TinyML: Tiny functional language interpreter

What you need to know about F#

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Two sides of this video

Introducing the F# language

- Some practical information
- Enough so that you can use it!
- Some important things omitted

Introducing ML-style languages

- Background for our TinyML
- Basic features & principles
- Some weird corner cases!

Getting started with F#

F# and .NET runtime

- .NET SDK for Mac, Linux, Windows
- OSS with .NET Foundation since 2017
- https://dotnet.microsoft.com

F# editors and tools

- Microsoft Visual Studio (Win only)
- JetBrains Rider (Win, Linux, Mac)
- VS Code with Ionide (Win, Linux, Mac)
- https://ionide.io

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F# project types

Script-based development

- Write code in `.fsx` file
- Run using F# Interactive REPL
- Can select & run out-of-order!

Project-based development

- Project `.fsproj` with `.fs` sources
- Standard build and run workflow
- Live reload with Fable and JavaScript

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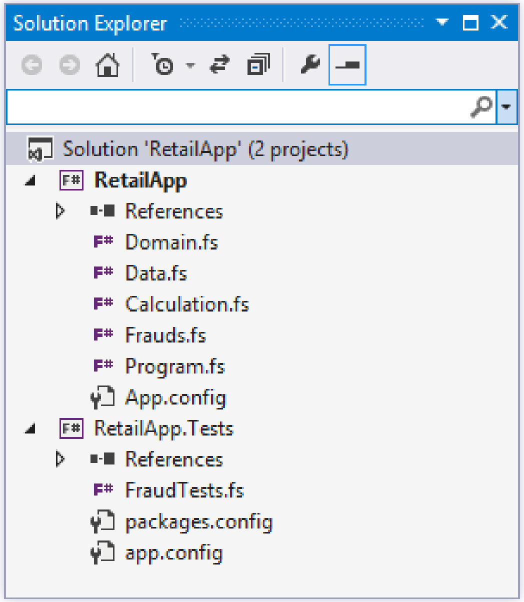
F# project structure

Declaration order matters!

- Helper function and types
- Types defining domain model
- Operations for working with it
- User interface

How to organize F# projects

- Namespaces or modules
- Type declarations
- Functions (inside modules)



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Data type declarations in F#

Tuples and records
Store multiple values of different types

Discriminated unions
Represent one of multiple possible options

Collections, lists and maps
Multiple values of the same type

Recursive declarations
Type that can include values of itself

Type aliases
Shorthand for a type with a long name

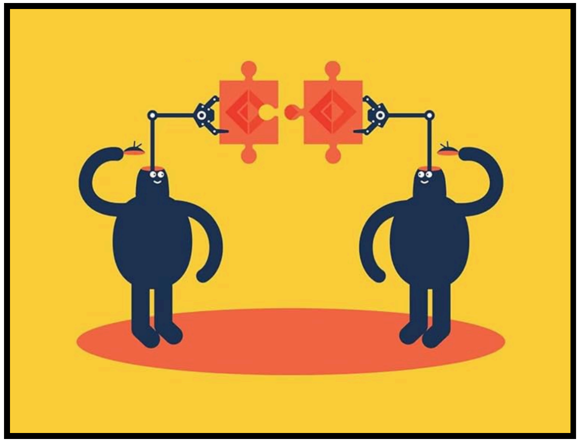
Demo

Simple expression evaluator

Selected advanced features

Lists and maps

- Immutable collections
- Linked (cons) lists with head/tail
- Key-value maps with lookup



Recursion and laziness

- Recursive functions using `let rec`
- Works also for values, but beware!
- `Lazy<T>` to represent lazy values

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Demo

Maps, lazy values, recursion

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Language features and theory

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Language features of TinyML (1/2)

```
(* Functions *)
let f = (fun x -> 10 + x)
f 32

(* Tuples *)
let t = (1, "hi")
fst t
snd t

(* Unions *)
let c1 = Case1(10)
let c2 = Case2(32)
match c1 with
| Case1 n -> n + 32
| Case2 n -> n + 10
```

Functions but only with single argument

Tuples of two element with getters

Unions without tag name with two cases

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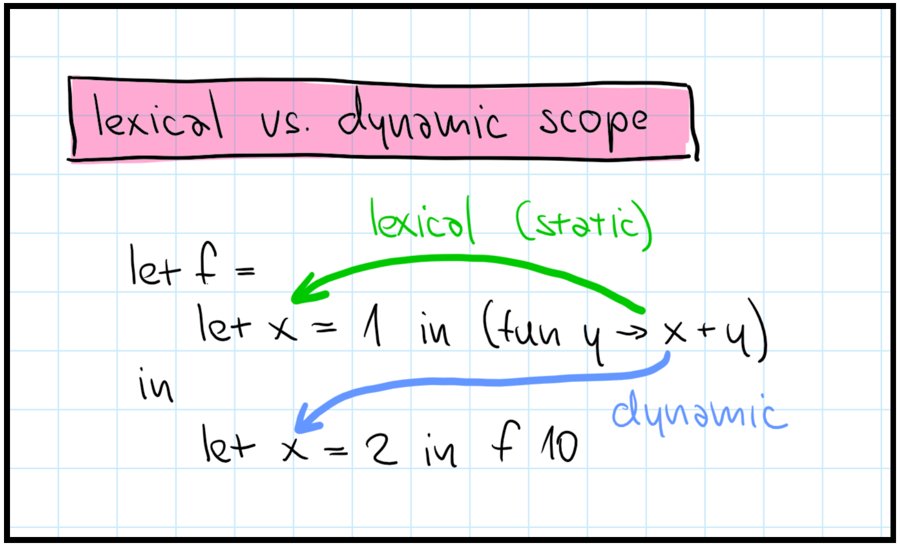
```
(* Let bindings *)
let x = 10 in x * 32

(* Let desugaring *)
(fun x -> x * 32) 10

(* Conditionals *)
if e then 10 else 32

(* Both are expressions *)
1 + (if e then 41 else 1)
1 + (let x = 1 in x + x)

(* Currying *)
let add = fun a -> fun b -> a + b
in (add 10) 32
```

Language features of TinyML (2/2)

`let` is a syntactic sugar

Everything (`if` and `let` too) is an expression

Functions that return functions (currying) if you need multiple parameters



Variable scoping

Lexical

Based on static block structure in code

Function value needs to capture variables (closure)

Dynamic

Based on dynamic evaluation structure

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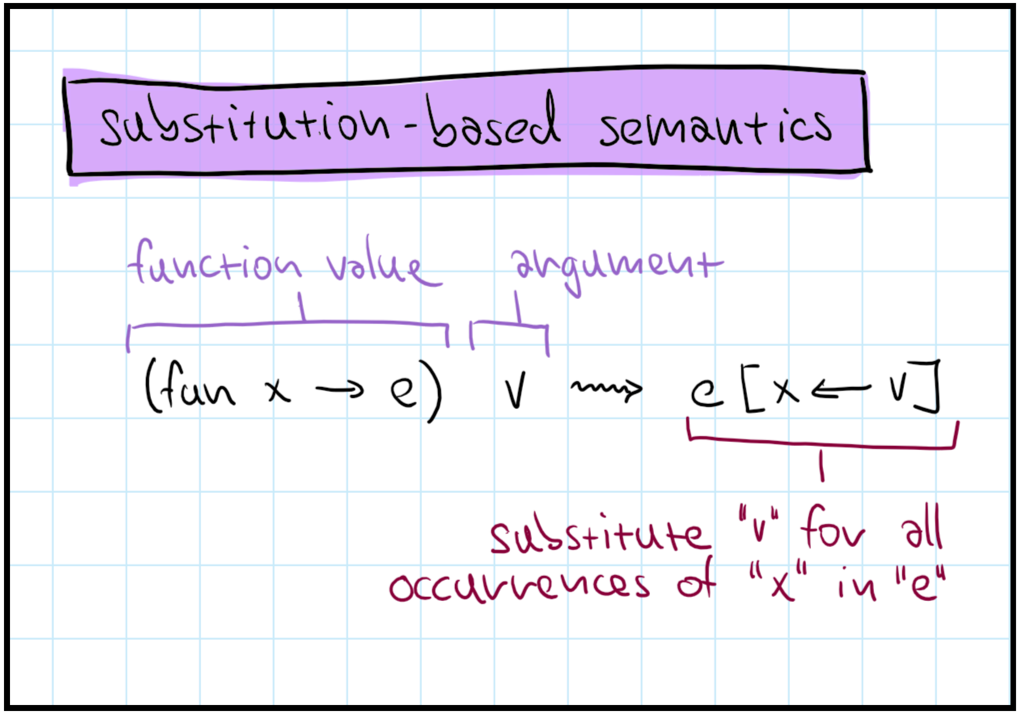


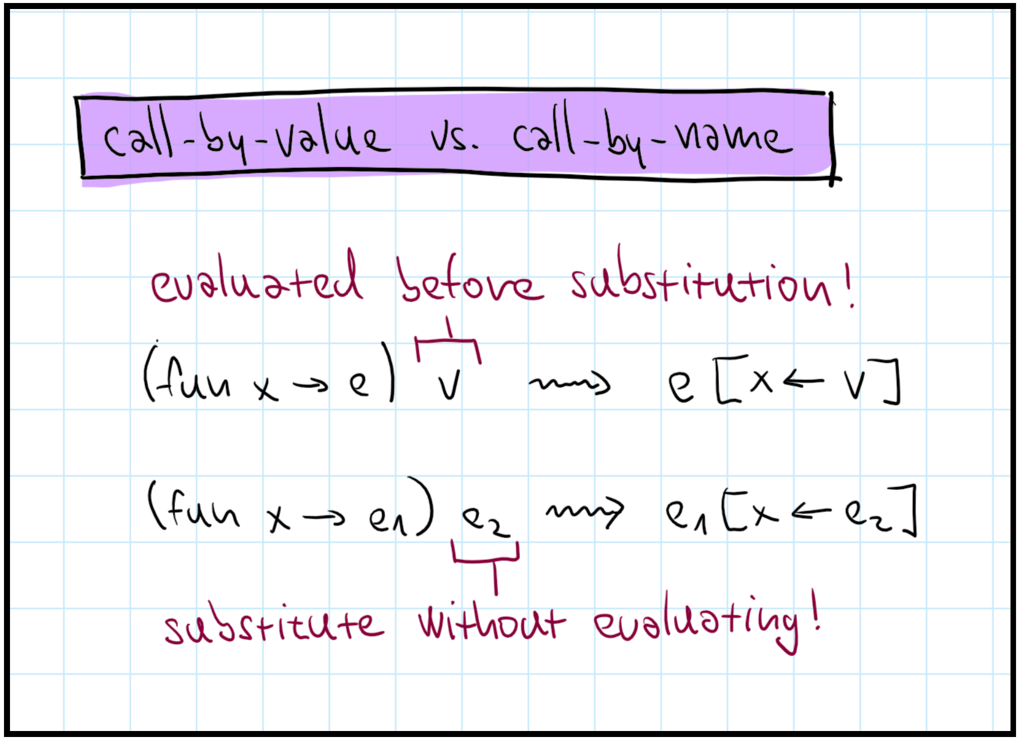
Operational semantics

Formally specify how expression evaluate

Substitution-based

We do not need variable context!

Call-by-name vs. call-by-value



Call-by-value (strict)

Evaluates function arguments first (ML)

Call-by-name (lazy)

Evaluates arguments when needed (Haskell)

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Interpreter and step-by-step guide

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```
type Expression =
   | Constant of int
   | Binary of
       string *
       Expression *
       Expression

val evaluate :
   Expression -> int
```

Basic interpreter structure (0/2)

`Expression` is the source code that user writes

`evaluate` takes expression and returns the result

```
type Value =
  | Number of int

type Expression =
  | Constant of int
  | Binary of
      string *
      Expression *
      Expression

val evaluate :
  Expression -> Value
```

Basic interpreter structure (1/2)

Adding values as the result of evaluation

`Value` is what we get as the result

`evaluate` takes expression and returns value

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Basic interpreter structure (2/2)

```
type Value =
  | Number of int

type Expression =
  | Constant of int
  | Binary of
      string *
      Expression *
      Expression
  | Variable of string

type VariableContext =
  Map<string, Value>

val evaluate :
  Expression -> VariableContext -> Value
```

Adding variables and variable context

Variable can store only values (call-by-value)

`evaluate` takes context

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Demo

Adding values and variables

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Lab overview

TinyML interpreter step-by-step

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TinyML - Basic tasks

1. Simple numerical evaluator as the starting point
   This has already been done for you :-)
2. Add unary operators (-) and conditional
   We only have numbers, so treat `1` as `true`
3. Functions and application
   Tricky! Closure needs to capture variables!
4. Let binding as syntactic sugar
   Evaluate `let` by treating it as apply/lambda
5. Add a simple data type - tuples
   New value, constructor and destructor

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TinyML - Bonus & super tasks

1. Add more data types - unions
   New value, constructor and destructor (match)
2. Add support for recursion
   Needs `Lazy<Value>` in variable context to work
3. Add unit and create a list value
   `Case1(Const(1), Case1(Const(2), Case2(Unit)))`
4. Implement call-by-name semantics
   Change variable context to store expressions
5. Implement evaluation by substitution
   Toy approach, but you learn the semantics

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Lessons learned

Functional language interpreter

- Distinguishing `Value` and `Expression`
- Recursive function with variable scope
- Call-by-value and lexical variable scoping!
- Nice constructor and destructor symmetry

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