

CSE 341: Programming Languages

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Lecture 2— Functions, pairs, and lists

What is a programming language?

Here are separable concepts for defining and evaluating a language:

- syntax: how do you write the various parts of the language?
- semantics: what do programs mean? (One way to answer: what are the evaluation rules?)
- idioms: how do you typically use the language to express computations?
- libraries: does the language provide “standard” facilities such as file-access, hashtables, etc.? How?
- tools: what is available for manipulating programs in the language?

Our focus

This course: focus on semantics and idioms to make you a better programmer

Reality: Good programmers know semantics, idioms, libraries, and tools

Libraries are crucial, but you can learn them on your own.

Goals for today

- Add some more absolutely essential ML constructs
- Discuss lots of “first-week” gotchas
- Enough to do first 5 homework problems (next 3 after Friday)
 - And we will learn better constructs soon
 - (and `also`, `orelse` also quite useful)

Note: These slides make much more sense in conjunction with `lec2.sml`.

Recall a program is a sequence of bindings...

Function Definitions

... A second kind of binding is for functions (kinda like Java methods without fields, classes, statements, ...)

Syntax: $\text{fun } x_0 (x_1 : t_1, \dots, x_n : t_n) = e$

Typing rules:

1. Context for e is (the function's context extended with $x_1:t_1, \dots, x_n:t_n$ *and*:
2. $x_0 : (t_1 * \dots * t_n) \rightarrow t$ *where*:
3. e has type t in this context

(This “definition” is circular because functions can call themselves and the type-checker “guessed” t .)

(It turns out in ML there is always a “best guess” and the type-checker can always “make that guess”. For now, it’s magic.)

Evaluation: *A function is a value.*

Function Applications (a.k.a. Calls)

Syntax: $e_0 (e_1, \dots, e_n)$ (parens optional for one argument)

Typing rules (all in the application's context):

1. e_0 must have some type $(t_1 * \dots * t_n) \rightarrow t$
2. e_i must have type t_i (for $i=1, \dots, i=n$)
3. $e_0 (e_1, \dots, e_n)$ has type t

Evaluation rules:

1. e_0 evaluates to a function f in the application's environment
2. e_i evaluates to value v_i in the application's environment
3. result is f 's body evaluated in an environment extended to bind x_i to v_i (for $i=1, \dots, i=n$).

("an environment" is actually the environment where f was defined)

Some Gotchas

- The * between argument types (and pair-type components) has nothing to do with the * for multiplication
- In practice, you almost never have to write argument types
 - But you do for the way we will use pairs in homework 1
 - And it can improve error messages and your understanding
 - But *type inference* is a very cool thing in ML
 - Types unneeded for other variables or function return-types
- Context and environment for a function body includes:
 - Previous bindings
 - Function arguments
 - The function itself
 - But *not* later bindings

Recursion

- A function can be defined in terms of itself.
- This “makes sense” if the calls to itself (recursive calls) solve “simpler” problems.
- This is more powerful than loops and often more convenient.
- Many, many examples to come in 341.

Pairs

Our first way to build *compound data* out of simpler data:

- Syntax to build a pair: (e_1, e_2)
- If e_1 has type t_1 and e_2 has type t_2 (in current context), then (e_1, e_2) has type $t_1 * t_2$.
 - (I wish it were (t_1, t_2) , but it isn't.)
- If e_1 evaluates to v_1 and e_2 evaluates to v_2 (in current environment), then (e_1, e_2) evaluates to (v_1, v_2) .
 - (Pairs of values are values.)
- Syntax to get part of a pair: $\#1\ e$ or $\#2\ e$.
- Type rules for getting part of a pair: _____
- Evaluation rules for getting part of a pair: _____

Lists

We can have pairs of pairs of pairs... but we still “commit” to the amount of data when we write down a type.

Lists can have *any* number of elements:

- `[]` is the empty list (a value)
- More generally, `[v1, v2, ..., vn]` is a length n list
- If `e1` evaluates to `v` and `e2` evaluates to a list `[v1, v2, ..., vn]`, then `e1::e2` evaluates to `[v, v1, v2, ..., vn]` (a value).
- `null e` evaluates to true if and only if `e` evaluates to `[]`
- If `e` evaluates to `[v1, v2, ..., vn]`, then `hd e` evaluates to `v1` and `tl e` evaluates to `[v2, ..., vn]`.
 - If `e` evaluates to `[]`, a *run-time exception* is raised (this is different than a type error; more on this later)

List types

A given list's elements must all have the same type.

If the elements have type `t`, then the list has type `t list`. Examples:
`int list`, `(int*int) list`, `(int list) list`.

What are the type rules for `::`, `null`, `hd`, and `tl`?

- Possible exceptions do not affect the type.

Hmmm, that does not explain the type of `[]` ?

- It can have any list type, which is indicated via `'a list`.
- That is, we can build a list of any type from `[]`.
- *Polymorphic* types are 3 weeks ahead of us.
 - Teaser: `null`, `hd`, and `tl` are not keywords!

Recursion again

Functions over lists that depend on all list elements will be recursive:

- What should the answer be for the empty list?
- What should the answer be for a non-empty list? (*Typically in terms of the answer for the tail of the list!*)

Functions that produce lists of (potentially) any size will be recursive:

- When do we create a small (e.g., empty) list?
- How should we build a bigger list out of a smaller one?

Sharing, no mutation, etc.

Does `tl` copy the list or share its result with the tail of its argument?

What about our elegant `append`?

It doesn't matter!!!

- *All* that worrying you did in Java about aliasing, object identity, copying versus updating, equal vs. same-object is only relevant when you have assignment statements!
 - A great reason not to use them.

In ML, if `append ([1,2], [3,4,5])` produces `[1,2,3,4,5]`, you cannot tell how much sharing there is, so you don't have to think about it.

- Implementation tends to get the efficiency of sharing (`tl` is fast and doesn't make a "new" list), but without mutation there are no complications.