Example solutions (fall 2019)

This is a subset of the questions that were asked in Java on 6.031 Fall 2019 Quiz 2. They have been translated to TypeScript here.

The problems in this quiz refer to the code for mutable `MutInfoEntry` and immutable `ImInfoEntry`, at the end of this quiz.

You may detach the code pages.

Train stations, airports, and other transit hubs often have displays that show upcoming departures or arrivals along with other information: a track or gate number, delays, cancellations, etc.

For this quiz, an *information board* is made of several *information board entries*. Each entry has limited space: 16 characters to display a *destination* and 12 characters for a *status*. Both are restricted to upper-case letters, digits, colons, and spaces. For example, a board with three entries:

```
WASHINGTON DC    11:05 AM

LONDON HEATHROW  11:55 AM

HONG KONG        DELAYED
```

In order to show more information, the board cycles each entry through a looping sequence of up to four statuses. For example, if WASHINGTON DC and LONDON HEATHROW have 2-status loops, and HONG KONG has a 3-status loop, then every few seconds the board will update:

```
WASHINGTON DC    ON TIME
LONDON HEATHROW  ON TIME
HONG KONG        NEW DEPRTURE
```

```
WASHINGTON DC     11:05 AM
LONDON HEATHROW   11:55 AM
HONG KONG          1:40 PM
```

```
WASHINGTON DC     ON TIME
LONDON HEATHROW   ON TIME
HONG KONG         DELAYED
```

```
WASHINGTON DC     11:05 AM
LONDON HEATHROW   11:55 AM
HONG KONG         NEW DEPRTURE
```

```
WASHINGTON DC     ON TIME
LONDON HEATHROW   ON TIME
HONG KONG          1:40 PM
```

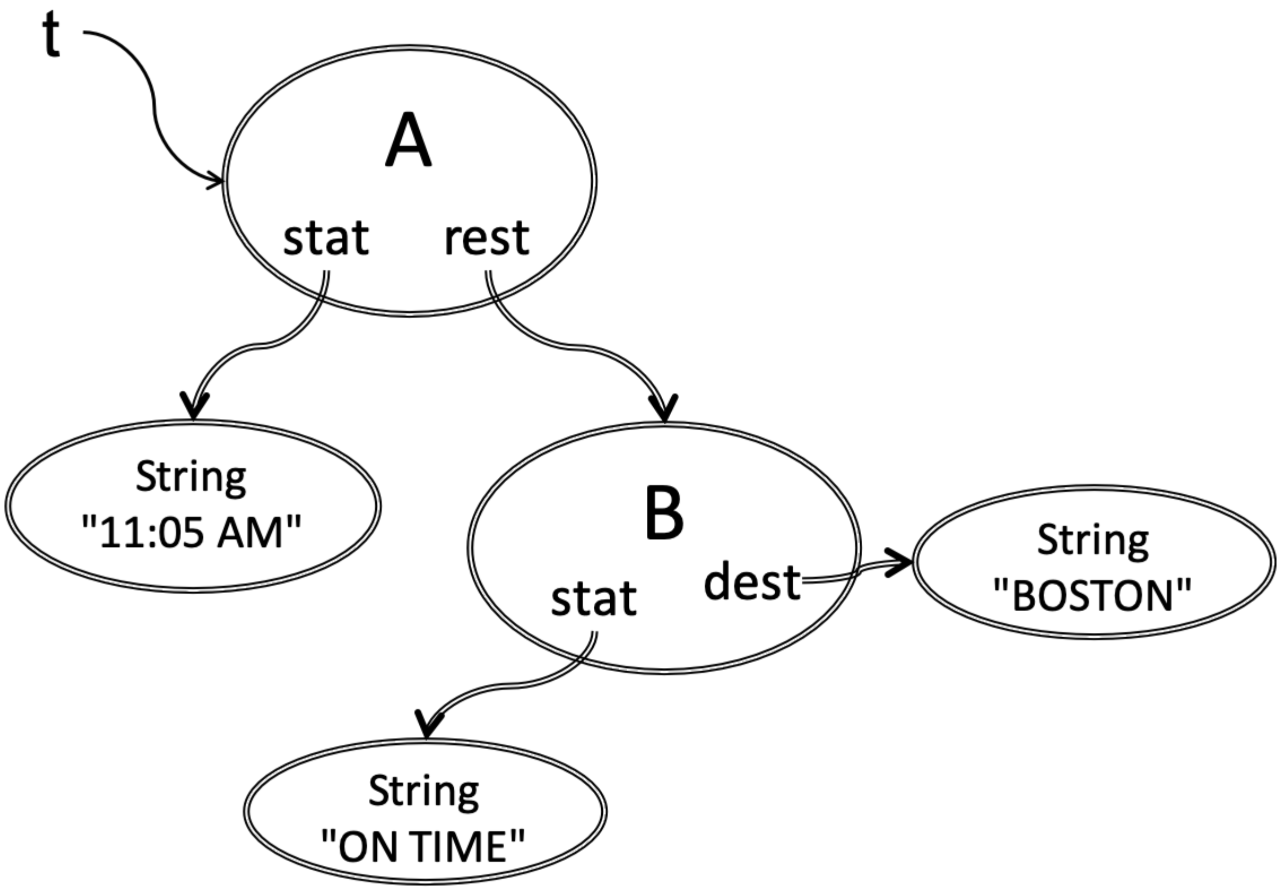
... and so on.

---

2. (26 points) Recursive Datatypes

Suppose we want to implement `ImInfoEntry` (an *immutable* information board entry) as a recursive data type with two variants. The two variants are called A and B.

The snapshot diagram below shows how the datatype represents an information board entry `t` with destination "BOSTON" and two statuses "11:05 AM" and "ON TIME", whose current status is "11:05 AM".



(a) Write a datatype definition that corresponds to the snapshot diagram and implements `ImInfoEntry`.

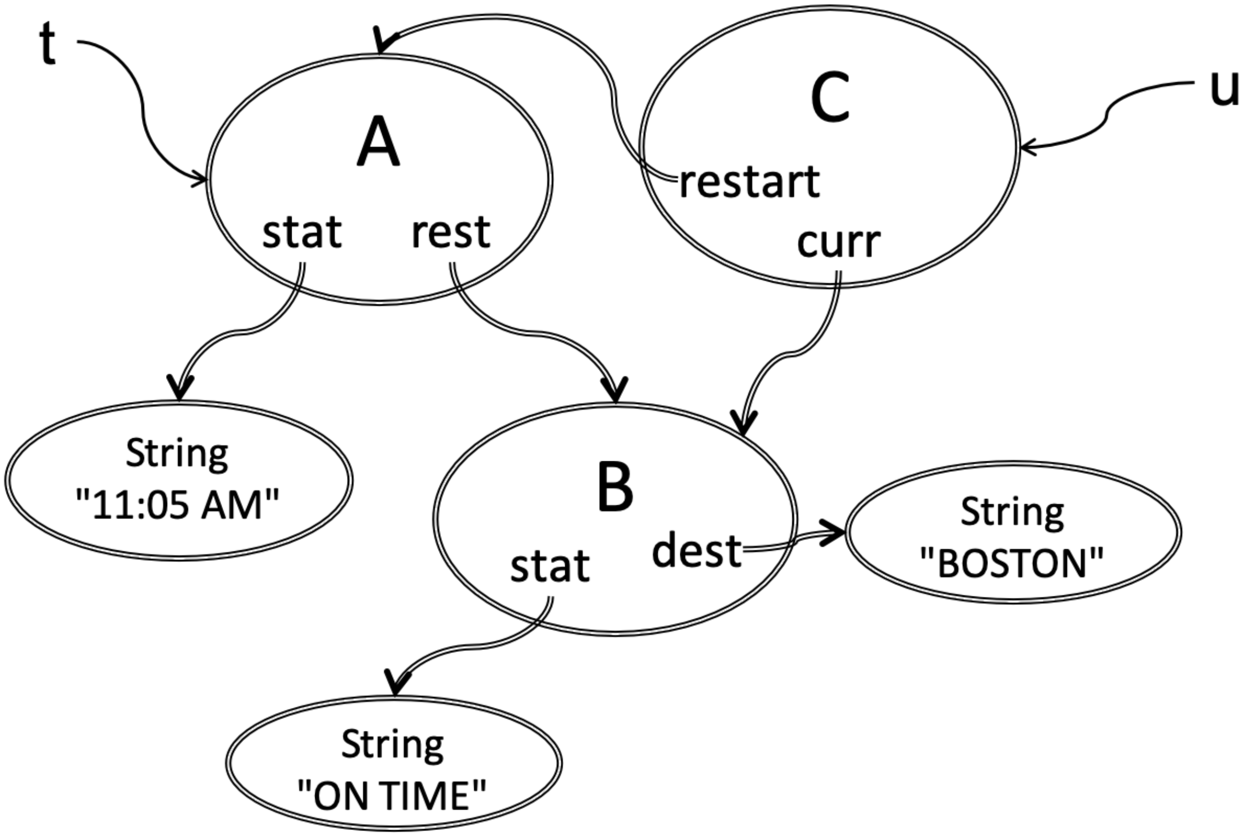
`ImInfoEntry =`

> A(stat:string, rest:ImInfoEntry) + B(stat:string, dest:string)

(b) Fill in the blanks to implement `destination()`, `status()`, and `size()` for variants A and B:

```
export class A implements ImInfoEntry {
  ...
  public destination(): string { return this.rest.destination() ; }


  public status(): string      { return this.stat ; }


  public size(): number        { return 1 + this.rest.size() ; }
}

export class B implements ImInfoEntry {
  ...
  public destination(): string { return this.dest ; }


  public status(): string      { return this.stat ; }


  public size(): number        { return 1 ; }
}
```

To help implement the `nextEntry` operation, we add one more variant `C`. The result of `u = t.nextEntry()` is shown in the snapshot diagram below.



(c) Fill in the blanks to implement `nextEntry()` for all three variants.

```
export class A implements ImInfoEntry {
  ...
  public nextEntry(): ImInfoEntry {
      return new C(this, this.rest);
  }
}

export class B implements ImInfoEntry {
  ...
  public nextEntry(): ImInfoEntry {

      return _______________________________________________________ ;

  }
}

export class C implements ImInfoEntry {
  ...
  public nextEntry(): ImInfoEntry {
    if (this.curr.size() === 1) { // curr has reached the end of the list

      return _______________________________________________________ ;

    } else {

      return _______________________________________________________ ;
    }
  }
}
```

> Solution:
>
> From the example and code shown for `A.nextEntry()`, the datatype definition is now:
>
> ```
> ImInfoEntry = A(stat:string, rest:ImInfoEntry)
>             + B(stat:string, dest:string)
>             + C(restart:ImInfoEntry, curr:ImInfoEntry)
> ```
>
> The `C` variant represents an information entry whose current status is `curr.status()` (i.e., possibly advanced farther down the list), and whose future statuses follow the `rest` pointers from `curr` until the end of the list (a `B` variant), and then loop back to `restart`.
>
> So the given code for `A.nextEntry()` constructs a `C` whose `restart` is the `A`

object and whose current status is the successor of the `A` object:

```
export class A implements ImInfoEntry {
  ...
  public nextEntry(): ImInfoEntry {
      return new C(this, this.rest);
  }
}
```

Here is the simplest answer for `B.nextEntry()`:

```
export class B implements ImInfoEntry {
  ...
  public nextEntry(): ImInfoEntry {
      return this;
  }
}
```

...because `B` represents an entry with only 1 status, so it immediately loops back to itself. Another possible answer is `new C(this, this)`.

Here is the simplest answer for `C.nextEntry()`:

```
export class C implements ImInfoEntry {
  ...
  public nextEntry(): ImInfoEntry {
    if (this.curr.size() === 1) { // curr has reached the end of the li

      return this.restart;

    } else {

      return new C(this.restart, this.curr.nextEntry());
    }
  }
}
```

As before, `new C(this.restart, this.restart)` would also work for the first return statement.

Note that `C` is an immutable object, so it's necessary to create a fresh `C` here rather than, say, reassigning `this.curr = this.curr.nextEntry()`.

> Note also that `this.curr.rest` is not correct, because `this.curr` might refer to any `ImInfoEntry` variant -- A, B, or even C. `this.curr` doesn't necessarily point to a A object, and so the `rest` instance variable doesn't necessarily exist on that object.

3. (22 points) Grammars

(a) Which of these regular expressions accept (fully match) every legal status and destination string, and reject (fail to fully match) at least one illegal string? Circle YES or NO.

```
[A-Z0-9: ]+
        matches every legal string?              YES      NO

        rejects at least one illegal string?     YES      NO
```

> Solution:
>
> NO to matching every legal string -- it does not match the empty string, which is a legal status.
>
> YES to rejecting at least one illegal string -- for example, it rejects the illegal string `","`.

```
([A-Z]*|[0-9]*|:*| *)+
        matches every legal string?              YES      NO

        rejects at least one illegal string?     YES      NO
```

> Solution:
>
> YES to matching every legal string. The parenthesized regex can match any legal character, and can also match the empty string. The parenthesized regex must then match at least once, because of the `+` operator applied to it, but because the parenthesized regex can match the empty string, this means that the overall regex can also match the empty string.
>
> YES to rejecting at least one illegal string -- for example, it rejects the illegal string `","`.

```
[A-Z]*[0-9]*[:]*[ ]*
        matches every legal string?              YES      NO

        rejects at least one illegal string?     YES      NO
```

> Solution:
>
> NO to matching every legal string -- it does not match `"11:05 AM"`, for example, because once the colon has matched `[:]*`, there is no way to match the remaining digits and letters in the string.
>
> YES to rejecting at least one illegal string -- for example, it rejects the illegal string `","`.

```
.*[A-Z0-9: ]*
        matches every legal string?              YES      NO

        rejects at least one illegal string?     YES      NO
```

> Solution:
>
> YES to matching every legal string, because `.*` can match the empty string at the start, and then `[A-Z0-9: ]*` can match the rest of a legal string.
>
> NO to rejecting at least one illegal string, because this regex actually matches all possible strings -- `.*` can match the entire string first, and then `[A-Z0-9: ]*` can be satisfied by matching the empty string at the end.

(b) Suppose an information board entry is represented as a string of text as in this example:

```
WASHINGTON|NEW DEPRTURE,TRACK 2,11:35AM
```

Complete the grammar below so that it can be used to parse an information board entry, with starting nonterminal `infoentry`. Your grammar must use the `destination` and `status` nonterminals shown, which you can assume have been defined with a correct answer from part (a).

For the purpose of this grammar, assume that statuses and destinations have **no maximum length**, and an information board entry has **no maximum number of statuses**.

```
destination ::= *a correct regular expression from part (a)*
status ::= *a correct regular expression from part (a)*
```

```

```

> Solution:

```
infoentry ::= destination '|' status ( ',' status )*
```

Here is another solution that avoids using the repetition operator `*` by introducing a new nonterminal:

```
infoentry ::= destination '|' statuses
statuses ::= status   |   status ( ',' status )*
```

And here is a solution that enforces the maximum number of statuses (which was not required by the instructions):

```
infoentry ::= destination '|' statuses
statuses ::= status
           | status ',' status
           | status ',' status ',' status
           | status ',' status ',' status ',' status
```

4. (26 points) Map/Filter and Callbacks

Suppose we add `map` and `filter` operations to `ImInfoEntry`, to transform the (cyclic) stream of status messages that an information board entry displays:

```
map: ImInfoEntry x (string -> string) -> ImInfoEntry
filter: ImInfoEntry x (string -> boolean) -> ImInfoEntry
```

These operations affect only the statuses of an `ImInfoEntry`, not its destination.

(a) Of the four kinds of ADT operations, what kind(s) of operations is `ImInfoEntry.map`? Leave extra boxes blank:

> Solution: Producer

(b) Use `map` to replace every English status message found in the `translations` map below with its corresponding French translation.

```
let translations: Map<string, string> = new Map([["ON TIME",   "A LHEURE"
],
                                                 ["CANCELED", "SUPPRIME"]]);

let train1: ImInfoEntry = parseImInfoEntry("MONTREAL|ON TIME,11:05 AM");
// train1 has statuses "ON TIME", "11:05 AM"

let train2: ImInfoEntry = train1.map((...MAP...));
// train2 has statuses "A LHEURE", "11:05 AM"
```

Write a function to replace **`(...MAP...)`** in the code above:

```
```

> Solution:
>
> ```
> status => translations.get(status) ?? status
> ```

(c) Write a function that, if passed to **`filter`** (not `map`), would transform the stream of status messages in a way that cannot be a legal abstract value of the `ImInfoEntry` type.

```
```

> Solution:
>
> This filter function would fail to match all possible status messages, which is illegal because an information entry must have at least one status:
>
> ```
> status => false
> ```

Now suppose that a mutable information board entry `MutInfoEntry` also has a `map` operation:

```
map: MutInfoEntry x (string => string) => void
```

`MutInfoEntry.map` transforms all statuses subsequently returned by the entry, as shown in this example:

```
const toFrench: string => string = ...MAP...; // a correct answer to part (b) above
const train: MutInfoEntry = new MutInfoEntry("MONTREAL");
train.nextStatus();  // returns ""
train.map(toFrench);
train.setStatuses(["ON TIME","11:05 AM"]);
train.nextStatus();  // returns "A LHEURE"
train.nextStatus();  // returns "11:05 AM"
train.setStatuses(["CANCELED"]);
train.nextStatus(); // returns "SUPPRIME"
```

(d) What kind(s) of operation is `MutInfoEntry.map`? Leave extra boxes blank:

> Solutions:
>
> Mutator.
>
> Note that "observer" is not a good answer here, because the `map` operation by itself returns no information to the client, and doesn't even necessarily call the client's transform function with any statuses (yet).

To implement `map`, the rep of `MutInfoEntry` now has a third field:

```
private f: string => string;
```

and its abstraction function is (only relevant parts shown):

> AF(`destination`, `statuses`, `f`) = the info board entry with current status `f(statuses[0])` and looping through future statuses `f(statuses[1])`, ..., `f(statuses[statuses.length-1])`, `f(status[0])`, and so on... [rest of AF elided]

The `MutInfoEntry` methods are implemented to obey this AF and behave as shown in the code above.

(e) Write a function for the initial value of `f` for a new `MutInfoEntry` object.

Solutions:

It should be the identity function, e.g.:

```
status => status
```

(f) During which of the numbered lines in the example code above (d) is the `toFrench` function called? List all line numbers that apply, or write NEVER if `toFrench` is never called. Note that this question is asking about **`toFrench`**.

Solutions:

Lines 6, 7, 9. `toFrench` must be called by every `nextStatus()` call after it is installed.

Line 3 is not correct because `toFrench` has not been called yet.

Line 4 is not correct because `toFrench` is passed just as a reference to the function, not a call.

Lines 5, and 8 are not correct because the abstraction function declares that `statuses` in the rep is a list of untransformed statuses. The map function should not be called when the statuses are stored, only when they are displayed. Calling `toFrench` during these lines is possible (perhaps by a fast-failing `checkRep()` method) but not necessary.

(g) What should `MutInfoEntry` 's rep invariant comment say about `f` ? Note that this question is asking about **`f`**.

Solutions:

`f` is a function that requires a valid status as input (the precondition) and returns a valid status (postcondition). Without this constraint, the `nextStatus()` operation is unable to satisfy its postcondition.

A statement that includes only the postcondition -- e.g. " `f` returns only valid statuses" --

> is too strong, because it excludes many valid functions. For example, the identity function can return an invalid status if it is given an invalid status.
>
> A statement that speaks only about the current state of the object -- e.g. "`f(statuses[i])` is a valid status for all `i`" -- is not strong enough. There may be some valid status `s` *not currently* in `statuses` where `f(s)` is invalid. `setStatuses()` would have to accept `s` as one of the new statuses, but this would break the rep.
>
> A statement that repeats the type signature of `f`, e.g. "`fl is a function from strings to strings", is not strong enough, and is unnecessary to include in the rep invariant comment because the type declaration already states it.

Code

```
/**
 *  An information board entry that shows a destination (e.g. "WASHINGTON D
 *  and current status (e.g. "DELAYED") in a cycle of 1 to 4 statuses
 *  (e.g. [ "DELAYED", "NEW DEPRTURE", "11:55 AM" ]).
 *
 *  A valid destination is up to 16 characters, consisting only of
 *  upper-case letters A-Z, digits, colons, or spaces.
 *
 *  A valid status is up to 12 characters, consisting only of
 *  upper-case letters A-Z, digits, colons, or spaces.
 */
export interface ImInfoEntry {

    /** @return the destination*/
    destination(): string;

    /** @return the currently-shown status */
    status(): string;

    /** @return the entry with the same destination and statuses,
     *          showing the next status in the cycle  */
    nextEntry(): ImInfoEntry;

    /** @return number of statuses in the cycle, integer from 1 to 4 */
    size(): number;
}
```

```
/**
 * @param entry information board entry represented as a string according
 *        to the grammar in Problem 3
 * @return corresponding information board entry value
 */
export function parseImInfoEntry(entry: string): ImInfoEntry { ... }

/**
 *  An information board entry that shows a destination (e.g. "WASHINGTON D
 *  and cycles through a list of 1 to 4 statuses (e.g. [ "11:05 AM", "ON TI
 *  or [ "NOW BOARDING", "TRACK 3" ]).
 *
 *  A valid destination is up to 16 characters, consisting only of
 *  upper-case letters A-Z, digits, colons, or spaces.
 *
 *  A valid status is up to 12 characters, consisting only of
 *  upper-case letters A-Z, digits, colons, or spaces.
 */
export class MutInfoEntry {

    private statuses: string[] = [];

    // Abstraction function:
    //   <elided>
    // Rep invariant:
    //   - destination is a valid destination (defined above)
    //   - statuses has 1-4 elements, each of which is a valid status (defi

    /** Create a new information board entry with the given destination and
     *  a single empty status.
     *  @param destination a valid destination (defined above) */
    public constructor(public readonly destination: string) {
        statuses.push("");
    }

    /**  @return the destination */
    public destination(): string { return destination; }

    /** @return the next status to display, infinitely cycling through this
     *          info board entry's statuses in order  */
    public nextStatus(): string {
        const status: string = statuses.shift()
        statuses.push(status); // put it back on end so that statuses cycle
        return status;
    }
```

```
    /** Set the statuses. The first status in the list will be displayed ne
     *  @param statuses new statuses, a 1- to 4-item list of valid statuses
    public setStatuses(statuses: string[]): void {
        this.statuses = [...statuses];
    }
}
```