

Advanced Java Notes

Advanced OO Features

Key Design Patterns

Factory / Singleton Pattern

Using constructors as the publicly accessible means of obtaining initialized objects is fragile. Using a factory approach is more flexible in the face of changing requirements, and can support all the modes of use that a regular constructor can.

Constructors might still be necessary, for the initialization of final fields, or if a class is not final, but these can be private (for final initialization) or default/protected for initialization by child classes.

Builder Pattern

The builder pattern simplifies creation of objects that have many fields, particularly if not all are always required. The builder supports the “fluent” style of use, like this:

```
Flower f = Flower.builder()
    .petals(7)
    .color("Yellow")
    .latinName("Narcissus")
    .build();
```

A well encapsulated class should never expose an incompletely or improperly initialized object, the builder pattern facilitates this for classes that require complex initialization.

Strategy, Command, State, and Visitor patterns

These patterns all work on the principle that in OO an object is a mixture of state and behavior. Therefore, using a variable or method argument allows behavior to be changed dynamically at runtime. This is inherently more flexible than traditional implementation-inheritance.

Lab for Builder Pattern

Implement the builder for a class `LatinNamedFlower` with the fields indicated in this sample code. Use a static nested class to help with the implementation.

The final keyword

final variables must be provably assigned exactly once.

Reference-type final variables do not prevent modification of the object referred to.

final methods cannot be overridden

final classes cannot be subclassed

Subclassing carries responsibilities that are often overlooked (not least, the symmetry of equality. It's probably a safer default behavior to make all new classes final until you've given real thought to what inheritance implies for this class.

Flyweight Pattern (String Interning)

Where many instances of “equivalent” data might be created (e.g. text such as “<customer>” showing up as repeated tags in XML data streams), rather than make a new instance every time, create a pool and hand out instances from that. This requires some kind of factory approach, rather than a constructor. The pattern can also be used where large parts of objects' data are common or frequently repeated, even if some detail of every instance differs. This pattern can create a kind of run-time variable variant of the enum concept.

Equality

The primary purpose of the equals method is to find objects in collections. The meaning of equivalence is more subtle, and almost always both domain-entity and usage dependent. Providing equality mandates providing a hashCode. Equal objects must return equal hashcodes. Collections often use equality to find objects within themselves. Be very careful if equality testing is supported on objects that are mutable.

Lab for Equality and Collections

Define a simple class with a String and an int field, for example, Flower with attributes int petalCount and String color. Create a HashSet and populate it with three of these objects. Define simple equals and hashCode methods for this. Create a second object with the same fields as one of the elements in the set, and prove that you cannot add this, and that the set reports that it already contains the object.

If your class does not provide setter methods add them now. Modify the object in the set for which you created a duplicate and show that the set now no longer finds the object already present in the set. Next modify the duplicate so that it matches the now-modified set member, and see if you can find the existing item in the set. What behavior do you see and why?

Features and application of enum type

Individual enum classes can have programmer defined constructors, which must be private. They can also have fields and methods like any other class.

Example, including invocation of a non-default constructor:

```
public enum Suit {
    HEARTS, DIAMONDS, CLUBS, SPADES(true);
    private boolean isTrumps;

    private Suit() { this(false); }
    private Suit(boolean isTrumps) {
```

```

        this.isTrumps = isTrumps;
    }

    public String toPrettyName() {
        StringBuilder rv = new StringBuilder(
            name().toLowerCase());
        rv.setCharAt(0,
            Character.toUpperCase(rv.charAt(0)));
        if (isTrumps) {
            rv.append(" (Trumps)");
        }
        return rv.toString();
    }
}

```

Use enums to represent business domain elements that are fixed in number, but avoid using them if the number might change over the life of the program. This error requires the program to be edited, recompiled, and restarted if a new element is invented. In the more dynamic situation, the “flyweight” pattern should probably be used instead.

Inner classes

Moving a class into another class creates an instance inner.

Instance inners must “belong” to an instance of the enclosing class; that is, have an implicit reference to an instance of the outer class.

Classes defined inside another class may be labeled static. This causes them to be associated with the class as a whole, not a single instance. These are called nested classes.

Anonymous inner classes must be instantiated in exactly one place in the source code. They do not have a name, and allow some syntax to be left out, making them shorter, and more readable. More than one instance can be created if that section of code is executed more than once.

If an anonymous inner is defined in a method, it may refer to variables in that method provided the variables are either final or in Java 8, “effectively final”. This is Java’s implementation of a “closure”

Advanced Exception Handling

Design with exceptions

The try/catch mechanism allows separation of happy-path concerns from error-recovery concerns.

The finally block should be used for cleanup / release of finite OS resources other than memory.

Careful thought should be given to the exceptions that are thrown out of a method. Do not expose implementation details, and be sure to report something meaningful to the caller at the level of abstraction of your object's API. The most common complaint about checked exceptions is that the caller doesn't know what to do about the problem, suggesting bad encapsulation or abstraction in the object throwing the exception.

Create a "semantic exception" that is specific to your API (unless a pre-existing one is exactly suitable) and throw that. Use the exception's cause to report the underlying implementation problem for logging.

Good design seeks an API that requires minimum knowledge; seek to avoid APIs that can be misused if an alternate form would be robust.

The try-with-resources structure

Resource must implement `AutoCloseable`

Resources must be declared and initialized in the try parameter block. Separate/terminate them with semicolons:

```
try (
    FileReader in = new FileReader("input");
    FileWriter out = new FileWriter("output");
) { ... }
```

Multi-catch

Multiple alternate formal parameter types can be used in Java 7+ catch blocks:

`catch(IOException | SQLException ex)`

These must not be on the same inheritance path

The parameter's actual type will be the nearest common ancestor

If rethrown, the methods throws clause need only refer to `IOException` and `SQLException`, not the common ancestor

Suppressed exceptions

Exceptions thrown during closing might become suppressed to allow an original cause of failure to be expressed to the caller. These are accessible to the caller via the `getSuppressed` method.

Lab for Multi-Catch

Define three sibling exceptions `AException`, `BException`, and `CException`. These can be direct subclasses of the base `Exception` class. Ensure that you define all the constructors that delegate to the parent class.

Define a method `flaky` that throws the three exceptions you defined. Code it so that it completes normally or throws one of these exceptions randomly.

Define another method caller that calls the flaky method. If flaky throws either AException or BException, these should be caught by the same handler using the multi-catch syntax. The handler should print a message. CException should be caught separately. Next arrange that the caller method rethrows AException and BException. What declaration is necessary on the caller method?

Lab for AutoCloseable

Define a simple class MyCloseable that implements AutoCloseable. Allow the object to identify itself based on a String passed into the constructor. Print a message that includes this identity when the close method is called.

Write a method using the old style try block and allocate a MyCloseable object. Use an explicit finally block to close the resource. In the try block, use a random number generator to throw a checked exception half the time and print a message when this occurs. Declare this on the method and try/catch it in the caller printing a message noting that the exception was caught. Run the code, and determine that the checked exception reaches the caller.

Modify the close method in the MyCloseable object so that half the time it throws an IOException. Print a message to indicate that this behavior is being performed. Run the code a few more times, and notice what happens when the close exception arises, both when the checked exception does, and does not arise.

Modify the code to use a try-with-resources structure instead of the traditional try/finally. Run the code a few more times, and determine how the behavior has changed.

Modify the code so that it allocates two MyCloseable objects, with different identities, in the resources block. Run the code, and observe the order the messages are printed by the close operations.

Generics

Defining a generic class / interface

```
class Thing<E> { // declare type variable E
    E item; // use it for variables etc.
```

Type erasure and non-reifiable types

Generic type information is unavailable, and cannot be used, at runtime:

```
E[] data = new E[]; // fails, cannot instantiate array of E
```

Bounded generic types

```
class Thing<E extends Xxx>
class Thing<E extends AClass & AnIf & OtherIf>
```

Defining a generic method

First <E> is generic type variable declaration, all other E are using the type:

```
<E> E findOne(Collection<E> c, Predicate<E> p) {  
    for (E item : c) {
```

Wildcard types

<? extends Thing>: generic type that must be assignment compatible with Thing

<? super Thing>: generic type that must accept assignment of a Thing

Dynamic Java

Annotations

Annotations are labels on parts of source code. Define as:

```
public @interface MyAnnotation { }
```

Annotations might survive only in source, or into classfile, or survive all the way into the running java.lang.Class object in memory. This is controlled by annotating the annotation's declaration:

```
@Retention(@RetentionPolicy...
```

Control legitimate source constructs to which the annotation may be applied using:

```
@Target({@ElementType...
```

Runtime annotation processing with reflection

Load and instantiate a class with:

```
Class cl = Class.forName("com.useful.MyStuff");  
Object obj = cl.newInstance(); // 0-arg constructor
```

Find methods, fields:

```
cl.getDeclaredMethods() returns methods declared in this class  
cl.getMethods() gets accessible methods in this class  
cl.get[Declared]Fields similar methods for accessing fields
```

Find annotations on method or field objects:

```
method/field.getAnnotation(Class<T> annotationClass)
```

Invoke methods:

```
method.invoke(Object target, Object ... args)
```

For static methods target is null

Accessing fields

```
Field f = ...;
f.set(Object target, Object value);
Object val = f.get(Object target);
```

Disable accessibility checks

```
fieldOrMethod.setAccessible(true);
```

Annotations with fields

Annotations can carry key / value pairs (literals in source, and read-only at runtime), which can have default values:

```
public @interface MyAnnotation {
    public String name() default "Fred";
    public int value();
}
```

Valid types are: primitives, wrappers, String, Class, an enum, an annotation, or an array of these

Applying annotations

If any annotation field does not have a default value, the use must specify that field's value. Do this with comma-separated x=y format:

```
@MyAnnot(name="Fred", value=10)
```

The special key named `value` can be assigned without the key being used provided it's the *only* key being defined in the annotation:

```
@MyAnnot(99) //value=99, name="Fred" (the default)
```

Lab for Dependency Injection

Create an annotation called `SetMe`. The annotation should be applicable only to fields, and be visible at runtime. It should accept one mandatory argument of type `String`. Create a class called `Framework` and give that class a main method.

The main method should read textual key value pairs from a properties file. The keys should include "Instantiate" and the value associated with that key should be a fully qualified class name. Arrange that the main method loads and instantiates the named class, storing a reference to it in a variable called `target`.

The main method should proceed by scanning all the fields in the class. For each field that carries the `SetMe` annotation, extract the parameter value of the annotation and use that as a

key to perform a lookup in the properties file. Assign the value that's found into the field in the target object.

Finally, arrange that the main method prints out the textual value of the target object (simply use the toString method).

Build a class to be used as the target value. Ensure that at least two String fields are annotated with SetMe. Give the annotations parameters, and ensure that the parameters are entered against those keys in the properties file. Give the class a toString method that reports the values of all the fields.

Add the fully qualified name of the class to the properties file and run the program.

More Java 8 Enhancements

New interface method types

Java 8 allows interfaces to define static methods, and default methods. Default methods are instance methods with implementations which will be used in a class if, and only if, no class-based implementation is available. They are intended for interface expansion while avoiding breaking all legacy code that does not implement the new method.

Method references

Method references create lambda expressions using a shorthand of the form: X::y These exist in four forms:

- 1) X is a classname, y is a static method
- 2) X is a classname, y is an instance method
- 3) X is an instance reference, y is an instance method
- 4) X is a classname, y is new

Generally, arguments to the lambda will be mapped to the arguments of the method, however, in case 2) the first lambda argument becomes the instance on which the method is invoked, and the remaining lambda arguments become the arguments to the method.

Collections API enhancements

Several new methods were added to the Collection and Map interfaces. Some of these take functional interface arguments, examples include:

```
Iterable.forEach(Consumer c)
Collection.removeIf(Predicate p)
Map.compute[IfPresent/Absent] (
    K key, BiFunction remappingFunction)
```

Lab for Collections Enhancements

Create two `Map<LocalDate, String>` objects, one called `workCalendar`, and the other called `personalCalendar`, and initialize them with some events with simple, short, textual descriptions (such as Birthday, Meeting, Vacation). Ensure that some dates are common to both maps. Using the `merge` method of `Map`, arrange to create a new map that contains all the events from both calendars. Where more than one event occurs on the same day, present them as a comma separated string in the value of the map, for example:

Birthday, Vacation

Lab for Method References

Take the behavior that combines two events into a comma separated string used in merging the two maps and embed it in a static function that can be called using a method reference. Modify the `merge` invocation to use that method reference.

Functional Java

Basic functional programming concepts

Behavior is passed as arguments and return values

Methods can take behavior as an argument, and return modified behavior as a return.

Provides reuse at a function level, not just at object level

Lambda expressions

When an interface with a single abstract method is to be implemented, it's sufficient to provide only the parameter list of the method, and the method body:

```
BiPredicate<String> bps =  
    (s,t)->{return s.length() > t.length();};
```

(s,t) are the formal parameter list, inferred to be of type `String`.

The brace-delimited block shown in the code is the method body.

If the block / method-body contains only a single statement returning an expression, then the example can be reduced to:

```
BiPredicate<String> bps =  
    (s,t)->s.length() > t.length();
```

If the method takes only a single argument, the parentheses around it can be omitted:

```
Predicate<String> ps = s -> s.length() > 3;
```

Standard functional interfaces

The package `java.util.function` defines 43 functional interfaces covering many single and two argument methods with different return types, and variations for primitive argument and return types.

Lab for Functional Operations

If you do not already have it, create an interface called `Criterion<E>` such that it defines an abstract method and three default methods:

```
boolean test(E e);
default Criterion<E> negate();
default Criterion<E> and(Criterion<E> c);
default Criterion<E> or(Criterion<E> c);
```

The test method takes a generic object as an argument, and returns true or false, representing some kind of test on the argument object.

The negate operation should return a criterion that inverts the sense of the test performed by the original criterion. The and and or operations should take a second Criterion as an argument, and return a new Criterion object that computes the effect of combining the original and argument criteria according to the standard rules of boolean logic.

Next create a number of objects of varying kinds (for example a `LocalDate`, a `String`). Define some tests using lambda expressions for these objects and assign them to variables of `Criterion<E>` type (choose an appropriate value for the type `E`). For example, tests might represent “is the string longer than 3 characters”, “does the string start with a lowercase letter”. Run the tests on the appropriate objects, printing out the results. Then create combined tests using the existing tests and the operations and, or and negate. So, for example, you should be able to assign a variable

```
Criterion<String> longAndLower =
    longString.and(lowerString);
```

Apply the combined tests to your example objects, and print the results.

Streams

Basic concepts

A Java 8 Stream represents a lazy, potentially infinite, sequence of data items, with standard transformations that can be applied to create a final result. It is one of a number of Monad-like features of Java 8 (along with `Optional` and `CompletableFuture`).

Two broad categories of operations are known as terminal and non-terminal operations.

Non-terminal operations return another stream object, possibly of a different data type. Primitive streams are also defined, so as to avoid unnecessary boxing and unboxing.

Stream operations should generally not have side effects, treating all data as immutable. This supports thread-safety and the parallel execution model that streams offer.

A Stream implements `AutoCloseable`, although this is only needed if the underlying data is coming from a non-memory source (such as the filesystem).

Key operations

`forEach`, `filter`, `map`, `flatMap`, `reduce` and `collect`

Note that `reduce` is intended as an entirely immutable operation, but might result in a large GC load due to high volume of intermediate objects. The collect operations support mutating collections, with each thread in a concurrent stream using a thread-specific collection “bucket” followed by a single threaded aggregation after the main streams have completed.

The `Collectors` class provides a number of useful pre-created collection capabilities, notably including the `groupingBy` behavior that builds a Map from the data using programmer supplied key extraction and an optional downstream collector to post process each stream item into the map's value field.

More ways of obtaining Streams

Streams factories: `Stream.builder`, `Stream.empty`, `Stream.generate`, `Stream.iterate`, `Stream.of`

`StreamSupport` can make a stream from a `Spliterator`, and `Iterable` has a default method for providing a `Spliterator`, facilitating creation of a Stream from an `Iterable`.

Streams are also returned from several methods in `java.nio.file.Files`

Concurrent Streams

Streams support parallel operations if created as such from a collection (`aCollection.parallelStream()`), but streams might also be handled as sequential, ordered or unordered

Concurrent modes often have hidden impediments/costs, particularly any necessary to maintain ordering, but also during collect operations, where data might need to be merged after processing, or might need to be collected into a thread-safe collection.

Lab for Streams

A concordance is a table of word frequencies in a document; a concordance of this sentence is:

| | |
|-------------|-----|
| a | : 4 |
| concordance | : 2 |
| is | : 2 |
| table | : 1 |
| of | : 2 |
| word | : 1 |

```
frequencies : 1
in          : 1
document   : 1
this       : 1
senten ce  : 1
```

Use the streams API to create a concordance for the text of “Pride and Prejudice” by Jane Austen. The book can be obtained as a plain text (UTF 8) document from gutenberg.org.

First create the concordance and print it out.

Second, modify the output so that only the most frequent 200 words are printed, and those are printed in descending order of frequency.

Threading

Thread and Runnable

`java.lang.Thread` defines a “virtual CPU”, this runs code starting in the `run` method of a `Runnable`.

Start the Thread execution using `aThread.start()`

Thread cooperation

If two threads are sharing data, and any the data might mutate, all kinds of problems can arise unless care is taken to ensure that an appropriate “happens-before” relationship is established between the mutating thread and the reading thread.

If a happens-before relationship exists between two statements `a` and `b` in code, then the effects of `a` that are observed by `b` will be visible to `b`. Normal sequential processing creates the happens-before relationships expected, but code optimization by reordering of unobserved effects is still possible.

8 language-defined happens-before relationships:

1. In code executed by a single thread, program order defines happens-before relationships.
2. If `a` happens-before `b`, and `b` happens-before `c`, then `a` happens-before `c`.
3. The monitor unlock when a thread exits a synchronized block happens-before a subsequent monitor lock operation by another thread synchronizing on the same object.
4. The write to a volatile variable happens-before a subsequent read of the same variable.
5. The `Thread.start()` call happens-before any code executed by that thread.
6. The termination of a thread happens-before any code that determines the thread has terminated (using `join` or `isAlive` methods)

7. A call to `Thread.interrupt()` happens-before the thread determines that it has been interrupted (using the methods `interrupted`, or `isInterrupted`, or by catching an `InterruptedException`)
8. The completion of a constructor happens-before the start of a `finalize` method of that object.

Blocking threads

“Busy waiting” is generally wasteful of CPU. Instead, threads can be made to block (become non-runnable) awaiting conditions that will be caused by other threads using the `wait()` and `notify()` primitives of `Object`. These are hard to use well, however, and `ReentrantLock` or `ReentrantReadWriteLock` are generally preferred. Java's libraries also include a `Semaphore` class, but this can be hard to use well too.

Simple approach to thread safety

The so-called “pipeline architecture” which has become popular again recently in a number of message passing toolkits is easy to use and simple enough to give high confidence in the implementation. Implement the pipeline using an implementation of `java.util.concurrent.BlockingQueue` (probably the `ArrayBlockingQueue`)

Ensure that data are only mutated by a thread that is the sole owner of a pointer to that object at the time of mutation. Pass the data to another thread using `myQueue.put`, and receive it using `myQueue.take`.

Thread pools

Threads are expensive to create, and they are finite kernel resources. Reusing them is preferable to one time use. Pools are provided by the core APIs through the `ExecutorService` interface. The `Executors` class has static factory methods for creating them.

Executor services can run `Runnable` jobs, or `Callable<X>` jobs. When a `Callable<X>` is `submit()`ted, a handle on that job is returned. The handle implements `Future<X>` and provides job control and data access methods: `isDone()`, `cancel()`, `isCanceled()`, `get()`.

Cancellation of a running job requires the cooperation of that job's code, responding to the interrupt mechanism and shutting down cleanly. Jobs that have not been started are simply removed from the queue when canceled.

The `ForkJoinPool` provides a pool that is designed for a specific type of job that can divide itself into fractions, such that each fraction is executed in a separate thread. On completion of the task fractions, the partial results are passed back to the parent fractions which then merge the results back together to create a “final answer”.

Synchronizers

Several synchronization (timing) mechanisms are provided by the core APIs, including the Thread's join method, the CyclicBarrier, and the CountdownLatch.

Concurrent collections

Where collections will be shared across multiple threads, be sure to use a thread-safe collection. The java.util.concurrent package has several to choose among.

Concurrency and scalability

Amdahl's law shows that blocking threads reduces scalability, and should be minimized. Java's concurrency packages include several utilities designed to help minimize this. These include the LongAccumulator and DoubleAccumulator classes in the java.util.concurrent.atomic package, CopyOnWrite... and Skip... data structures.

For simulations, use the ThreadLocalRandom class rather than Math.random.

ThreadLocal variables

If data should be associated with a particular request (such as credentials of original requester, or transaction information) a ThreadLocal type variable might be useful. Typically, a singleton wrapper will be used to provide access to a single instance of the ThreadLocal type, and each call to get() made on that singleton object will provide a data item that is created on a per-thread basis. You must provide the initialValue() behavior used for initialization.

ThreadLocal variables can also provide a means of avoiding concurrency issues by giving each thread its own data, avoiding race conditions, and the locking that might otherwise be used to correct such problems. This is exemplified by the ThreadLocalRandom class, which should be used in highly concurrent random number generation, such as simulations.

CompletableFuture

The CompletableFuture API provides an easy means to chain a sequence of asynchronous tasks. Each can be executed in a separate thread drawn from a pool. The API handles passing data from the result of one task to the input of the next task.

The API also facilitates integrating other tools, such as AsynchronousFileChannel; complete and related methods allow control both of the life cycle of a CompletableFuture object, and the data (or exception) passed on to the next stage in the chain.

The CompletableFuture follows the monadic approach; the monad embodies the concurrency and deals with callbacks so that the main threadpool that drives the execution can operate in a non-blocking manner. The traditional monad methods of map and flatmap have different names,

specifically the flatmap behavior (which is key to wrapping old-style callback operations) is named `thenCompose`, or `thenComposeAsync`. The regular map operation, which would be used for cpu-bound transformation operations, is presented in the `thenCompose` and `thenComposeAsync` methods.

`CompletableFuture` methods that include `Async` in their names are at liberty to select a different thread from the underlying pool (by default the `ForkJoinPool`) to execute the next pipeline stage.