HUNGARIAN LOTTERY

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> This problem is related to the Hungarian lottery. In case you are not familiar with it: players pick 5 distinct numbers from 1 to 90. There is a weekly lottery picking event when the lotto organization picks 5 distinct numbers randomly between 1 and 90 – just like the players did. A player's reward then depends on how many of the player's numbers match with the ones selected at the lotto picking. A player wins if they have 2, 3, 4 or 5 matching numbers.

The Problem

At the lottery event, right after picking the numbers, a computer shall be able to report quickly that how many winners are in each category, for example:

Numbers matching	Winners
5	0
4	12
3	818
2	22613

This report shall be generated as soon as possible after picking the winning numbers. The players' numbers are known a few minutes before the show starts. In peak periods, there are currently about 10 million players.

One of the goals is to have an optimized solution that can report the results in 100ms or less.

Full specs are here.

Running

Ensure the following requirements are met:

- go 1.23
- GNU Make

First, build the solution using:

```
$ make build
```

If compilation is successful, it should produce a binary artifact named `hungarian-lottery` in the main folder.

You can run it passing the input file as the first argument:

```
$ ./hungarian-lottery <input-file>
```

Optionally, the `--debug` flag can print additional information, such as processing times. Example:

```
$ ./hungarian-lottery my-file.txt --debug
```

Input

The input should be an ASCII text file composed of an arbitrary number of lines. Each line should represent a player from the lottery and should contain 5 distinct numbers that were picked by that player. The numbers must be separated by whitespace.

For example, these text contents represent the picks of 5 players:

```
45 81 67 78 16
29 66 14 80 41
58 67 71 32 22
63 61 46 7 16
66 46 67 13 7
```

The following criteria must be met for a line to be considered valid:

- The line must specify 5 distinct numbers.
- Numbers should range from 1 to 90, inclusive.
- The player's numbers must be distinct, i.e., the same line should not repeat any numbers.

If a line from the input file does not fit any of the above criteria, it will be SKIPPED and a warning will be printed in the standard output.

The lottery picks should be specified in the standard input (`stdin`) in the same format, and subject to the same validation, followed by a new line. Example:

```
11 45 12 87 58
```

The lottery picks must only be inputted AFTER the program outputs the following line in the standard output (`stdout`):

```
READY
```

Output

For each lottery pick that was inputted to the program, the output will be a line containing 4 numbers. The first number will be total count of players with 2 wins, the second number will be the total number of players with 3 wins, and so on.

Example:

```
225397 8174 99 1
```

Translating to:

Numbers matching	Winners
5	1
4	99
3	8174
2	225397

A typical program session looks like the following. In this example, the optional `--debug` flag was passed to show execution times.

```
~/git/hungarian-lottery  main ±  make build
~/git/hungarian-lottery  main ±  ./hungarian-lottery 10m-v2.txt --debug
INFO[0000] loading input file 10m-v2.txt
WARN[0003] skipping line 1240001: no repeated numbers should be picked - '70 6 20 46 70'
WARN[0003] skipping line 1240016: invalid quantity of picked numbers - '84 12 68 26 47 40'
WARN[0003] skipping line 1240021: no repeated numbers should be picked - '40 11 57 36 40'
WARN[0003] skipping line 1240028: invalid quantity of picked numbers - '5 34 24 42'
WARN[0003] skipping line 1240036: picked number is out of range - '85 21 67 93 2'
WARN[0003] skipping line 1240051: picked number is out of range - '10 85 69 -7 50'
READY
11 12 13 14 15
225397 8174 99 1
INFO[0010] took: 30 ms
20 30 40 50 60
225203 8135 103 0
INFO[0030] took: 31 ms
11 13 17 23 31
224836 8066 102 1
INFO[0067] took: 31 ms
```

Development Tasks

Running the unit test suite:

```
make test
```

Using code linters:

1. Install `golangci-lint` from [here](). This is system dependent.
2. Run `make lint`.

Solution Design

The solution was designed with the following constraints in mind:

> ...to have an optimized solution that can report the results in 100ms or less.

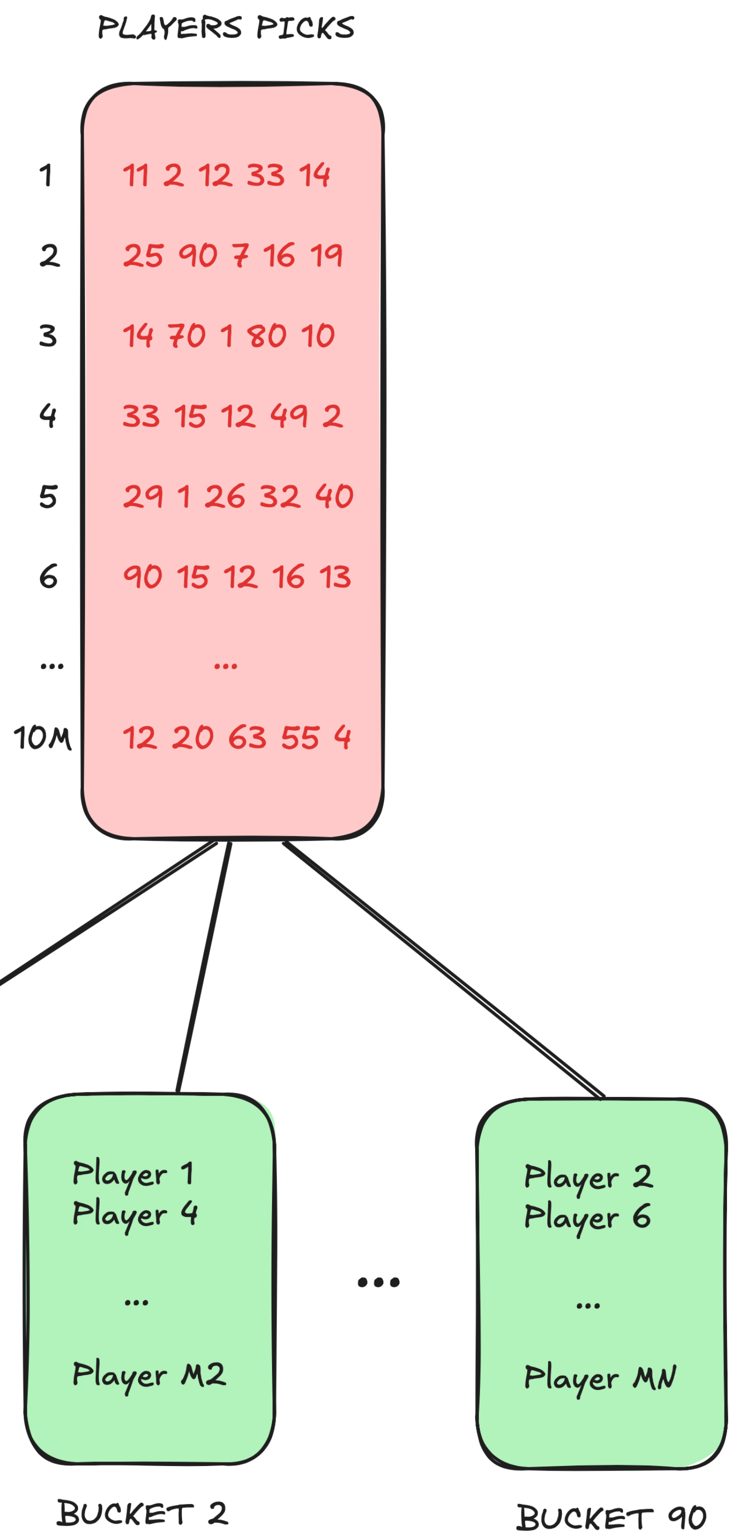
and

> In peak periods, there are currently about 10 million players.

Memory constraints were not specified, therefore we optimized for CPU performance.

First, we assign each player a unique sequential numeric ID, starting from 1. These correspond roughly to the lines of the input file. For example, `2000423`. If there are no errors in the file, this should map exactly to line 2000423.

For efficiently retrieving the players that picked a given lottery number, we use bucket-sort. We create an array with 90 buckets, where index `N-1` represents the bucket of lottery number `N`. This bucket should store the IDs of all players that picked number `N`, regardless of the order that it was picked.



As the input file is parsed, the player picks are stored into these buckets. For performance reasons, we traverse the file twice, once to determine the necessary array allocations, and another to store the player picks. This is in order to avoid the wasteful array resizing and inefficient data copy that happens during slice appends, when the capacity of the array is not known beforehand.

```
buckets := make([][]int32, 90)
for i := 0; i < len(buckets); i++ {
    buckets[i] = make([]int32, 0, allocation[i])
}
```

When the lottery picks are given in the input, we retrieve 5 buckets corresponding to these numbers. For example:

```
11 45 12 87 58
```

which map to the following:

```
buckets[10]
buckets[44]
buckets[11]
buckets[86]
buckets[57]
```

Since the goal is to determine the total number of wins for different categories, we must find the intersections between the 5 buckets that were picked by the lottery. By counting how many distinct player IDs intersect among these buckets, we can easily reach to the problem solution.

Performance Considerations

One naive approach to find these intersections would be using a hash map. Traverse all the buckets, adding each player ID as key to a hash map. The values would count how many times the player IDs appear.

```
matches := make(map[int32]int32, 10000000)
for _, pick := range picks {
    for _, playerID := range buckets[pick-1] {
        matches[playerID] += 1
    }
}
```

However, this was not performant under 100ms. In my local benchmarks, finding the solution took ~ 450ms (your mileage may vary). While hash maps are memory efficient data structures, and have a theoretical *O(1)* access time, in practice there is some significant overhead that becomes apparent when dealing with 10 million of entries.

Since memory consumption was not a concern that was mentioned in the specs, we can extrapolate a little. I have replaced the hash map with a sparse array, where the index of the array corresponds to the player ID. The array is sparse because for most players, there will be zero wins. We are only interested in those players that have 2 or more wins.

```
matches := make([]int32, 10000000)
for _, pick := range picks {
    for _, playerID := range buckets[pick-1] {
        matches[playerID-1] += 1
    }
}
```

Benchmarks

Because accessing the index of an array is significantly more performant than accessing the key of a hash map, I was able to implement a solution that performs under ~ 30ms. Much better than the previous ~ 450ms. Again, your mileage may vary.

For reference, the machine used to run these benchmarks was:

```
MacBook Pro (Retina, 15-inch, Mid 2015)
2.5 GHz Quad-Core Intel Core i7
16 GB 1600 MHz DDR3
```

Memory Usage

The only drawback of using a sparse array to store all player matches is that much more memory is used. For 10 million players, and considering the `int32` type, this sparse array consumes 40MB of RAM, most of it being empty. It is not very much by modern standards, but it may pose a challenge if the number of players reach the billions.

Asymptotic Runtime

Let *n* be the number of players, also the number of correct lines in the input file.

Traversing the input file and writing the player IDs into the buckets is a *O(2n)* operation. This is because we traverse the file twice, in order to determine array allocations. Because the capacity of the buckets is determined beforehand, adding a player to the bucket is *O(1)*. All this happens before we are `READY` to accept lottery picks inputs, therefore we don't care much.

From the lottery input we pick 5 buckets in *O(1)* time (direct array indexing). Then, we traverse these buckets, storing the number of intersections in a sparse array of size *n*. To traverse a bucket is *O(n/90)* operation, which is almost 2 orders of magnitude, or 9000% (*90 times*) faster than traversing an array of all *n* players in a linear fashion. Also, this operation could be further parallelized for faster processing times.

Lastly, we must traverse the sparse array to count the number of wins. This takes *O(n)* time.

Total execution time for computing an input of lottery picks:

> 5 × *O(n/90)* + *O(n)*

which is equivalent to:

> *O(n)*

Scaling to Billions of Players

The solution was designed for 10 million players, and it performs using a mix of bucket sort and sparse array techniques.

Since sparse arrays consume a significant portion of memory, the first challenge is having enough RAM to account for it. The sparse array used to store 2 Billion Players would consume 8GB alone, and you must double that usage to account for the buckets too. However, while a bit aggressive, this is still pretty much doable by modern standards.

The biggest challenge is to traverse the 90 buckets efficiently in order to build the sparse array, then traverse the sparse array again in order to consolidate the lottery results.

One strategy we haven't explored yet, but could easily be applied here would be leveraging multiple threads. Modern CPUs have limited clocks, but may accommodate several cores. Some datacenters have servers with hundreds of CPUs.

Go is a perfect language for multithreading, since goroutines are known for being lightweight threads. They have a very small overhead compared to traditional threads in other languages.

We could have 5 threads, one for each bucket picked by the lottery. We would consolidate the results into the sparse array, in parallel. Then again, the array could be broken into smaller chunks and counted, also in parallel by many goroutines. The Map-Reduce pattern is a great fit here. Break a large data set into smaller chunks (Map), process them in parallel, then consolidate the results of the computation (Reduce).

We must be careful, however, to prevent race conditions between threads. We should avoid the use of mutexes, which can be very costly. The solution should be designed cleverly, and use channels to serialize the data.

The idea is to distribute the input to several goroutines, which would process their respective chunks in parallel, pushing the results of those computations to a serial channel. Another goroutine listens to the channel and consolidates the results into the array in a serial manner, avoiding race conditions or the need for mutexes.

■