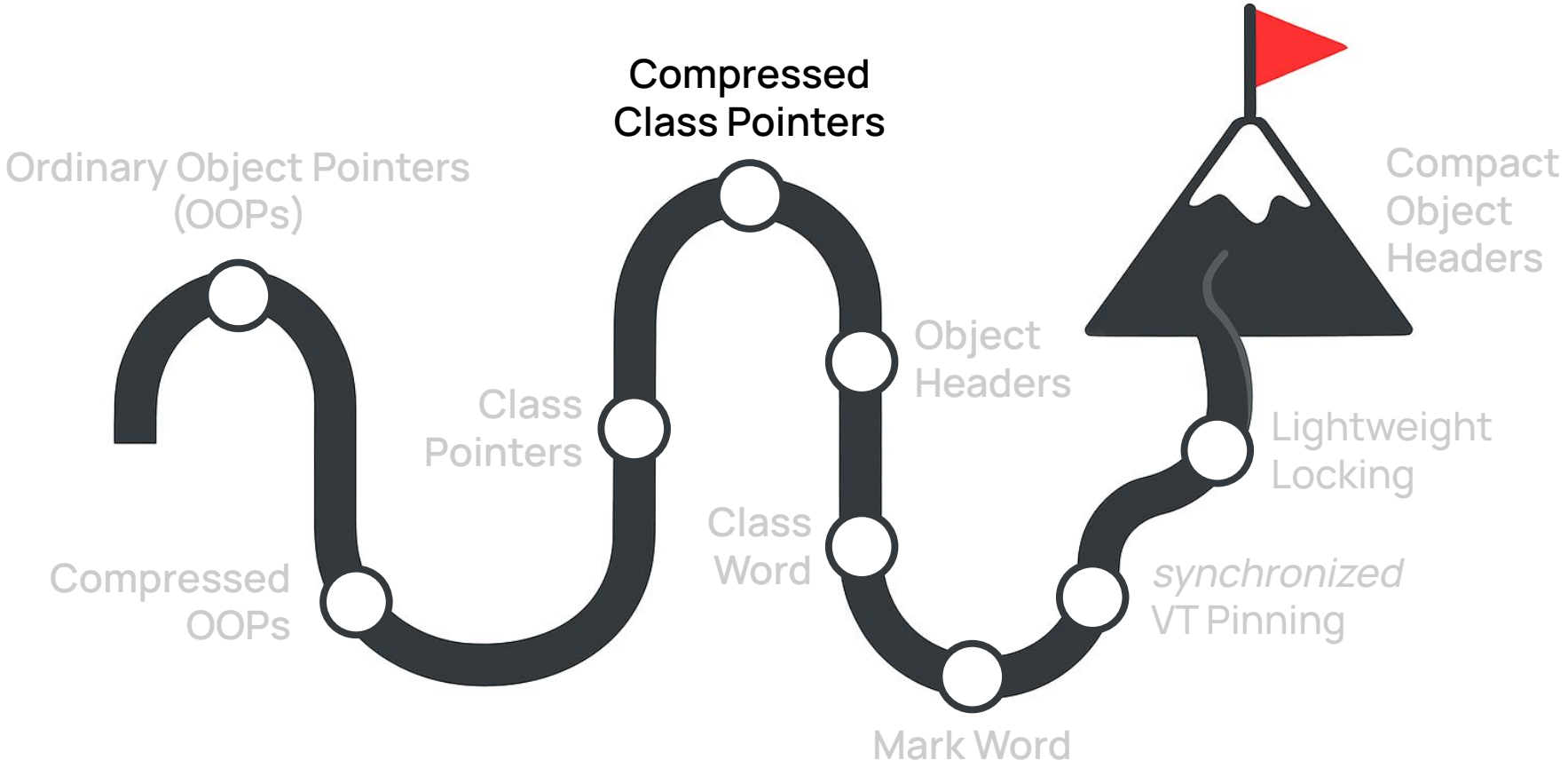
```
-XX:-UseCompressedClassPointers
```

since Java 25:
Deprecated

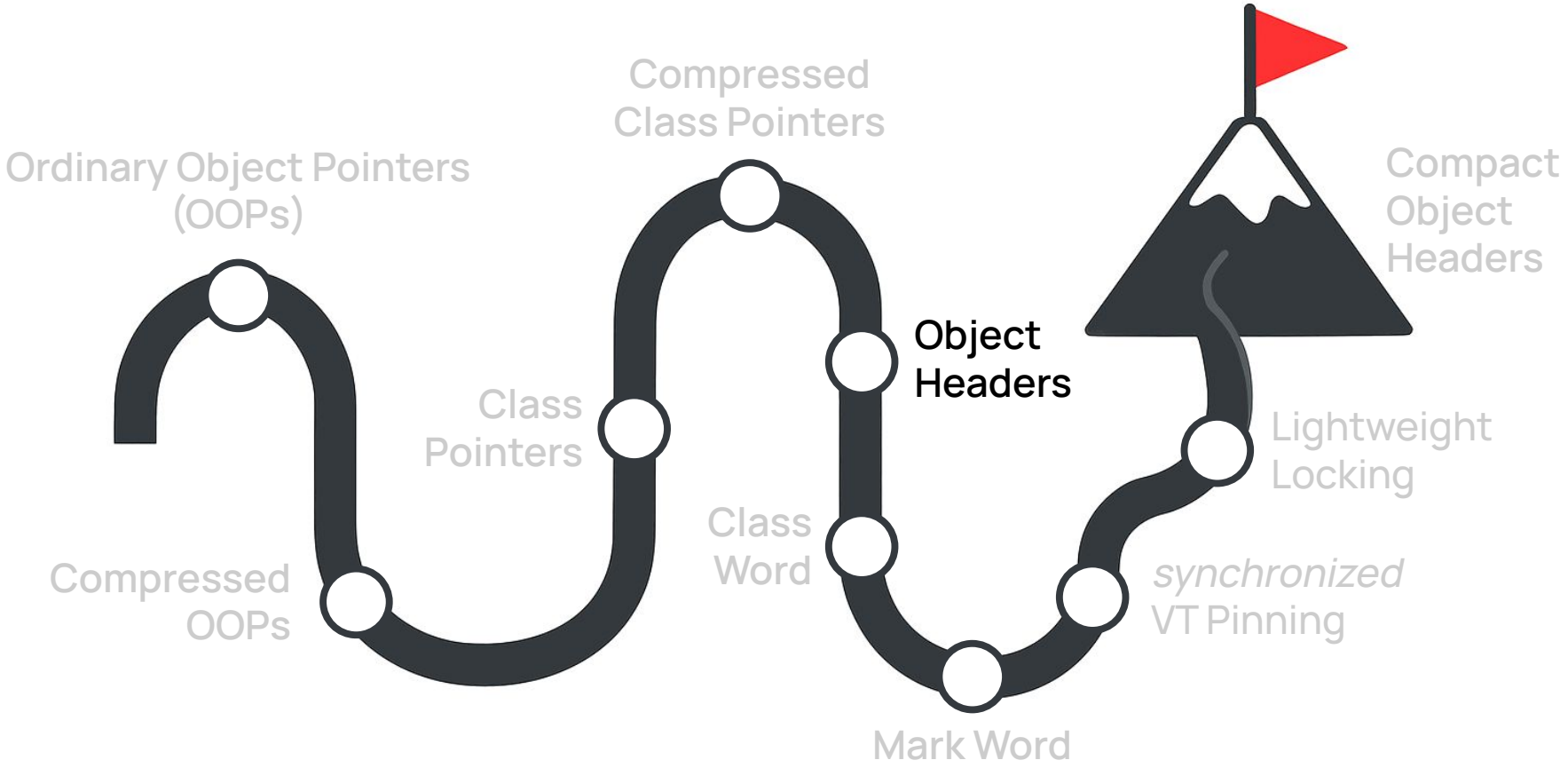
Compressed Class Pointers



Journey into the JVM

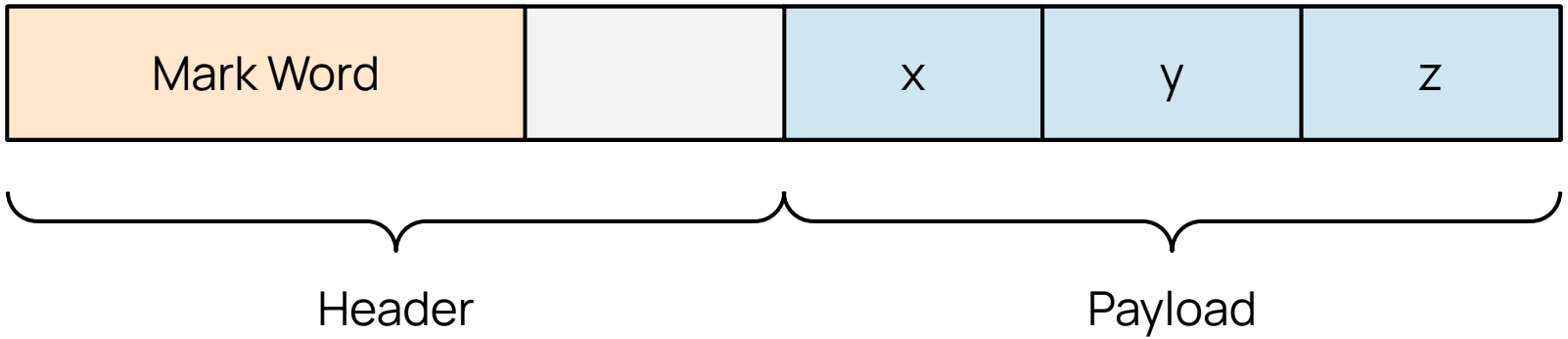


Journey into the JVM



Object Headers

A Java object:



Object Headers

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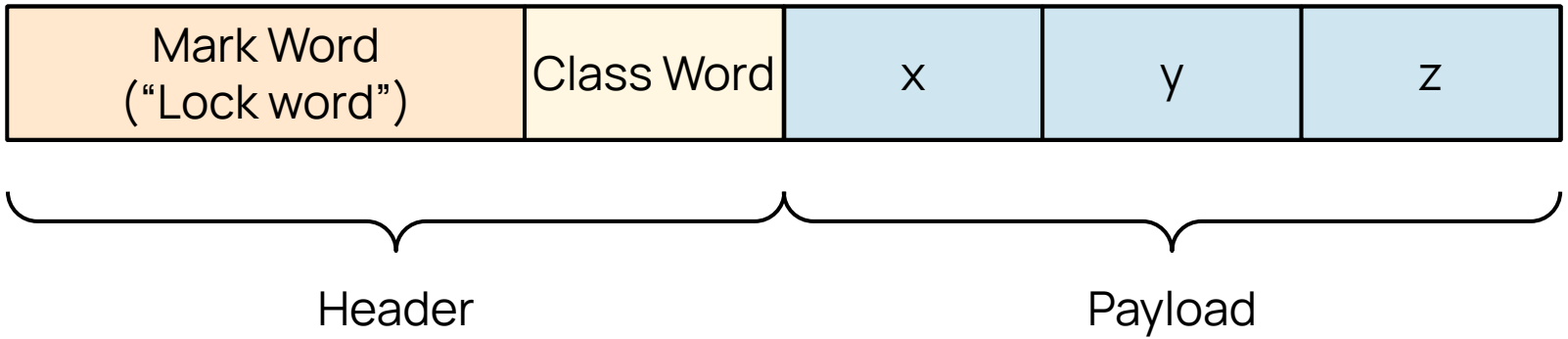
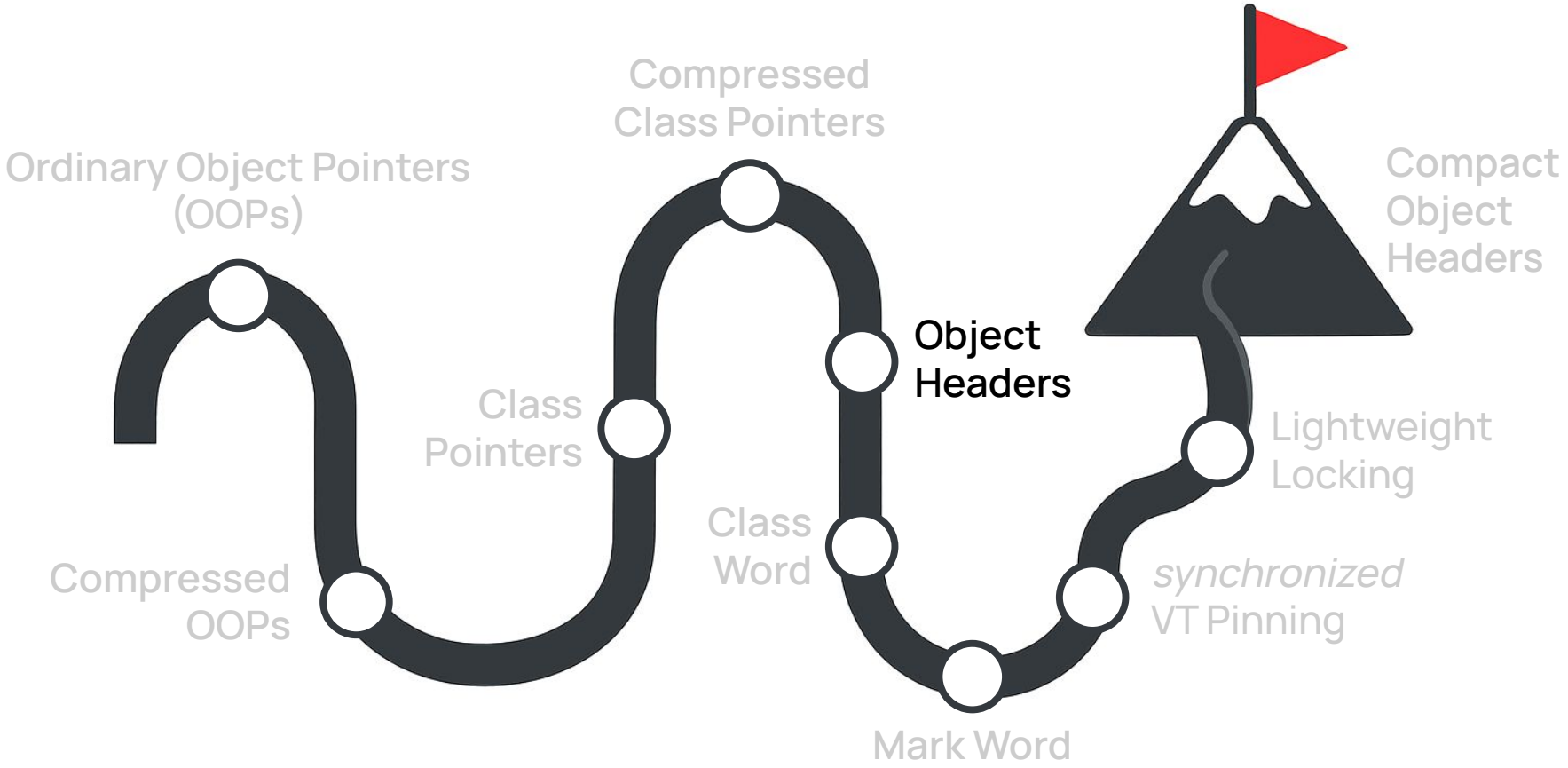
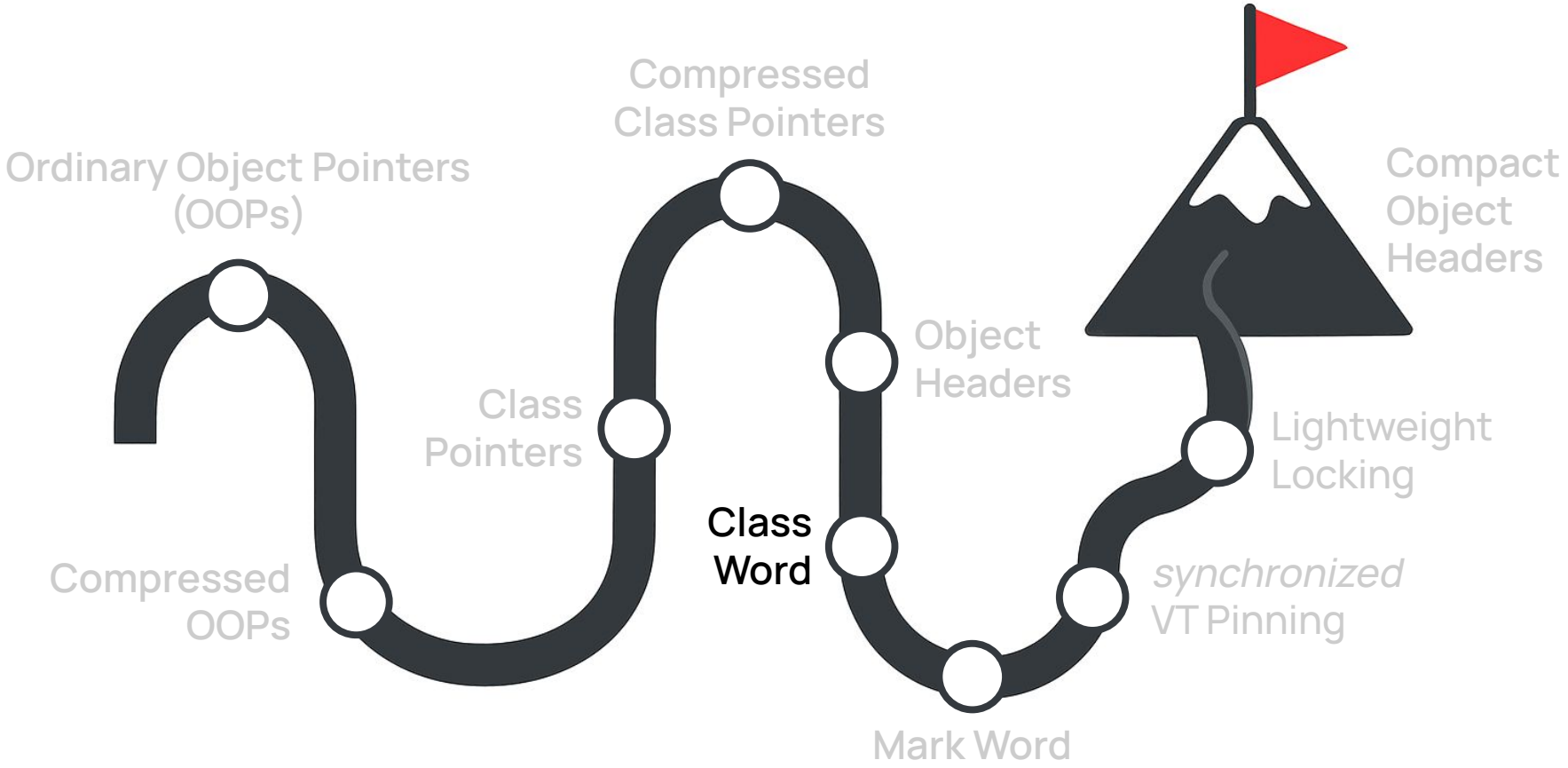


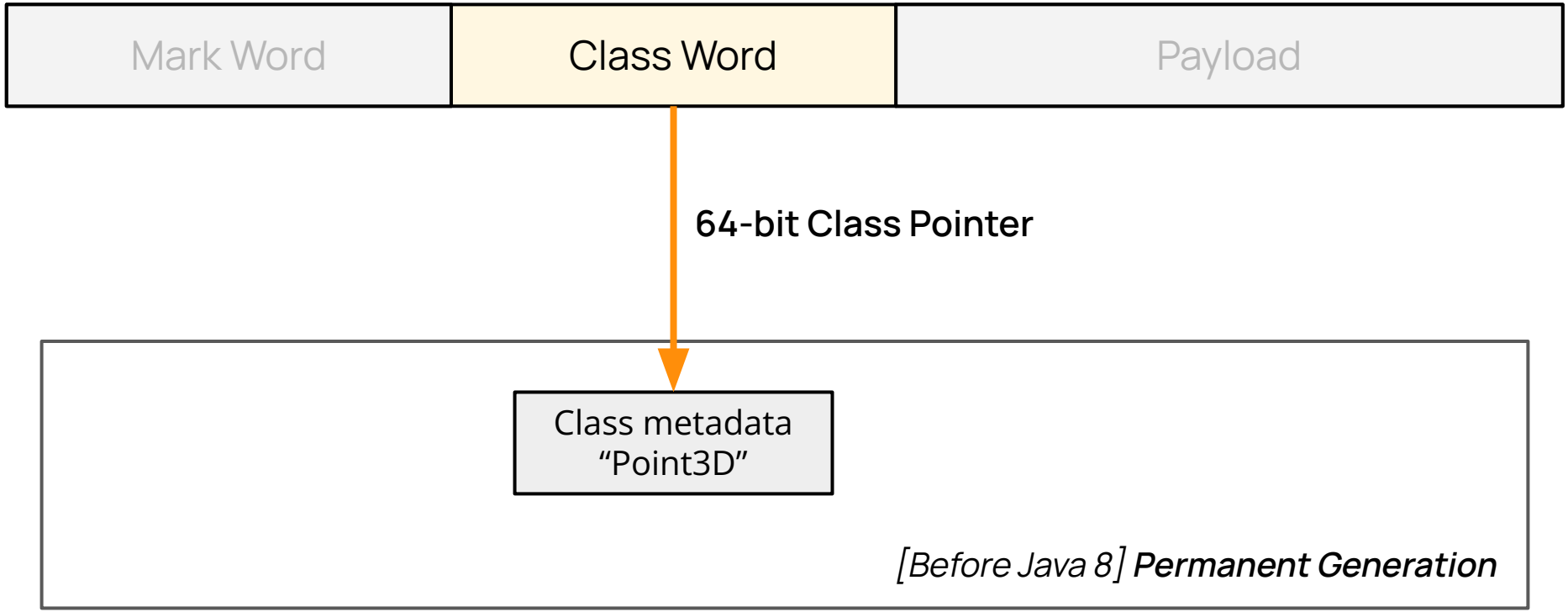
Journey into the JVM



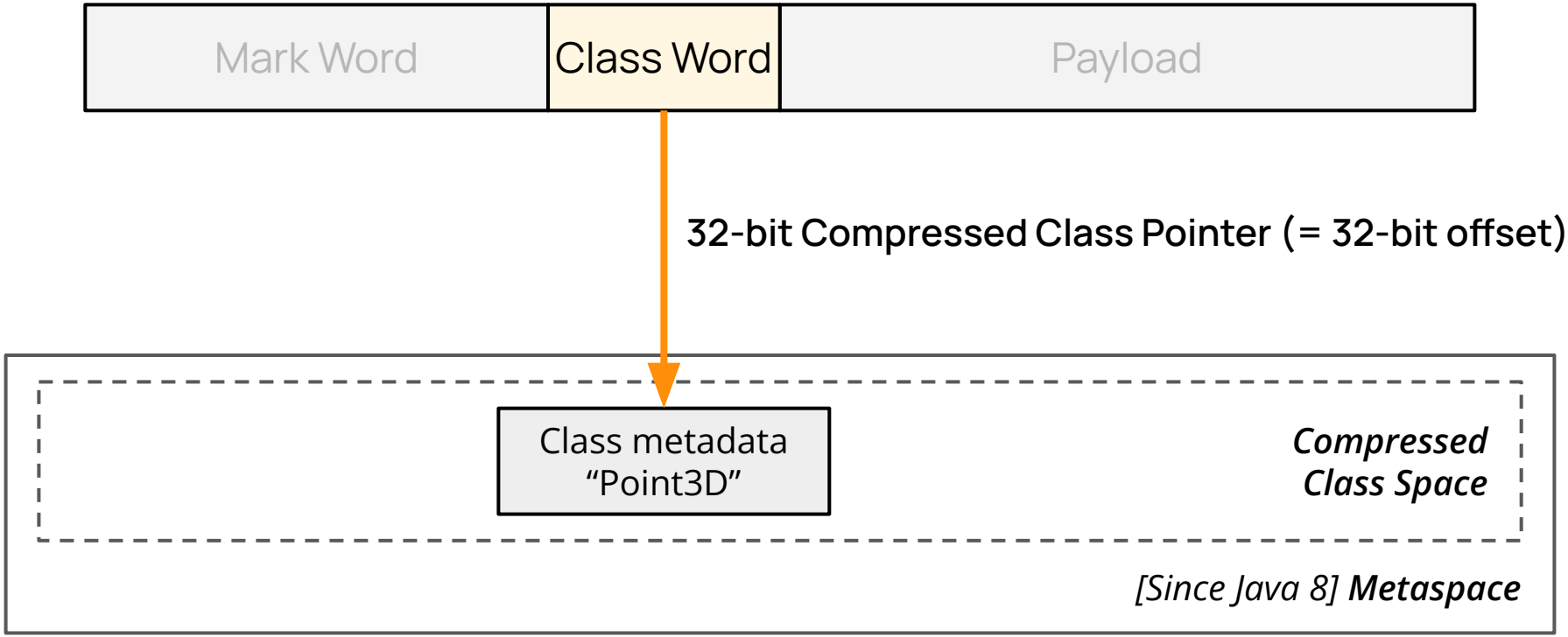
Journey into the JVM



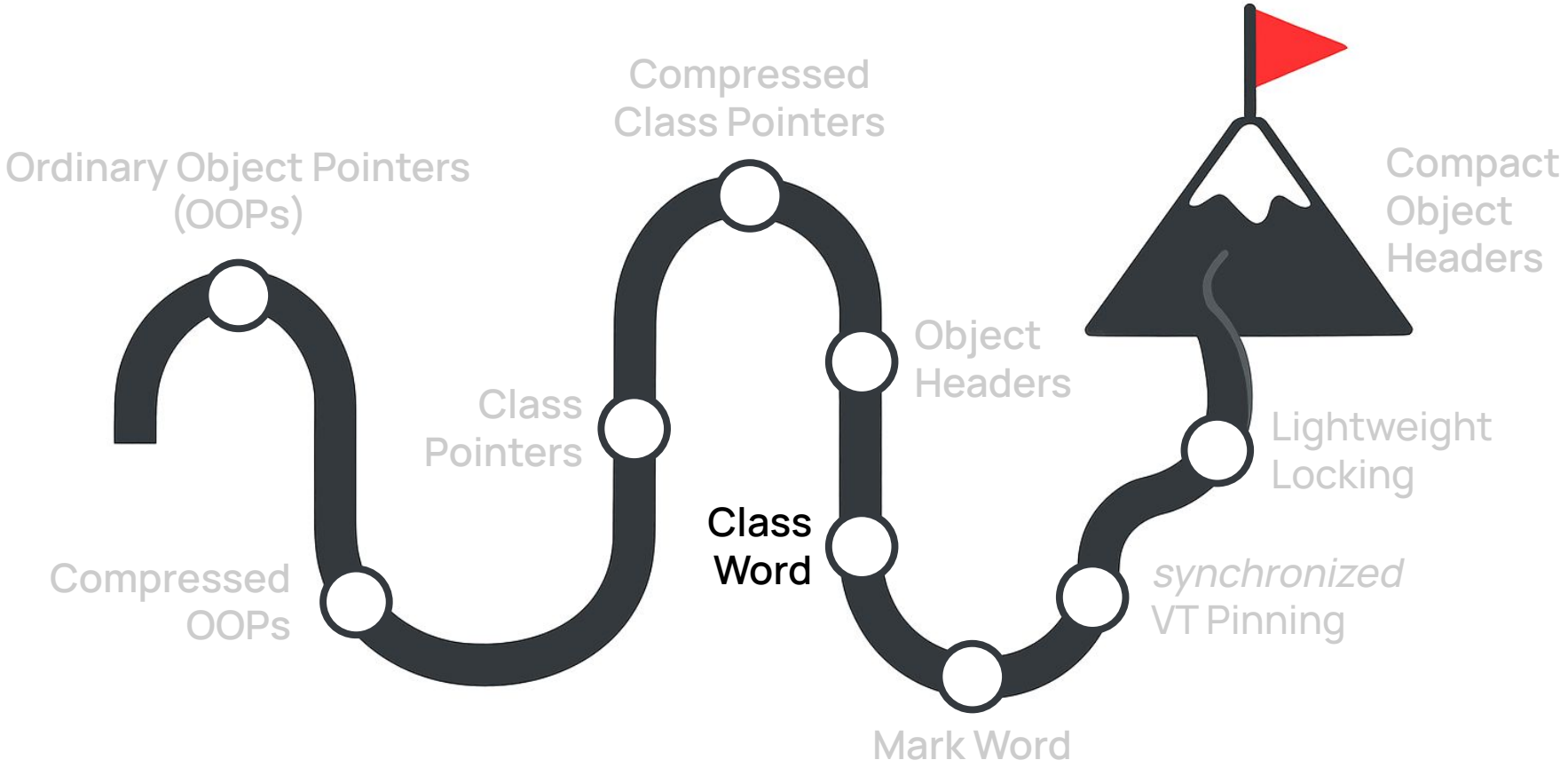
Class Word


Mark Word
Class Word
Payload
64-bit Class Pointer
Class metadata
“Point3D”
[Before Java 8] Permanent Generation

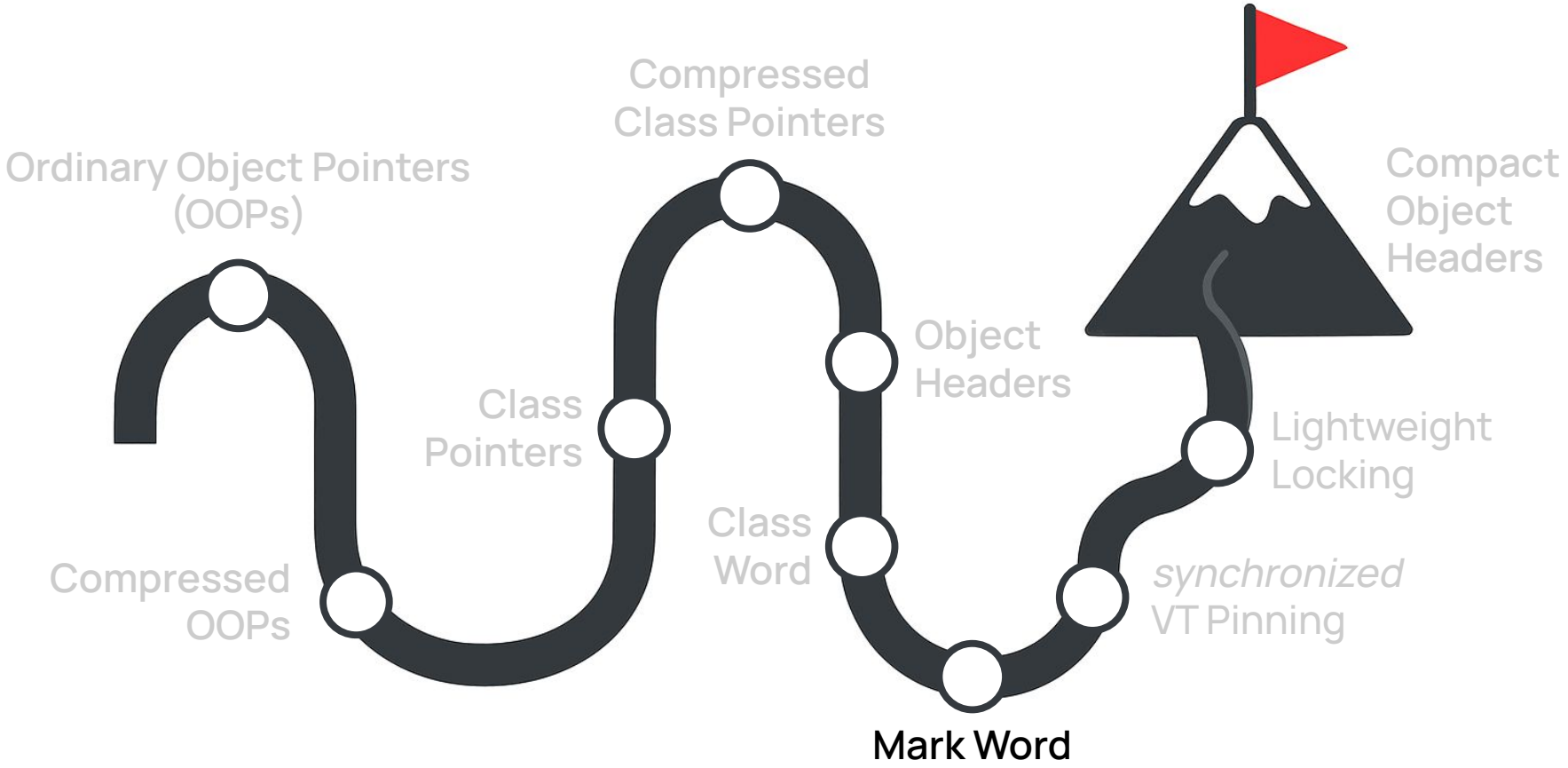
Class Word


Mark Word
Class Word
Payload
32-bit Compressed Class Pointer (= 32-bit offset)
Class metadata
“Point3D”
Compressed
Class Space
[Since Java 8] Metaspace

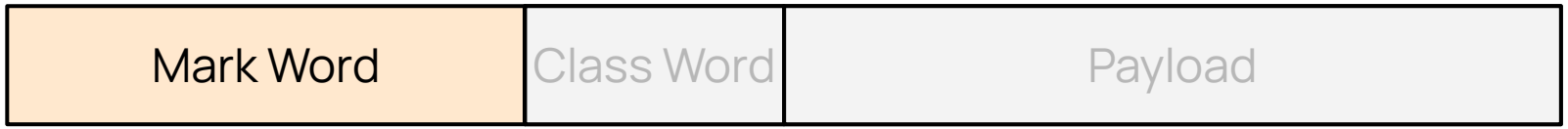
Journey into the JVM



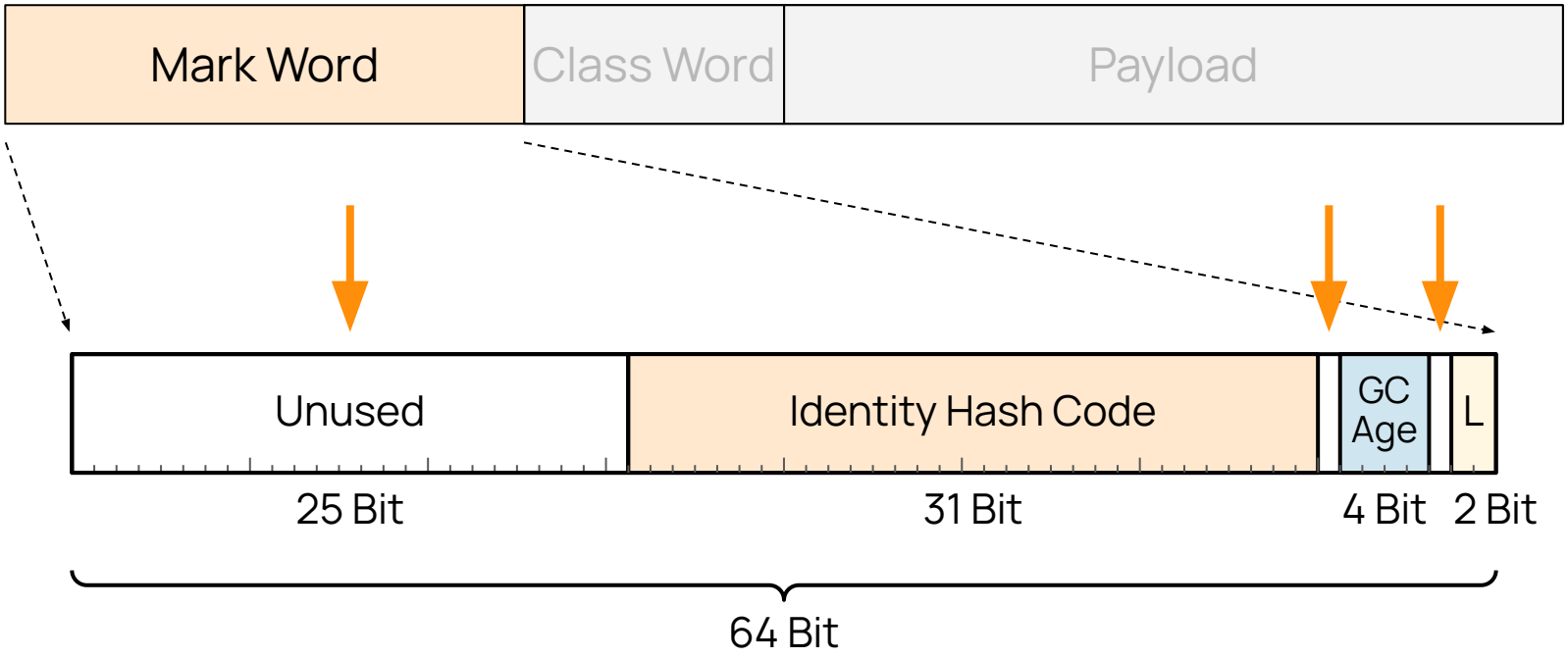
Journey into the JVM



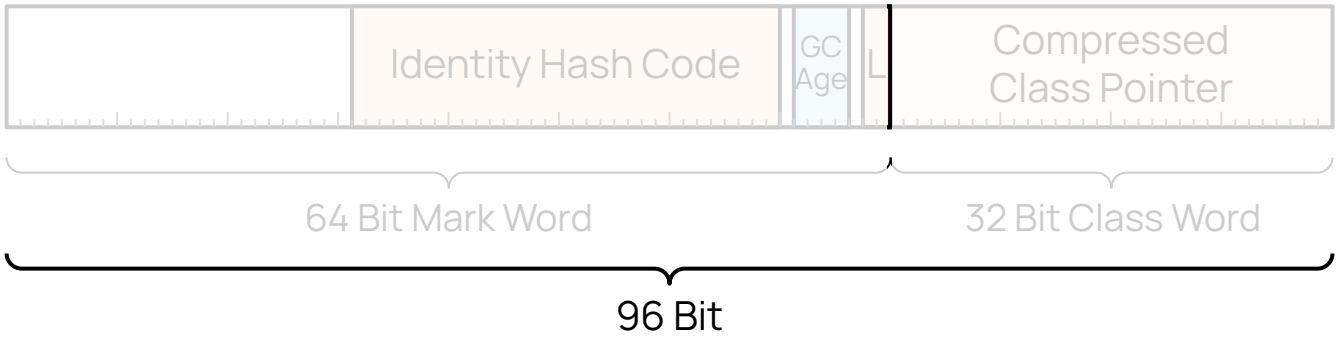
Mark Word



Mark Word

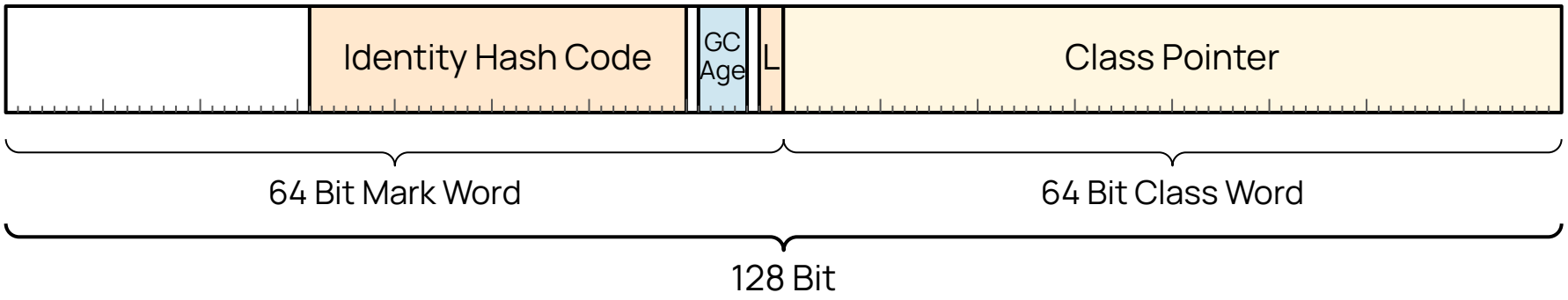

Mark Word
Class Word
Payload
Unused
Identity Hash Code
GC Age
L
25 Bit
31 Bit
4 Bit
2 Bit
64 Bit

Object Header



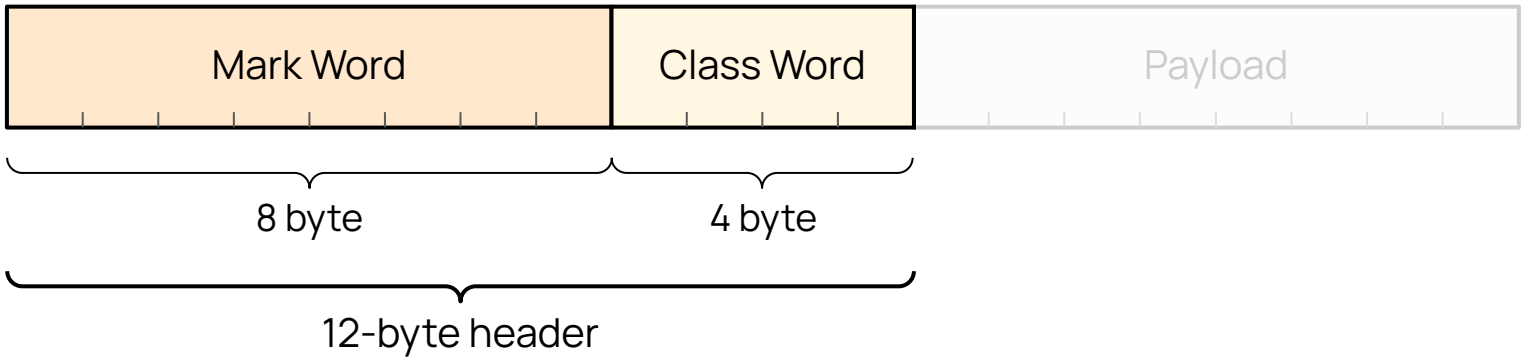
Object Header

-XX:-UseCompressedClassPointers (deprecated since Java 25):



Java Object with Header and Payload

A `java.lang.Long` object:



Java Object with Header and Payload

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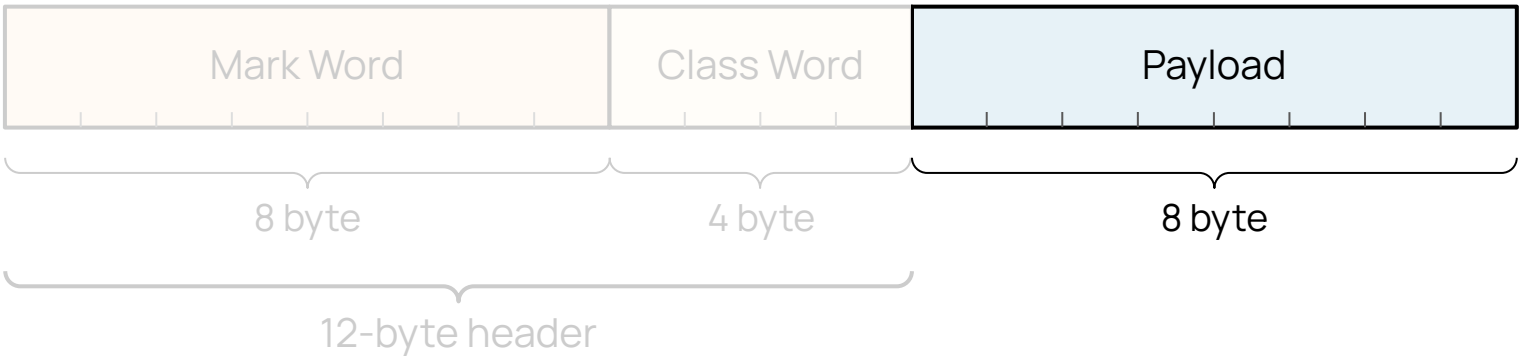
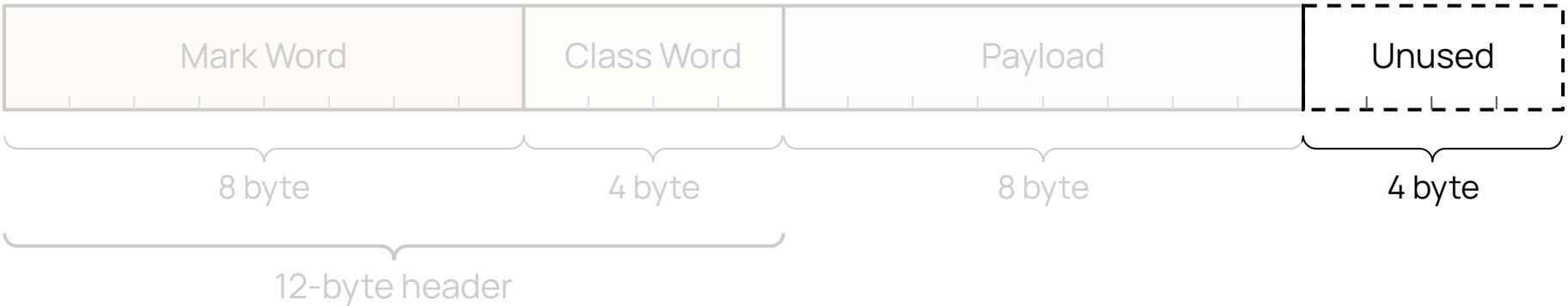


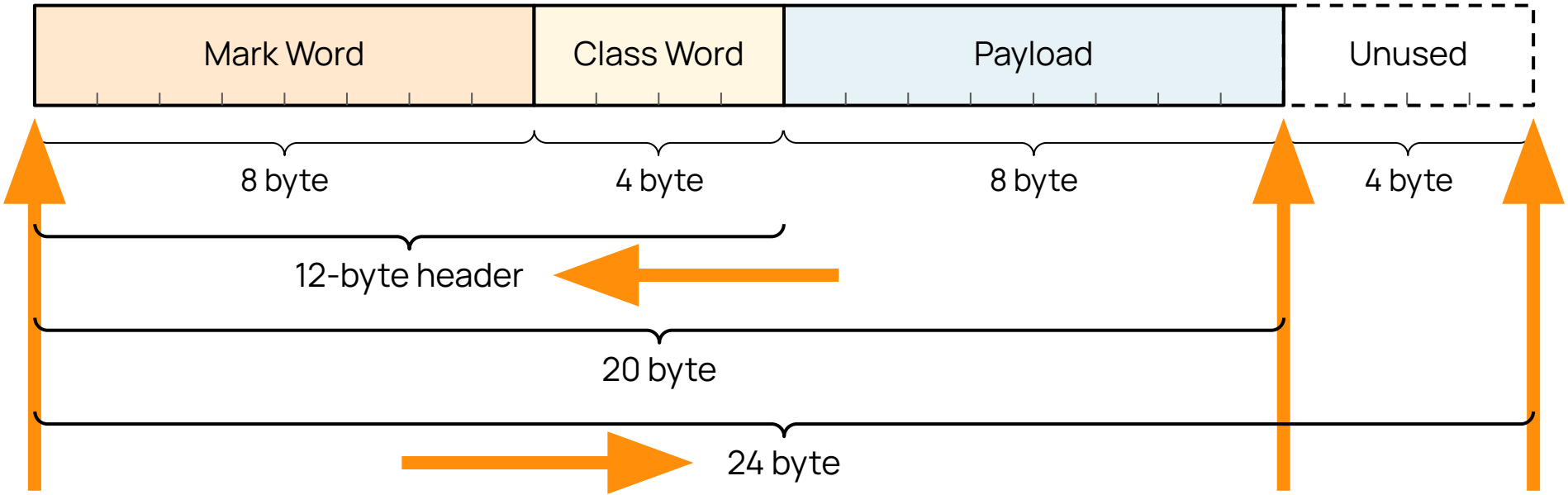
Java Object with Header and Payload

A `java.lang.Long` object:



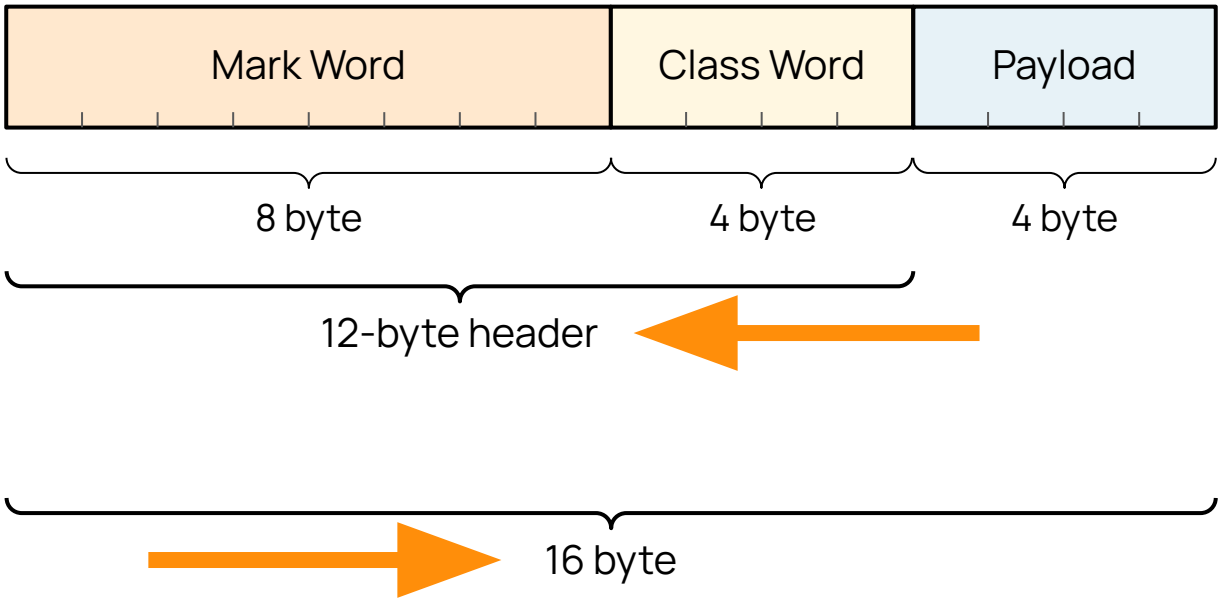
Java Object with Header and Payload

A `java.lang.Long` object:



Java Object with Header and Payload

A `java.lang.Integer` object:



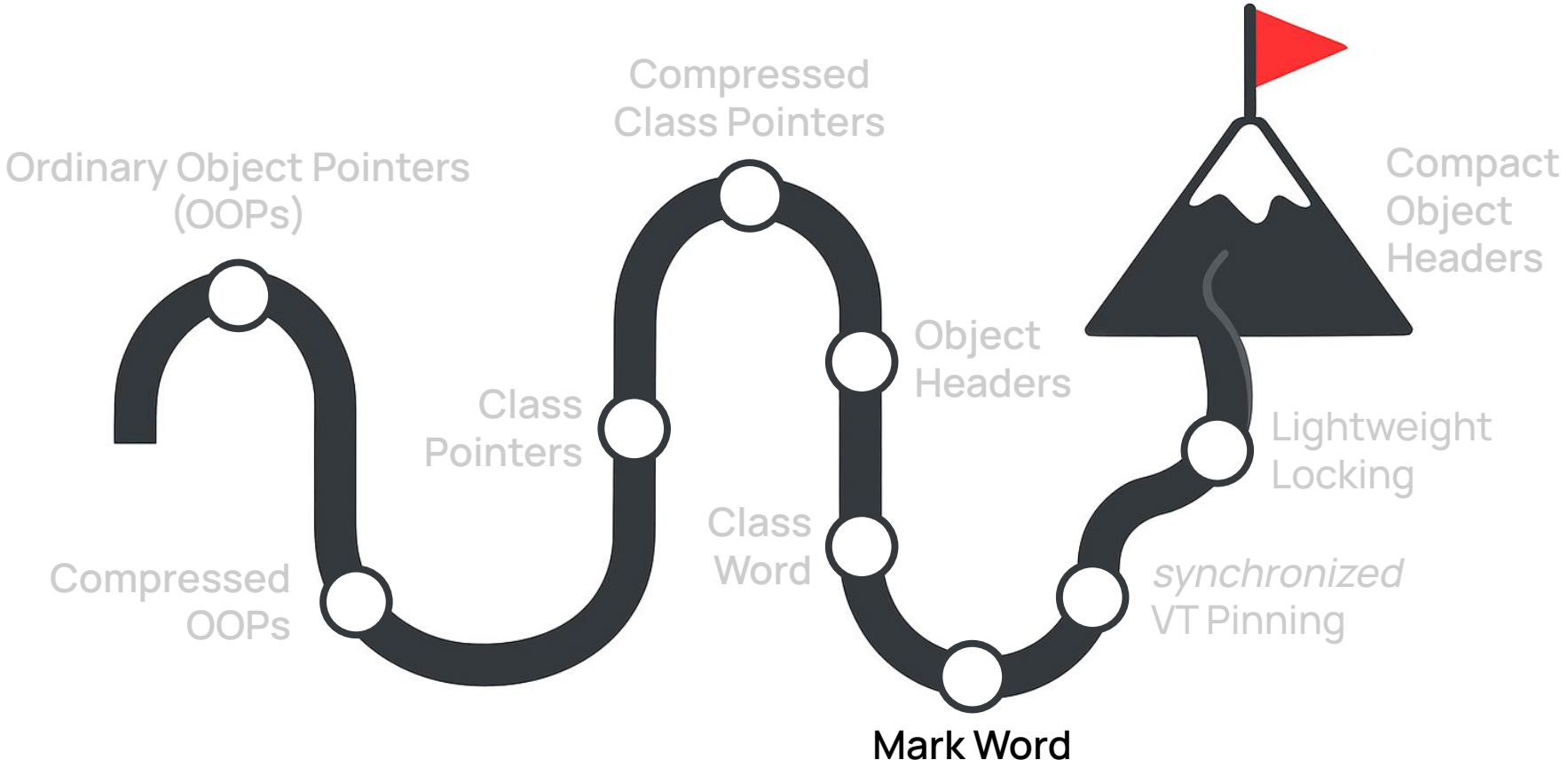
Java Object Size

Typical object size:	32~64 bytes
Typical object header overhead:	~ 20 %

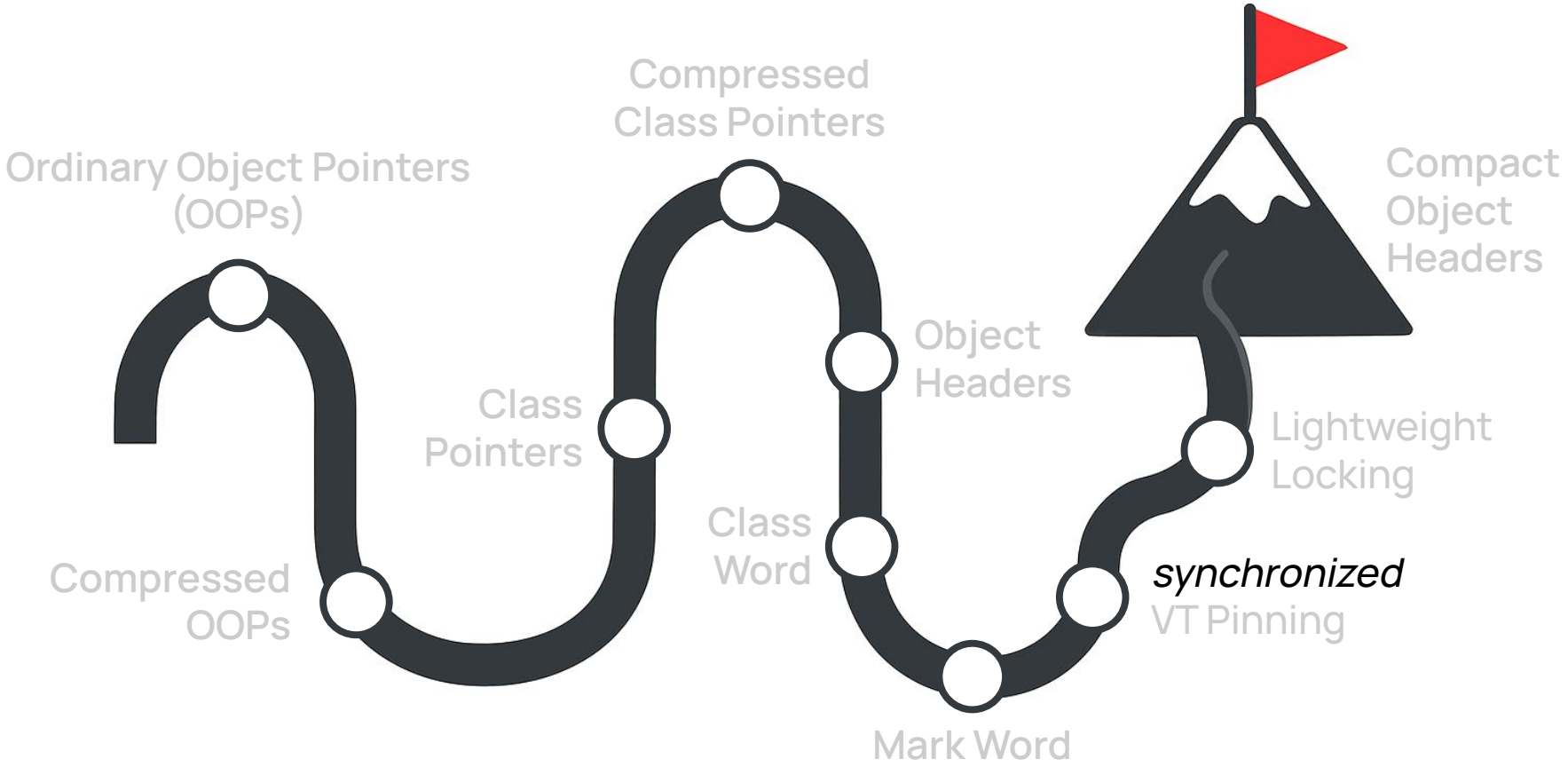
→ Project “Lilliput”

“The goal of this Project is to explore techniques to downsize Java object headers in the Hotspot JVM from 128 bits to 64 bits or less, reducing Java’s memory footprint.”

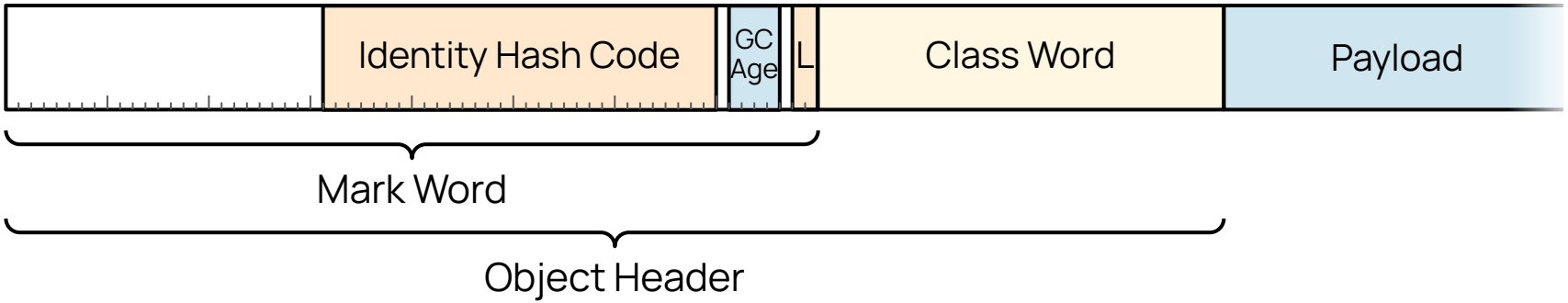
Journey into the JVM



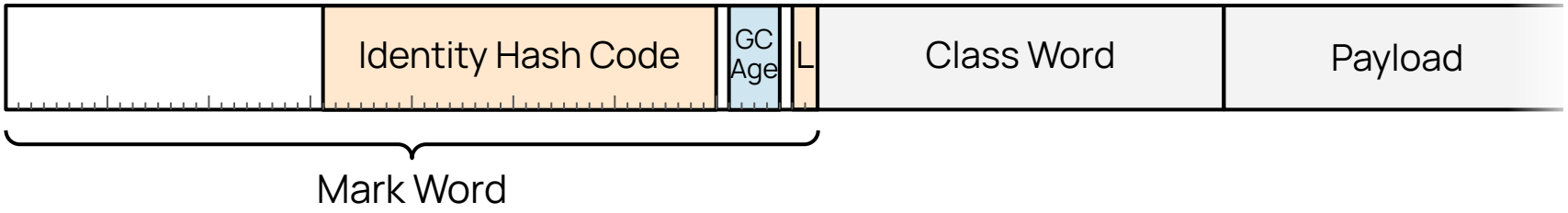
Journey into the JVM



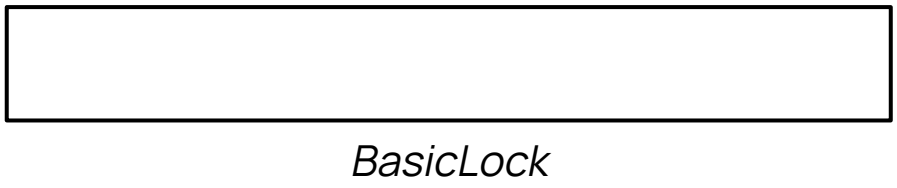
Java Heap

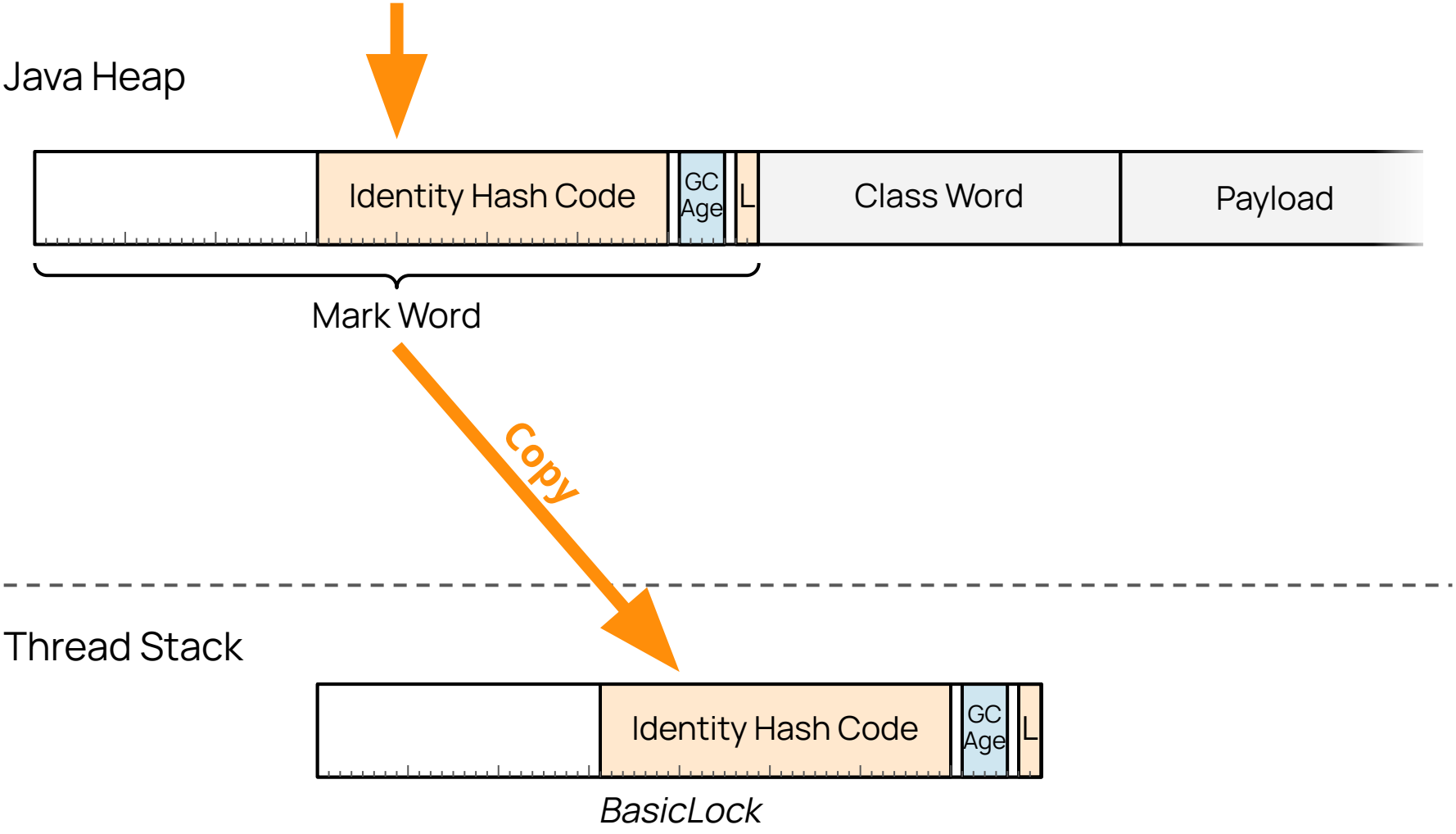

Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
Object Header

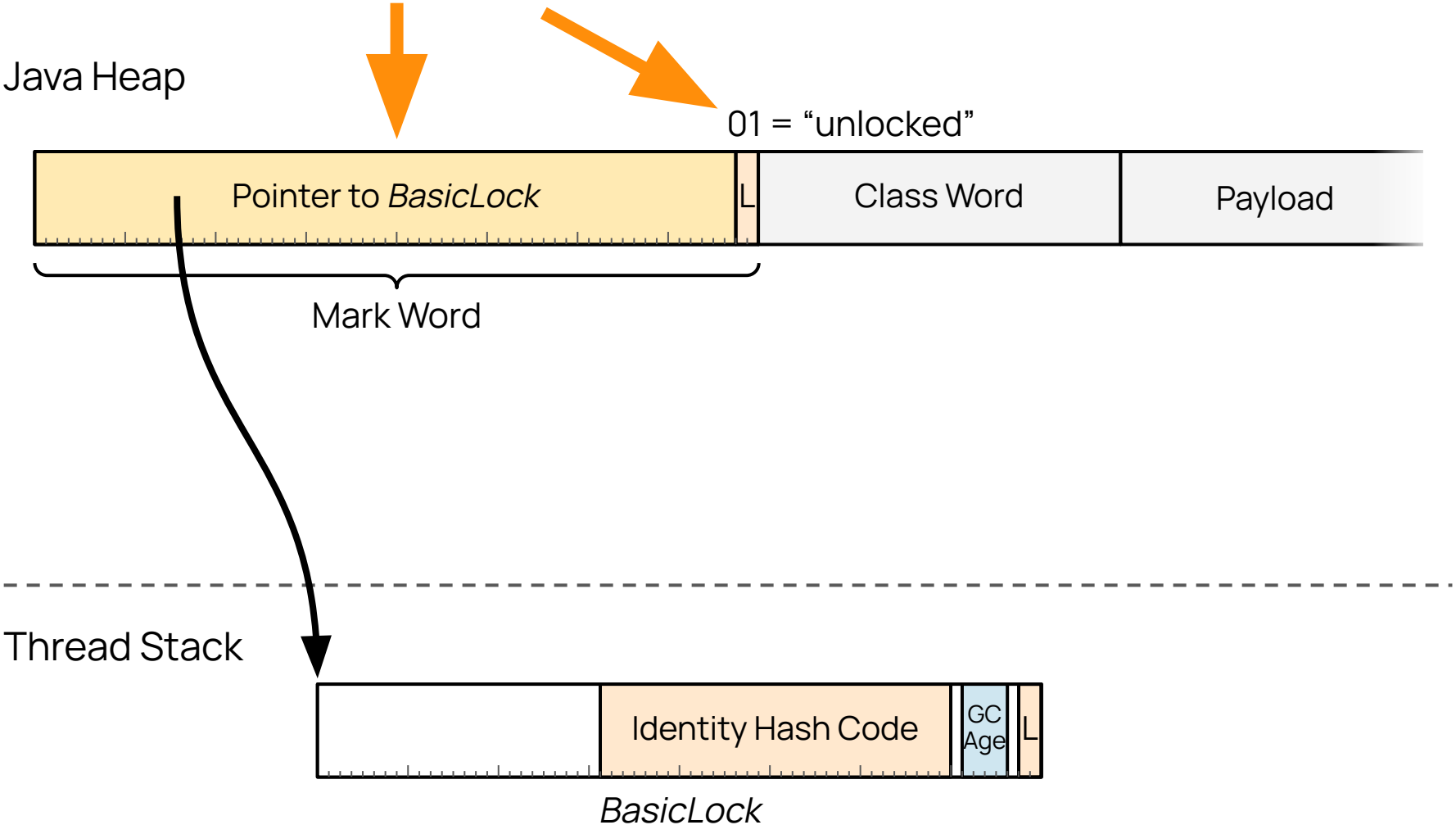
Java Heap

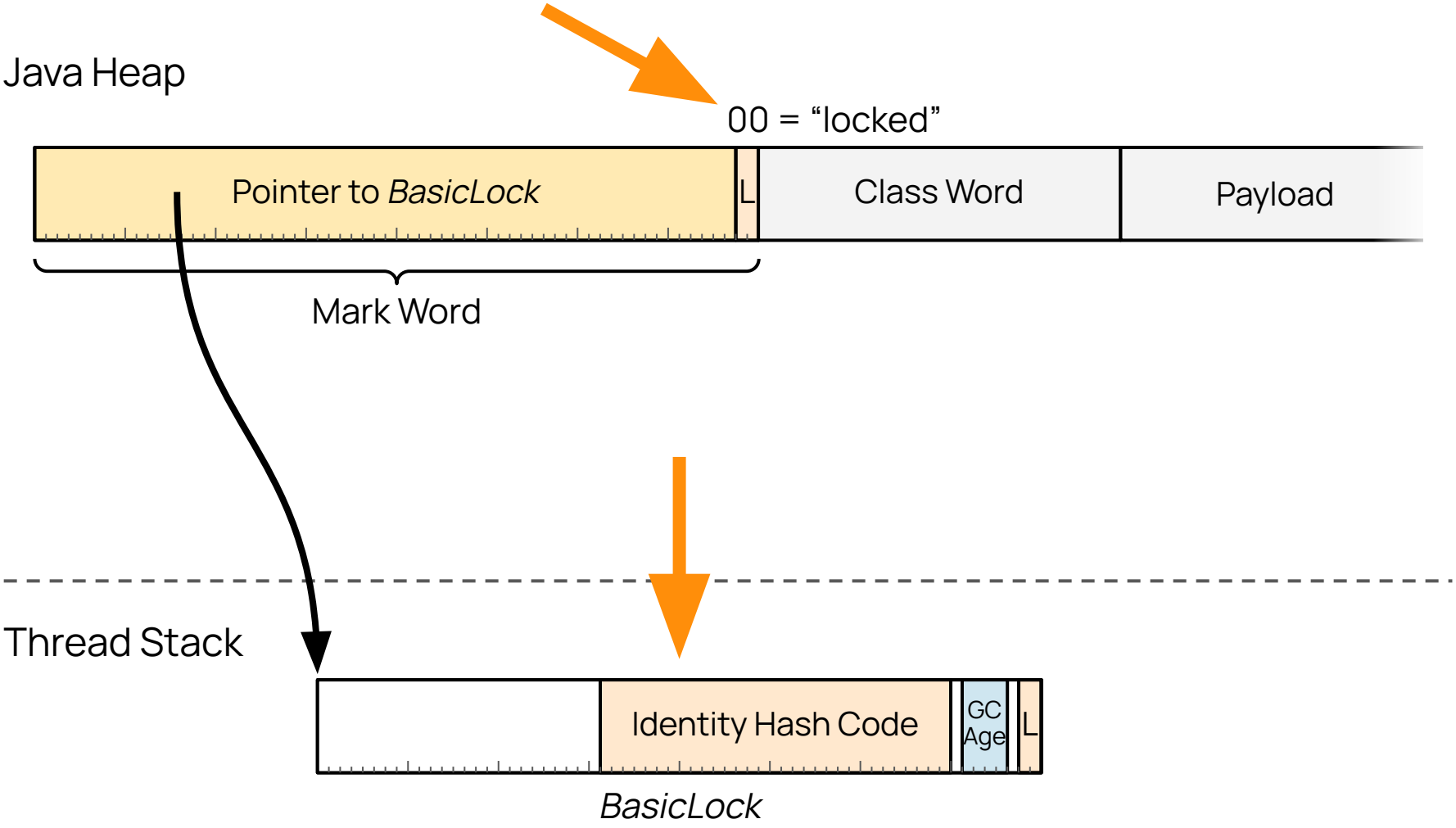


Thread Stack

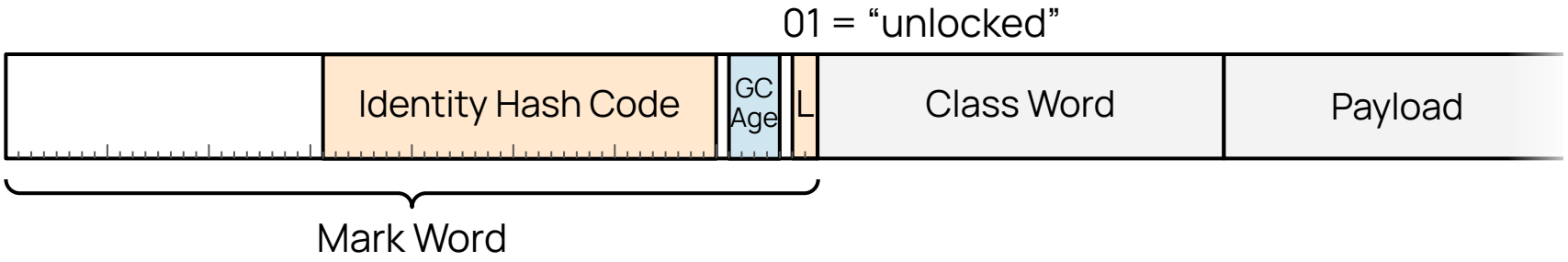



Java Heap
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
Copy
Thread Stack
Identity Hash Code
GC Age
L
BasicLock

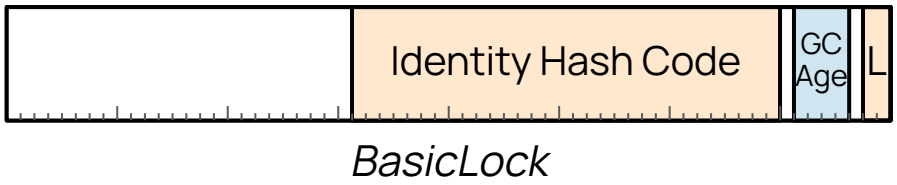

Java Heap
01 = “unlocked”
Pointer to *BasicLock*
L
Class Word
Payload
Mark Word
Thread Stack
Identity Hash Code
GC Age
L
BasicLock

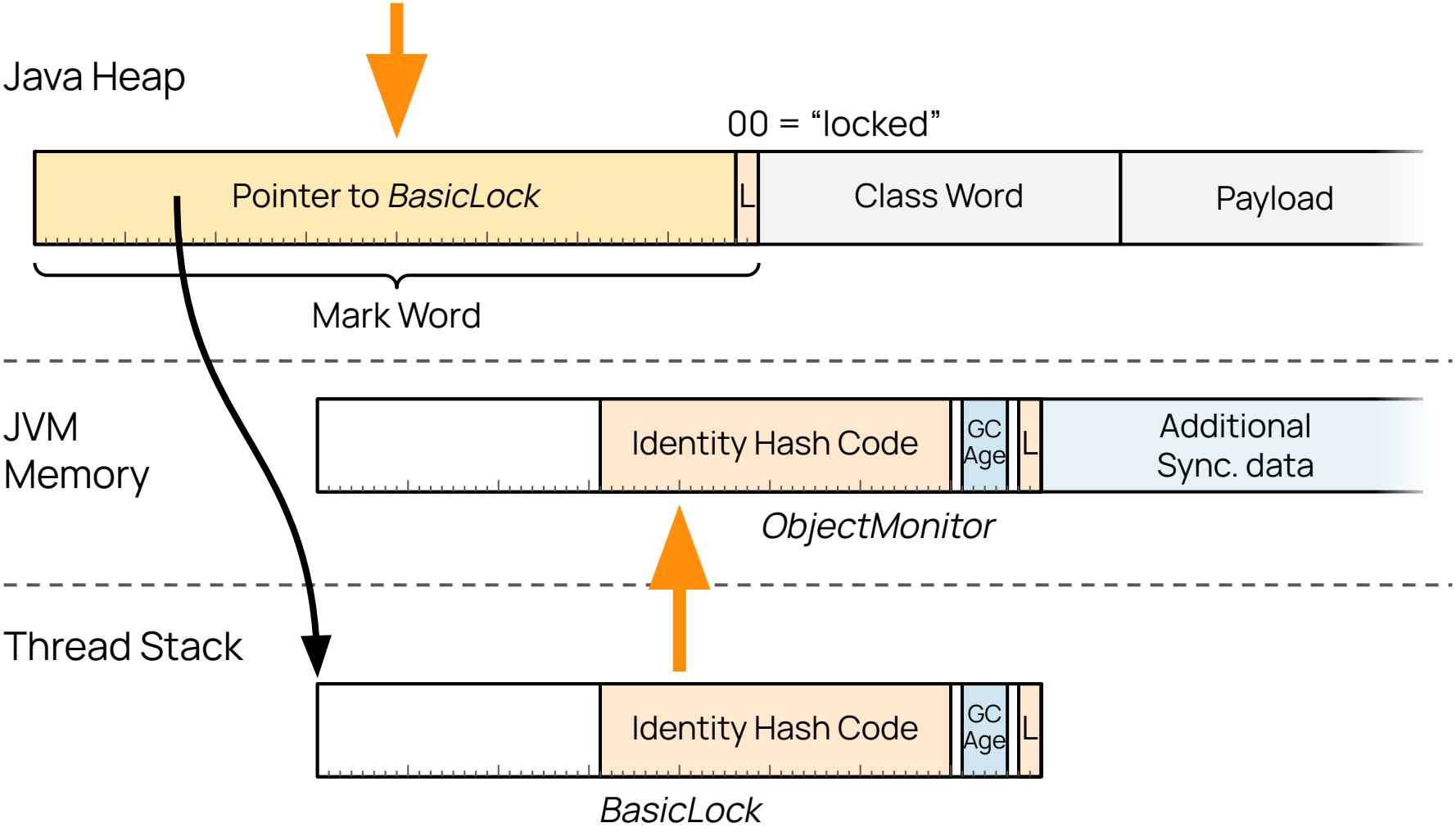

Java Heap
00 = “locked”
Pointer to *BasicLock*
L
Class Word
Payload
Mark Word
Thread Stack
Identity Hash Code
GC Age
L
BasicLock

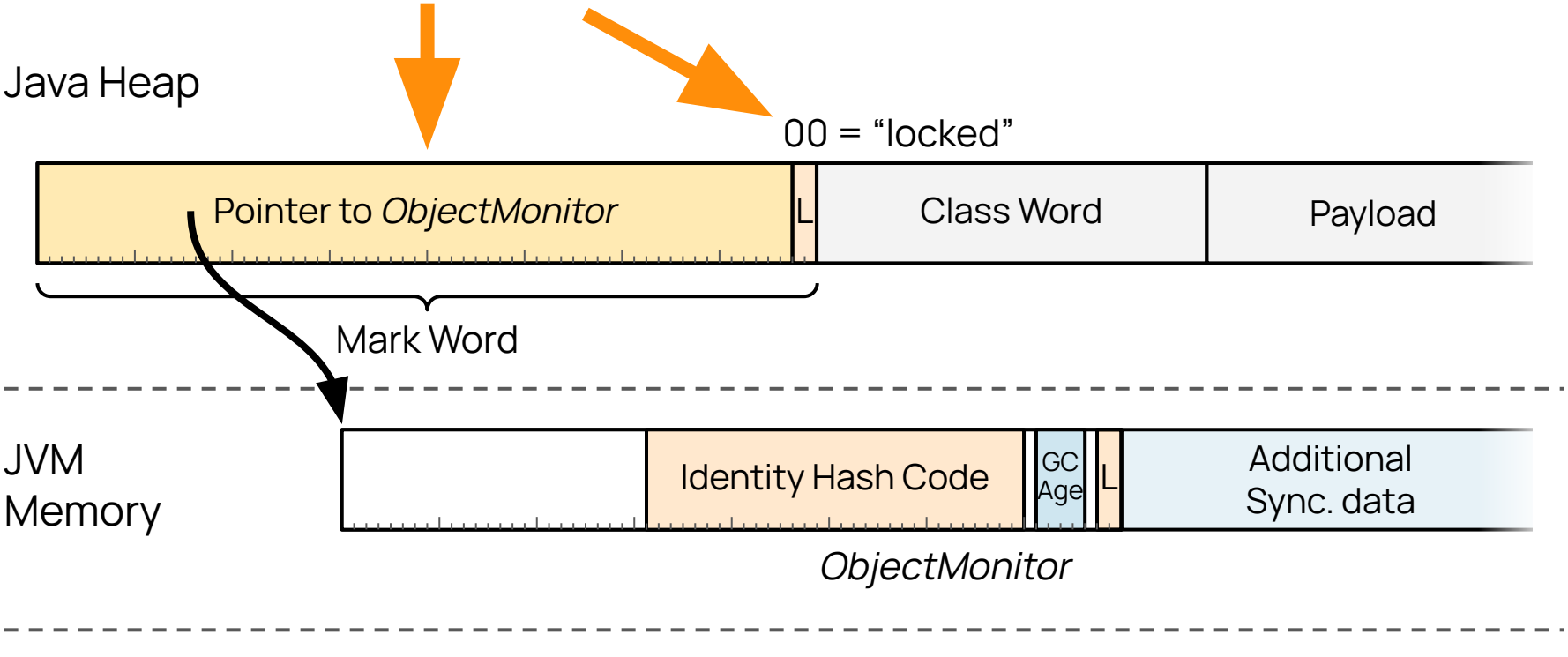
Java Heap

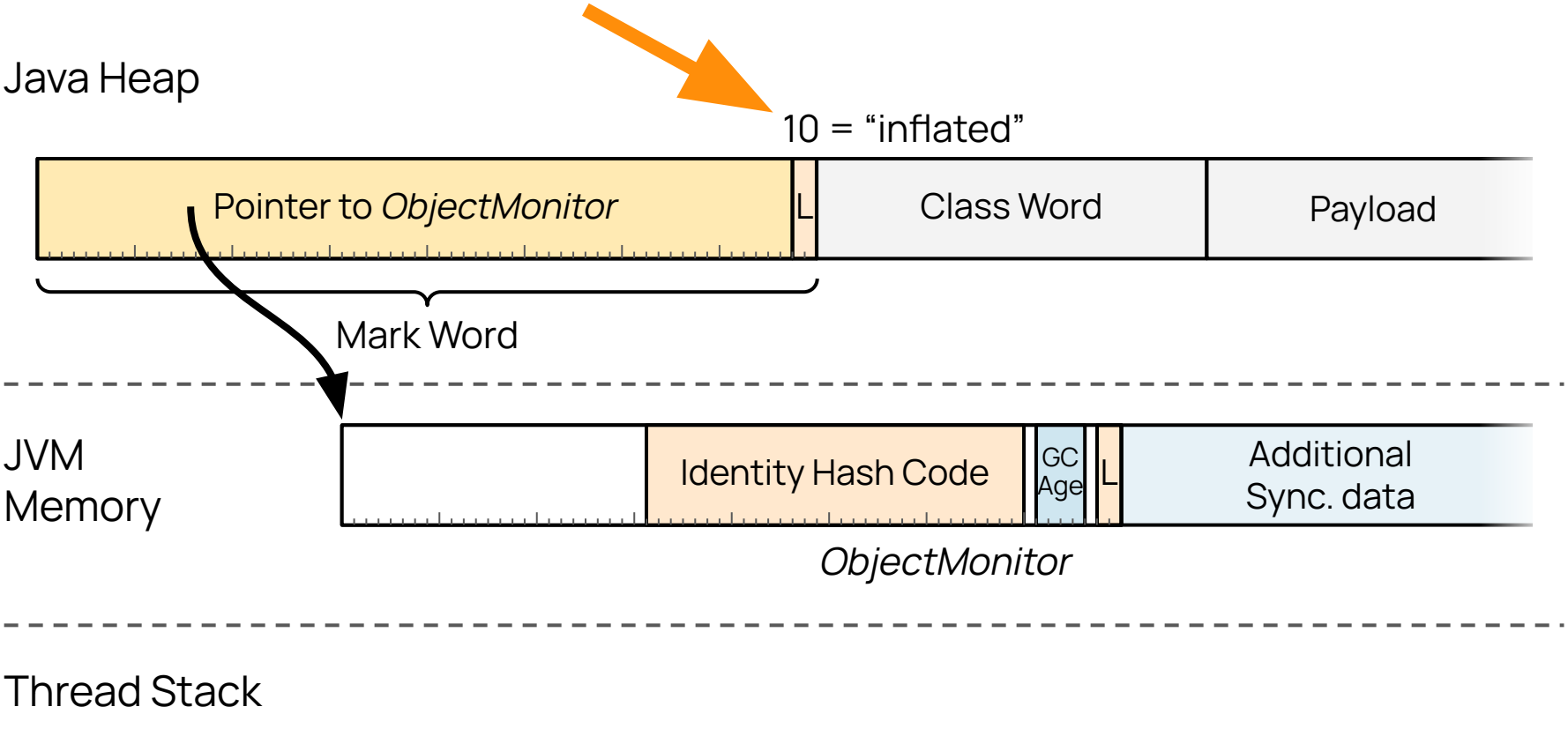


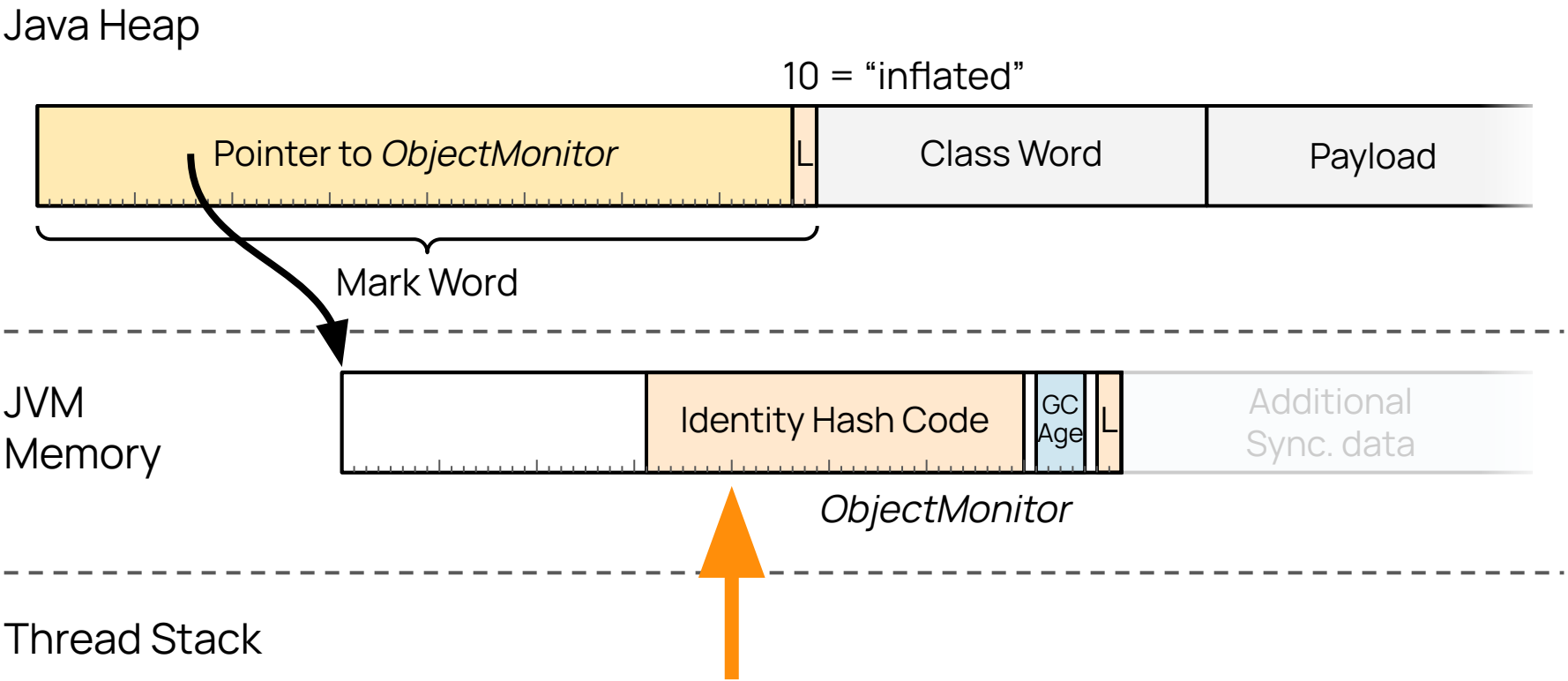
Thread Stack

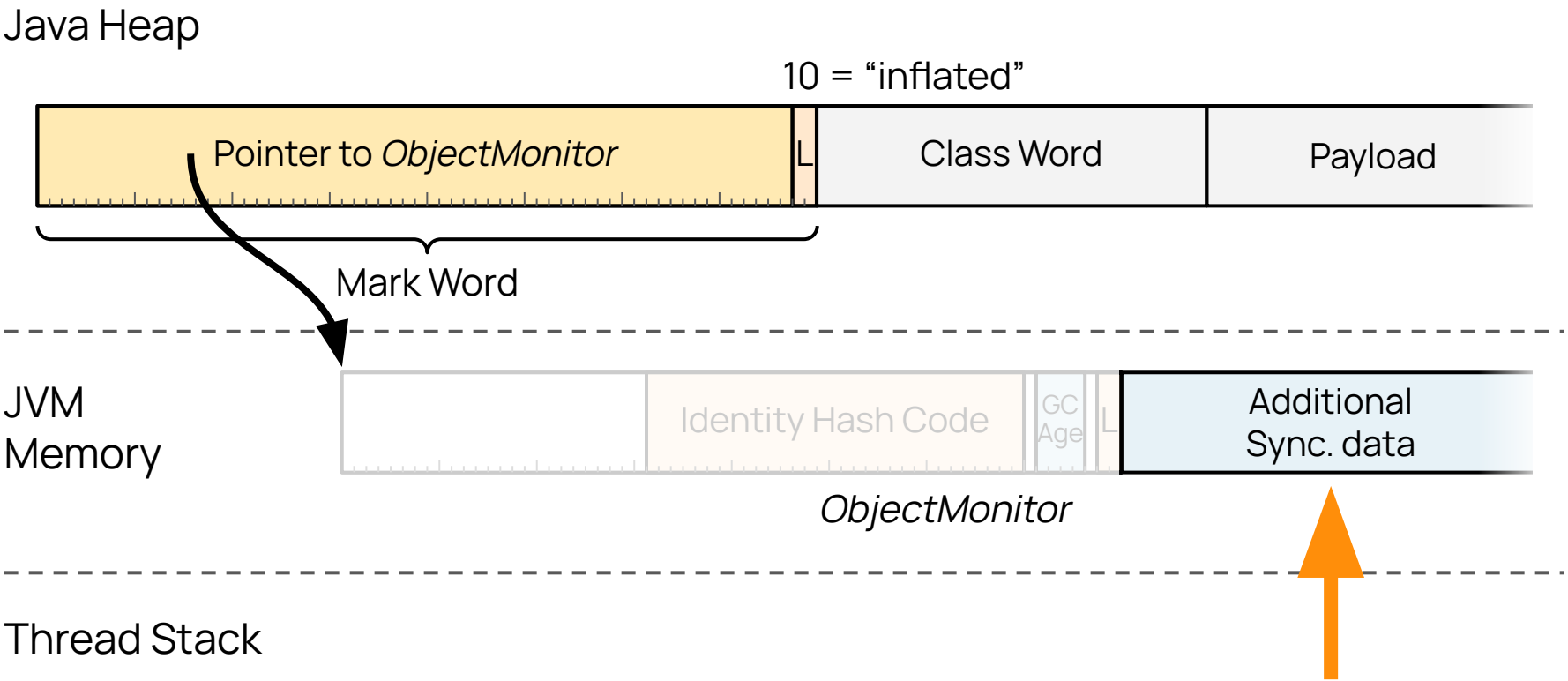


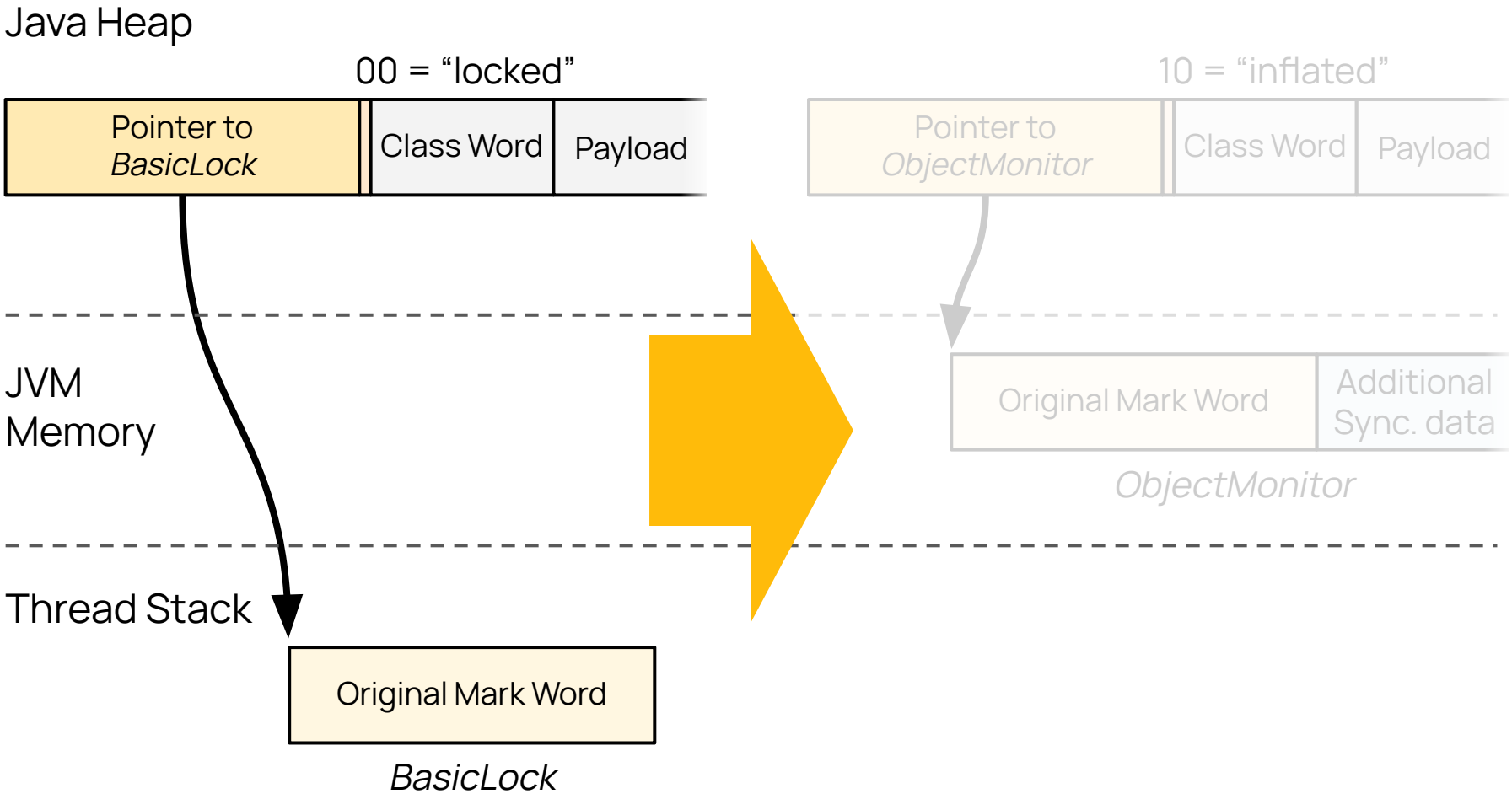

Java Heap
00 = “locked”
Pointer to *BasicLock*
L
Class Word
Payload
Mark Word
JVM
Memory
Identity Hash Code
GC
Age
L
Additional
Sync. data
ObjectMonitor
Thread Stack
Identity Hash Code
GC
Age
L
BasicLock

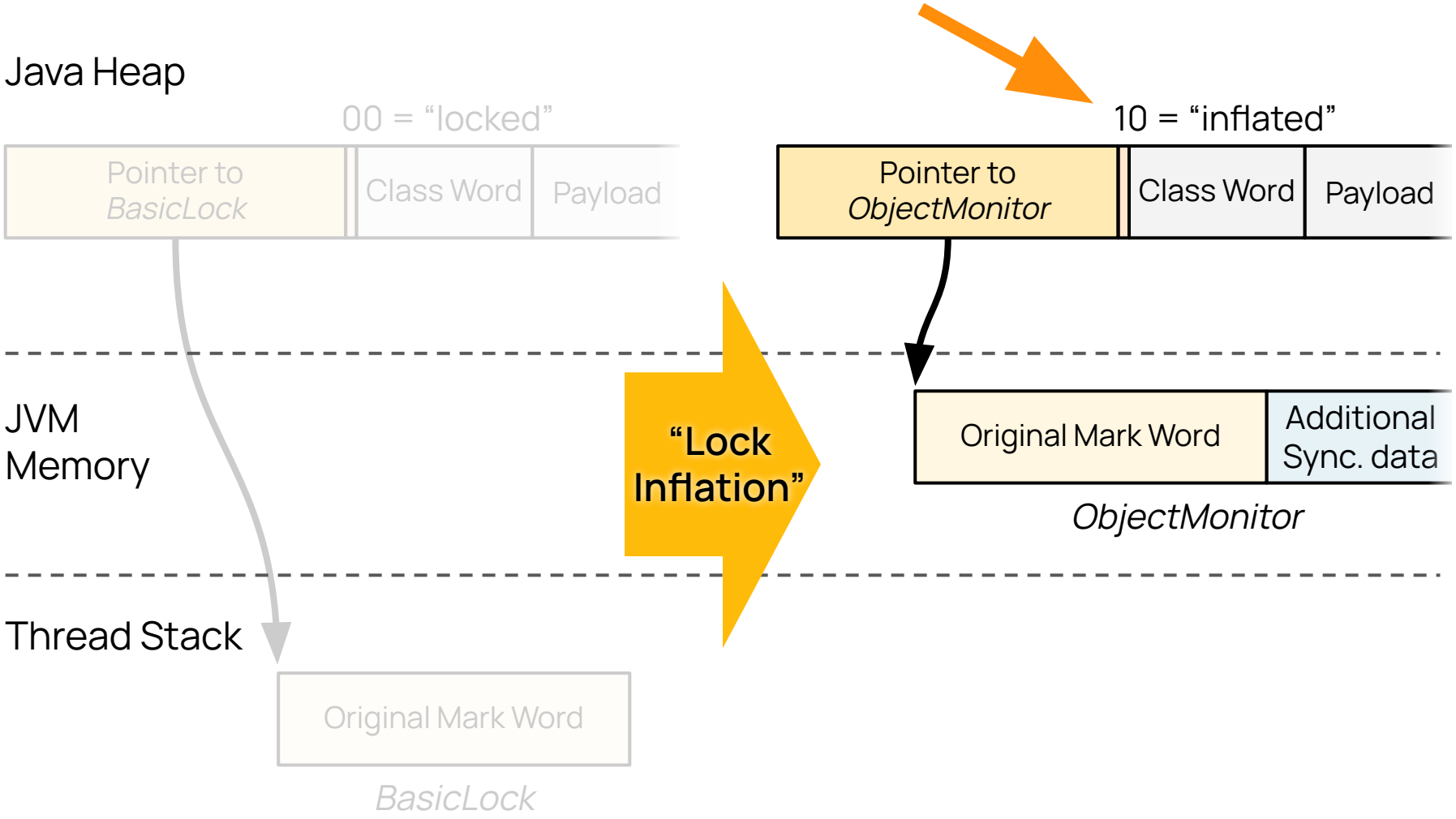

Java Heap
00 = “locked”
Pointer to ObjectMonitor
L
Class Word
Payload
Mark Word
JVM
Memory
Identity Hash Code
GC
Age
L
Additional
Sync. data
ObjectMonitor
Thread Stack


Java Heap
10 = “inflated”
Pointer to *ObjectMonitor*
L
Class Word
Payload
Mark Word
JVM
Memory
Identity Hash Code
GC
Age
L
Additional
Sync. data
ObjectMonitor
Thread Stack


Java Heap
10 = “inflated”
Pointer to ObjectMonitor
L
Class Word
Payload
Mark Word
JVM
Memory
Identity Hash Code
GC
Age
L
Additional
Sync. data
ObjectMonitor
Thread Stack

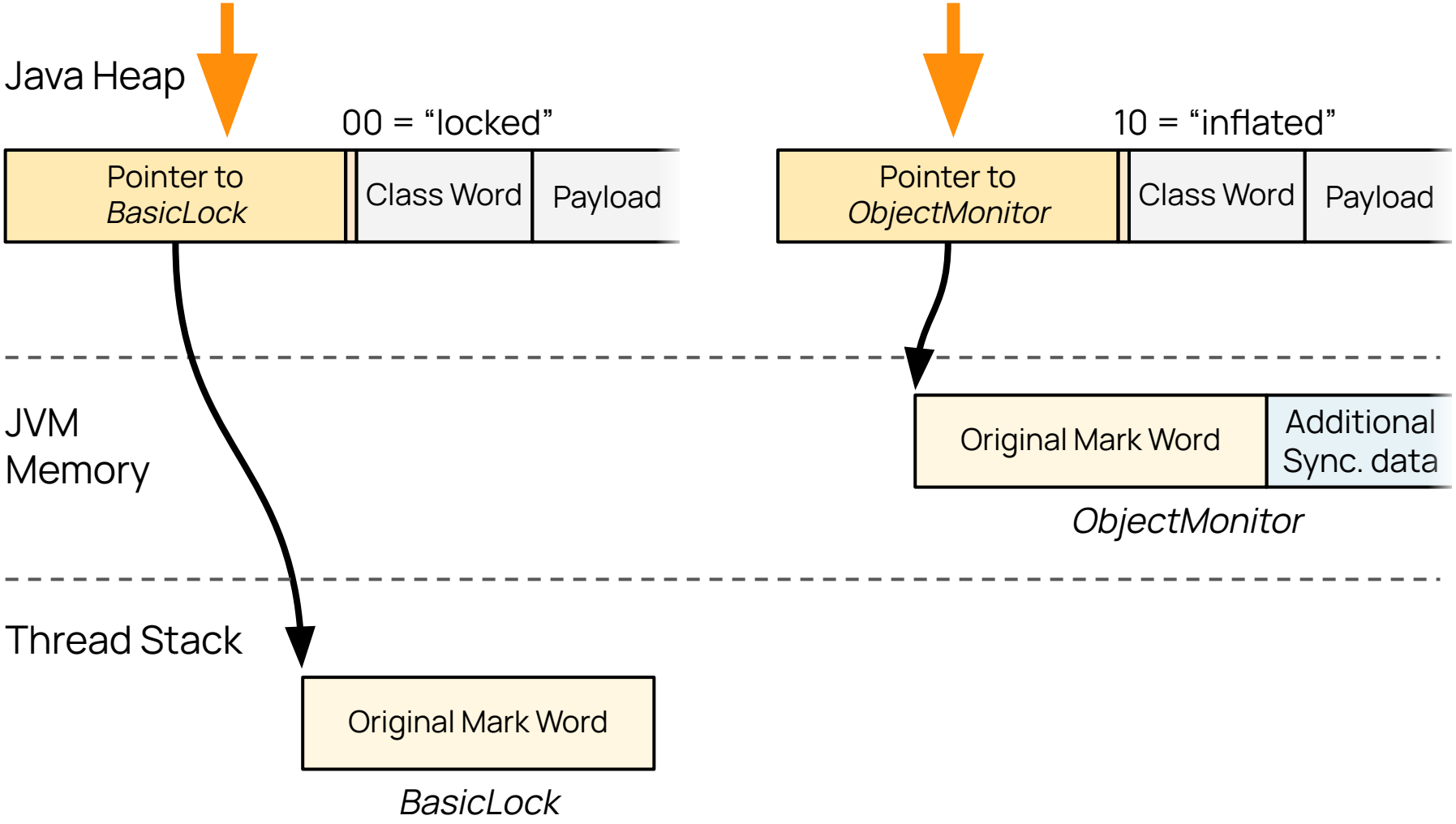

Java Heap
10 = “inflated”
Pointer to *ObjectMonitor*
L
Class Word
Payload
Mark Word
JVM
Memory
Identity Hash Code
GC
Age
L
Additional
Sync. data
ObjectMonitor
Thread Stack

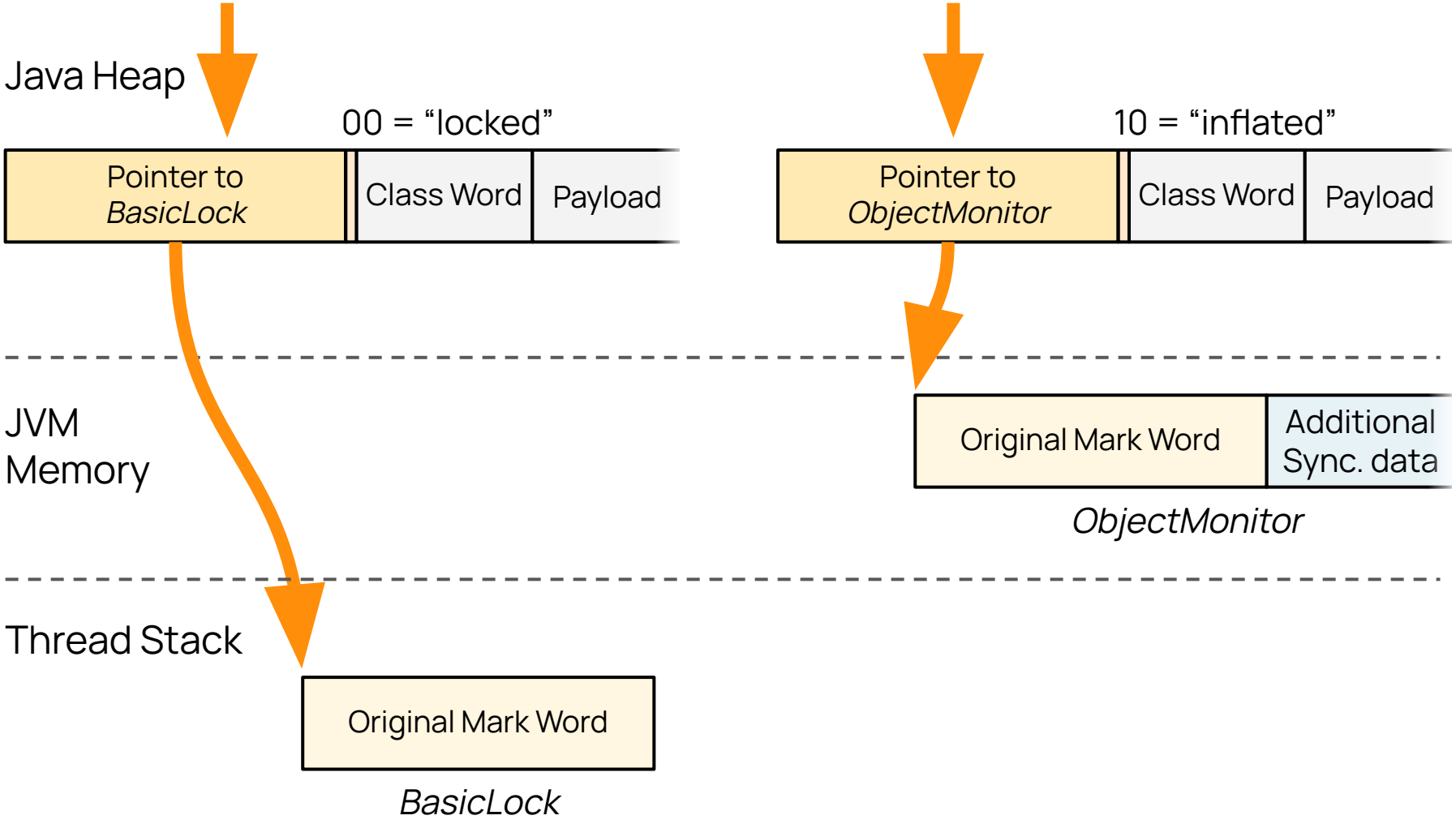

Java Heap
00 = “locked”
Pointer to
BasicLock
Class Word
Payload
10 = “inflated”
Pointer to
ObjectMonitor
Class Word
Payload
JVM
Memory
Original Mark Word
Additional
Sync. data
ObjectMonitor
Thread Stack
Original Mark Word
BasicLock

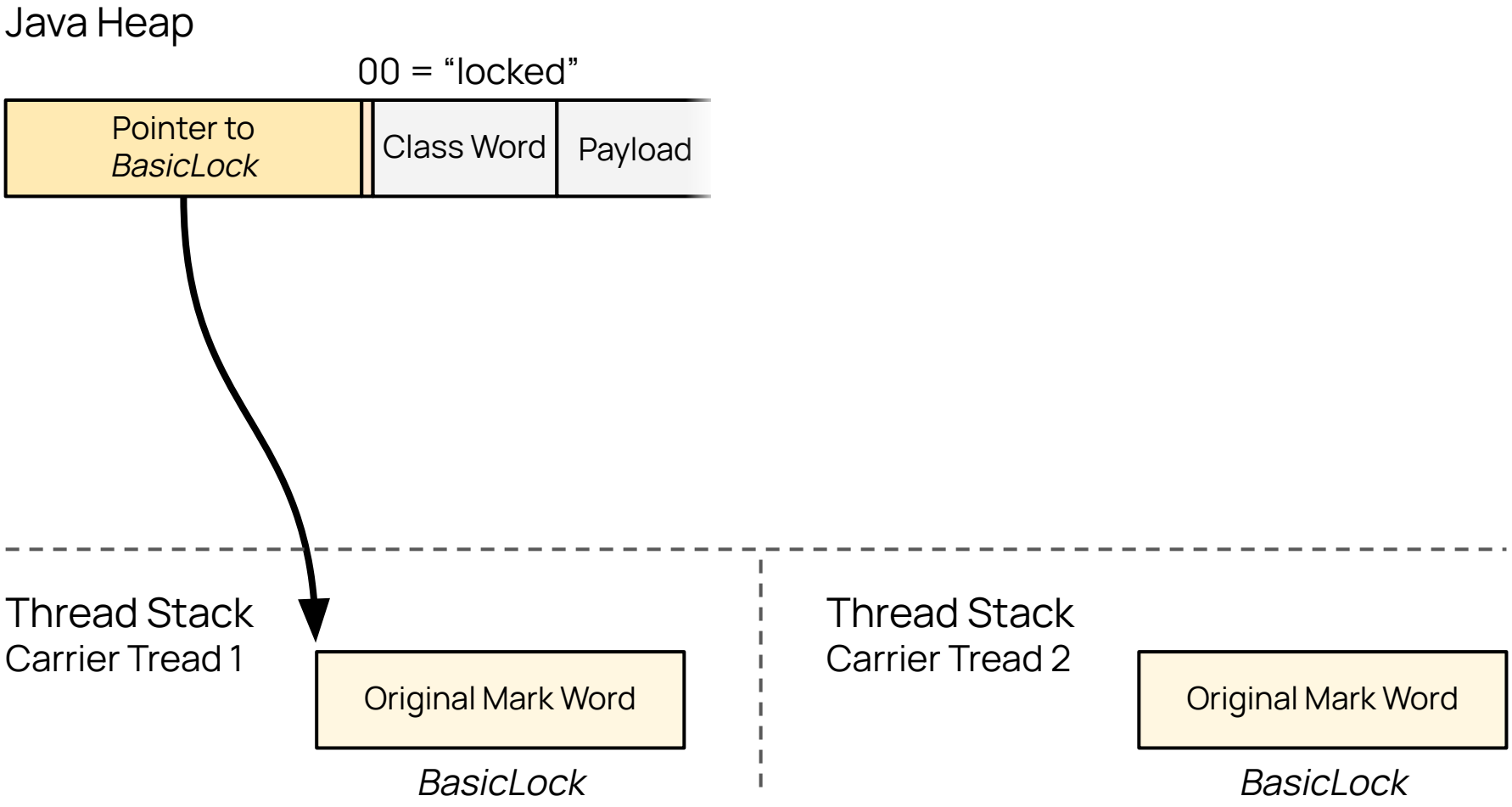

Java Heap
00 = “locked”
Pointer to BasicLock
Class Word
Payload
10 = “inflated”
Pointer to ObjectMonitor
Class Word
Payload
JVM Memory
“Lock Inflation”
Original Mark Word
Additional Sync. data
ObjectMonitor
Thread Stack
Original Mark Word
BasicLock

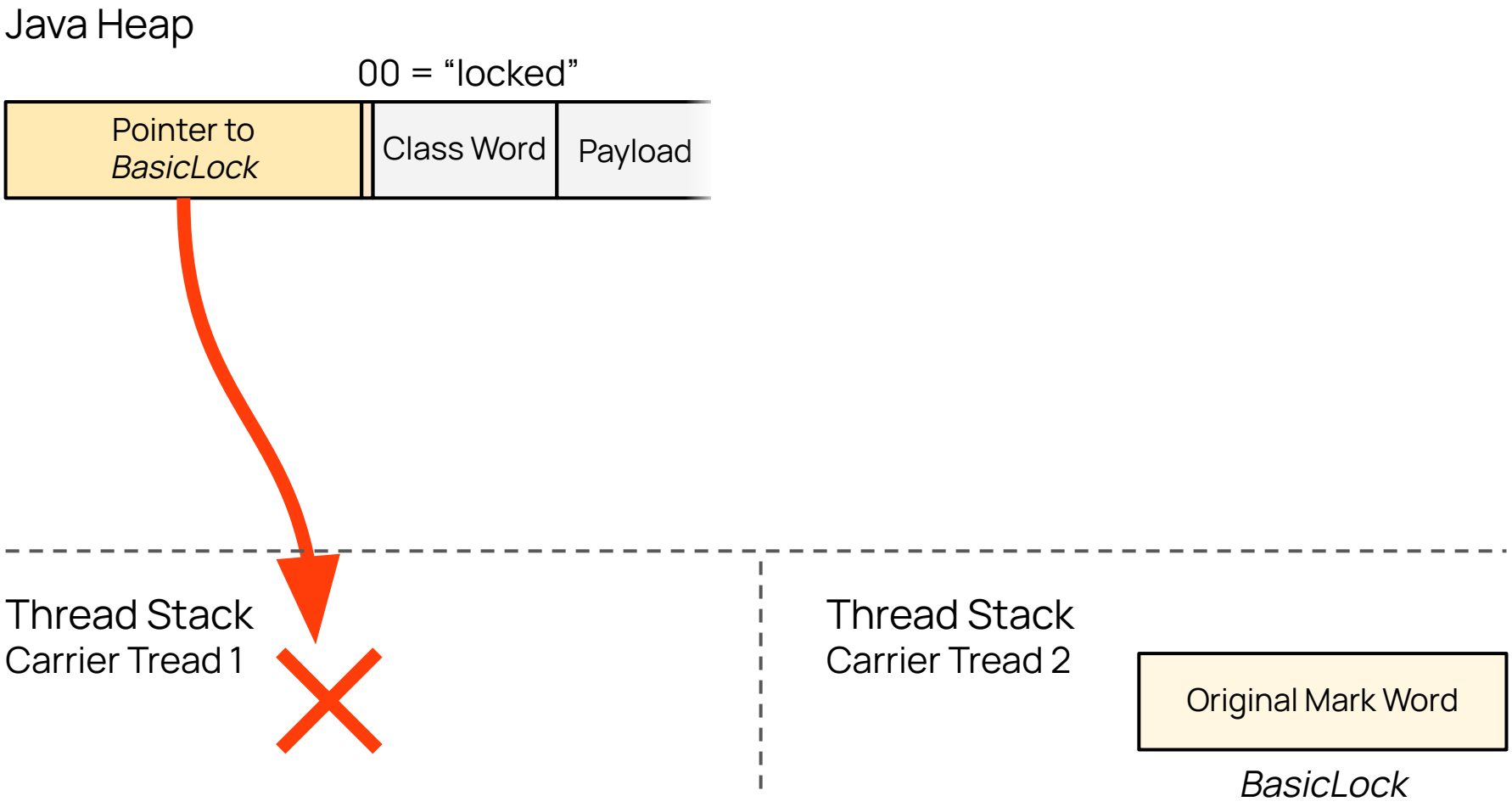
“Stack Locking”

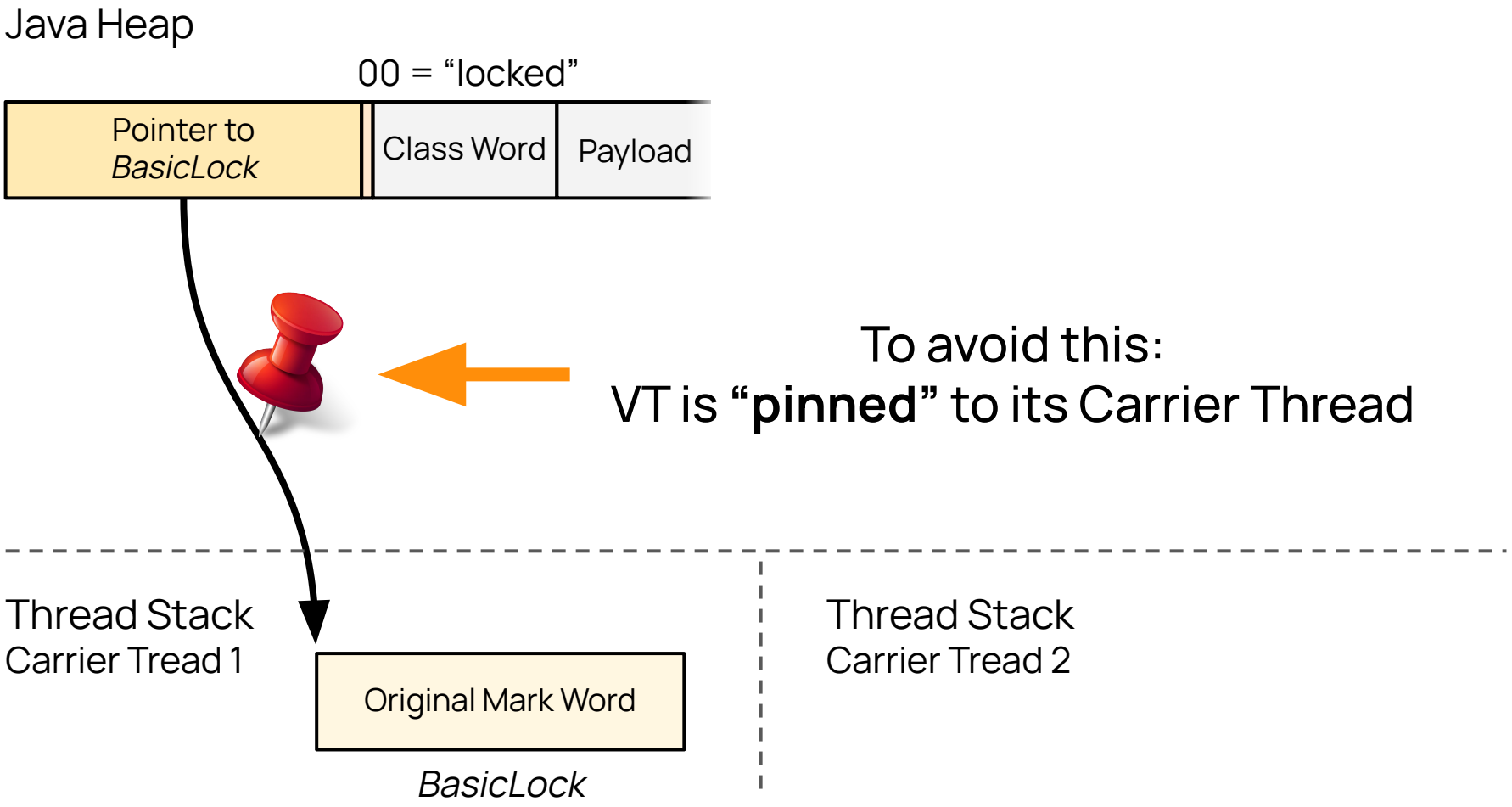
“Legacy Stack Locking”


Java Heap
00 = “locked”
Pointer to
BasicLock
Class Word
Payload
10 = “inflated”
Pointer to
ObjectMonitor
Class Word
Payload
JVM
Memory
Original Mark Word
Additional
Sync. data
ObjectMonitor
Thread Stack
Original Mark Word
BasicLock

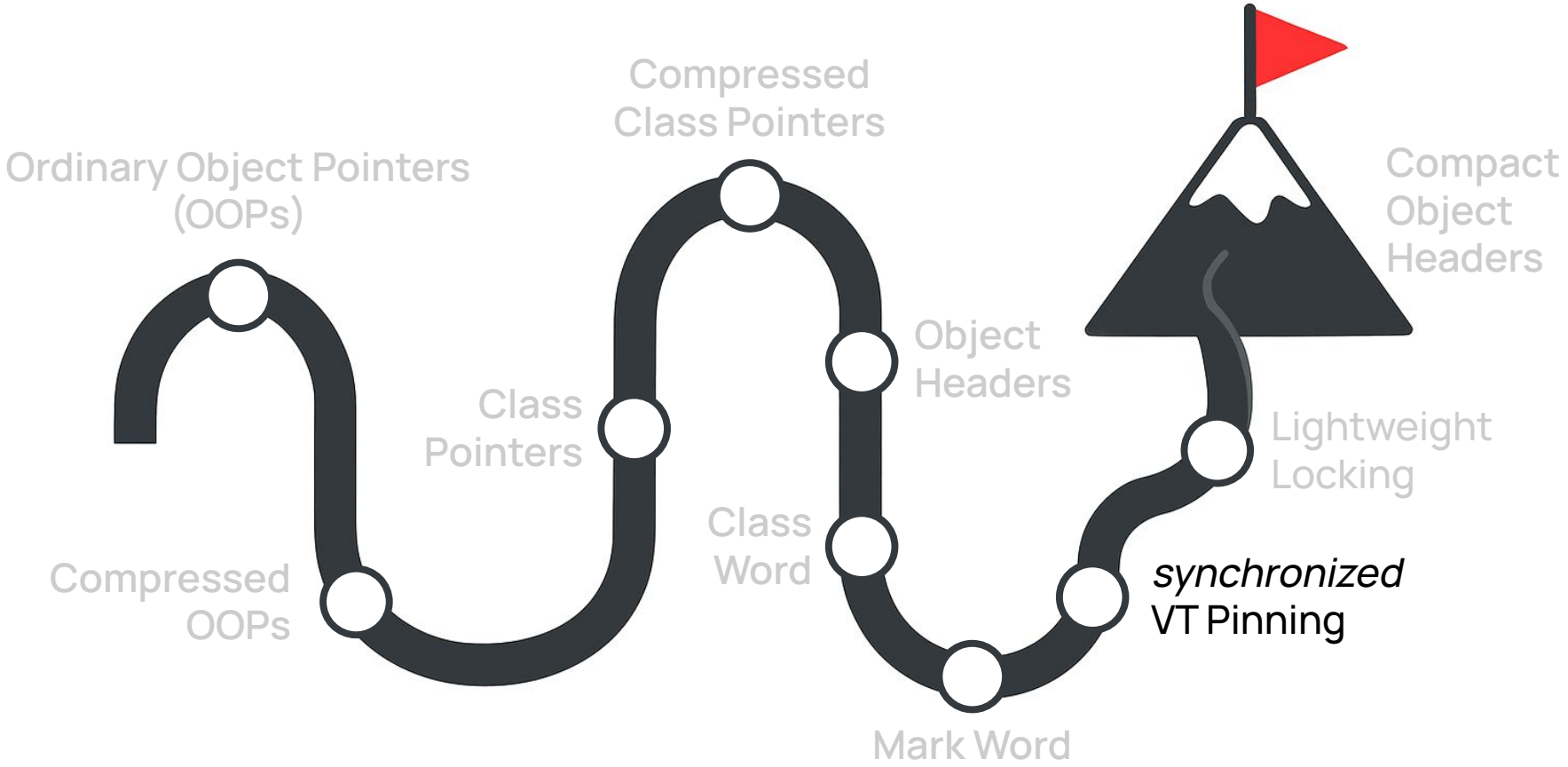

Java Heap
00 = “locked”
Pointer to
BasicLock
Class Word
Payload
10 = “inflated”
Pointer to
ObjectMonitor
Class Word
Payload
JVM
Memory
Original Mark Word
Additional
Sync. data
ObjectMonitor
Thread Stack
Original Mark Word
BasicLock


Java Heap
00 = “locked”
Pointer to
BasicLock
Class Word
Payload
Thread Stack
Carrier Tread 1
Original Mark Word
BasicLock
Thread Stack
Carrier Tread 2
Original Mark Word
BasicLock

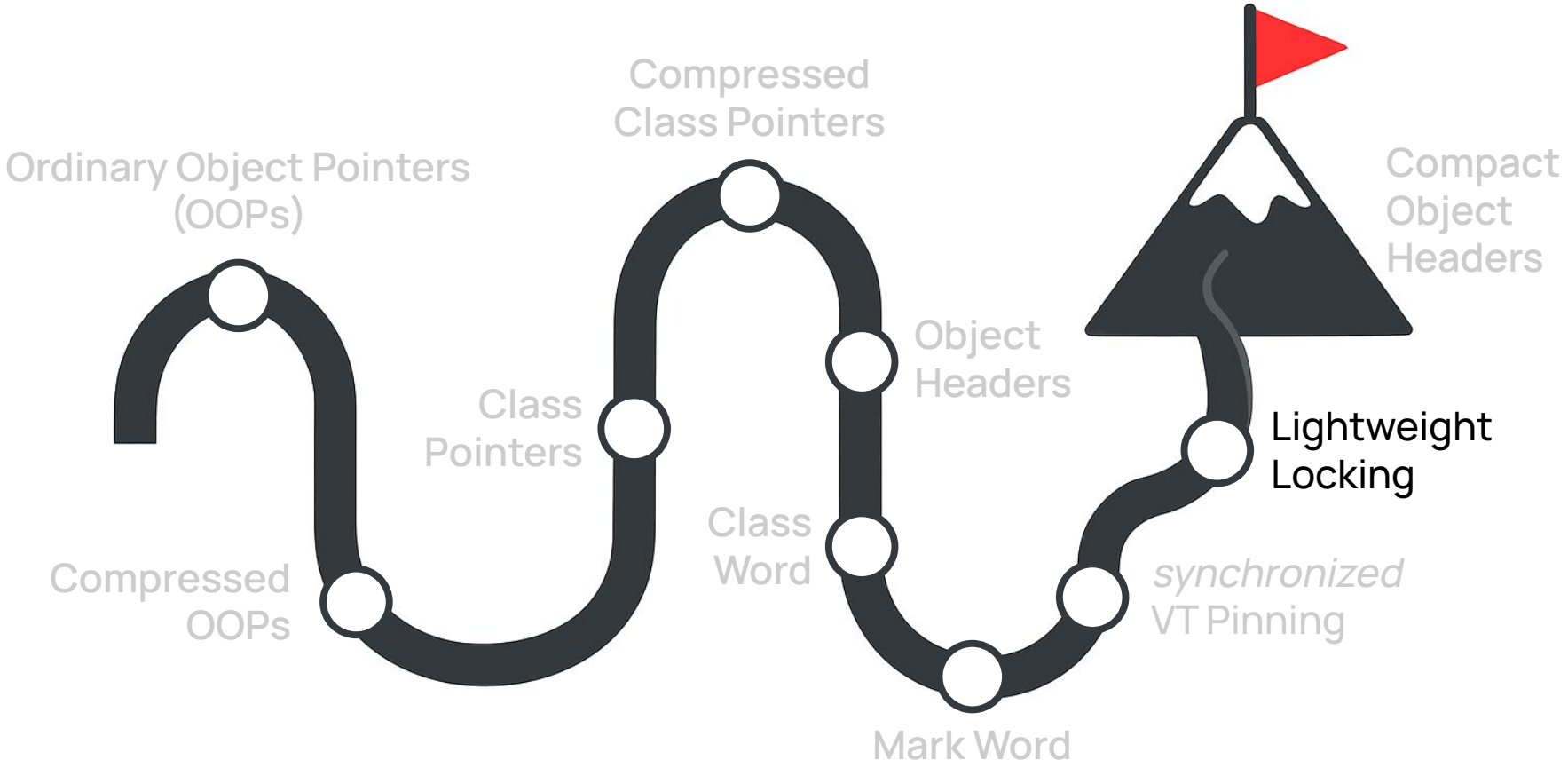

Java Heap
00 = “locked”
Pointer to
BasicLock
Class Word
Payload
Thread Stack
Carrier Tread 1
Thread Stack
Carrier Tread 2
Original Mark Word
BasicLock


Java Heap
00 = “locked”
Pointer to
BasicLock
Class Word
Payload
To avoid this:
VT is “pinned” to its Carrier Thread
Thread Stack
Carrier Tread 1
Original Mark Word
BasicLock
Thread Stack
Carrier Tread 2

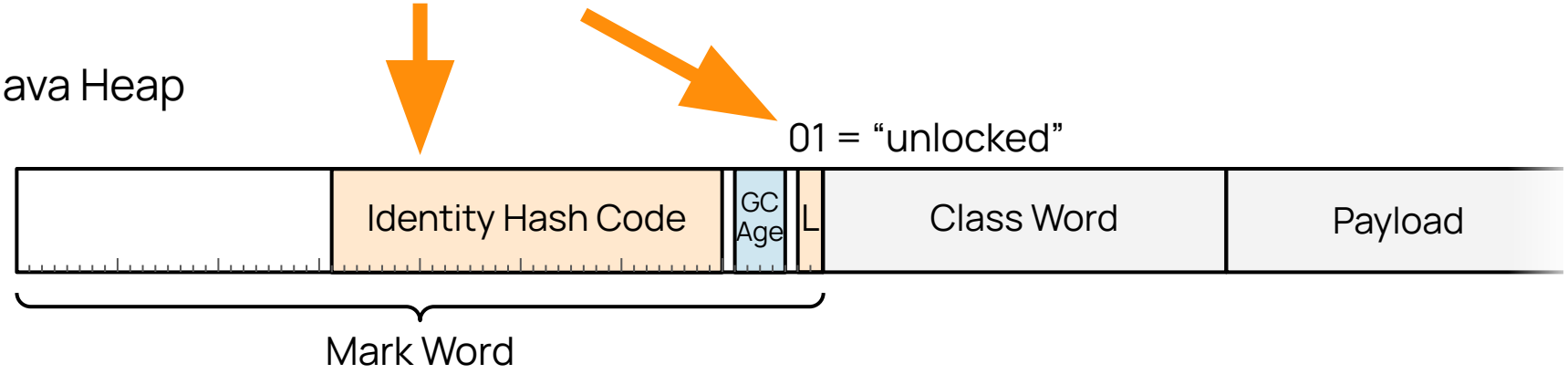
Journey into the JVM



Journey into the JVM

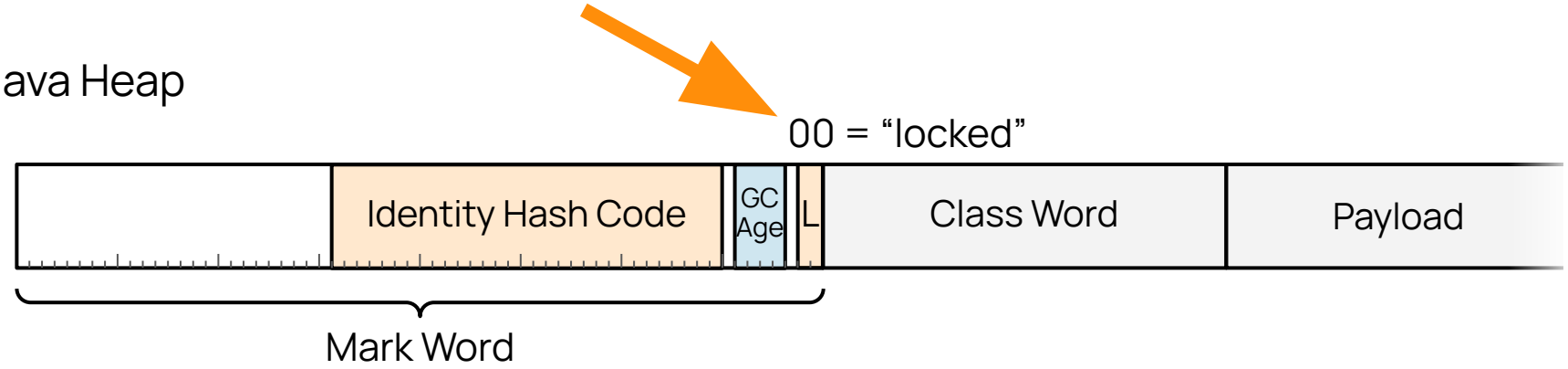


Java Heap

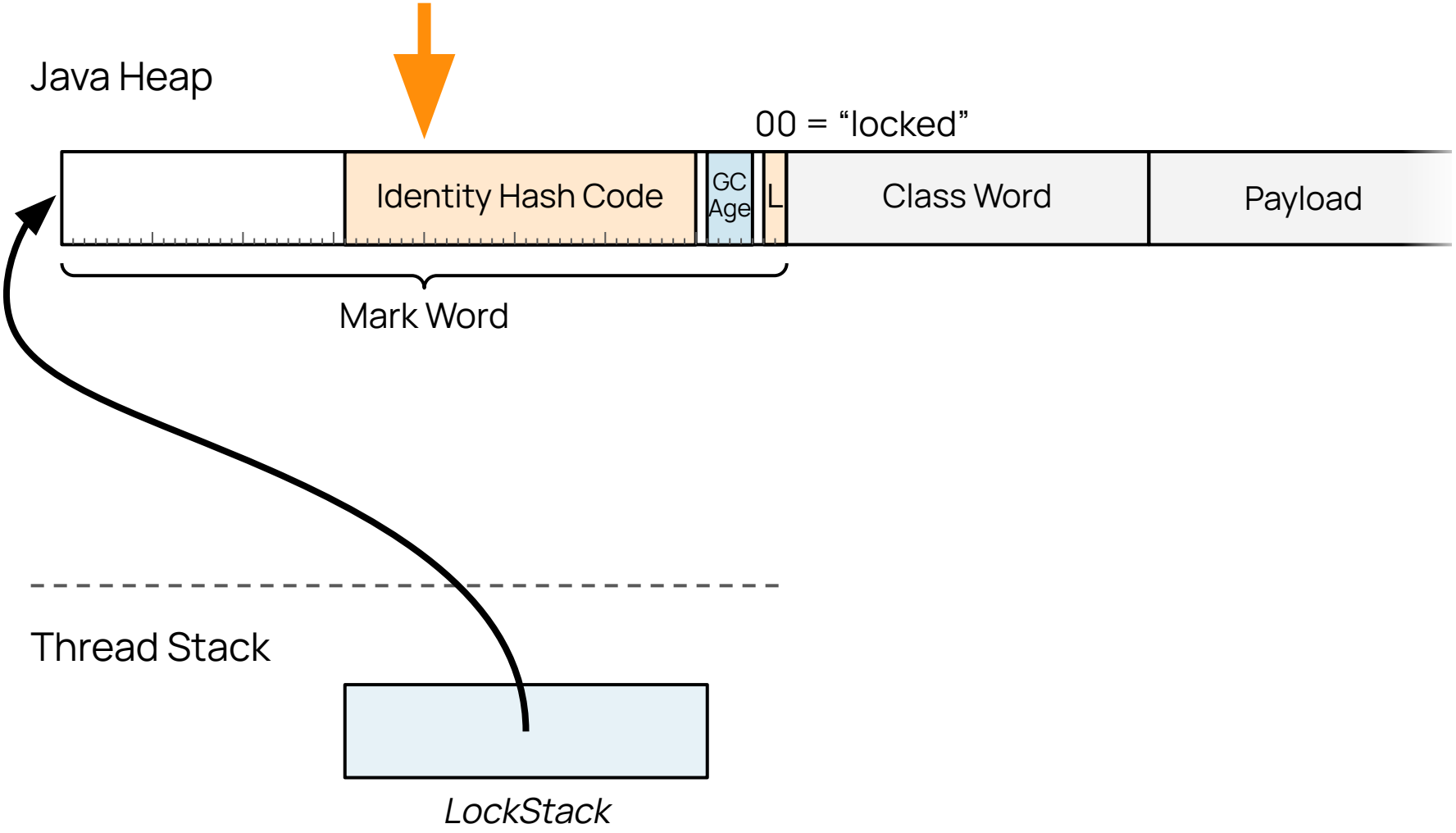


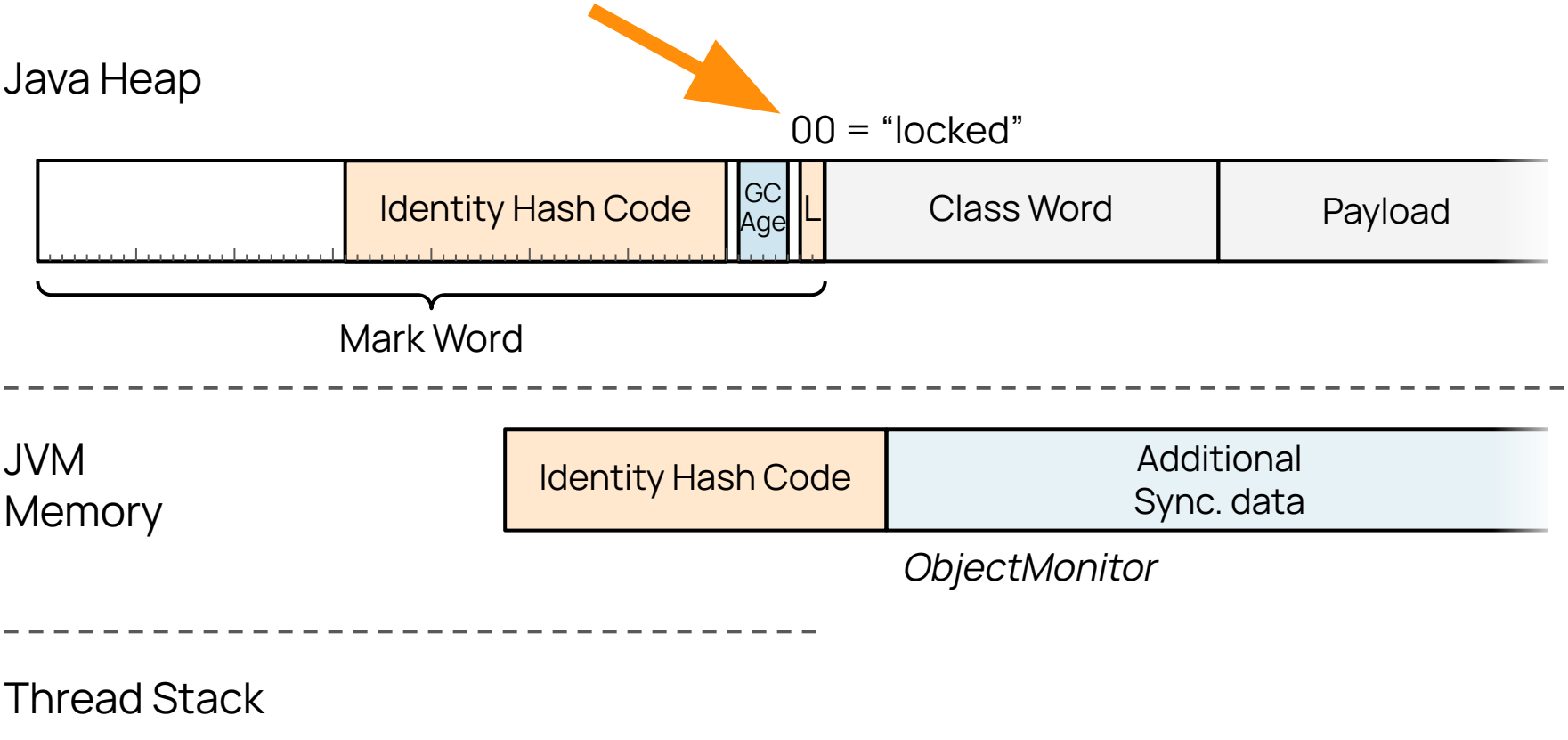
Thread Stack

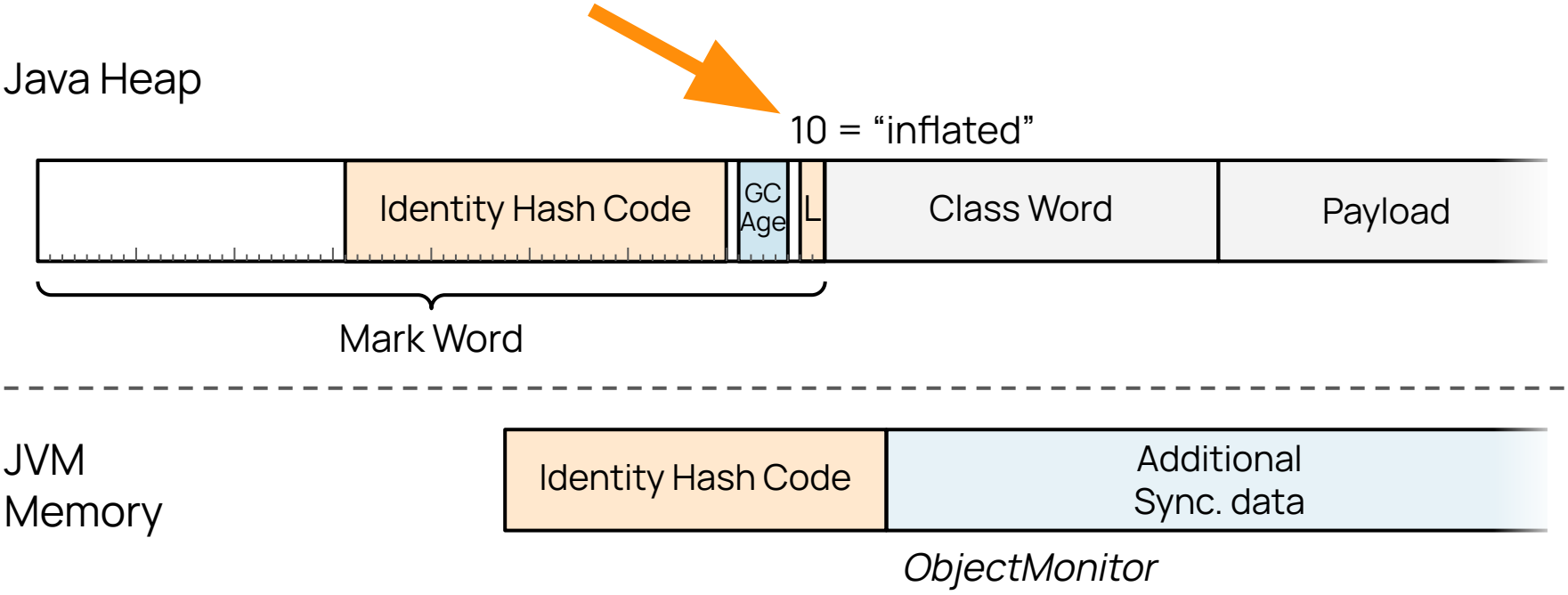
Java Heap



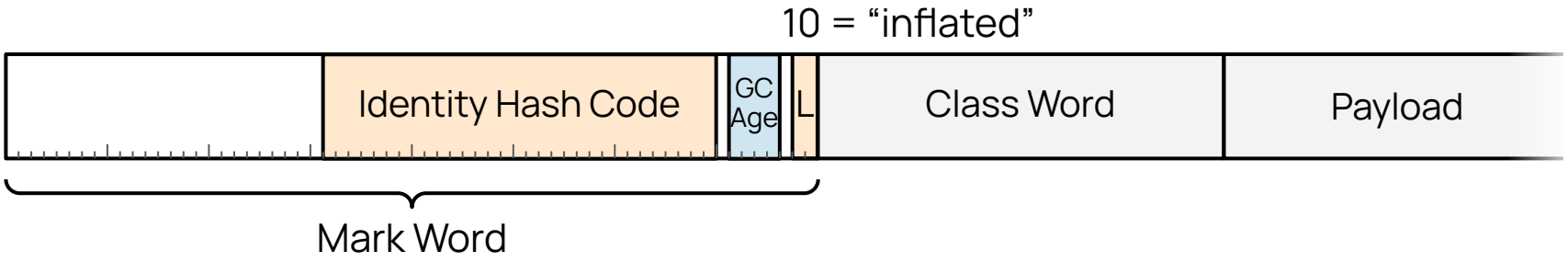
Thread Stack


Java Heap
00 = “locked”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
Thread Stack
LockStack


Java Heap
00 = “locked”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Identity Hash Code
Additional Sync. data
ObjectMonitor
Thread Stack


Java Heap
10 = “inflated”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Identity Hash Code
Additional Sync. data
ObjectMonitor
Thread Stack

Java Heap



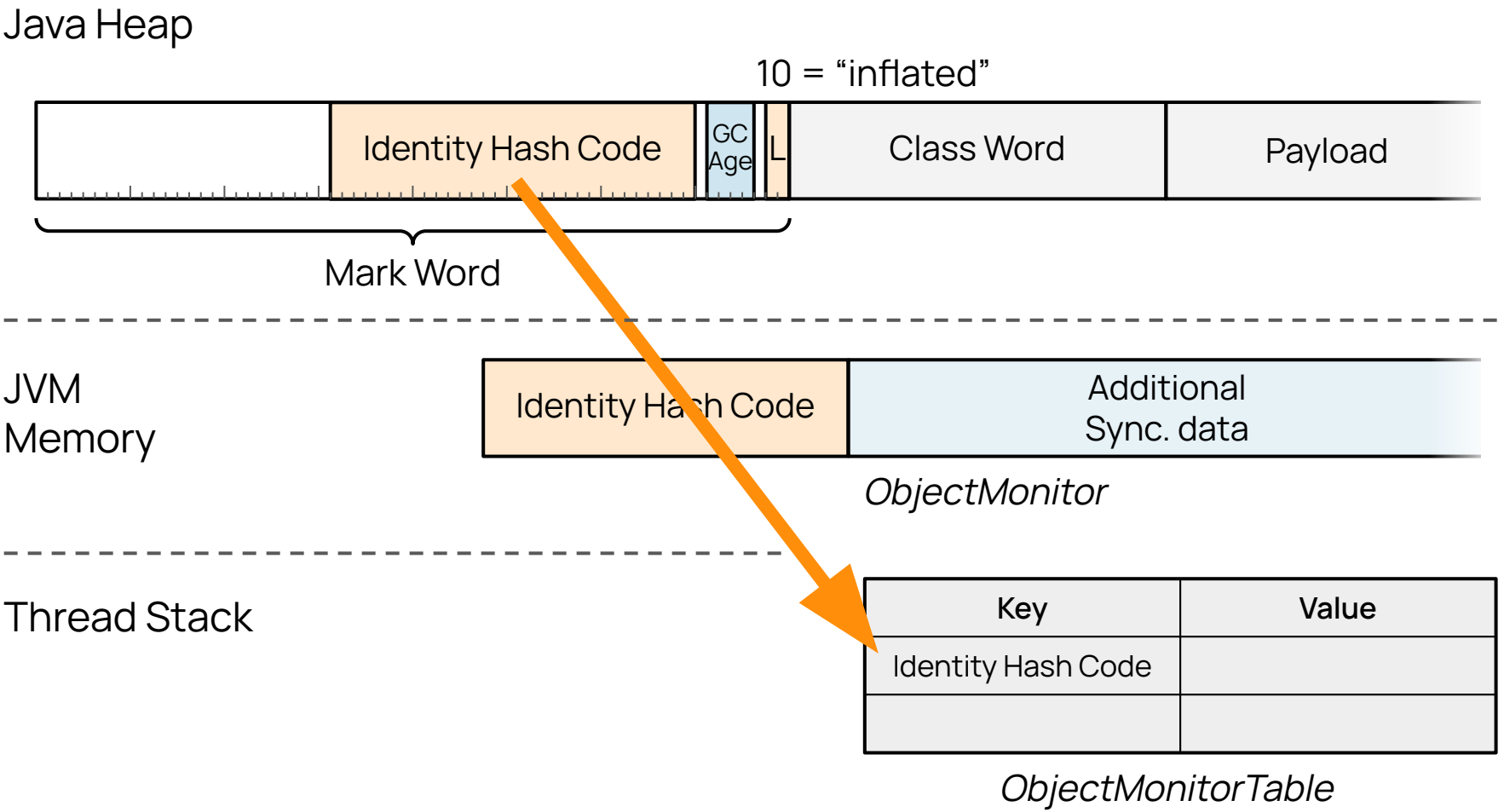
JVM Memory

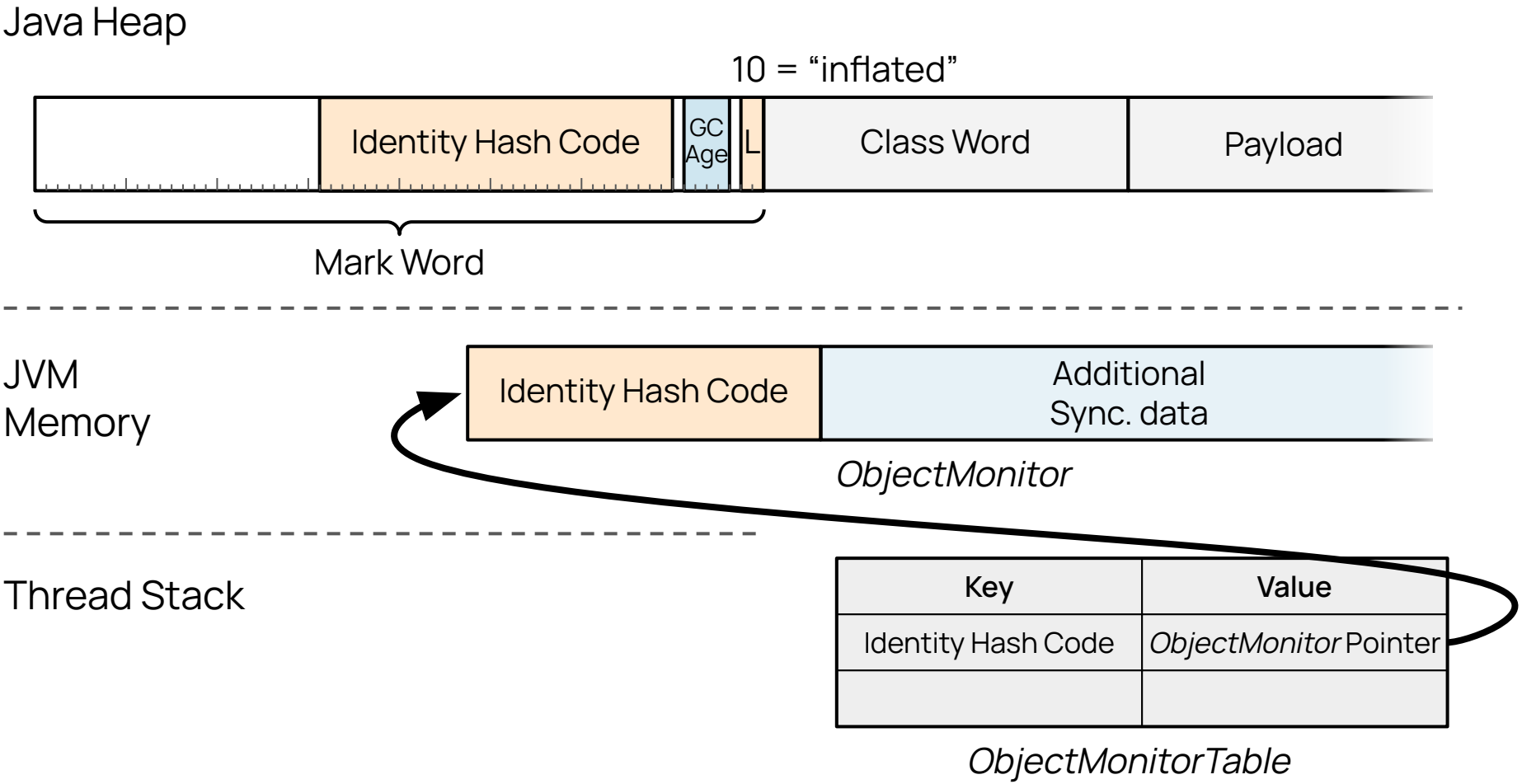
ObjectMonitor

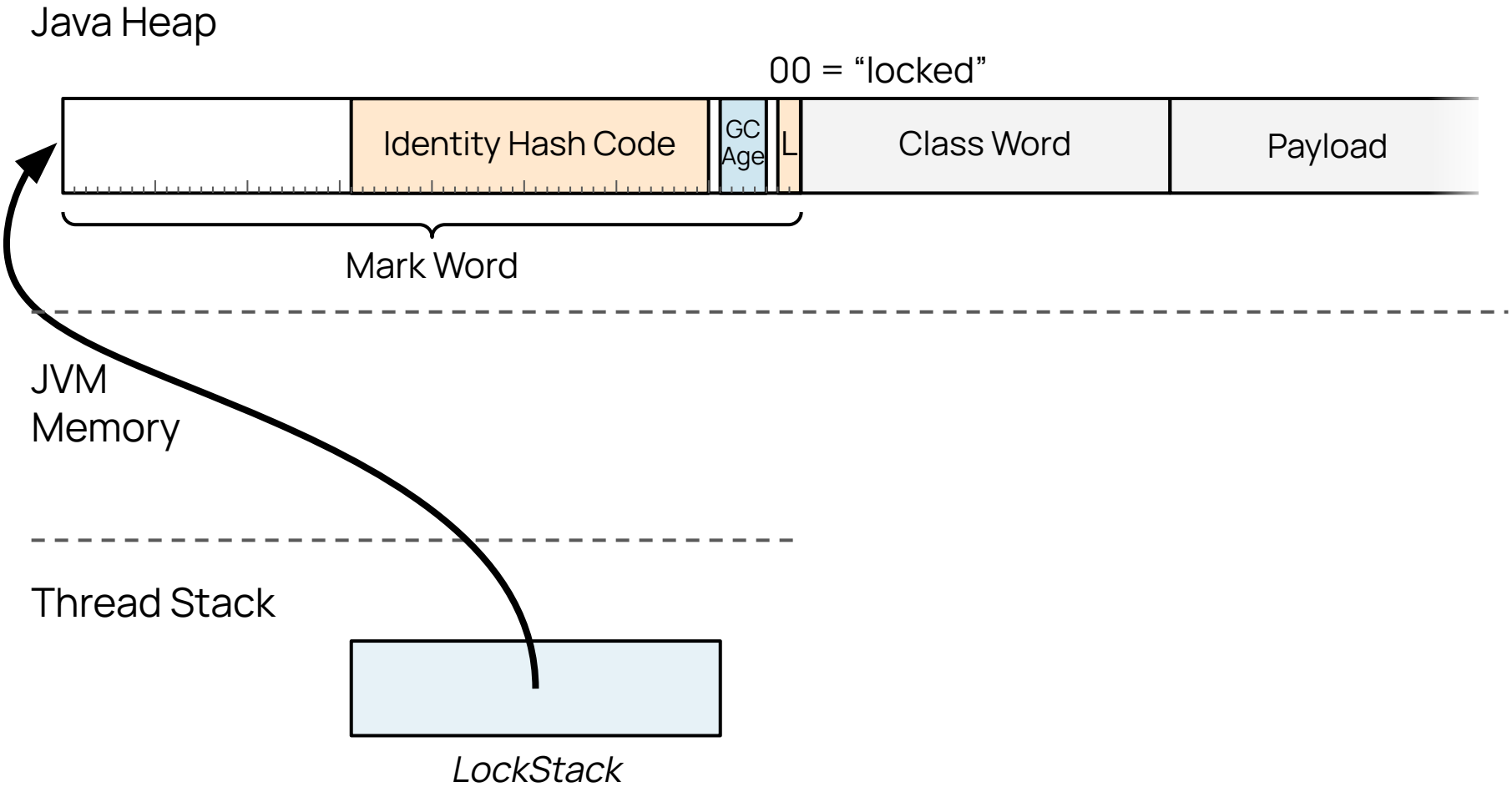
Thread Stack

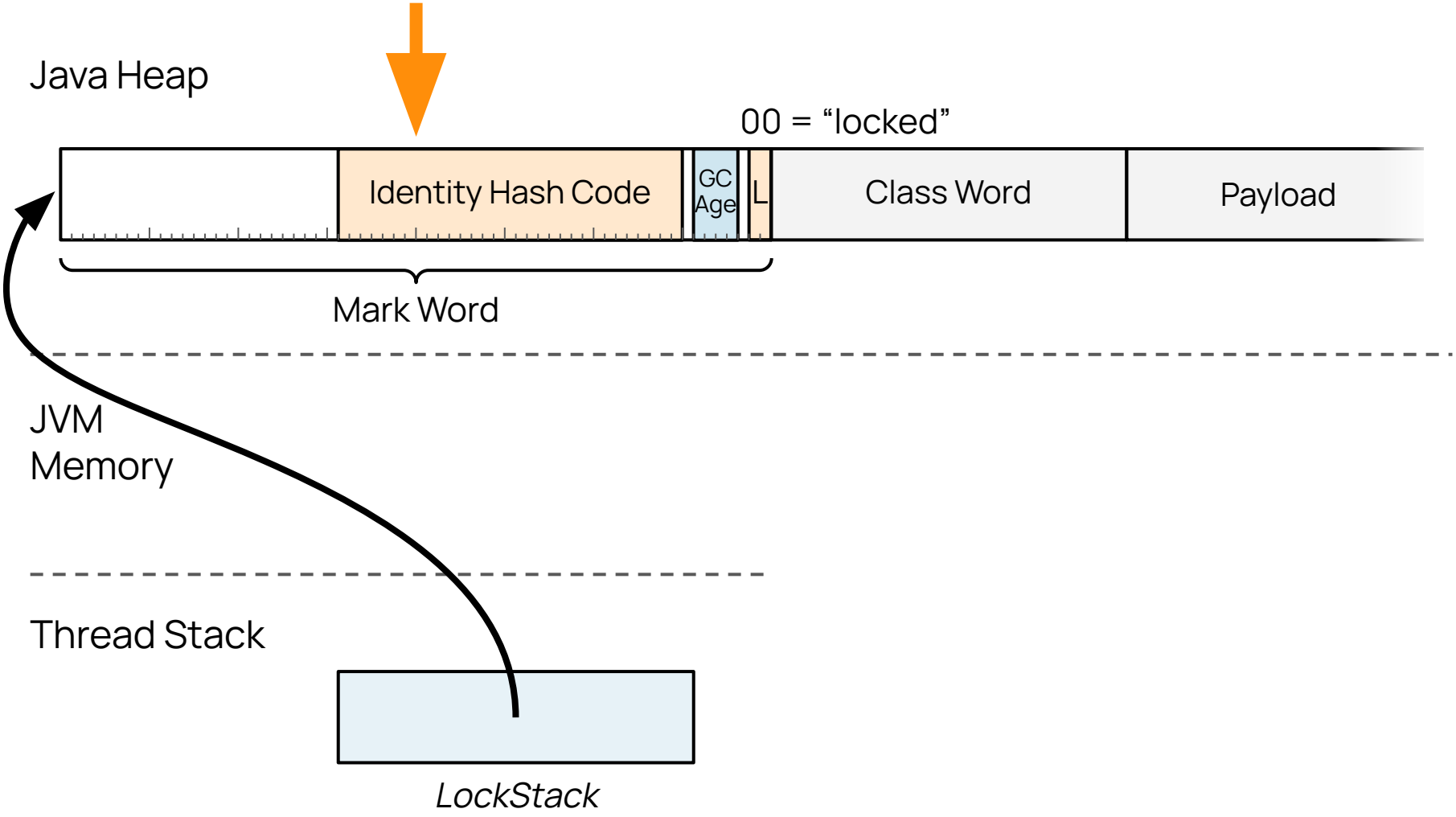
Key	Value

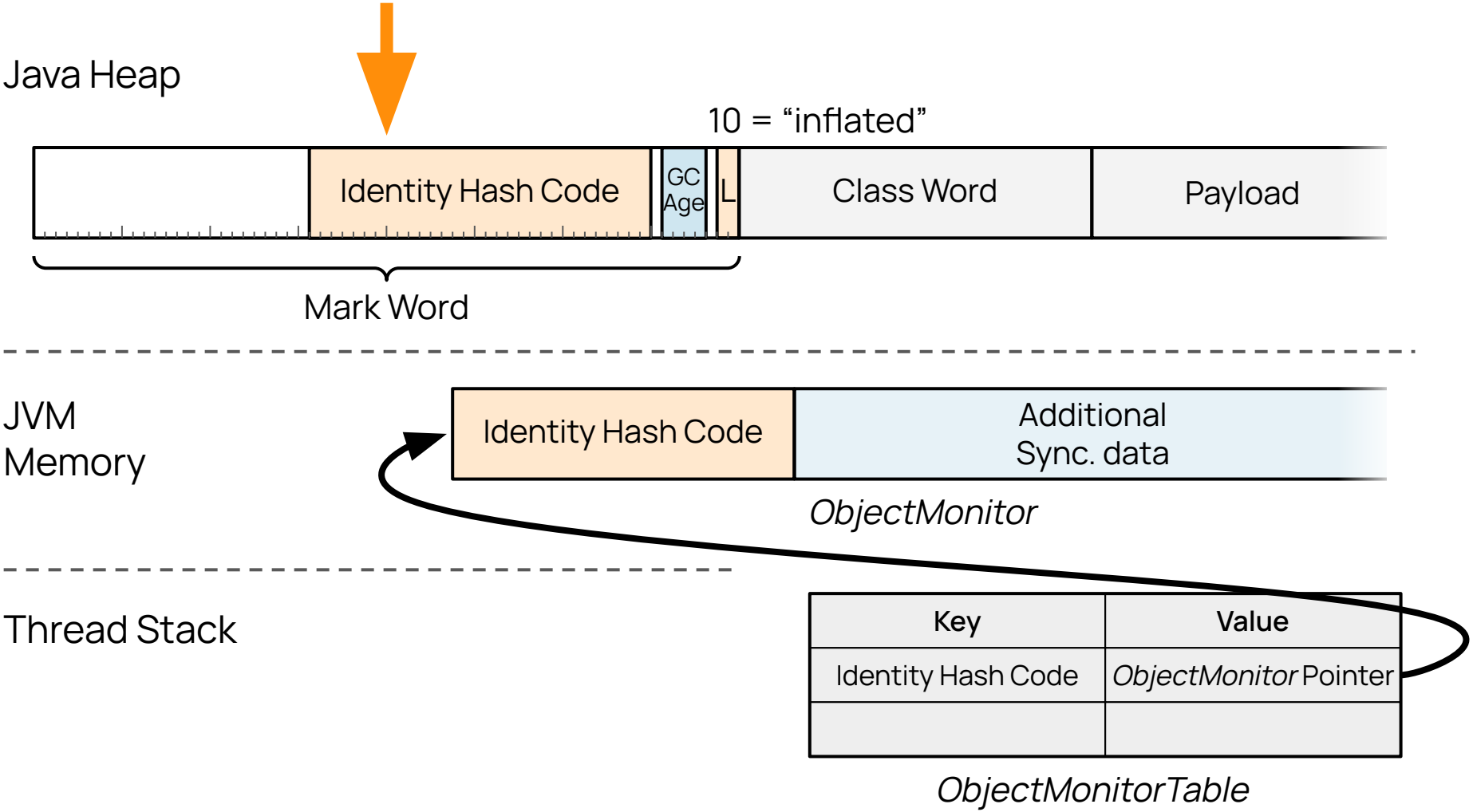
ObjectMonitorTable

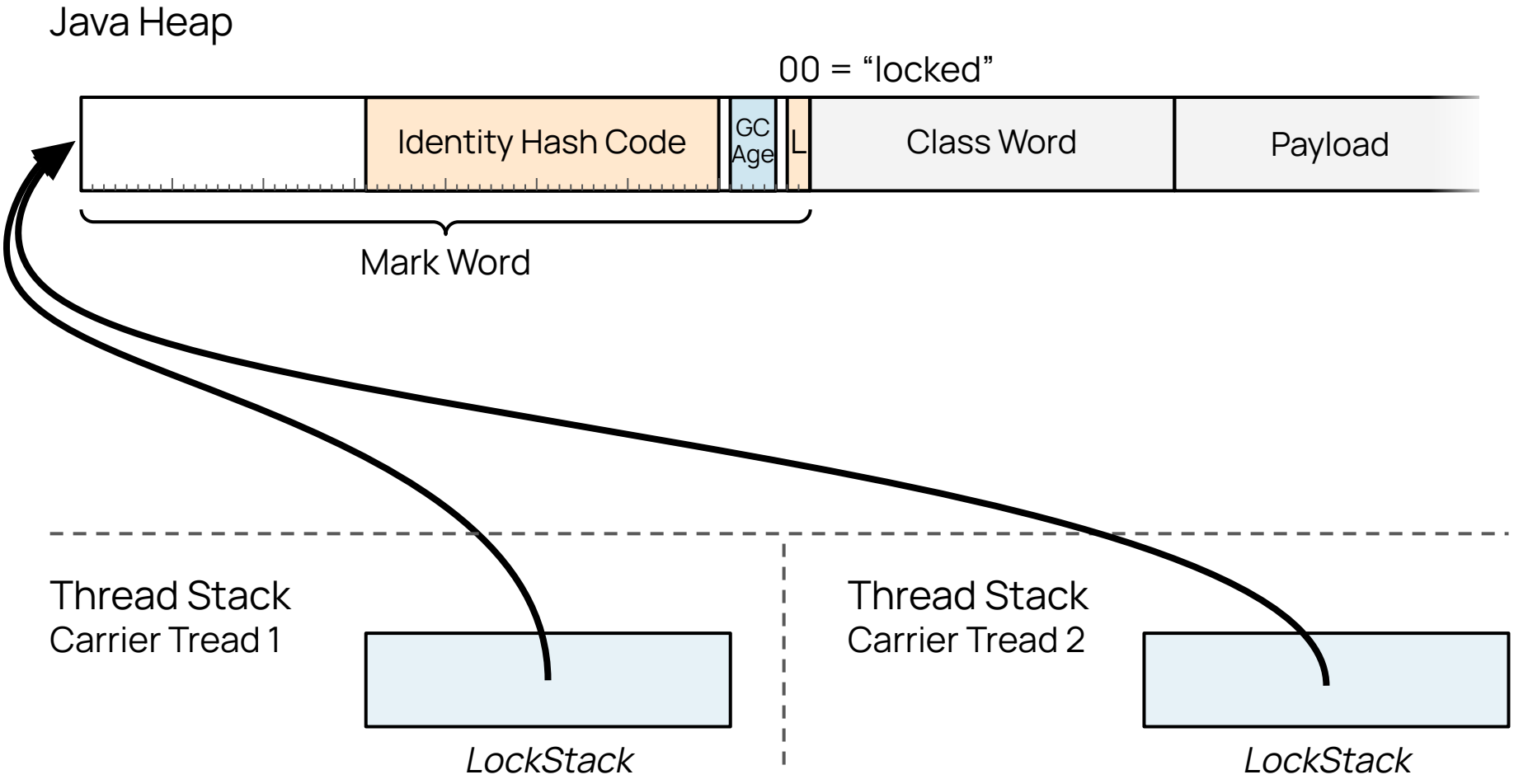

Java Heap
10 = “inflated”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Identity Hash Code
Additional Sync. data
ObjectMonitor
Thread Stack
Key
Value
Identity Hash Code
ObjectMonitorTable


Java Heap
10 = “inflated”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Identity Hash Code
Additional Sync. data
ObjectMonitor
Thread Stack
Key
Value
Identity Hash Code
ObjectMonitor Pointer
ObjectMonitorTable


Java Heap
00 = “locked”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Thread Stack
LockStack


Java Heap
00 = “locked”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Thread Stack
LockStack


Java Heap
10 = “inflated”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
JVM Memory
Identity Hash Code
Additional Sync. data
ObjectMonitor
Thread Stack
Key
Value
Identity Hash Code
ObjectMonitor Pointer
ObjectMonitorTable


Java Heap
00 = “locked”
Identity Hash Code
GC Age
L
Class Word
Payload
Mark Word
Thread Stack
Carrier Tread 1
LockStack
Thread Stack
Carrier Tread 2
LockStack

Lightweight Locking

Enable Lightweight Locking in Java 21 + 22:

```
-XX:LockingMode=2
```

Enabled by default in Java 23.

Lightweight Locking

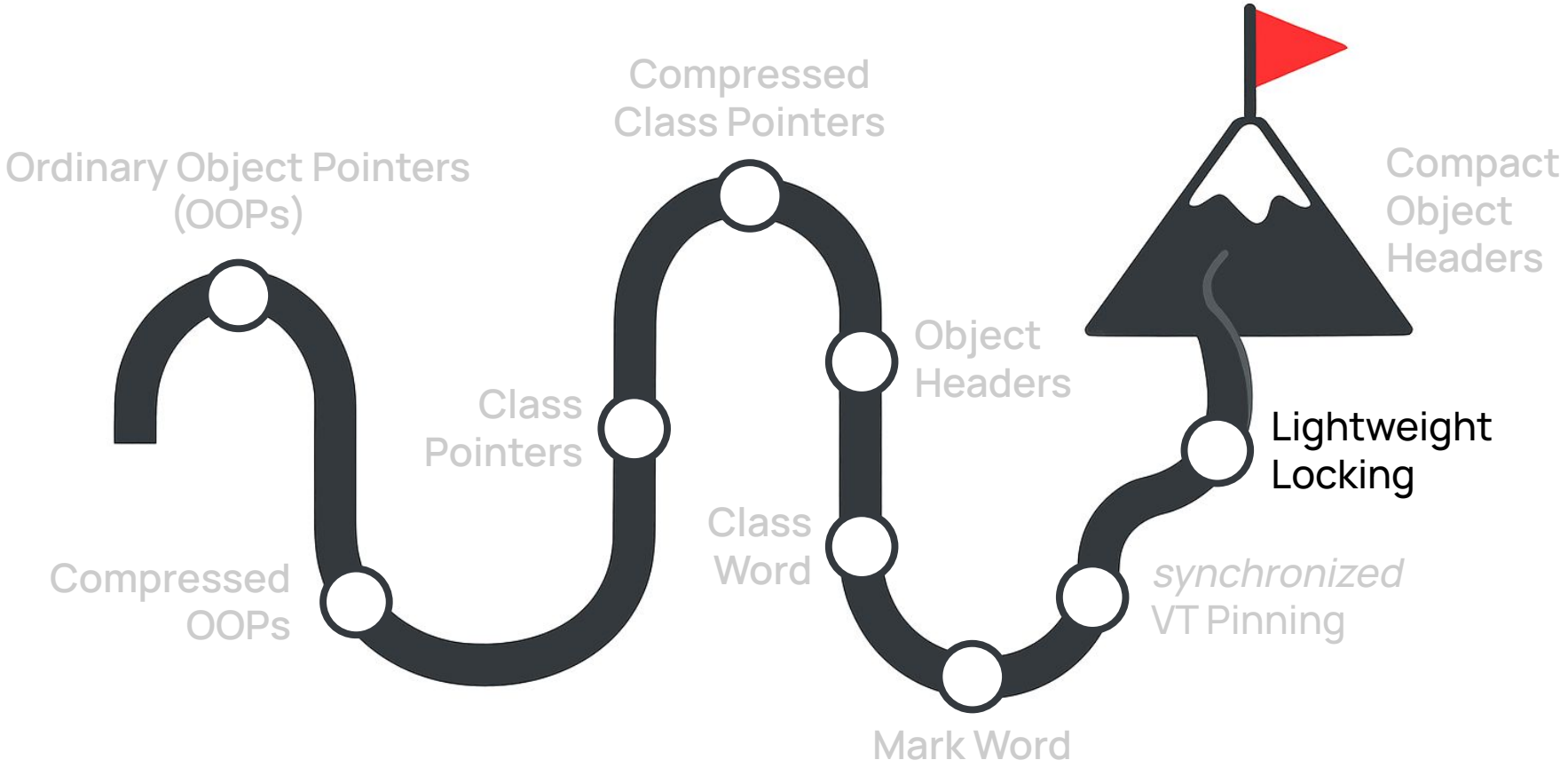
Switch back to Legacy Stack Locking since Java 23:

```
-XX:LockingMode=1
```

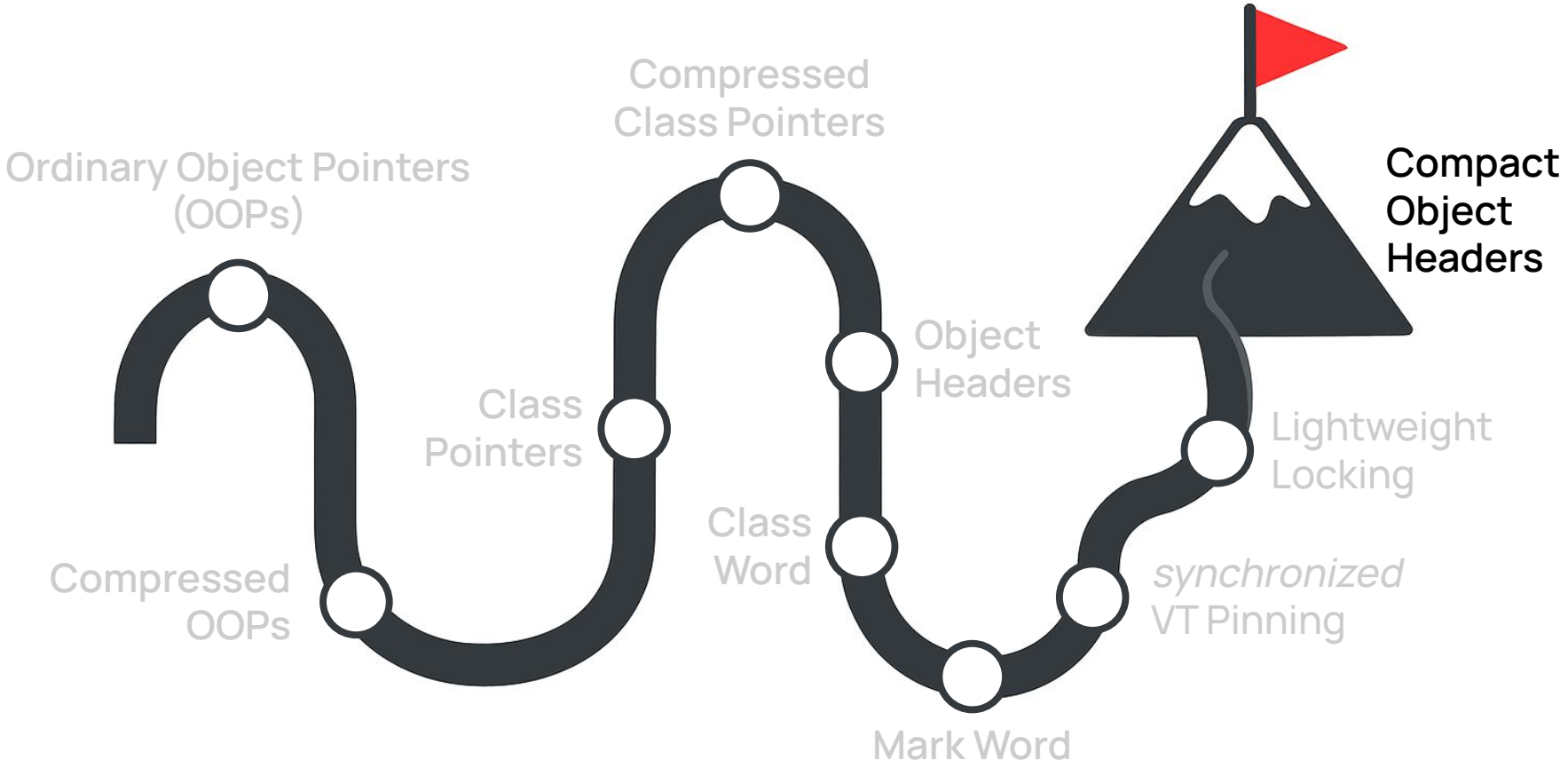
since Java 24:
Deprecated

→ Virtual threads will be pinned again in a `synchronized` block.

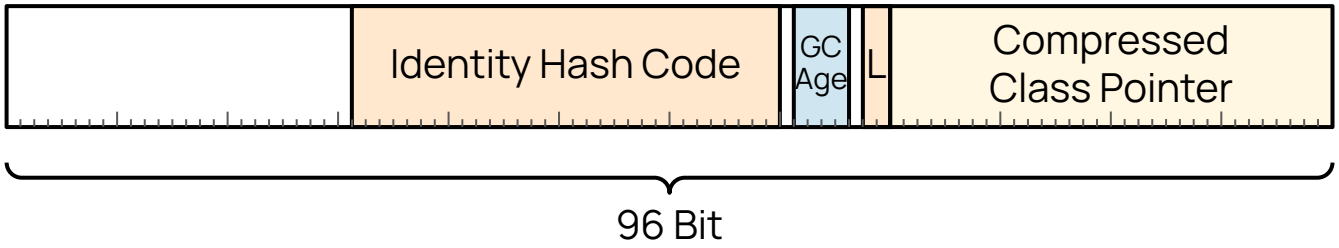
Journey into the JVM



Journey into the JVM



Compact Object Headers

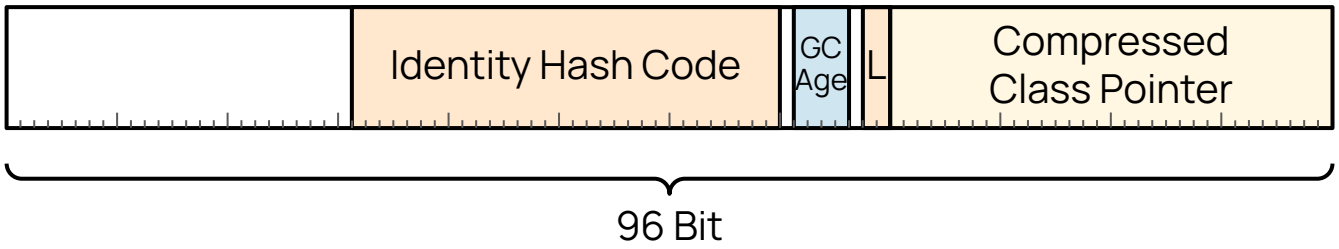


`-XX:-UseCompressedClassPointers`:

Compact Object Headers

`-XX:-UseCompressedClassPointers`

Compact Object Headers



JEP 450: Compact Object Headers (Experimental)

Owner	Roman Kennke
Type	Feature
Scope	Implementation
Status	Closed / Delivered
Release	24
Component	hotspot / runtime
Discussion	hotspot dash dev at openjdk dot org
Effort	L
Duration	L
Relates to	JEP 519: Compact Object Headers
Reviewed by	Aleksey Shipilev, Erik Österlund, John Rose, Stefan Karlsson, Thomas Stuefe
Endorsed by	Vladimir Kozlov
Created	2022/10/07 19:27
Updated	2025/04/15 14:03
Issue	8294992

Summary

Reduce the size of object headers in the HotSpot JVM from between 96 and 128 bits down to 64 bits on 64-bit architectures. This will reduce heap size, improve deployment density, and increase data locality.

Goals

When enabled, this feature

- Must reduce the object header size to 64 bits (8 bytes) on the target 64-bit platforms (x64 and AArch64),
- Should reduce object sizes and memory footprint on realistic workloads,
- Should not introduce more than 5% throughput or latency overheads on the target 64-bit platforms, and only in infrequent cases, and
- Should not introduce measurable throughput or latency overheads on non-target 64-bit platforms.

JEP 519: Compact Object Headers

Owner	Roman Kennke
Type	Feature
Scope	Implementation
Status	Closed / Delivered
Release	25
Component	hotspot / runtime
Discussion	hotspot dash dev at openjdk dot org
Effort	S
Duration	XS
Relates to	JEP 450: Compact Object Headers (Experimental)
Reviewed by	Coleen Phillimore, Stefan Karlsson, Vladimir Kozlov
Endorsed by	Vladimir Kozlov
Created	2025/04/15 14:01
Updated	2025/08/24 18:03
Issue	8354672

Summary

Change compact object headers from an experimental feature to a product feature.

Non-Goals

It is not a goal to make compact object headers be the default object-header layout.

Motivation

Compact object headers were introduced as an alternative object-header layout by JEP 450 in JDK 24. Features of this size are best introduced carefully and gradually, so we introduced it as an experimental feature.

Since JDK 24, compact object headers have proven their stability and performance.

They have been tested at Oracle by running the full JDK test suite. They have also been tested at Amazon by hundreds of services in production, most of them using backports of the feature to JDK 21 and JDK 17.

OpenJDK

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Bluesky

Bylaws · Census
Legal · AI

Workshop

JEP Process

Source code
GitHub
Mercurial

Tools
Git
jtreg harness

Groups
(overview, archive)
Adoption
Build
Client Libraries
Compatibility & Specification Review
Compiler
Conformance
Core Libraries
Governing Board
HotSpot
IDE Tooling & Support
Internationalization
Members
Networking
Porters
Quality
Security
Serviceability
Vulnerability
Web

Projects
(overview, archive)
Amber
Babylon
Brisbane

JEP 534: Compact Object Headers by Default

Owner	Roman Kennke
Type	Feature
Scope	JDK
Status	Integrated
Release	27
Component	hotspot / runtim...
Discussion	hotspot dash runtime dash dev at openjdk dot org
Effort	XS
Duration	XS
Relates to	JEP 519: Compact Object Headers
Reviewed by	Vladimir Kozlov
Endorsed by	Vladimir Kozlov
Created	2025/07/01 13:36
Updated	2026/05/28 12:07
Issue	8361187

Summary

Make compact object headers the default object header layout in the HotSpot JVM. Compact object headers reduce object headers from 96 bits down to 64 bits on 64-bit architectures, thereby reducing heap size, improving deployment density, and increasing data locality.

Non-Goals

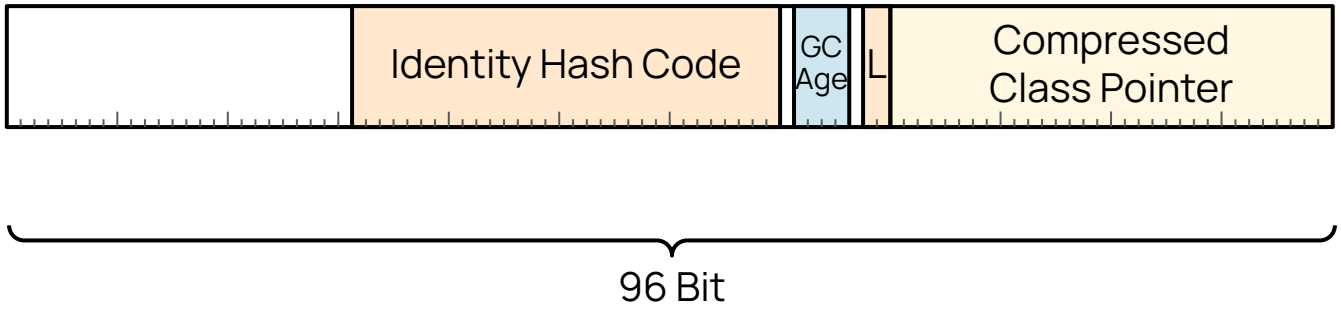
- It is not a goal to remove the old 96-bit object header layout at this time.

Motivation

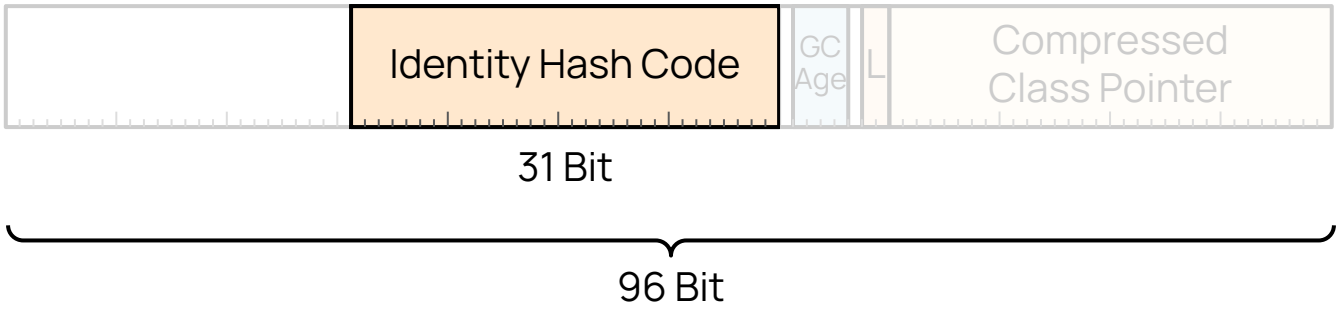
Compact object headers were introduced as an alternative object-header layout via JEP 450 (JDK 24), and turned into a full product feature via JEP 519 (JDK 25). Features of this size are best introduced carefully and gradually, so we have not turned it on by default, yet.

Since JDK 24, compact object headers have proven their stability and performance.

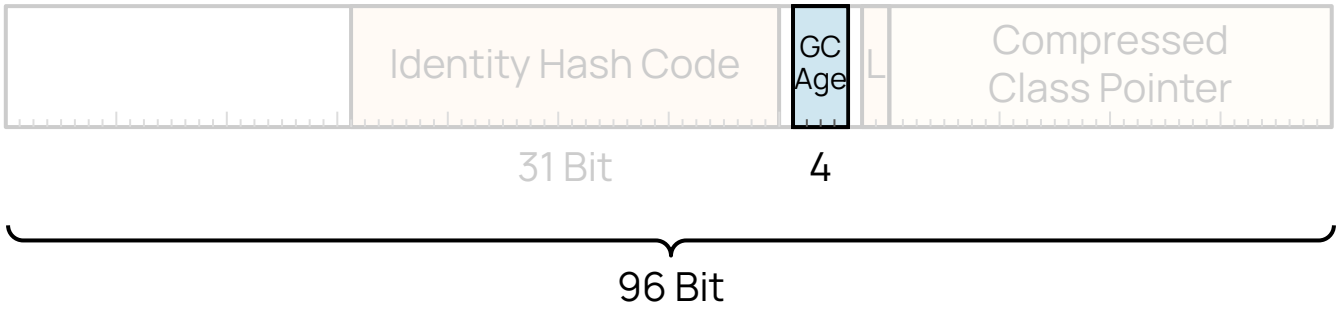
Compact Object Headers



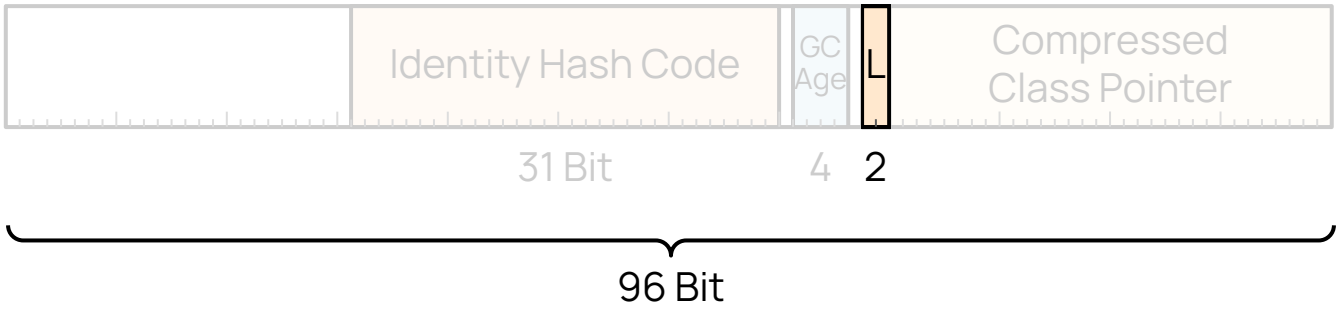
Compact Object Headers



Compact Object Headers



Compact Object Headers



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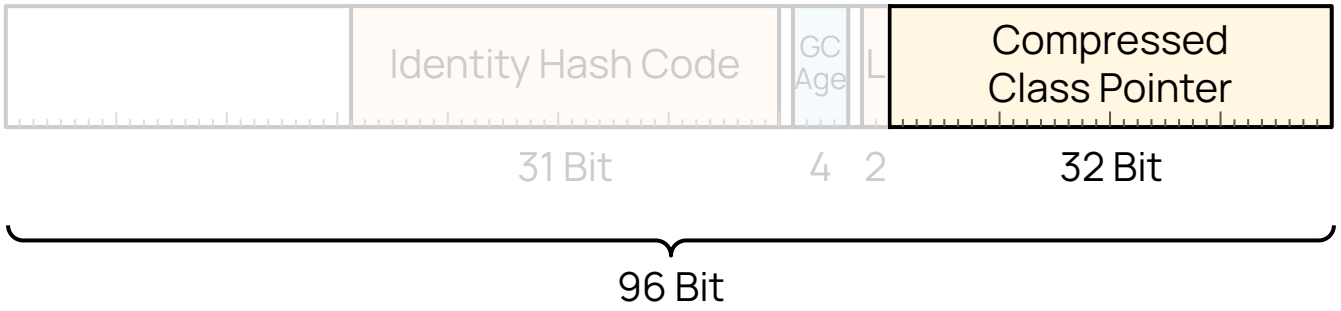
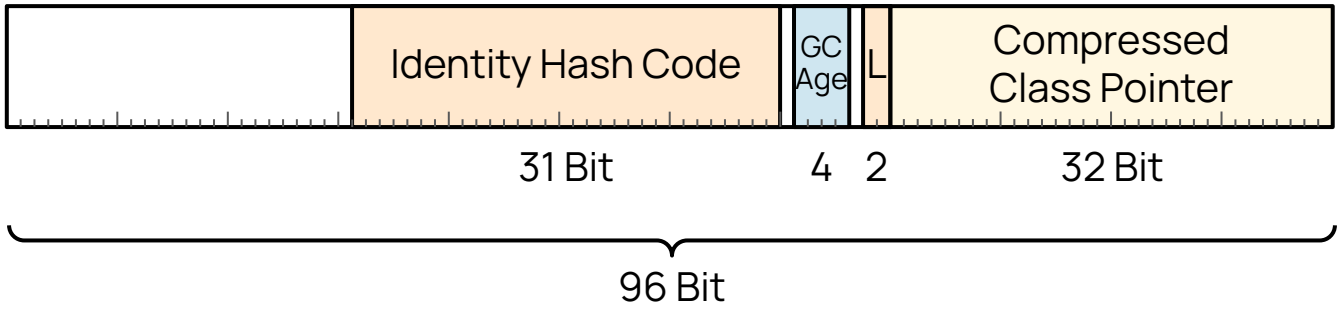


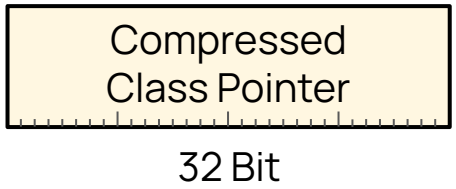
Compact Object Headers



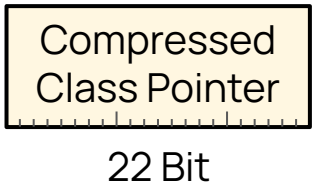
31 Bit
+ 4 Bit
+ 2 Bit
+ 32 Bit

= 69 Bit

Compact Object Headers



Compact Object Headers



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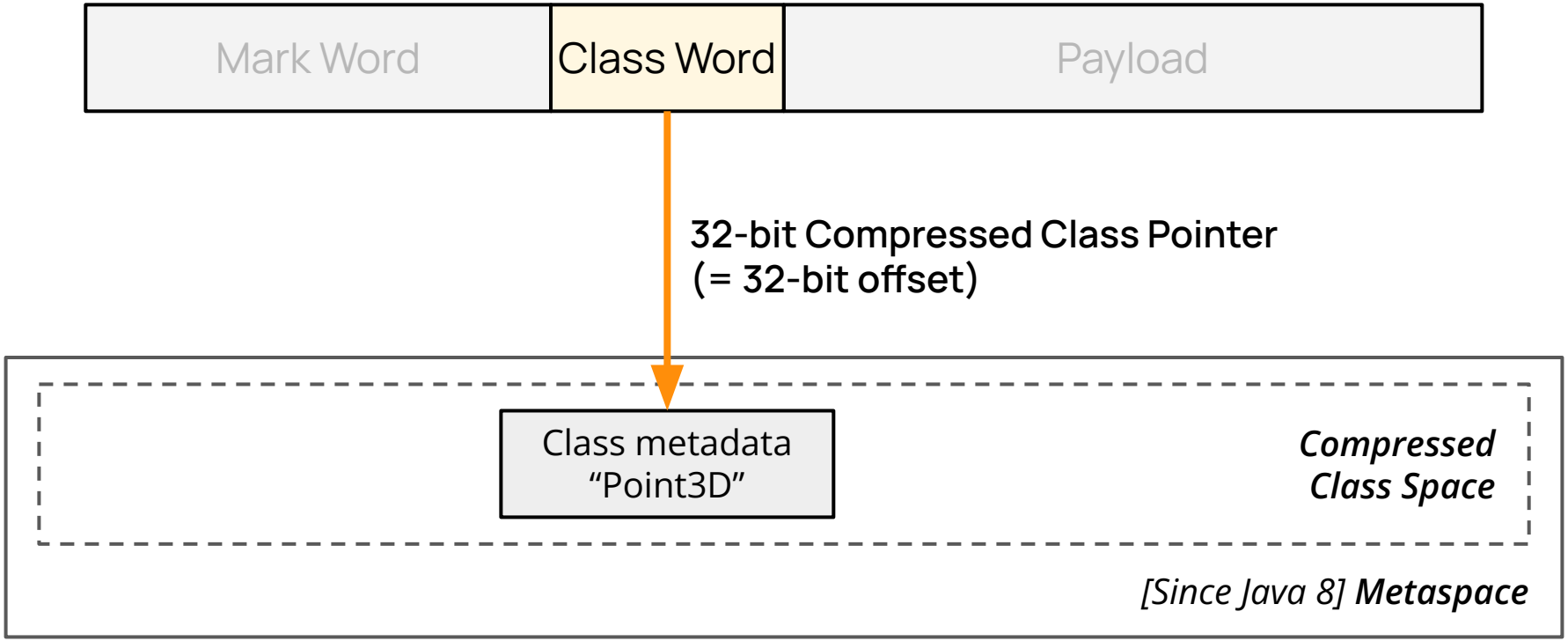

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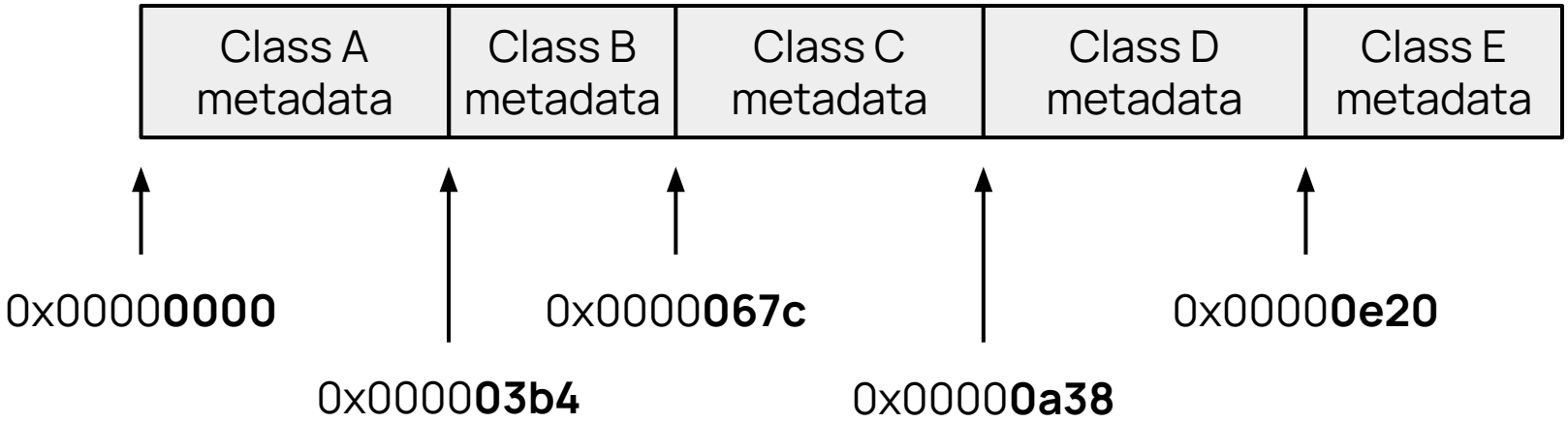
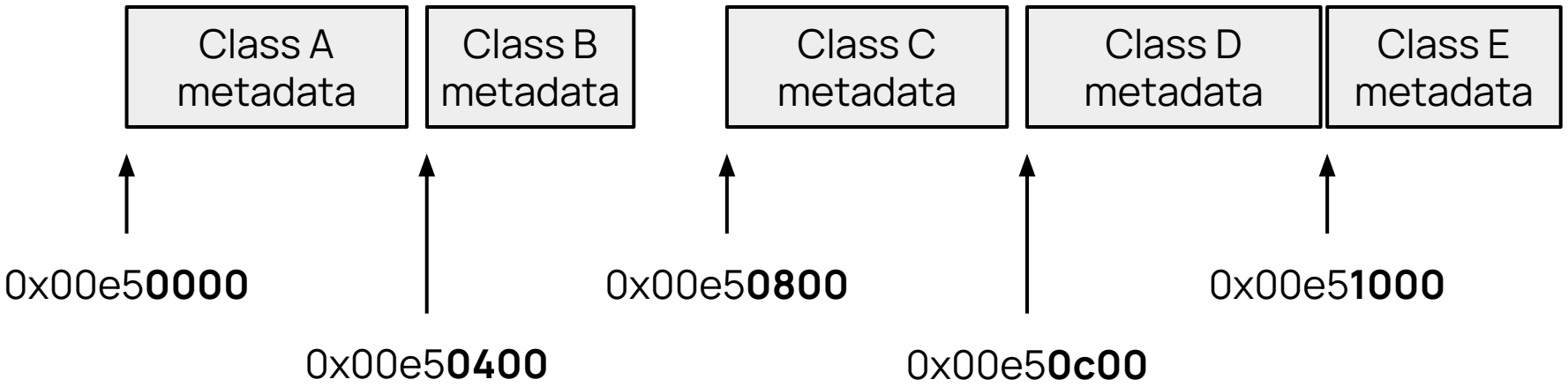


Compact Object Headers



Compact Object Headers

0x00e5**0000**	0b00000000111001010000000000
0x00e5**0400**	0b00000000111001010000010000
0x00e5**0800**	0b00000000111001010000100000
0x00e5**0c00**	0b00000000111001010000110000
0x00e5**1000**	0b00000000111001010001000000

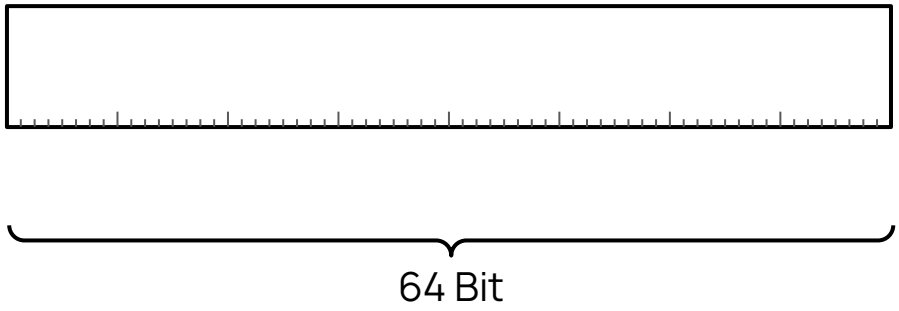
Trailing 10 bits

Compact Object Headers

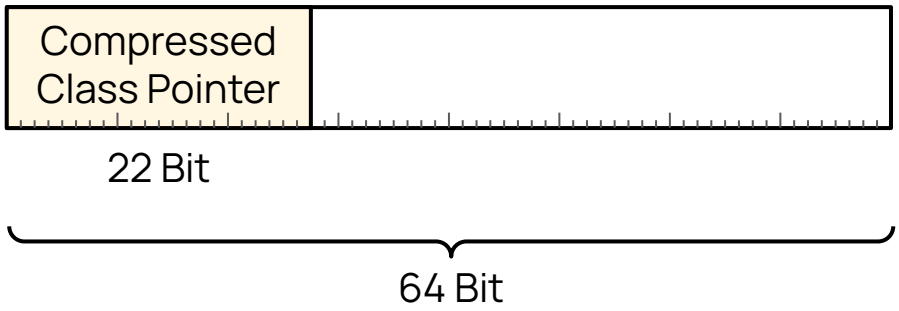
0x00e5**0000**	0b00000000111001**000000**0000000000
0x00e5**0400**	0b00000000111001**000001**0000000000
0x00e5**0800**	0b00000000111001**000010**0000000000
0x00e5**0c00**	0b00000000111001**000011**0000000000
0x00e5**1000**	0b00000000111001**000100**0000000000

Leading 22 bits

Compact Object Headers



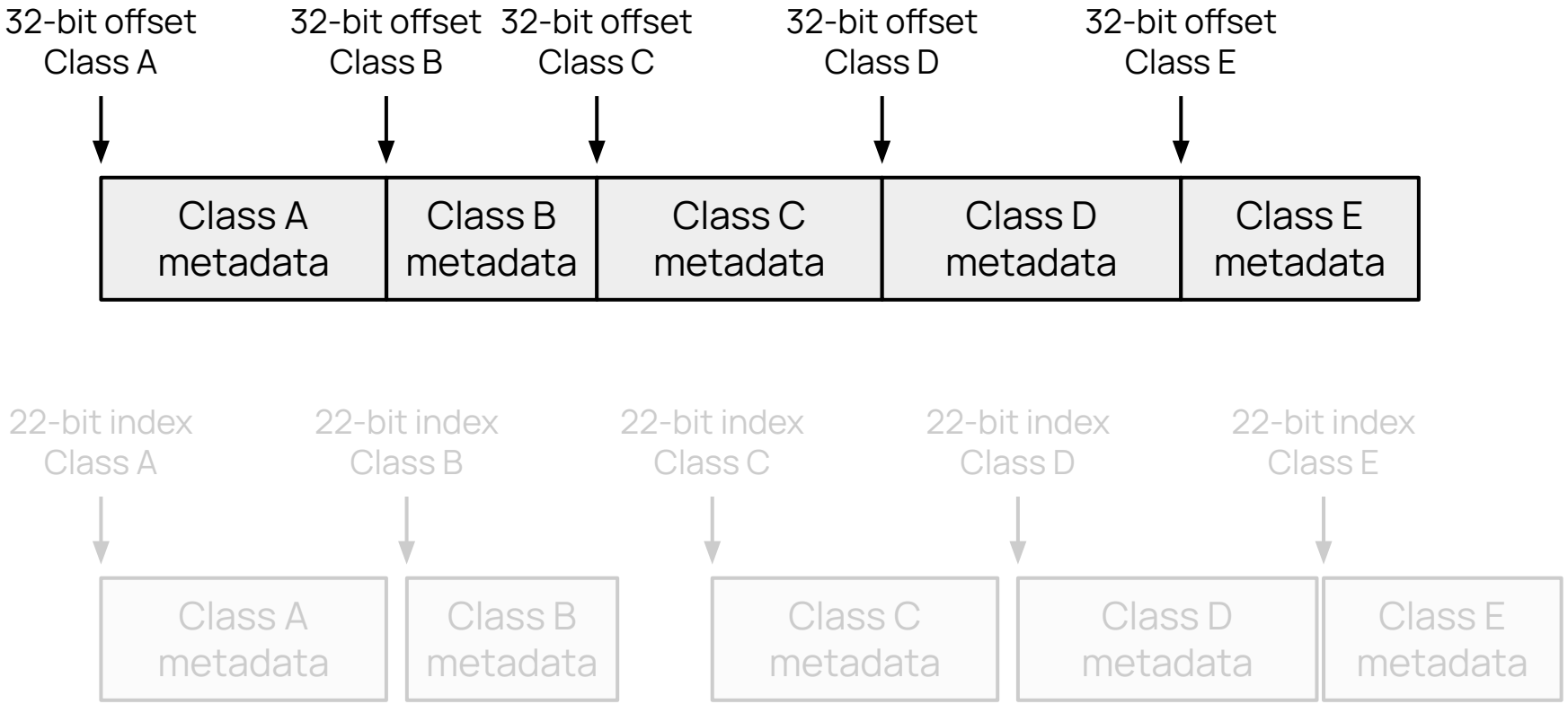
Compact Object Headers



Addressable with 22 bit: 2^{22} = 4,194,304 classes

Addressable with 32 bit: 2^{32} bytes / (768 bytes / class)
≈ 5,600,000 classes

Compact Object Headers



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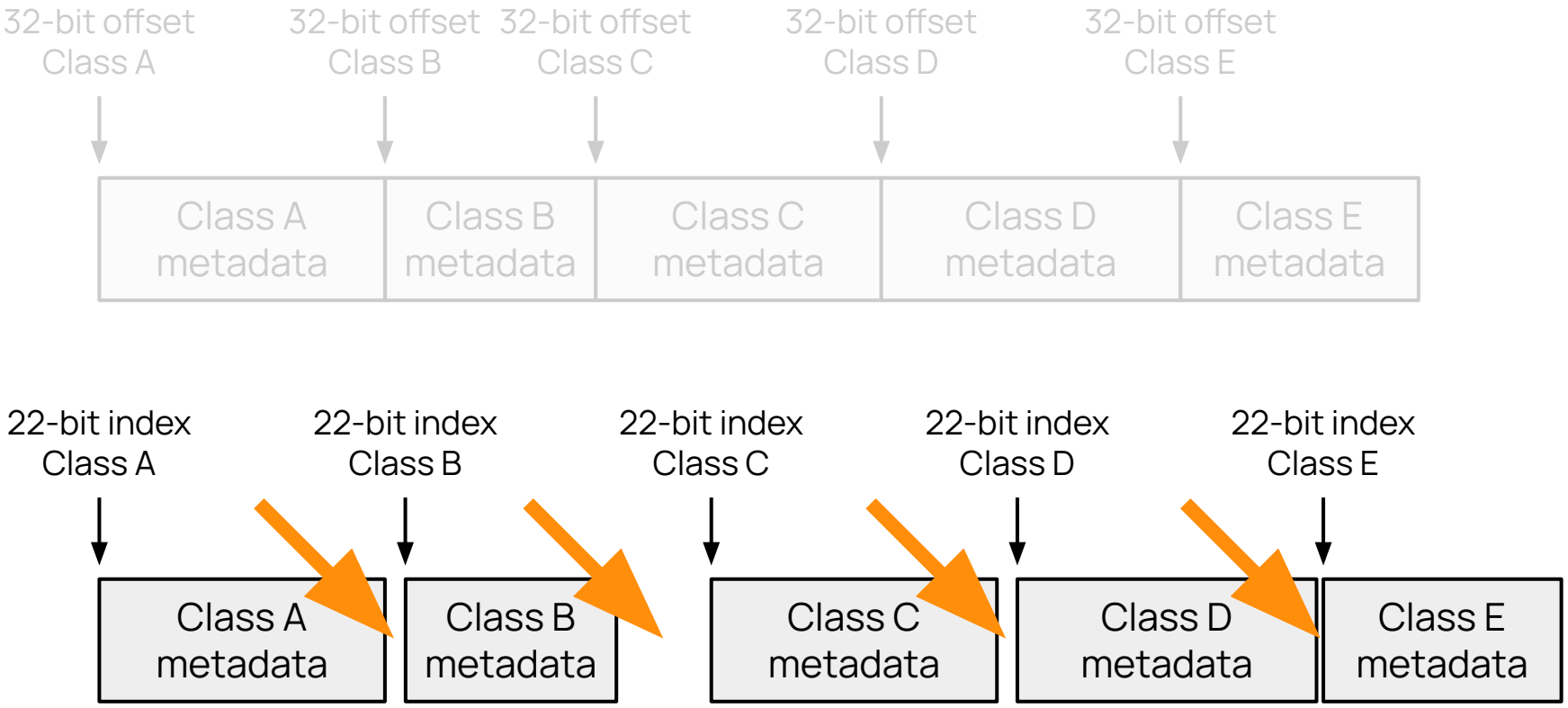

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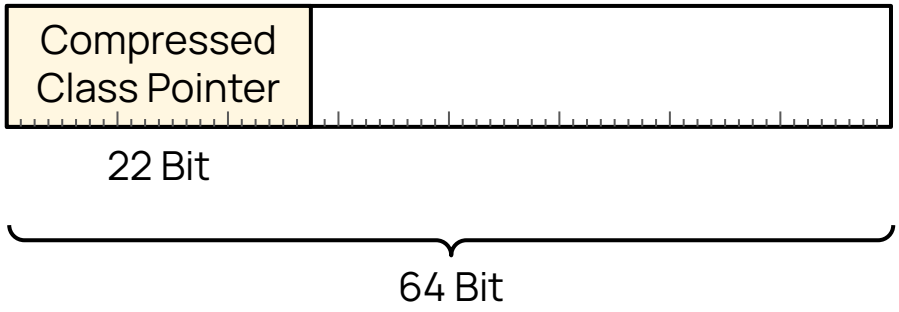
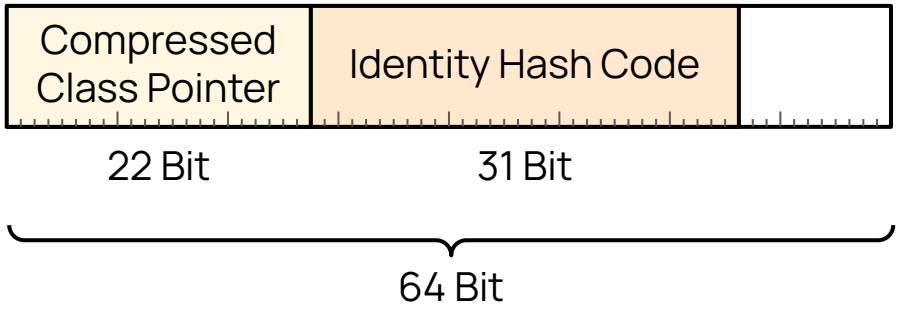
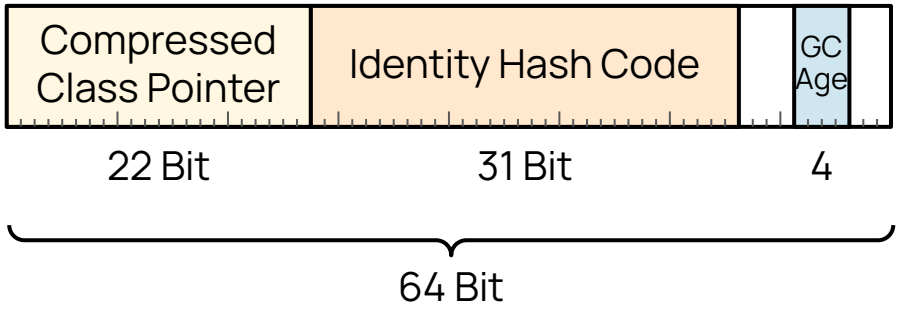


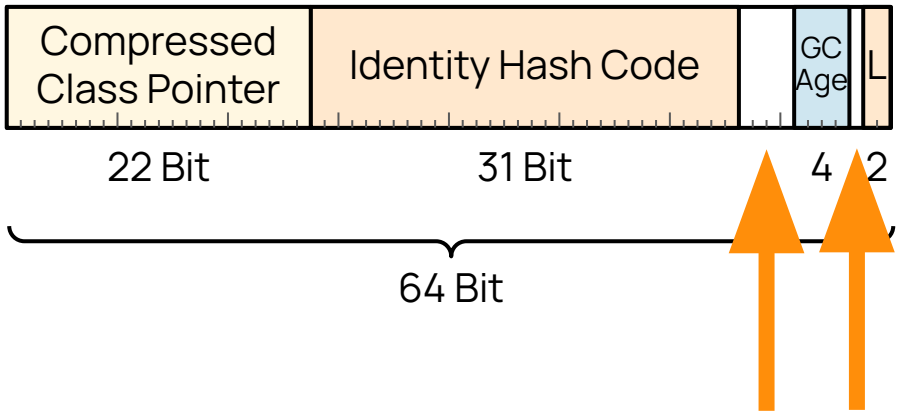
Compact Object Headers



Compact Object Headers



Compact Object Headers



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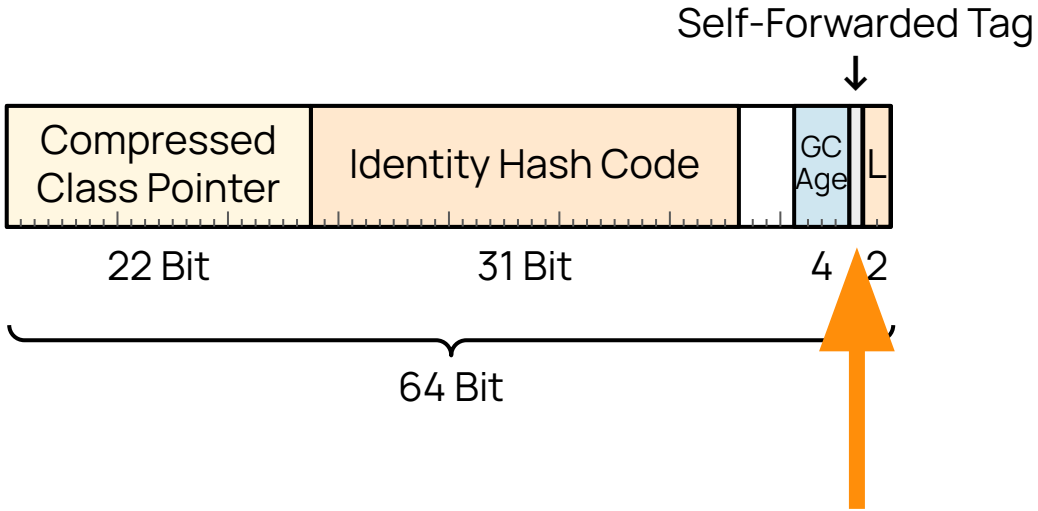
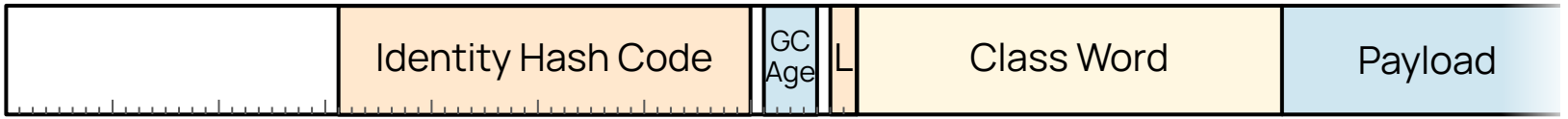


Compact Object Headers



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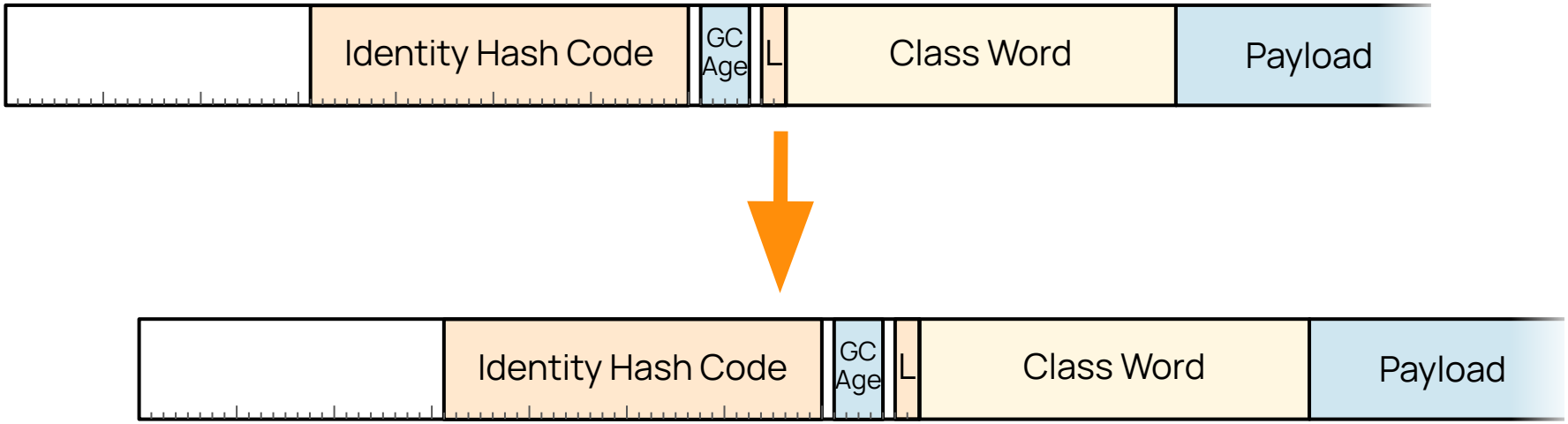

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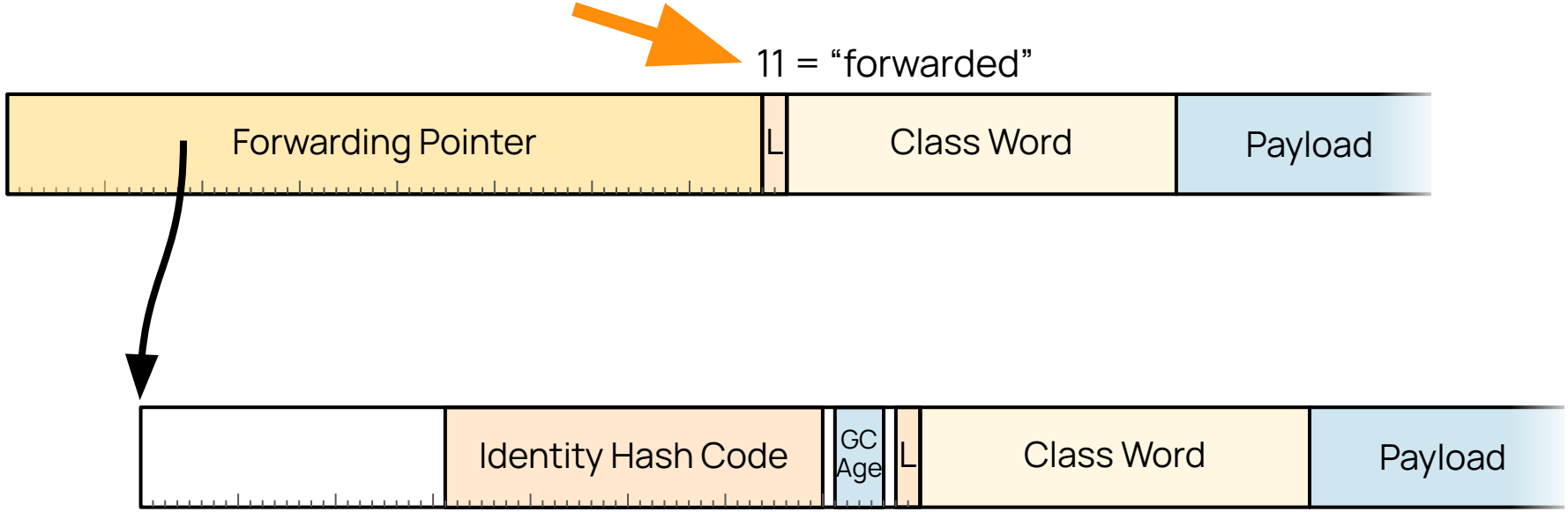

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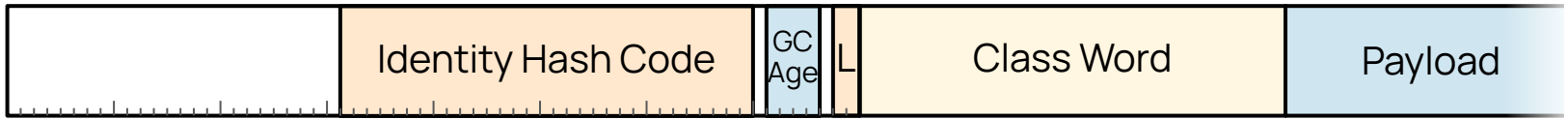
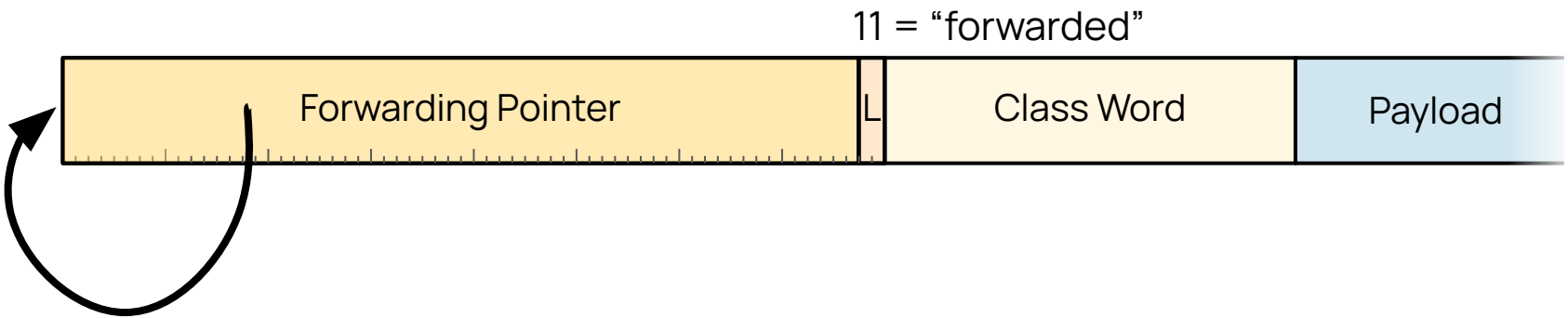


Compact Object Headers



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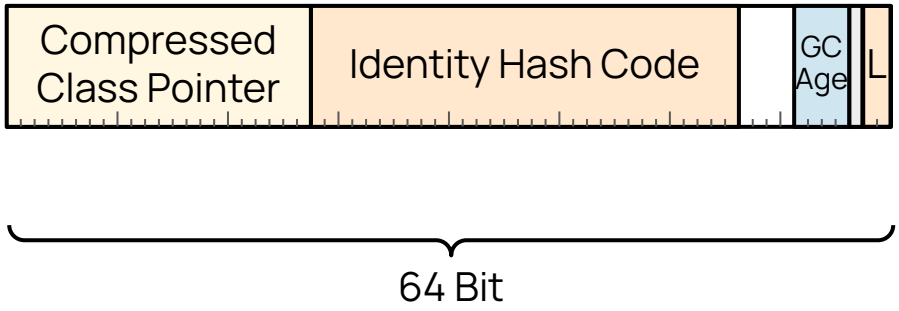

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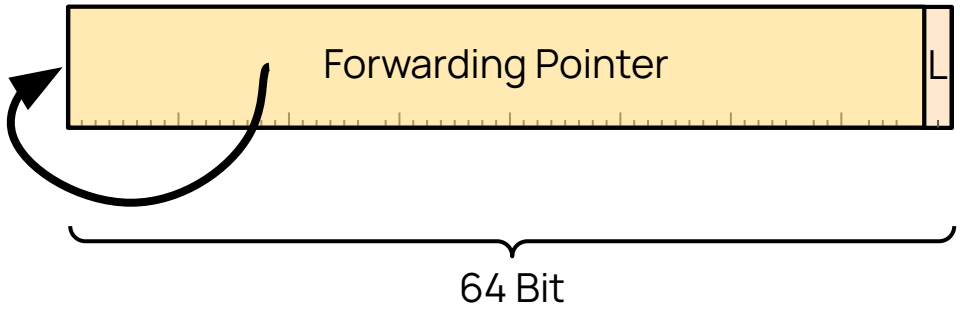

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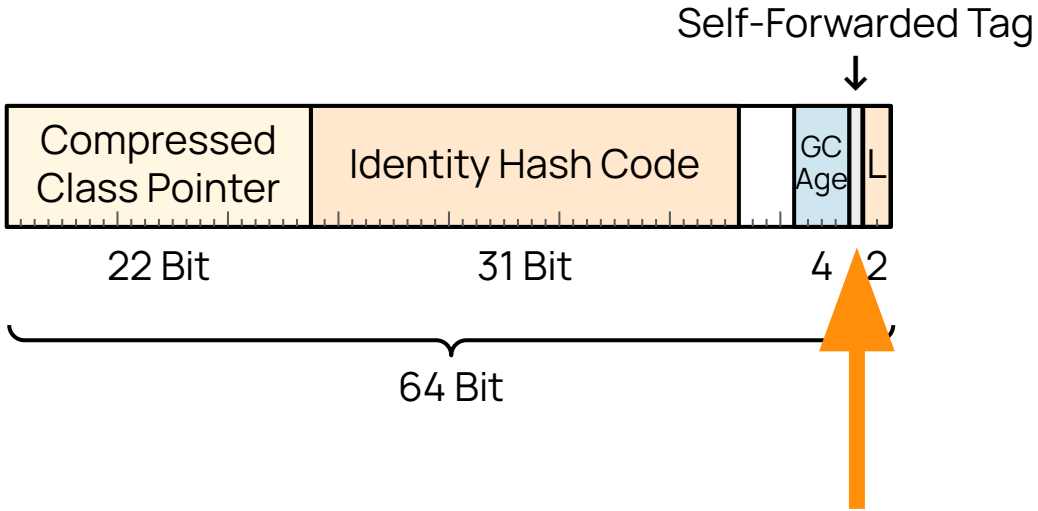

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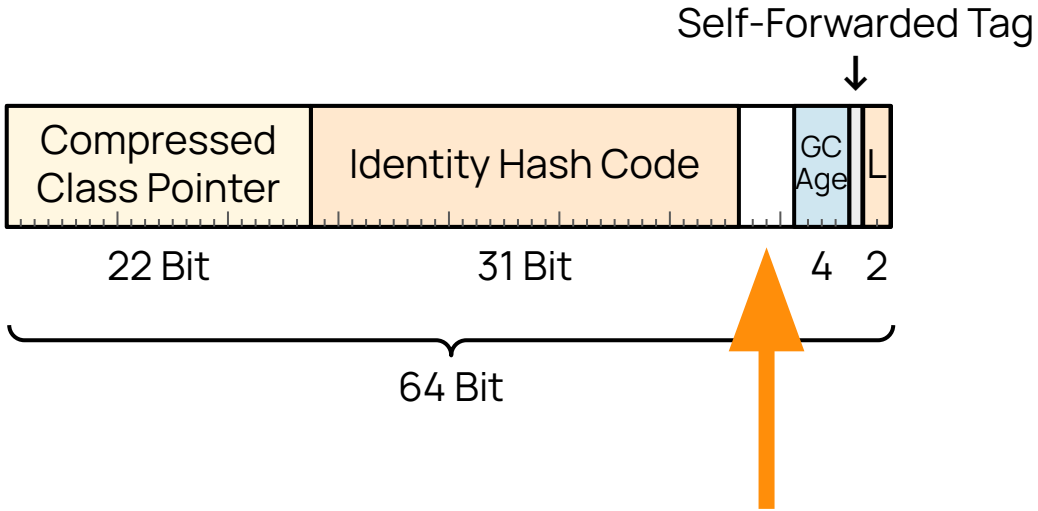
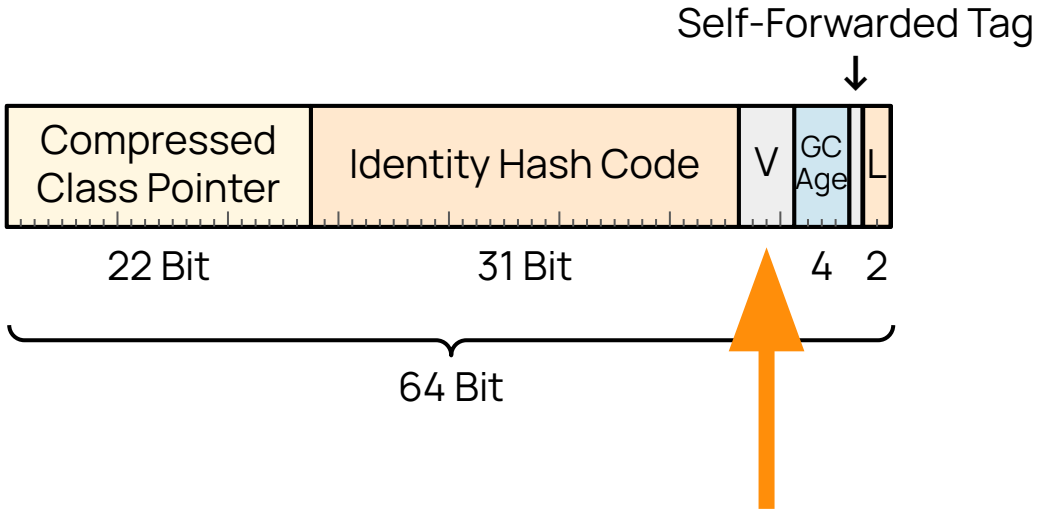
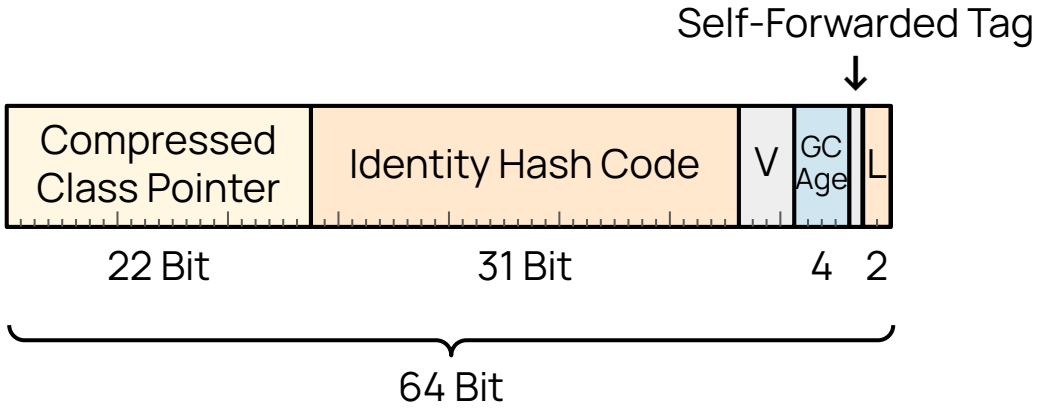


Compact Object Headers



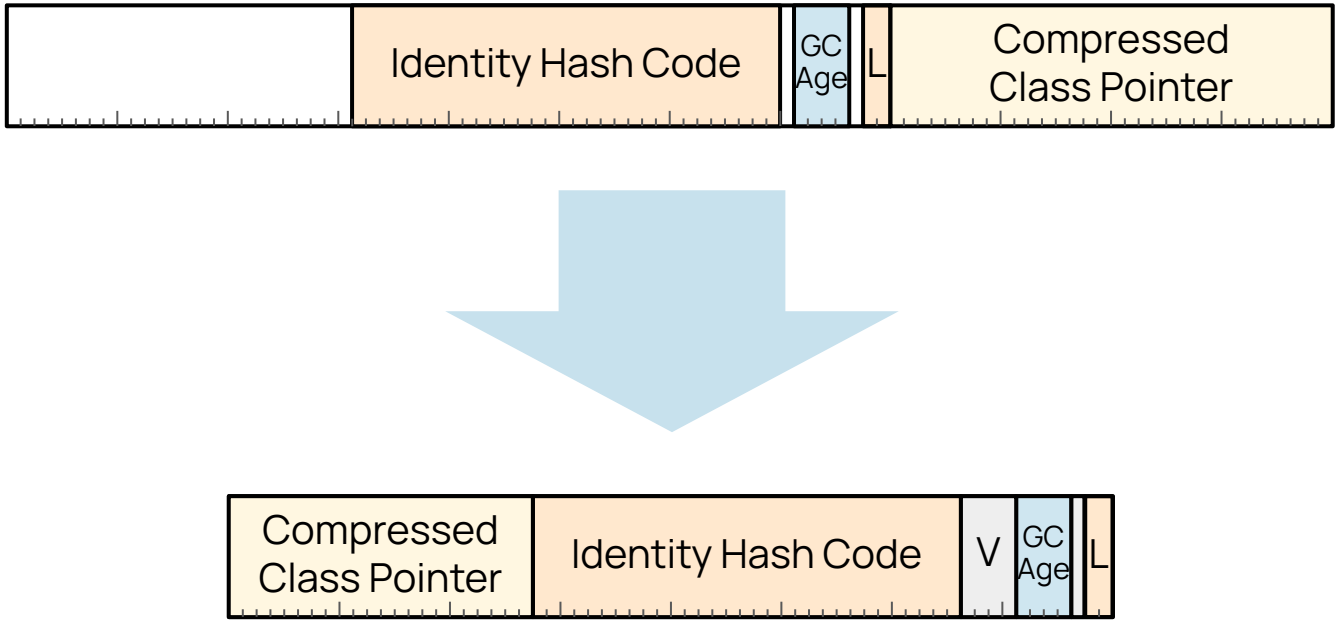
Compact Object Headers



Java 25: `-XX:+UseCompactObjectHeaders`

Java 27: enabled by default

Compact Object Headers



“Was it worth it?”

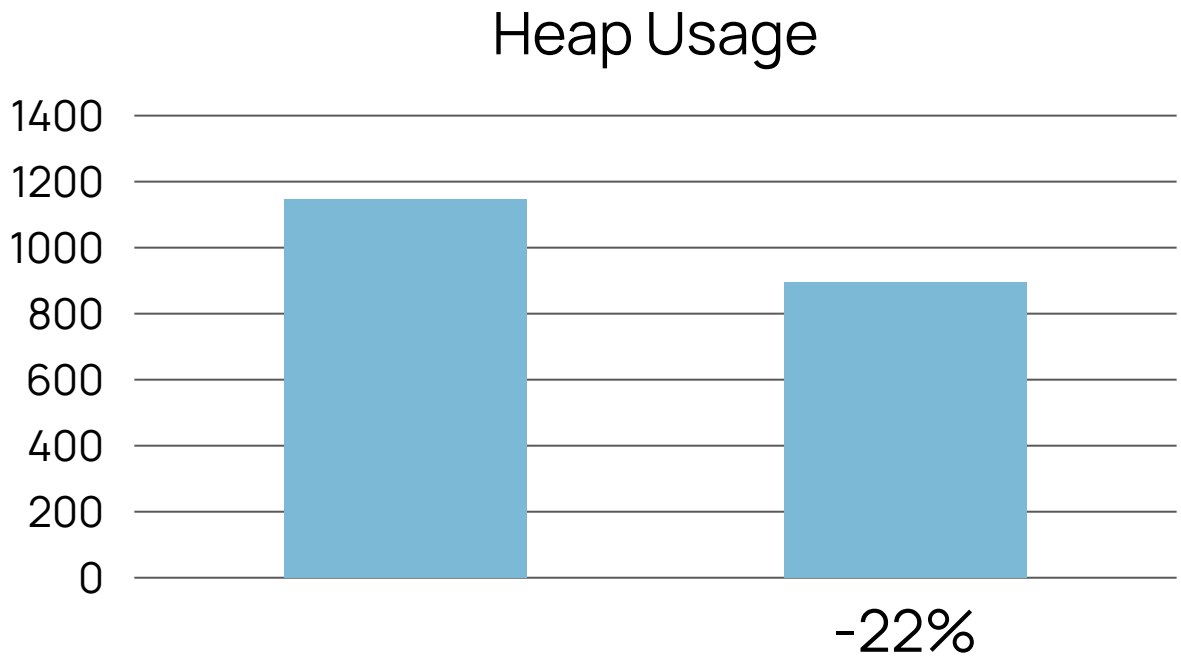
Compact Object Headers

"Early adopters of Project Lilliput who have tried it with real-world applications confirm that **live data is typically reduced by 10%–20%**."

Source: https://openjdk.org/jeps/450

OpenJDK

Compact Object Headers



Source: https://github.com/rkennke/talks/blob/master/Lilliput-FOSDEM-2025.pdf

aws

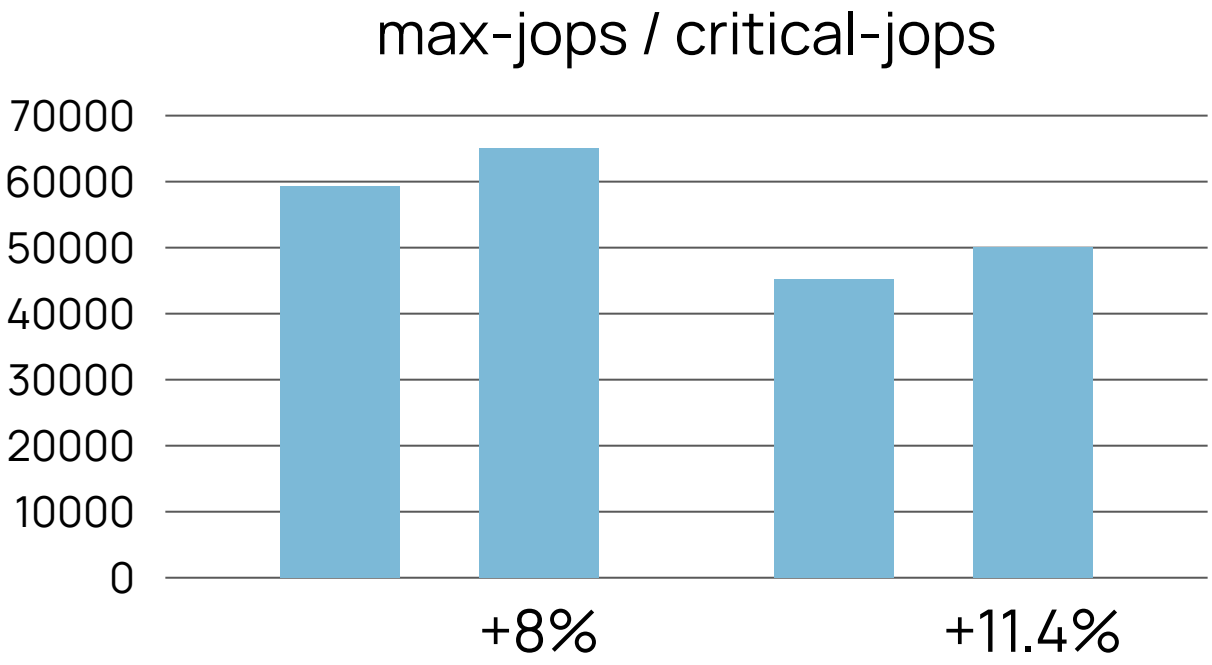
Compact Object Headers

"Java object memory usage
is **reduced by about 5-10%**."

Source:
https://www.alibabacloud.com/blog/compact-object-headers-in-dragonwell-jdk-reducing-costs-and-increasing-efficiency-for-java-applications_601065

Alibaba

Compact Object Headers



Source: https://github.com/rkennke/talks/blob/master/Lilliput-FOSDEM-2025.pdf

aws

Compact Object Headers

“The exact gain varies depending on the workload (especially the number of small objects created), **but in many cases, it was about 10% faster!**”

Source:
https://www.reddit.com/r/scala/comments/1jptiv3/xxusecompactobjectheaders_is_your_new_turbo/

plokhotnyuk
u/plokhotnyuk

Compact Object Headers

"Max(absolute throughput)
and critical (low latency required throughput)
are **improved by 6.17% and 9.01% respectively**."

Source:
https://www.alibabacloud.com/blog/compact-object-headers-in-dragonwell-jdk-reducing-costs-and-increasing-efficiency-for-java-applications_601065

Alibaba

Compact Object Headers

To enable in Java 25: `-XX:+UseCompactObjectHeaders`

As of Java 27: Enabled by default

Limitations:

~~`-XX:-UseCompressedClassPointers`~~

~~`-XX:LockingMode=1` (Legacy Stack Locking)~~

Max. 8 TB Heap (ZGC: no limit)

Outlook: “Lilliput 2”

→ 32-bit headers

OpenJDK Wiki

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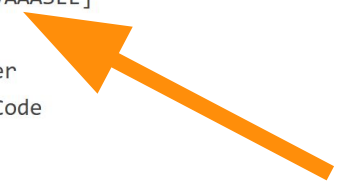
- Kulla
- Lanai

Lilliput 2 - 4-byte headers

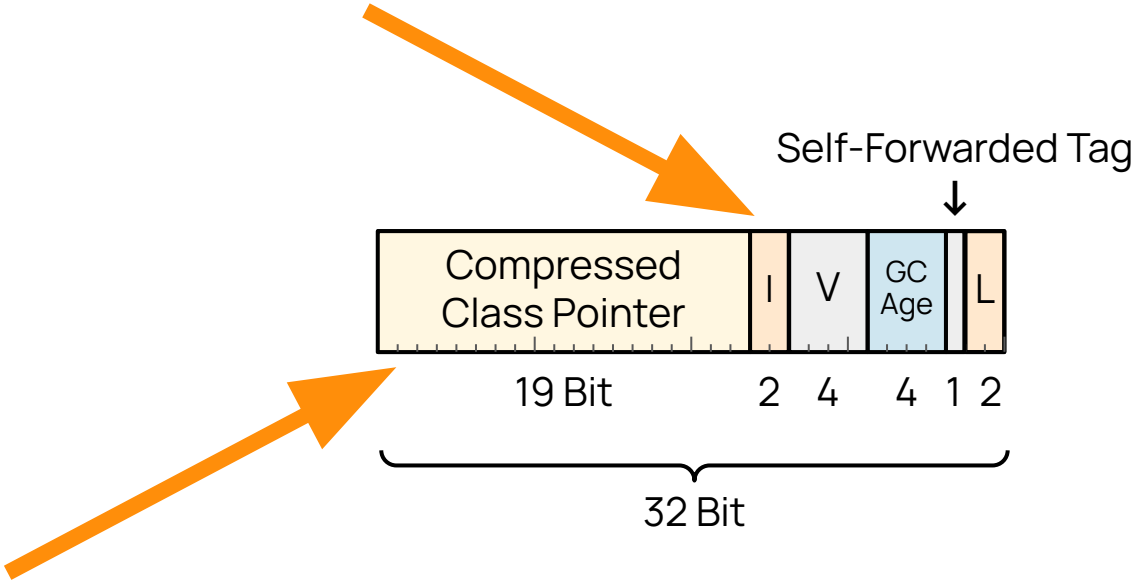
Created by Roman Kennke on Apr 18, 2024

Header layout

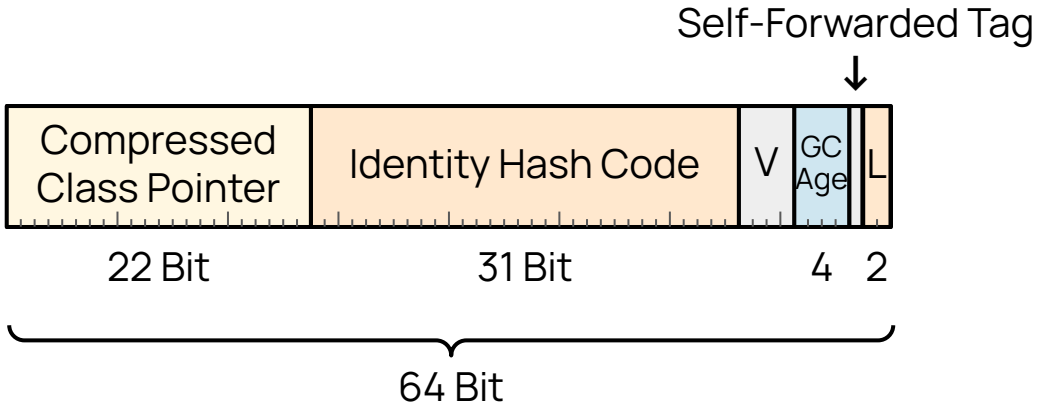
```
32                13     6   2 0
 [CCCCCCCCCCCCCCCCCCCCHHVVVVAAASLL]

C - Compressed Class-Pointer
H - Compact Identity Hash-Code
V - Valhalla Bits
A - GC Age Bits
S - Self-Forwarding Bits
L - Lock-Bits
```



“Lilliput 2”

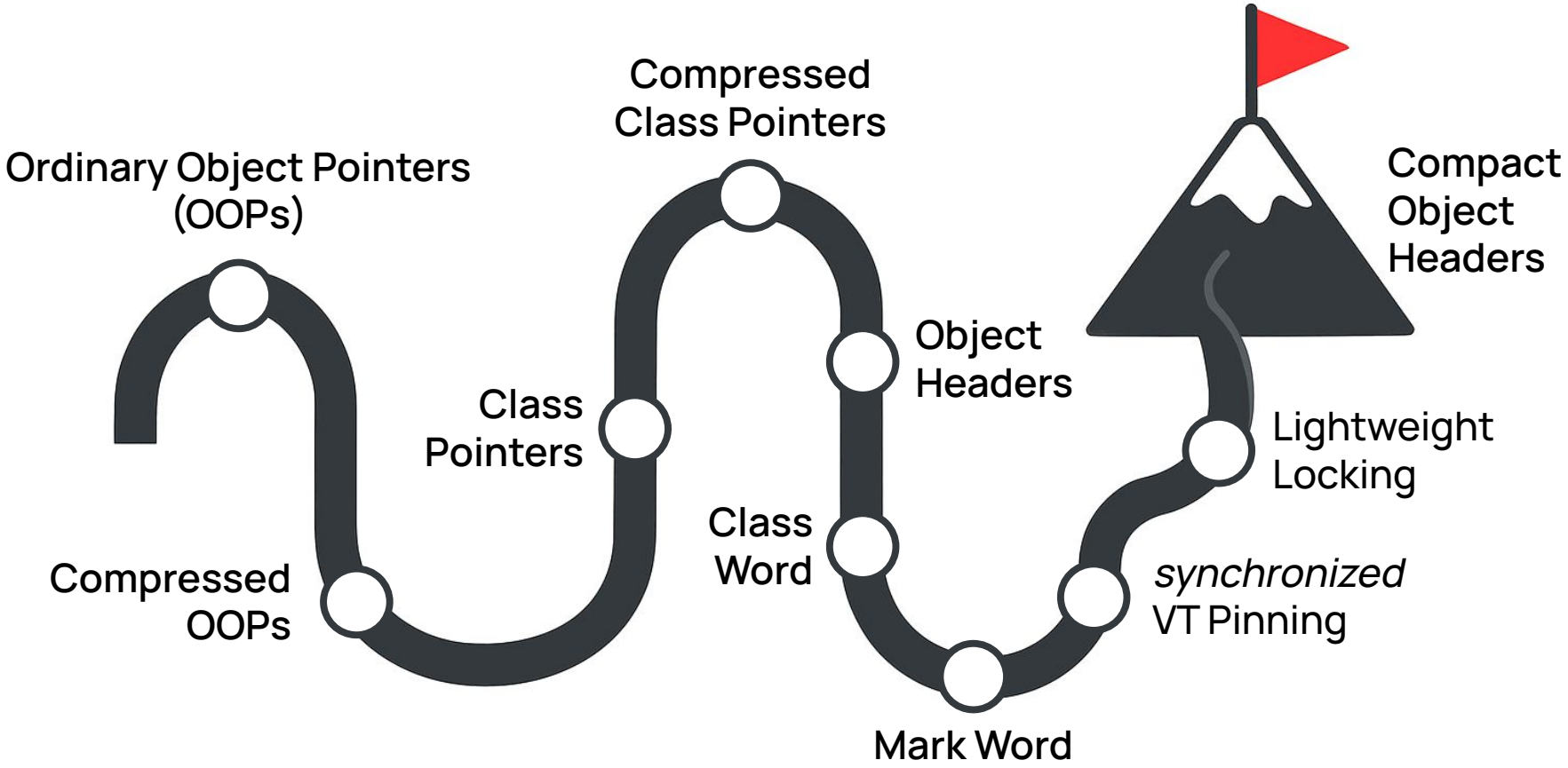

Self-Forwarded Tag
Compressed Class Pointer
I
V
GC Age
L
19 Bit
2
4
4
1
2
32 Bit

Compact Object Headers




```
-XX:+UseCompactObjectHeaders
```

Journey into the JVM



Links + Slides

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Java Expert, Speaker, Trainer

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https://www.happycoders.eu/

https://linkedin.com/in/sven-woltmann/

https://youtube.com/c/happycoders

LinkedIn