Architecture of software systems

Course 8: Data structures, memory management , garbage collector

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Data structures

- primitives: boolean, byte, char, int, long, float, double
  - without implicit allocation
  - placed in frame in variables or operand stack
- objects
  - every object is descendant of Object by default
    - methods – clone(), equals, getClass(), hashCode(), wait(…), notify (…), finalize()
  - objects for primitives: Boolean, Byte, Character, Integer, Long, Float, Double; can be **null**; all are **immutable** objects (final values)
  - other objects
- arrays
  - special data structure which store a number of items of the same type in linear order; have the defined limit
  - JAVA automatically check limitations
  - allocated on the heap
  - multi-dimensional arrays = arrays of arrays; ragged array

Autoboxing, Unboxing

- automatic conversion from primitive to object representation and vice versa
- since JAVA 5
- for example
  - autoboxing for Integer is based on valueOf(int) and intValue() methods

```
int myInt = 3;
myInt.toString();
```

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» for example

  » autoboxing for Integer is based on valueOf(int) and intValue() methods

```
int myInt = 3;
myInt.toString();
```

» works only during assignment or parameter passing

```
String a = myInt+"";
```

Autoboxing, Unboxing

- automatic conversion from primitive to object representation and vice versa
- since JAVA 5
- for example
  - autoboxing for Integer is based on valueOf(int) and intValue() methods

```
int myInt = 3;
myInt.toString();
```

- works only during assignment or parameter passing

```
String s = myInt+"";
```

```
Integer.toString(myInt);
```

- example: count word frequency, histogram

```
public static void main(String[] args) {
    Map<String, Integer> m = new TreeMap<String, Integer>();
    for (String word : args) {
        Integer freq = m.get(word);
        m.put(word, (freq == null ? 1 : freq + 1));
    }
    System.out.println(m);
}
```

- boxing a

Example

```
int i = 2;
int j = 2;
ArrayList<Integer> list = new ArrayList<Integer>();
list.add(i);
list.add(j);
System.out.printf(Boolean.toString(i==j));
System.out.printf(Boolean.toString(list.get(0)==list.get(1)));
System.out.printf(Boolean.toString(list.get(0).equals(list.get(1))));
```

» what is the output? and what is the output for i=2000 and j=2000 ?

Example

```
int i = 2;
int j = 2;
ArrayList<Integer> list = new ArrayList<Integer>();
list.add(i);
list.add(j);
System.out.printf(Boolean.toString(i==j));
System.out.printf(Boolean.toString(list.get(0)==list.get(1)));
System.out.printf(Boolean.toString(list.get(0).equals(list.get(1))));
```

» what is the output? and what is the output for i=2000 and j=2000 ?

true	true
true	false
true	true

» but not after serialization, there is no readResolve !

Integer – usage of identity semantics

» similar concept as in multiton; Integer itself is **Immutable** (final)

```
public static class Integer {
    private final int value;

    public Integer(int value) {
        this.value = value;
    }

    public int intValue() {
        return value;
    }

    public static Integer valueOf(int i) {
        if(i >= -128 && i <= IntegerCache.high)
            return IntegerCache.cache[i + 128];
        else
            return new Integer(i);
    }
}
```

Integer

```
// set from vm option -XX:AutoBoxCacheMax=<size>
private static String integerCacheHighPropValue;

private static class IntegerCache {
    static final int high;
    static final Integer cache[];

    static {
        final int low = -128;

        int h = 127;
        if (integerCacheHighPropValue != null) {
            int i = Long.decode(integerCacheHighPropValue).intValue();
            i = Math.max(i, 127);
            h = Math.min(i, Integer.MAX_VALUE - -low);
        }
        high = h;

        cache = new Integer[(high - low) + 1];
        int j = low;
        for(int k = 0; k < cache.length; k++)
            cache[k] = new Integer(j++);
    }

    private IntegerCache() {}
}
```

Widening vs. autoboxing

```java
public static void hello(Integer x) {
    System.out.println("Integer");
}

public static void hello(long x) {
    System.out.println("long");
}

public static void main(String[] args) {
    int i = 5;
    hello(i);
}
```

```java
public static void hello(Integer x) {
    System.out.println("Integer");
}

public static void hello(Long x) {
    System.out.println("long");
}

public static void main(String[] args) {
    int i = 5;
    hello(i);
}
```

» what are the outputs?

Widening vs. autoboxing

```
public static void hello(Integer x) {
    System.out.println("Integer");
}

public static void hello(long x) {
    System.out.println("long");
}

public static void main(String[] args) {
    int i = 5;
    hello(i);
}
```

```
public static void hello(Integer x) {
    System.out.println("Integer");
}

public static void hello(Long x) {
    System.out.println("long");
}

public static void main(String[] args) {
    int i = 5;
    hello(i);
}
```

- what are the outputs?

  long / **Integer**

- why?

  prefer widening before autoboxing

  cannot use autoboxing to widen primitives -> error if no hello(Integer) method

Example

```java
public static class ShortSet {
    public static void main(String args[]) {
        Set<Short> s = new HashSet<Short>();
        for (short i = 0; i < 100; i++) {
            s.add(i);
            s.remove(i - 1);
        }
        System.out.println(s.size());
    }
}
```

» what is the outputs?

Example

```
public static class ShortSet {
    public static void main(String args[]) {
        Set<Short> s = new HashSet<Short>();
        for (short i = 0; i < 100; i++) {
            s.add(i);
            s.remove(i - 1);
        }
        System.out.println(s.size());
    }
}
```

» what is the outputs?

100 - because we are removing Integers instead of Short !!

» correct:

```
public static class ShortSet {
    public static void main(String args[]) {
        Set<Short> s = new HashSet<Short>();
        for (short i = 0; i < 100; i++) {
            s.add(i);
            s.remove((short) (i - 1));
        }
        System.out.println(s.size());
    }
}
```

Method overloading

» method is identified by its signature

```
public static void method(Object obj) {
    System.out.println("method with param type - Object");
}

public static void method(String obj) {
    System.out.println("method with param type - String");
}

public static void main(String[] args) {
    method(null);
}
```

» can be compiled and what is the output?

Method overloading

» method is identified by its signature

```
public static void method(Object obj) {
    System.out.println("method with param type - Object");
}

public static void method(String obj) {
    System.out.println("method with param type - String");
}

public static void main(String[] args) {
    method(null);
}
```

» can be compiled and what is the output?

- **YES** – no ambiguity

method with parameter type – String

» due to JLS specification:

“The Java programming language uses the rule that the *most specific* method is chosen.”

Method overloading

```
public static void method(Object obj){
    System.out.println("method with param type - Object");
}

public static void method(String str){
    System.out.println("method with param type - String");
}

public static void method(StringBuffer strBuf){
    System.out.println("method with param type - StringBuffer");
}
 public static void main(String[] args) {
     method(null);
 }
```

» can be compiled and what is the output?

Method overloading

```
public static void method(Object obj){
    System.out.println("method with param type - Object");
}

public static void method(String str){
    System.out.println("method with param type - String");
}

public static void method(StringBuffer strBuf){
    System.out.println("method with param type - StringBuffer");
}
public static void main(String[] args) {
    method(null);
}
```

- can be compiled and what is the output?
  - **NO** – cannot find “most specific”, both are sub-classes of Object but not in the same inheritance hierarchy

Method overloading

```
public static void method(Object obj, Object obj1) {
    System.out.println("method with param types - Object, Object");
}

public static void method(String str, Object obj) {
    System.out.println("method with param types - String, Object");
}

public static void main(String[] args) {
    method(null, null);
}
```

» can be compiled and what is the output?

Method overloading

```
public static void method(Object obj, Object obj1) {
    System.out.println("method with param types - Object, Object");
}

public static void method(String str, Object obj) {
    System.out.println("method with param types - String, Object");
}

public static void main(String[] args) {
    method(null, null);
}
```

» can be compiled and what is the output?

- **YES**

method with param types – String, Object

Method overloading

- BUT

```
public static void method(Object obj, String obj1) {
    System.out.println("method with param types - Object, String");
}

public static void method(String str, Object obj) {
    System.out.println("method with param types - String, Object");
}
```

- this cannot be compiled – cannot identify “most specific”

Method overloading

```
public static void hello(Collection x) {
    System.out.println("Collection");
}

public static void hello(List x) {
    System.out.println("List");
}

public static void main(String[] args) {
    Collection col = new ArrayList();
    hello(col);
}
```

» can be compiled and what is the output?

Method overloading

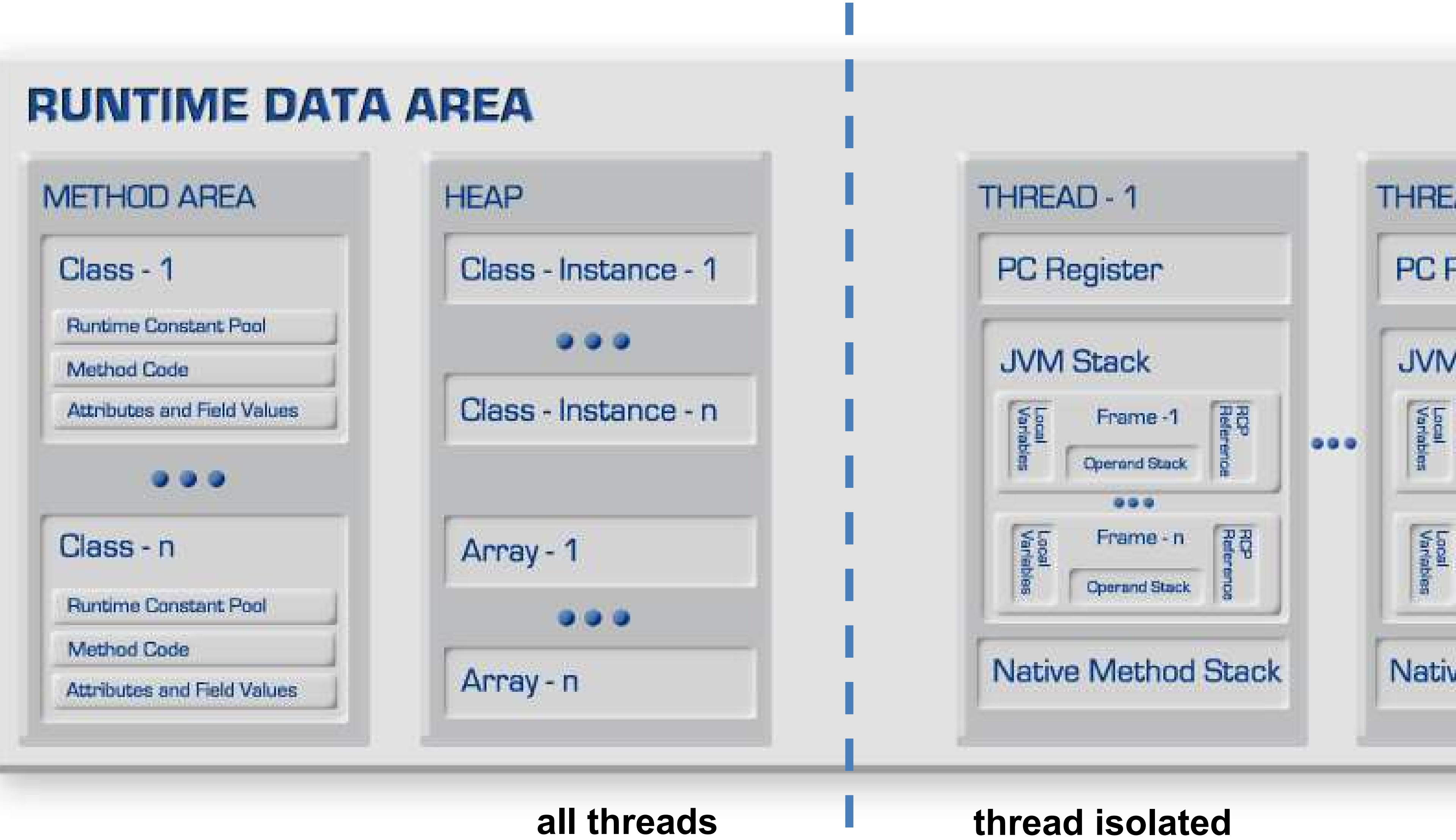
```
public static void hello(Collection x) {
    System.out.println("Collection");
}

public static void hello(List x) {
    System.out.println("List");
}

public static void main(String[] args) {
    Collection col = new ArrayList();
    hello(col);
}
```

» can be compiled and what is the output?
  - **YES**

Collection

- compile time resolution not run-time type

JVM Memory



RUNTIME DATA AREA
METHOD AREA
Class - 1
Runtime Constant Pool
Method Code
Attributes and Field Values
Class - n
Runtime Constant Pool
Method Code
Attributes and Field Values
HEAP
Class - Instance - 1
Class - Instance - n
Array - 1
Array - n
THREAD - 1
PC Register
JVM Stack
Local Variables
Frame - 1
Operand Stack
RCP Reference
Local Variables
Frame - n
Operand Stack
RCP Reference
Native Method Stack
all threads
thread isolated

Memory management

» explicit vs. *automatic*
  - no crashes due to errors – e.g. usage of de-allocated objects
  - no memory (space) leaks

» garbage collection managed by ***garbage collector***
  - live objects (transiently reachable from **roots** – thread frames, static fields) remain in memory
  - dead are reclaimed

» <u>desired garbage collection characteristics:</u>
  - allocation performance - find a block of unused memory with certain size
  - avoid fragmentation (e.g. by compaction)
  - efficiency without long pauses in application run
  - no bottleneck for multi-threaded (multi-core/multi-CPUs) systems

» <u>design architectures:</u>
  - serial vs. parallel
  - concurrent vs. stop-the-world
  - compacting vs. non-compacting vs. copying

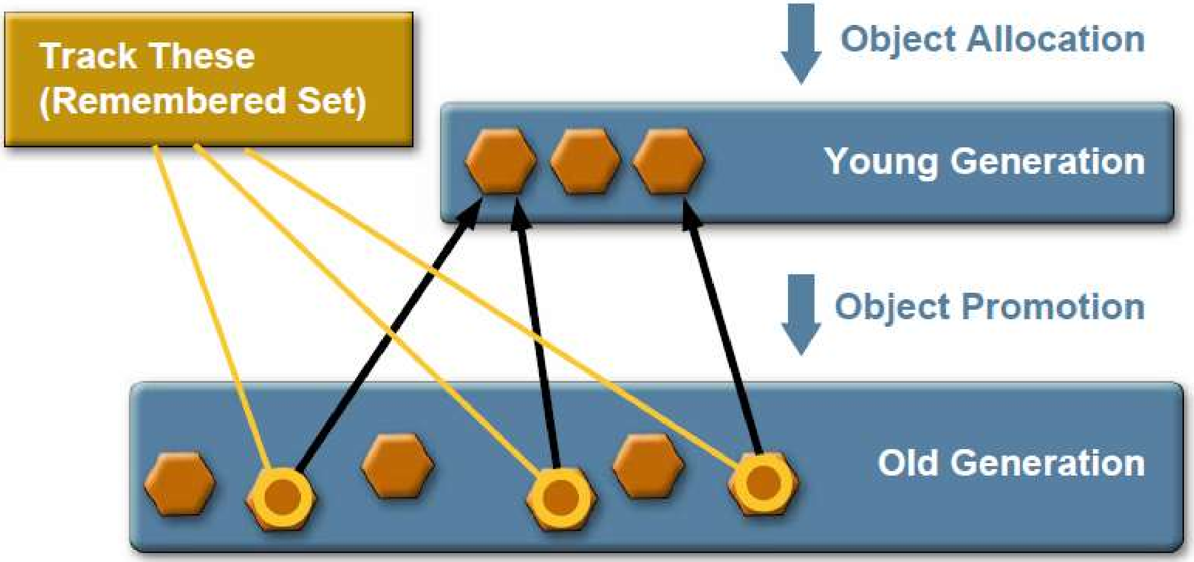
Generational concept

» heap divided into generations based on object ages:
  - young – frequent GC, small size -> fast GC
  - old – rare GC, large size -> slow GC

» promotion (tenuring) objects based on survival of objects during GC

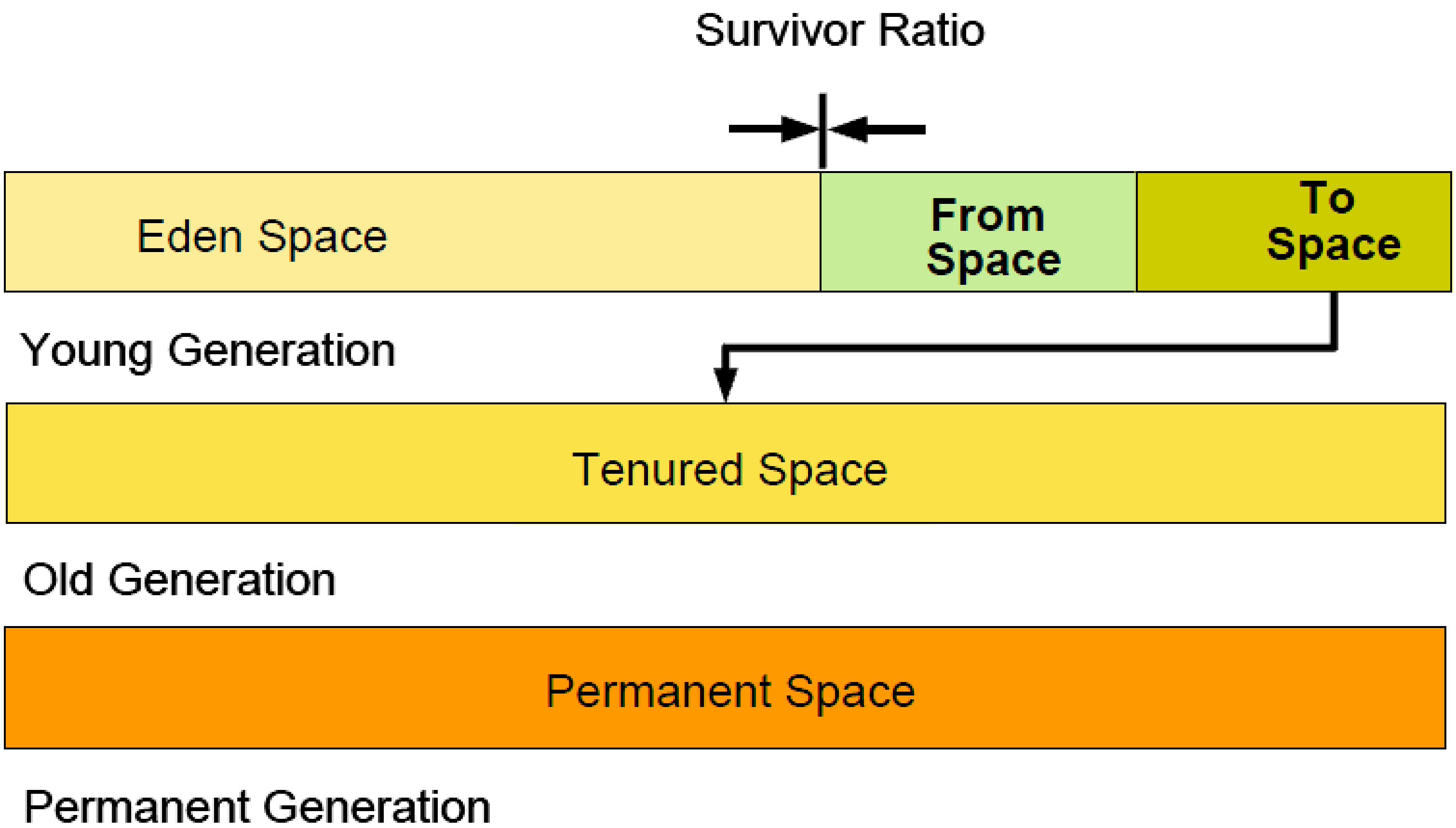
» based on weak **generational hypothesis**:
  - most allocated objects are not referenced for long – they die young
  - few references from older to younger object exist

» need track old-to-young references



JAVA heap layout

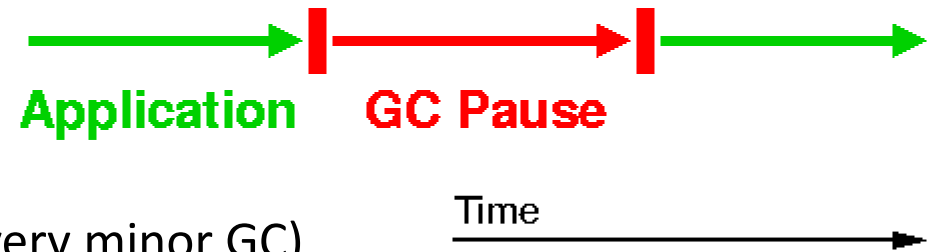
» *minor (young)* vs. *major (old)* GC – different algorithms
» major GC can be invoked by young GC if there is no space in tenured space



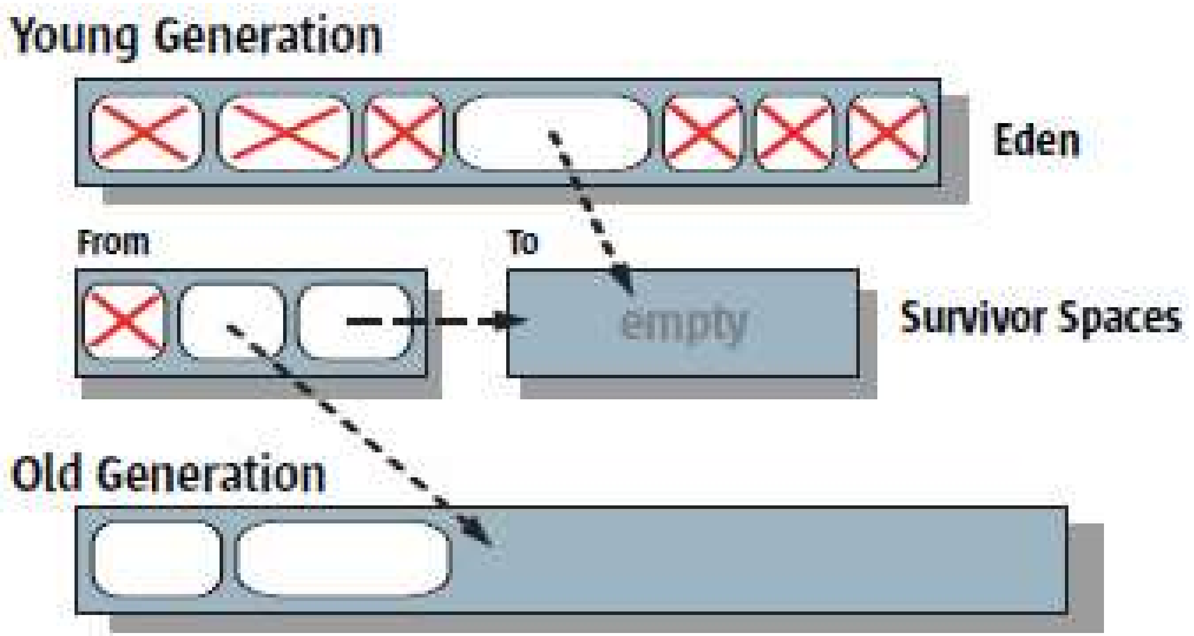
Fast object allocation

- based on *bump-the-pointer* technique
  - track previously allocated object
  - fit new object into remainder of generation end
- thread-local allocation buffers (TLABs)
  - remove concurrency bottleneck
  - each thread has very small exclusive area (about 1% of Eden in total)
  - infrequent full TLABs implies synchronization (based on CAS)
  - exclusive allocation takes about *10 native instructions*

- young collection -> old generations collection serially in *stop-the-world* fashion



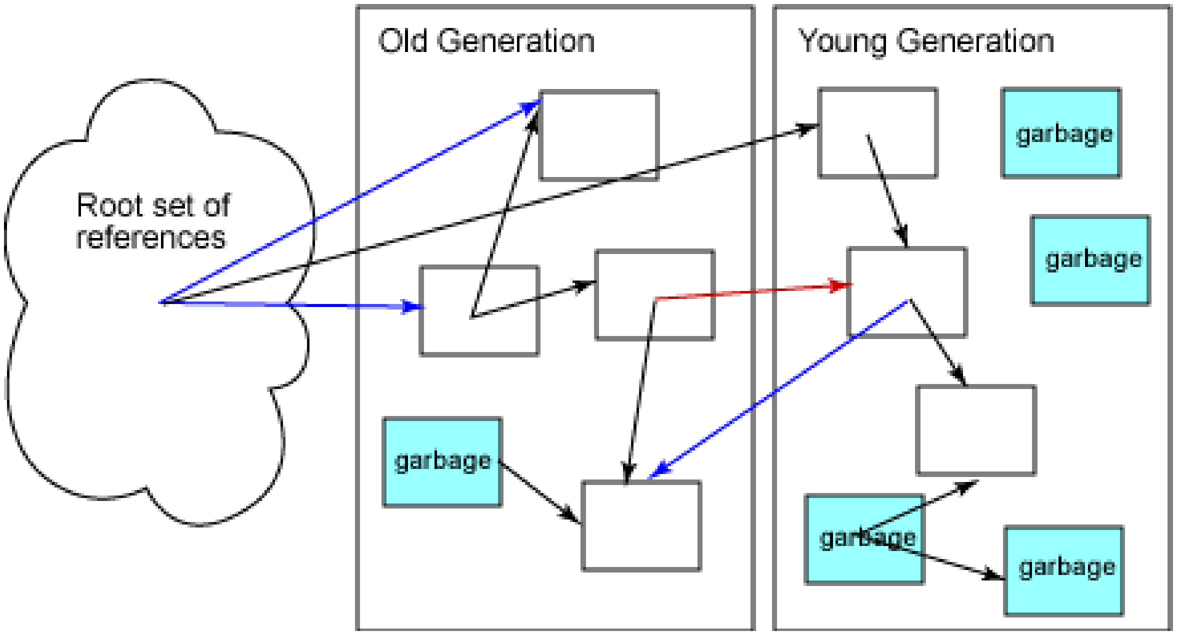
- young generation:
  - age of object (incremented every minor GC)
  - efficiency is proportional to number of copied objects !



Young generation live object detection – IBM version

» maintains separate list of old-to-young references as they are created

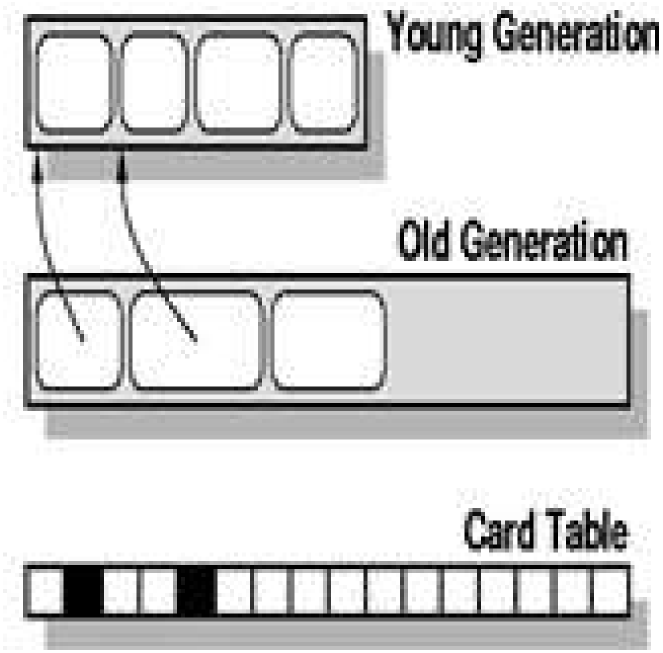
» maintain the list during object promotion, introduce new, remove old



» red – old-to-young, blue – to old (don't need trace during minor collection)

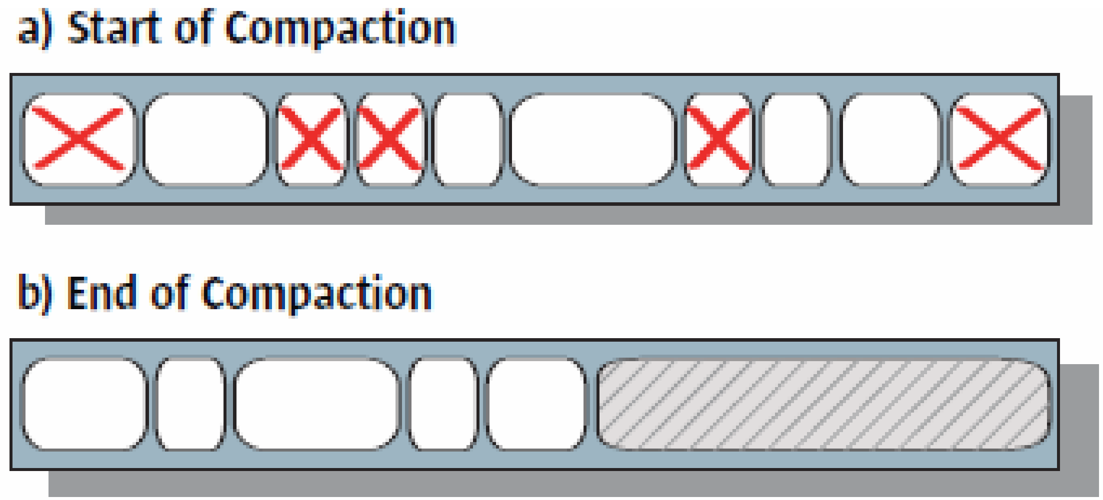
Young generation live object detection – Sun version

- identification of live objects based on card table structure (boolean)
- 512-byte chunks in old generation (smaller than memory page)
- every update to a reference marks dirty
- bytecode interpreter and JIT uses reference write barrier to maintain card table
- only dirty cards are scanned for old-to-young references
- finally marks are cleared



Serial collector

- old and permanent generation:
  - using *mark-sweep-compact* algorithm
  - allocation can use *bump-the-pointer* technique



- default in Java 5.0 for client JVM
- effectively handles application with 64MB heaps
- `-XX:+UseSerialGC`