Advanced Topics in OCaml

Concepts of Programming Languages
Lecture 11

CAS CS 320

Recap
HOFs Beyond Lists

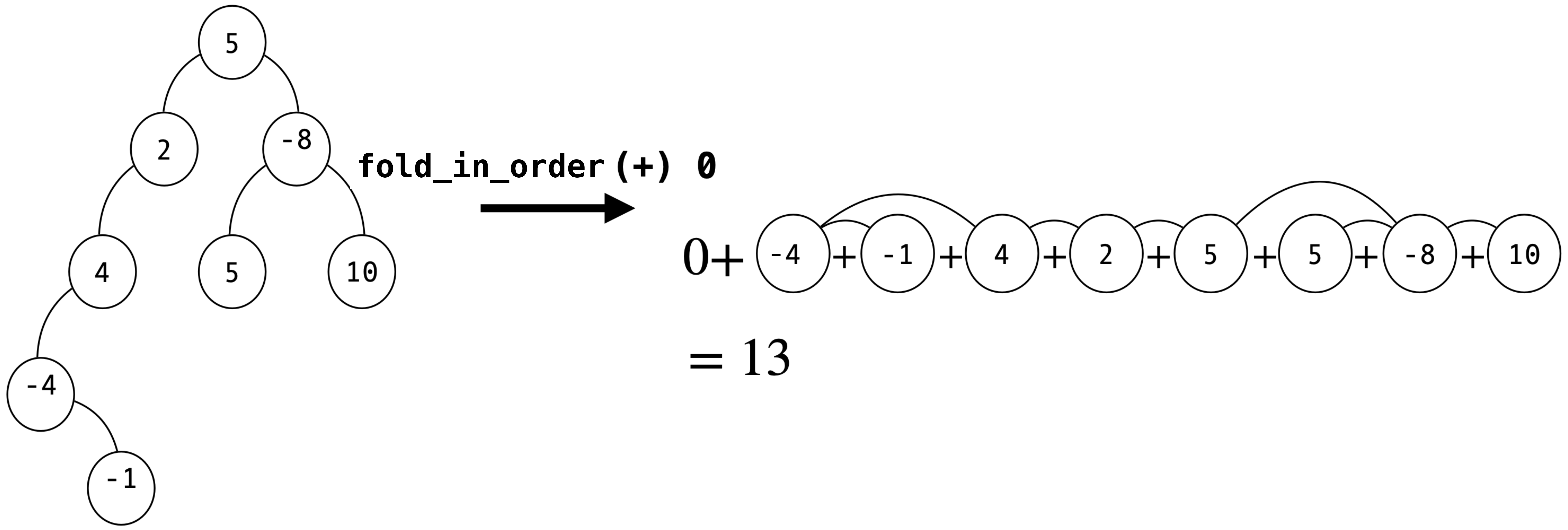
Trees

```
type 'a tree =
  | Leaf
  | Node of 'a * 'a tree * 'a tree

let map f t =
  let rec go t =
    match t with
    | Leaf -> Leaf
    | Node (x, l, r) -> Node (f x, go l, go r)
  in go t
```

Mapping over a tree maintains the structure but recursively updates values with **f**

Fold over Trees (The Picture)



Practice Problem

Implement the function

val fold_in_order :
(‘a -> ‘b -> ‘a) -> ‘a -> ‘b tree -> ‘a

so that **fold_in_order op base t n** *does* an **in-order** fold for trees

It is equivalent to "flattening" the tree into a list, and then folding that list

(This is different from what is given in the textbook)

Outline

- » Practice **typing derivation** with HOFs
- » Give a short tutorial on **ounit** a unit test framework for OCaml
- » A quick look at **modules** in OCaml (another very cool feature)

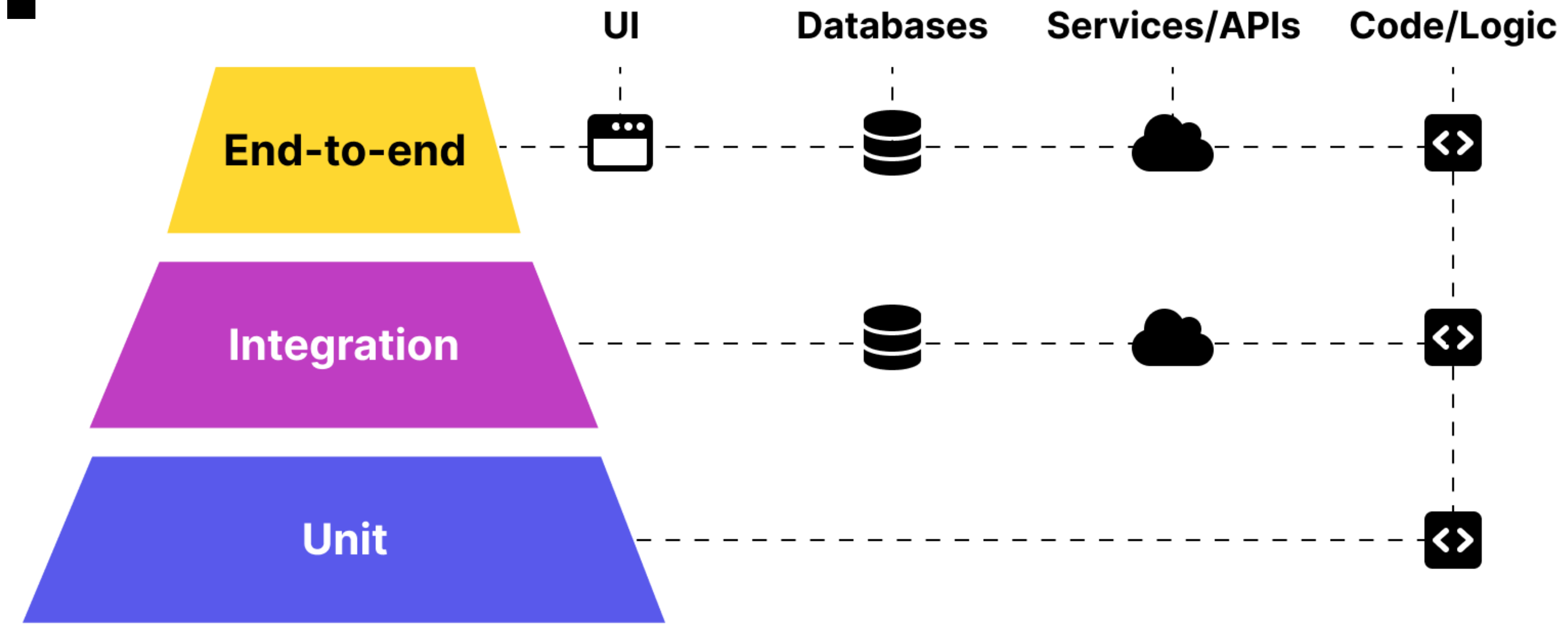
Typing Derivation for fold_right

$$\Gamma = \{\text{foldr} : (\alpha \to \beta \to \beta) \to \alpha \text{ list} \to \beta \to \beta,$$
$$\text{op} : \alpha \to \beta \to \beta,$$
$$l : \alpha \text{ list},$$
$$\text{base} : \beta\}$$
$$\Gamma' = \Gamma, x : \alpha, xs : \alpha \text{ list}$$

$$\dfrac{\dfrac{\text{VAR}}{\Gamma \vdash l : \alpha \text{ list}} \quad \dfrac{\text{VAR}}{\Gamma \vdash \text{base} : \beta} \quad \dfrac{\dfrac{\text{VAR}}{\Gamma' \vdash \text{op} : \alpha \to \beta \to \beta} \quad \dfrac{\text{VAR}}{\Gamma' \vdash x : \alpha} \quad \dfrac{\dfrac{}{\Gamma' \vdash \text{foldr} : \overset{(\alpha\to\beta\to\beta)}{\to \alpha \text{ list} \to \beta \to \beta}} \quad \dfrac{}{\Gamma' \vdash \text{op} : \alpha \to \beta \to \beta} \quad \dfrac{}{\Gamma' \vdash xs : \alpha \text{ list}} \quad \dfrac{}{\Gamma' \vdash \text{base} : \beta}}{\Gamma' \vdash \text{foldr op } \overset{xs}{\cancel{\text{base}}} \ \overset{\text{base}}{\cancel{xs}} : \beta}}{\Gamma, x : \alpha, xs : \alpha \text{ list} \vdash \text{op } x \ (\text{foldr op } \overset{xs}{\cancel{\text{base}}} \ \overset{\text{base}}{\cancel{xs}}) : \beta}}{\{\text{foldr} : (\alpha \to \beta \to \beta) \to \alpha \text{ list} \to \beta, \text{op} : \alpha \to \beta \to \beta, \text{base} : \beta, l : \alpha \text{ list}\} \vdash \\ \text{match } l \text{ with } \mid [\,] \to \text{base} \mid x :: xs \to \text{op } x \ (\text{foldr op } \overset{xs}{\cancel{\text{base}}} \ \overset{\text{base}}{\cancel{xs}}) : \beta}$$

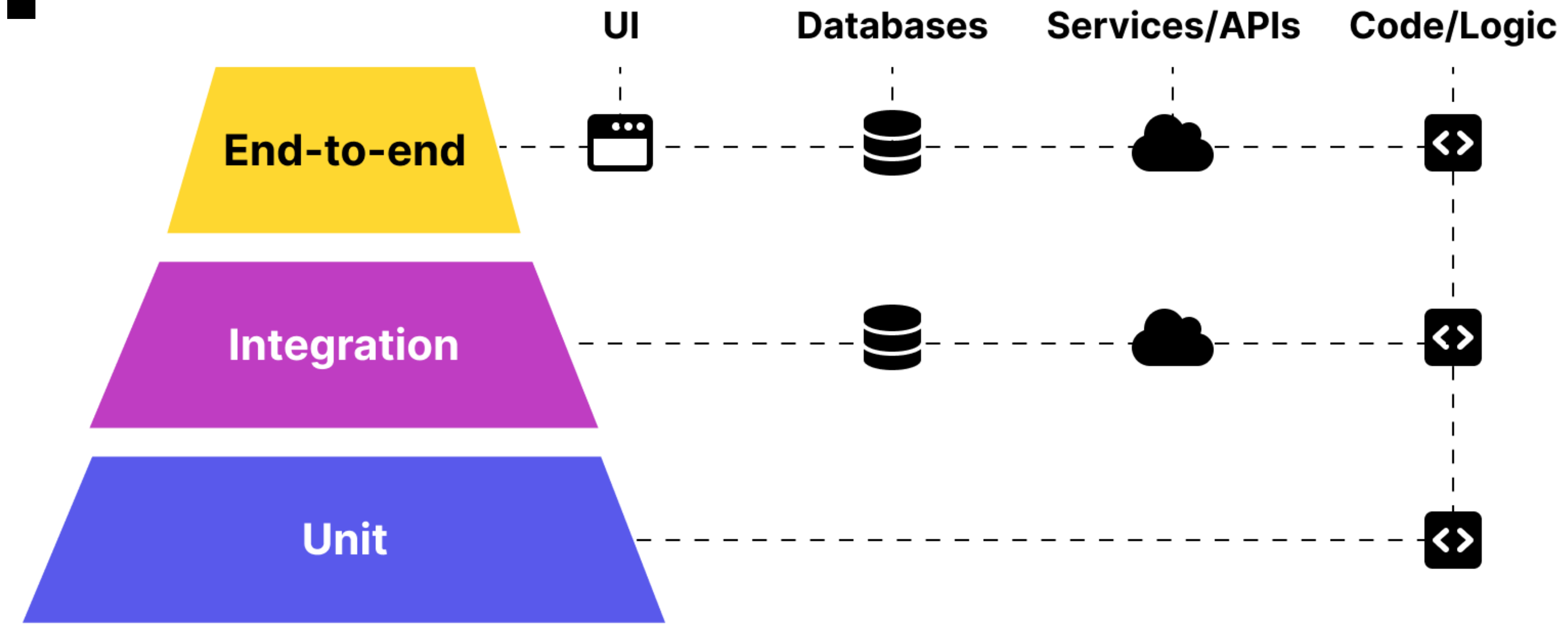
Unit Testing

High Level



https://katalon.com/resources-center/blog/unit-testing-vs-functional-testing

High Level



`unit tests` `verify our code on a collection of hand-chosen inputs`

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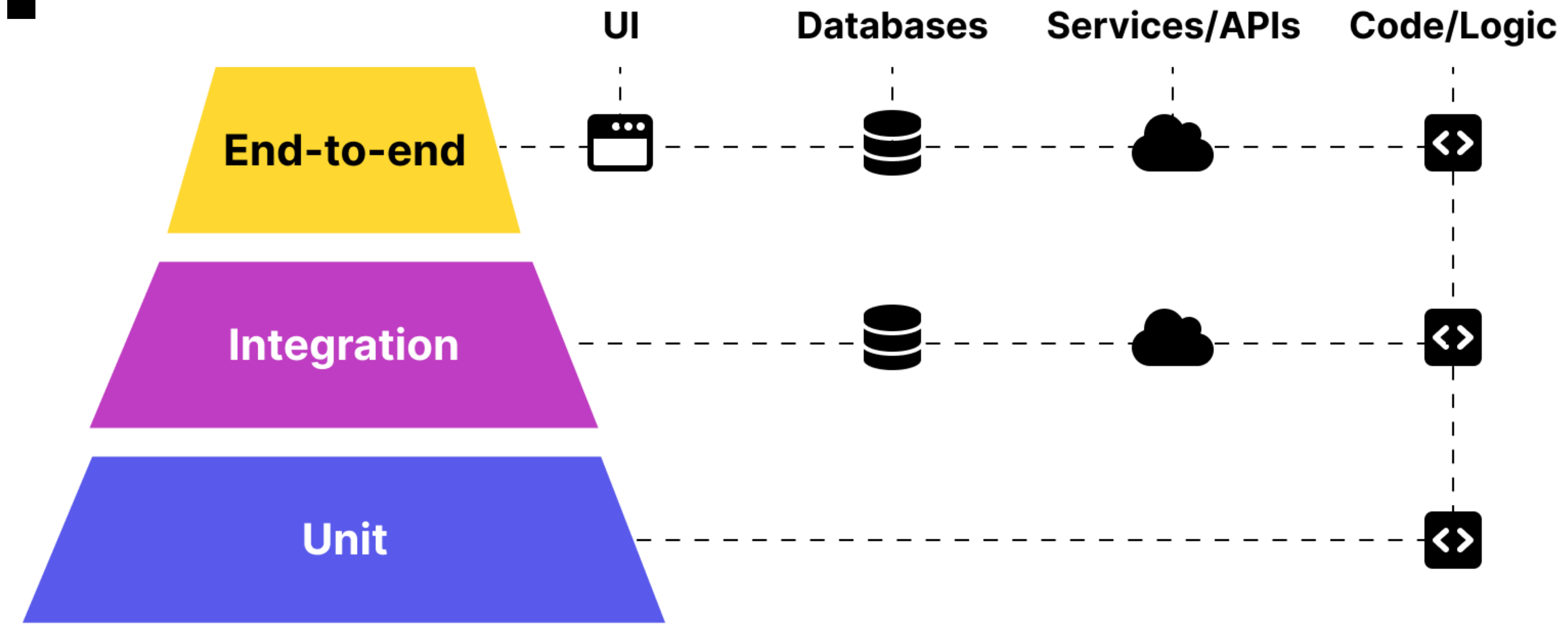

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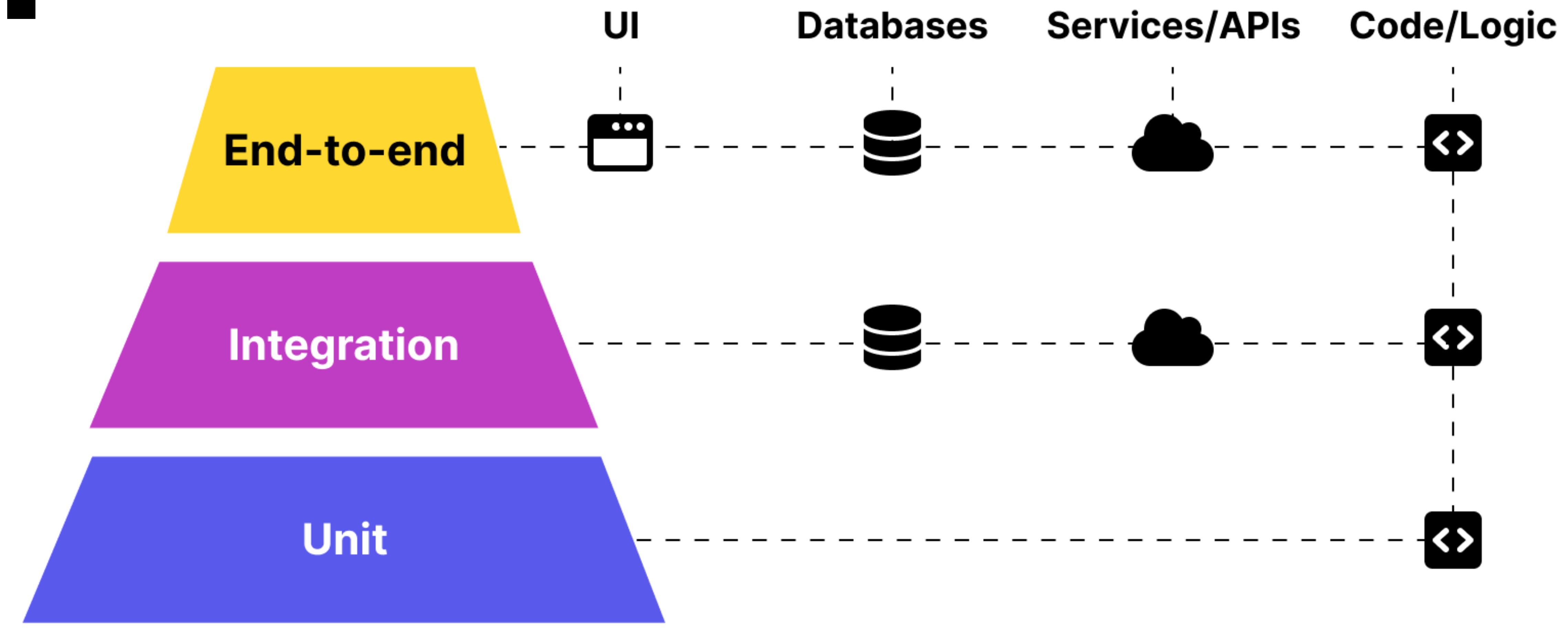

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It's distinct from **fuzz testing** or **randomized testing** in which random inputs are checked

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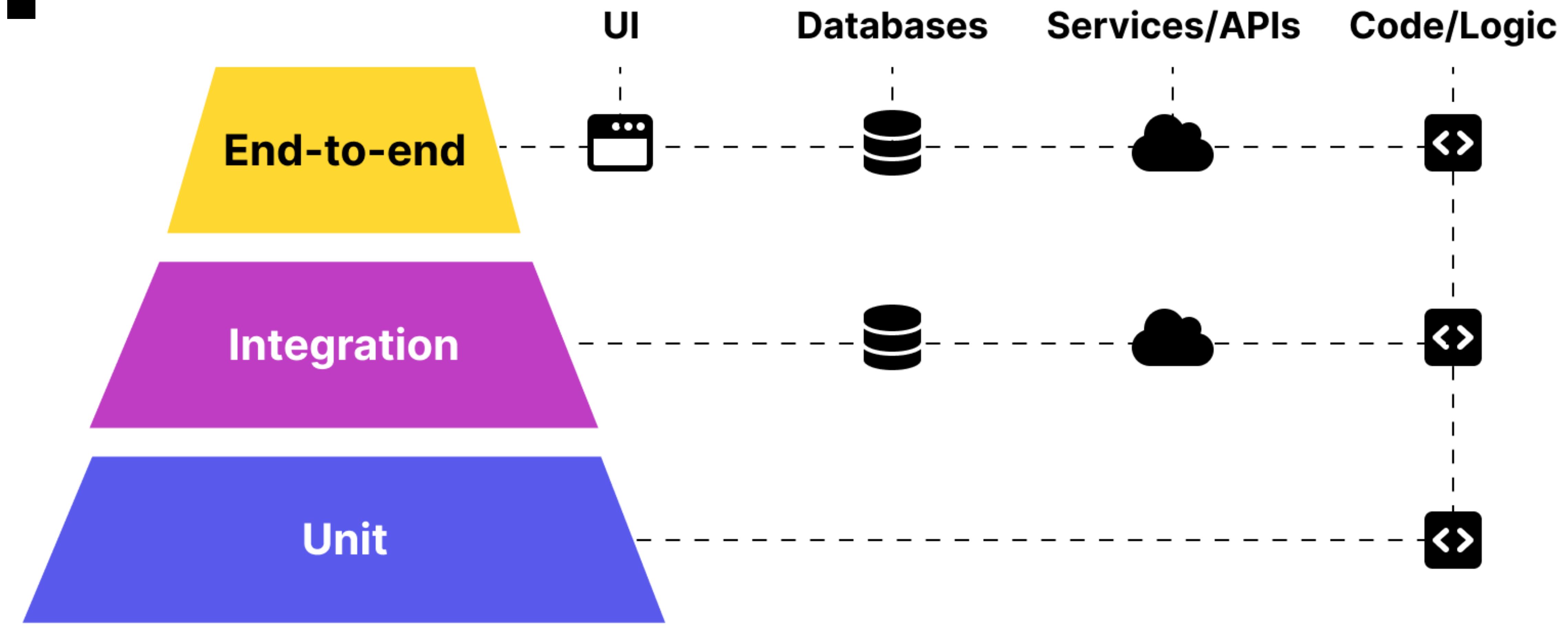

unit tests verify our code on a collection of hand-chosen inputs

It's the easiest kind of testing and the "first line of defense"

It's distinct from **fuzz testing** or **randomized testing** in which random inputs are checked

It's also distinct from an area of CS called ***software verification***, which uses computers to *prove* that our programs are correct

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Words of Warning

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There are many unit testing frameworks out there. We'll use **OUnit2** which is very good, but by no means the most featured

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We are already using OUnit2 for testing assignments and projects, so you need to know how to read and write tests in this framework

Set-up

```
(test
 (name test_PROG)
 (libraries ounit2))
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*We will always do this for you in your projects, but it's good to know how to do for our own projects**

**I know no one is using OCaml for personal projects, but I can hope...*

Important Functions

`(>::)`	creates a labelled test
`(>:::)`	creates a labelled test suite
`assert_equal`	compares two values in a unit test
`assert_raises`	checks that an expression raises the right exception
`run_test_tt_main`	runs a test suite

Example Test Suite

```
let tests = "test suite for sum" >::: [
  "empty" >:: (fun _ -> assert_equal 0 (sum []));
  "singleton" >:: (fun _ -> assert_equal 1 (sum [1]));
  "two_elements" >:: (fun _ -> assert_equal 3 (sum [1; 2]));
]

let _ = run_test_tt_main tests
```

test/test_<PROG>.ml

Each test is given a name, the suite is given a name as well

Each test is wrapped in an anonymous function *(why?)*

Unit Testing with OUnit

Benefits:

- » Tests can be run in parallel
- » Failed tests don't block!

Downsides:

- » More code to read and write
- » Output is a bit difficult to read...

Modules

High Level

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Modules attempt to capture multiple programming patterns with a single construct:

High Level

```
module Interpreter = struct
  let type_check = ...
  let eval = ...
end
```

(1)

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1. **Namespaces:** a way of separate coding into logical units

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2. **Abstraction/Encapsulation:** a way of abstracting away implementation details and organizing core functionality (e.g., of a data structure)

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module Interpreter = struct
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```
module Stack = struct
  type 'a t = 'a list
  let push x s = x :: s
  let pop s = match s with
    | [] -> None
    | x :: xs -> Some (x, xs)
end
```

(2)

High Level

Modules attempt to capture multiple programming patterns with a single construct:

1. **Namespaces:** a way of separate coding into logical units

2. **Abstraction/Encapsulation:** a way of abstracting away implementation details and organizing core functionality (e.g., of a data structure)

3. **Code Reuse:** a way to write general code that can be instantiated in different settings

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```

(2)

```
module VarSet = Set.Make(String)
module Context = Map.Make(String)
```

(3)

Structures

```
module Foo = struct
  let double (x : int) : int = x + x

  let is_whitespace (c : char) =
    List.mem c [' '; '\n'; '\t'; '\r']

  let version = 225

end
```

Structures

A **structure** is a collection of definitions used to define a **module**

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Structures are *not* first-class values, we *must* use the **module** keyword when defining a structure

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Structures

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We can put anything in a structure that we can put in a standalone .ml file (and vice versa, more on this later)

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Signatures

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module type FOO =
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Signatures

A **signature** is a collection of *specifications*

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A module **implements** a signature if it's defined as a structure which has the values required by the signature

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General Syntax

```
module ModuleName : SIG_NAME = struct
  val val_name1 : ty
  val val_name2 : ty
  ...
end
```

```
module L = List
module S = String
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Trick: We can write shorthand names for module names we use frequently

Signature Inference and Interface Files

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let helper (x : int) : int = ……
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foo.ml

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val double : int -> int

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```

foo.mli

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In fact, we've been defining modules the entire time: *every file defines a module, whose name is the same as the filename (capitalized)*

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We can make signatures of files explicit with **.mli** files

Working with Modules

```
module type FOO =
  sig
    val double : int -> int
    val is_whitespace : char -> bool
    val version : int
    exception MyException
  end
```

```
let check c =
  if Foo.version > 300 && Foo.is_whitespace c
  then "okay"
  else "not okay"
```

Once a module is defined, we can use values defined therein by **dot notation**

(This should feel somewhat familiar, again, we've been working with modules this whole time)

Opening Modules

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open Foo

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If there are multiple definition of the function, the most recent open prevails

.(...) Syntax

```
let check c =
  Foo.(if version > 300 && is_whitespace c
       then "okay"
       else "not okay")
```

It's possible to parenthesize expressions after the dot notation!

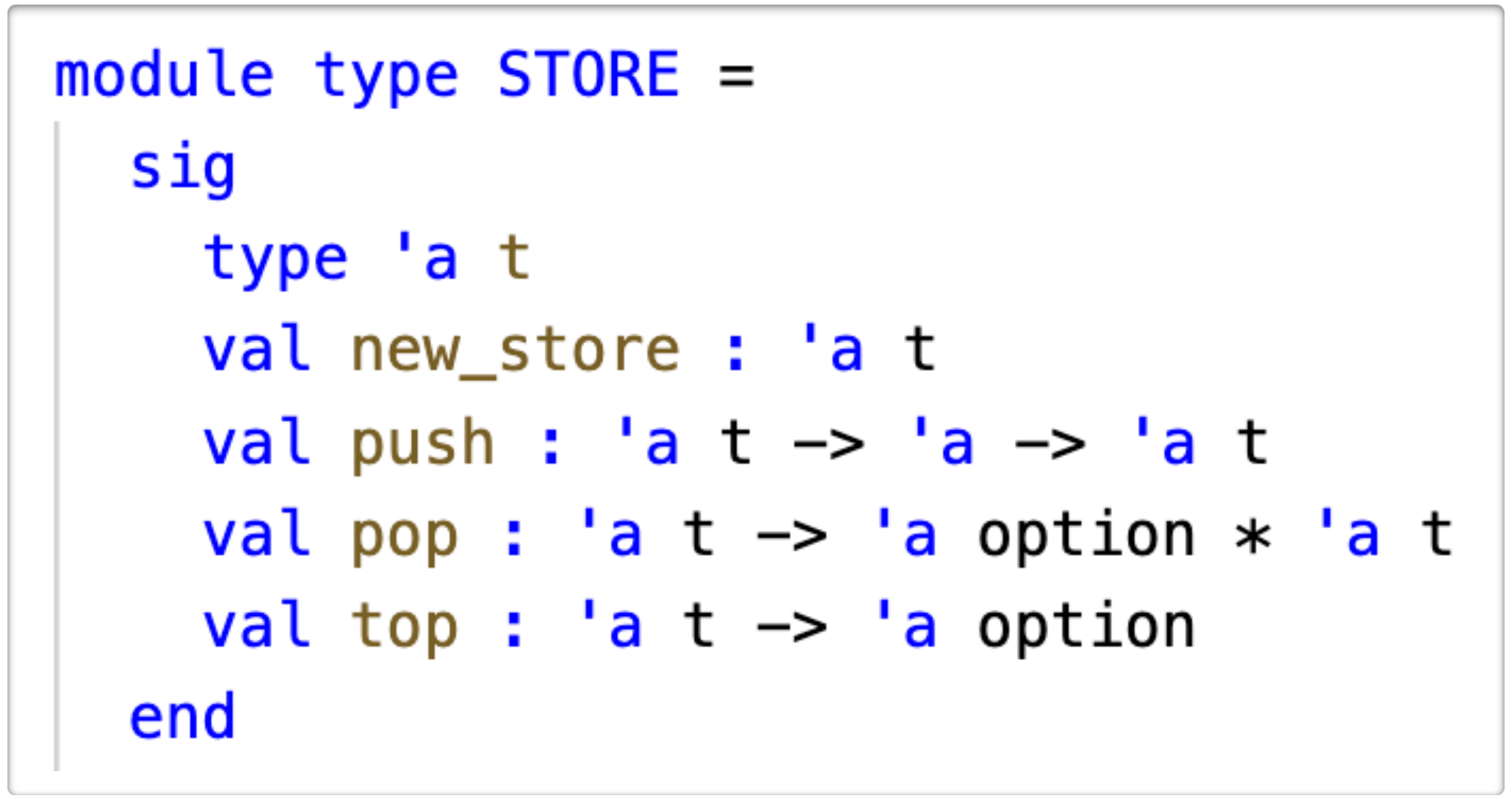
This will evaluate the expression *as if* the module was opened

Functional Data Structures

Interfaces for Functional Data Structures

```
module type STORE =
  sig
    type 'a t
    val new_store : 'a t
    val push : 'a t -> 'a -> 'a t
    val pop : 'a t -> 'a option * 'a t
    val top : 'a t -> 'a option
  end
```

Interfaces for Functional Data Structures



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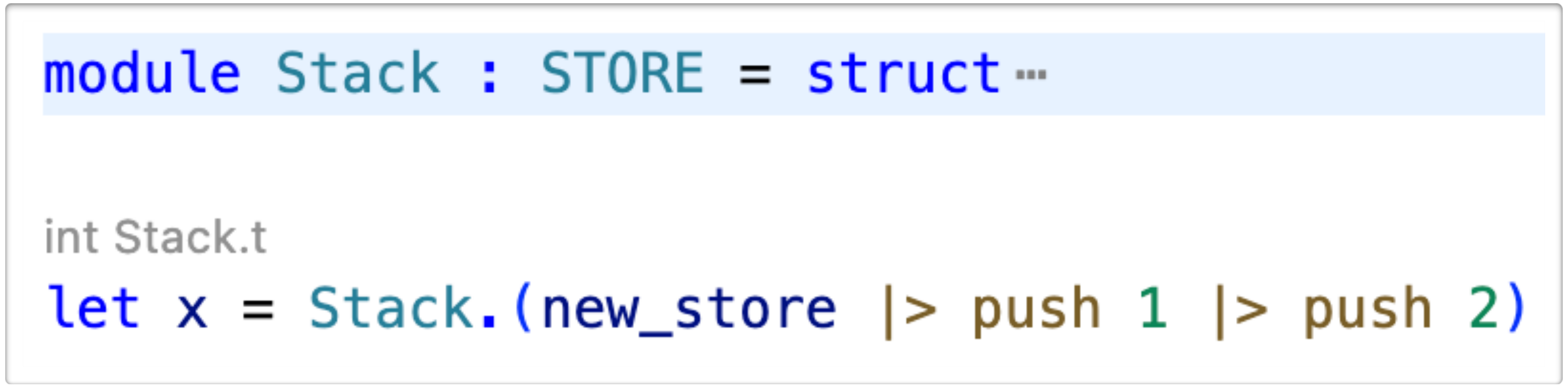
So we can define modules which expose an abstract interface, *without* exposing the data representation

This allows us to "swap out" our store type without affecting any code which depends on the module

This is just good abstraction: don't expose the low-level details unless it's necessary

Abstract Types are Opaque



```
module Stack : STORE = struct…


int Stack.t
let x = Stack.(new_store |> push 1 |> push 2)
```

We can't make *any* assumptions about an abstract type if we don't expose it

Our code must still work if the abstract type changes

Important: This is not OOP

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  end
```

A module is not the same thing as a class, from which objects are instantiated (i.e., there is no **new** constructor)

Functions in structures are not *methods* of a given type of object

(and there's still no mutability)

demo

(modules of stores)

Summary

We can test our code with **unit test** frameworks like OUnit2

We can **encapsulate** data and define **interfaces** for types or data structures all with the same construct

When we write code in a file, we're building a module