CSE 341
Lecture 2

lists and tuples; more functions; mutable state

Ullman 2.4.1, 2.4.3; 3 - 3.2; 2.3

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Comments

```
(* comment text *)
```

```
(* Computes n!, or 1*2*3*...*n-1*n.
   precondition: n >= 0 *)
fun factorial(n) =
    if n = 0 then 1
    else n * factorial(n - 1);
```

Running an ML program (1.2)

- an ML program can be thought of as a series of *bindings* between names (variables, functions, etc.) and values

- from your operating system's terminal / console:

  ```
  sml filename.sml
  ```

  - preferred; gives a cleaner environment

- running a program from within ML interpreter:

  ```
  use "filename.sml";
  ```

  - drawback: any previous definitions still exist (a "dirty environment")

Lists (2.4.3)

```
[expr1, expr2, ..., exprN]
```

- **list**: contains 0 or more values of the *same* type

  ```
  val lst = [42, ~7, 19];
  ```

  val lst = [42,~7,19] : int list

- The empty list is written as `[]` or `nil`

- You do *not* access a list's elements by indexes. Instead:

  `hd(`***`list`***`)` returns the list's first element

  `tl(`***`list`***`)` returns the list of all elements except the first

  - Does `tl` copy the list, or use a reference? Does it matter?

Concat and cons: growing lists

- concatenate two lists: ***`list1 @ list2`***

  `[10, 20] @ [30, 40];`

  val it = [10,20,30,40] : int list

  "concat"

- attach an element onto a list: ***`element :: list`***

  `10 :: [20, 30];`

  val it = [10,20,30] : int list

  "cons"

  - How would we attach an element to the end of a list?

equivalent to *`[element] @ list`*

More about lists

- find out a list's length with the `length` function:

```
length(["ab","cd","e"]) → 3
```

- strings can be converted to/from lists

```
explode("CSE")          → [#"C", #"S", #"E"]
implode([#"H", #"i"])   → "hi"
concat(["ab","cd","e"]) → "abcde"
```

- ML has a `List` structure with many other functions such as `List.find`, `List.rev`, and `List.partition`

Exercise

- Define a function named `sum` that takes a list of integers as a parameter and computes the sum of its elements. A list that contains no elements has a sum of 0.
  - example: `sum([1, 7, ~2, 15])` should produce 21

- Define a function named `last` that takes a list of integers as a parameter and produces the last element of the list. You may assume that the list is non-empty.
  - example: `last([1, 7, ~2, 15])` should produce 15

Exercise solutions

```
fun sum(lst) =
    if lst = [] then 0
    else hd(lst) + sum(tl(lst));
```

```
fun last(lst) =
    if length(lst) = 1 then hd(lst)
    else last(tl(lst));
```

Parametric polymorphism

- What are the types of hd and `tl`? (and `length`?)

```
- hd;
val it = fn : 'a list -> 'a

- tl;
val it = fn : 'a list -> 'a list
```

- **parametric polymorphism**: ability of a function to handle values identically without depending on their type
  - language is more expressive; still handles types properly
  - similar to generics in Java (e.g. `ArrayList<String>`)
  - can we write a function using parametric polymorphism?

Tuples (2.4.1)

```
(expr1, expr2, ..., exprN)
```

- **tuple**: contains *1* or more values of *any* type

```
val t = (42, 19, 4.6, "hi");
```

*val t = (42,19,4.6,"hi") : int * int * real * string*

- You can access a tuple's elements by 1-based indexes:

```
#2(t);
```

val it = 19 : int

More about tuples

- The type of a tuple is written as its element types with *
  - The type of `(1, 2.7)` is `int * real`
  - What is the type of `(true, ~1, 7)` ?

- lists and tuples can be nested

```
[[4, 3], [~7], [55, 99, 1]]
(42, 19.6, ("hi", "bye", true), ~7, "ok")
```

Tuple as parameter list

- A tuple can be passed as a parameter list to a function:

```
- fun max(a, b) = if a > b then a else b;
val max = fn : int * int -> int

- val nums = (7, 24);
val nums = (7,24) : int * int


- max(nums);
val it = 24 : int
```

Exercise

- Define a function named `convertNames` that accepts a list of ("first-name", "last-name") tuples and produces a list of "last-name, first-name" strings. For the list:

```
val names = [("Hillary", "Clinton"),
             ("Barack", "Obama"),
             ("Joseph", "Biden")];
```

The call of `convertNames(names);` should produce:

```
["Clinton, Hillary", "Obama, Barack", "Biden, Joseph"];
```

Approaching a problem

- One strategy: think procedurally and write *pseudo-code*:

```
– create new result list = [].
– for each element e of list:
    – convert e into "last, first" format.
    – append e onto result list.
– return result list.
```

- How do we express these computations recursively?
- Can we simplify the problem? Can we break it down?

Helper functions

- Write a *helper function* to solve part of the problem:
    - create new result list = [].
    - for each element e of list:
        - **convert e into "last, first" format.**
        - append e onto result list.
    - return result list.

```
fun lastFirst(name : string*string) =
        #2(name) ^ ", " ^ #1(name);
```

or, expand the tuple in the definition:

```
fun lastFirst(first, last) =
        last ^ ", " ^ first;
```

Thinking recursively

- Useful questions to ask:
  - What is the base case?
  - How would I handle a case that is "one-above" the base? (That is, one iteration/call away from being a base case?)
  - How do I target a small part of the problem and solve it?
  - What recursive call(s) will solve the rest of the problem?

Exercise solution

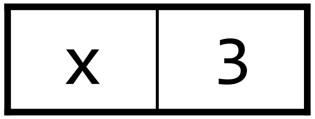
```
fun lastFirst(first, last) = last ^ ", " ^ first;

fun convertNames(lst) =
    if lst = [] then []
    else lastFirst(hd(lst)) ::
            convertNames(tl(lst));
```

Mutable state

- **mutable state**: Ability for data to be modified after creation / declaration.
  - Example:

```
int x = 3;
…
x = 7;
```



- Mutable state is good, right? Do we ever *not* have it?
  - constants (`public static final` …)
  - Strings (`s.toLowerCase();`)
  - objects with only `get` methods, no `set` ("immutable")

Why are Strings immutable?

- Why was Java designed with immutable strings?

```
public Employee(String name, ...) {
    this.name = name;
    ....                     // how could this code
}                            // be abused if Strings
                             // were mutable in Java?
public String getName() {
    return name;
}
```

- J. Bloch, *Effective Java*, #15: "Minimize mutability."

- But what if I *want* a mutable string?
  - `StringBuilder`, `StringBuffer`

Side effects

- **Q:** Is it always okay to replace the expression:

  `f(x) + f(x)` with: `2 * f(x)` ?

  - maybe; `f` might do something besides return its value
    - might produce output, e.g. `System.out.println`
    - might increment a global counter, change a field value, etc.

- **side effect**: When a function, in addition to producing a value, modifies state or has an external interaction.
  - *referential transparency*: if call can always be replaced with result value
  - *idempotent*: if it always returns the same result for the same input

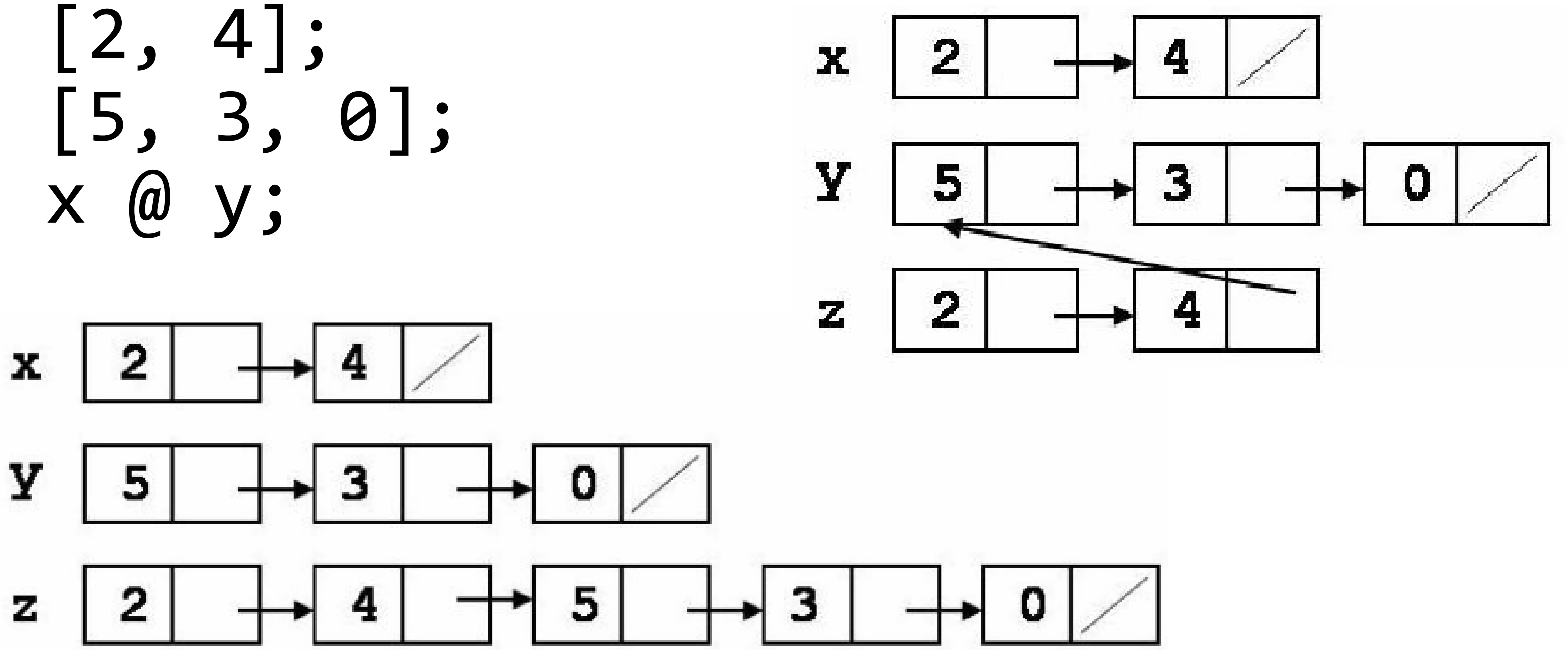
Minimizing side effects

- ML (like many func.langs.) tries to minimize side effects
  - (almost) everything is immutable
  - variables' values cannot be changed (only re-defined)
  - functions' behavior depends only on their inputs

- Benefits of this philosophy?
  - the compiler/interpreter can heavily *optimize* the code
  - much easier to understand/predict behavior of code; code can be more thoroughly *verified* for correctness
  - *robust*; hard for one chunk of code to damage another
  - lack of side effects reduces *dependency* between code
    - allows code to be more easily parallelized

Sharing

```
val x = [2, 4];
val y = [5, 3, 0];
val z = x @ y;
```



- Does z have a copy of y? Or refer to the same list?
  - in Java: it's important to know what is shared
    - – if somebody changes z, it might change x or y, too
  - in ML: **doesn't matter**; data is immutable