Principles of Software Construction: Objects, Design, and Concurrency

Part 4: Et cetera

Design case study: Java lambdas and streams

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Administrivia

- Homework 5 Best Frameworks available today
- Homework 5c due Tuesday, 11:59 p.m.

Key concepts from Tuesday

Prefix sums (a.k.a. inclusive scan, a.k.a. scan)

- Goal: given array `x[0…n-1]`, compute array of the sum of each prefix of x

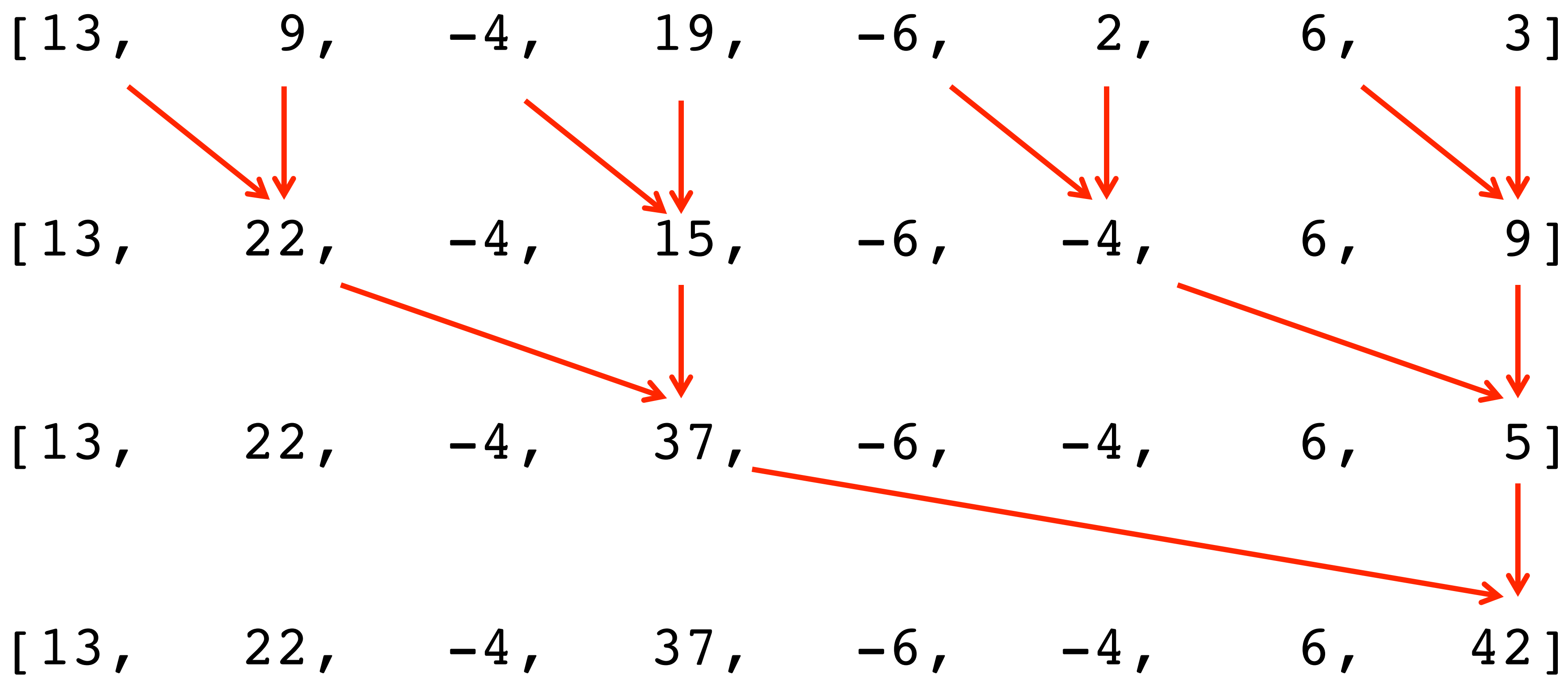
```
[ sum(x[0…0]),
  sum(x[0…1]),
  sum(x[0…2]),
  …
  sum(x[0…n-1]) ]
```

- e.g., `x =` `[13, 9, -4, 19, -6, 2, 6, 3]`

  prefix sums: `[13, 22, 18, 37, 31, 33, 39, 42]`

Parallel prefix sums algorithm, upsweep

Compute the partial sums in a more useful manner



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Parallel prefix sums algorithm, downsweep

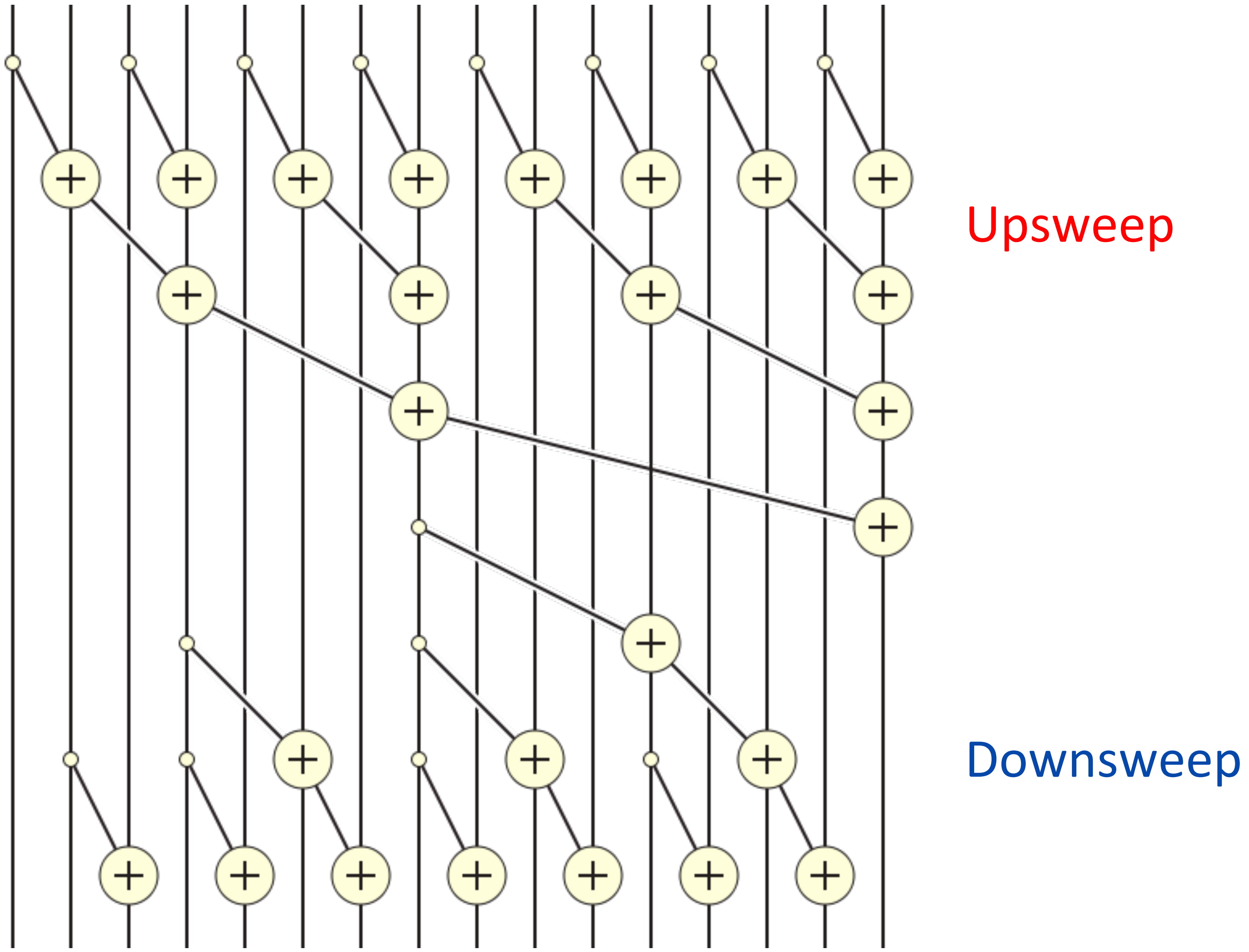
Now unwind to calculate the other sums

```
[13,   22,   -4,   37,   -6,   -4,    6,   42]

[13,   22,   -4,   37,   -6,   33,    6,   42]

[13,   22,   18,   37,   31,   33,   39,   42]
```

- Recall, we started with:

```
[13,    9,   -4,   19,   -6,    2,    6,    3]
```

Doubling array size adds two more levels



Recall from Thursday: Fork/join in Java

- The `java.util.concurrent.ForkJoinPool` class
  - Implements `ExecutorService`
  - Executes `java.util.concurrent.ForkJoinTask<V>` or
    `java.util.concurrent.RecursiveTask<V>` or
    `java.util.concurrent.RecursiveAction`
- In a long computation:
  - Fork a thread (or more) to do some work
  - Join the thread(s) to obtain the result of the work

Parallel prefix sums algorithm

- How good is this?
  - Work: O(n)
  - Depth: O(lg n)
- See `PrefixSumsParallelArrays.java`
- See `PrefixSumsSequential.java`
  - n-1 additions
  - Memory access is sequential
- For `PrefixSumsSequentialWithParallelWork.java`
  - About 2n useful additions, plus extra additions for the loop indexes
  - Memory access is non-sequential
- The punchline:
  - Don't roll your own. Know the libraries
  - Cache and constants matter

Today

- Java lambdas and functional interfaces
- Java streams

Lambdas, briefly

- Term comes from λ-Calculus
  - Everything is a function!
- A lambda (λ) is an *anonymous* function

Does Java have lambdas?

A. Yes, it’s had them since the beginning
B. Yes, it’s had them since anonymous classes (1.1)
C. Yes, it’s had them since Java 8 — the spec says so!
D. No, never had ’em, never will

Function objects in Java 1.0

```
class StringLengthComparator implements Comparator {
    private StringLengthComparator() { }
    public static final StringLengthComparator INSTANCE =
            new StringLengthComparator();

    public int compare(Object o1, Object o2) {
        String s1 = (String) o1, s2 = (String) o2;
        return s1.length() - s2.length();
    }
}

Arrays.sort(words, StringLengthComparator.INSTANCE);
```

Function objects in Java 1.1

```
Arrays.sort(words, new Comparator() {
    public int compare(Object o1, Object o2) {
        String s1 = (String) o1, s2 = (String) o2;
        return s1.length() - s2.length();
    }
});
```

"Class Instance Creation Expression" (CICE)

Function objects in Java 5

```
Arrays.sort(words, new Comparator<String>() {
   public int compare(String s1, String s2) {
       return s1.length() - s2.length();
   }
});
```

CICE with generics

Function objects in Java 8

```
Arrays.sort(words,
    (s1, s2) -> s1.length() - s2.length());
```

- They feel like lambdas, they're called lambdas

Lambda syntax

Syntax	Example
parameter -> expression	x -> x * x
parameter -> block	s -> { System.out.println(s); }
(parameters) -> expression	(x, y) -> Math.sqrt(x*x + y*y)
(parameters) -> block	(s1, s2) -> { System.out.println(s1 + "," + s2); }
(parameter decls) -> expression	(double x, double y) -> Math.sqrt(x*x + y*y)
(parameters decls) -> block	(List<?> list) -> { Arrays.shuffle(list); Arrays.sort(list); }

Method references: more succinct than lambdas

- A static method
  - e.g., `Math::cos`
- An unbound instance method (whose receiver is unspecified)
  - e.g., `String::length`
  - The resulting function has an extra argument for the receiver
- A bound instance method of a specific object
  - e.g., `System.out::println`
- A constructor
  - e.g., `Integer::new, String[]::new`

No function types in Java, only *functional interfaces*

- Interfaces with only one abstract method
- Optionally annotated with `@FunctionalInterface`
- Some functional interfaces you know
  - `java.lang.Runnable`
  - `java.util.concurrent.Callable`
  - `java.util.Comparator`
  - `java.awt.event.ActionListener`
  - Many, many more in `java.util.function`

Function interfaces in `java.util.function`

BiConsumer<T,U>
BiFunction<T,U,R>
BinaryOperator<T>
BiPredicate<T,U>
BooleanSupplier
Consumer<T>
DoubleBinaryOperator
DoubleConsumer
DoubleFunction<R>
DoublePredicate
DoubleSupplier
DoubleToIntFunction
DoubleToLongFunction
DoubleUnaryOperator
Function<T,R>
IntBinaryOperator
IntConsumer
IntFunction<R>
IntPredicate
IntSupplier
IntToDoubleFunction
IntToLongFunction
IntUnaryOperator
LongBinaryOperator
LongConsumer
LongFunction<R>
LongPredicate
LongSupplier
LongToDoubleFunction
LongToIntFunction
LongUnaryOperator
ObjDoubleConsumer<T>
ObjIntConsumer<T>
ObjLongConsumer<T>
Predicate<T>
Supplier<T>
ToDoubleBiFunction<T,U>
ToDoubleFunction<T>
ToIntBiFunction<T,U>
ToIntFunction<T>
ToLongBiFunction<T,U>
ToLongFunction<T>
UnaryOperator<T>

Some Function<String,Integer>

Description	Code
Lambda	`s -> Integer.parseInt(s)`
Lambda w/ explicit param type	`(String s) -> Integer.parseInt(s)`
Static method reference	`Integer::parseInt`
Constructor reference	`Integer::new`
Instance method reference	`String::length`

Anonymous class ICE	new Function<String, Integer>(){
	    public Integer apply(String s) {
	        return s.length();
	    }
	}

Java streams

- A stream is a bunch of data objects, typically from a collection, array, or input device, for processing
- Processed by a *pipeline*
  - **A single *stream generator* (data source)**
  - **Zero or more *intermediate stream operations***
  - **A single *terminal stream operation***

Stream examples: Iteration

```
// Iteration over a collection
static List<String> stringList = ...;
stringList.stream()
      .forEach(System.out::println);

// Iteration over a range of integers
IntStream.range(0, 10)
      .forEach(System.out::println);

// A mini puzzler: what does this print?
"Hello world!".chars()
      .forEach(System.out::print);
```

Puzzler solution

```
"Hello world!".chars()
      .forEach(System.out::print);
```

Prints `"721011081081113211911111410810033"`

The `chars` method on `String` returns an `IntStream`

How do you fix it?

```
"Hello world!".chars()
      .forEach(x -> System.out.print((char) x));
```

- Now prints `"Hello world!"`
- Morals:
  - Streams only for object ref types, `int`, `long`, and `double`
  - Type inference can be confusing

Stream examples: mapping, filtering

```
List<String> longStrings = stringList.stream()
      .filter(s -> s.length() > 42)
      .collect(Collectors.toList());

List<String> firstLetters = stringList.stream()
      .map(s -> s.substring(0,1))
      .collect(Collectors.toList());

List<String> firstLetterOfLongStrings =
      stringList.stream()
              .filter(s -> s.length() > 42)
              .map(s -> s.substring(0,1))
              .collect(Collectors.toList());
```

Stream examples: duplicates, sorting

```
List<String> dupsRemoved = stringList.stream()
      .map(s -> s.substring(0,1))
      .distinct()
      .collect(Collectors.toList());

List<String> sortedList = stringList.stream()
      .map(s -> s.substring(0,1))
      .sorted()  // Buffers everything until terminal op
      .collect(Collectors.toList());
```

Stream examples: bulk predicates

```
boolean allStringHaveLengthThree = stringList.stream()
      .allMatch(s -> s.length() == 3);

boolean anyStringHasLengthThree = stringList.stream()
      .anyMatch(s -> s.length() == 3);
```

Streams are processed lazily

- Data is pulled by terminal operation, not pushed by source
  - Infinite streams are not a problem
- Intermediate operations can be fused
  - Multiple intermediate operations usually don't cause multiple traversals
- Intermediate results usually not stored
  - But there are exceptions (e.g., sorted)

Easy parallelism: `.parallelStream()`

```
List<String> longStrings = stringList.parallelStream()
      .filter(s -> s.length() > 42)
      .collect(Collectors.toList());

List<String> firstLetters = stringList.parallelStream()
      .map(s -> s.substring(0,1))
      .collect(Collectors.toList());

List<String> firstLetterOfLongStrings =
      stringList.parallelStream()
              .filter(s -> s.length() > 42)
              .map(s -> s.substring(0,1))
              .collect(Collectors.toList());
```

Stream interface is a monster (1/3)

```
public interface Stream<T> extends BaseStream<T, Stream<T>> {
 // Intermediate Operations
 Stream<T> filter(Predicate<T>);
 <R> Stream<R> map(Function<T, R>);
 IntStream mapToInt(ToIntFunction<T>);
 LongStream mapToLong(ToLongFunction<T>);
 DoubleStream mapToDouble(ToDoubleFunction<T>);
 <R> Stream<R> flatMap(Function<T, Stream<R>>);
 IntStream flatMapToInt(Function<T, IntStream>);
 LongStream flatMapToLong(Function<T, LongStream>);
 DoubleStream flatMapToDouble(Function<T, DoubleStream>);
 Stream<T> distinct();
 Stream<T> sorted();
 Stream<T> sorted(Comparator<T>);
 Stream<T> peek(Consumer<T>);
 Stream<T> limit(long);
 Stream<T> skip(long);
```

Stream interface is a monster (2/3)

```
// Terminal Operations
void forEach(Consumer<T>);          // Ordered only for sequential streams
void forEachOrdered(Consumer<T>);  // Ordered if encounter order exists
Object[] toArray();
<A> A[] toArray(IntFunction<A[]> arrayAllocator);
T reduce(T, BinaryOperator<T>);
Optional<T> reduce(BinaryOperator<T>);
<U> U reduce(U, BiFunction<U, T, U>, BinaryOperator<U>);
<R, A> R collect(Collector<T, A, R>); // Mutable Reduction Operation
<R> R collect(Supplier<R>, BiConsumer<R, T>, BiConsumer<R, R>);
Optional<T> min(Comparator<T>);
Optional<T> max(Comparator<T>);
long count();
boolean anyMatch(Predicate<T>);
boolean allMatch(Predicate<T>);
boolean noneMatch(Predicate<T>);
Optional<T> findFirst();
Optional<T> findAny();
```

Stream interface is a monster (3/3)

```
  // Static methods: stream sources
  public static <T> Stream.Builder<T> builder();
  public static <T> Stream<T> empty();
  public static <T> Stream<T> of(T);
  public static <T> Stream<T> of(T...);
  public static <T> Stream<T> iterate(T, UnaryOperator<T>);
  public static <T> Stream<T> generate(Supplier<T>);
  public static <T> Stream<T> concat(Stream<T>, Stream<T>);
}
```

In case your eyes aren't glazed yet

```
public interface BaseStream<T, S extends BaseStream<T, S>>
   extends AutoCloseable {
 Iterator<T> iterator();
 Spliterator<T> spliterator();
 boolean isParallel();
 S sequential();  // May have little or no effect
 S parallel();    // May have little or no effect
 S unordered();   // Note asymmetry wrt sequential/parallel
 S onClose(Runnable);
 void close();
}
```

It keeps going: `java.util.stream.Collectors`

```
... toList()
... toMap(...)
... toSet(...)
... reducingBy(...)
... groupingBy(...)
... partitioningBy(...)

        .
        .
        .
```

`Optional<T>`: another way to indicate the absence of a result

It also acts a bit like a degenerate stream

```
public final class Optional<T> {
  boolean isPresent();
  T get();

  void ifPresent(Consumer<T>);
  Optional<T> filter(Predicate<T>);
  <U> Optional<U> map(Function<T, U>);
  <U> Optional<U> flatMap(Function<T, Optional<U>>);
  T orElse(T);
  T orElseGet(Supplier<T>);
  <X extends Throwable> T orElseThrow(Supplier<X>) throws X;
}
```

Stream practice

- Given a `List<String> words`, use streams to:
  - Generate a `List<String>` of all words containing the substring "heat"
  - Determine if any word contains the substring "aoeu" (a boolean)
- Challenge: Convert some operation in your Carcassonne solution to use streams… (or at least identify some operations that you might convert)

Stream parallelism: Your mileage may vary

- Consider this for-loop (.96 s runtime; dual-core laptop)

```
long sum = 0;
for (long j = 0; j < Integer.MAX_VALUE; j++) sum += j;
```

- Equivalent stream computation (1.5 s)

```
long sum = LongStream.range(0, Integer.MAX_VALUE).sum();
```

- Equivalent parallel computation (.77 s)

```
long sum = LongStream.range(0,Integer.MAX_VALUE)
        .parallel().sum();
```

- Carefully handcrafted parallel code (.48 s)

When to use a parallel stream, loosely speaking

- When operations are independent, and
- Either or both:
  - Operations are computationally expensive
  - Operations are applied to many elements of efficiently splittable data structures
  - Roughly: Number of elements * Cost/element >> 10,000
- **Always measure before and after parallelizing!**

When not to…

- Use a parallel stream…
- Use a stream...

Summary

- API design: "Fun and easy to learn and use…?"
- When to use a lambda
  - Always, in preference to CICE
- When to use a method reference
  - Almost always, in preference to a lambda
- When to use a stream
  - When it feels and looks right
- When to use a parallel stream
  - Number of elements * Cost/element >> 10,000
- Keep it classy!
  - Java is not a functional language