

Programmering og Problemløsning

Datalogisk Institut, Københavns Universitet

Arbejdsseddel 5 - individuel opgave

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7. oktober - 15. oktober.
Afleveringsfrist: lørdag d. 15. oktober kl. 22:00.

I denne periode skal vi arbejde med abstrakte datatype, biblioteker og applikationer. En abstrakt datatype er et koncept som f.eks. lister, som kan beskrives vha. dets interface med signaturfiler og implementeres som et bibliotek i implementationsfiler. Biblioteker i F# kaldes også for moduler. Denne arbejdsseddels læringsmål er:

- at lave et bibliotek og en tilhørende applikation,
- at kunne oversætte biblioteksfiler og applikationsfiler både med `dotnet fsi` og `run`,
- at kunne arbejde med generiske moduler,

Opgaverne er opdelt i øve- og afleveringsopgaver. I denne periode skal I arbejde individuelt med jeres afleveringsopgaver. Regler for gruppe- og individuelle afleveringsopgaver er beskrevet i ”Noter, links, software m.m.” → ”Generel information om opgaver”.

Øveopgaver (in English)

500 In an earlier assignment, you implemented a small set of functions for vector operations in F#:

(a) addition of vectors

```
add: vec -> vec -> vec
```

(b) multiplication of a vector and a constant

```
mul: vec -> float -> vec
```

(c) rotation of a vector

```
rot: vec -> float -> vec
```

and wrote a small program to test these functions. Convert your earlier programs into a library called `Vec`, consisting of a signature file, an implementation file, and an application file. Create a `.fsproj` project file, and run the code using first `dotnet fsi` and then `dotnet run`.

5ø1 A linked list is an abstract datastructure, handily built in to F#.

In this exercise you will create two implementations of a linked list, one only supporting `int` and a generic linked list that can be used with any datatype, just like the built-in F# lists.

- (a) Write off the following signature in `intLinkedList.fsi` and write a corresponding implementation in `intLinkedList.fs`

```
module IntLinkedList
type intLinkedList = Nil | Cons of int * intLinkedList
val head : intLinkedList -> int
val tail : intLinkedList -> intLinkedList
val isEmpty : intLinkedList -> bool
val length : intLinkedList -> int
val add : int -> intLinkedList -> intLinkedList
```

Write a small test program to ensure your implementation works as expected. You can take inspiration from the following listing:

```
open IntLinkedList
let emptyList = Nil
let l1 = Cons (1, Nil)
let l2 = Cons (1, Cons (2, Nil))
let l3 = add 3 l2
isEmpty emptyList |> printfn "Empty list is empty: %A"
isEmpty l1 |> not |> printfn "Non-empty list is not empty: %A"
head l1 = 1 |> printfn "head gives the first element: %A"
tail l1 = Nil |> printfn "tail gives the rest of the list: %A"
length l3 = 3 |> printfn "l3 has length 3: %A"
```

- (b) In the previous sub-exercise the linked list is restricted to the type `int`. In this sub-exercise you should construct a generic linked list module.
- (c) Write off and finish the following signature in `LinkedList.fsi` and write a corresponding implementation in `LinkedList.fs`.

```
module LinkedList
type LinkedList<'a> = Nil | Cons of 'a * intLinkedList<'a>
val head : LinkedList<'a> -> 'a
val tail : ?? // Fill in yourself
val isEmpty : ?? // Fill in yourself
val length : ?? // Fill in yourself
val add : ?? // Fill in yourself
```

Write a small test-program showing you can construct linked lists of all types. You should be able to reuse all of your test from the previous sub-exercise and thus create linked lists of `LinkedList<int>`, as well as the following:

```
open LinkedList
let emptyList = Nil
let l1Float = add 2.0 emptyList |> add 3.14 // A float list
let l1String = add "Linked lists are cool!" emptyList
let l2String = add "What is cool?" l1String
// A list of int lists
let intLstLst = add l1 emptyList |> add l2 |> add emptyList
// a list of string lists
let strLstLst = add l1String emptyList |> add l2String
```

- (d) Implement `fold` for your linked list module, similar to `List.fold`.
- (e) Implement `foldBack` for your linked list module, similar to `List.foldBack`.
- (f) Implement `map` for your linked list module, similar to `List.map`.

Afløversopgaver (in English)

In the following, you are to work with the abstract datatype known as a *queue*. A queue consists of a sequence that supports the following operations:

- Checking whether the sequence is empty.
- Dequeueing (*Removing*) an element from the front (“left”).
- Enqueueing (*Adding*) an element at the end (“right”).

Queues appear often in real life: Standing in line at a shop counter, orders await in a queue for their turn to be shipped in an online shop, students waiting to be examined at oral examinations. *Purely functional queues* are a data type defined by their element type, the following set of operations, and the properties they must satisfy.

```
// types
type element // type of elements in the queue
type queue // type of queues with such elements
// values and functions
// the empty queue
val emptyQueue: queue
// add an element at the end of a queue
val enqueue: element -> queue -> queue
// check if the queue is empty
val isEmpty: queue -> bool
// remove the element at the front of the queue
// precondition: isEmpty(q) == false
val dequeue: queue -> element * queue
```

These queues are called (*purely*) *functional* because the enqueue and dequeue operations return a *new* queue when they are called, without destroying the old queue. In particular, it is possible to add an element e_1 to a queue q_0 of length 15 resulting in a queue q_1 of length 16, then to add another element e_2 to q_0 resulting in a queue q_2 of length 16, but different from q_1 in the last element, whereupon we have 3 separate queues, each of which we can use in future operations: q_0 , q_1 and q_2 .¹

In this exercise, you are to work with functional queues in F#. We’ll leave off the “functional” below.

5i0 In the following you are to create a dotnet project for the assignment.

¹There are also *ephemeral* (also called *imperative*) queues, where enqueue and replace the original queue with the new queue such that there is always just one “current” queue that changes over time. Ephemeral queues have more limited functionality and are easier to implement efficiently using imperative data structures, which we will encounter later in the course.

- (a) Using the dotnet command line tool, create a new F# console application named 5i.
dotnet new console -lang "F#" -o 5i
- (b) Rename the file Program.fs to testQueues.fs.
- (c) Update 5i.fsproj to compile testQueues.fs instead of Program.fs.
- (d) Ensure the project works by running dotnet build and dotnet run.

5i1 In the following, you are to implement your own queue module using lists in F# to represent the (sequence of elements in) a queue. The module is to be called IntQueue.

- (a) Given the description of the abstract datatype Queue above, write a signature file intQueue.fsi for the functional queues.
- (b) Write an implementation file intQueue.fs, implementing the signature file above using lists in F# where the elements are F# integers.
- (c) Add intQueue.fsi and intQueue.fs to 5i.fsproj, so they are compiled *before* testQueues.fs.
- (d) In testQueues.fs, show your implementation works by using your queue. As a minimum, you should add the following series of tests of your IntQueue module:

```
let intQueueTests () =
    let q0 = IntQueue.emptyQueue
    let emptyTestResult = IntQueue.isEmpty q0
    emptyTestResult
    |> printfn "An empty queue is empty: %A"

    let e1,e2,e3 = 1,2,3
    let q1 = q0 |> IntQueue.enqueue e1
                |> IntQueue.enqueue e2
                |> IntQueue.enqueue e3
    let nonEmptyTestResult = IntQueue.isEmpty q1

    nonEmptyTestResult
    |> printfn "A queue with elements is not empty: %A"

    let (e,q2) = IntQueue.dequeue q1
    let dequeueTestResult = e = e1
    dequeueTestResult
    |> printfn "First in is first out: %A"

    let allTestResults =
        emptyTestResult &&
        nonEmptyTestResult &&
        dequeueTestResult

    allTestResults
    |> printfn "All IntQueue tests passed: %A"
    // Return the test results as a boolean
    allTestResults

// Run the IntQueue tests
let intQueueTestResults = intQueueTests ()
```

5i2 A problem with the queue specification above is that there is a precondition on the dequeue operation: A programmer must always ensure that the argument to dequeue is nonempty before calling dequeue. In other words, even though the F# type system does not flag it as an error, it *is* an error (by the programmer) to call dequeue with the empty queue.

In the following, you are to implement another version of your queue module using lists in F# to represent the (sequence of elements in) a queue, with error handling. The module is to be called `SafeIntQueue`, the signature file `safeIntQueue.fsi` and the implementation file `safeIntQueue.fs`.

Change the queue specification such that `SafeIntQueue.dequeue` returns an `(element option) * queue value` and remove the precondition. Add the new module to `5i.fsproj` and in `testQueues.fs`, add a corresponding test suite that shows your implementation works; that is, its operations perform queuing and dequeuing, and, additionally `SafeIntQueue.dequeue(emptyQueue)` returns `None`.

5i3 A queue is an abstract datatype, and as such the operations of a queue should not depend on the type of elements. In the following you are to implement a *generic queue*, so it is possible to create queues of any type, e.g. queues of `int`, queues of `float`, queues of `string` or even queues of `queue`.

The module is to be called `Queue`, the signature file `queue.fsi` and the implementation file `queue.fs`. Add the new module to `5i.fsproj` and in `testQueues.fs`, add a corresponding test suite that shows your implementation works; that is, its operations perform queuing and dequeuing, and additionally that you can build queues of different types with the same generic library. As a minimum, demonstrate queues of `int`, `float` and `string`.

Krav til afleveringen

Afleveringen skal bestå af

- en zip-fil, der hedder `5i.zip`
- en opgavebesvarelse i pdf-format.

Zip-filen skal indeholde:

- filen `README.txt` som er en tekstfil indeholdende jeres navn og en beskrivelse af hvordan man bygger projektet og kører jeres test.
- en `src` mappe med følgende og kun følgende filer:

`5i.fsproj`,
`intQueue.fsi`, `intQueue.fs`,
`safeIntQueue.fsi`, `safeIntQueue.fs`,
`queue.fsi`, `queue.fs`,
`testQueues.fs`

svarende til afleveringsopgaverne. Funktionerne skal være dokumenteret med ifølge dokumentationsstandarden ved brug af `<summary>`, `<param>` og `<returns>` XML tagsne.

- pdf-dokumentet skal være lavet med \LaTeX , benytte opgave.tex skabelonen, ganske kort dokumentere din løsning og indeholde evt. figurer.

God fornøjelse.