String: a Programming Example

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String Processing

String (or text) processing is important

Conversions beween different formats: files, documents, XML, web/database, etc.

I think functional programming is good for this kind of application

We will look at a simple example here: how to break a text into a list of words, that can be used for various things like:

- counting the number of words in the text
- printing the text with a given maximal line length in characters (breaking lines when next word does not fit in)

Strings

F# has a data type `string` for strings

We will *not* use this type for now

Rather, we will use lists of characters, of type `char list`

One reason: we then get a good exercise in list programming

Later, we'll bring up the `string` datatype

We will then redo the example using strings rather than lists of characters

Breaking a String Into Words

Words are sequences of characters separated by one or more *whitespace* characters: space, newline, tab

(In F#: `' '`, `'\n'`, `'\t'`)

We want a function that converts a list of characters into a list of its words. Words are also lists of characters

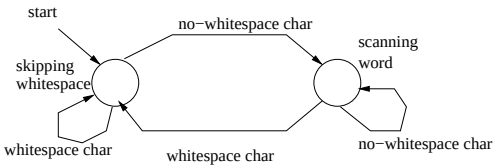
```
string2words : char list -> (char list) list
```

For instance,

```
string2words ['A';'l';'l';'a';'n';' ';'t';'a';'r';' ';' ';
              '\t';' ';'\n';'k';'a';'k';'a';'n']
=>
[['A';'l';'l';'a';'n'];['t';'a';'r'];['k';'a';'k';'a';'n']]
```

How code `string2words`?

We need a mental model. This is a simple parsing problem, which can be solved by a *finite automaton* with two states:



Common design pattern: one function per state. When new character read the function for the new state is called

We'll use a variation of this pattern: in each state we will *look ahead* and count the number of characters before changing to the other state:

- whitespace: count characters until non-whitespace char, then drop that number of characters and call the other function on rest of list
- word: count characters until whitespace char, then save that number of characters into list of characters and call the other function on rest of list

We can define a general list function `drop` to skip a number of characters:

`drop 3 [1;4;2;5;6]` $\Longrightarrow$ `[5;6]`

(`drop n s` returns the list remaining after `take n s`)

Exercise: define `drop`! (A solution on next slide)


```
let rec drop n l =
  if n < 0 then
    failwith "Negative argument"
  else
    match (n,l) with
    | (0,_)     -> l
    | (_,x::xs) -> drop (n-1) xs
    | (n,[]) -> failwith "List too short"
```

(This function is a little inefficient. Why?)

A First Solution

Functions to count characters until next whitespace and next no-whitespace, respectively:

```
let rec find_ws l =
  match l with
  | []    -> 0
  | c::cs -> if c = ' ' || c = '\n' ||  c = '\t'
             then 0 else 1 + find_ws cs

let rec find_nows l =
  match l with
  | []    -> 0
  | c::cs -> if c \= ' ' && c \= '\n' &&  c \= '\t'
             then 0 else 1 + find_nows cs
```

Functions `string2words` and `string2words1` corresponding to states "skipping whitespace" and "scanning word", respectively:

```
let rec string2words s =
  match s with
  | [] -> []
  | _  -> string2words1 (drop (find_nows s) s)
and     string2words1 s =
  match s with
  | [] -> []
  | _  -> let n = (find_ws s)
          in take n s :: string2words (drop n s)
```


This is a *mutually recursive* definition. The functions recursively call each other

The keyword "`and`" is used to link mutually recursive declarations (why would it not work with ordinary "`let rec`" for the second declaration?)

Note how the words are collected into separate lists by `take`

Also note that "`::`" in `string2words1` puts the list of characters as *element* into the list, so the returned list is a list of *lists of characters* (not list of characters)

A More Elegant Slution

This solution works fine, but is a bit clumsy

In particular, `find_ws` and `find_nows` are very similar

They do precisely the same, but with negated conditions!

Can we "factor out" the common structure?

Yes, if we can make the condition a *parameter* to a more general function!

Let's see on next slide how to do this . . .

A More General Character Count Function

F# has *higher order functions*

They are functions that take other functions as arguments, or return functions as result

We can thus define a function `find` that takes a *predicate* `p` on characters as first arguments and counts the number of characters up to the first character `c` such that `p c = true`:

```
let rec find p l =
  match l with
  | []    -> 0
  | x::xs -> if p x then 0 else 1 + find p xs
find : (char -> bool) -> (char list) -> int
```

(`find` will actually have a more "general" type. More on this later)

Predicate to check for whitespace:

```
let ws c =
  match c with
  | ' '  -> true
  | '\n' -> true
  | '\t' -> true
  | _    -> false
ws : char -> bool
```


Then simply:

```
let find_ws s = find ws s
```

For `find_nows`, we must have a negated whitespace-predicate:

```
let not_ws c = not (ws c)
```

We get:

```
let find_nows s = find not_ws s
```

(A more elegant solution, avoiding these declarations, would be to use nameless functions but we haven't introduced them yet)

Final Solution

```
module String2words
  let ws c =
    match c with
    | ' '  -> true
    | '\n' -> true
    | '\t' -> true
    | _    -> false

  let not_ws c = not (ws c)

  let rec find p l =
    match l with
    | []    -> 0
    | x::xs -> if p x then 0 else 1 + find p xs

  let find_ws s = find ws s

  let find_nows s = find (not_ws) s
```


Final Solution, Part 2

```
let rec string2words s =
  match s with
  | [] -> []
  | _  -> string2words1 (drop (find_nows s) s)
and     string2words1 s =
  match s with
  | [] -> []
  | _  -> let n = (find_ws s)
          in take n s :: string2words (drop n s)
```

Applications of `string2words`

Let's do the two applications mentioned before:

- counting the number of words in the text
- printing the text with a given maximal line length in characters (breaking lines when next word does not fit in)

Can you figure out how to do them?

How to do them

The first is easy: use the `List.length` function from the `List` module

```
let wordcount s = List.length (string2words s)
```

The second is more interesting . . .

A function `words2lines linelen ws`, where `linelen` is the line length and `ws` is a list of words to be printed

Idea: keep a current position on the line, check length of next word, if greater than `linelen` then start new line else output word on current line and update position

Current position passed as argument

Local function to do this, so `words2lines` does not need to have this extra argument

We will use the *append* (or *concatenate*) operation "@" on lists:

`[1;2;3] @ [4;2]` $\Longrightarrow$ `[1;2;3;4;2]`

The Solution

```
words2lines linelen ws =
  let rec
    w2l l pos =
      match l with
      | []    -> []
      | w::ws -> if pos + List.length w < linelen
                 then w @ [' '] @ w2l ws (pos + List.length w + 1)
                 else '\n' :: w @ [' '] @ w2l ws (List.length w + 1)
  in w2l ws 0
```

Not perfect. Leaves space at end of each line. Somewhat poor treatment of words longer than line length – always new line even if the long word is first in list

Exercise: write a new solution that handles these cases better

Strings

`string` is a one of the builtin datatypes in F#

Strings are really a kind of immutable arrays, holding characters

There is a `String` module with operations on strings

Basic syntax for string constants: a string of characters inside `"..."`:

```
"abc is bcd"
```

Familiar syntax for control characters: `\n` (newline), `\t` (tab), `\\` (backslash), etc.

```
"Line 1\nSecond line"
```

Empty string: `""`

Operations on Strings

Concatenation, or append: `+`

`"abc" + "xyz"` $\Longrightarrow$ `"abcxyz"`

Selection of character from strings is done by indexing, `s.[i]`. String indices start from 0

`"abc".[0]` $\Longrightarrow$ `'a'`, `"abc".[1]` $\Longrightarrow$ `'b'`, `"abc".[2]` $\Longrightarrow$ `'c'`

Note that a character is returned, not a string

More Operations on Strings

Selection of substring, `s.[i..j]`:

`"abc".[0..1]` $\Longrightarrow$ `"ab"`

Also `s.[i..]` (all elements in `s` from `i` and up), `s.[..i]` (all elements in `s` up to `i`):

`"abc".[1..]` $\Longrightarrow$ `"bc"`, `"abc".[..1]` $\Longrightarrow$ `"ab"`

Note that here a string is returned, not a character

Length of string: `String.length`

`String.length "abc"` $\Longrightarrow$ `3`

Even More Operations on Strings

Some operations on strings use “dot” notation (object method style), some examples:

`s.Length` (same as `String.length s`)

`s.ToUpper()`, `s.ToLower()`

`"abc".ToUpper()` $\Longrightarrow$ `"ABC"`

`"AbC".ToLower()` $\Longrightarrow$ `"abc"`

This syntax is really quite alien to functional languages, but is present in F# due to its connections to the .NET with its object-oriented nature

If we don’t like it, we can easily define wrapper functions to hide it:

```
let toupper s = s.ToUpper()
```

String Programming Example Revisited

We now redo the example of breaking a string into words, with strings

It turns out we can still keep the same design

Our function `string2words` will map from `string` to `string list`

The heart of the `char list` solution is in the selection and skipping of substrings in the functions `string2words` and `string2words1`

How do this with strings rather than lists of characters?

Use substring selection `s.[i..j]`!

`string2words` and `string2words1` must be modified to take an extra argument that gives the position where the substring to pick or skip starts

This position argument acts like a pointer telling where the current substring starts

The same holds for `find` (and thus `find_ws`, and `find_nows`)

New declarations on next page


```
let rec find p pos s =
  if pos >= String.length s
  then 0
  else if p (s.[pos]) then 0 else 1 + find p (pos + 1) s

let find_ws pos s = find ws pos s
let find_nows pos s = find (not_ws) pos s

let rec string2words pos s =
  if pos >= String.length s
  then []
  else  string2words1 (pos + find_nows pos s) s
and     string2words1 pos s =
  if pos >= String.length s
  then []
  else let n = (find_ws pos s)
       in s.[pos..pos+n-1] :: string2words (pos + n) s
```