Programming Languages and Techniques (CIS1200)

Lecture 35

Swing IV: Paint revisited, Design Patterns

Advanced Java

Chapter 31

We are almost done!

- ~~**Monday** (4/21): Swing III: Abstract Classes, Timer based games~~
- **Wednesday** (4/23): Swing IV: Design Patterns / Advanced Java Topics
- *Recitation: Final exam review*
- **Friday** (4/25): *Bonus Lecture: CIS and Sustainability (Dr. Benjamin Pierce)*

- **Monday** (4/29): *Bonus Lecture: OCaml at Jane Street (Dr. Richard Eisenberg)*
- **Tuesday** (4/30): Game project due at midnight
- **Wednesday** (4/31): Semester recap
- *No recitation!*

- **Wednesday** (5/7): Final exam, 9-11AM

38: How far along are you on the Game?

0

I haven't started yet

0%

I have the basic design implemented

0%

I'm about halfway done, I think

0%

I'm nearly finished

0%

I'm done!

0%

Paint Revisited
(thoroughly discussed in Chap 31)

Using Anonymous Inner Classes

Refactoring for OO Design

(See PaintA.java … PaintF.java)

Advanced Java

Advanced Java

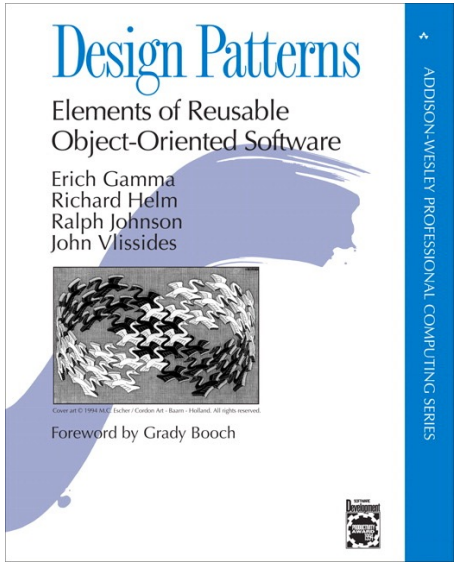
- Design Patterns (MVC)
- Java Streams (and lambdas)
- Threads & Synchronization
- Garbage Collection
- Hashing: HashSets & HashMaps
- Packages, package scope
- JVM (Java Virtual Machine) and compiler details:
  - class loaders, security managers, just-in-time compilation
- Advanced Generics
  - *Bounded Polymorphism*: type parameters with 'extends' constraints
    `class C<A extends Runnable> { … }`
  - Type Erasure
  - Interaction between generics and arrays
- Reflection
  - The `Class class`

The slides touch on these. Lecture will cover only some parts...

For all the beautiful details:
Java Language Specification
http://docs.oracle.com/javase/specs/

Design Patterns

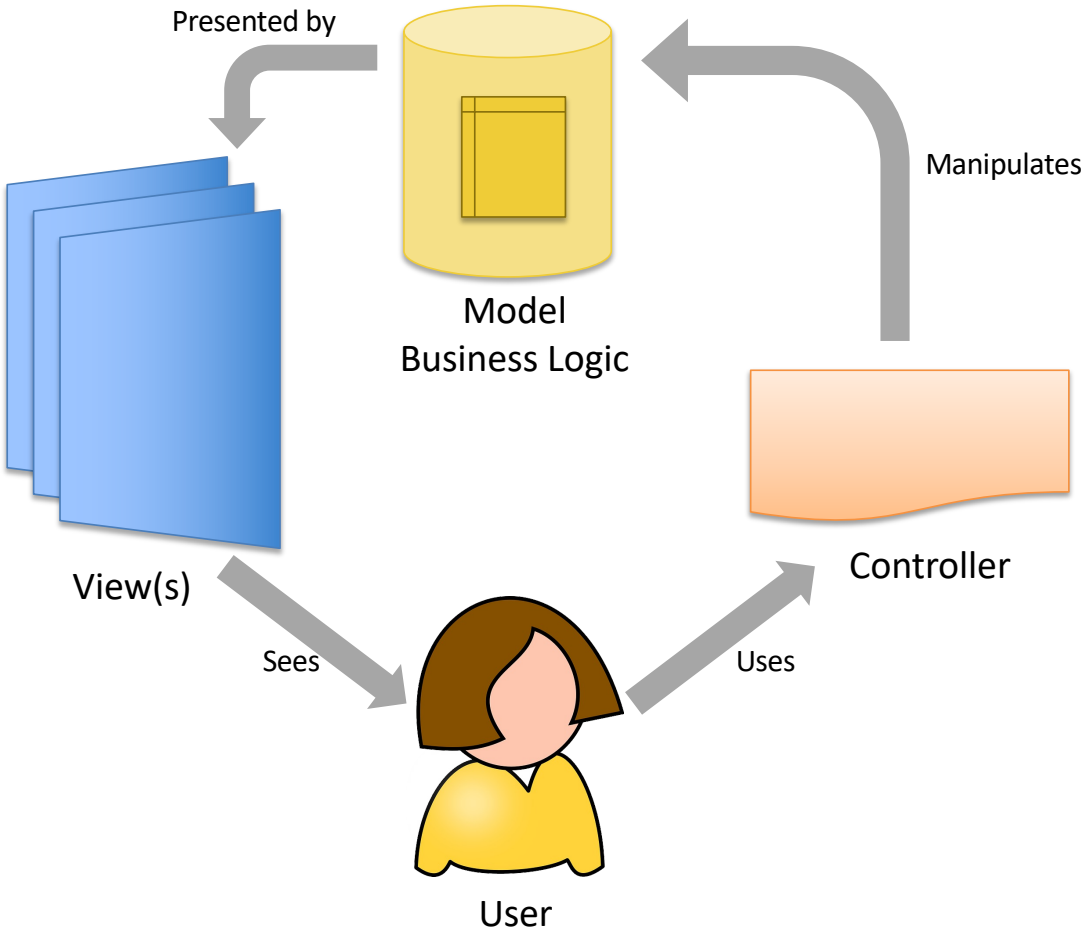
- Design Patterns
  - Influential OO design book published in 1994 (so a bit dated)
  - Identifies many common situations and "patterns" for implementing them in OO languages



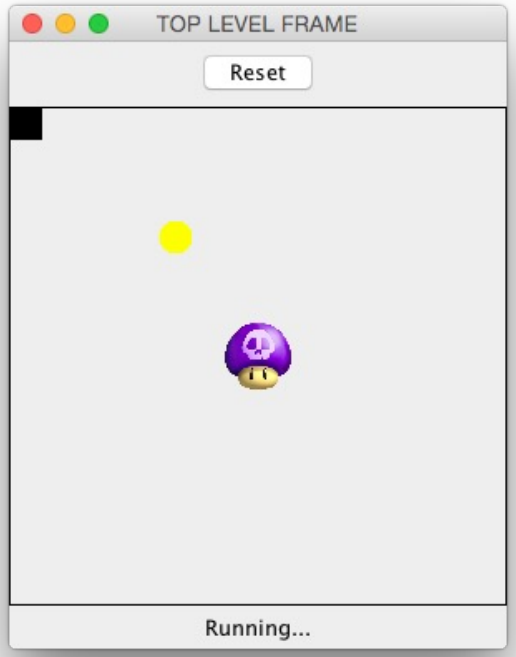
- Some we have seen explicitly:
  - e.g. *Iterator* pattern
- Some we've used but not explicitly described:
  - e.g. The parts of the Chat HW uses the *Factory* pattern
- Some are workarounds for OO's lack of some features:
  - e.g. The *Visitor* pattern is like OCaml's fold + pattern matching

Model View Controller
Design Pattern

Model-View-Controller Design Pattern



Example 1: Mushroom of Doom



Example: MOD Program Structure

- GameCourt, GameObj + subclass local state
  - object location & velocity
  - status of the game (playing, win, loss)
  - how the objects interact with eachother (tick)

Model

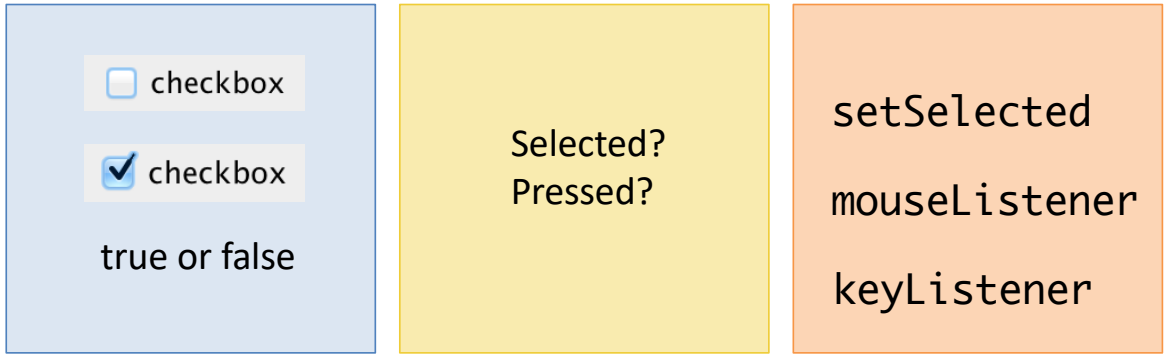
- Draw methods
  - paintComponent in GameCourt
  - draw methods in GameObj subclasses
  - status label

View

- Game / GameCourt
  - Reset button (updates model)
  - Keyboard control (updates square velocity)

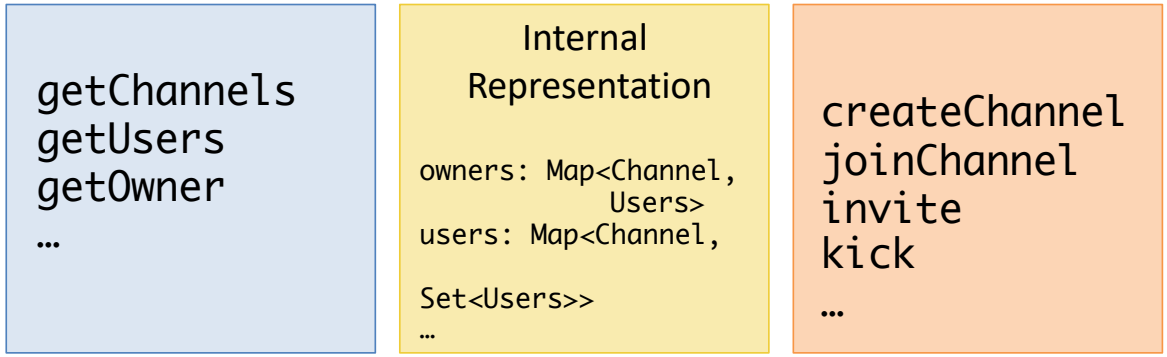
Controller

Example: CheckBox



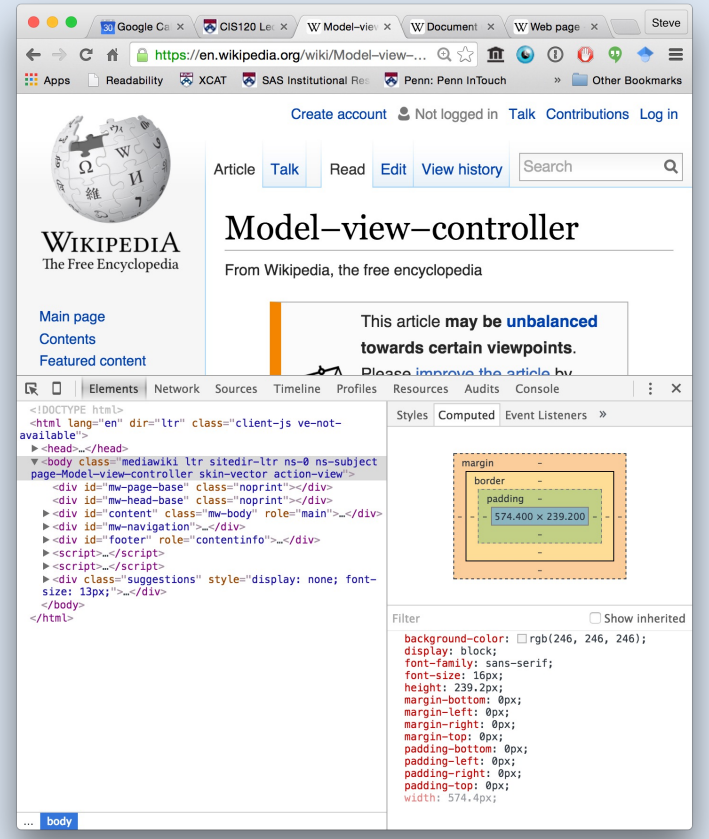

```
Class JToggleButton.ToggleButtonModel

boolean   isSelected()              Checks if the button is selected.
void   setPressed(boolean b)        Sets the pressed state of the button.
void   setSelected(boolean b)       Sets the selected state of the button.
```

Example: Chat Server



ServerModel

Example: Web Pages



Views

Internal Representation: DOM (Document Object Model)

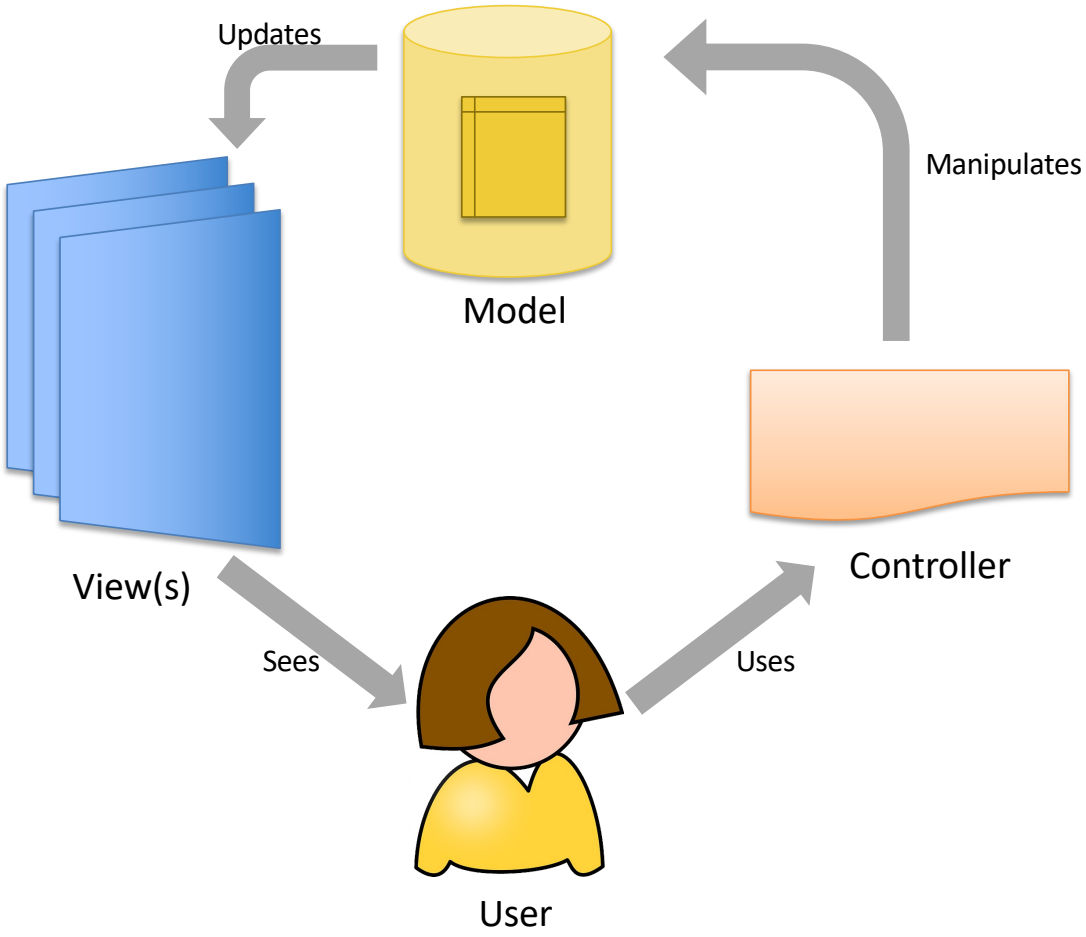
Model

JavaScript API

```
document.
addEventListener()
```

Controllers

MVC Pattern


Updates
Model
Manipulates
View(s)
Controller
Sees
Uses
User

MVC Benefits?

- Decouples "model logic" from how state is presented and manipulated
  - Suggests how to decompose the design to make it more flexible
- Multiple views
  - e.g. from different angles, or for different users
- Multiple controllers
  - e.g. mouse vs. keyboard interaction
- Key benefit: Makes the model **testable** independent of the GUI

Hash Sets & Hash Maps

array-based implementation of sets and maps

Hash Sets and Maps: The Big Idea

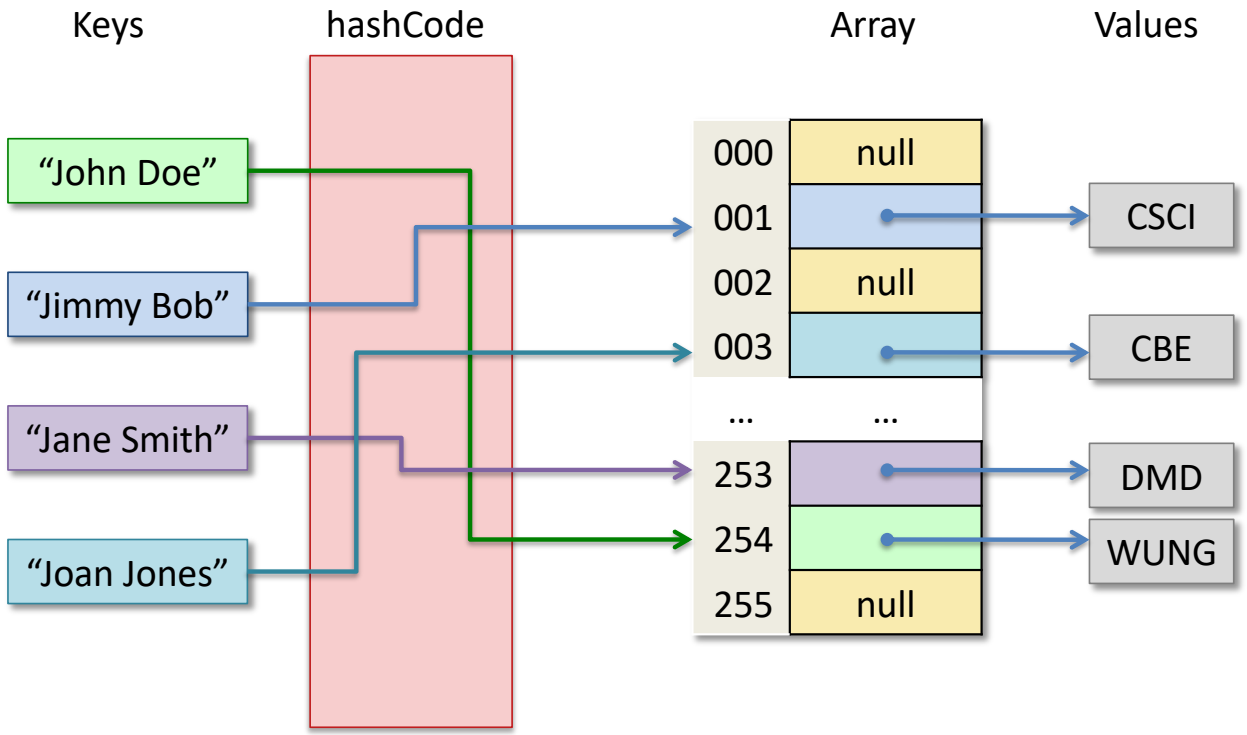
Combine:

- the advantage of arrays
  - *efficient* random access to its elements
- with the advantage of a map data structure
  - arbitrary keys (not just integer indices)

How?

- Create an index into an array by *hashing* the key
  - A *hash function* turns a value of some type into an int
  - Java's Object class has a hashCode method
  - Generally, the space of keys is much larger than the space of hashes, so, unlike array indices, hashCodes might not be unique

Hash Maps, Pictorially



A schematic HashMap taking Strings (student names) to Undergraduate Majors. The hashCode takes each string name to an integer code, which we then take "mod 256" to get an array index between 0 and 255.

For example, `"John Doe".hashCode()` mod 256 is 254.

Hash Collisions

- Uh Oh: Indices derived via hashing may not be unique!

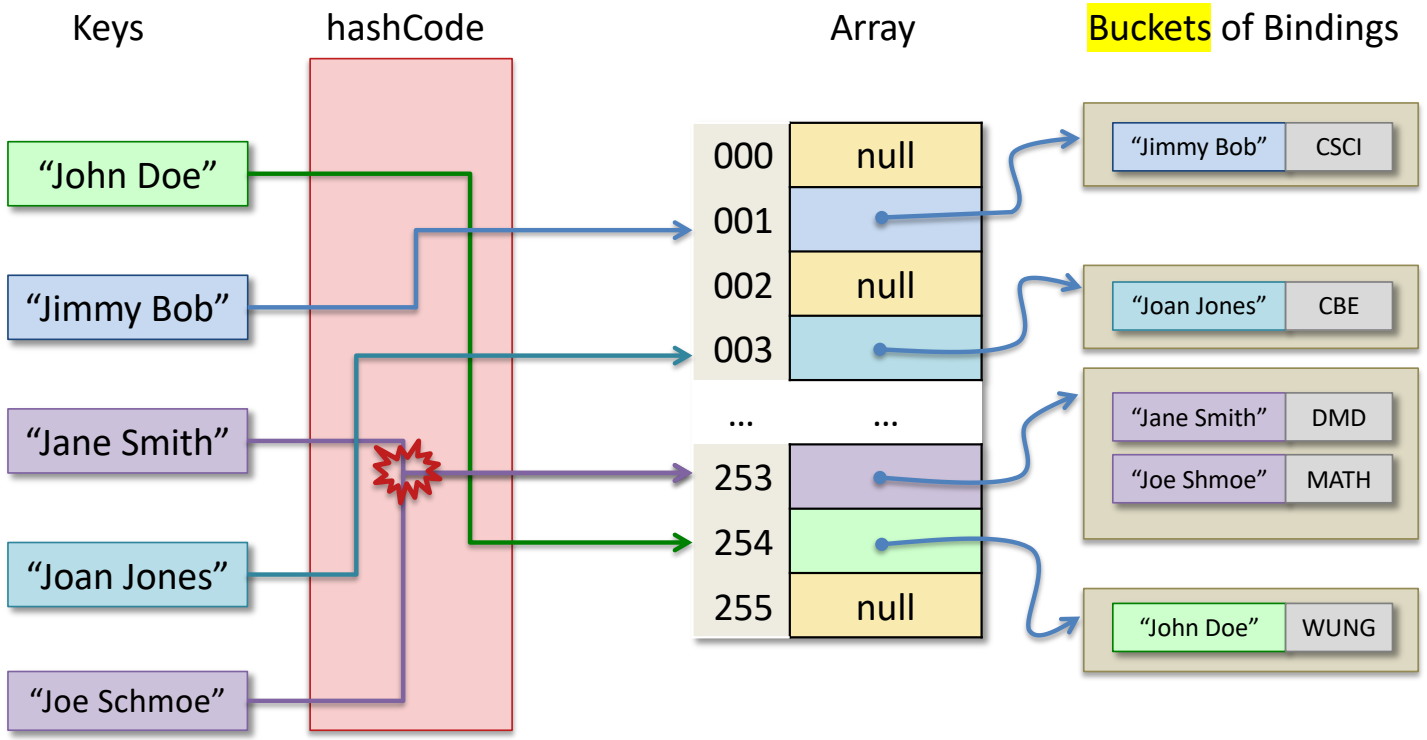
  `"Jane Smith".hashCode() % 256` ➔ 253

  `"Joe Schmoe".hashCode() % 256` ➔ 253

- Good hashCode functions make it *unlikely* that two keys will produce the same hash

- But, it can still sometimes happen that two keys produce the same index – that is, their hashes *collide*

Bucketing and Collisions



Here, "Jane Smith".hashCode() and "Joe Schmoe".hashCode() happen to collide. The *bucket* at the corresponding index of the Hash Map array stores the map data.

Bucketing and Collisions

- Using an array of *buckets* (not the only solution to the collision problem)
  - Each bucket stores the mappings for keys that have the same hash
  - Each bucket is itself a map from keys to values (implemented by a linked list or binary search tree)
  - The buckets can't use hashing to index the values – instead they use key equality (via the key's equals method)
- To look up a key in the Hash Map:
  1. Find the right bucket by indexing the array through the key's hash
  2. Search linearly through the bucket contents to find the value associated with the key
- If the buckets get big, resize the array (cf. Chapter 32)

What gets printed to the console?

0

```
public class Point {
	private final int x;
	private final int y;
	public Point(int x, int y) { this.x = x; this.y =
y; }
	public int getX() { return x; }
	public int getY() { return y; }
}

// somewhere else…
Map<Point,String> m = new HashMap<Point,String>();
m.put(new Point(1,2), "House");
System.out.println(m.containsKey(new Point(1,2)));
```

True

0%

False

0%

I have no idea

0%

Hashing and User-defined Classes

```
public class Point {
    private final int x;
    private final int y;
    public Point(int x, int y) { this.x = x; this.y = y;
}
    public int getX() { return x; }
    public int getY() { return y; }
}

// somewhere else…
Map<Point,String> m = new HashMap<Point,String>();
m.put(new Point(1,2), "House");
System.out.println(m.containsKey(new Point(1,2)));
```

What gets printed to the console?

1. true
2. false
3. I have no idea

ANSWER: 2 – hashCode not implemented

HashCode Requirements

Whenever you override `equals` you must also override `hashCode` in a consistent way:

- whenever `o1.equals(o2) == true` you must ensure that `o1.hashCode() == o2.hashCode()`

Why? Because comparing hashes is supposed to be a quick approximation for equality.

- Note: the converse often doesn't hold
  - `o1.hashcode() == o2.hashCode()` does *not* necessarily mean that o1.equals(o2)

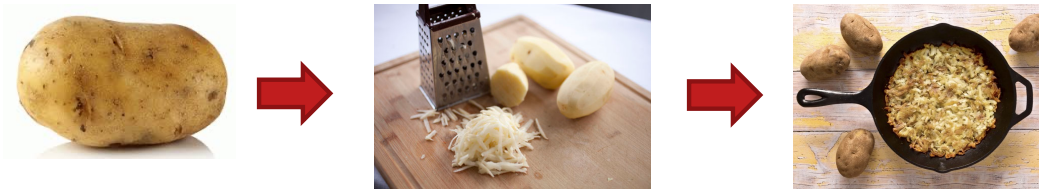
Example for Point

```
public class Point {
   @Override
    public int hashCode() {
        final int prime = 31;
        int result = 1;
        result = prime * result + x;
        result = prime * result + y;
        return result;
    }
}
```

- Examples:
  - `(new Point(1,2)).hashCode()` yields 994
  - `(new Point(2,1)).hashCode()` yields 1024
- Note that equal points (in the sense of `equals`) have the same hashCode
- Why 31? Prime chosen to create more uniform distribution
- Note: Tools (e.g. IntelliJ) can *generate* this code

Recipe: Computing Hashes

- What is a good recipe for computing hash values for your own classes?
  - intuition: "smear" the data throughout all the bits of the resulting



1. Start with some constant, arbitrary, non-zero int in `result`.
2. For each significant field f of the class (i.e. each field used when computing equals), compute a "sub" hash code `c` for the field:
   - For boolean fields: `(f ? 1 : 0)`
   - For byte, char, int, short: `(int) f`
   - For long: `(int) (f ^ (f >>> 32))`
   - For references: 0 if the reference is null, otherwise use the `hashCode()` of the field.
3. Accumulate those subhashes into the result by doing (for each field's `c`):
   `result = prime * result + c;`
4. return `result`

Hash Map Performance

- Hash Maps can be used to efficiently implement Maps and Sets
  - There are many different strategies for dealing with hash collisions with various time/space tradeoffs
  - Real implementations also dynamically rescale the size of the array (which might require re-computing the bucket contents)
  - See CIS 1210 for more info!

- If the hashCode function gives a good (close to uniform) distribution of hashes, the buckets are expected to be small (only one or two elements)
- If the hashCode function gives a bad distribution (e.g. always return the same answer), the buckets will be large (and performance will be bad)

- Performance depends on workload

NOTE: Terminological Clash

- The word "hash" is also used in *cryptography*
  - SHA-1, SHA-2, SHA-3, MD5, etc.
- All hash functions reduce large objects to short summaries
- Cryptographic hashes have some extra requirements:
  - Are "one way" (i.e. very hard to *invert)*
  - Should only very rarely have collisions
  - Are considerably more expensive to compute than hashCode (so not suitable for hash tables)

- Never use hashCode when you need a cryptographic hash!
  - See CIS 3310 for more details

Threads & Synchronization

Avoid Race Conditions!

(Multithreaded.java)

Threads

- Java programs can be *multithreaded*
  - more than one "thread" of control operating simultaneously
- A `Thread` object can be created from any class that implements the `Runnable` interface
  - `start`: launch the thread
  - `join`: wait for the thread to finish
- Abstract Stack Machine:
  - Each thread has its *own* workspace and stack
  - All threads *share* a common heap
  - Threads can communicate via shared references

Uses + Perils

- Threads are useful when one program needs to do multiple things simultaneously
  - display game animation + process user input
  - chat server interacting with multiple chat clients
  - can hide latency: do work in one thread while another thread waits (e.g. for long running computation or network I/O)

- Problem: Race Conditions
  - What happens when one thread tries to read a memory location at the same time another thread is writing it?
  - What if more than one thread tries to write different values at the same time?

(Unsynchronized) Implementation

```
interface Counter {
  public void inc();
  public int get();
}

class UnsynchronizedCounter implements Counter {
  private int cnt = 0;

  public void inc() {
    cnt = cnt + 1;
  }

  public int get() {
    return cnt;
  }
}
```

Setting up a Computation Thread

```
// The computation thread increments the counter 1000 times
class CounterUser implements Runnable {
  private Counter c;
  private int id;

  CounterUser(int id, Counter c) {
    this.id = id;
    this.c = c;
  }

  @Override
  public void run() {
    for (int i = 0; i < 1000; i++) {
      c.inc();
    }
  }
}
```

First Try: Two Threads & One Counter

```
public class MultiThreaded {

  public static void main(String[] args) {
    Counter c = new UnsynchronizedCounter();

    // set up a race on the shared counter c
    Thread t1 = new Thread(new CounterUser(1, c));
    Thread t2 = new Thread(new CounterUser(2, c));
    t1.start();
    t2.start();
    try {
      t1.join();
      t2.join();
    } catch (InterruptedException e) {
    }
    System.out.println("Counter value = " + c.get());
  }

}
```

Create thread 1

Create thread 2

Start thread 1

Start thread 2

Wait for thread 1 to finish

Wait for thread 2 to finish

Multithreaded.java

0

1

0%

2

0%

3

0%

4

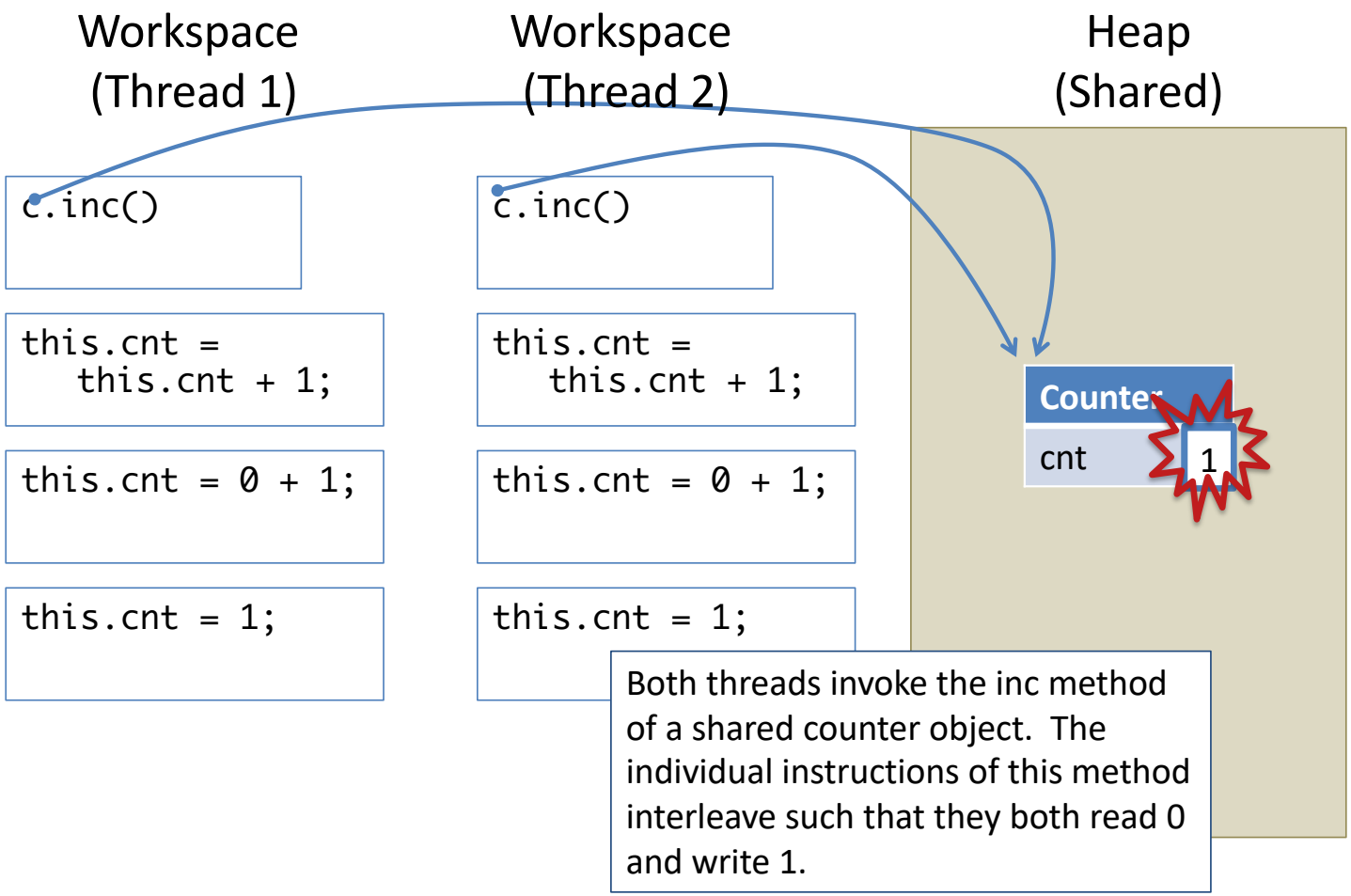
0%

What behavior do you expect from Multithreaded.java?

1. The program will print "Counter value = 1000"
2. The program will print "Counter value = 2000"
3. The program will print "Counter value = ????" for some other number ????
4. The program will throw an exception.

Answer: The program with print "Counter value = *val*"
for 1000 <= val <= 2000.
The answer will likely be *different* each time the program is run!!!!

Data Races


Workspace (Thread 1)
Workspace (Thread 2)
Heap (Shared)
c.inc()
this.cnt = this.cnt + 1;
this.cnt = 0 + 1;
this.cnt = 1;
c.inc()
this.cnt = this.cnt + 1;
this.cnt = 0 + 1;
this.cnt = 1;
Counter
cnt
1
Both threads invoke the inc method of a shared counter object. The individual instructions of this method interleave such that they both read 0 and write 1.

The `synchronized` keyword

- Synchronized methods are *atomic*
  - At most **one** thread can be executing code within an atomic method at a time
  - Other threads must wait their turn
- Careful use eliminates data races
- Tradeoff
  - less concurrency means worse performance

Second Try: use Synchronization

```
//This class uses synchronization
class SynchronizedCounter implements Counter {
  private int cnt = 0;

  public synchronized void inc() {
   cnt = cnt + 1;
  }

  public synchronized int get() {
   return cnt;
  }
}
```

Using The New Counters

```
public class MultiThreaded {

  public static void main(String[] args) {

    Counter c = new SynchronizedCounter();

    // set up a race on the shared counter c
    Thread t1 = new Thread(new CounterUser(1, c));
    Thread t2 = new Thread(new CounterUser(2, c));
    t1.start();
    t2.start();
    try {
      t1.join();
      t2.join();
    } catch (InterruptedException e) {
    }

    System.out.println("Counter value = " + c.get());
  }

}
```

New!!

Multithreaded.java with Synchronization

0

1

0%

2

0%

3

0%

4

0%

Now what behavior do you expect from Multithreaded.java?

1. The program will print "Counter value = 1000"
2. The program will print "Counter value = 2000"
3. The program will print "Counter value = ????" for some other number ????
4. The program will throw an exception.

Answer: The program with print “Counter value = 2000” every time.

Other Synchronization in Java

Need *thread safe* libraries:

- `java.util.concurrent` has `BlockingQueue` and `ConcurrentMap`
- help rule out synchronization errors
- Note: Swing is *not* thread safe!

- Java also provides *locks*
  - objects that act as synchronizers for blocks of code

- *Deadlock*: cyclic dependency in synchronization of locks
  - Thread A waiting for lock held by B,
    Thread B waiting for lock held by A

Immutability!

- Note that *read-only* data structures are immune to race conditions
  - It's OK for multiple threads to **read** a heap location simultaneously
  - Less need for locking, synchronization

- As always: immutable data structures simplify your code

Real-world example:

FaceBook's Haxl Library

- Library written in Haskell
- Concurrency / Distributed Database
- https://github.com/facebook/Haxl

Garbage Collection & Memory Management

Cleaning up the Heap

Memory Management

- The Java Abstract Machine stores all objects in the heap.
  - We imagine that the heap has limitless space…
    … but: real machines have limited amounts of memory
- *Manual memory management*
  - C and C++
  - The programmer explicitly allocates heap objects (`malloc` / `new`)
  - The programmer explicitly de-allocates the objects (`free` / `delete`)
- *Automatic memory management (garbage collection)*
  - Reference Counting: Objective C, Swift, Python, many scripting languages
  - Mark & sweep/Copying GC: Java, OCaml, C#, Haskell (and most other 'managed' languages)

Manual Memory Management

See manmem.c

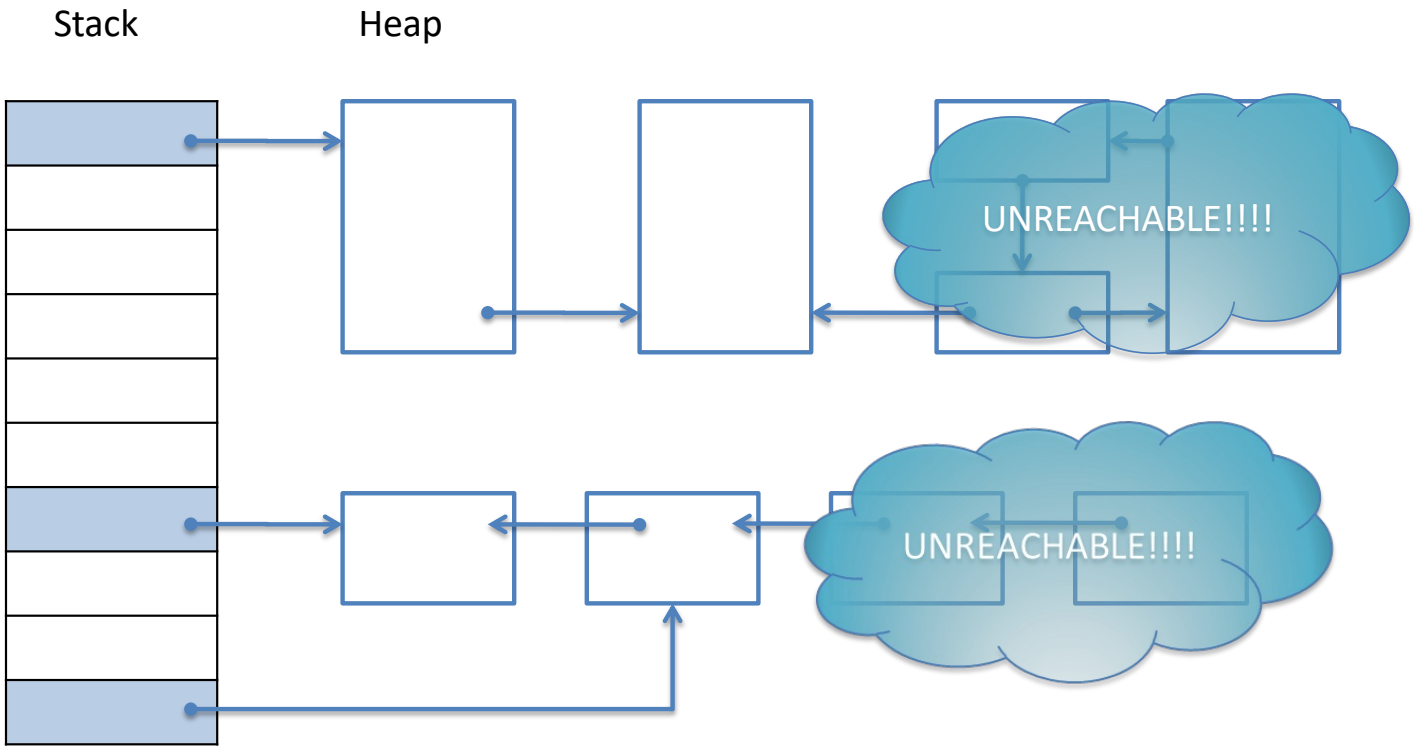
Why Garbage Collection?

- Manual memory management (as in C) is cumbersome & error prone
  - Freeing the same reference twice is ill defined (crashes or other bugs)
  - Explicit `free` isn't modular: To properly free all allocated memory, the programmer has to know what code "owns" each object. Owner code must ensure `free` is called just once.
  - Not calling `free` leads to *space leaks*: memory never reclaimed. Especially problematic for long-running programs.

- Garbage collection
  - Have the language runtime system determine when an allocated chunk of memory will no longer be used and free it automatically
  - Extremely convenient and safe
  - Garbage collection does impose costs (performance, predictability)
  - Space leaks less likely, but can still occur

Graph of Objects in the Heap

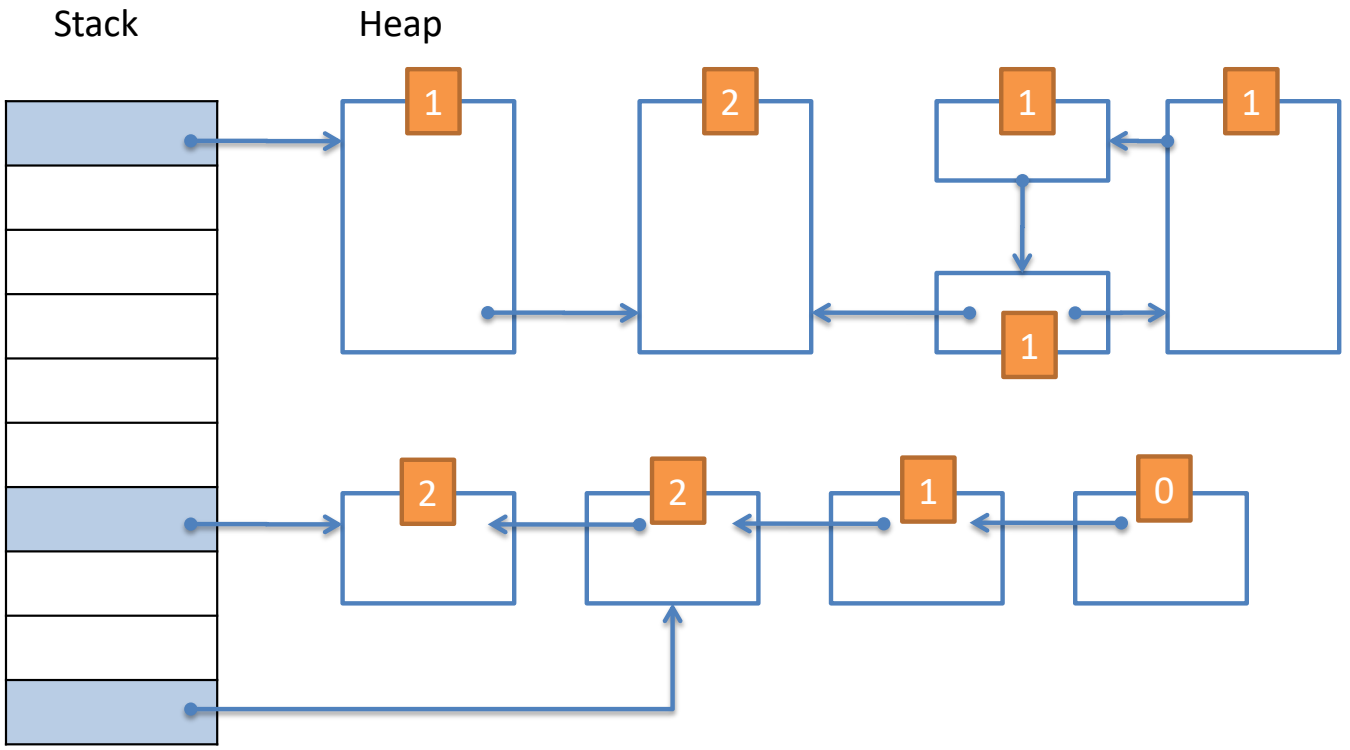
- References in the stack and global static fields are *roots*



Reference Counting

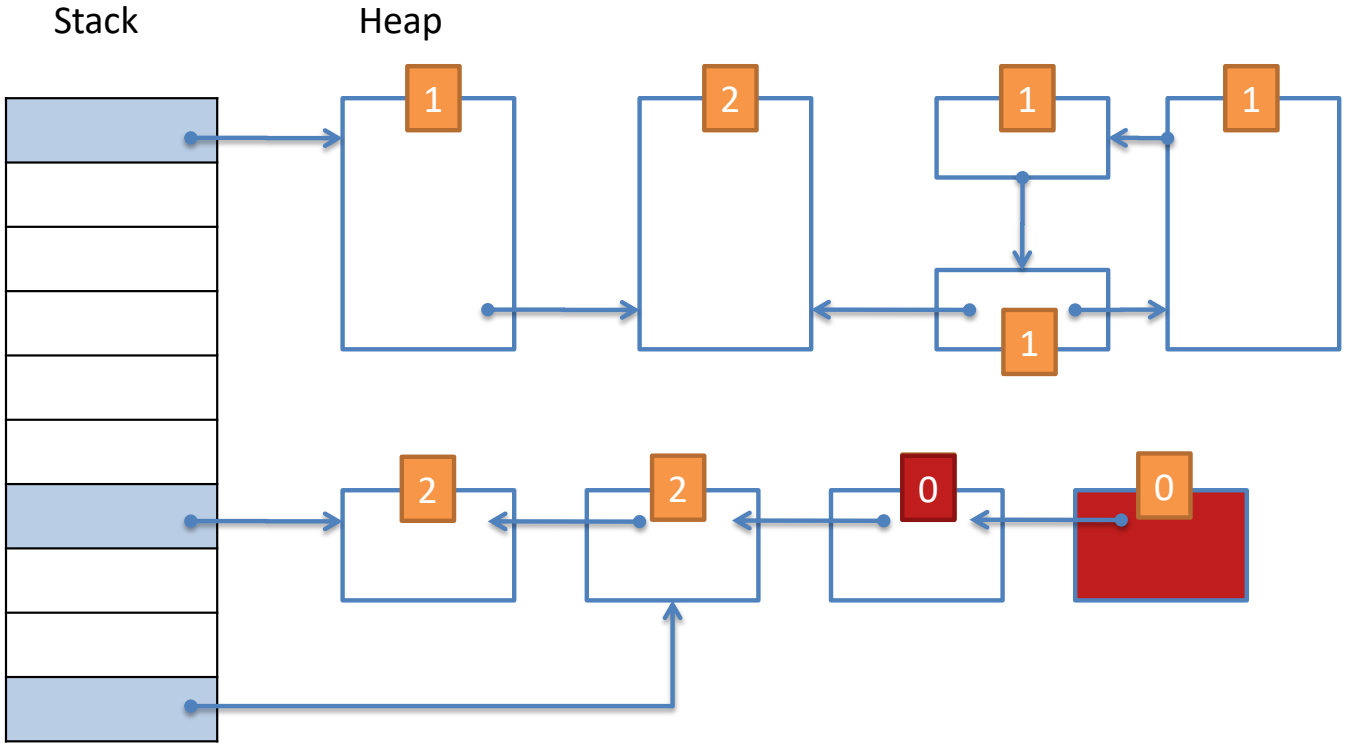
Reference Counting

- Each heap object tracks how many references point to it:



Reference Counting

- When reference count goes to 0, reclaim that space
  - and decrement counts for objects pointed to by that object



Reference Counting

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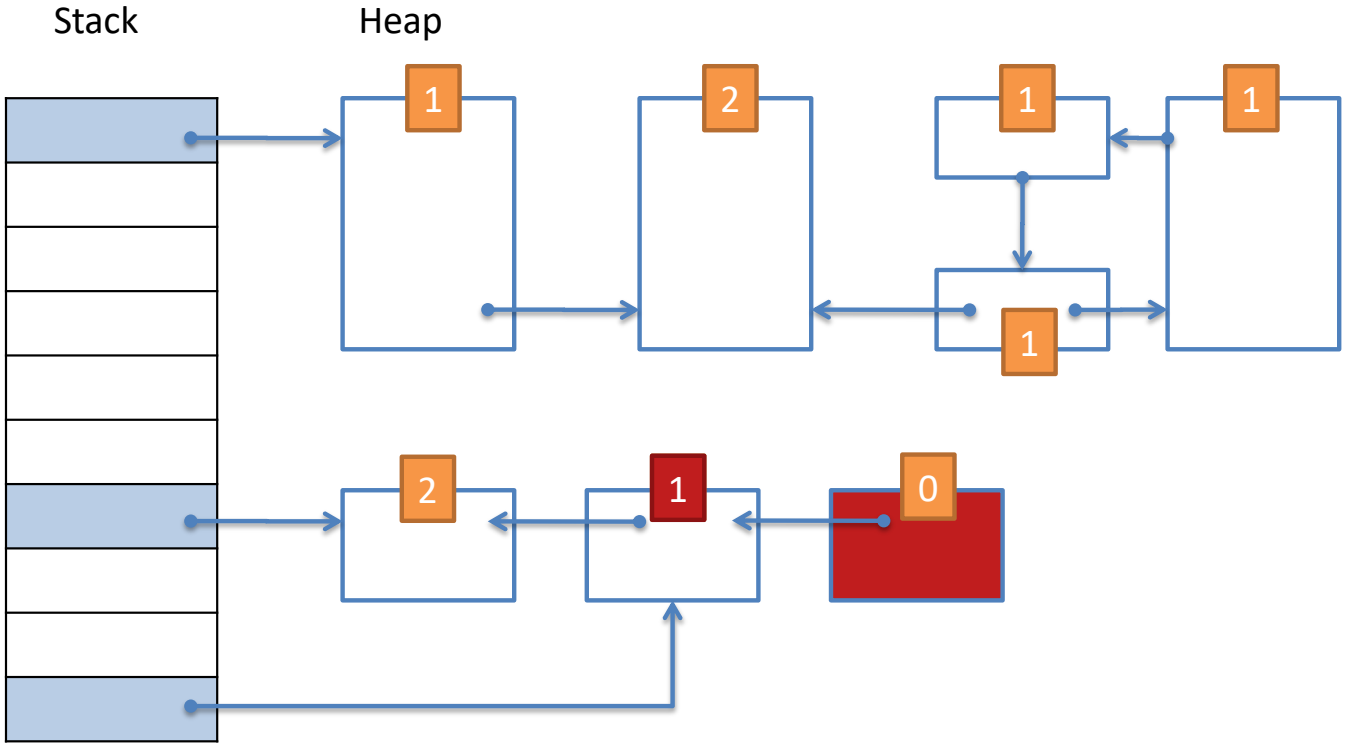
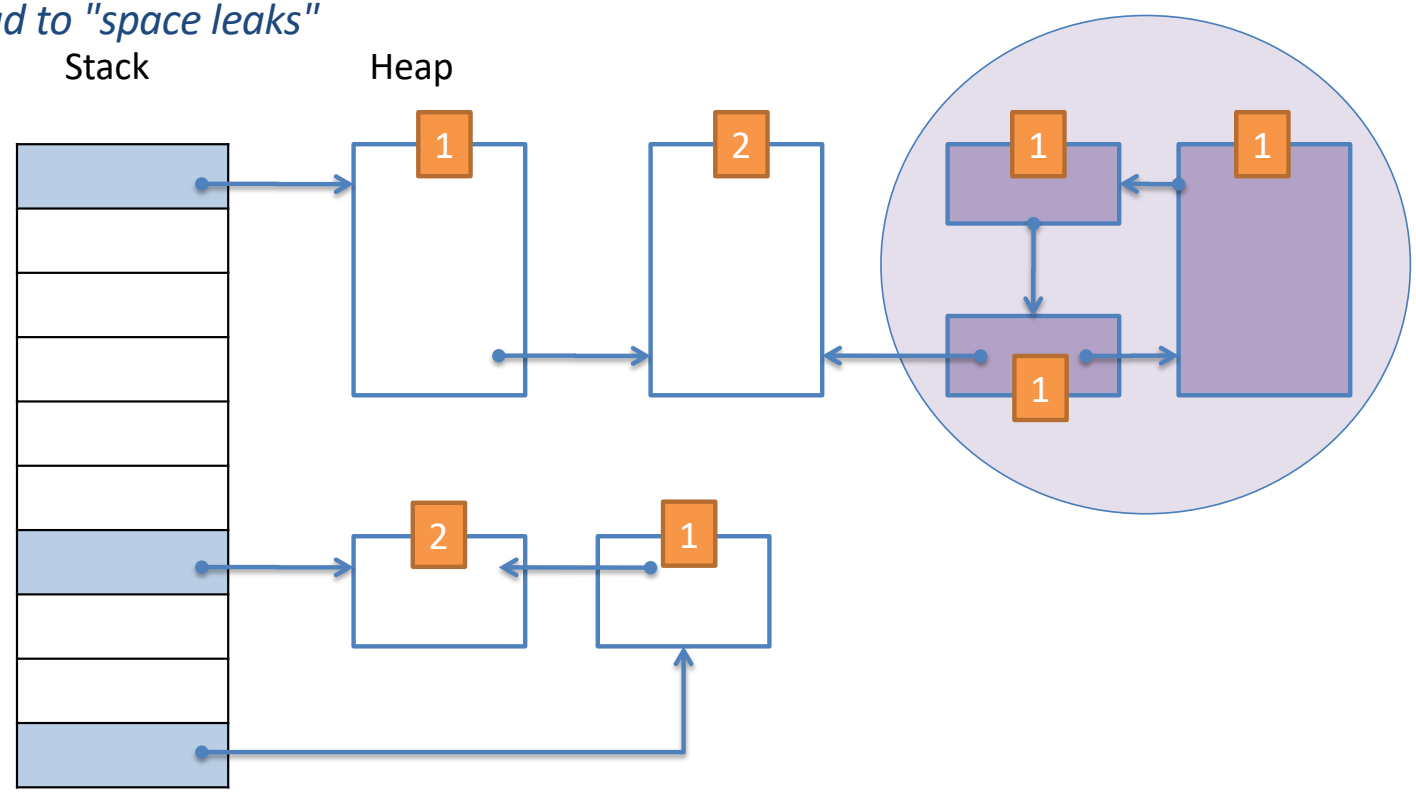


Problem: Cyclic Data

- Cycles of data will never decrement to 0!
  - *Can lead to "space leaks"*



Dealing with Cycles

- Option 1: Require programmers to explicitly null-out references to break cycles
- Option 2: Periodically run mark & sweep GC to collect cycles
- Option 3: Require programmers to distinguish “weak pointers” from “strong pointers”
  - *weak pointers*: if all references to an object are “weak” then the object can be freed even with non-zero reference count
  - “Back edges” in the object graph should be designated as weak
  - (Aside: weak pointers useful in other GC settings too)

Mark & Sweep / Copying

Traverse the Heap

Memory Use & Reachability

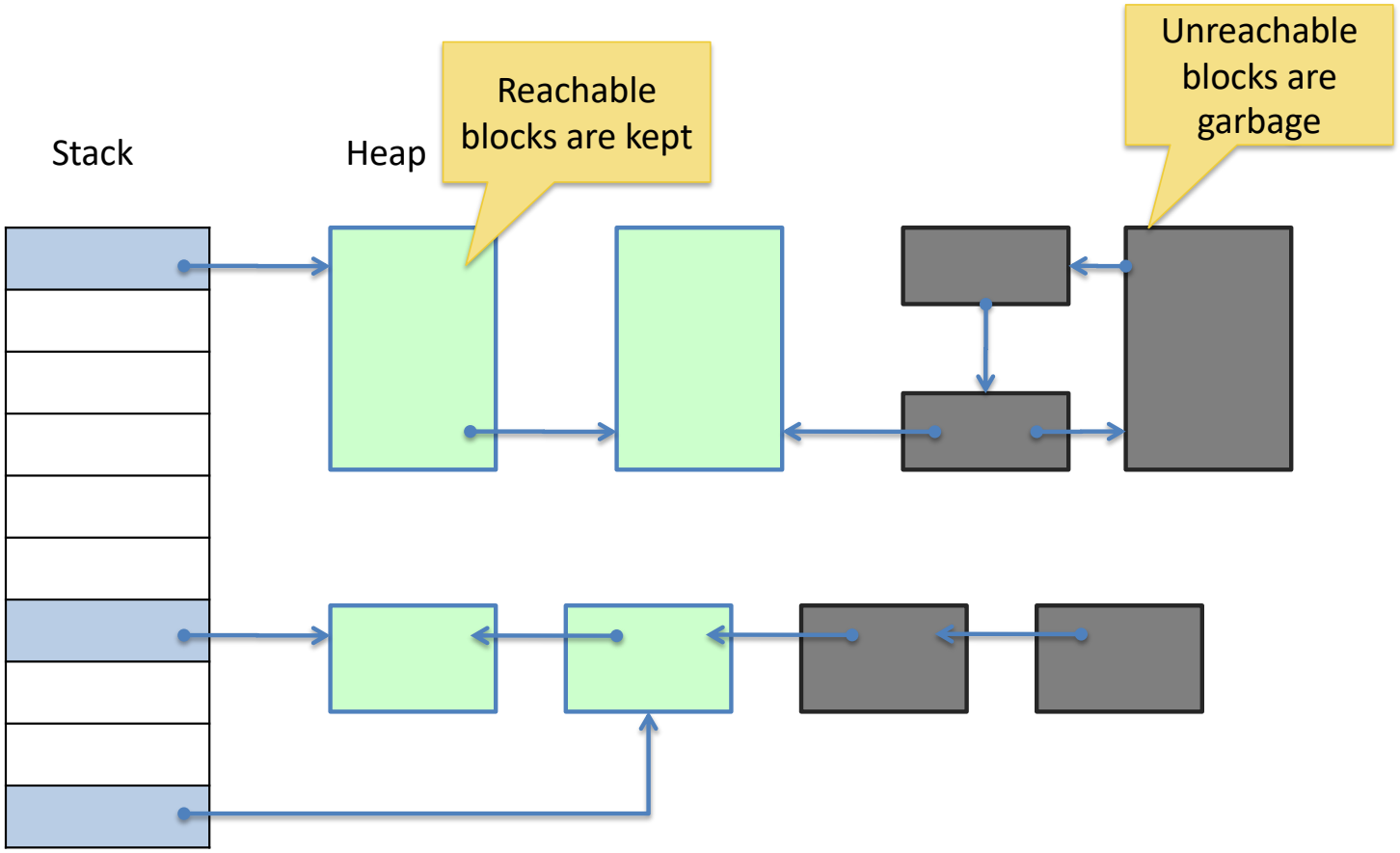
- When is a chunk of memory no longer needed?
  - In general, this question is undecidable.

- We can approximate it by freeing memory that we're sure is not needed because it can't be reached from any *root* references.
  - A *root reference* is one that might be accessible directly from the program
  - Root references include (global) static fields and references in the stack.
- If an object can be reached by traversing pointers from a root, it is *live*.
- It is safe to reclaim all heap allocations not reachable from a root (such objects are *garbage* or *dead* objects).

Mark and Sweep Garbage Collection

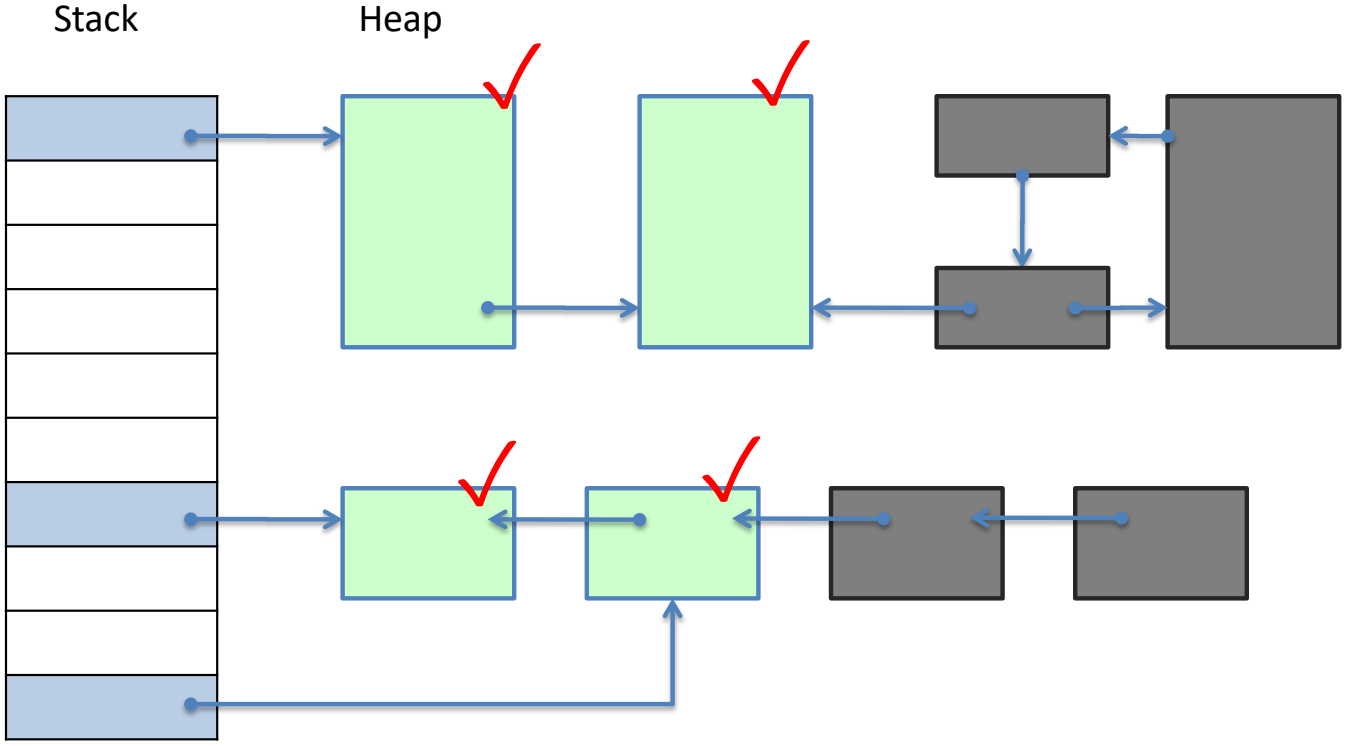
- Classic algorithm with two phases:
- Phase 1: Mark
  - Start from the roots
  - Do depth-first traversal, marking every object reached.
- Phase 2: Sweep
  - Walk over *all* allocated objects and check for marks.
  - Unmarked objects are reclaimed.
  - Marked objects have their marks cleared.
  - Optional: compact all live objects in heap by moving them adjacent to one another. (Needs extra work & indirection to “patch up” references)
- (In practice much more complex: "generational GC")

Results of Marking Graph



Second Phase: Drop "Unreachable"

- Sweep over all objects, dropping the ones marked as unreachable and keeping the ones marked reachable.



Costs & Implications

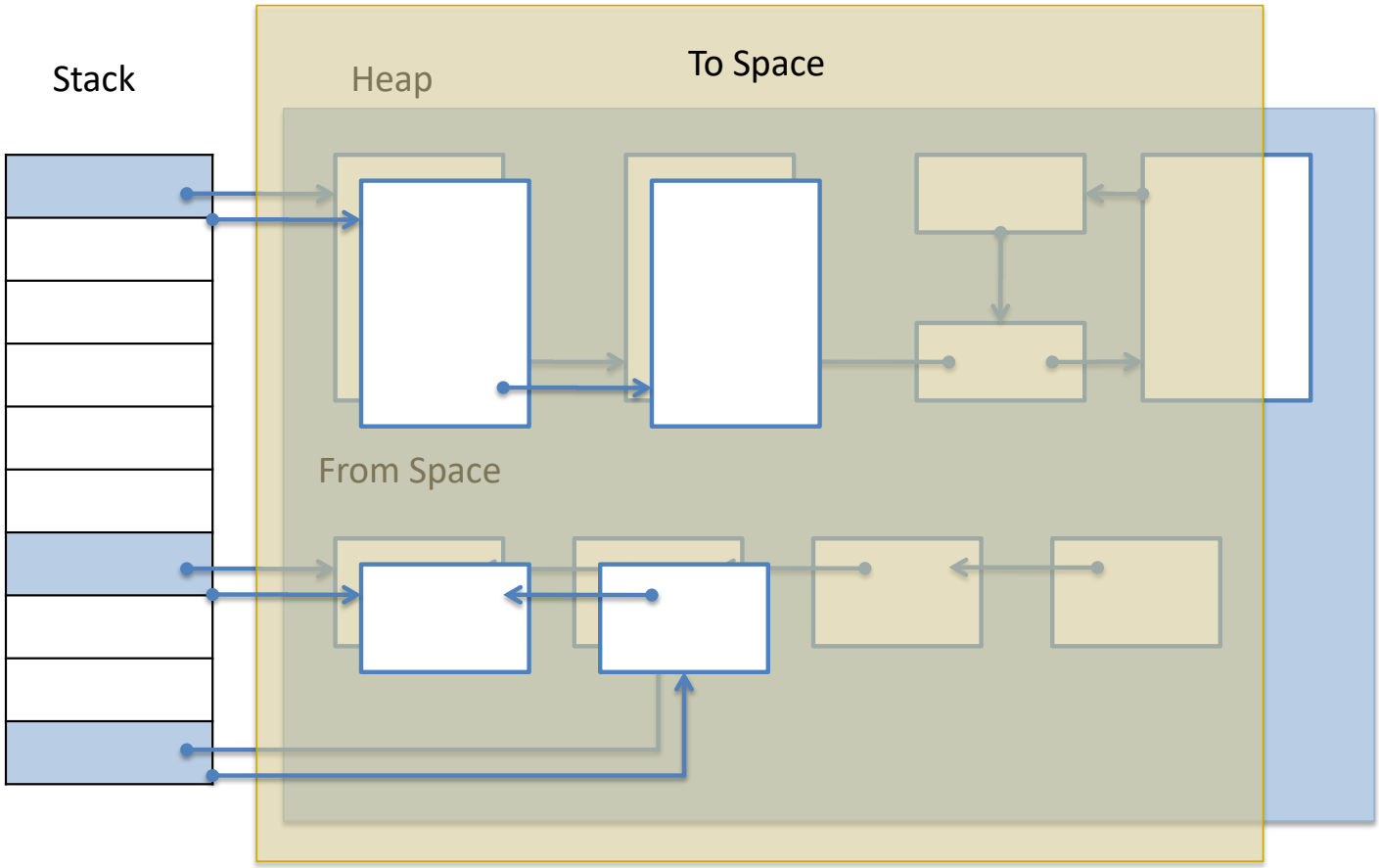
- Need to generalize to account for objects that have multiple outgoing pointers.
- Mark & Sweep algorithm reads all memory in use by the program (even if it's garbage!)
  - Running time is proportional to the total amount of allocated memory (both live and garbage).
  - Can pause the programs for long times during garbage collection.

Copying Garbage Collection

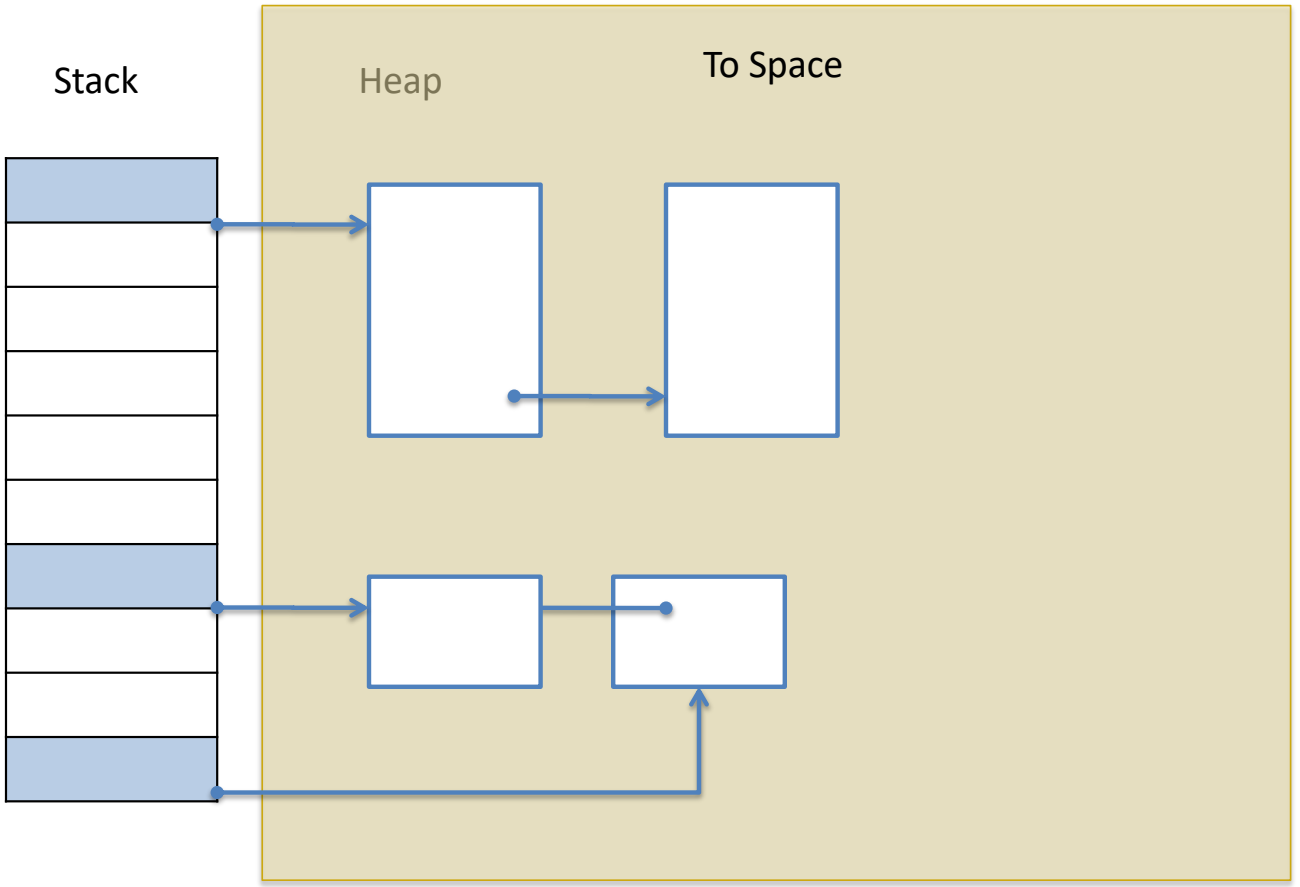
- Like mark & sweep: collects all garbage.
- Basic idea: use *two* regions of memory
  - One region is the memory in use by the program. New allocation happens in this region.
  - Other region is idle until the GC requires it.

- Garbage collection algorithm:
  - Traverse over live objects in the active region (called the "*from- space*"), copying them to the idle region (called the "*to-space*").
  - After copying all reachable data, switch the roles of the from-space and to-space.
  - All dead objects in the (old) from-space are discarded en masse.
  - A side effect of copying is that all live objects are compacted together.

Copy from "From" to "To"



Discard the "From Space"



GCDemo

See GCTest.java

Garbage Collection Take Aways

- Big idea: the Java runtime system tries to free-up as much memory as it can automatically.
  - Almost always a big win, in terms of convenience and reliability

- Sometimes can affect performance:
  - Lots of dead objects might take a long time to collect
  - When garbage collection will be triggered can be hard to predict, so there can be "pauses" (modern GC implementations try to avoid this!)
  - Global data structures can have references to "zombie" objects that won't be used, but are still reachable ⇒ "space leak".

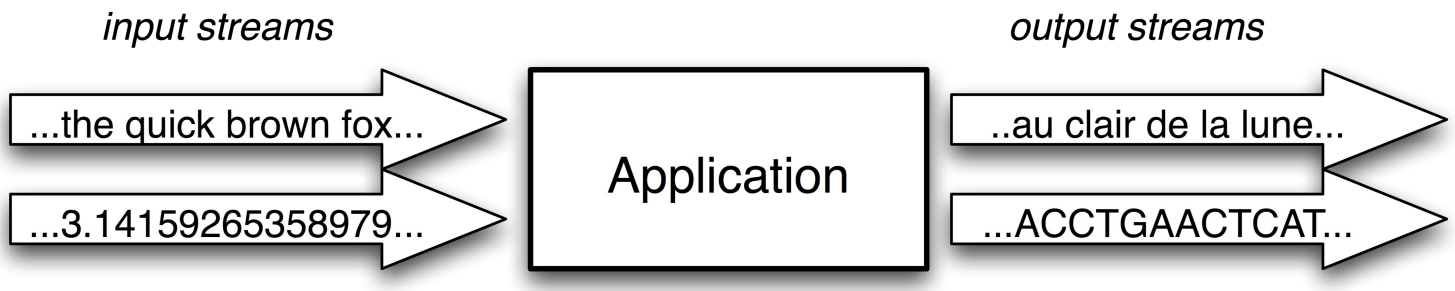
- There are many advanced programming techniques to address these issues:
  - Configuring the GC parameters
  - Explicitly triggering a GC phase
  - "Weak" references

Functional Programming + Streams

(See Streams.java)

I/O Streams

- The *stream* abstraction represents a communication channel with the outside world.
  - can be used to read or write a potentially unbounded number of data items (unlike a list)
  - data items are read from or written to a stream one at a time
- The Java I/O library uses subtyping to provide a unified view of disparate data sources and sinks.



Streams redux

- Use *streams* of elements to support functional-style operations on collections
- Key differences between streams and collections:
  - No storage (i.e., not a data structure)
  - Functional in nature (i.e., do not modify the source)
  - Possibly unbounded (i.e., computations on infinite streams can complete in finite time)
  - Consumable (i.e., similar to Iterator)
  - Lazy-seeking
    - "Find the first input String that begins with a vowel" doesn't need to look at *all* Strings from the input

Creating Streams (1)

- From a `Collection` via the `stream()` and `parallelStream()` methods
- From an array via `Arrays.stream()`
- The lines of a file can be obtained from `BufferedReader.lines()`
- Streams of random numbers can be obtained from `Random.ints();`
- Numerous other stream-bearing methods in the JDK

Creating Streams (2)

- Can create your own Low-Level Stream
- Similar to having a custom class like `WordScanner` that implements `Iterator`

- `Spliterator` – parallel analogue to `Iterator`
  - (Possibly infinite) Collection of elements
  - Support for:
    - Sequentially advancing elements (similar to `next()`)
    - Bulk Traversal (performs the given action for each remaining element, *sequentially* in the current thread)
    - Splitting off some portion of the input into another spliterator, which can be processed in *parallel* (much easier than doing threads manually!)

Stream Pipeline Operations

- Intermediate (Stream-producing) operations
  - E.g., `filter`, `map`, `sorted`
  - Similar to transform in Ocaml
  - Return a new stream
  - Always lazy (produce elements as needed, not ahead of time)
  - Traversal of the source does not begin until the terminal operation of the pipeline is executed
- Terminal (value- or side-effect-producing) operations
  - E.g. `forEach`, `reduce`, `findFirst`, `allMatch`, `max`, `min`
  - Similar to fold in Ocaml
  - Produce a result or side-effect
- Combined to create Stream pipelines

Lambdas, Streams, Pipelines

The Beauty and Joy of functional programming, now in Java!

```
roster.stream()
      .filter(p ->
              p.getHomeSchool().equals("SEAS")
              && p.getAge() >= 18
              && p.getAge() <= 25)
      .map(p -> p.getEmailAddress())
      .forEach(email -> System.out.println(email));
```

```
int sum = widgets.stream()
                 .filter(b -> b.getColor() == RED)
                 .mapToInt(b -> b.getWeight())
                 .sum();
```

Functional Programming + Parallelism

(See Streams.java)

Functional Programming + Parallelism

- Parallelism by design in Java 1.8
  - Streams are functional in nature (i.e., do not modify the source)
  - `Spliterator`
- Much easier than doing it manually
  - No need for `synchronized`
  - No need for locks
  - Don't have to worry about race conditions!
- Use `parallelStream()` (instead of `stream()`)!
  - Java will automatically create the necessary threads and scale based on your computer's hardware

Sample Problem

- Given a list of numbers, find the sum of the squares of the numbers

- **Iterative Approach**

```
int sum = 0;
for (int i = 0; i < list.size(); i++) {
   int x = list.get(i);
   sum += x * x;
}
```

- Works, more likely to have bugs (off-by-one), harder to parallelize

Sample Problem

- Given a list of numbers, find the sum of the squares of the numbers

- **Functional Approach**
- Use `transform` and `fold` (aka `map` and `reduce` in Java)

```
list.parallelStream()
    .map(x -> x * x)
    .reduce(0, Integer::sum);
```

- Less likely to have bugs, much easier to parallelize