Time Series Data and CompletableFuture example in Java

Full code for all the examples can be found here.

How to run the program

```
mvn clean compile verify exec:java
```

Preface

Suppose we want to calculate an *air quality index* based on two values:

- air temperature
- percentage of carbon monoxide in the air

Given the following symbols:

symbol	meaning
`AQi`	air quality index
`T`	air temperature in Celsius degrees
`Tm`	maximum air temperature in C°
`C`	percentage of carbon monoxide in the air

We may calculate the `AQi` with the following sorry excuse of a formula:

$$AQi = \frac{\frac{T \cdot 100}{T_m} + C}{2}$$

DISCLAIMER: please note that this formula is in no way scientific, and it's intended for educational purposes only. I don't want environmentalists and real scientists chasing me around with math formulas and accusations of quackery. Also, I saw a chance for a pretty LaTeX equation and I took it, because aesthetics... and it makes me look smart, which I certainly am not[1].

What the formula attempts to say is that as the temperature and the carbon monoxide percentage rise, the air quality decreases. Yeah, this is totally unscientific but bear with me for the sake of argumentation, please.

I assume a maximum temperature of 40C°. So, for instance:

```
$ bc -l
bc 1.06
```

[1] this is my revenge for all the bad math grades at school.

```
Copyright 1991-1994, 1997, 1998, 2000 Free Software Foundation, Inc.
This is free software with ABSOLUTELY NO WARRANTY.
For details type 'warranty'.
t=60; c=100; tm=40; (((t * 100) / tm) + c) / 2
125.00000000000000000000
t=60; c=50; tm=40; (((t * 100) / tm) + c) / 2
100.00000000000000000000
t=40; c=50; tm=40; (((t * 100) / tm) + c) / 2
75.00000000000000000000
t=40; c=10; tm=40; (((t * 100) / tm) + c) / 2
55.00000000000000000000
t=20; c=10; tm=40; (((t * 100) / tm) + c) / 2
30.00000000000000000000
t=10; c=5; tm=40; (((t * 100) / tm) + c) / 2
15.00000000000000000000
t=10; c=0.5; tm=40; (((t * 100) / tm) + c) / 2
12.75000000000000000000
```

From this we can derive the following totally unscientific table:

AQi	meaning
125 to ∞	horrible death
100 to 125	painful death
75 to 100	death
55 to 75	it is acceptable[2]
30 to 55	this is fine[3]
15 to 30	fine and dandy
12.75 to 15	pretty cool
-∞ to 12.75	welcome to Yakutsk, probably

Service providers

Suppose we have internet services that expose temperature and carbon monoxide level monitoring values. These services might expose an api that gives us time series data[4].

So, for instance, we might call a temperature monitoring service, and it would respond with time series data like this:

---

2 

timestamp	value
`2021-01-20T08:00:00Z`	`10.1`
`2021-01-20T08:02:00Z`	`10.3`
`2021-01-20T08:05:00Z`	`10.7`
`2021-01-20T08:06:00Z`	`10.9`
`2021-01-20T08:06:19Z`	`11.0`
`2021-01-20T08:06:42Z`	`11.1`
`2021-01-20T08:09:00Z`	`11.3`

A carbon monoxide percentage monitoring service might instead respond with data that looks like this:

[3] 

[4] Time series data, also referred to as time-stamped data, is a sequence of data points indexed in time order. Time-stamped is data collected at different points in time. These data points typically consist of successive measurements made from the same source over a time interval and are used to track change over time.

timestamp	value
`2021-01-20T08:01:00Z`	`2.0`
`2021-01-20T08:02:00Z`	`2.3`
`2021-01-20T08:06:00Z`	`2.8`
`2021-01-20T08:07:00Z`	`2.9`
`2021-01-20T08:08:00Z`	`3.3`

Please note that I have sorted the data by timestamp to make it a bit more readable, but you shouldn't make assumptions on the sort order of the data returned by an external provider. Not that this is of any importance here as...

The algorithm

...our algorithm now requires:

1. concatenating the temperature and carbon monoxide percentage data
2. sorting by timestamp

id	timestamp	value	type
1	`2021-01-20T08:00:00Z`	`10.1`	`T`
2	`2021-01-20T08:01:00Z`	`2.0`	`C`
3	`2021-01-20T08:02:00Z`	`10.3`	`T`
4	`2021-01-20T08:02:00Z`	`2.3`	`C`
5	`2021-01-20T08:05:00Z`	`10.7`	`T`
6	`2021-01-20T08:06:00Z`	`10.9`	`T`
7	`2021-01-20T08:06:00Z`	`2.8`	`C`
8	`2021-01-20T08:06:19Z`	`11.0`	`T`
9	`2021-01-20T08:06:42Z`	`11.1`	`T`
10	`2021-01-20T08:07:00Z`	`2.9`	`C`
11	`2021-01-20T08:08:00Z`	`3.3`	`C`
12	`2021-01-20T08:09:00Z`	`11.3`	`T`

> type: T is temperature and C is carbon monoxide percentage

Our task now is to scan the data, starting from the beginning, one row at a time, computing the air quality index as we go forward, step by step.

The first thing to note here is that to compute our `AQi` formula we need to have both values for `T` and `C`. In other words, the first time point where we can apply our formula is that with id `2` as we have a value for `T` in id `1` and a value for `C` in id `2`. So we take our values (`10.1` for `T` and `2.0` for `C`), apply the formula, and we have a first `AQi` value of `13.625` which we associate with the timestamp in id `2`, as that is the moment our computation refers to. Our first `AQi` entry in the resulting time series should now look like this:

timestamp	value
`2021-01-20T08:01:00Z`	`13.625`

From now on, our calculation can be applied to every remaining element in the time series, keeping in mind that we must correlate each value with the most recent value of the other type. In other words:

for id	pick values from id
`2`	`1, 2`
`3`	`2, 3`
`4`	`3, 4`
`5`	`4, 5`
`6`	`4, 6`
`7`	`6, 7`
`8`	`7, 8`
`9`	`7, 9`
`10`	`9, 10`
`11`	`9, 11`
`12`	`11, 12`

You can think of this kind of motion as a rolling time window as you have a window that moves forward in time focusing on the most recent data for our specific `T` and `C` measures at each step[5].

Rolling Time Window

Go ahead, scroll down. You're going to see it.

Step 01: T = 10.1, C = 2.0, AQi = 13.625

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

[5] I like to think of this movement as a kind of dance, and I find it sexy. I think I'm a creep, I'm a weirdo.

Window: ids 1-2

Step 02: T = 10.3, C = 2.0, AQi = 13.875

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 2-3

Step 03: T = 10.3, C = 2.3, AQi = 14.025

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 3-4

Step 04: T = 10.7, C = 2.3, AQi = 14.525

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 4-5

Step 05: T = 10.9, C = 2.3, AQi = 14.775

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 4-6

Step 06: T = 10.9, C = 2.8, AQi = 15.025

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 6-7

Step 07: T = 11.0, C = 2.8, AQi = 15.150

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 7-8

Step 08: T = 11.1, C = 2.8, AQi = 15.275

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 7-9

Step 09: T = 11.1, C = 2.9, AQi = 15.325

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 9-10

Step 10: T = 11.1, C = 3.3, AQi = 15.525

id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 9-11

Step 11: T = 11.3, C = 3.3, AQi = 15.775

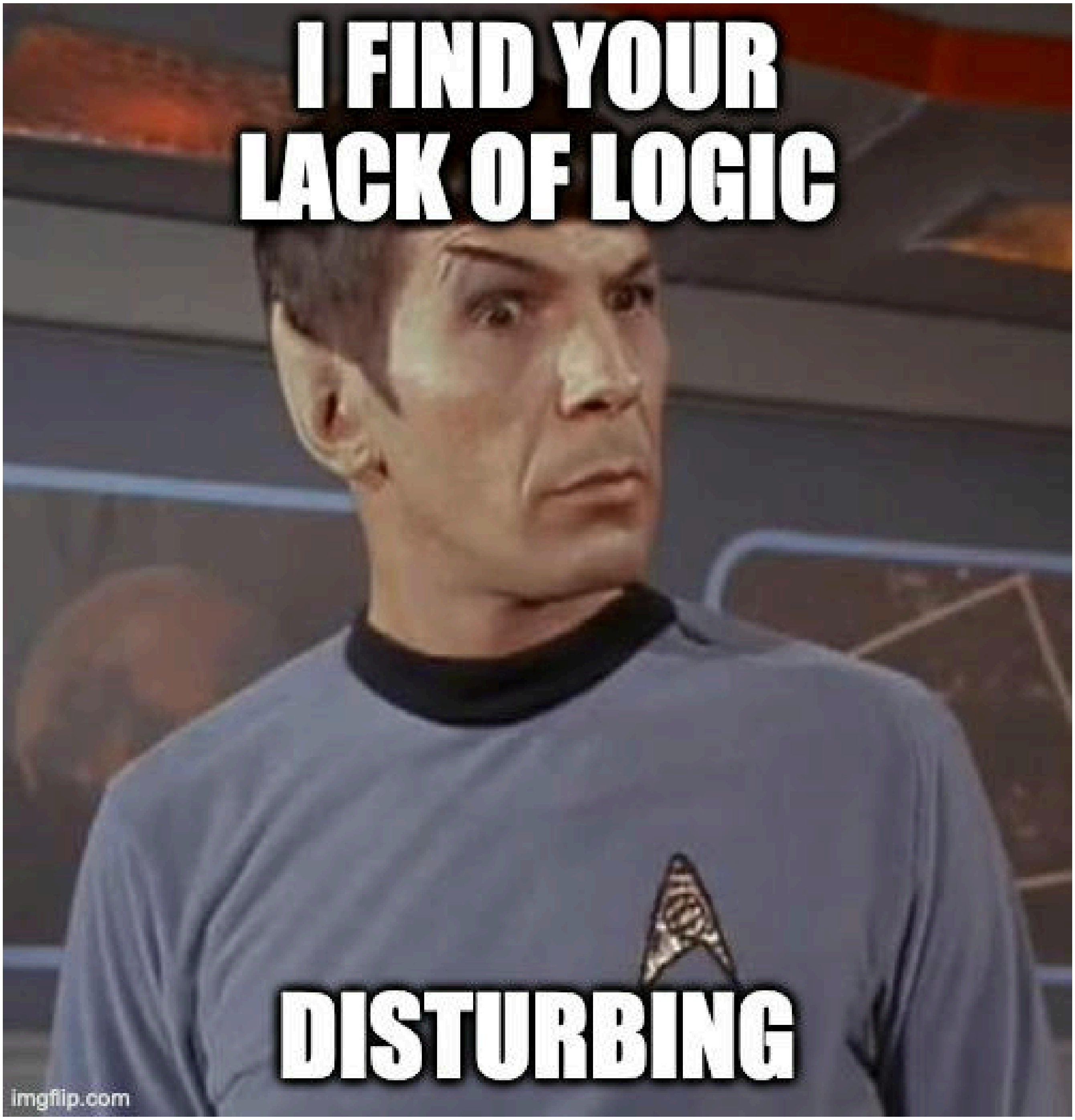
id	1	2	3	4	5	6	7	8	9	10	11	12
T	10.1		10.3		10.7	10.9		11.0	11.1			11.3
C		2.0		2.3			2.8			2.9	3.3	

Window: ids 11-12

Given the above, our complete resulting time series for the `AQi` is:

timestamp	value
`2021-01-20T08:01:00Z`	`13.625`
`2021-01-20T08:02:00Z`	`13.875`
`2021-01-20T08:02:00Z`	`14.025`
`2021-01-20T08:05:00Z`	`14.525`
`2021-01-20T08:06:00Z`	`14.775`
`2021-01-20T08:06:00Z`	`15.025`
`2021-01-20T08:06:19Z`	`15.150`
`2021-01-20T08:06:42Z`	`15.275`
`2021-01-20T08:07:00Z`	`15.325`
`2021-01-20T08:08:00Z`	`15.525`
`2021-01-20T08:09:00Z`	`15.775`

If you've looked closely, you might have noticed that we have a couple duplicate timestamps in our results, specifically `2021-01-20T08:02:00Z` and `2021-01-20T08:06:00Z`. These represent a time paradox as it appears that our `AQi` has two different values at the same time.



We both know this data is eventually going to show up on a web page. Also, we wouldn't want one of those hipster javascript frontend developers to point out a lack of logic or, worse, an inconsistency in our data to us, wouldn't we?

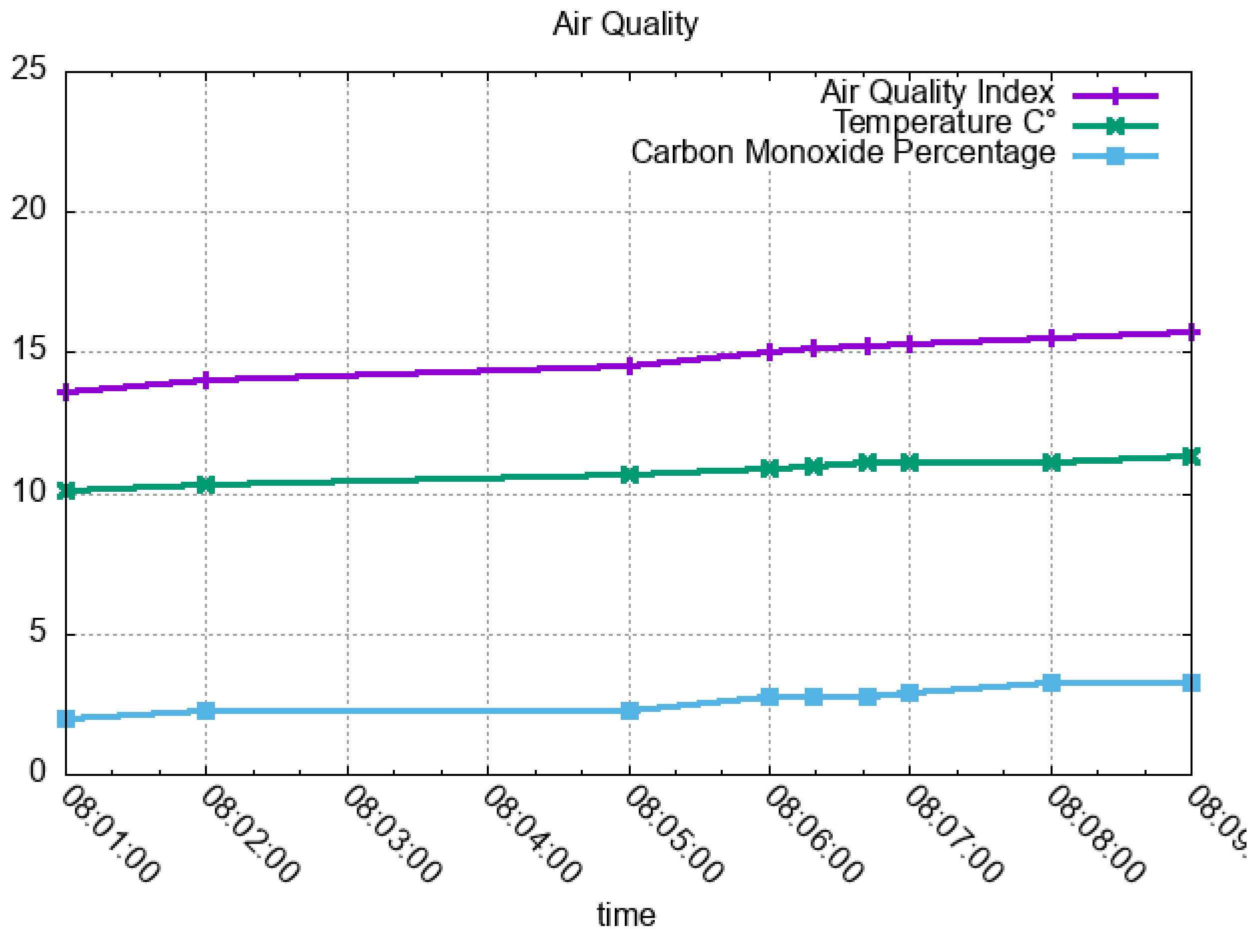
Yeah, I thought so. So, my idea is that we can safely discard the first entry of a duplicate timestamp as it refers to a calculation with stale data. Why? Well, consider the values for the first duplicate timestamp: `2021-01-20T08:02:00Z`. The first time we computed the `AQi`, we picked data from id `2` and `3` and id `2` refers to a previous timestamp, specifically `2021-01-20T08:01:00Z`. The second time we computed the `AQi`, we were using data from id `3` and `4`, which both refer to timestamp `2021-01-20T08:02:00Z`, so this computation's result is more relevant than the previous one which we stamped with the same `2021-01-20T08:02:00Z` timestamp.

The same thing applies to the `AQi` entry with timestamp `2021-01-20T08:06:00Z` as the first computation was using ids `4` and `6` while the second was considering ids `6` and `7` which are fresher than the timestamp in id `4`.

So we erase a couple entries, and our clean result set now looks like this:

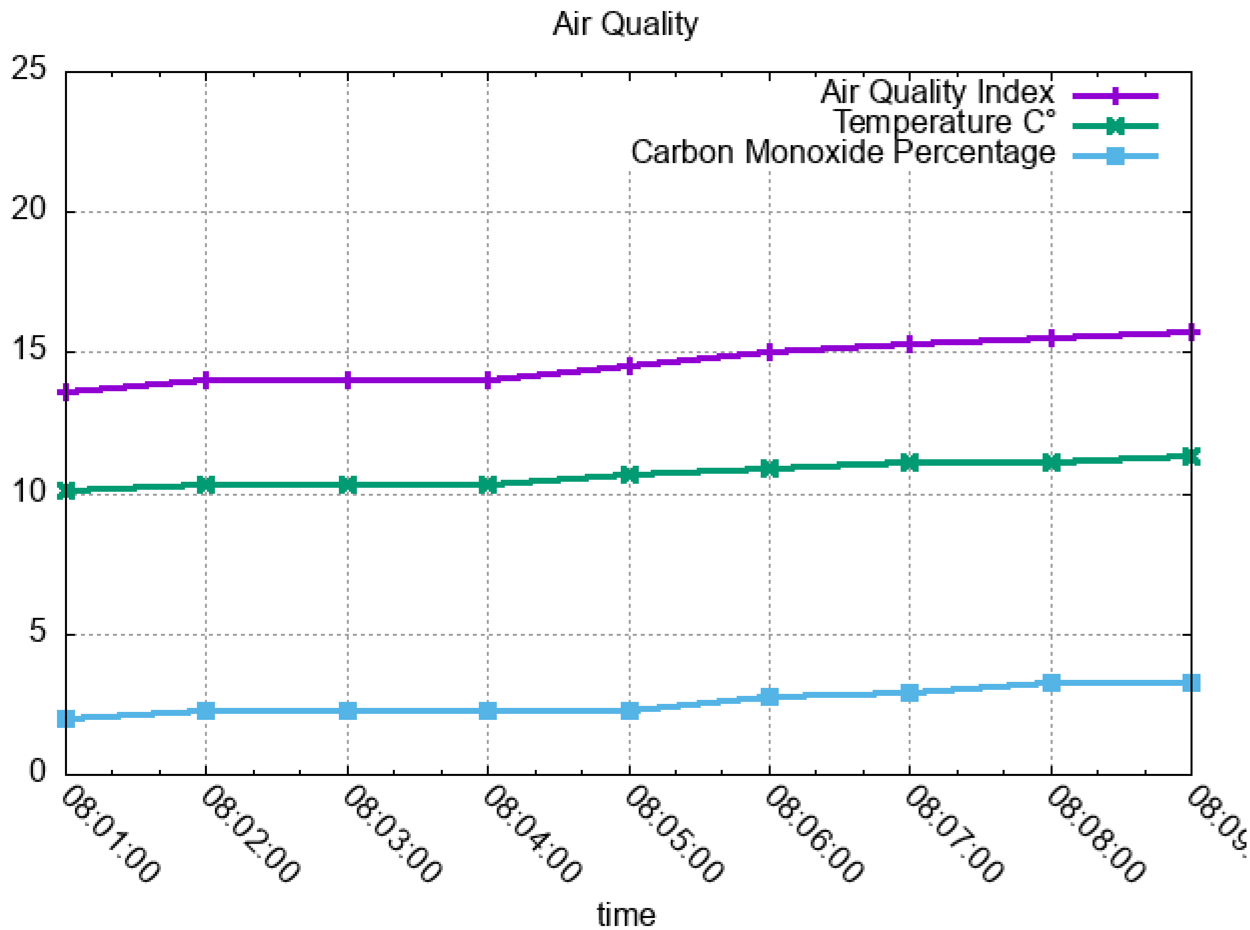
timestamp	value
`2021-01-20T08:01:00Z`	`13.625`
`2021-01-20T08:02:00Z`	`14.025`
`2021-01-20T08:05:00Z`	`14.525`
`2021-01-20T08:06:00Z`	`15.025`
`2021-01-20T08:06:19Z`	`15.150`
`2021-01-20T08:06:42Z`	`15.275`
`2021-01-20T08:07:00Z`	`15.325`
`2021-01-20T08:08:00Z`	`15.525`
`2021-01-20T08:09:00Z`	`15.775`

Just as an equation is an excuse to brush up on some LaTeX, a good time series is an excellent candidate for gnuplot.



Real data is of course much more chaotic than this, and you might want to normalize the result by an arbitrary time interval, say one minute:

timestamp	value
`2021-01-20T08:01:00Z`	`13.625`
`2021-01-20T08:02:00Z`	`14.025`
`2021-01-20T08:03:00Z`	`14.025`
`2021-01-20T08:04:00Z`	`14.025`
`2021-01-20T08:05:00Z`	`14.525`
`2021-01-20T08:06:00Z`	`15.025`
`2021-01-20T08:07:00Z`	`15.325`
`2021-01-20T08:08:00Z`	`15.525`
`2021-01-20T08:09:00Z`	`15.775`



Makes sense? I certainly hope so.

Let's get coding

Time to write some code. First of all, let's define an interface for our `AQi` calculator, so we can provide different implementations later on.

The code for this interface can be seen here.

This interface makes for a convenient place to implement the `AQi` formula:

```
static double airQualityIndex(double temperature, double
carbonMonoxidePercentage, double maxTemperature) {
    return (((temperature * 100) / maxTemperature) + carbonMonoxidePercentage) /
2;
}
```

This method takes a temperature, a carbon monoxide percentage, a max temperature and returns the `AQi`. Nice.

The interesting bit however is this method:

```
List<TimeValue> calculate(List<TimeValue> temperatures, List<TimeValue>
carbonMonoxidePercentages);
```

This says that the `calculate` method takes two lists of `TimeValues`: the first is a list of temperatures and the other is a list of carbon monoxide percentages. It then returns a list of `TimeValues`, only this time the list is representing air quality indices.

What is a `TimeValue`? You can see its definition here. Although this seems horribly complicated due to the verbosity of the Java language and a few implementation details, you can think of a time value as just a convenient way to represent an `Instant` in time and its associated `value`. Nothing fancy, really.

Coding like it's 1984

Now that we have a basic framework for our calculations, let's write a first implementation using the old school style. The complete code for this is here. Let's take a look.

Our calculator takes the max temperature in its constructor and stores its value in the `maxTemperature` instance constant as we'll need its value later when invoking the `AQi` function.

Our `calculate` method should start with these two steps:

1. concatenate the temperature and carbon monoxide percentage data in a single data structure
2. sort the resulting data by timestamp

Step 1 is implemented by this code:

```
// key = time value type (C = carbonMonoxidePercentage, T = temperature)
// concatenated with the timestamp as a string
Map<String, TimeValue> timeValuesByType = new HashMap<>();

for (TimeValue temperature : temperatures) {
    timeValuesByType.put("T".concat(temperature.ts()), temperature);
}

for (TimeValue carbonMonoxidePercentage : carbonMonoxidePercentages) {
    timeValuesByType.put("C".concat(carbonMonoxidePercentage.ts()),
carbonMonoxidePercentage);
}
```

The key in our `timeValuesByType` variable is a string concatenation of the letter `T` for temperature or `C` for carbon monoxide percentage, followed by the timestamp. We need to do this in order to later distinguish between the two types of values. The key string will look like this: `T2021-02-03T08:00:00.000Z`.

The sorting is done by this bit:

```
Map<String, TimeValue> timeValuesByTypeSortedByTimestamp = new LinkedHashMap<>();
List<String> keysSortedByTimestamp = new ArrayList<>(timeValuesByType.keySet());
keysSortedByTimestamp.sort(comparing(s -> timeValuesByType.get(s).timestamp()));

for (String key : keysSortedByTimestamp) {
    timeValuesByTypeSortedByTimestamp.put(key, timeValuesByType.get(key));
}
```

This is just overcomplicated Java lingo for having our map sorted by the timestamp we have in the Java map values. We declare a `timeValuesByTypeSortedByTimestamp` map, implemented by a `LinkedHashMap` because we want to preserve the iteration order of the map entries. Then we wrap all the keys in our original `timeValuesByType` map in an ArrayList as we need a `List` in order to then invoke `sort` on it. The comparator function we are passing to sort is picking the timestamp of the relative entry in the original `timeValuesByType` map. We then iterate `keysSortedByTimestamp`, adding entries to our `timeValuesByTypeSortedByTimestamp` map.

Now we are declaring a map for the results of our `AQi` calculations and a couple variables we'll need later:

```
Map<Instant, Double> airQualityIndexMap = new HashMap<>();
TimeValue lastTemperature = null;
TimeValue lastCarbonMonoxidePercentage = null;
```

Here begins the fun part. We cycle through the map entries in our previously defined `timeValuesByTypeSortedByTimestamp` variable.

```
for (Map.Entry<String, TimeValue> entry :
timeValuesByTypeSortedByTimestamp.entrySet()) {
    ...
```

We know that if the key begins with a `T`, we have a temperature value and, in such case we store it in the `lastTemperature` variable. Otherwise, the value must be of type `C` for carbon, so we do the same for the `lastCarbonMonoxidePercentage` variable.

```
if (entry.getKey().startsWith("T")) {
    lastTemperature = entry.getValue();
} else if (entry.getKey().startsWith("C")) {
    lastCarbonMonoxidePercentage = entry.getValue();
}
```

At this point, if we have a value both for `T` and `C`, we can proceed to calculate our `AQi` and store its value in the `airQualityIndexMap` variable.

```
if (lastTemperature != null && lastCarbonMonoxidePercentage != null) {
    airQualityIndexMap.put(
        mostRecent(lastTemperature.timestamp(),
lastCarbonMonoxidePercentage.timestamp()),
        airQualityIndex(lastTemperature.value(),
lastCarbonMonoxidePercentage.value(), maxTemperature)
    );
}
```

We are picking the most recent timestamp between the two `TimeValues` using a handy helper function that we defined earlier in our calculator interface.

An intended side effect of using a map for this data structure is that, when we `put` a new value for an existing timestamp, the entry gets overwritten by the most recent one. This solves our problem with duplicate timestamps.

At the end of the cycle, our results are almost ready. We just need to sort by timestamp again and return the values as a `List` of `TimeValues`.

```
List<Instant> keys = new ArrayList<>(airQualityIndexMap.keySet());
keys.sort(Instant::compareTo);
List<TimeValue> results = new ArrayList<>();
```

```
for (Instant key : keys) {
    results.add(TimeValue.of(key, airQualityIndexMap.get(key)));
}
```

Functional elegance

Can we do better than this? Absolutely. Let's use an elegant weapon for a more civilized age: functional programming. Our FunctionalAirQualityIndexCalculator is quite slimmed down, but that's just because the main logic behind the calculations is now in the AirQualityIndexCollector.

Our new calculator is much simpler now. The first part is quite involved so let's take a look at it first:

```
List<TypedTimeValue> timeSeries = Stream.concat(
   temperatures.stream().map(e -> new TypedTimeValue(TypedTimeValue.Type.T, e)),
   carbonMonoxidePercentages.stream().map(e -> new
TypedTimeValue(TypedTimeValue.Type.C, e))
).collect(Collectors.toUnmodifiableList());
```

There are several functional patterns at work here:

- the temperatures and carbon monoxide percentage data are streamed and mapped into a type wrapper in order to later understand if the data we're looking at is of type `T` or `C`
- the two resulting streams are concatenated using `Stream.concat`
- in the end we collect the concatenated stream into an unmodifiable `List<TypedTimeValue>`

```
return timeSeries.stream().parallel()
    .collect(AirQualityIndexCollector.toUnmodifiableList(maxTemperature));
```

The `timeSeries` is then streamed in parallel into a collector that does the real work and returns an unmodifiable `List<TimeValue>` with the air quality indices.

Let's take a look at the collector.

```
public class AirQualityIndexCollector
        implements Collector<TypedTimeValue, Queue<TypedTimeValue>,
List<TimeValue>> {
    ...
```

We're implementing the `Collector` interface. The type parameters we are providing here express three things:

- we are collecting values of type `TypedTimeValue`
- our internal accumulator is using a `Queue<TypedTimeValue>`
- at the end of our work, we are returning a `List<TimeValue>`

A `Queue` is just a thread safe `List`. We provide the implementation using the supplier method:

```
@Override
public Supplier<Queue<TypedTimeValue>> supplier() {
```

```
    return ConcurrentLinkedQueue::new;
}
```

In this case, the implementation is a `ConcurrentLinkedQueue` which, again, is just sort of a thread safe `ArrayList`.

```
@Override
public BiConsumer<Queue<TypedTimeValue>, TypedTimeValue> accumulator() {
    return Queue::add;
}
```

The accumulator method must return a function which the collector uses to accumulate the input data. As you can see, we simply return a reference to the `add` method in `Queue`.

```
@Override
public BinaryOperator<Queue<TypedTimeValue>> combiner() {
    return (typedTimeValues, typedTimeValues2) -> {
        typedTimeValues.addAll(typedTimeValues2);
        return typedTimeValues;
    };
}
```

The combiner method must return a function that combines two accumulators. The implementation should pick all elements from the second accumulator and add them to the first one, which doesn't sound very functional in terms of immutability but in this case mutation is an expected behavior, and it's totally fine.

```
@Override
public Function<Queue<TypedTimeValue>, List<TimeValue>> finisher() {
    ...
```

Finally, the finisher must return a function which takes all the accumulated values in our `Queue<TypedTimeValue>` and return a `List<TimeValue>` with our air quality indices.

```
final Map<Instant, TimeValue> aqiAccumulator = new HashMap<>();
```

This is a map that is going to collect all the air quality indices. As you can see, it's indexed by a timestamp, so we won't get duplicate entries as more recent calculations for the same timestamps are put into the map replacing the stale ones.

```
return accumulator -> {
   accumulator.stream()
           .map(TypedTimeValue::timestamp)
           .sorted()
           .forEach(entryTS -> {
               final TimeValue lastTemperature = getClosest(accumulator,
TypedTimeValue.Type.T, entryTS);
               final TimeValue lastCarbonMonoxidePercentage =
getClosest(accumulator, TypedTimeValue.Type.C, entryTS);

               if (lastTemperature != null && lastCarbonMonoxidePercentage !=
null) {
```

```
                   Instant timestamp = mostRecent(lastTemperature.timestamp(),
lastCarbonMonoxidePercentage.timestamp());
                   aqiAccumulator.put(timestamp, TimeValue.of(timestamp,
airQualityIndex(lastTemperature.value(), lastCarbonMonoxidePercentage.value(),
maxTemperature)));
               }
           });

   return aqiAccumulator.values().stream()
           .sorted()
           .collect(Collectors.toUnmodifiableList());
};
```

This is quite a mouthful but let's go through it bit by bit. We are streaming the accumulated data, extracting the timestamp, sorting by it and, for each timestamp we look for the temperature and carbon monoxide percentage data with the closest timestamp. *Closest* means that the timestamp we're evaluating must be before of or equal to the timestamp in question.

If we have both data (`T` and `C`), we can proceed to calculate the `AQi` and put its value into the `aqiAccumulator` map.

In the end, all we have to do is to stream the values in the `aqiAccumulator` map, sort by timestamp and collect them in an unmodifiable `List<TimeValue>`.

Sorting like this is possible since we made our `TimeValue` class implement `Comparable<TimeValue>`.

There are several points in the `finisher` method where I look into the datastructures I'm iterating on, which, again, doesn't look very kosher in terms of functional programming, but it's okay as I know that the data I'm examining isn't being changed by a concurrent thread under the hood.

Is this better than our old school calculator? I'm not sure. This is still quite verbose, but to me it seems easier to read as most of the code is expressed in a declarative style rather than an imperative one.

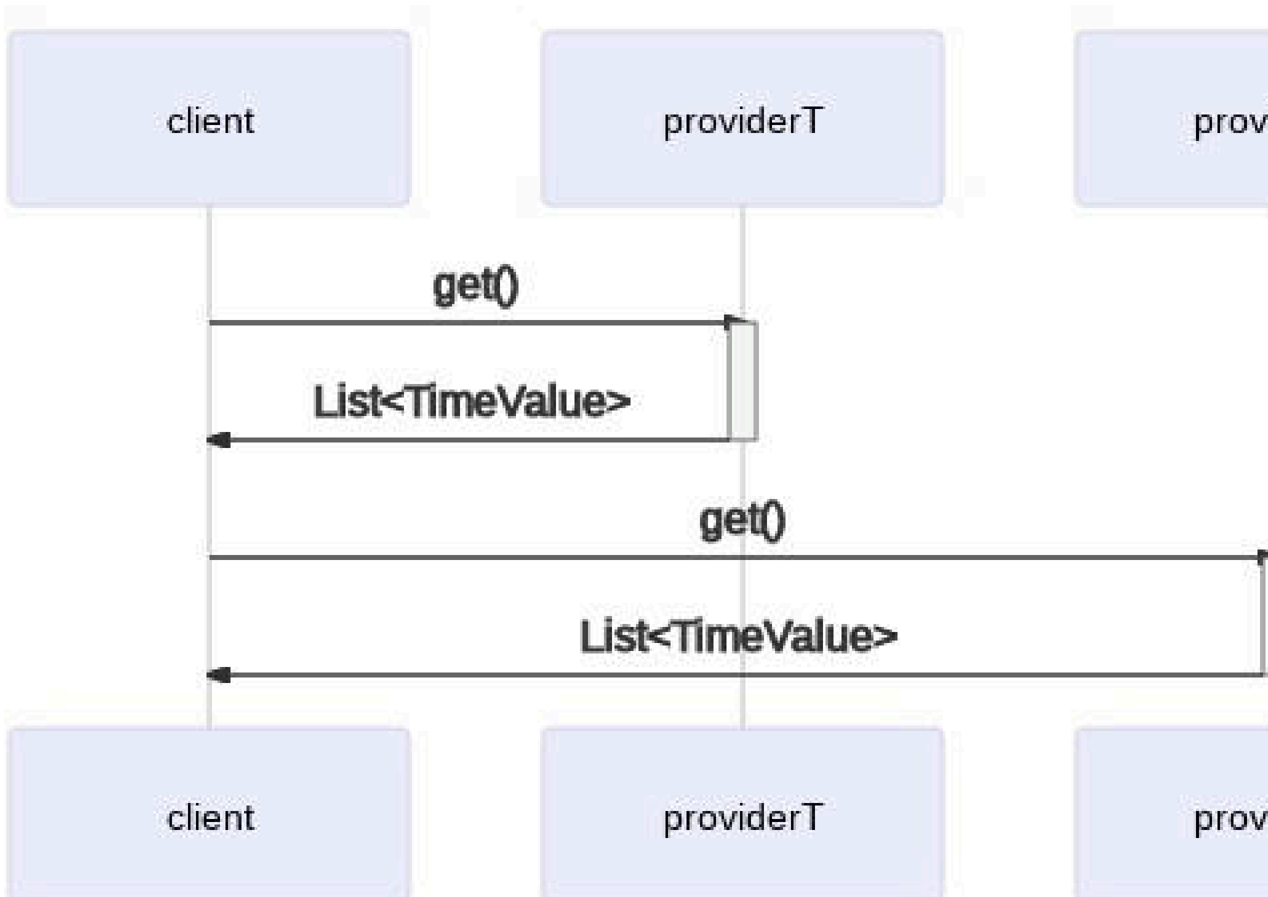
Concurrency considerations

As we need to retrieve two different sets of data from two different providers (one for temperature data and one for carbon monoxide percentage data), we might want to run the clients in parallel. This has an advantage over traditional single threaded execution where you would have to serialize the calls to the providers.

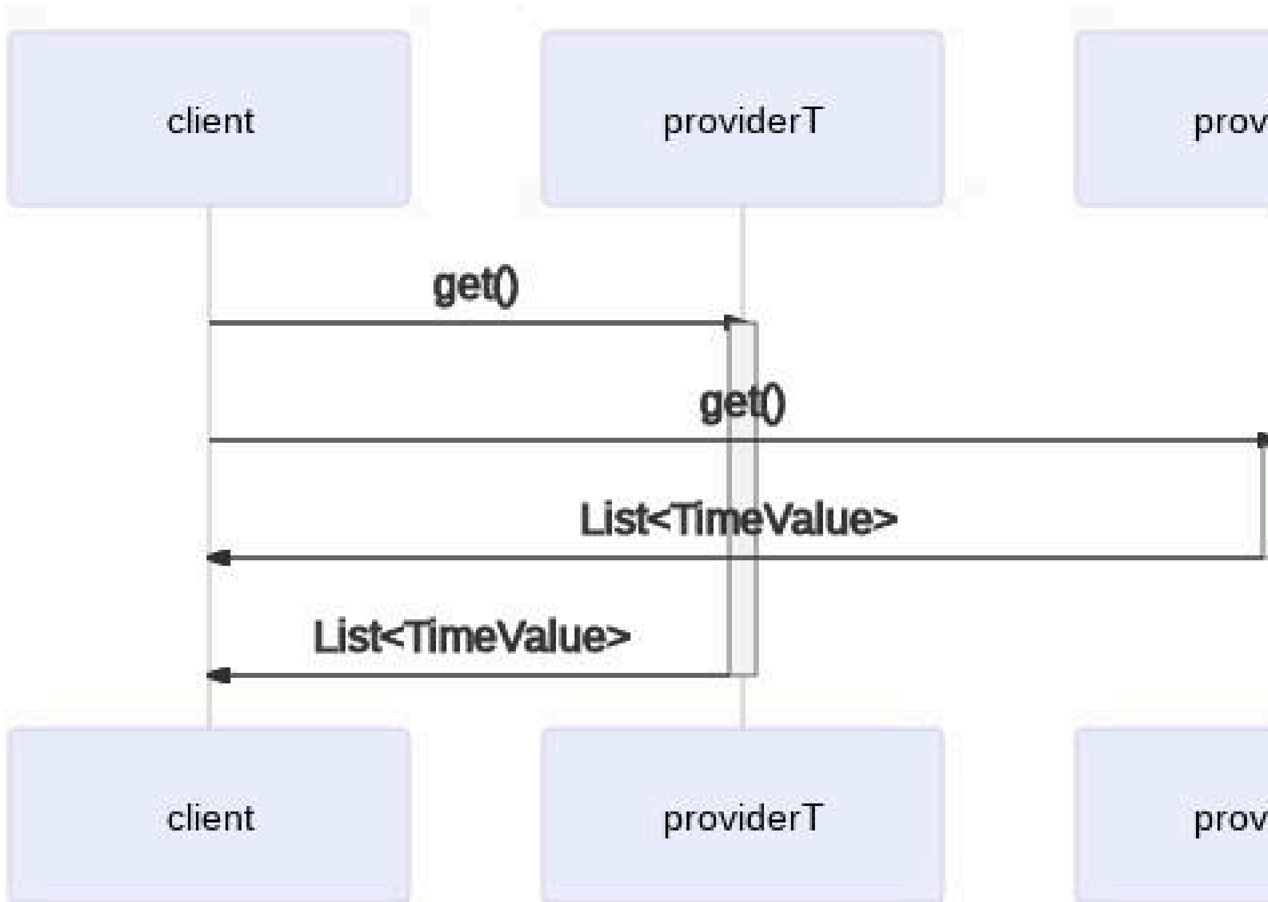
In a single threaded environment, you might write code like this:

```
TimeValueProvider providerT = new TemperatureTimeValueProvider();
TimeValueProvider providerC = new CarbonMonoxidePercentageProvider();
List<TimeValue> timeValuesT = providerT.get();
List<TimeValue> timeValuesC = providerC.get();
```

This translates to the following serial execution model:



As we said, we can do better than this. In a multithreaded environment, we can spawn the two clients concurrently and start processing their data as soon as we receive a response from both. This saves us some time and potentially speeds up our overall response time.



How do we implement this execution model in our code? There are several options but the most popular and the one I personally like the most is to use `CompletableFutures`, which were introduced in Java 8 if I recall correctly.

A `CompletableFuture` is a container for a computation. You provide it the code you want to execute and the Java runtime takes care of running it concurrently in a threaded scheduler. The scheduler is of course customizable but the defaults are okay for our simple case here. You can see the complete example here.

In my example I have declared my `CompletableFutures` like this:

```
CompletableFuture<List<TimeValue>> timedValuesFuture1 =
CompletableFuture.supplyAsync(() -> {
   log("Calling provider1...");
   List<TimeValue> timeValues = provider1.get();
   log(String.format("provider 1 returned: %s\n", timeValues));
   return timeValues;
});
```

This is a bit verbose as I wanted to include some logging to show you how this code runs in parallel. I might as well have written:

```java
CompletableFuture<List<TimeValue>> timedValuesFuture1 =
CompletableFuture.supplyAsync(provider1::get);
```

This is still verbose but definitely better than before. As the computation in our `CompletableFuture` returns a `List<TimeValue>`, the `supplyAsync` method returns a `CompletableFuture<List<TimeValue>>`, which is Java's way of saying that the `timedValuesFuture1` variable is a `CompletableFuture` holding a `List<TimeValue>`. Please note that the code we are passing to the `supplyAsync` method is inside a lambda. What this means is that our code doesn't get executed in the `supplyAsync` method but the Java runtime is free to choose when it's the best time to run it. The default scheduler will generally start running your `CompletableFutures` as soon as they are defined but you need to understand that this is not necessarily so and that defining a lambda doesn't mean it gets executed at the point of declaration.

We now need a way to make sure our `CompletableFutures` have completed their execution before going on. This is done by composing our futures and calling the `join` method on the resulting future:

```java
CompletableFuture.allOf(timedValuesFuture1, timedValuesFuture2).join();
```

The `allOf` method returns a new `CompletableFuture` which wraps the futures we're passing to it. On this new future we then call `join` which blocks until all the wrapped futures have finished executing.

After this line, we are sure that our threads have run, so we can get the data we need from our original futures with the `join` method:

```java
List<TimeValue> timeValues1 = timedValuesFuture1.join();
List<TimeValue> timeValues2 = timedValuesFuture2.join();
```

Example output

When you run the application, you should see output similar to this:

```
2021-02-03T17:50:26.772545406 --- [main] Hello concurrent world!
2021-02-03T17:50:26.801737530 --- [ForkJoinPool.commonPool-worker-3] Calling
provider1...
2021-02-03T17:50:26.802105151 --- [main] Calling allOf(...).join()
2021-02-03T17:50:26.802202415 --- [ForkJoinPool.commonPool-worker-5] Calling
provider2...
2021-02-03T17:50:27.834127796 --- [ForkJoinPool.commonPool-worker-5] provider 2
returned: [TimeValue{timestamp=2021-01-18T08:00:22Z, value=76.629},
TimeValue{timestamp=2021-01-18T08:00:45Z, value=90.241}]
2021-02-03T17:50:27.834702562 --- [ForkJoinPool.commonPool-worker-3] provider 1
returned: [TimeValue{timestamp=2021-01-18T08:00:24Z, value=30.318},
TimeValue{timestamp=2021-01-18T08:00:35Z, value=13.521},
TimeValue{timestamp=2021-01-18T08:00:35Z, value=29.518},
TimeValue{timestamp=2021-01-18T08:00:36Z, value=0.818},
TimeValue{timestamp=2021-01-18T08:00:46Z, value=8.695},
TimeValue{timestamp=2021-01-18T08:00:50Z, value=31.233},
TimeValue{timestamp=2021-01-18T08:00:51Z, value=24.675},
TimeValue{timestamp=2021-01-18T08:00:53Z, value=38.477}]
```

```
2021-02-03T17:50:27.835040844 --- [main] After allOf(...).join()
2021-02-03T17:50:27.852793190 --- [main] timeValues =
[TimeValue{timestamp=2021-01-18T08:00:24Z, value=76.212},
TimeValue{timestamp=2021-01-18T08:00:35Z, value=75.212},
TimeValue{timestamp=2021-01-18T08:00:36Z, value=39.337},
TimeValue{timestamp=2021-01-18T08:00:45Z, value=46.143},
TimeValue{timestamp=2021-01-18T08:00:46Z, value=55.989},
TimeValue{timestamp=2021-01-18T08:00:50Z, value=84.161},
TimeValue{timestamp=2021-01-18T08:00:51Z, value=75.964},
TimeValue{timestamp=2021-01-18T08:00:53Z, value=93.217}]
```

You can see there are three different threads at work here:

1. main
2. ForkJoinPool.commonPool-worker-3
3. ForkJoinPool.commonPool-worker-5

It's interesting to note here that in this specific run `allOf(...).join()` was called much before calling provider 2 and both results were returned from providers.

Your output will definitely be different as:

1. the threads' execution order is non-deterministic
2. the providers' values are generated randomly

Conclusion

You've made it! This was quite the run. I hope it's been entertaining. I spent quite a bit of time on this as I was trying to dig deeper into some issues I've had at work. I suggest you do the same when you run into problems that need some clarification on your side. I also hope you found this useful.

Bonus


Readi
memes
reddi
Readi
memes
githu

Credits

Document Information