A First Look at ML
ML

- Meta Language
- One of the more popular functional languages (which, admittedly, isn’t saying much)
- Edinburgh, 1974, Robin Milner’s group
- There are a number of dialects
- We are using Standard ML, but we will just call it ML from now on
Standard ML of New Jersey
- 1+2*3;
val it = 7 : int
- 1+2*3
=
val it = 7 : int

Type an expression after − prompt; ML replies with value and type

After the expression put a ;. (The ; is not part of the expression.)

If you forget, the next prompt will be =, meaning that ML expects more input. (You can then type the ; it needs.)

Variable it is a special variable that is bound to the value of the expression you type
Outline

- Constants
- Operators
- Defining Variables
- Tuples and Lists
- Defining Functions
- ML Types and Type Annotations
- 1234;
val it = 1234 : int
- 123.4;
val it = 123.4 : real

Integer constants: standard decimal, but use tilde for unary negation (like \(\sim 1\))

Real constants: standard decimal notation

Note the type names: \texttt{int}, \texttt{real}
- `true;`
val it = true : bool
- `false;`
val it = false : bool

Boolean constants `true` and `false`

ML is case-sensitive: use `true`, not `True` or `TRUE`

Note type name: `bool`
"fred";
val it = "fred" : string
"H";
val it = "H" : string
"H";
val it = #"H" : char

String constants: text inside double quotes

Can use C-style escapes: \n, \t, \, \", etc.

Character constants: put # before a 1-character string

Note type names: **string** and **char**
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- ~ 1 + 2 - 3 * 4 div 5 mod 6;
val it = ~1 : int
- ~ 1.0 + 2.0 - 3.0 * 4.0 / 5.0;
val it = ~1.4 : real

Standard operators for integers, using ~ for unary negation and − for binary subtraction

Same operators for reals, but use / for division

Left associative, precedence is {+,-} < {* , / , div , mod} < {~}. 
- "bibity" ^ "bobity" ^ "boo";
val it = "bibitybobityybooo" : string
- 2 < 3;
val it = true : bool
- 1.0 <= 1.0;
val it = true : bool
- "$d" > "$c";
val it = true : bool
- "abce" >= "abd";
val it = false : bool

String concatenation: ^ operator

Ordering comparisons: <, >, <=, >=, apply to string, char, int
and real

Order on strings and characters is lexicographic
- 1 = 2;
val it = false : bool
- true <> false;
val it = true : bool
- 1.3 = 1.3;

Error: operator and operand don't agree
[equality type required]
operator domain: '"Z * '"Z
operand: real * real
in expression:
1.3 = 1.3

Equality comparisons: = and <>

Most types are equality testable: these are equality types

Type real is not an equality type
- \(1 < 2 \text{ or else } 3 > 4;\)
val it = true : bool
- \(1 < 2 \text{ andalso } \neg(3 < 4);\)
val it = false : bool

Boolean operators: **andalso, orelse, not.** (And we can also use \(=\) for equivalence and \(<>\) for exclusive or.)

Precedence so far: \{**orelse**\} < \{**andalso**\} < \{,,\},<,>,<=\} < \{+,-,^\} < \{*,/,,div,mod\} < \{~,not\}
- true orelse 1 div 0 = 0;
val it = true : bool

Note: andalso and orelse are short-circuiting operators: if the first operand of orelse is true, the second is not evaluated; likewise if the first operand of andalso is false.

Technically, they are not ML operators, but keywords.

All true ML operators evaluate all operands.
- if 1 < 2 then "x" else "y";
val it = "x" : char
- if 1 > 2 then 34 else 56;
val it = 56 : int
- (if 1 < 2 then 34 else 56) + 1;
val it = 35 : int

Conditional expression (not statement) using if .. then .. else ...

Similar to C's ternary operator: (1<2) ? 'x' : 'y'

Value of the expression is the value of the then part, if the test part is true, or the value of the else part otherwise

There is no if .. then construct
Practice

What is the value and ML type for each of these expressions?

1 * 2 + 3 * 4
"abc" ^ "def"
if (1 < 2) then 3.0 else 4.0
1 < 2 or else (1 div 0) = 0

What is wrong with each of these expressions?

10 / 5
"a" = "b" or 1 = 2
1.0 = 1.0
if (1 < 2) then 3
- 1 * 2;
val it = 2 : int
- 1.0 * 2.0;
val it = 2.0 : real
- 1.0 * 2;

Error: operator and operand don't agree
[literal]
    operator domain: real * real
    operand: real * int
    in expression:
        1.0 * 2

The * operator, and others like + and <, are overloaded to have one meaning
on pairs of integers, and another on pairs of reals

ML does not perform implicit type conversion
- `real(123);`
val it = 123.0 : real
- `floor(3.6);`
val it = 3 : int
- `floor 3.6;`
val it = 3 : int
- `str #"a";`
val it = "a" : string

Built-in conversion functions: `real (int to real), floor (real to int), ceil (real to int), round (real to int), trunc (real to int), ord (char to int), chr (int to char), str (char to string)`

You apply a function to an argument in ML just by putting the function next to the argument. Parentheses around the argument are rarely necessary, and the usual ML style is to omit them.
Function Associativity

- Function application is left-associative

- So \( f \ a \ b \) means \( (f \ a) \ b \), which means:
  - first apply \( f \) to the single argument \( a \);
  - then take the value \( f \) returns, which should be another function;
  - then apply that function to \( b \)

- More on how this can be useful later

- For now, just watch out for it
- `square 2+1;`
val it = 5 : int
- `square (2+1);`
val it = 9 : int

Function application has higher precedence than any operator

Be careful!
Practice

What if anything is wrong with each of these expressions?

trunc 5
ord "a"
if 0 then 1 else 2
if true then 1 else 2.0
chr(trunc(97.0))
chr(trunc 97.0)
chr trunc 97.0
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Define a new variable and bind it to a value using `val`.

Variable names should consist of a letter, followed by zero or more letters, digits, and/or underscores.
val fred = 23;
val fred = 23 : int
fred;
val it = 23 : int
val fred = true;
val fred = true : bool
fred;
val it = true : bool

You can define a new variable with the same name as an old one, even using a different type. (This is not particularly useful.)

This is not the same as assignment. It defines a new variable but does not change the old one. Any part of the program that was using the first definition of fred, still is after the second definition is made.
Suppose we make these ML declarations:

```ml
val a = "123";
val b = "456";
val c = a ^ b ^ "789";
val a = 3 + 4;
```

Then what is the value and type of each of these expressions?

- `a`
- `b`
- `c`
The Inside Story

- In interactive mode, ML wants the input to be a sequence of declarations.
- If you type just an expression `exp` instead of a declaration, ML treats it as if you had typed:
  
  ```
  val it = exp;
  ```
Garbage Collection

- Sometimes the ML interpreter will print a line like this, for no apparent reason:
  \[ \text{GC #0.0.0.0.1.3: (0 ms)} \]

- This is what ML says when it is performing a "garbage collection": reclaiming pieces of memory that are no longer being used

- We’ll see much more about this when we look at Java. For now, ignore it
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- val barney = (1+2, 3.0*4.0, "brown");
val barney = (3,12.0,"brown") : int * real * string
- val point1 = ("red", (300,200));
val point1 = ("red",(300,200)) : string * (int * int)
- #2 barney;
val it = 12.0 : real
- #1 (#2 point1);
val it = 300 : int

Use parentheses to form tuples

Tuples can contain other tuples

A tuple is like a record with no field names

To get i'th element of a tuple x, use #i x
- `(1, 2);`
val it = `(1,2) : int * int`
- `(1);`
val it = 1 : int
- `#1 (1, 2);`
val it = 1 : int
- `#1 (1);`

Error: operator and operand don't agree [literal]
operator domain: `{1:'Y; 'Z}`
operand: int
in expression:

(fn `{1=1,...} => 1) 1`

There is no such thing as a tuple of one
Tuple Type Constructor

ML gives the type of a tuple using * as a type constructor.

For example, int * bool is the type of pairs (x,y) where x is an int and y is a bool.

Note that parentheses have structural significance here: int * (int * bool) is not the same as (int * int) * bool, and neither is the same as int * int * bool.
- [1,2,3];
val it = [1,2,3] : int list
- [1.0,2.0];
val it = [1.0,2.0] : real list
- [true];
val it = [true] : bool list
- [(1,2),(1,3)];
val it = [(1,2),(1,3)] : (int * int) list
- [[1,2,3],[1,2]];
val it = [[1,2,3],[1,2]] : int list list

Use square brackets to make lists

Unlike tuples, all elements of a list must be the same type
Empty list is [] or nil

Note the odd type of the empty list: 'a list

Any variable name beginning with an apostrophe is a type variable; it stands for a type that is unknown

'a list means a list of elements, type unknown
The **null** test

- `null [];
  val it = true : bool
- `null [1,2,3];
  val it = false : bool`

- **null** tests whether a given list is empty
- You could also use an equality test, as in `x = []`
- However, **null x** is preferred; we will see why in a moment
List Type Constructor

- ML gives the type of lists using `list` as a type constructor.
- For example, `int list` is the type of lists of things, each of which is of type `int`.
- A list is not a tuple.
- [1,2,3]@[4,5,6];
val it = [1,2,3,4,5,6] : int list

The @ operator concatenates lists

Operands are two lists of the same type

Note: 1@[2,3,4] is wrong: either use [1]@[2,3,4] or 1::[2,3,4]
- val x = #"c"::[];
val x = ["c"] : char list
- val y = #"b"::x;
val y = ["b","c"] : char list
- val z = #"a"::y;
val z = ["a","b","c"] : char list

List-builder (cons) operator is ::

It takes an element of any type, and a list of elements of that same type, and produces a new list by putting the new element on the front of the old list
- `val z = 1::2::3::[];`
  `val z = [1,2,3] : int list`
- `hd z;`
  `val it = 1 : int`
- `tl z;`
  `val it = [2,3] : int list`
- `tl(tl z);`
  `val it = [3] : int list`
- `tl(tl(tl z));`
  `val it = [] : int list`

The `::` operator is right-associative.

The `hd` function gets the head of a list: the first element.

The `tl` function gets the tail of a list: the whole list after the first element.
- explode "hello";
val it = ["h", "e", "l", "l", "o"] : char list
- implode ["h", "i"]; 
val it = "hi" : string

The **explode** function converts a string to a list of characters, and the **implode** function does the reverse
Practice

What are the values of these expressions?

\[
\begin{align*}
\#2(3,4,5) \\
hd(1::2::nil) \\
hd(tl(#2([1,2],[3,4]))) \\
\end{align*}
\]

What is wrong with the following expressions?

\[
\begin{align*}
1@2 \\
hd(tl(tl[1,2])) \\
[1]::[2,3] \\
\end{align*}
\]
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Define a new function and bind it to a variable using `fun`

Here `fn` means a function, the thing itself, considered separately from any name we've given it. The value of `firstChar` is a function whose type is `string -> char`

It is rarely necessary to declare any types, since ML infers them. ML can tell that `s` must be a `string`, since we used `explode` on it, and it can tell that the function result must be a `char`, since it is the `hd` of a `char list`
Function Definition Syntax

\[
<\text{fun-def}> ::= \begin{array}{l}
\text{fun} \ <\text{function-name}> <\text{parameter}> = <\text{expression}> ;
\end{array}
\]

- \(<\text{function-name}>\) can be any legal ML name
- The simplest \(<\text{parameter}>\) is just a single variable name: the formal parameter of the function
- The \(<\text{expression}>\) is any ML expression; its value is the value the function returns
- This is a subset of ML function definition syntax; more in Chapter 7
Function Type Constructor

- ML gives the type of functions using \(-\to\) as a type constructor.

- For example, \texttt{int} \(-\to\) \texttt{real} is the type of a function that takes an \texttt{int} parameter (the \textit{domain type}) and produces a \texttt{real} result (the \textit{range type}).
All ML functions take exactly one parameter.

To pass more than one thing, you can pass a tuple.
fun fact n =
  if n = 0 then 1
  else n * fact(n-1);
val fact = fn : int -> int
  fact 5;
val it = 120 : int

Recursive factorial function
fun listsum x =  
  if null x then 0  
  else hd x + listsum(tl x);  
val listsum = fn : int list -> int  
listsum [1,2,3,4,5];  
val it = 15 : int

Recursive function to add up the elements of an int list

A common pattern: base case for null x, recursive call on tl x
fun length x = if null x then 0 = else 1 + length (tl x);
val length = fn : 'a list -> int
- length [true,false,true];
val it = 3 : int
- length [4.0,3.0,2.0,1.0];
val it = 4 : int

Recursive function to compute the length of a list

(This is predefined in ML, so you don’t need this definition.)

Note type: this works on any type of list. It is polymorphic.
fun badlength x = 
  if x=[] then 0 
  else 1 + badlength (tl x); 

val badlength = fn : 'a list -> int 

badlength [true,false,true];

val it = 3 : int

badlength [4.0,3.0,2.0,1.0];

Error: operator and operand don't agree 
[equality type required]

Same as previous example, but with \texttt{x=[]} instead of \texttt{null x}

Type variables that begin with two apostrophes, like \texttt{'a}, are restricted to equality types. ML insists on that restriction because we compared \texttt{x} for equality with the empty list.

That's why you should use \texttt{null x} instead of \texttt{x=[]}. It avoids unnecessary type restrictions.
```
- fun reverse L = 
=   if null L then nil
=   else reverse(tl L) @ [hd L];
val reverse = fn : 'a list -> 'a list
- reverse [1,2,3];
val it = [3,2,1] : int list
```

Recursive function to reverse a list

That pattern again
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ML Types So Far

- So far we have the primitive ML types `int`, `real`, `bool`, `char`, and `string`

- Also we have three type constructors:
  - Tuple types using `*`
  - List types using `list`
  - Function types using `->`
Combining Constructors

- When combining constructors, `list` has higher precedence than `*`, and `->` has lower precedence
  - `int * bool list` same as `int * (bool list)`
  - `int * bool list -> real` same as `(int * (bool list)) -> real`

- Use parentheses as necessary for clarity
fun prod(a,b) = a * b;
val prod = fn : int * int -> int

Why int, rather than real?

ML's default type for * (and +, and −) is
int * int -> int

You can give an explicit type annotation to get real instead…
- fun prod(a:real,b:real):real = a*b;
val prod = fn : real * real -> real

*Type annotation* is a colon followed by a type

Can appear after any variable or expression

These are all equivalent:

fun prod(a,b):real = a * b;
fun prod(a:real,b) = a * b;
fun prod(a,b:real) = a * b;
fun prod(a,b) = (a:real) * b;
fun prod(a,b) = a * b:real;
fun prod(a,b) = (a*b):real;
fun prod((a,b):real * real) = a*b;
Summary

- Constants and primitive types: `int`, `real`, `bool`, `char`, `string`
- Operators: `~`, `+`, `−`, `*`, `div`, `mod`, `/`, `^`, `::`, `@`, `<`, `>`, `<=`, `>=`, `=`, `<>`, `not`, `andalso`, `orelse`
- Conditional expression
- Function application
- Predefined functions: `real`, `floor`, `ceil`, `round`, `trunc`, `ord`, `chr`, `str`, `hd`, `tl`, `explode`, `implode`, `and`, `null`
Summary, Continued

- Defining new variable bindings using `val`
- Tuple construction using `(x, y, ..., z)` and selection using `#n`
- List construction using `[x, y, ..., z]`
- Type constructors `*`, `list`, and `->`
- Function declaration using `fun`, including tuple arguments, polymorphic functions, and recursion
- Type annotations