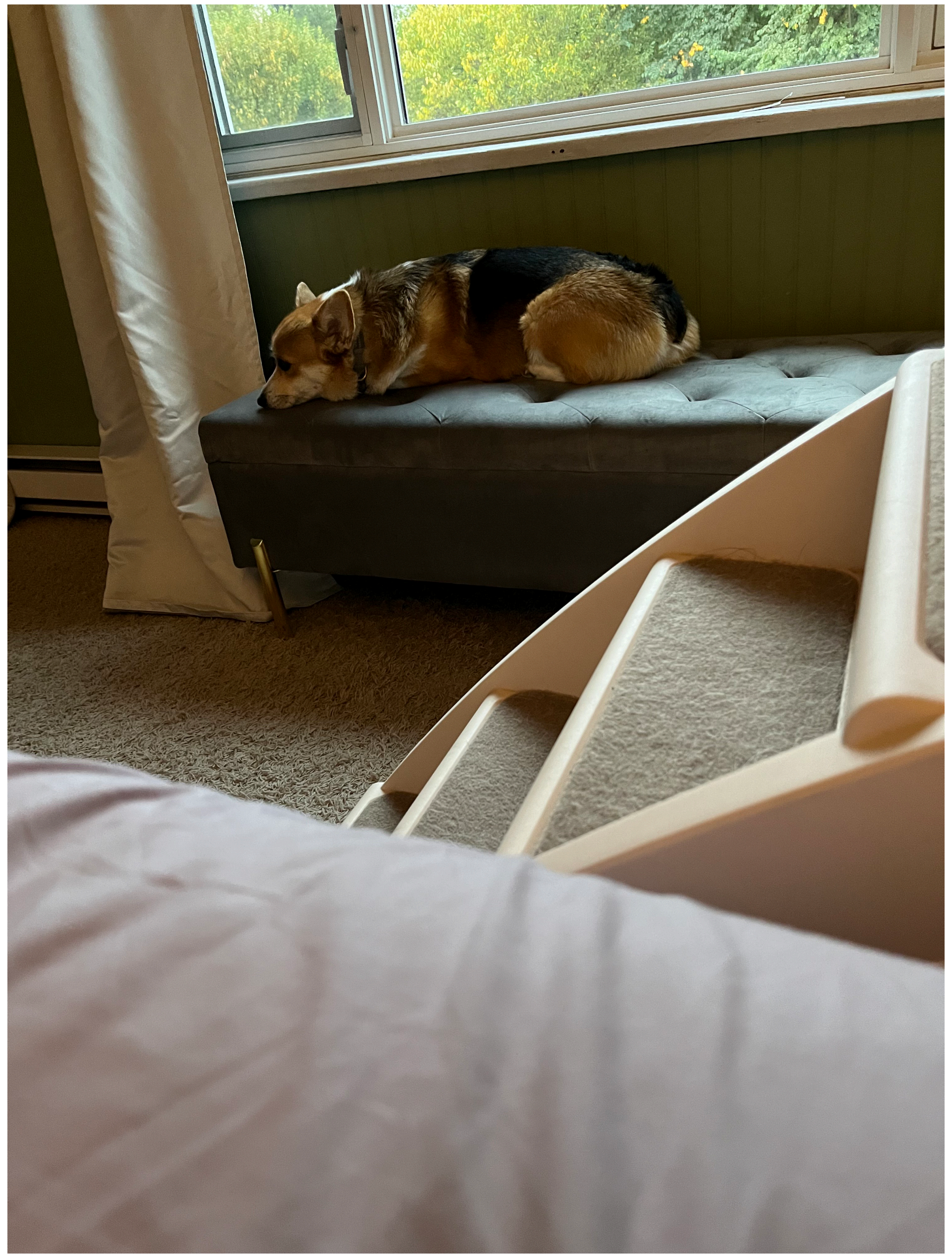
CMPT 383

Lecture 3: Haskell Lists (continued)



Anders Miltner

`remove_at` function

```
remove_at :: [a] -> Int -> [a]
remove_at []    _ = []
remove_at (h:t) 0 = t
remove_at (h:t) i = h:(remove_at t (i-1))
```

Fundamental Issues with FP

- Doubly-linked lists are not possible in pure FP
- Arrays are not possible in pure FP
- No O(1) access to list/array indices
    - No expected O(1) dictionary lookups
- And more…
- This is why I personally don't use Haskell, but it's still great for learning FP

`update_at` function

```haskell
update_at :: [a] -> Int -> a -> [a]
update_at []    _ _ = []
update_at (h:t) 0 v = v:t
update_at (h:t) i v = h:(update_at t (i-1) v)
```

List append

- Would like to be able to combine lists, rather than just prepend elements to list
- `[1,2] ++ [3,4] ++ [5] = [1,2,3,4,5]`
- `(++) :: [a] -> [a] -> [a]`

```
(++) :: [a] -> [a] -> [a]
(++) []      y = y
(++) (xh,xt) y = xh:(xt ++ y)
```

List reverse

- `reverse [1,2,3,4,5] = [1,2,3,4,5]`
- `reverse :: [a] -> [a]`
- `(++) :: [a] -> [a] -> [a]`

```
reverse :: [a] -> [a]
reverse []  = []
reverse h:t = (reverse t) ++ [h]
```

Correct, but inefficient

- Call append every time
- O(n^2)

```
reverse :: [a] -> [a]
reverse []  = []
reverse h:t = (reverse t) ++ [h]
```

```
(++) :: [a] -> [a] -> [a]
(++) []      y = y
(++) (xh,xt) y = xh:(xt ++ y)
```

Faster Solution: Tail Recursion

- In tail recursion, you use an “accumulator”
- Accumulate the result, then return it when finished with the list
- Try building using a helper `reverse’ :: [a] -> [a] -> [a]`

```
reverse :: [a] -> [a]
reverse l = reverse’ l []
  where reverse’ []  acc = acc
        reverse’ h:t acc = reverse’ t (h:acc)
```

Aside: Tail Call Optimization

- One negative thing about recursion is that it pops the call stack
- Does that need to be the case?
- If recursion does no computation after recursive call, what is the stack useful for
- Optimizing Haskell compiler (-O2 and above) will remove call stack
    - So does gcc!

```
reverse :: [a] -> [a]
reverse l = reverse’ l []
  where reverse’ []  acc = acc
        reverse’ h:t acc = reverse’ t (h:acc)
```

List Syntactic Sugar

- Can be annoying to write `a:b:c:d:[]`
  - `[a,b,c,d] = a:b:c:d:[]`
- Can be annoying to write `[1,2,3,4,5]`
  - `[1..5] = [1,2,3,4,5]`
- Can be annoying to write `[0,2,4,6,8]`
  - `[0,2..8] = [0,2,4,6,8]`
- Also `[x..]` gives infinitary list starting from x
- `[x,y..]` give infinitary list starting from x, with increments y-x

Strings!

- Strings are just lists of characters
  - `String = [Char]`
- So, operations on strings are just list operations
  - String concat: `(++)`
- One additional syntactic sugar:
  - `“abc” = [‘a’,’b’,’c’] = ‘a’:’b’:’c’:[]`

List Comprehensions

- Originally inspired from math set notation: { x | x in Nat, x % 2 == 0 }
- Also used in python
- Actually syntactic sugar
  - What for? The list monad! — see the desugaring later in the semester!

Generators

- Contain the source values for the comprehension
- `x <- [1,2,3,4]`
- `y <- [5,6,7,8]`
- `z <- [‘a’..’z’]`

Generator + Expression = Comprehension

- The generator binds elements of the list to variables
- The expression shows how to use the elements of the list
- What do you think the following expression evaluates to?
  - `[ x^2+1 | x <- [1,2,3,4,5] ]`
- `[2,5,10,17,26]`

Multi-Generator Drifting

- You can build comprehensions from more than one generator
- Corresponds to the “cartesian product” of the two lists
- What do you think the following expression evaluates to?
  - `[ 10*x + y | x <- [1,2,3], y <- [1,2,3] ]`
- `[11,12,13,21,22,23,31,32,33]`

Guards

- You can filter down to some subset of the elements
  - `[ 10*x + y | x <- [1,2,3], y <- [1,2,3], x % 2 == 0]`
- `[21,22,23]`

Using Comprehensions to Flex on Imperative Languages

```java
public void quickSort(int arr[], int begin, int end) {
    if (begin < end) {
        int partitionIndex = partition(arr, begin, end);

        quickSort(arr, begin, partitionIndex-1);
        quickSort(arr, partitionIndex+1, end);
    }
}
```

```java
private int partition(int arr[], int begin, int end) {
    int pivot = arr[end];
    int i = (begin-1);

    for (int j = begin; j < end; j++) {
        if (arr[j] <= pivot) {
            i++;

            int swapTemp = arr[i];
            arr[i] = arr[j];
            arr[j] = swapTemp;
        }
    }

    int swapTemp = arr[i+1];
    arr[i+1] = arr[end];
    arr[end] = swapTemp;

    return i+1;
}
```

```haskell
qs :: [a] -> [a]
qs (x:xs) = smaller ++ [x] ++ larger
  where smaller = qs [a | a <- xs, a <= x]
        larger  = qs [a | a <- xs, a > x ]
```