Immutable Collections

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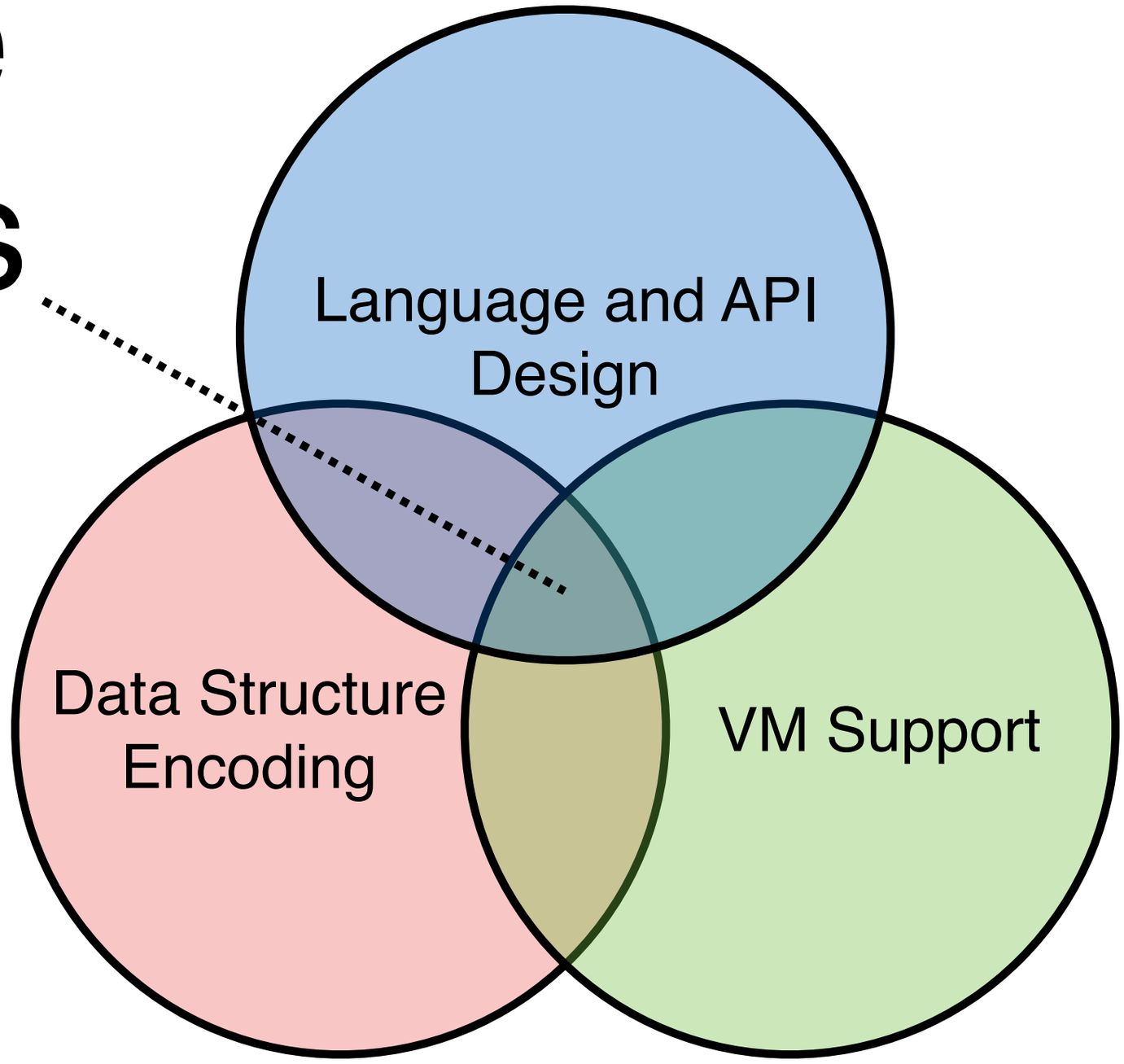

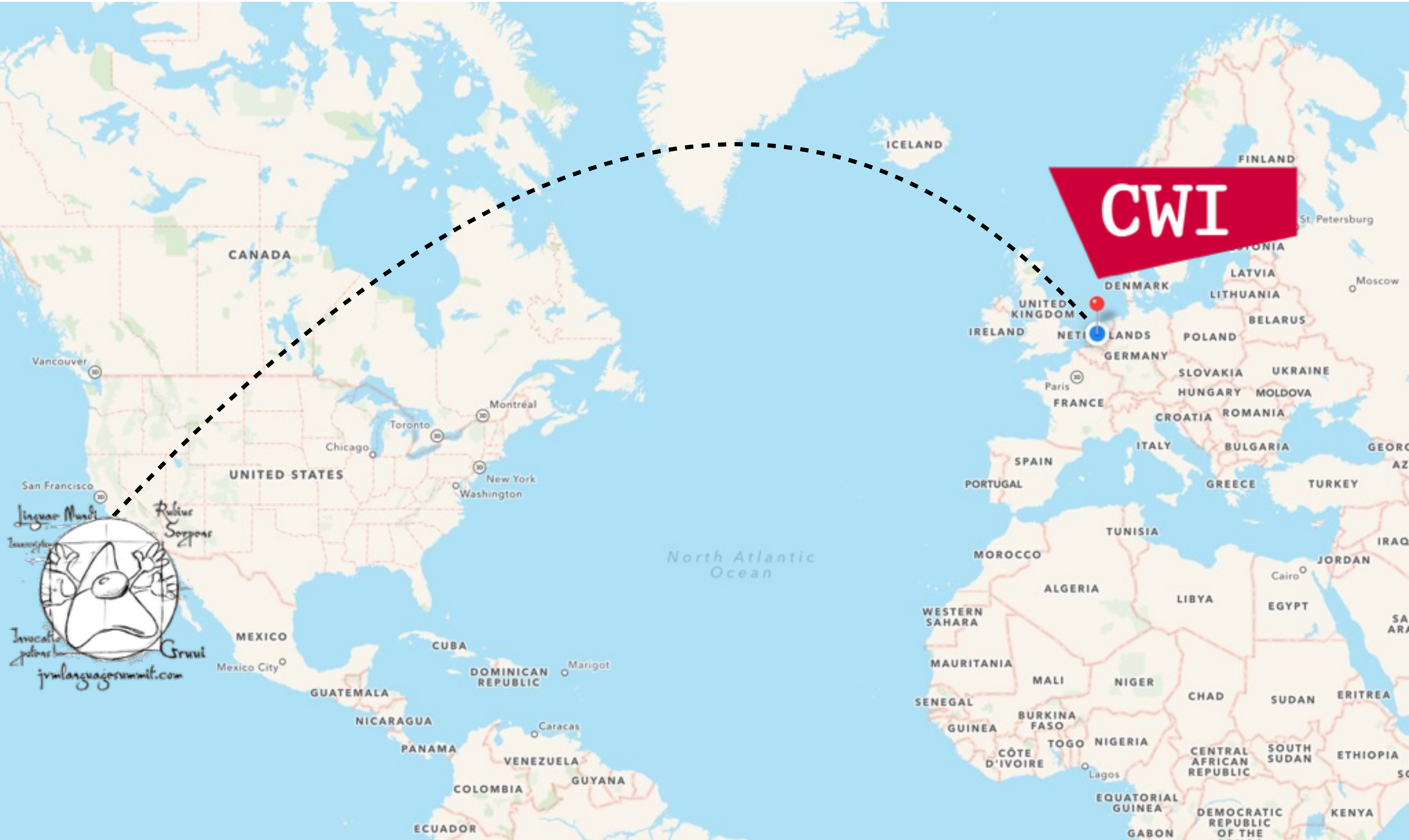
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SOUTH SUDAN
ETHIOPIA
EQUATORIAL GUINEA
GABON
DEMOCRATIC REPUBLIC OF THE
KENYA
Linguae Mundi
jvmlanguagesummit.com

"A collection represents a **group of objects** […]"

–java.util.Collection API

Data Type Semantics

lists, sets, maps, multi-maps, bags, …

Ordering

unordered (hashed), ordered

Update Semantics

mutable, transient, immutable

Processing Semantics

sequential, concurrent, parallel

Encoding

array/hashtable, linked list, tree, trie, …

Content

homogeneous, heterogeneous

…

Data Type Semantics

sets, maps, multi-maps

Ordering

unordered (hashed)

Update Semantics

immutable

Processing Semantics

sequential

Encoding

trie

Content

homogeneous, heterogeneous

...

Why Immutability?

- More Optimizations (Constant)
- Simple (Programming Model)
- Robust (Concurrency)

"**Classes should be immutable** unless there's a very good reason to make them mutable."

–Effective Java, 2nd Edition (Joshua Bloch, 2008)
Item 15: Minimize mutability

"**[Collections] should be immutable** unless there's a very good reason to make them mutable."

–Effective Java, 2nd Edition (Joshua Bloch, 2008)
Item 15: Minimize mutability

"Immutable [collections] provide **many advantages**, and their **only disadvantage is the potential for performance problems** under certain circumstances."

–Effective Java, 2nd Edition (Joshua Bloch, 2008)
Item 15: Minimize mutability

Immutable collections are **challenging to optimize**, but overall they **constitute a more sensible default**.

–Personal Opinion

Outline

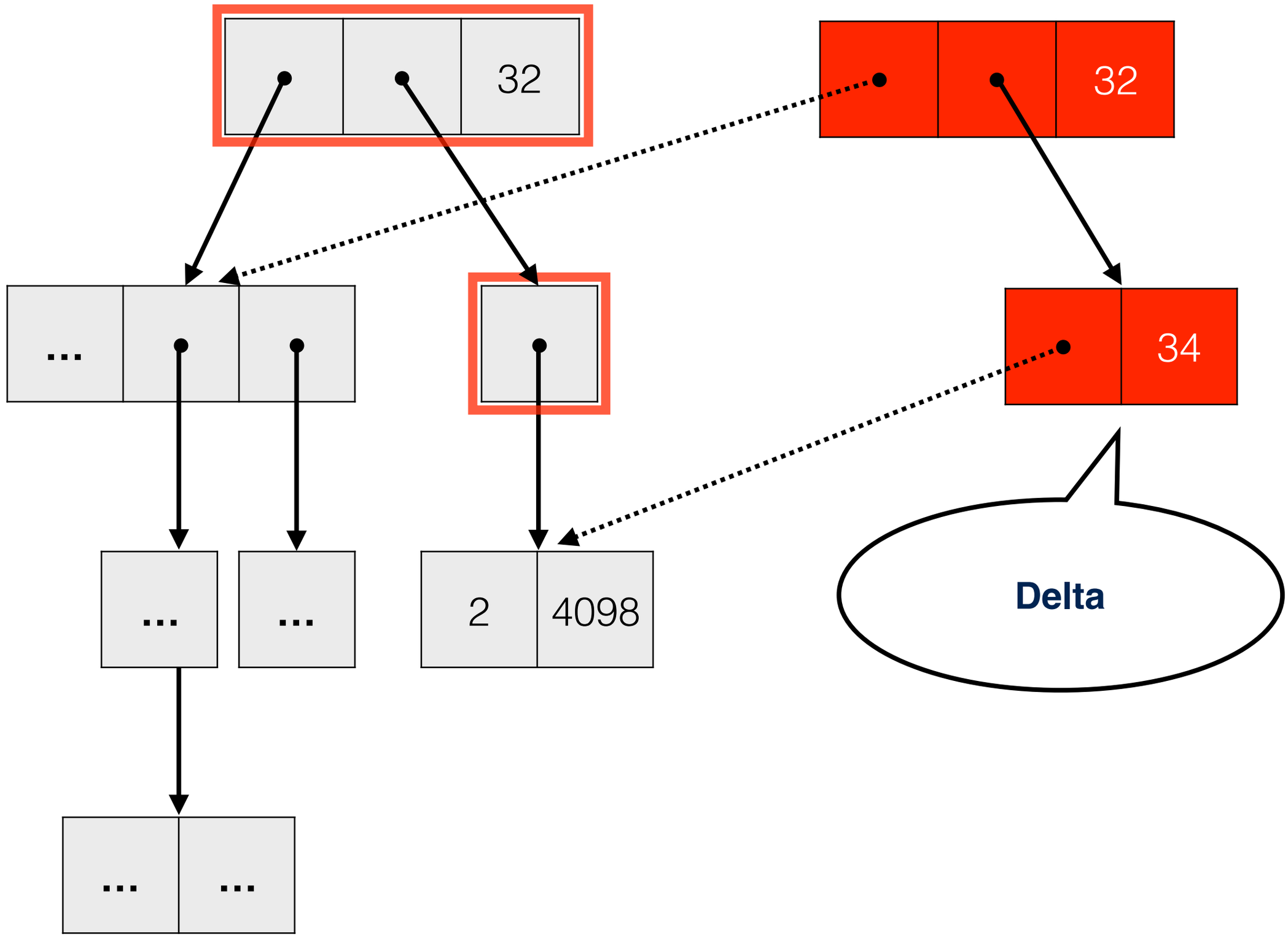
1. Core Principles & Encodings
2. Minimize Memory Footprint
3. Efficiency & Expressivity
4. Performance Challenges

Core Principles

```
Set<Integer> updatedSet =
  hugeSet.newInstanceWith(34);
```

```
Set<Integer> __tmp =
  new HashSet<>(hugeSet.size + 1);
__tmp.addAll(hugeSet);
__tmp.add(34);

Set<Integer> updatedSet =
  Collections.unmodifiableSet(__tmp);
```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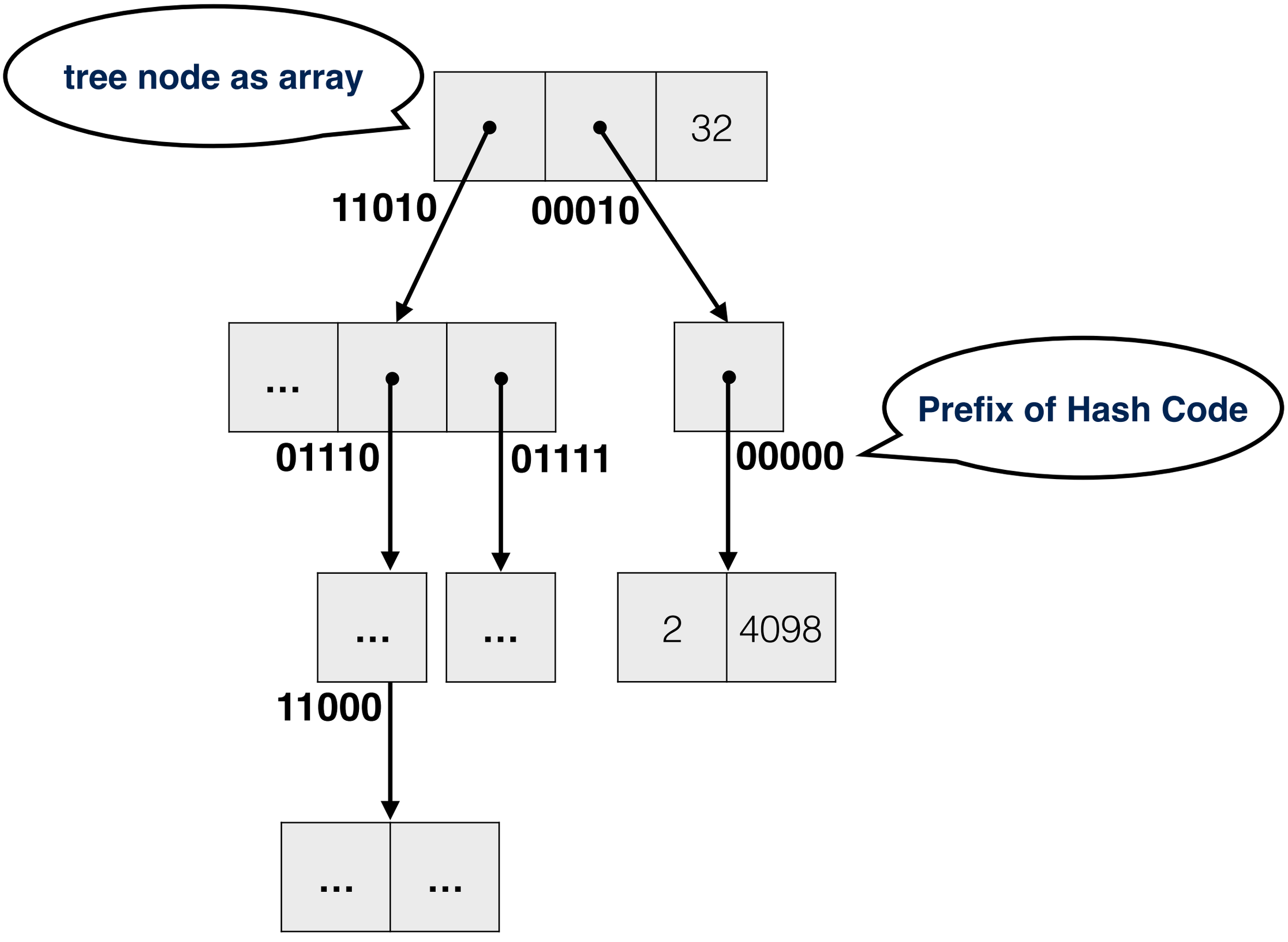
Clojure
http://clojure.org

Rascal
http://rascal-mpl.org

Scala
http://scala-lang.org

Hash Array Mapped Trie


tree node as array
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01110
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Prefix of Hash Code
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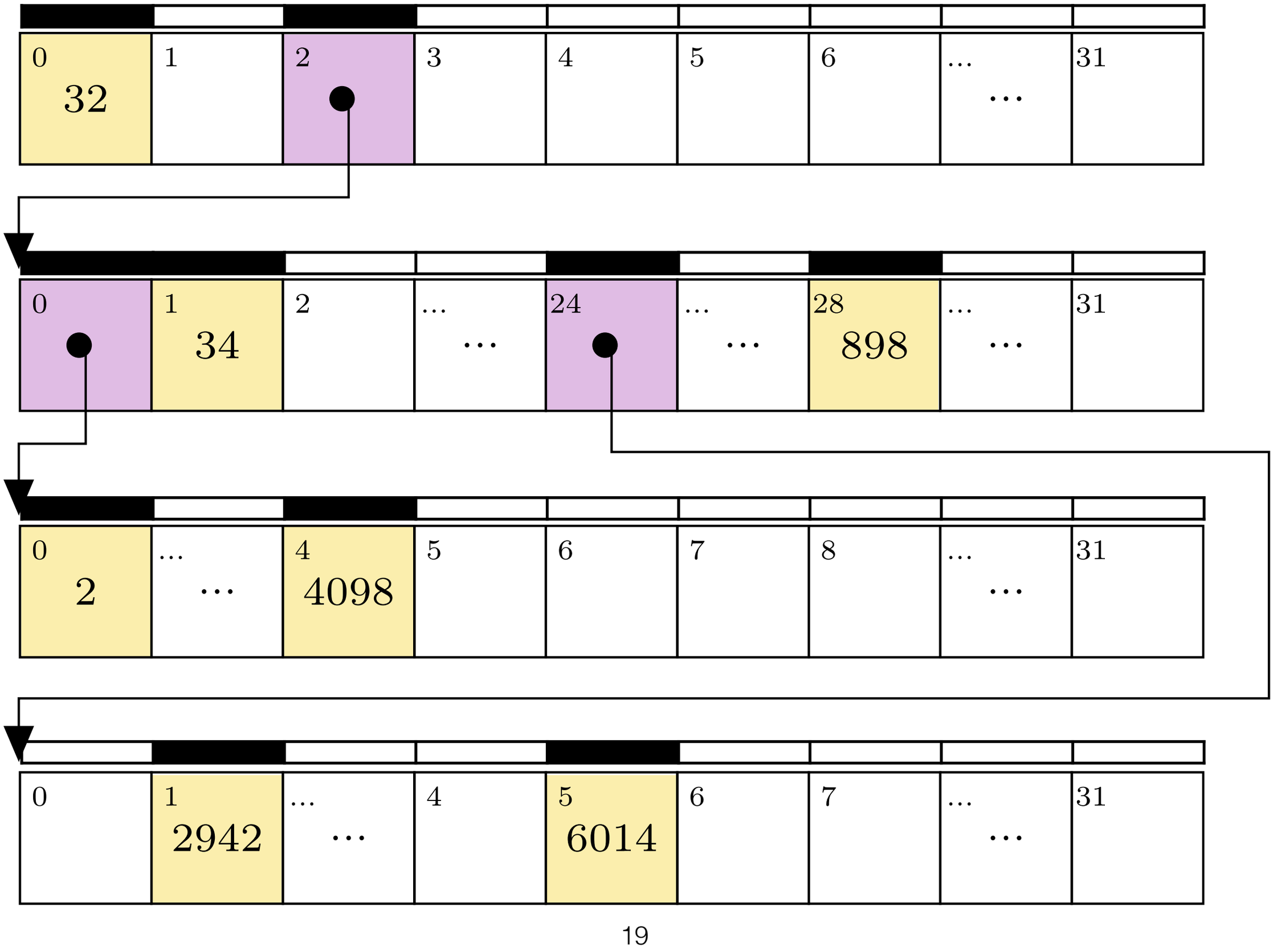
{2, 32, 34, 898,
2942, 4098, 6014}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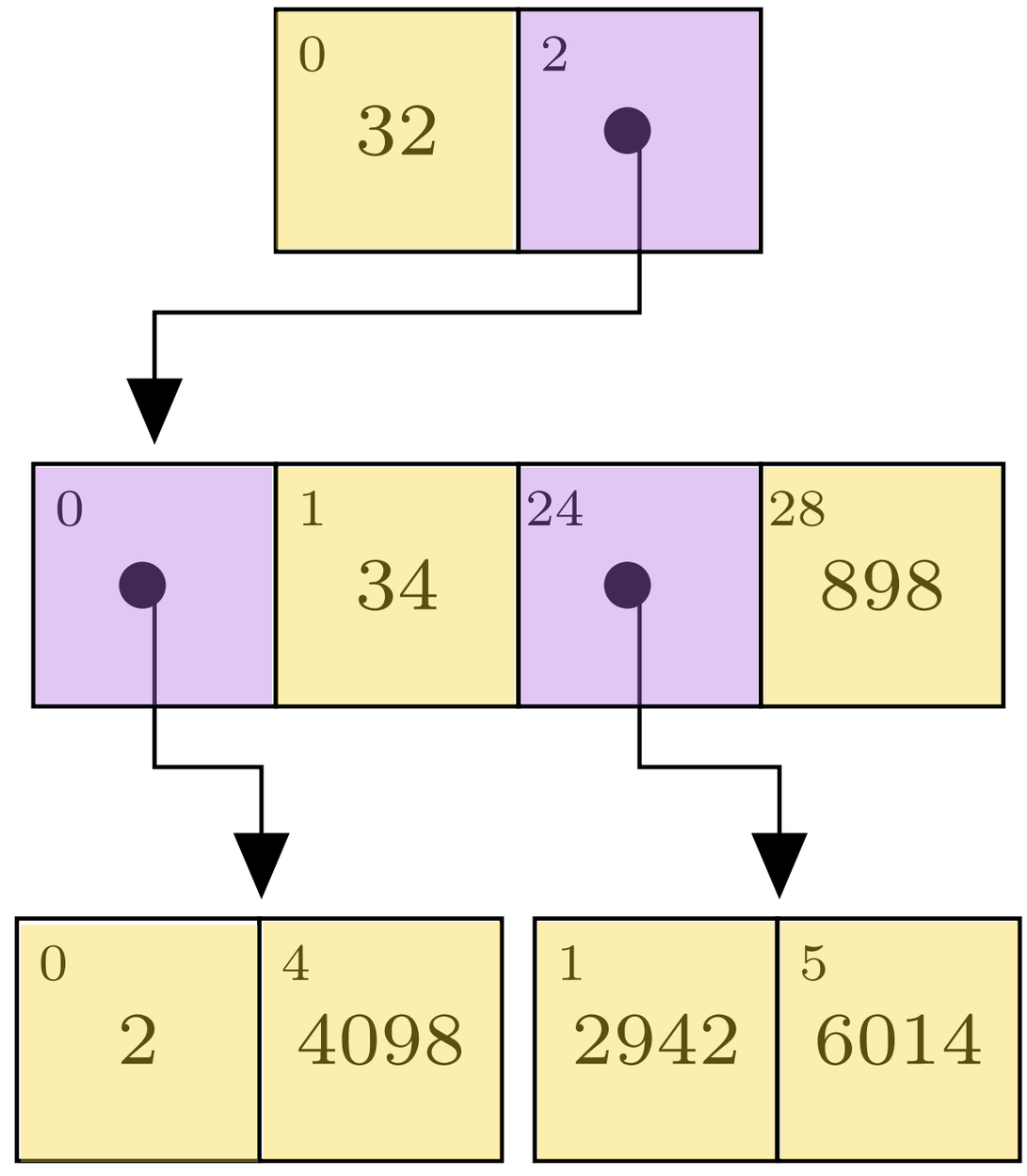
```
class Node {
  int bitmap;
  Object[] content;
}
```

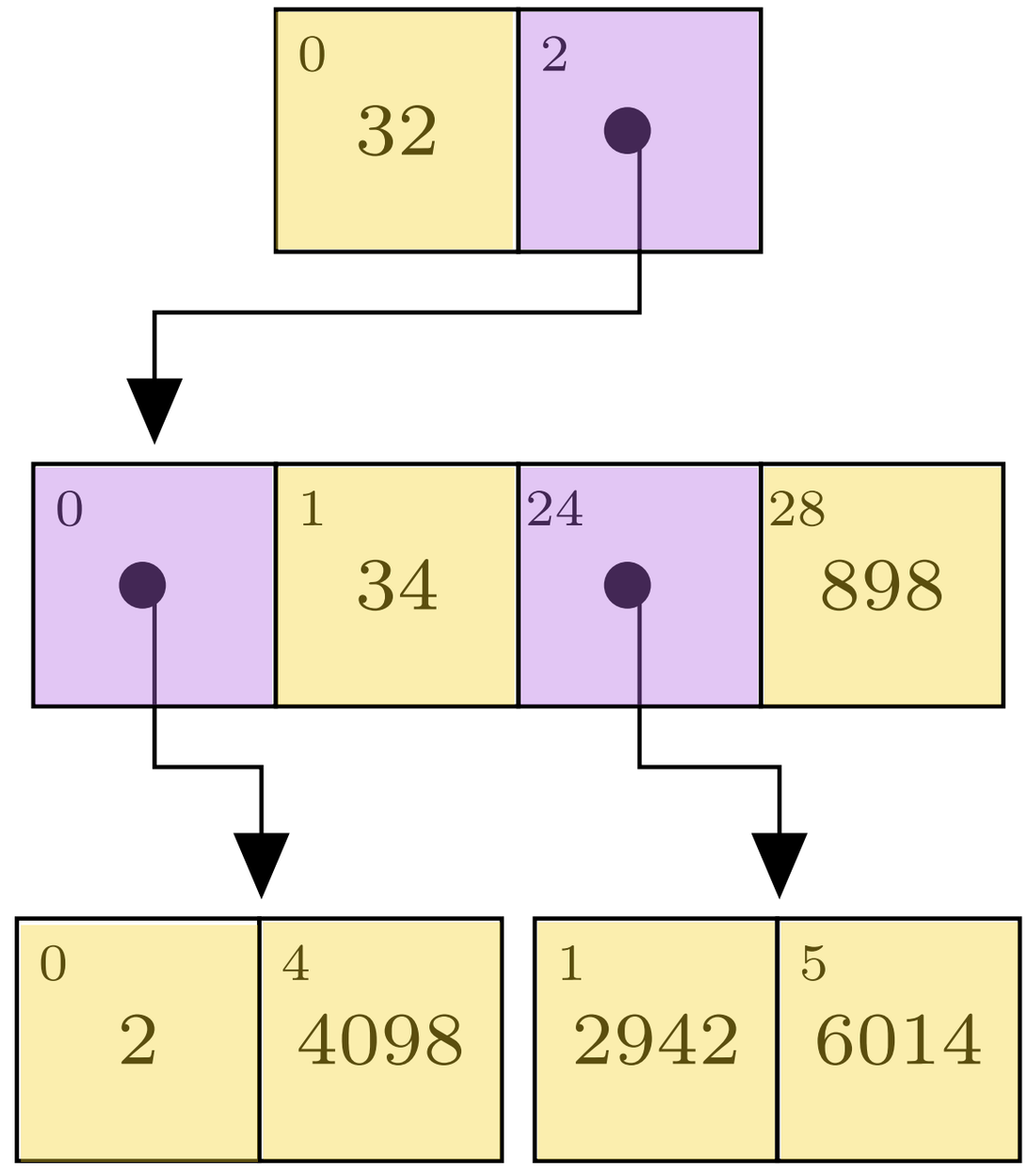


What can you expect?

- Shallow and Wide Search Trees ($\mathrm{Depth} <= 7$)
- Lookup/Insert/Delete in $\mathrm{O}(\log_{32}(\mathrm{n})) \cong \mathrm{O}(1)$
- Union/Subset (Structural Operations)

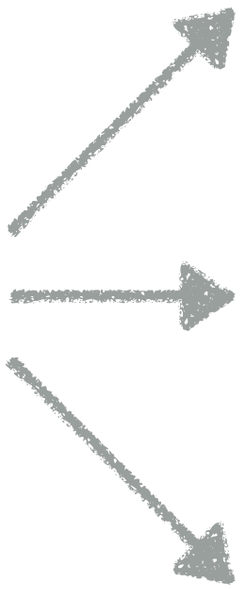
Minimize Memory Footprint by Specializing Class Layouts

```
class Node {
  int bitmap;
  Object[] content;
}
```



```
class ArrayList32 {
  /* 0 <= content.size <= 32 */
  Object[] content;
}
```

```
class ArrayList32 {
  Object[] content;
}
```



```
class List1 implements
    ImmutableList {
  Object slot0;
}

class List2 implements
    ImmutableList {
  Object slot0;
  Object slot1;
}

class List3 implements
    ImmutableList {
  Object slot0;
  Object slot1;
  Object slot2;
}

...
```

-  Small Footprints
-  Megamorphic Call Sites
-  Code Bloat

```
abstract class List2 implements ImmutableList {
  Object slot0;
  Object slot1;

  @Override
  public ImmutableList insertAtIndex(
      int index, Object item) {
    switch (index) {
      case 0:
        return new List3(item, slot0, slot1);
      case 1:
        return new List3(slot0, item, slot1);
      case 2:
        return new List3(slot0, slot1, item);
      default:
        throw new IllegalArgumentException();
    }
  }
}
```

-  Small Footprints
-  Monomorphic Call Sites
-  JIT-Friendly

Decoupling Data and Operations

```
abstract class List2 implements ImmutableList {
  Object slot0;
  Object slot1;
}
```

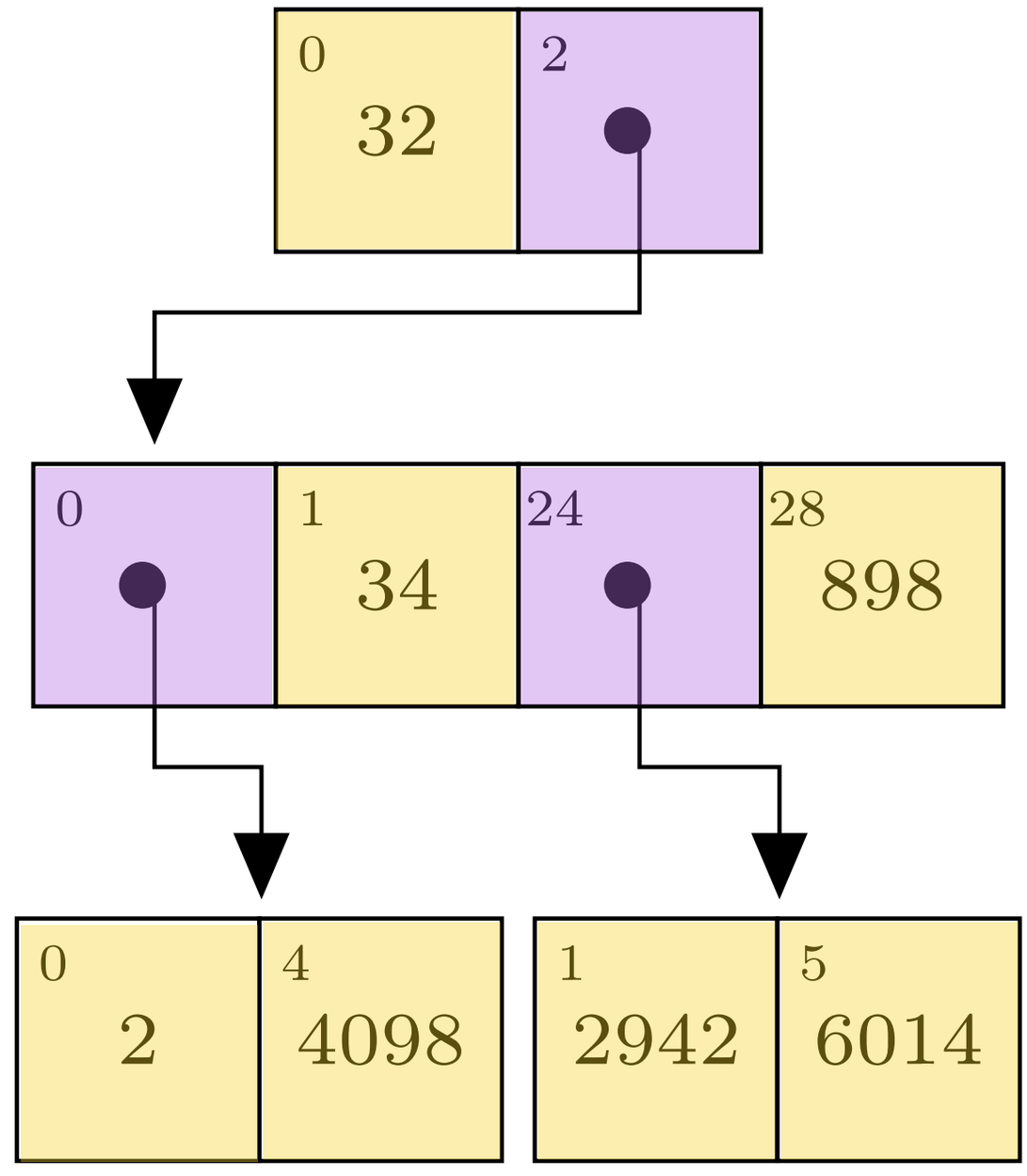
```
// viewing consecutive fields as arrays
createArrayView(List2.class,
                "slot0", “slot1”, Object.class);
```

```
ImmutableList insertAtIndex(int index, Object item) {
  ArrayView<Object> src = getArrayView();
  ImmutableList newList = allocateList(src.length + 1);
  ArrayView<Object> dst = newList.getArrayView();
  // copy 'src' and insert element at position 'index'
  arrayviewcopy(src, 0, dst, 0, index);
  dst.set(index, item);
  arrayviewcopy(src, index, dst, index + 1,
    src.length - index);

  return newNode;
}
```

Efficiency & Expressivity

```
class Node {
  int bitmap;
  Object[] content;
}
```



More Performant …

Up to 6x faster …

(speedup of iteration over Clojure / Scala)

Steindorfer, M. J., & Vinju, J. J. (2015). Optimizing Hash-Array Mapped Tries for Fast and Lean Immutable JVM Collections. OOPSLA'15.

… up to 28x faster …

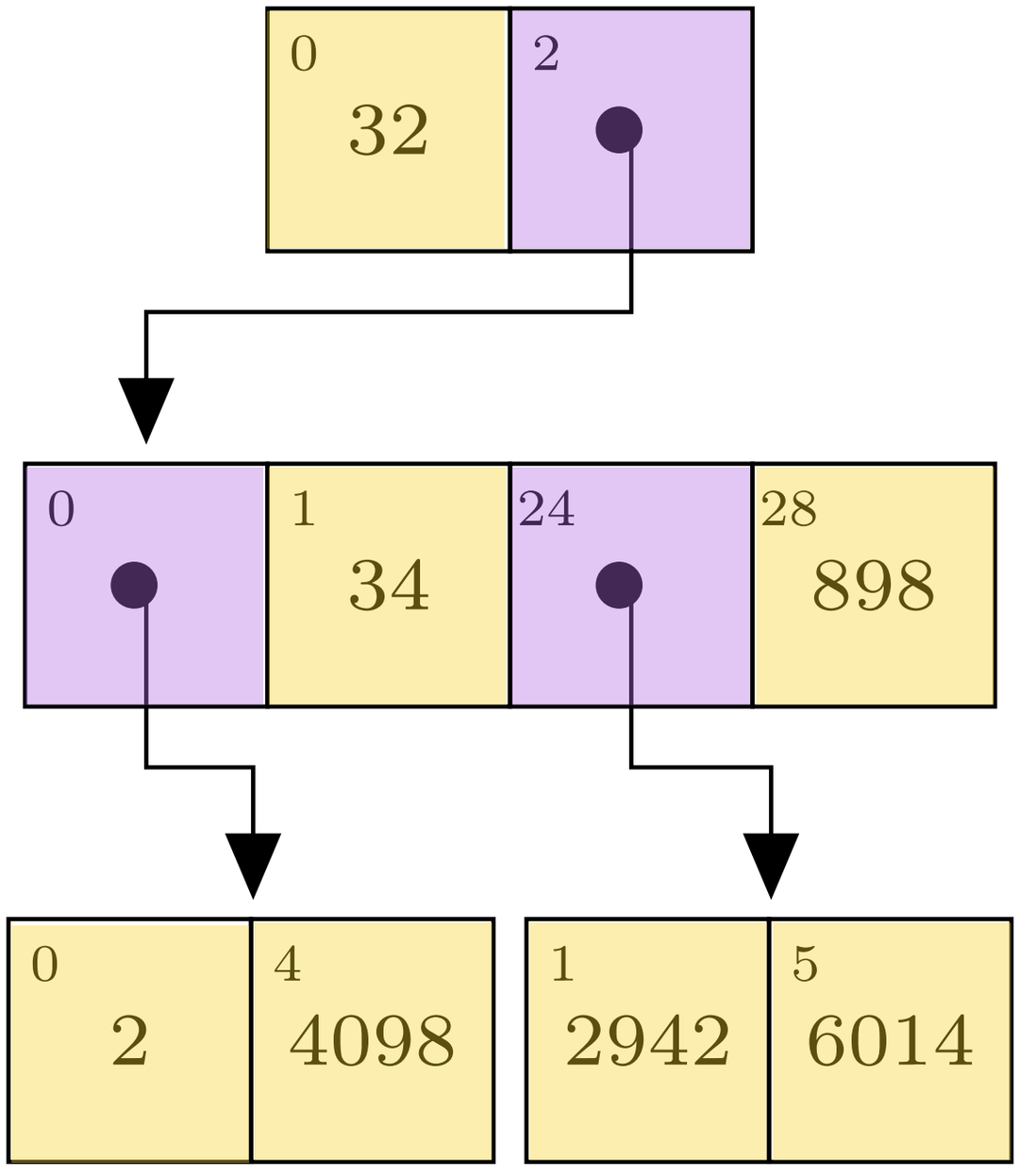
(speedup equality checking over Clojure / Scala)

Steindorfer, M. J., & Vinju, J. J. (2015). Optimizing Hash-Array Mapped Tries for Fast and Lean Immutable JVM Collections. OOPSLA'15.

… and up to 64% smaller.

(memory footprint reduction over Clojure / Scala)

Steindorfer, M. J., & Vinju, J. J. (2015). Optimizing Hash-Array Mapped Tries for Fast and Lean Immutable JVM Collections. OOPSLA'15.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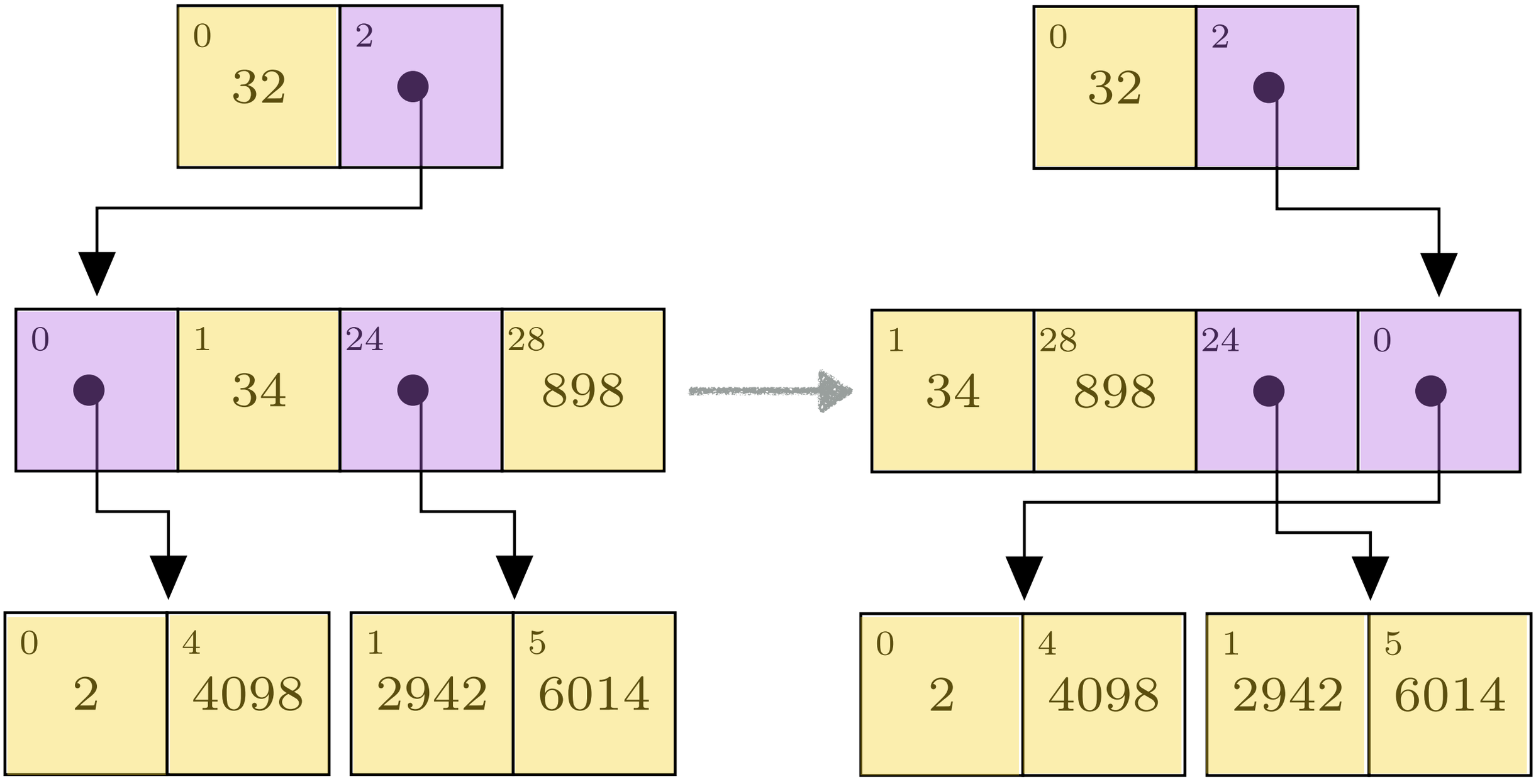
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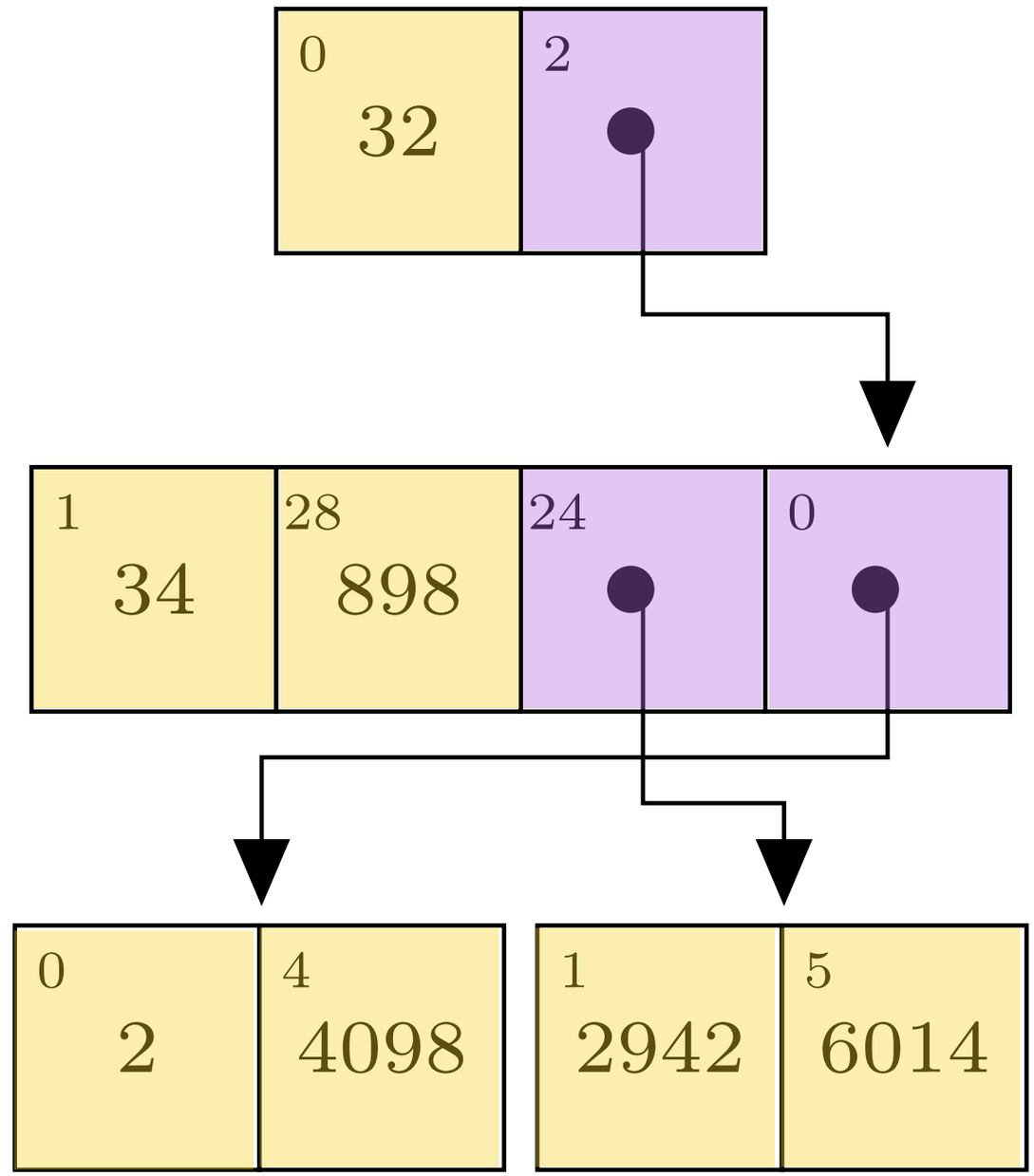
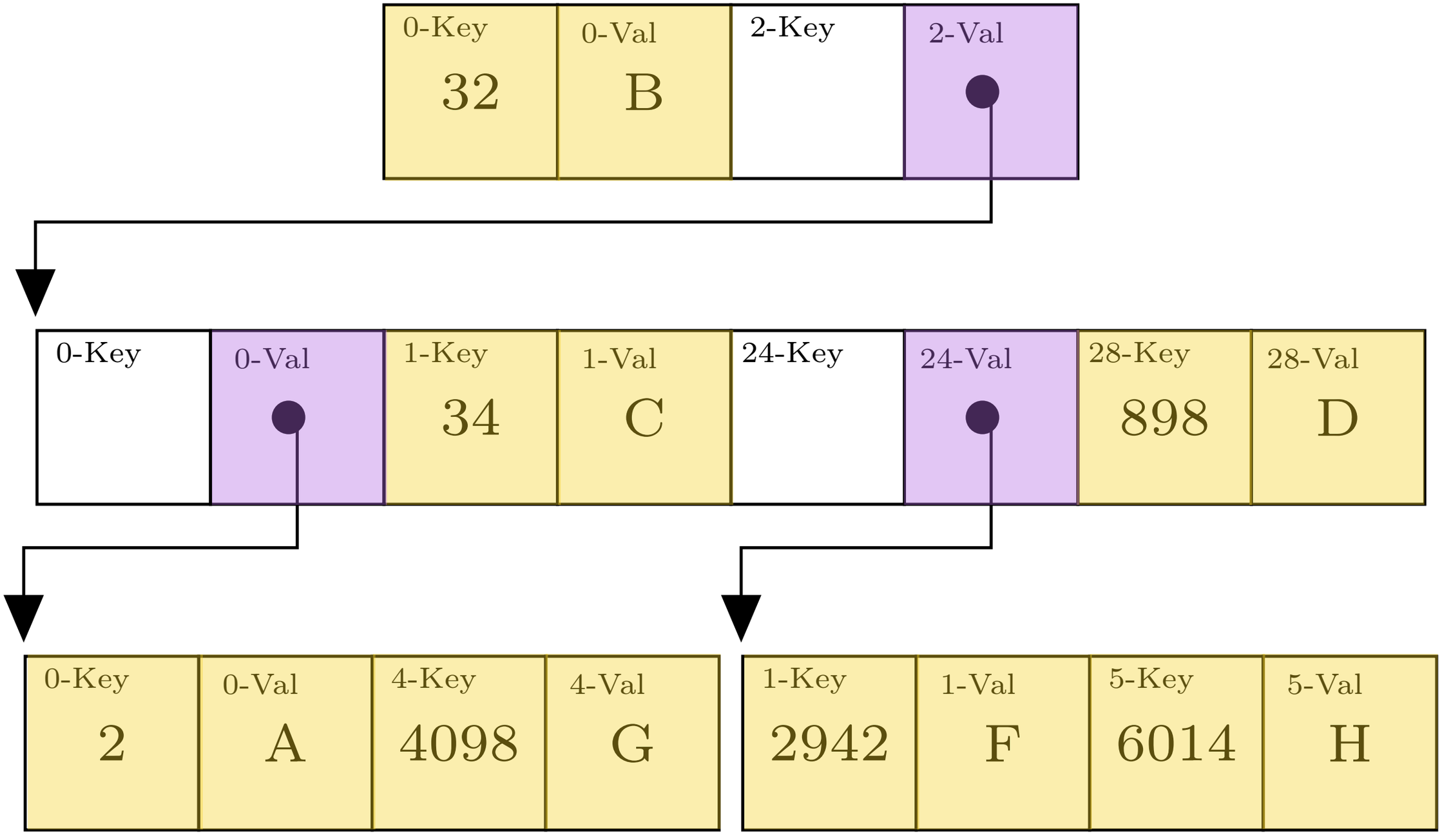
```
class Node {
   int datamap;
   int nodemap;
   Object[] content;
}
```

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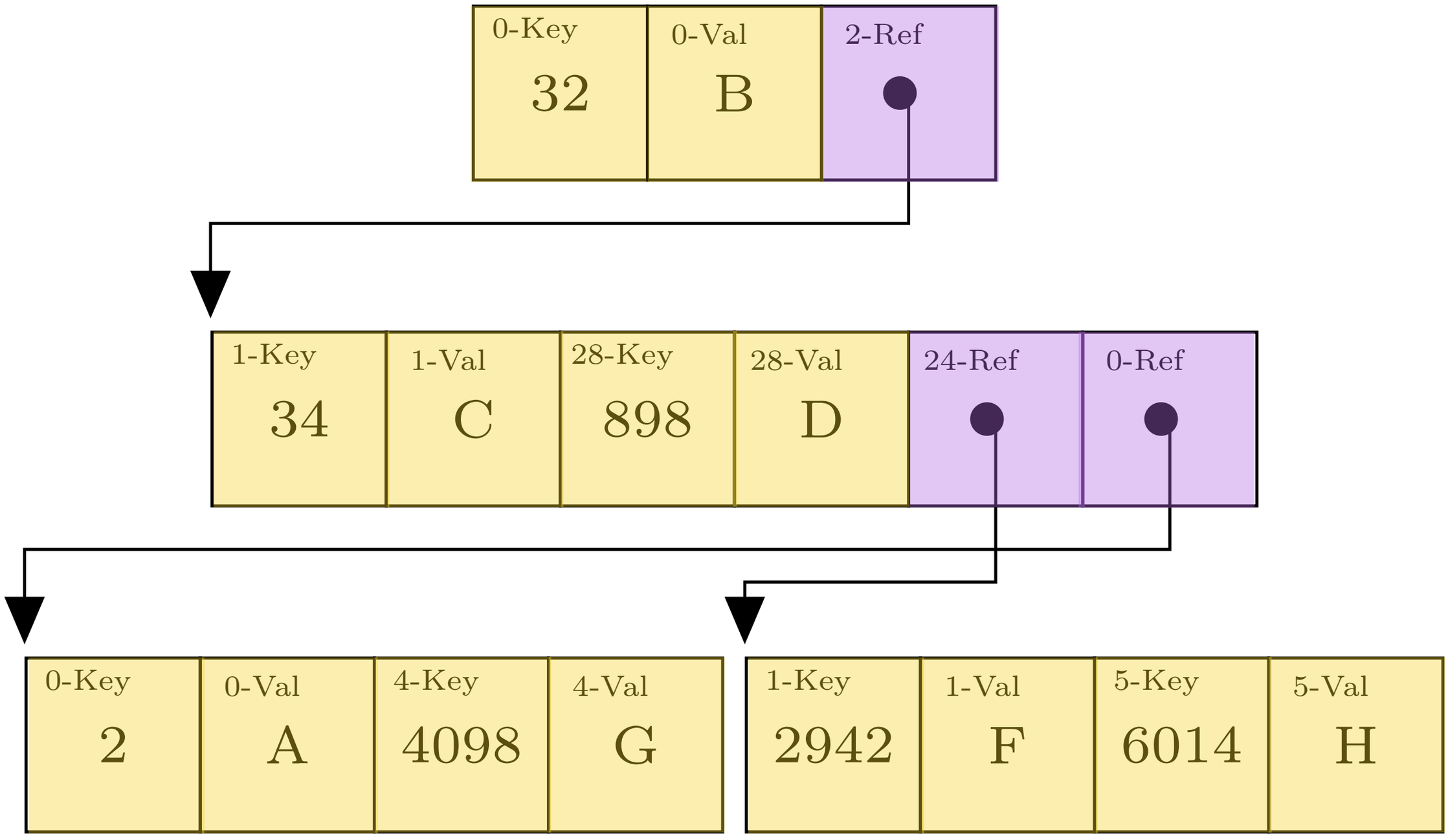
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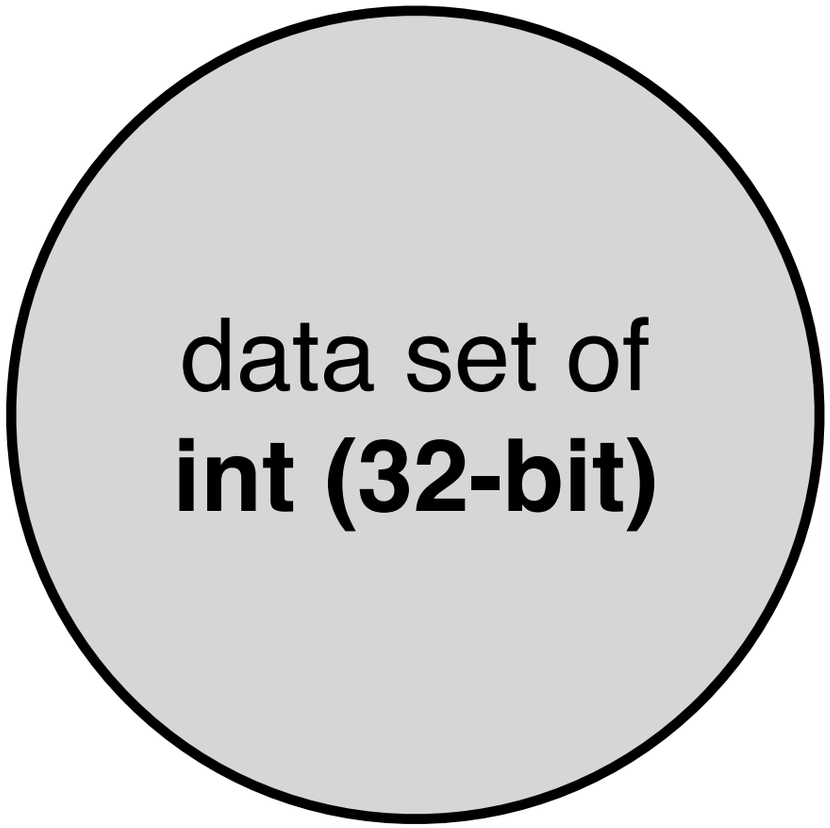
More Expressive …

Numeric Data Sets

Storing and Processing with Collections

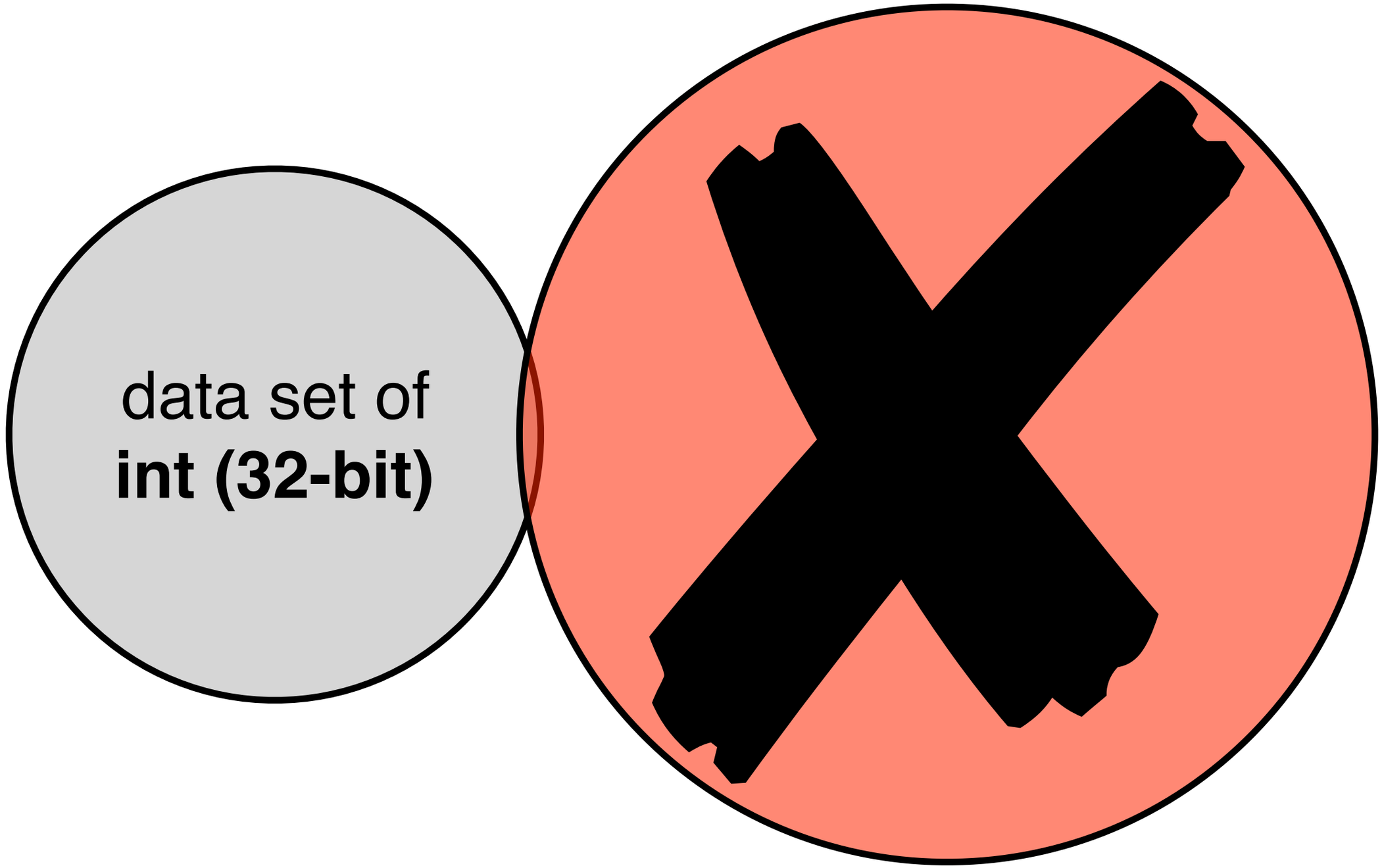
SPECIALIZED PRIMITIVE COLLECTION



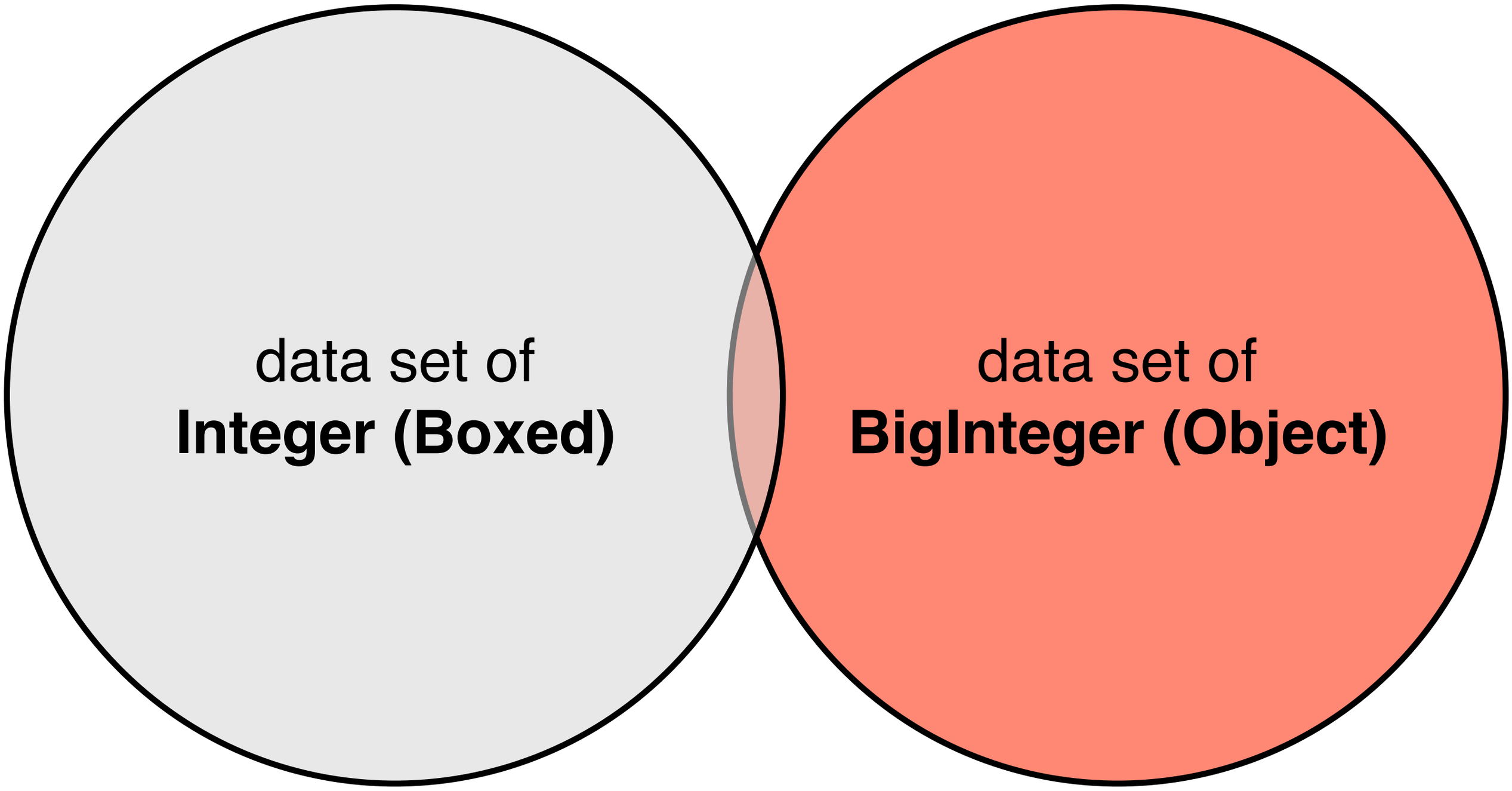
data set of
BigInteger (Object)

GENERIC COLLECTION

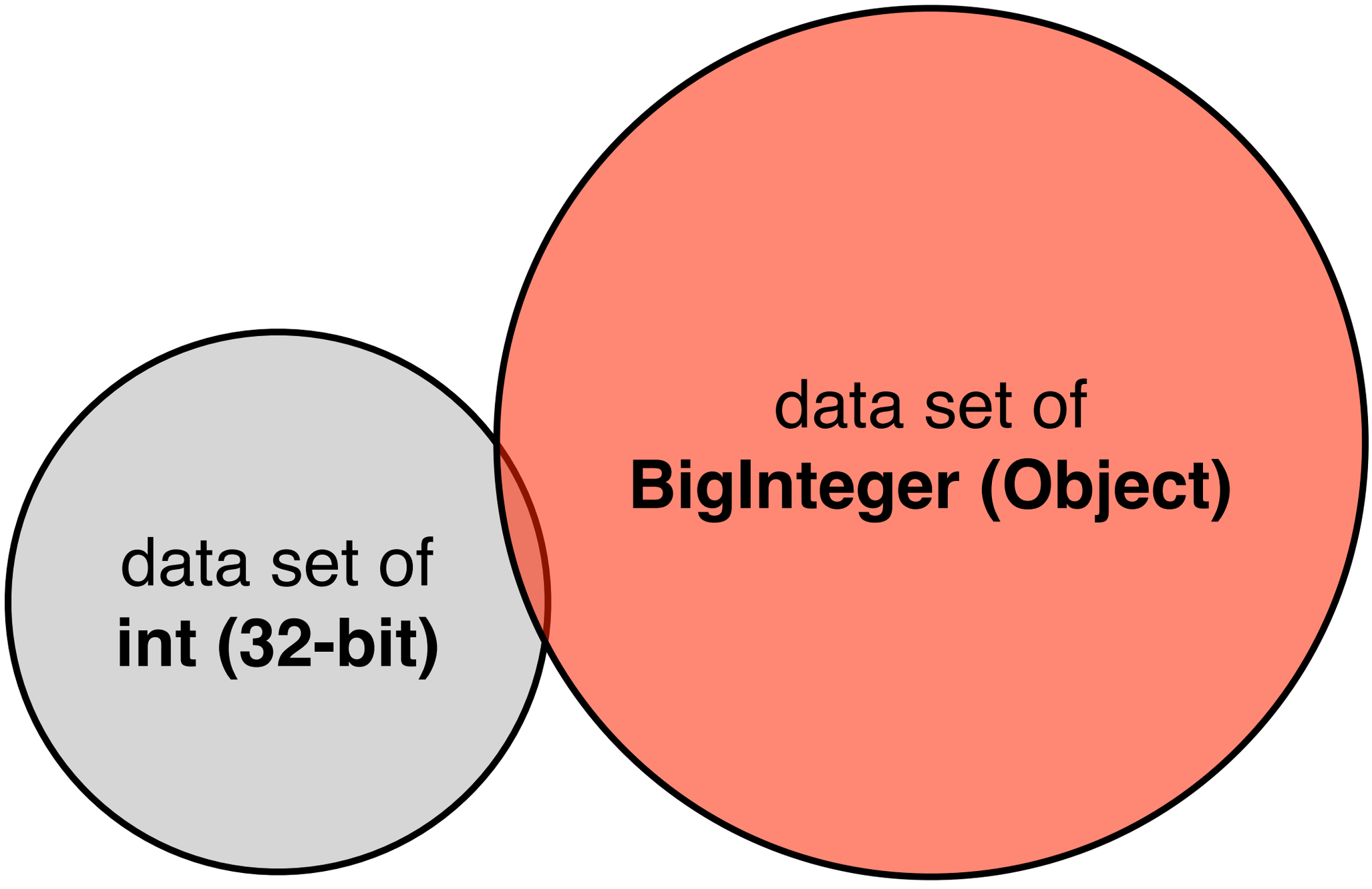
PRIMITIVE COLLECTION ???

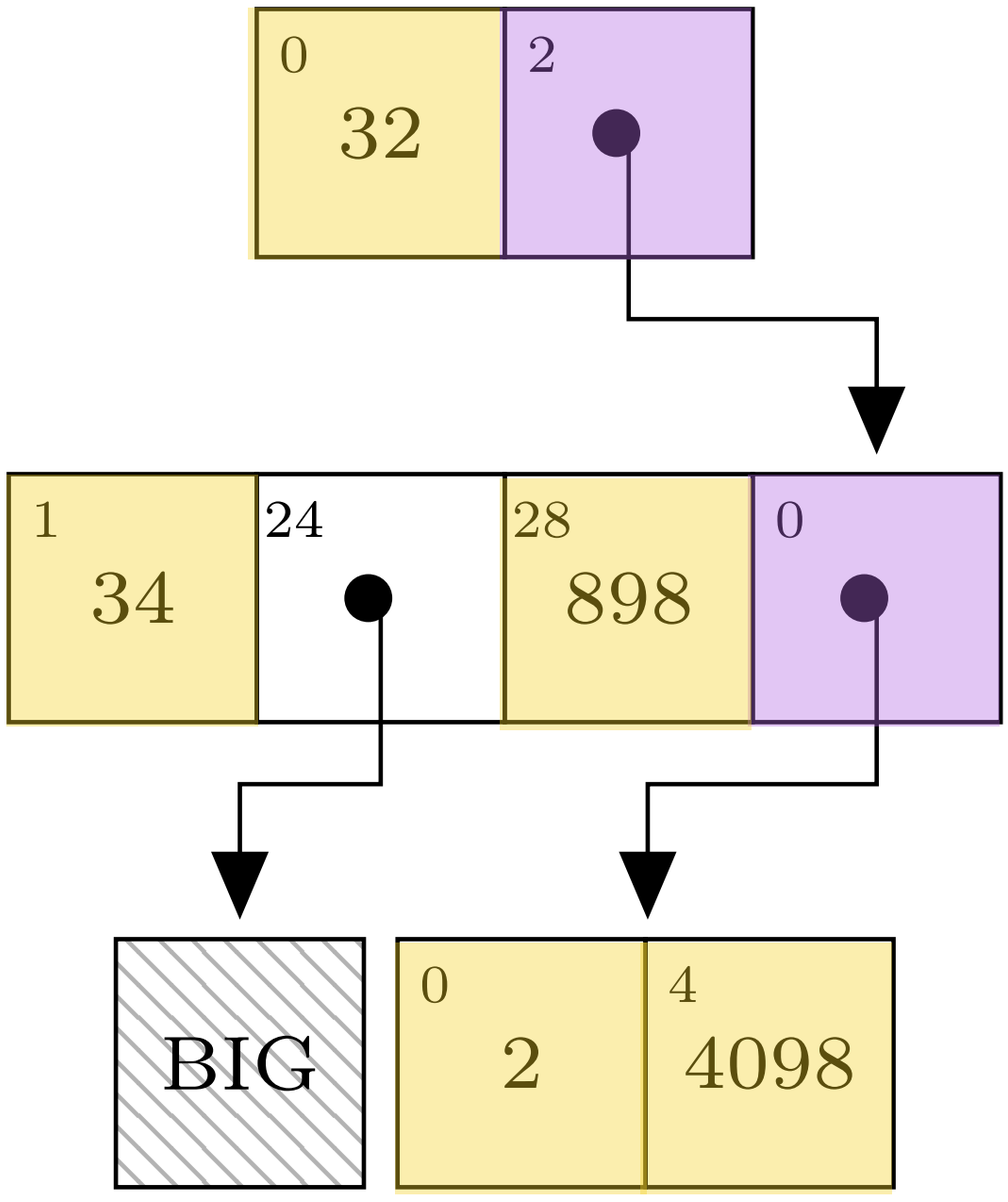


GENERIC COLLECTION ???



HETEROGENEOUS COLLECTIONS

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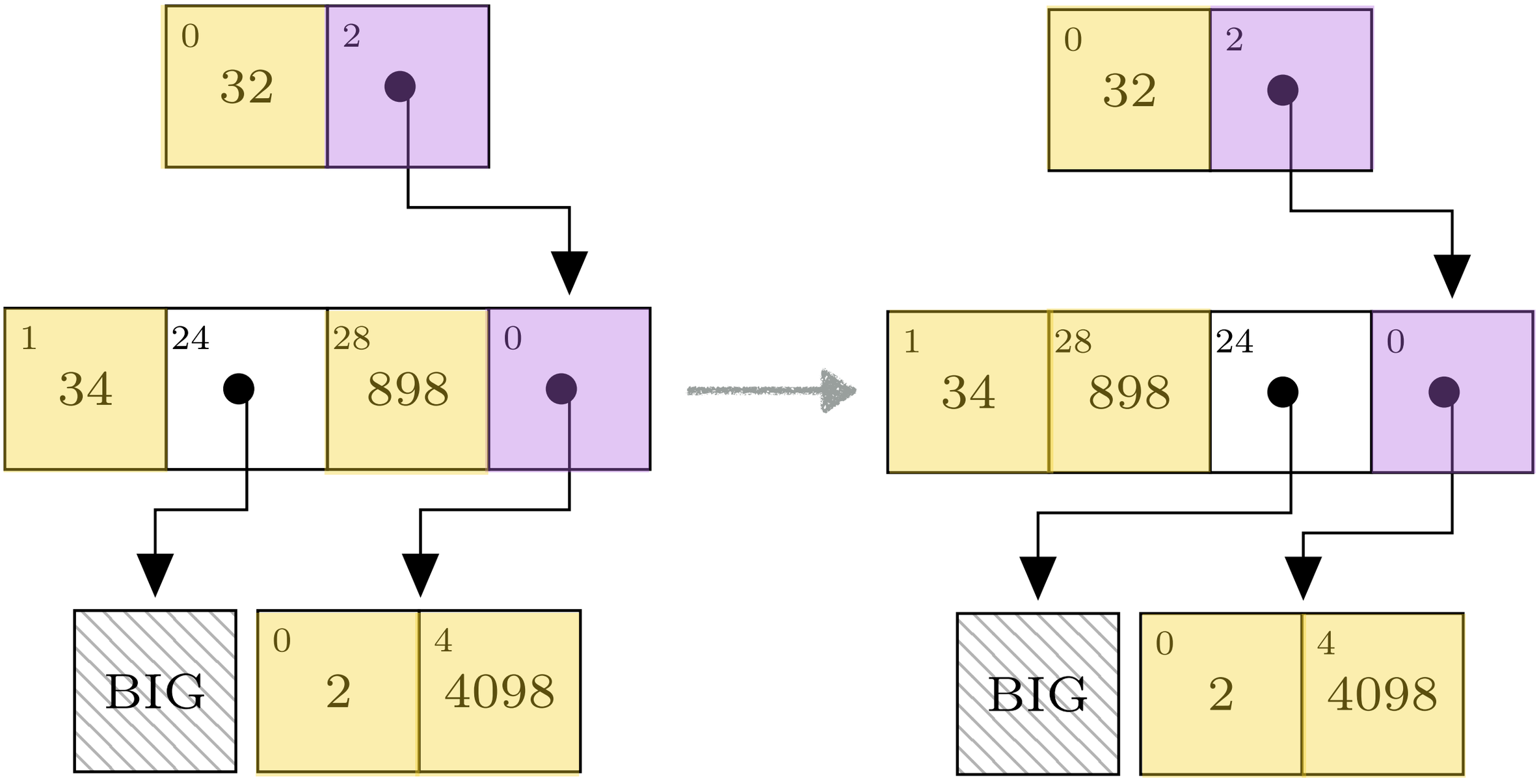
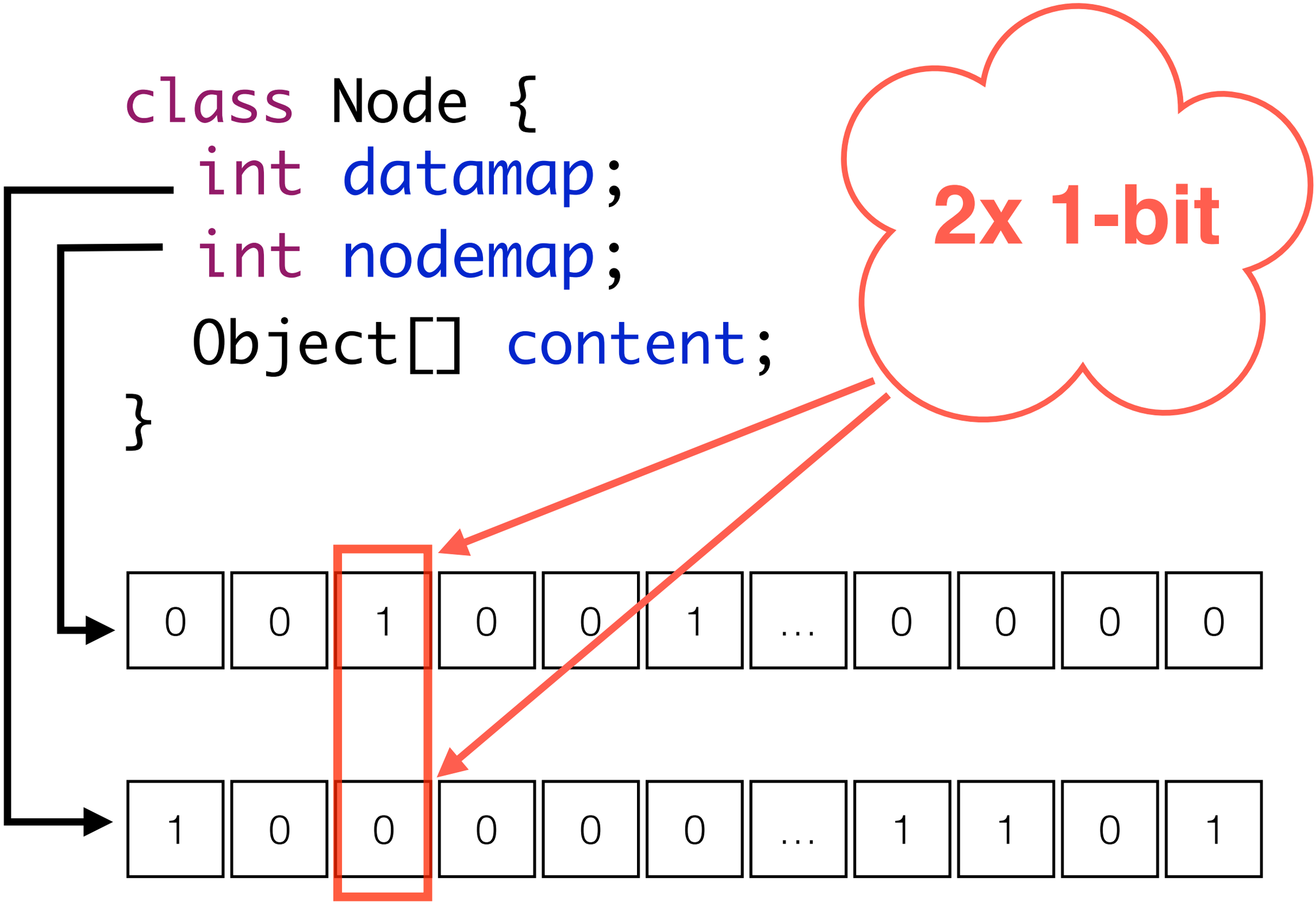


Steindorfer, M. J., & Vinju, J. J. (2016). Fast and Lean Immutable Multi-Maps on the JVM based on Heterogeneous Hash-Array Mapped Tries. To Appear.

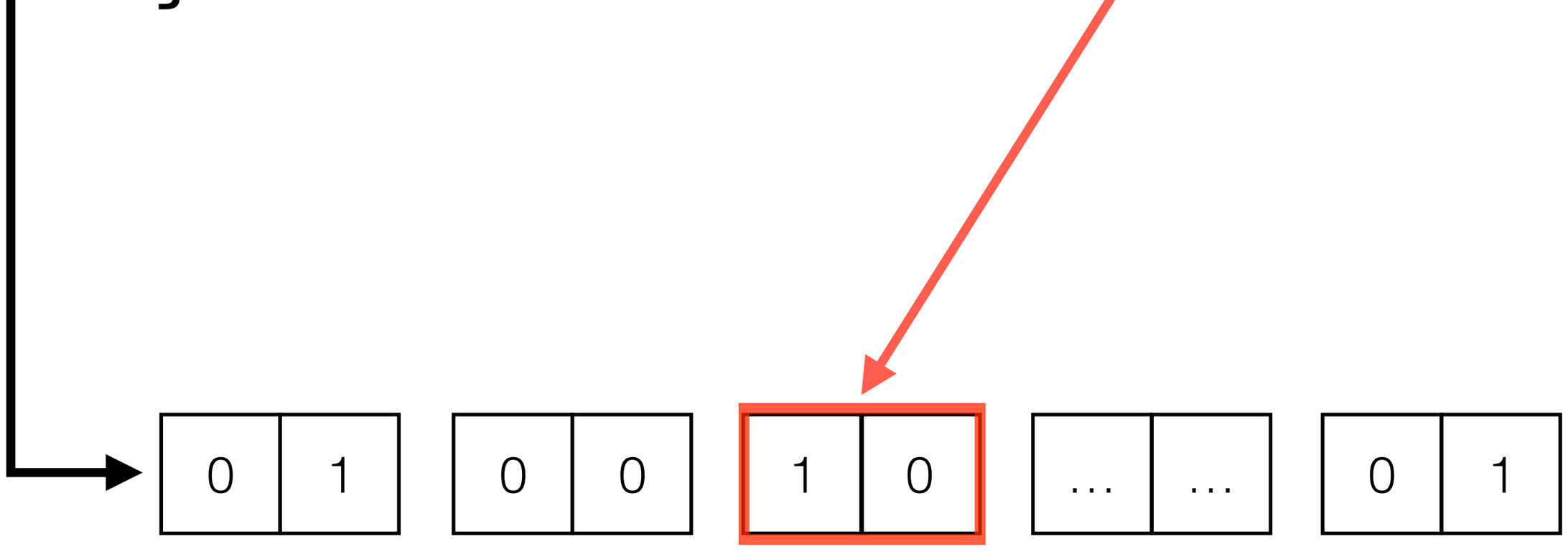
```
class Node {
  int datamap;
  int nodemap;
  Object[] content;
}
```



```
class Node {
  BitVector bitmap;

  Object[] content;
}
```

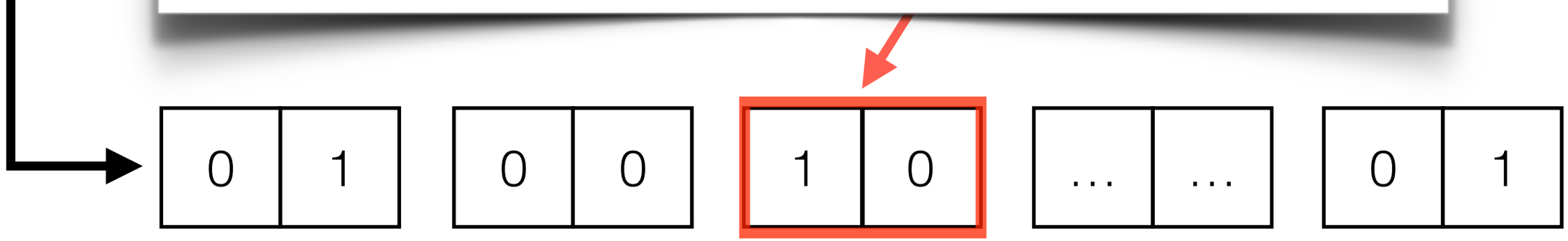
1x n-bit



```
class Node {
    BitVector bitmap;
```

Orthogonal To:

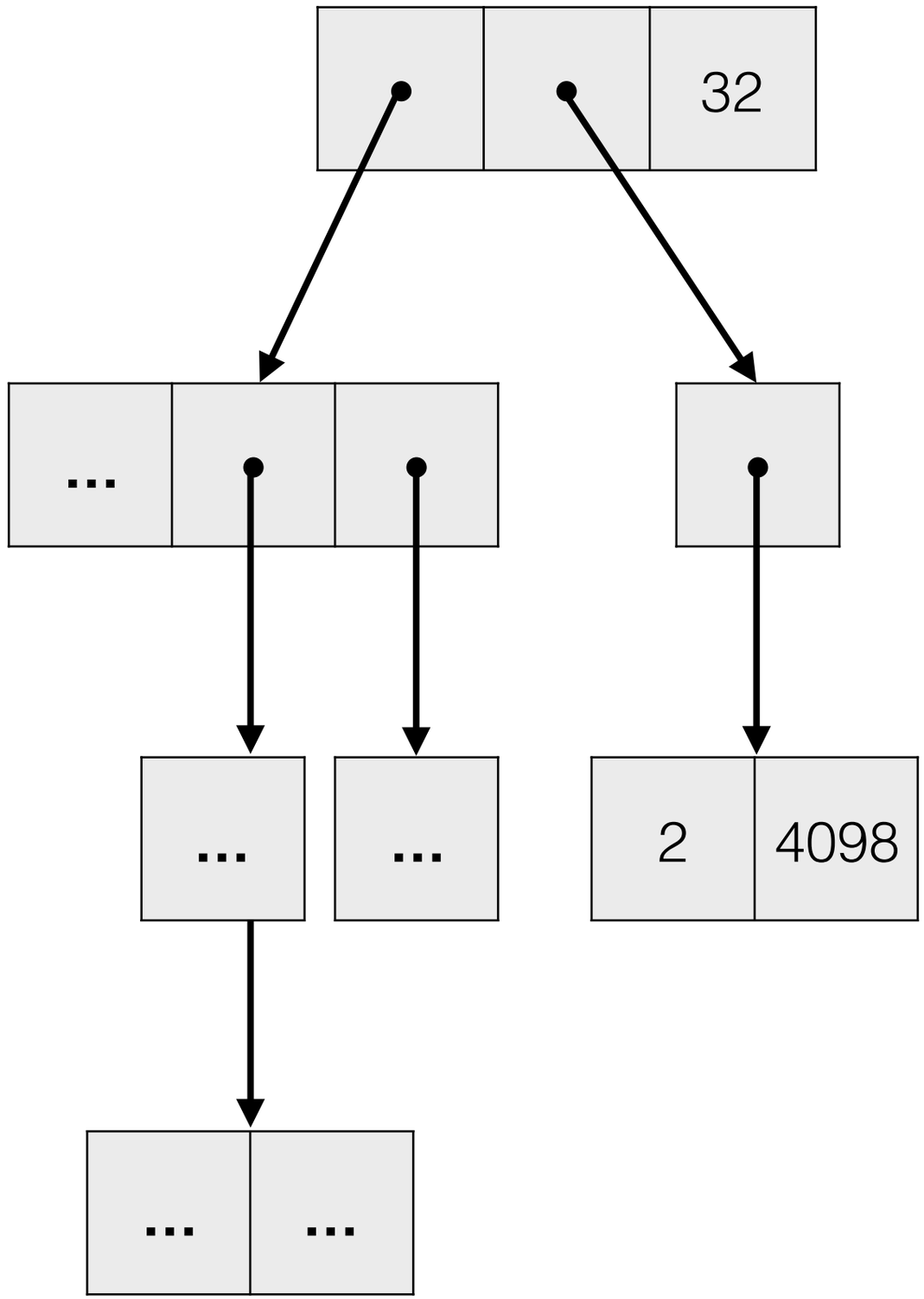
- Scala's Union Types
- Valhalla's Primitive Generics



Performance Challenges

Trees (as fast) as Arrays?

Improving Locality between Nodes.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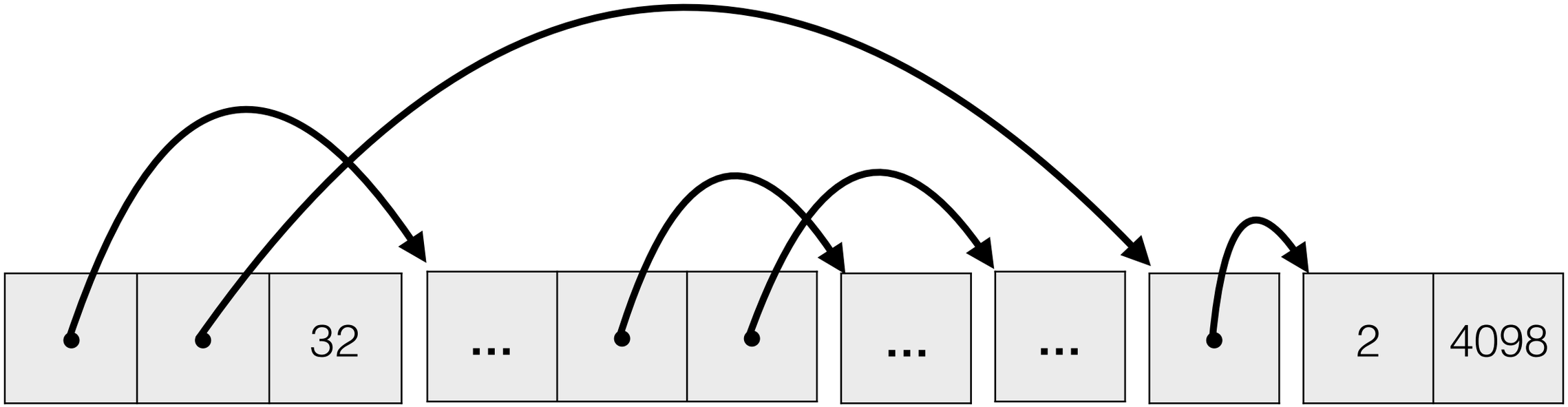
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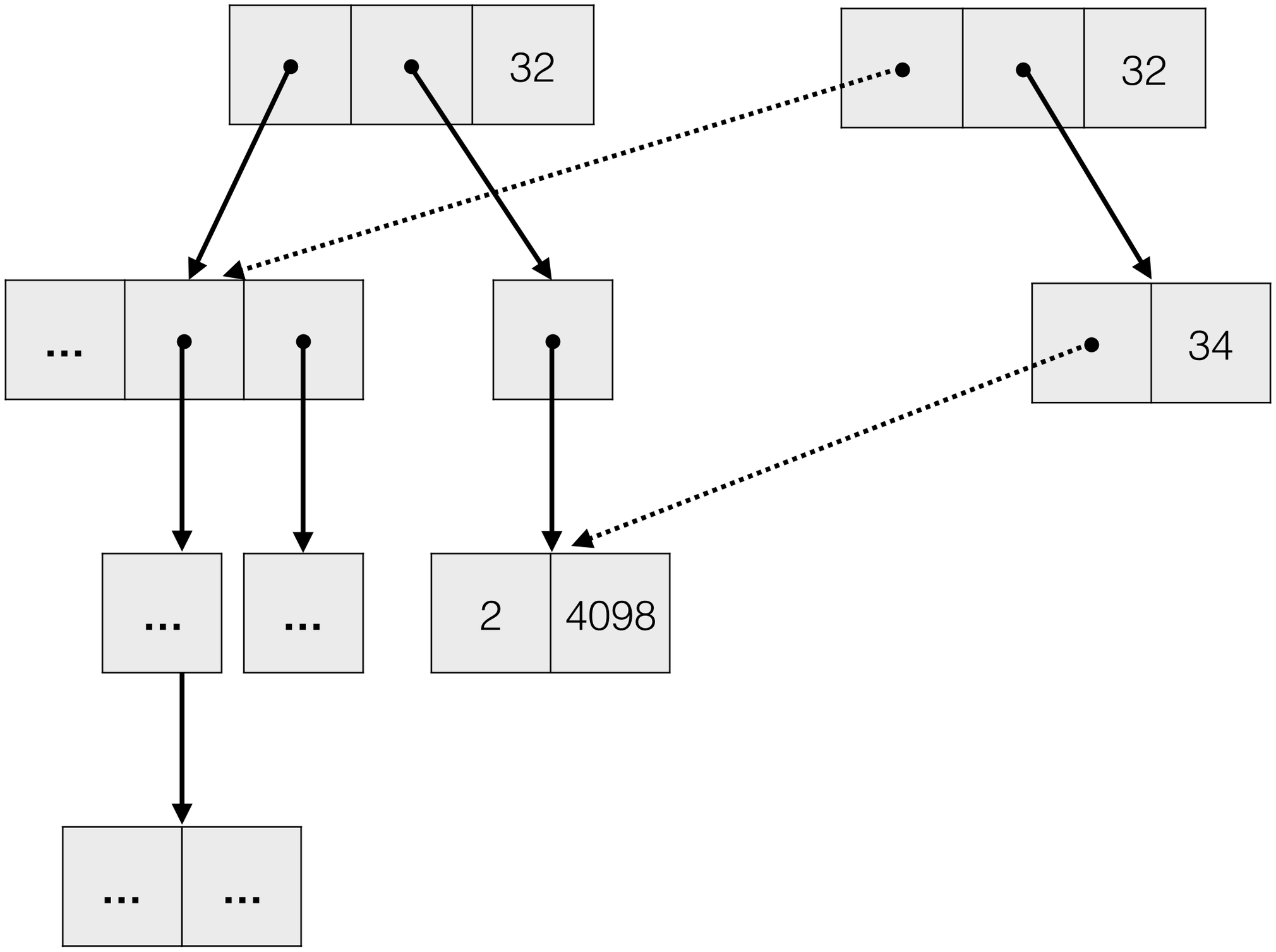
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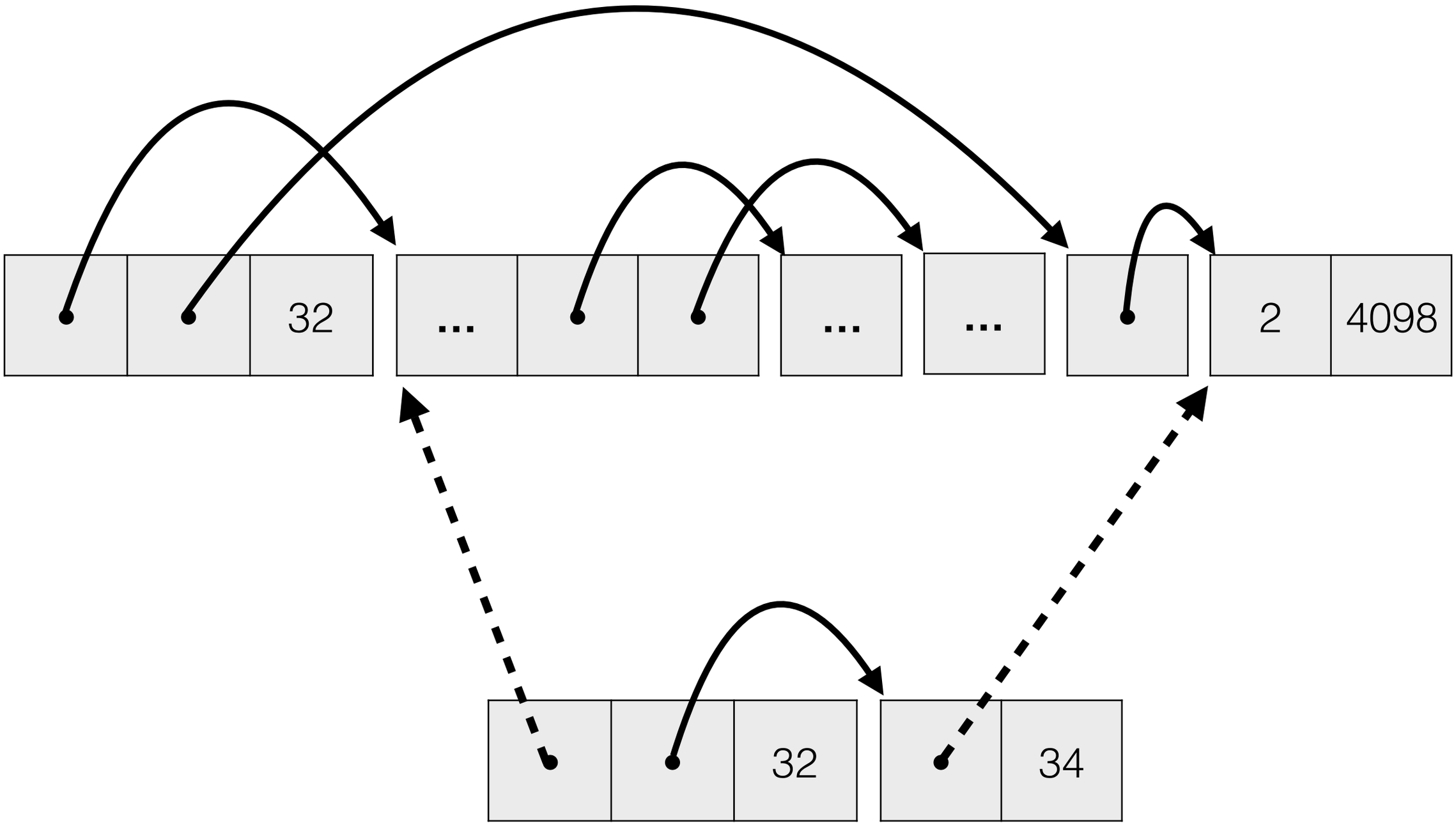
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Trees (as fast) as Arrays!

Summary

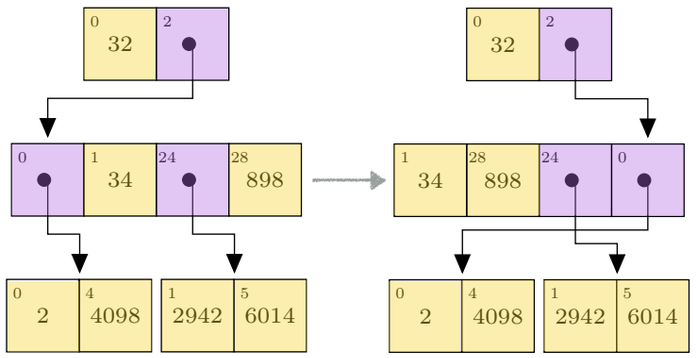
Clojure
http://clojure.org

Rascal
http://rascal-mpl.org

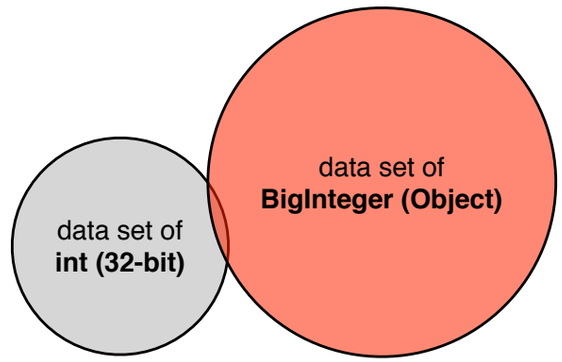
Scala
http://scala-lang.org

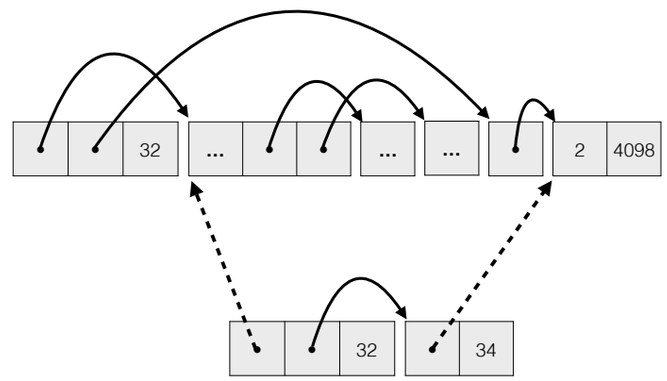

```
class ArrayList32 {
  Object[] content;
}
```

```
class List1 implements
    ImmutableList {
  Object slot0;
}

class List2 implements
    ImmutableList {
  Object slot0;
  Object slot1;
}

class List3 implements
    ImmutableList {
  Object slot0;
  Object slot1;
  Object slot2;
}

...
```

HETEROGENEOUS COLLECTIONS





```
Map<String, Long> wordCount = phrases.stream()
    .flatMap (toWordStream)
    .filter  (word -> word.length() > 0)
    .map     (word -> new Tuple<>(word, 1L))
    .collect (groupingBy(Tuple::getKey, counting()));
```

MISSING: IMMUTABLE COLLECTIONS

```
Map<String, Long> wordCount = phrases.stream()
    .flatMap (toWordStream)
    .filter  (word -> word.length() > 0)
    .map     (word -> new Tuple<>(word, 1L))
    .collect (groupingBy(Tuple::getKey, counting()));
```

usethesource/capsule

The Capsule Hash Trie Collections Library

Immutable Collections

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twitter: @loopingoptimism