Five different things

1. **Syntax:** How do you write language constructs?
2. **Semantics:** What do programs mean? (Evaluation rules)
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 = e_1, \ldots, f_n = e_n\}

Accessing components:
#myfieldname e

(Evaluation rules and type-checking as expected)
Example

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

Evaluates to

\{id = 1, name = "Matai"\}

And has type

\{id : int, name : string\}

If some expression such as a variable \(x\) has this type, then get fields with:

\#id \ x \quad \#name \ x

Note we did not have to declare any record types

- The same program could also make a

\{id=true, ego=false\} of type \{id:bool, ego:bool\}
By name vs. by position

• Little difference between \((4, 7, 9)\) and \{"f=4, g=7, h=9\}\n  – 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 \(\{1=e_1, \ldots, n=e_n\}\)
- \(t_1 \ast \ldots \ast t_n\) is another way of writing \(\{1:t_1, \ldots, n:t_n\}\)
- 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

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

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

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))
 Example:
  − 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:

```plaintext
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:

```
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., \( \text{C} \) or \( \text{C} \ x \) or \( \text{C} \ (\text{x}, \text{y}) \) 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