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 homework problems 1–6, 8, 10
  – (rest after Friday)
  – And we will learn better constructs soon
  – andalso, orelse also quite useful, especially in problem 1

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: \[ \text{fun } x_0 \ (x_1 : t_1, \ldots, x_n : t_n) = e \]

Typing rules:

1. Context for \(e\) is (the function’s context extended with) \[ x_1 : t_1, \ldots, x_n : t_n \text{ and } \]

2. \(x_0 : (t_1 \times \ldots \times t_n) \to t\) 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: \(A \text{ function is a value.}\)
Function Applications (a.k.a. Calls)

Syntax: \[ e_0 \ (e_1, \ldots, e_n) \] (parens optional for one argument)

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

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

(“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 \(t_1 \times t_2\).
  
  – (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: ____________
Tuples

Actually, you can have *tuples* with any number of parts:

- \((e_1, e_2, \ldots, e_n)\)
- \(t_1 * t_2 * \ldots * t_n\)
- \(#n \ e\) for any number \(n\)

Homework 1 uses \(\text{int} * \text{int} * \text{int}\).
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 \( t \text{ list} \). Examples: \( \text{int list} \), \( (\text{int*int}) \text{ list} \), \( (\text{int list}) \text{ list} \).

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 \texttt{tl} copy the list or share its result with the tail of its argument?

What about our elegant \texttt{append}?

It doesn’t matter!!!

- \textit{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 \texttt{append ([1,2],[3,4,5])} produces \texttt{[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 (\texttt{tl} is fast and doesn’t make a “new” list), but without mutation there are no complications.