Five different things

1. Syntax: How do you write language constructs?
3. Idioms: What are typical patterns for using language features to express your computation?
4. Libraries: What facilities does the language (or a well-known project) provide “standard”? (E.g., file access, data structures)
5. Tools: What do language implementations provide to make your job easier? (E.g., REPL, debugger, code formatter, …)

Not actually part of the language

These are 5 separate issues

In practice, all are essential for good programmers
Many people confuse them, but shouldn’t

Our Focus

This course focuses on semantics and idioms

• Syntax is usually uninteresting
  – A fact to learn, like “The American Civil War ended in 1865”
  – People obsess over subjective preferences

• Libraries and tools crucial, but often learn new ones “on the job”
  – We are learning semantics and how to use that knowledge to understand all software and employ appropriate idioms
  – By avoiding most libraries/tools, our languages may look “silly” but so would any language used this way

How to build bigger types

• Already know:
  – Have various base types like int bool unit char
  – Ways to build (nested) compound types: tuples, lists, options

• Coming soon: more ways to build compound types

• First: 3 most important type building blocks in any language
  – “Each of”: A t value contains values of each of t1 t2 … tn
  – “One of”: A t value contains values of one of t1 t2 … tn
  – “Self reference”: A t value can refer to other t values

Remarkable: A lot of data can be described with just these building blocks
Note: These are not the common names for these concepts

Examples

• Tuples build each-of types
  – int * bool contains an int and a bool

• Options build one-of types
  – int option contains an int or it contains no data

• Lists use all three building blocks
  – int list contains an int and another int list or it contains no data

• And of course we can nest compound types
  – ((int * int) option * (int list list)) option

Rest of this Lecture

• Another way to build each-of types in ML
  – Records: have named fields
  – Connection to tuples and idea of syntactic sugar

• A way to build and use our own one-of types in ML
  – For example, a type that contains an int or a string
  – Will lead to pattern-matching, one of ML’s coolest and strangest-to-Java-programmers features

• Later in course: How OOP does one-of types
  – Key contrast with procedural and functional programming
Records

Record values have fields (any name) holding values
\[ \{f_1 = v_1, \ldots, f_n = v_n\} \]

Record types have fields (and name) holding types
\[ \{f_1 : t_1, \ldots, f_n : t_n\} \]

The order of fields in a record value or type never matters
– REPL alphabetizes fields just for consistency

Building records:
\[
\{f_1 \ldots f_n = e_1 \ldots e_n\}
\]

Accessing components:
\[
\#\text{myfieldname e}
\]

(Evaluation rules and type-checking as expected)

Example

\[
\{\text{name = "Matai", id = 4 - 3}\}
\]

Evaluates to
\[
\{\text{id = 1, name = "Matai"}\}
\]

And has type
\[
\{\text{id : int, name : string}\}
\]

If some expression such as a variable \(x\) has this type, then get fields with:
\[
#\text{id x} #\text{name x}
\]

Note we did not have to declare any record types
– The same program could also make a
\[
\{\text{id=true,ego=false}\}
\]

of type \(\{\text{id:bool,ego:bool}\}\)

By name vs. by position

• Little difference between \((4, 7, 9)\) and \(\{f_1=4, f_2=7, f_3=9\}\)
  – Tuples a little shorter
  – Records a little easier to remember ‘what is where’
  – Generally a matter of taste, but for many (6? 8? 12?) fields, a record is usually a better choice

• A common decision for a construct’s syntax is whether to refer to things by position (as in tuples) or by some (field) name (as with records)
  – A common hybrid is like with Java method arguments (and ML functions as used so far):
    • Caller uses position
    • Callee uses variables
    • Could totally do it differently; some languages have

The truth about tuples

Previous lecture gave tuples syntax, type-checking rules, and evaluation rules
But we could have done this instead:
  – Tuple syntax is just a different way to write certain records
    – \((e_1, \ldots, e_n)\) is another way of writing \(\{1=e_1, \ldots, n=e_n\}\)
    – \(\times_1 \cdots \times_n\) is another way of writing \(\{1: \times_1, \ldots, n: \times_n\}\)
  – In other words, records with field names 1, 2, ...

In fact, this is how ML actually defines tuples
  – Other than special syntax in programs and printing, they don’t exist
  – You really can write \(\{1=4, 2=7, 3=9\}\), but it’s bad style

Syntactic sugar

“Tuples are just syntactic sugar for records with fields named 1, 2, … n”

• Syntactic: Can describe the semantics entirely by the corresponding record syntax
• Sugar: They make the language sweeter 😊

Will see many more examples of syntactic sugar
  – They simplify understanding the language
  – They simplify implementing the language

Why? Because there are fewer semantics to worry about even though we have the syntactic convenience of tuples

Another example we saw: andalso and orelse vs. if then else

Datatype bindings

A ‘strange’ (?) and totally awesome (!) way to make one-of types:
– A datatype binding

\[
\text{datatype mytype = TwoInts of int * int} \\
| \text{Str of string} \\
| \text{Pizza}
\]

• Adds a new type \text{mytype} to the environment
• Adds constructors to the environment: \text{TwoInts}, \text{Str}, and \text{Pizza}
• A constructor is (among other things), a function that makes values of the new type (or is a value of the new type):
  – \text{TwoInts} : int * int \to \text{mytype}
  – \text{Str} : string \to \text{mytype}
  – \text{Pizza} : \text{mytype}
The values we make

```ml
datatype mytype = TwoInts of int * int
  | Str of string
  | Pizza
```

- Any value of type `mytype` is made from one of the constructors
- The value contains:
  - A "tag" for "which constructor" (e.g., `TwoInts`)
  - The corresponding data (e.g., `(7, 9)`)
- Examples:
  - `TwoInts(3+4,5+4)` evaluates to `TwoInts(7,9)`
  - `Str(if true then "hi" else "bye")` evaluates to `Str("hi")`
  - `Pizza` is a value

Using them

So we know how to build datatype values; need to access them

There are two aspects to accessing a datatype value
1. Check what variant it is (what constructor made it)
2. Extract the data (if that variant has any)

Notice how our other one-of types used functions for this:
- `null` and `isSome` check variants
- `hd`, `tl`, and `valOf` extract data (raise exception on wrong variant)

ML could have done the same for datatype bindings
- For example, functions like "isStr" and "getStrData"
- Instead it did something better

Case

ML combines the two aspects of accessing a one-of value with a case expression and pattern-matching
- Pattern-matching much more general/powerful (Lecture 5)
- Example:
  ```ml
  fun f x = (* f has type mytype -> int *)
  case x of
    Pizza => 3
    | TwoInts(i1,i2) => i1+i2
    | Str s => String.size s
  ```
- A multi-branch conditional to pick branch based on variant
- Extracts data and binds to variables local to that branch
- Type-checking: all branches must have same type
- Evaluation: evaluate between `case ... of` and the right branch

Patterns

In general the syntax is:
```ml
case e0 of
  p1 => e1
  | p2 => e2
  ... | pn => en
```

- For today, each pattern is a constructor name followed by the right number of variables (i.e., `C x y` or `C(x,y)` or ...)
- Syntactically most patterns (all today) look like expressions
- But patterns are not expressions
  - We do not evaluate them
  - We see if the result of `e0` matches them

Why this way is better

0. You can use pattern-matching to write your own testing and data-extractions functions if you must
   - But do not do that on your homework
1. You cannot forget a case (inexhaustive pattern-match warning)
2. You cannot duplicate a case (a type-checking error)
3. You will not forget to test the variant correctly and get an exception (like `hd []`)
4. Pattern-matching can be generalized and made more powerful, leading to elegant and concise code