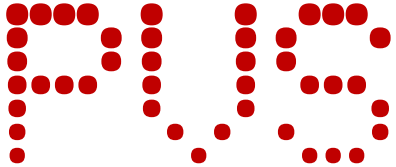
Empirical Study of Usage and Performance of Java Collections

[1]Diego Costa, [1]Artur Andrzejak, [1]Janos Seboek, [2]David Lo

[1]Heidelberg University, [2]Singapore Management University



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Published as:

Diego Costa, Artur Andrzejak, Janos Seboek, and David Lo. 2017. Empirical Study of Usage and Performance of Java Collections. In Proceedings of the 8th ACM/SPEC on International Conference on Performance Engineering (ICPE '17), L'Aquila, Italy — April 22 - 26, 2017

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Collections

- Collections are objects that **groups** multiple elements into a single unit.
  - Use its metadata to track, access and manipulate its elements

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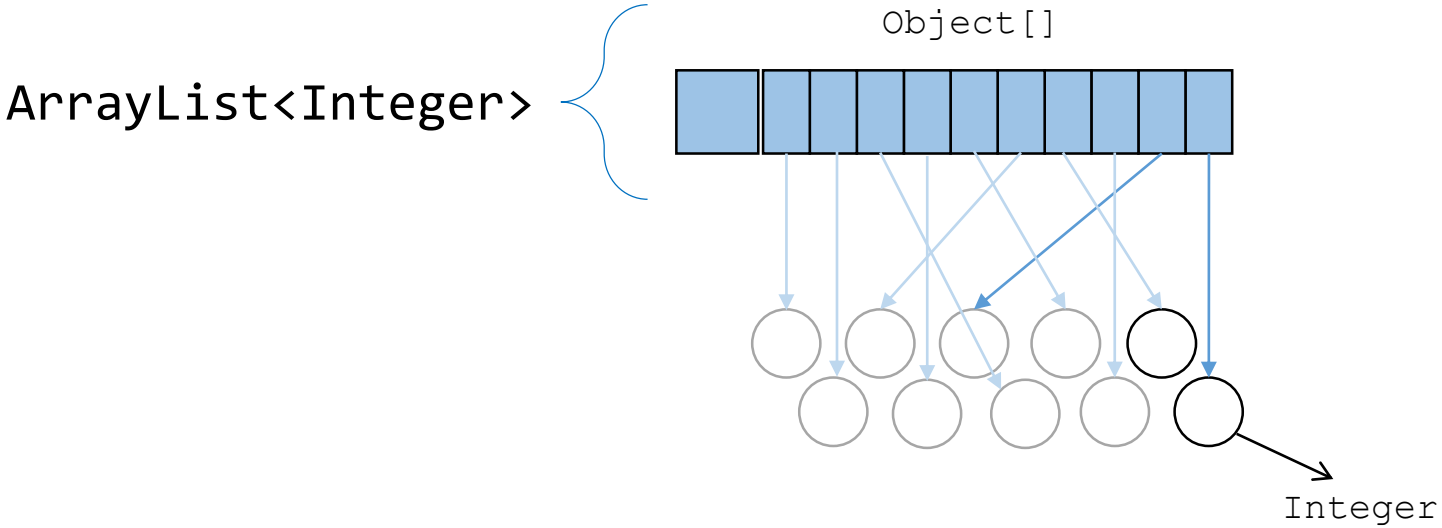

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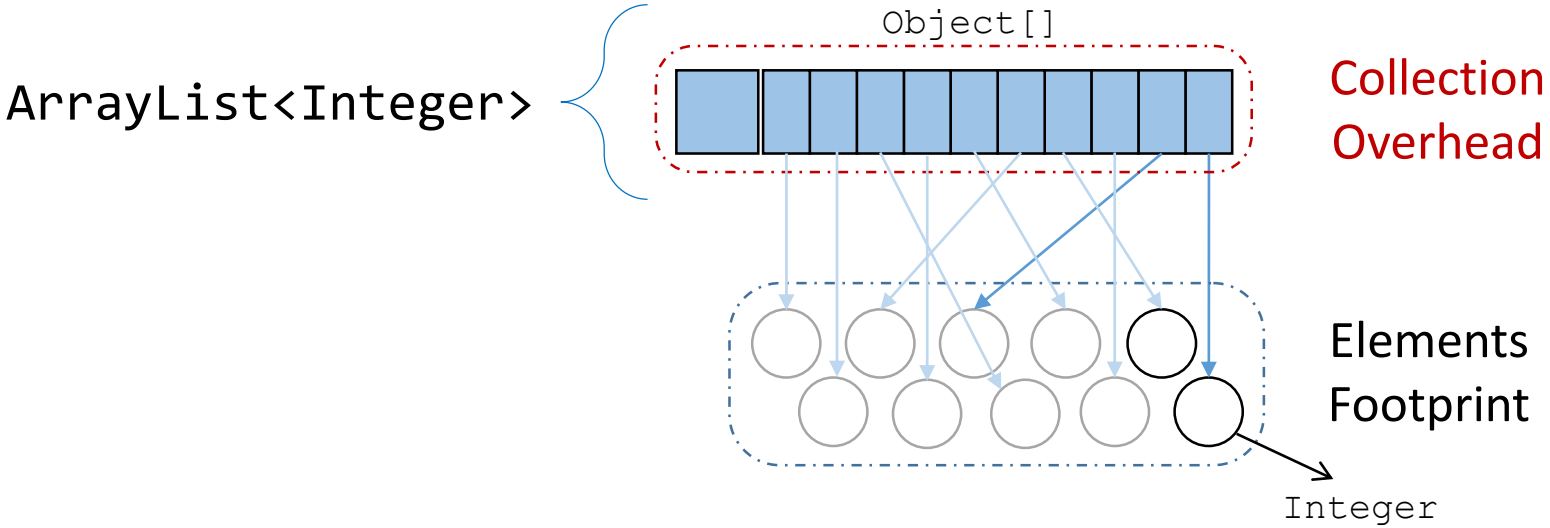

Motivation

- Numerous studies have identified the inefficient use of collections as the main cause of runtime bloat

Execution Time	Memory Usage	Energy Consumption
+17% Improv.	**+54% Improv.**	**+300% Improv.**
Configuration of one HashMap instance	Use of ArrayMaps instead of HashMaps	Use of ArrayList instead of LinkedList
[Liu et al. 2009]	[Ohad et al. 2009]	[Jung et al. 2016]

Collection Frameworks

- The Java Collection Framework offers a **Standard** implementation of the major collection abstractions
  - Stable and reliable framework
  - Easy to use
- However, there exist alternative libraries that provide a myriad of different implementations:
  - Primitive Collections (`IntArrayList`)
  - Immutable Collections
  - Multimaps (`Map<K, Collection>`)
  - Multisets (`Map<K, int>`)

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Unsupported features

Simplified API

Analysis of Performance Impact of Alternative Collections

Goal: Can we find alternatives to the Standard collection types which improve performance on time/memory?

1. Study on Collections Usage
   - How often do programmers use alternative implementations?

2. Experimental Evaluation of popular Java Collection Libraries
   - Are there better alternatives to the most commonly used Collections regarding performance?

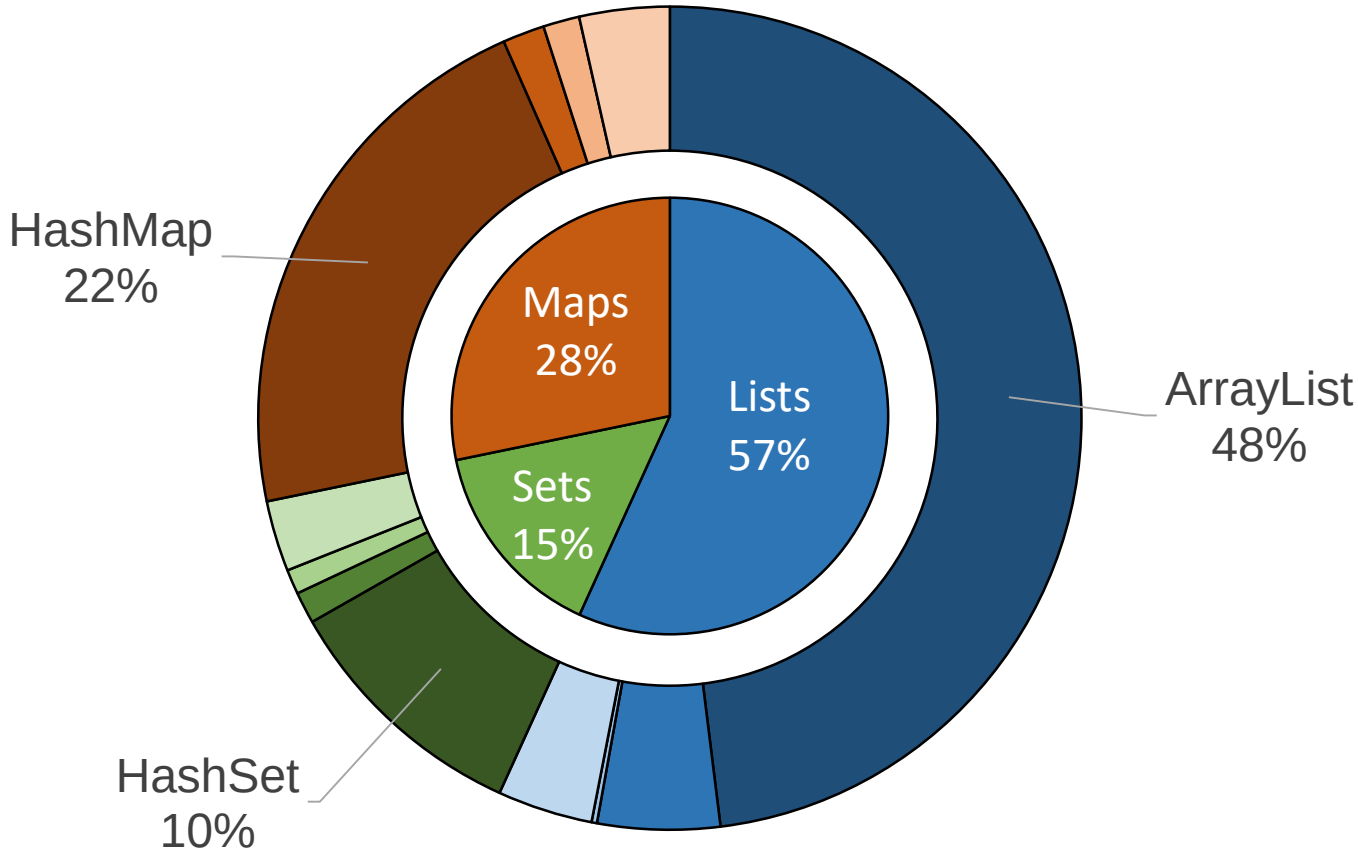
Study on Usage of Collections

- Dataset
  - We analyze the **GitHub Java Corpus**
    - 10K projects
    - 268 MLOC

- Static Analysis
  - Use of Java Parser to extract variable declaration and allocation sites of Types with suffix:

    {List, Map, Set, Queue, Vector}
  - Manually removed false-positives

Developers Rarely Use non-Standard Collections



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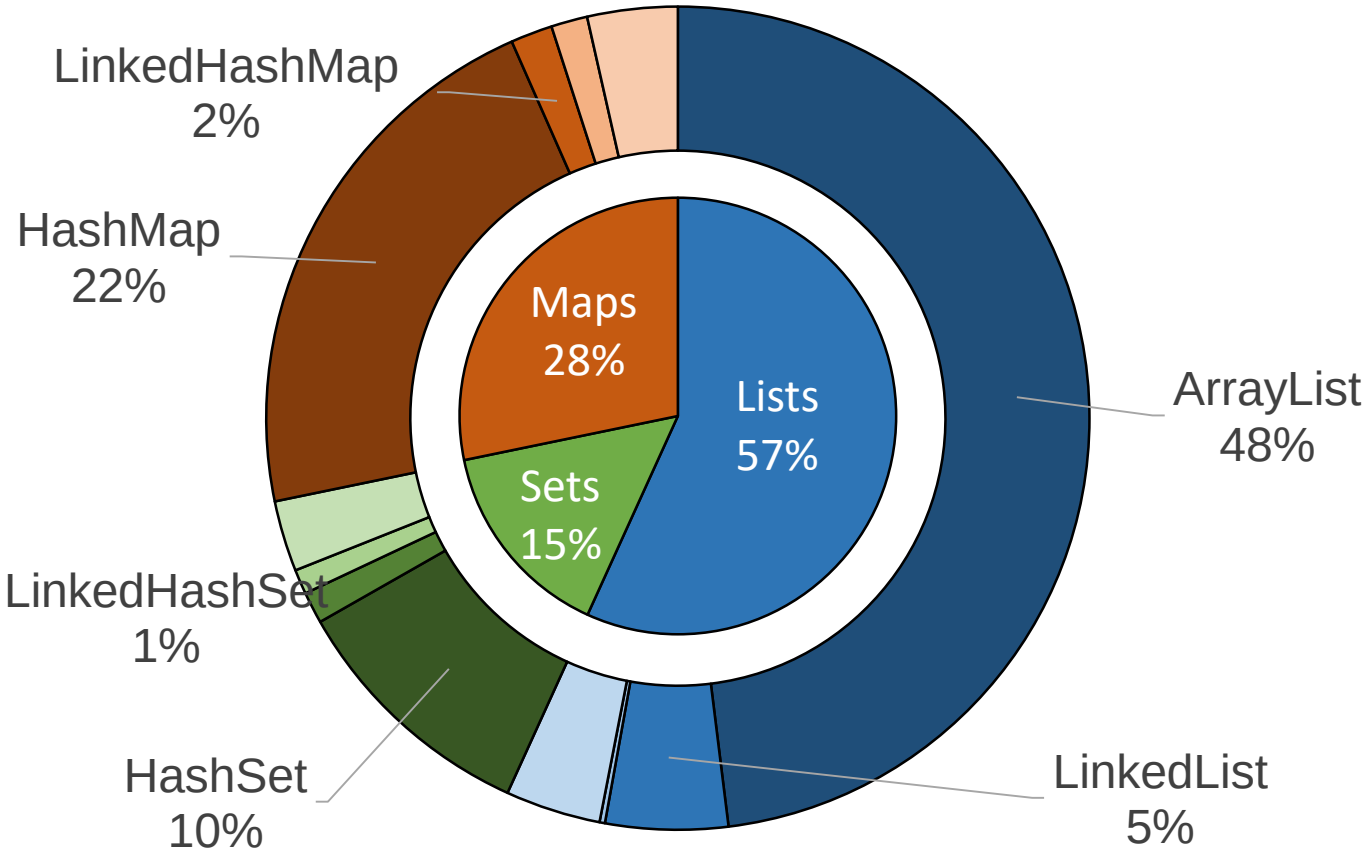

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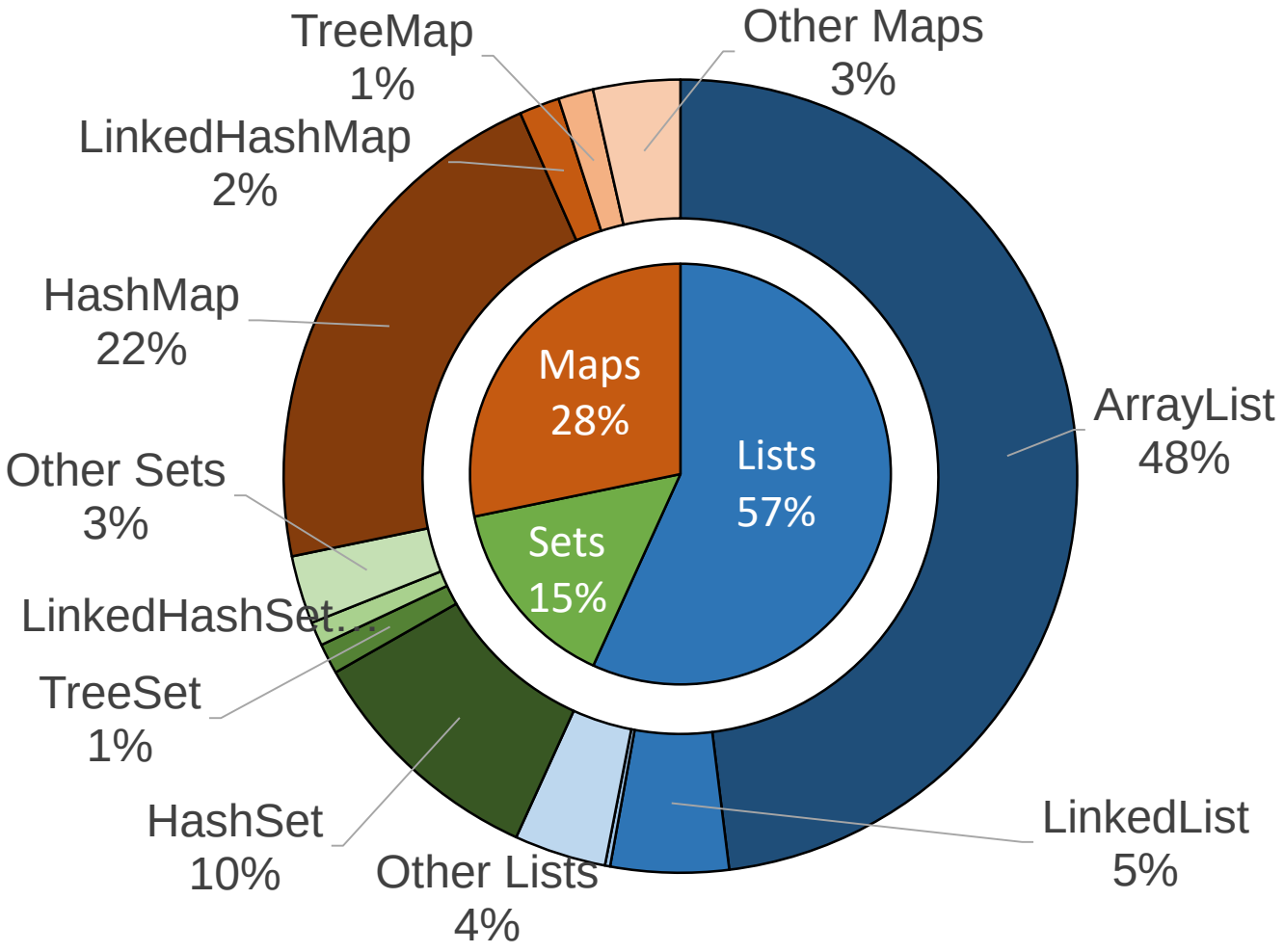
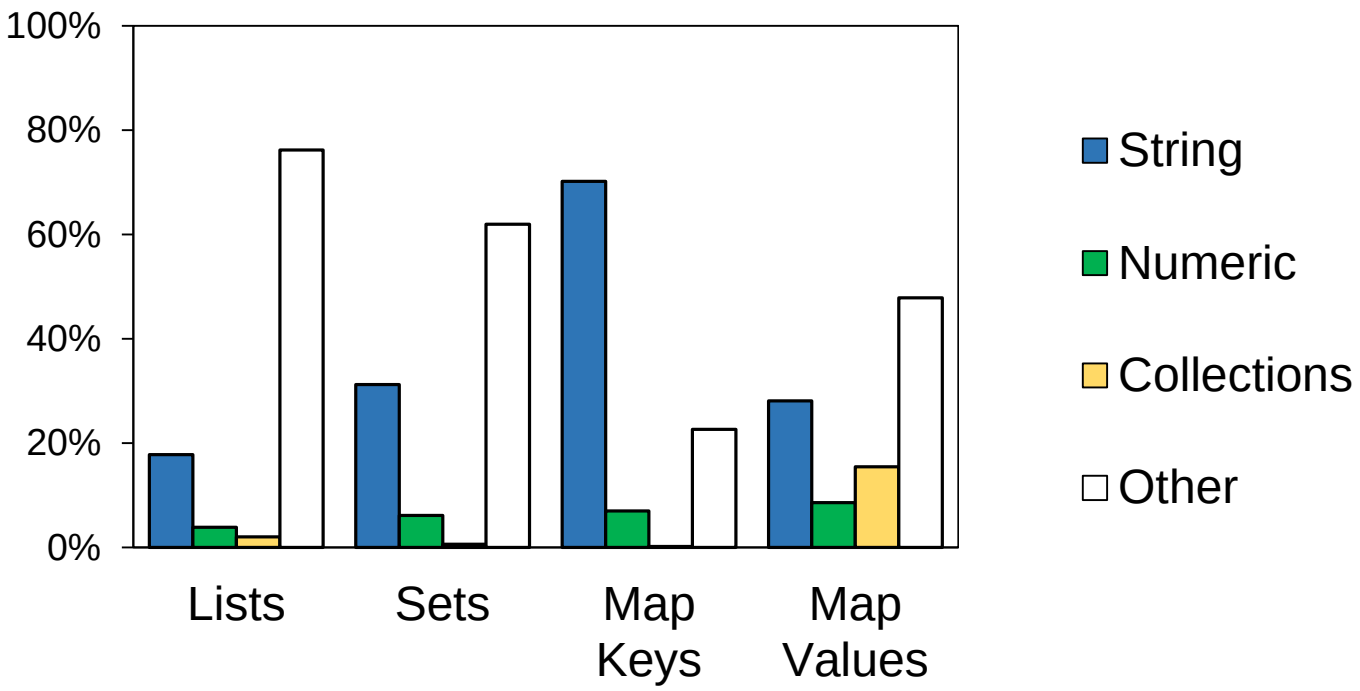


- Top 4 represent **86%** of all declared instantiations
- Non-Standard collections are declared **<4%**

Evaluate alternatives to ArrayList, HashMap, HashSet and LinkedList

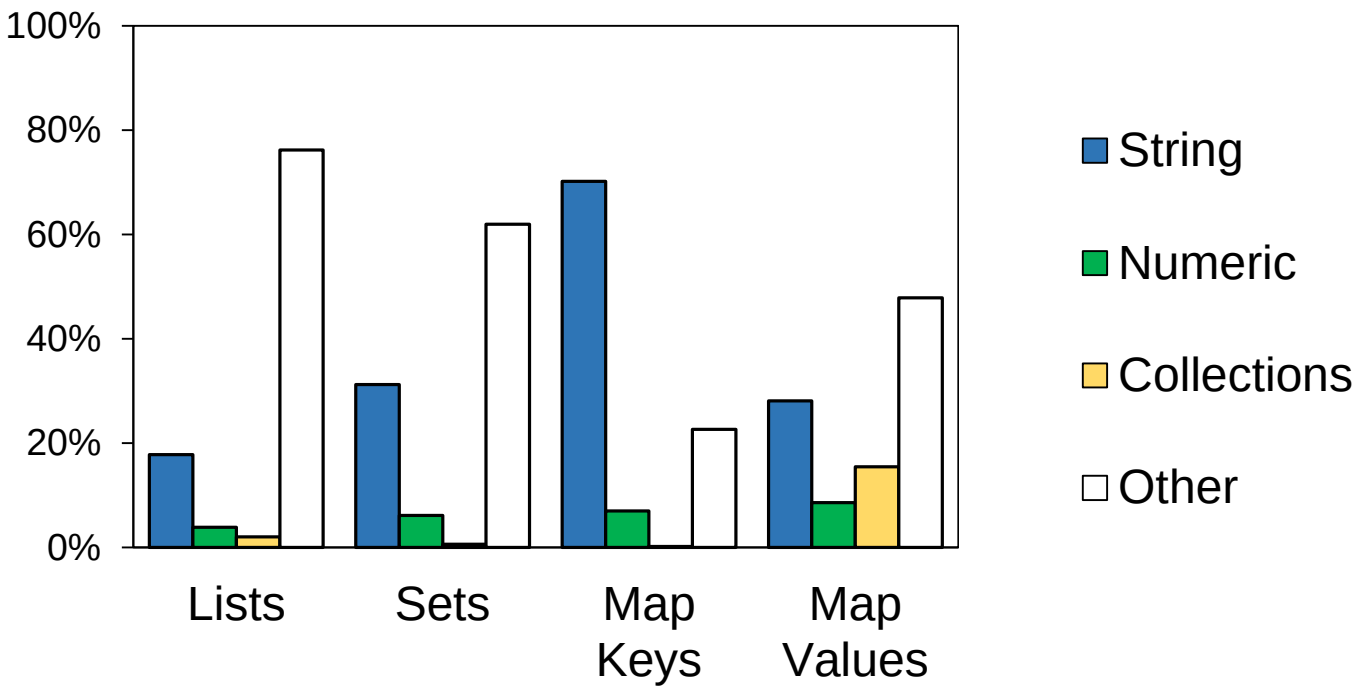
Commonly Used Element Data Types



From the categorized data types:

- Strings are the most commonly held data type, followed by Numeric

Commonly Used Element Data Types



From the categorized data types:

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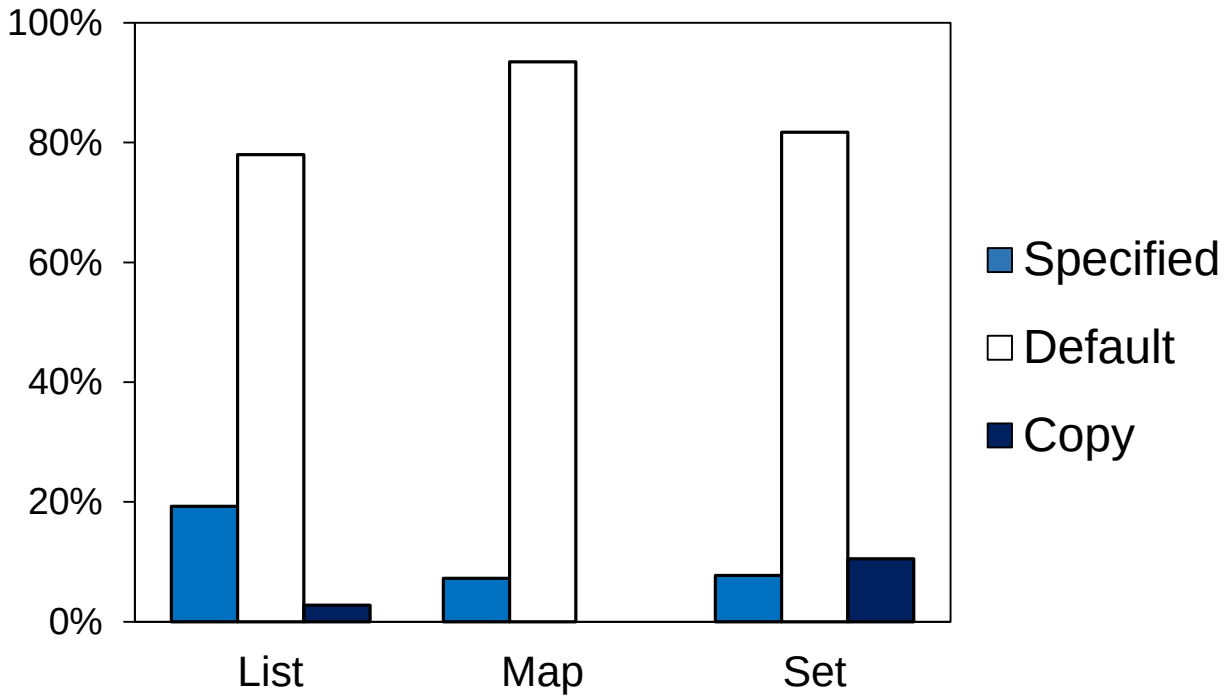
Evaluate collections holding Strings, Integer and Long

Initial Capacity is Rarely Specified



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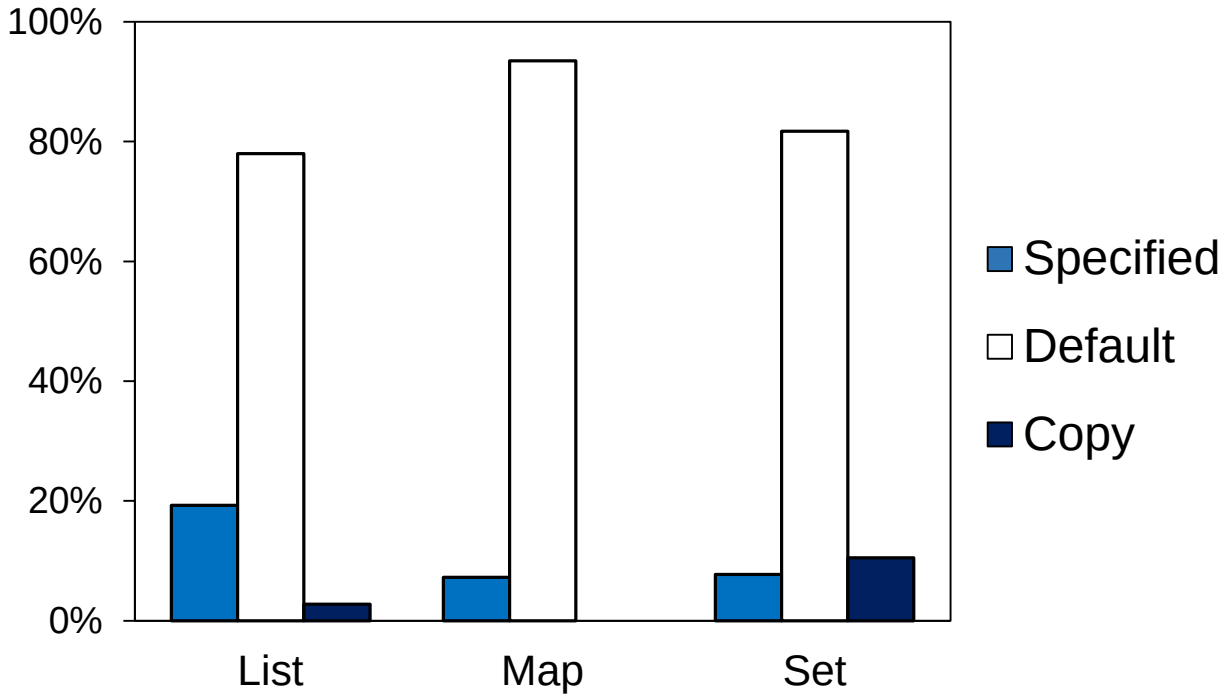

Evaluate collections with default Initial Capacity

Superior Alternatives

- **Superior Alternative:** a Non-Standard implementation that can outperform a Standard counterpart in terms of execution time and/or memory consumption.

- Can we find a superior alternative to the most commonly used collection types?

Experimental Study on Java Collections

- We selected 6 alternative libraries:
  - Repository Popularity (GitHub)
  - Appearance in previous partial benchmarks

Libraries	**Version**	**JCF Compatible**	**Available at**
Trove	3.0.3	yes	trove.starlight-systems.com
Guava	18.0	yes	github /google/guava
GSCollections	6.2.0	yes	/goldmansachs/gs-collections
HPPC	0.7.1	no	/carrotsearch/hppc
Fastutil	7.0.10	yes	/vigna/fastutil
Koloboke	0.6.8	yes	/leventov/Koloboke

Experimental Study on Java Collections

- Seven typical scenarios evaluated
  - populate, iterate, contains, get, add, remove, copy
- Collections holding from 100 to 1 million elements
- Alternatives to the most commonly used collections
  - JDK 1.8.0_65
  - ArrayList, HashMap, HashSet and LinkedList
    - Object collection alternatives
    - Primitive collection alternatives

CollectionsBench Suite

- We create a benchmark suite: **CollectionsBench**
  - Open Java Microbenchmark Harness

```
@Setup
public void setup() {
  fullList = this.createNewList();
  fullList.addAll(values); // Randomly
}                            generated

@Benchmark
public void iterate() {
  for (T element : fullList) {
    blackhole.consume(element);
   // Blackholes avoid dead-code
   // optimization
  }
}
```

CollectionsBench Suite

- We create a benchmark suite: **CollectionsBench**

Only the instantiation is needed for each collection type*

```
@Setup
public void setup() {
  fullList = this.createNewList();
  fullList.addAll(values); // Randomly
                           generated
}
```

```
return new ArrayList<T>();
return new LinkedList<T>();
return new FastList<T>();
```

```
@Benchmark
public void iterate() {
  for (T element : fullList) {
    blackhole.consume(element);
   // Blackholes avoid dead-code
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  }
}
```
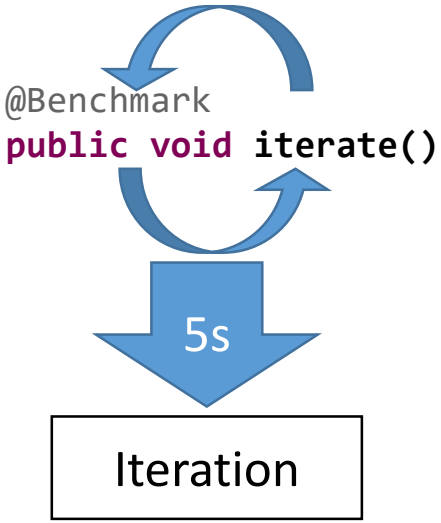

Here we measure:

- Execution time (ns)
- Collection Overhead (allocation)
  - GC Profiler

Experimental Planning

- To accomplish a **steady state** performance evaluation:



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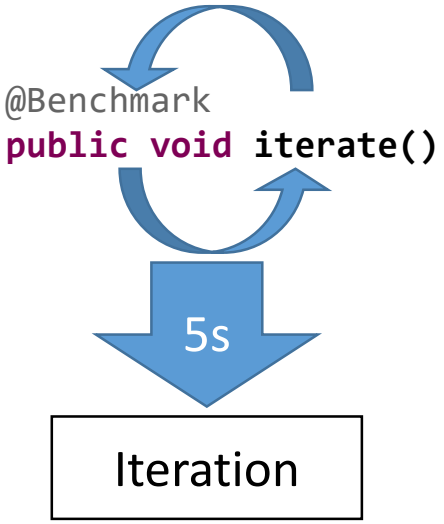

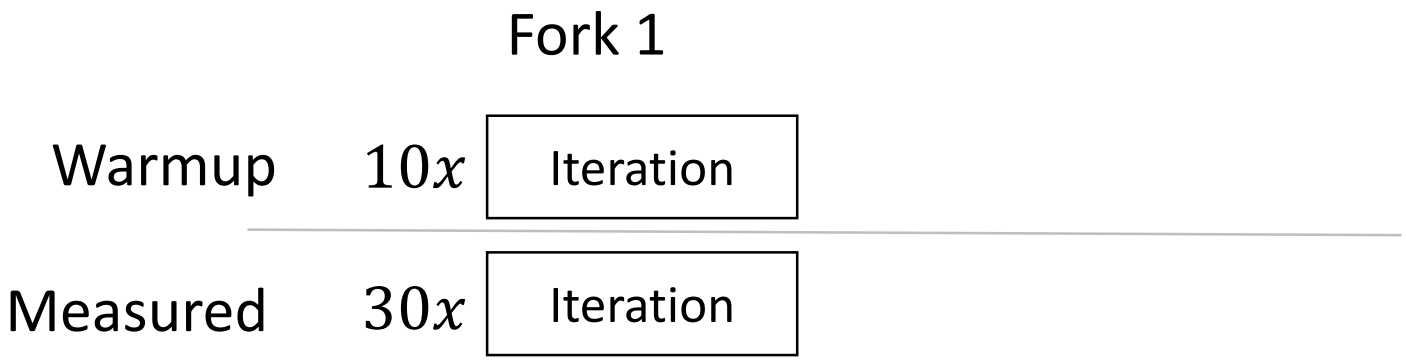

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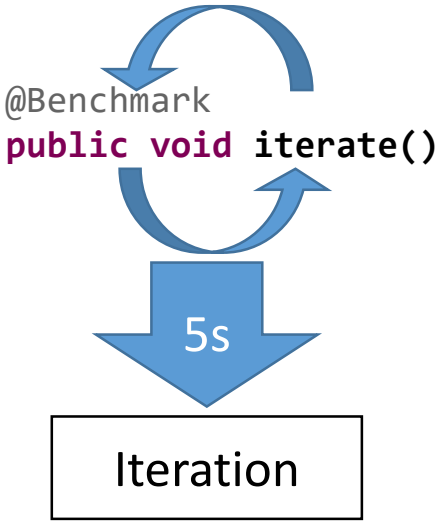

		Fork 1		Fork 2
Warmup	$10x$	Iteration	$10x$	Iteration
Measured	$30x$	Iteration	$30x$	Iteration

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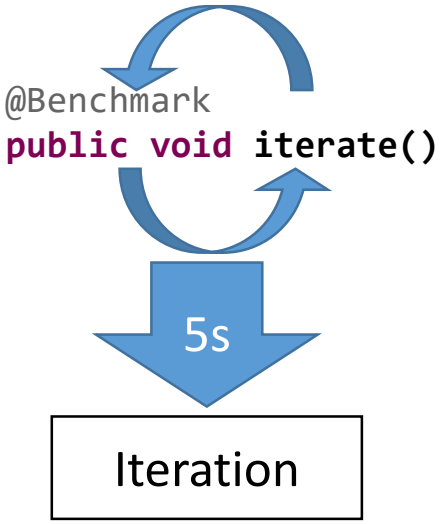

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Warmup	$10x$	Iteration	$10x$	Iteration
Measured	$30x$	Iteration	$30x$	Iteration

AVG Time ± CI (99%)

AVG Memory allocated ± CI (99%)

Reporting Speedup/Slowdown

- We present the results of **alternatives** normalized to the **Standard** implementation performances.
  - Means with overlapping CI are set to **zero**

- We use the following *speedup*/*slowdown* definitions*:*

$$S = \begin{cases} \frac{T_{std}}{T_{alt}}, if \;\; T_{std} > T_{alt} \\ -\frac{T_{alt}}{T_{std}}, otherwise \end{cases}$$

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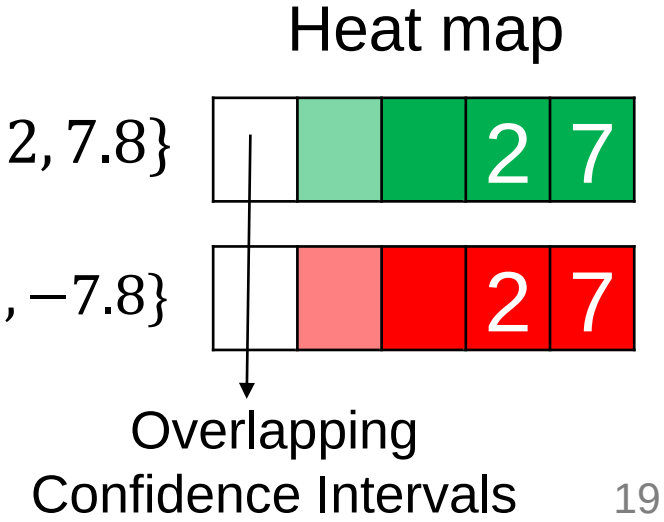
$$S = \begin{cases} \frac{T_{std}}{T_{alt}}, if \;\; T_{std} > T_{alt} \longrightarrow S = \{0, 1.5, 1.9, 2, 7.8\} \\ -\frac{T_{alt}}{T_{std}}, otherwise \longrightarrow S = \{0, -1.5, -1.9, -2, -7.8\} \end{cases}$$



Reporting Memory Overhead

- For the memory comparison we present the collection overhead reduction **per element** (with compressed object pointers)

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  For instance

  Collection X: **100** bytes per element
  Collection Y: **10** bytes per element

- Evaluated on the **copy** scenario

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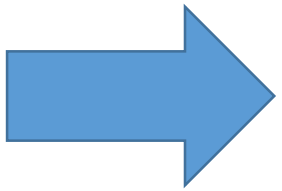
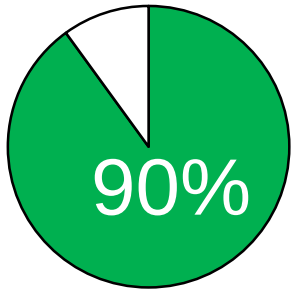


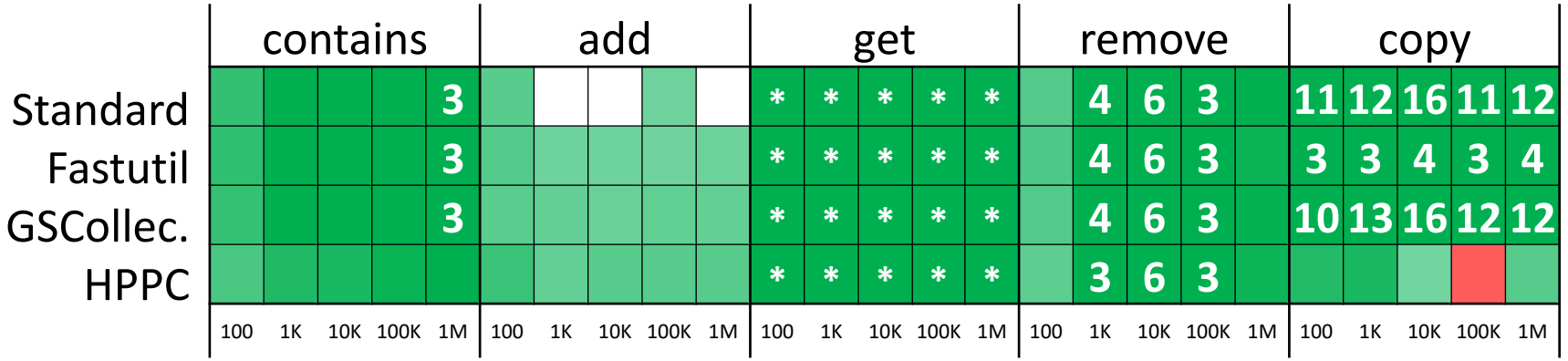


Reduction of Collection Overhead

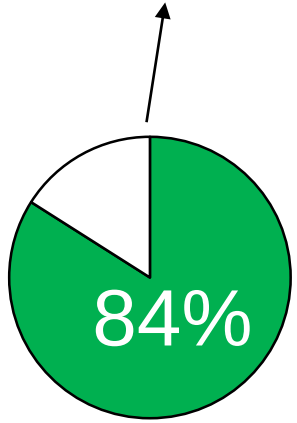
- Evaluated on the **copy** scenario

Superior Alternatives: LinkedList

- LinkedList was outperformed by **every** ArrayList alternative



JCF LinkedList$Entry consumes **24 bytes**



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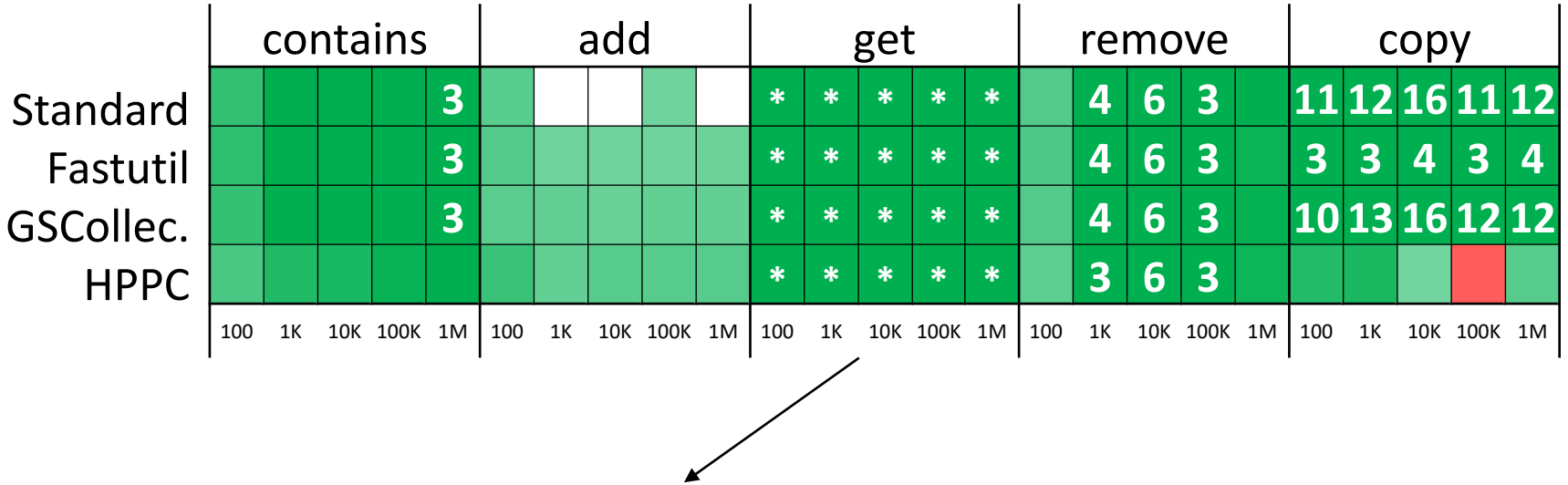

Asymptotic disadvantage

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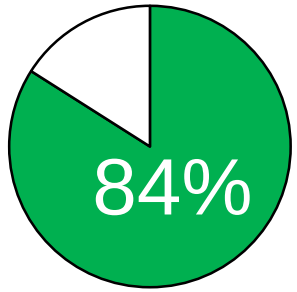

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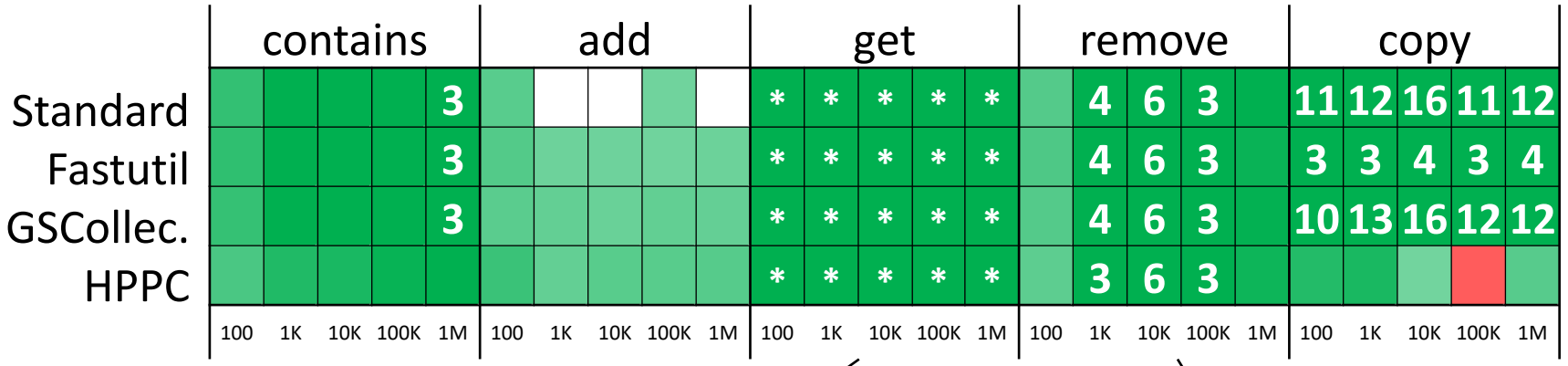

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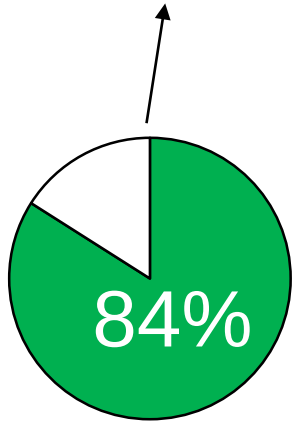
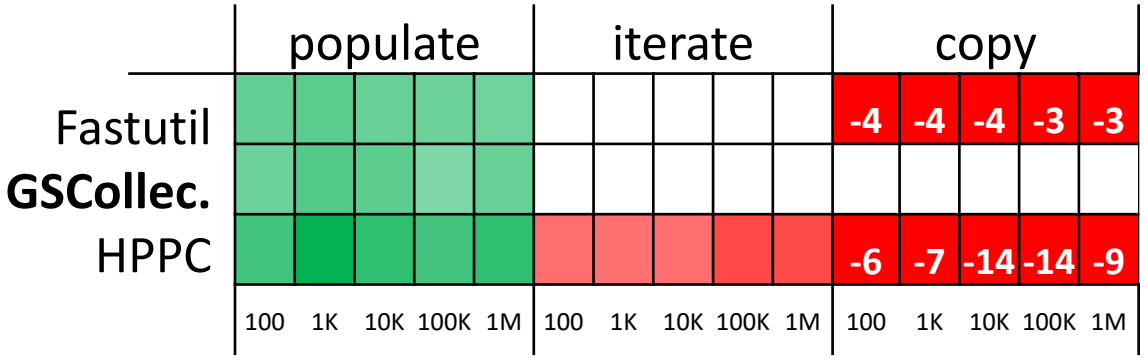


Reduction of Collection Overhead

```
public boolean remove(Object o)
```

Superior Alternatives: ArrayList

- *GSCollections* provides a superior alternative
  - Faster when populating the list (no time penalty)



No memory difference

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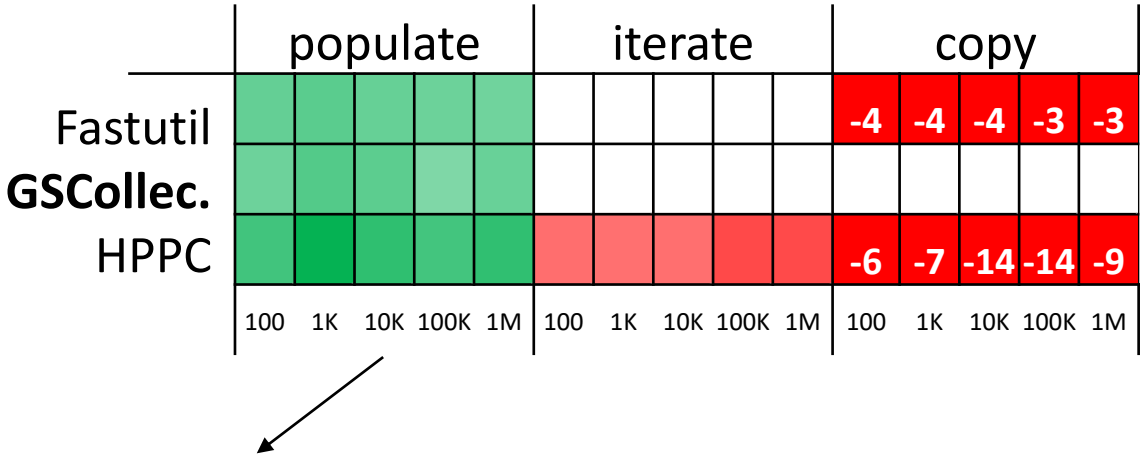

No memory difference

Distinct Array copy calls

Std: `Arrays.copyOf();`

Alt: `System.arraycopy();`

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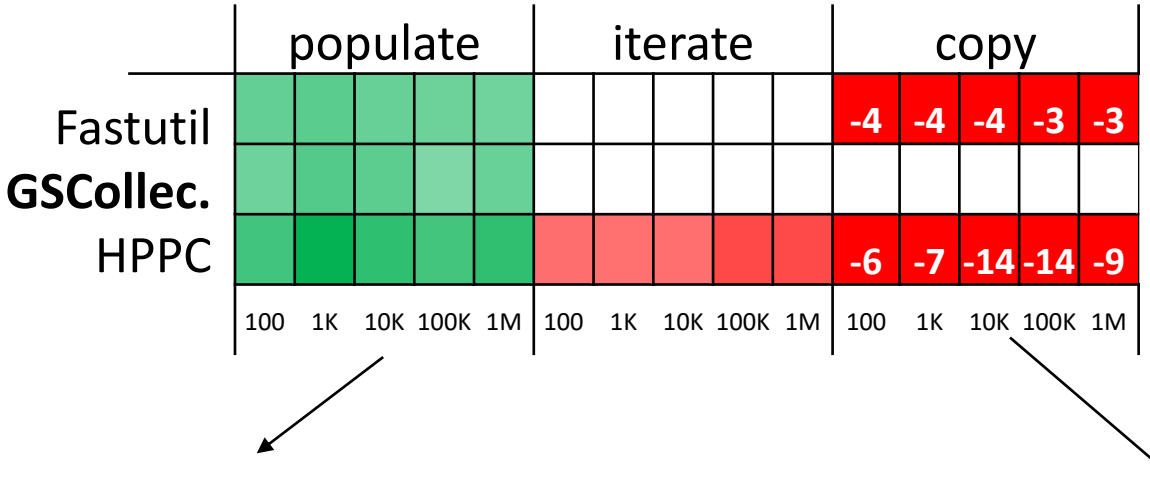

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Distinct Array copy calls

Std: `Arrays.copyOf();`

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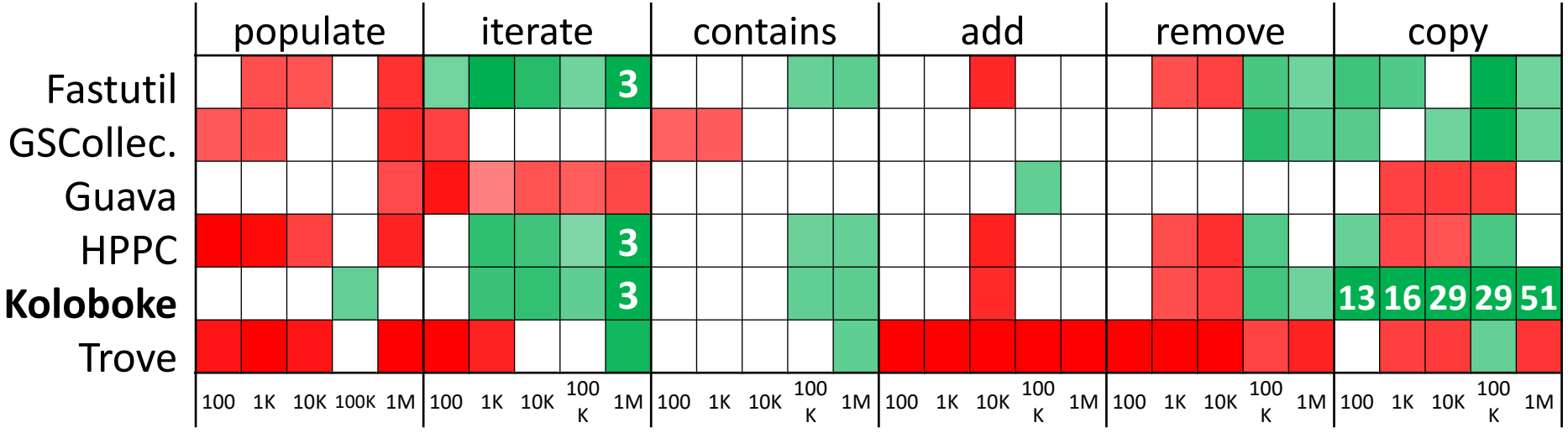
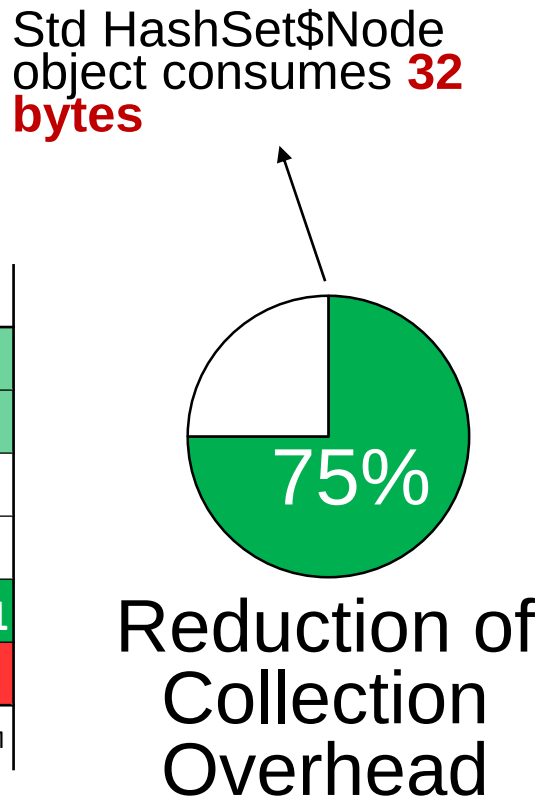
HPPC adds each element instead of copying the array

Superior Alternatives: HashSet

- Koloboke provides a superior alternative
  - Fastutil is a solid 2nd option





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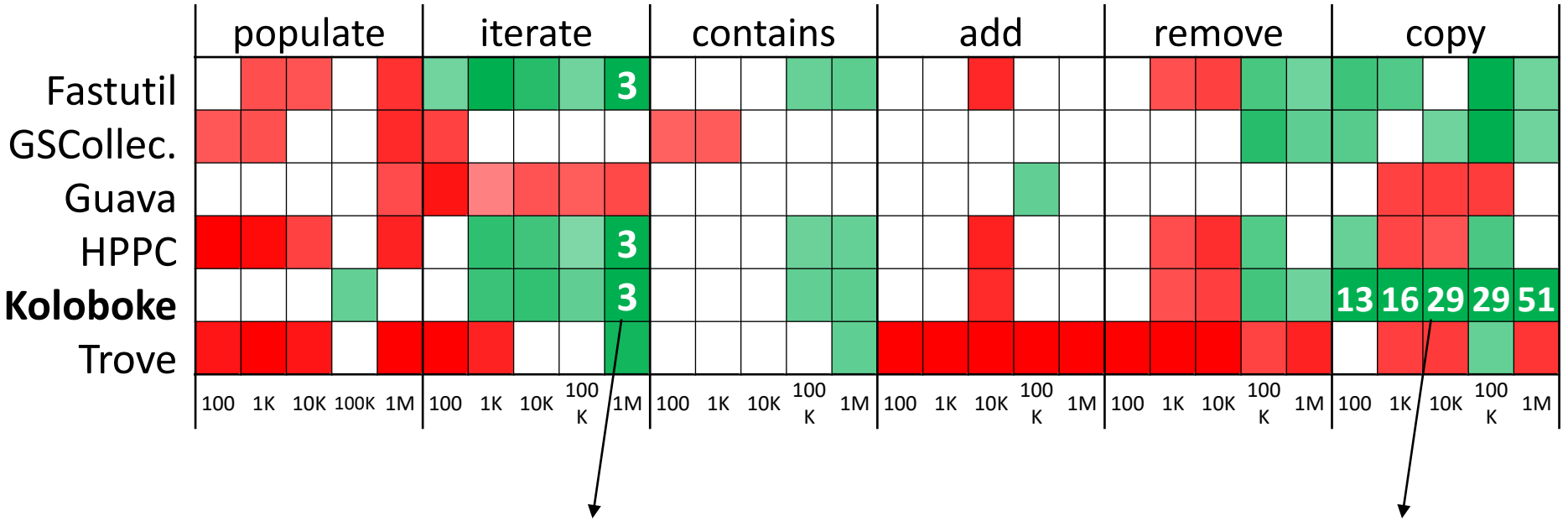
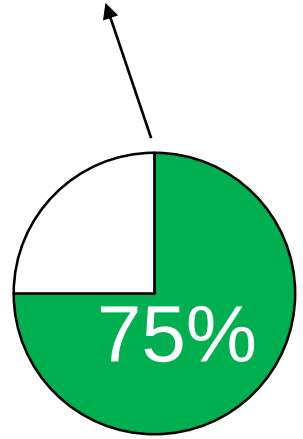


Impact of memory efficiency on time

Koloboke performs a memory copy of its HashTable

Std HashSet$Node object consumes **32 bytes**



Reduction of Collection Overhead

Superior Alternatives: HashMap

- Standard HashMap is a **solid** implementation
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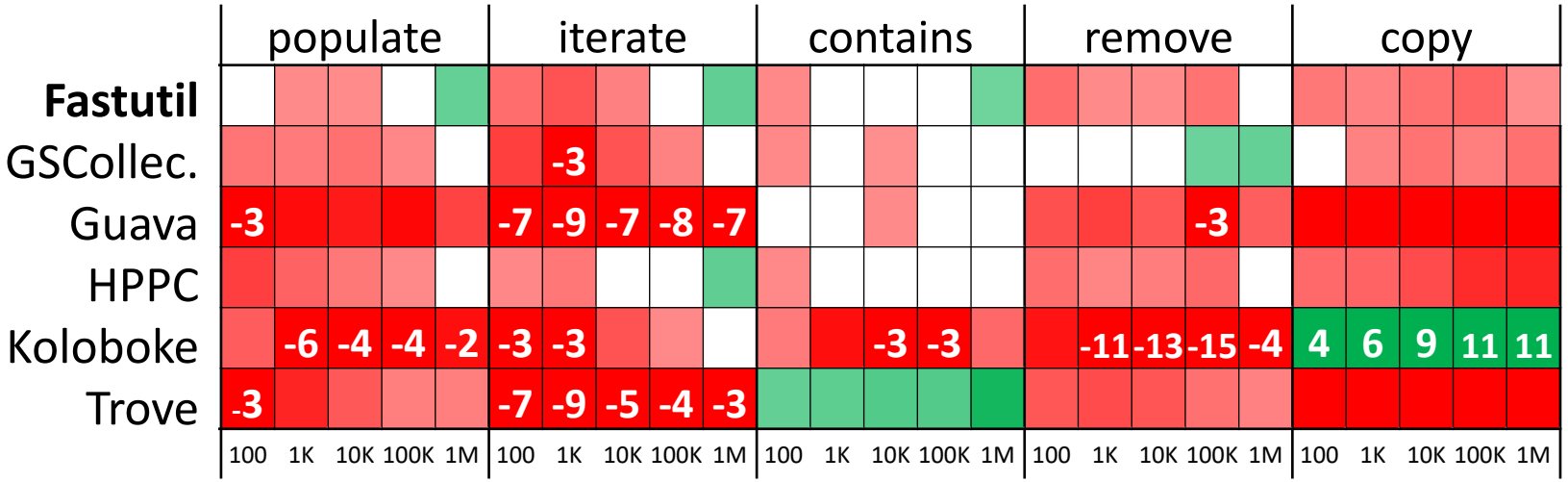

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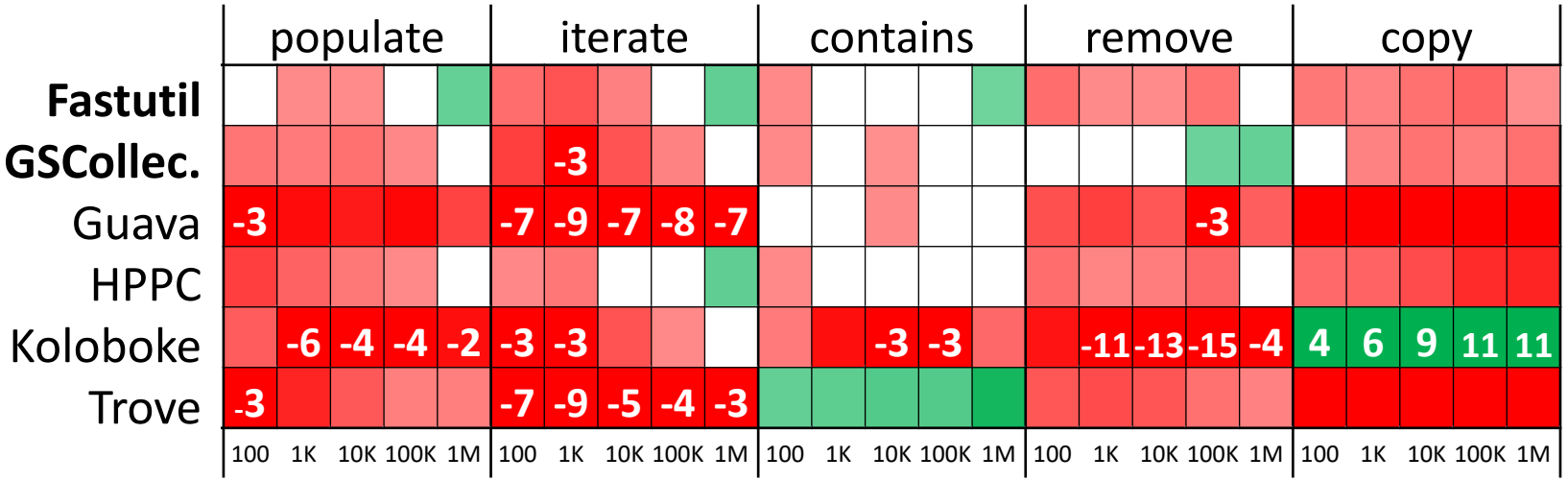
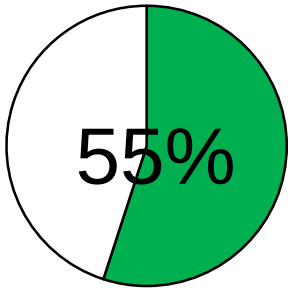


- Fastutil provides a superior alternative on memory consumption



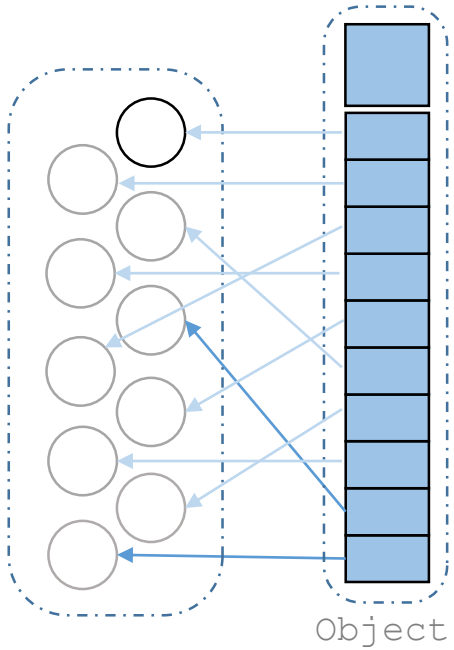
Reduction of Collection Overhead

Std. HashMap$Node object consumes **32 bytes**

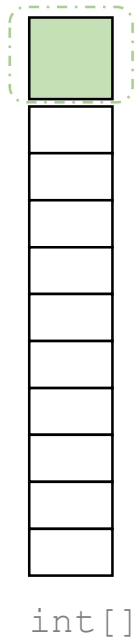
Object vs Primitive Collections

- Reducing collection footprint: overhead + element footprint

Object collection
ArrayList<>



Primitive collection
IntArrayList



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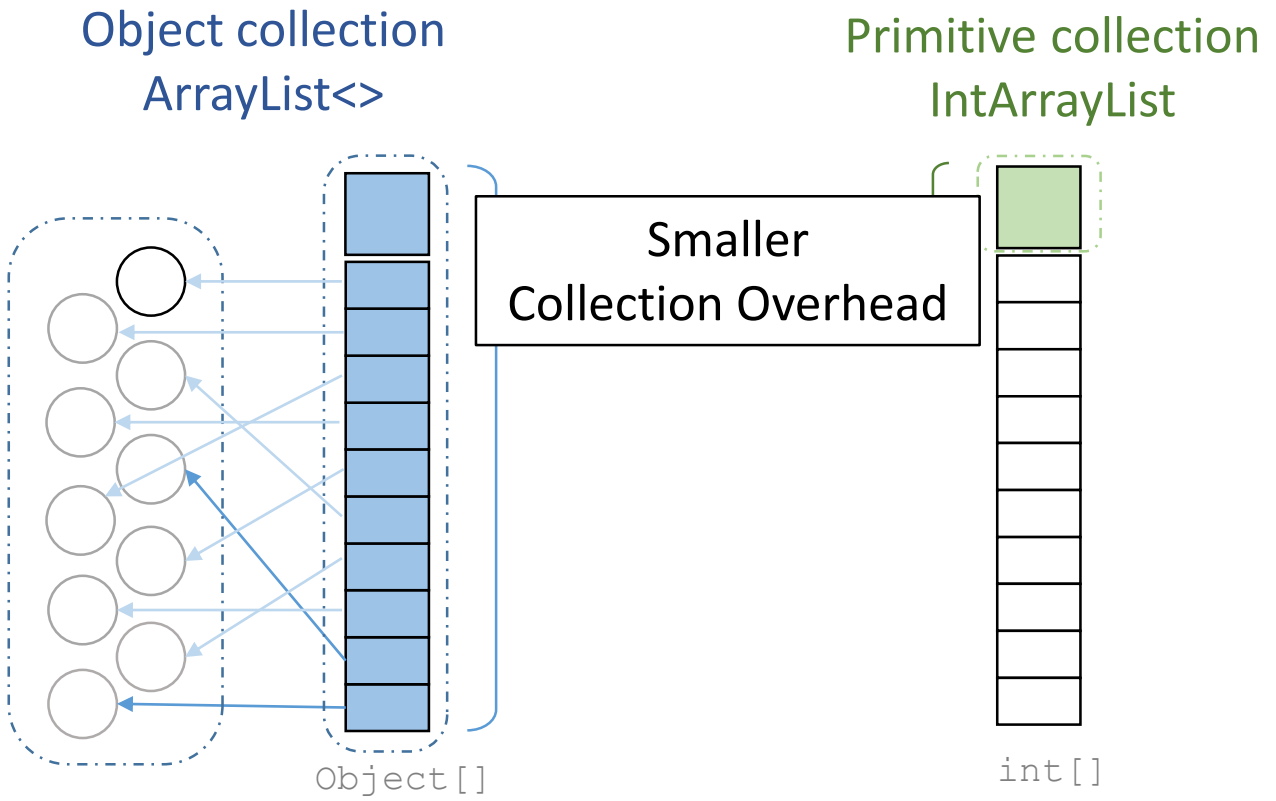

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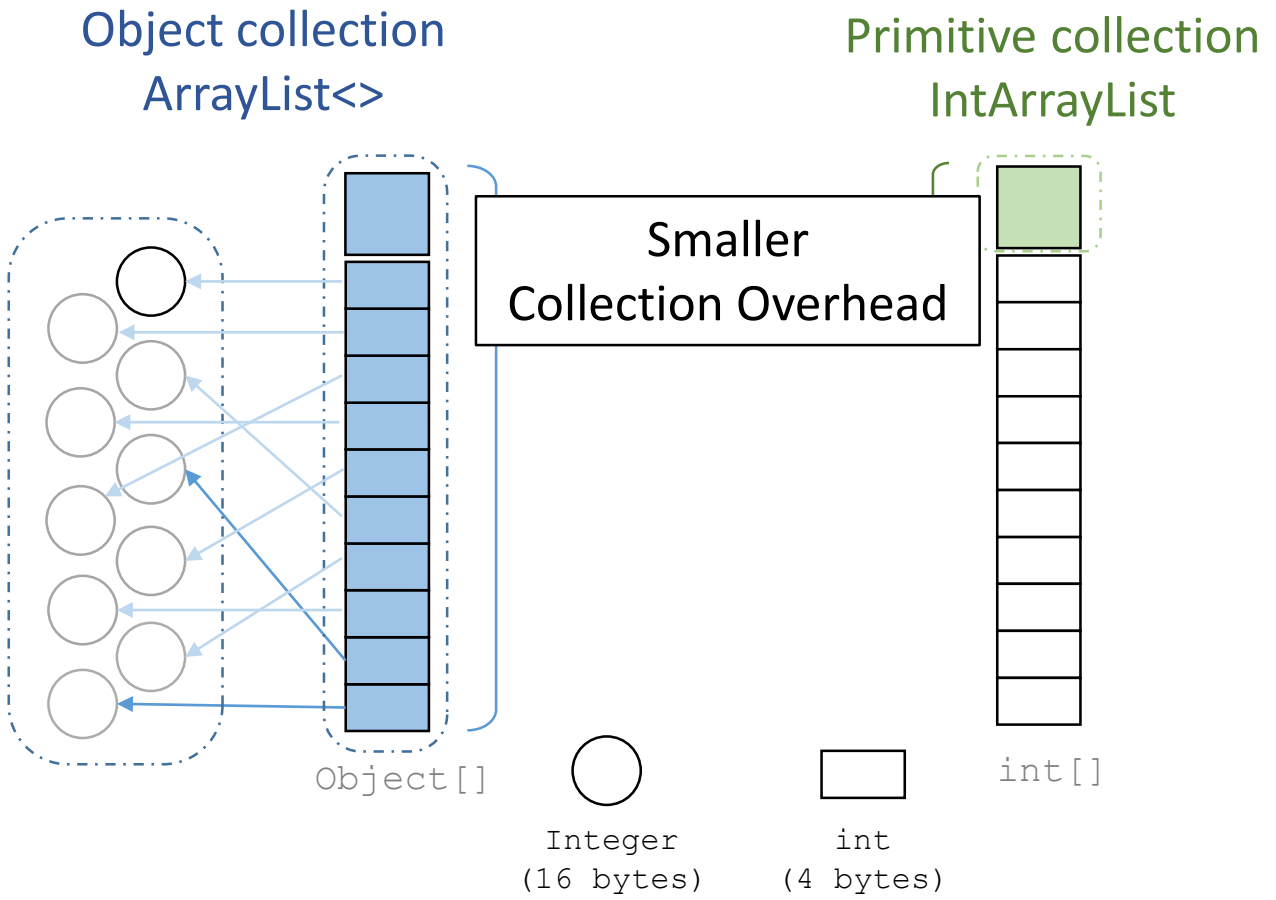

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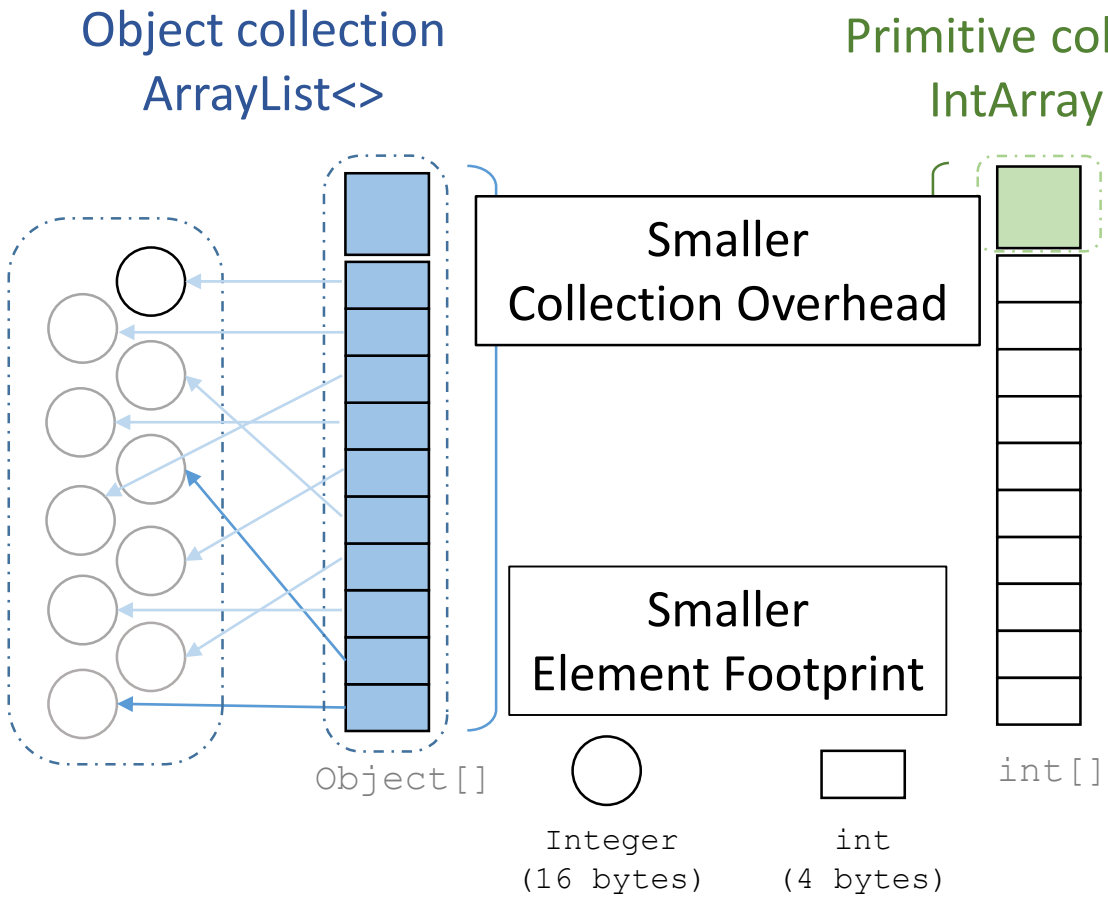
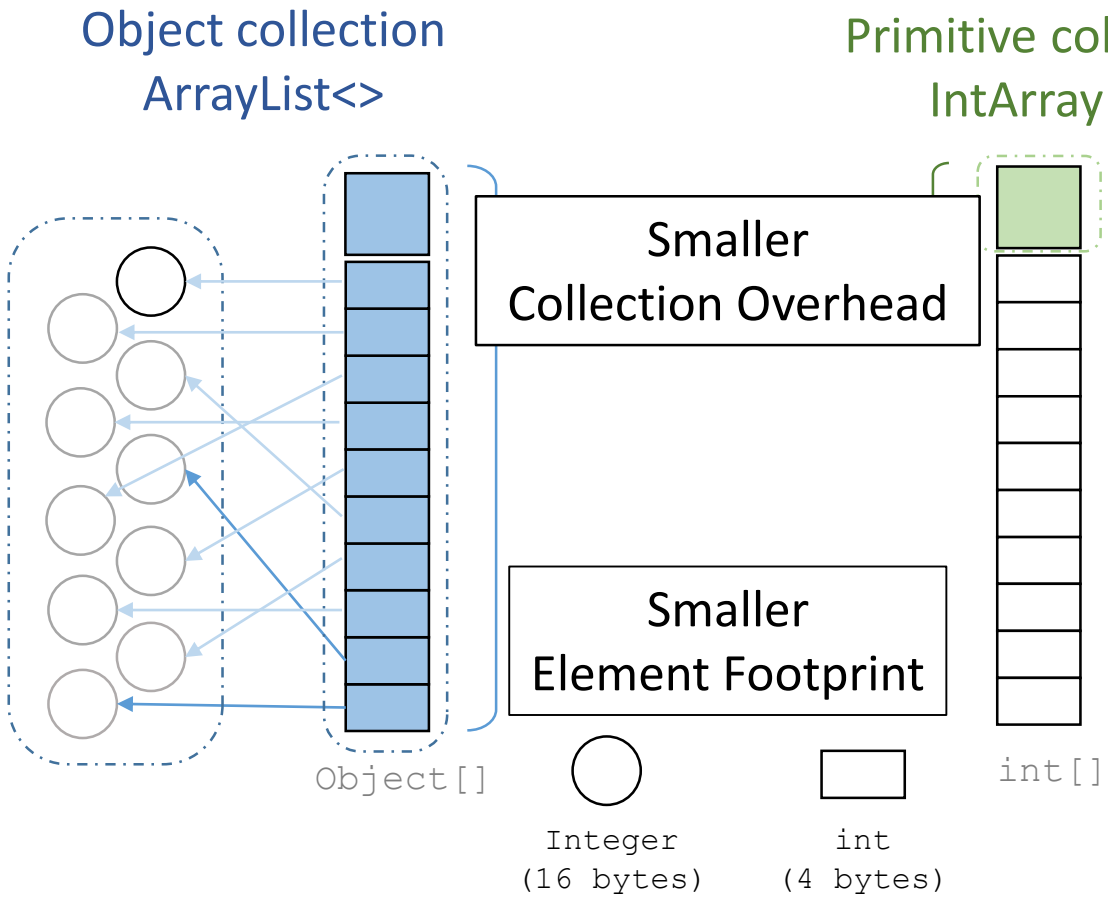


Object vs Primitive Collections

- Reducing collection footprint: overhead + element footprint



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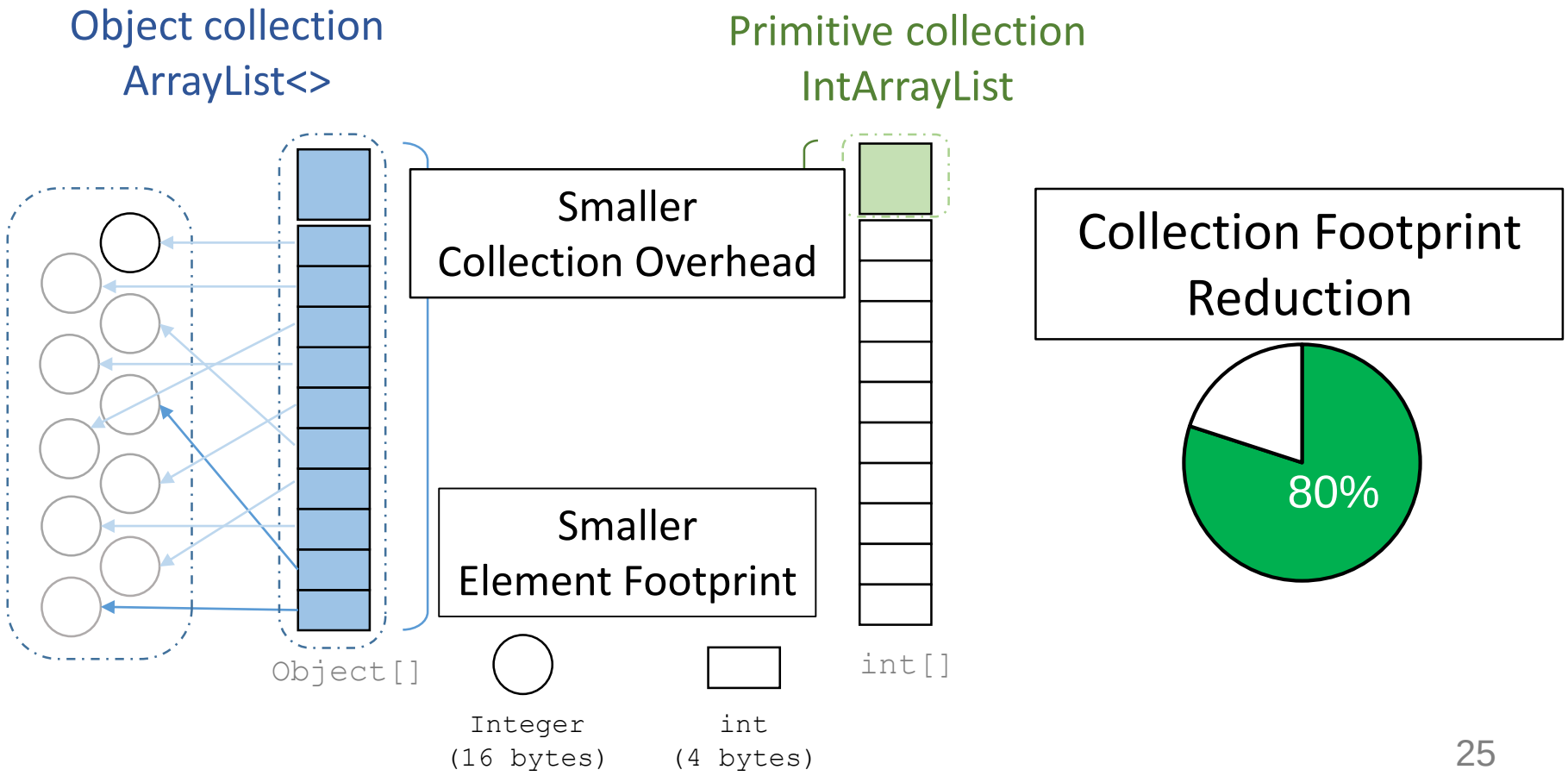
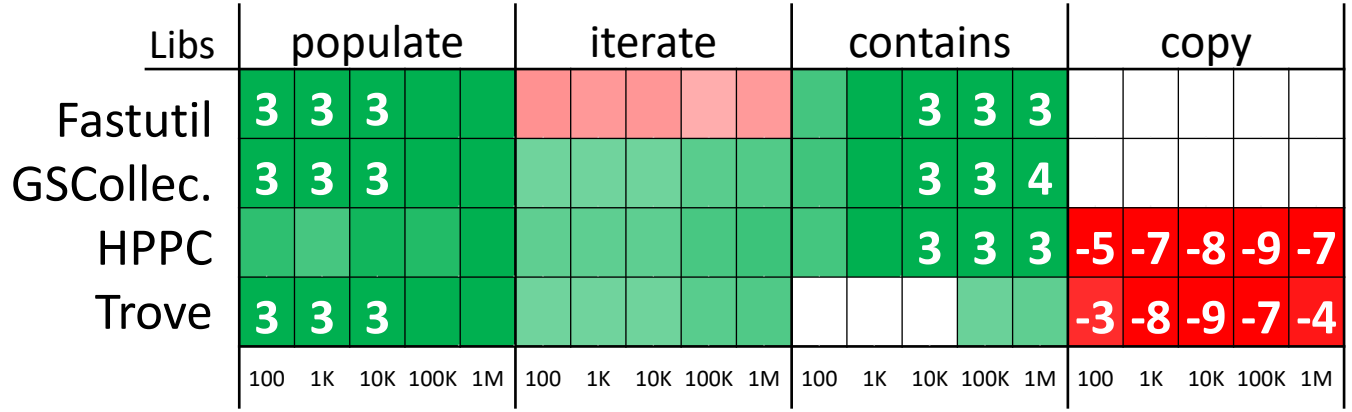


Superior Alternatives: Primitive Collections

- We found superior alternatives to all three abstraction types
  - Data Type: Integer to int
- Performance varies considerably from distinct libraries for multiple reasons

For instance, ArrayList primitive implementations



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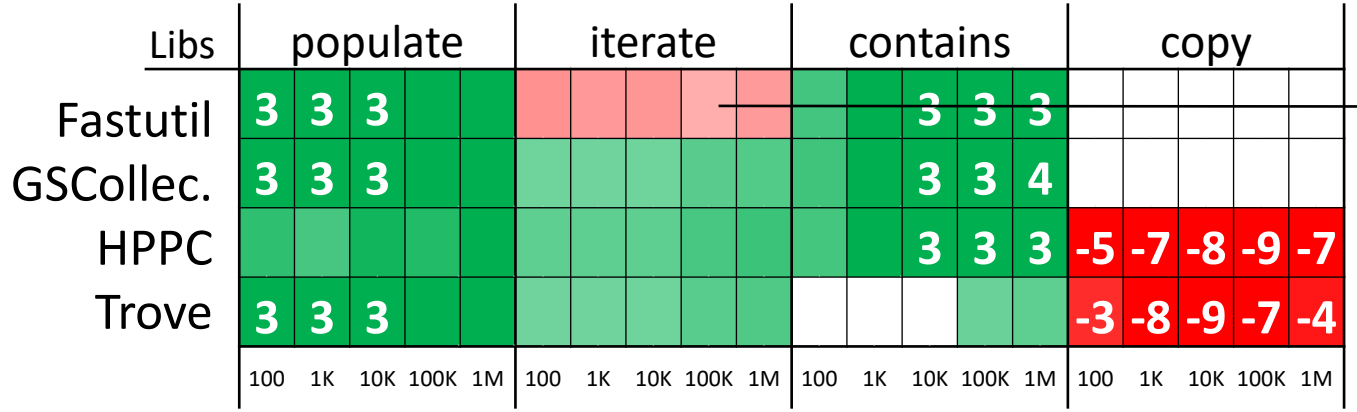

`for(Object..)`

5x slower than `for(IntProcedure)` commonly implemented

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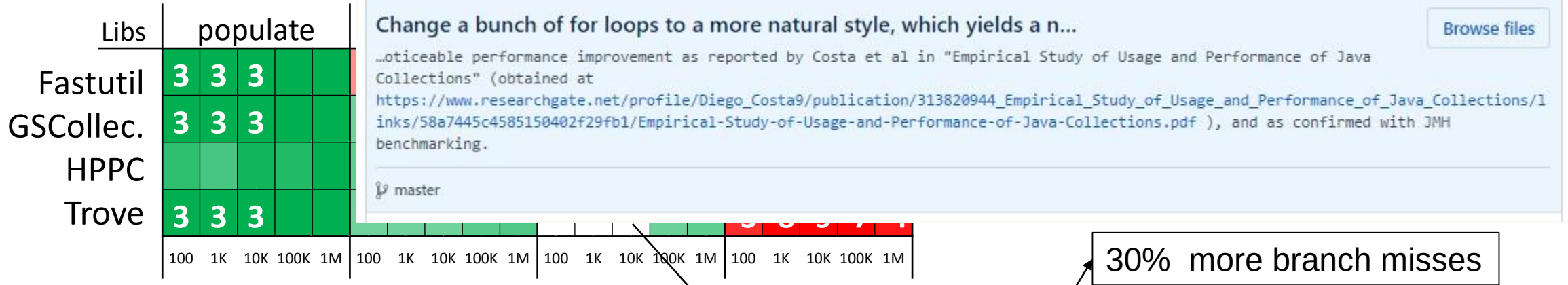
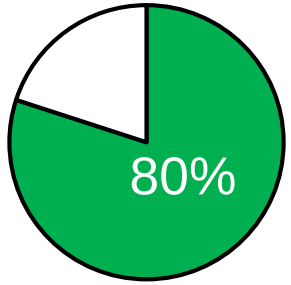
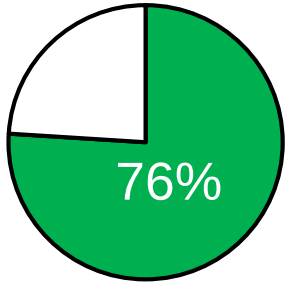
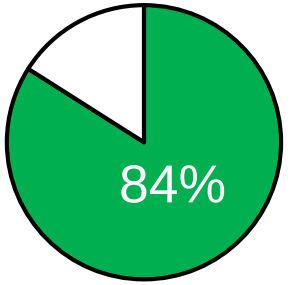


Superior Alternative: Primitive Collections

- GSCollections, Koloboke and Fastutil provide solid superior alternatives

	ArrayList	HashMap	HashSet
Footprint Reduction `Integer` → `int`			
Time impact (1M elements)	+2x populate +4x contains +2x remove	+2x populate -2x iterate +6x/+4x copy	+4x populate +4x/+3x iterate +33x/+7x copy

Summary

- There are performance opportunities on Alternative Collection Frameworks
  - Time/memory improvement with moderate refactor effort
- We provide a Guideline to assist developers on:
  - Identifying superior alternative implementations
  - Which scenarios an alternative could lead to a substantial performance improvement
- CollectionsBench is open-source and available at GitLab

Thank you for your time

Questions?

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