Programming Languages and Techniques (CIS1200)

Lecture 2

Value-Oriented Programming

CIS 1200

- If you are joining us today…WELCOME!
- Please check Ed for announcements and reminders
  – If you are already registered for the course, you should be signed up automatically
  – If not, you'll get added automatically when you enroll
- Read the course syllabus and Ch. 1 lecture notes and watch the first lecture, all available on the website
  – www.cis.upenn.edu/~cis1200/

Announcements (1)

- No class on Monday (Labor Day)

- Recitations and OH start next week

Announcements (2)

- Please *read…*
  - Chapter 2 of the lecture notes
  - OCaml style guide on the course website (https://www.seas.upenn.edu/~cis1200/current/ocaml_style)
- Homework 1: OCaml Finger Exercises
  - Instructions are on the Schedule page of course website
  - Code is available on Codio (see Ed)
  - Practice using OCaml to write simple programs
  - Due: *September 10th, at 11:59:59pm* (midnight)
  - Start early!
  - Start with first 4 problems
    (lists will be introduced next time!)

Homework Policies

- Projects will be (mostly) automatically graded with immediate feedback
  - We'll give you some tests with the assignment
  - You'll need to write your own tests
  - Our grading script will apply *additional* tests
  - Your code must compile to get *any* credit
- Multiple submissions *are allowed*
  - First few submissions: no penalty
  - Each submission after the first few will be penalized
- Late Policy
  - Submission up to 24 hours late costs 10 points
  - Submission 24-48 hours late costs 20 points
  - After 48 hours, no submissions allowed
- Style / Test cases
  - TA manual grading of non-testable properties
  - feedback on style from your TAs

Where to ask questions

- Course material
  - **Ed Discussion Board**
  - TA office hours (on website calendar, starts Tues 9/5)
  - Prof. office hours:
    Dr. Pierce Mon 3.30-5pm Levine 562
    Dr. Sheth Tue 10.30am-12.30pm Levine 264
    (both also by appointment)

- Tutoring available
- HW/Exam Grading: see website FAQ
- About CIS majors & Course Registration
  - CIS Undergraduate coordinators, Levine 308
  - cis-undergrad-advising@seas.upenn.edu

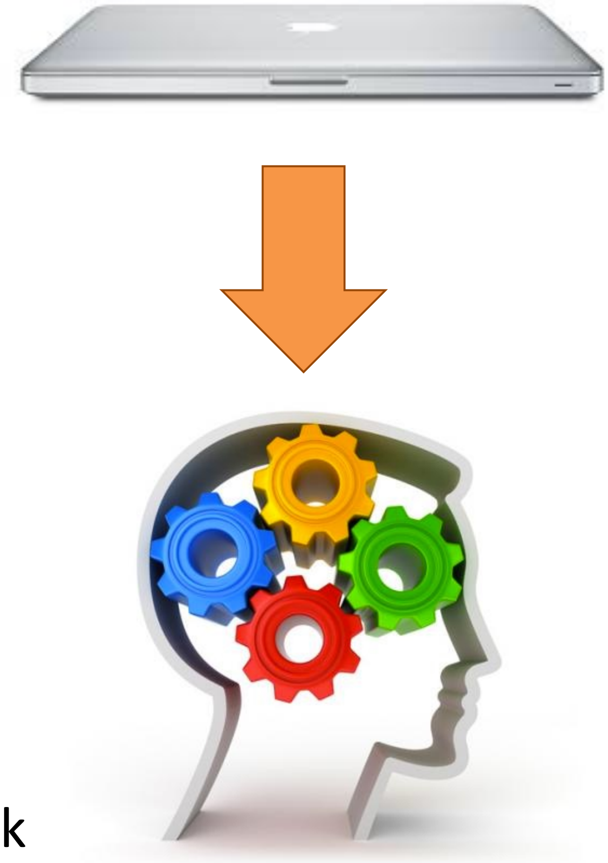
Poll Everywhere

- We will use *Poll Everywhere* for interactive quizzes during lecture
  - Answer with your phone or laptop
  - Useful for gauging your understanding
- We'll start using it next week

Poll Everywhere

No Devices during Lecture

- Laptops *closed*… minds *open*
  - Although this is a computer science class, the use of electronic devices – laptops, phones, etc., during lecture (*except for participating in quizzes*) is *prohibited*
- Why?
  - Device users tend to surf/chat/ email/game/text/tweet/etc.
  - They also distract those around them
  - Better to take notes *by hand*
  - You will get plenty of time in front of your computer while working on the homework :-)



Programming in OCaml

Codio

- Codio codio.com
  - *see Ed for enrollment info*
  - web-based development environment
  - *remote access for TA help*

- Under the hood:
  - linux virtual machine (Ubuntu)
  - pre-configured per project with everything you need
  - configurable editor

OCaml

- Industrial-strength, statically-typed *functional* programming language
- Lightweight, approachable setting for learning about program design

- See ocaml.org
  - CIS1200 uses only a small part of the language
  - We will cover everything you need to know

Who uses OCaml?

intel
facebook
JANE STREET
LexiFi
Google
CiTRIX
Microsoft
MLstate
cea
Microsoft Visual F#
my life
SimCorp
DASSAULT AVIATION

What is an OCaml module?

```
;; open Assert

let attendees (price:int) : int =
  (-15 * price) / 10 + 870

let test () : bool =
   attendees 500 = 120

;; run_test "attendees at 5.00" test

let x : int = attendees 500

;; print_int x
;; print_endline "end of demo"
```

- module import
- top-level function declarations (use `let` keyword)
- top-level identifier declarations (also use `let`)
- (top level) commands

What does an OCaml program do?

```
;; open Assert

let attendees (price:int) : int =
  (-15 * price) / 10 + 870

let test () : bool =
  attendees 500 = 120

;; run_test "attendees at 5.00" test

let x = attendees 500

;; print_int x
```

To know if the test will pass, we need to know whether this expression is true or false

To know what will be printed we need to know the value of this expression

To know what an OCaml program will do, we need to know what the value of each expression is

Value-Oriented Programming

pure, functional, strongly typed

Course goal

Strive for beautiful code.

- Beautiful code
  - is *simple*
  - is easy to understand
  - is easy(er) to get right
  - is easy to maintain
  - takes skill to write

Value-Oriented Programming

- Java, C, C#, C++, Python, Perl, etc. are tuned for an **imperative** programming style
  - Programs are full of *commands*
    - *"Change x to 5!"*
    - *"Increment z!"*
    - *"Make this point to that!"*
- OCaml, on the other hand, promotes a **value-oriented** style
  - We've seen that there are a few *commands*…

    `print_endline, run_test`

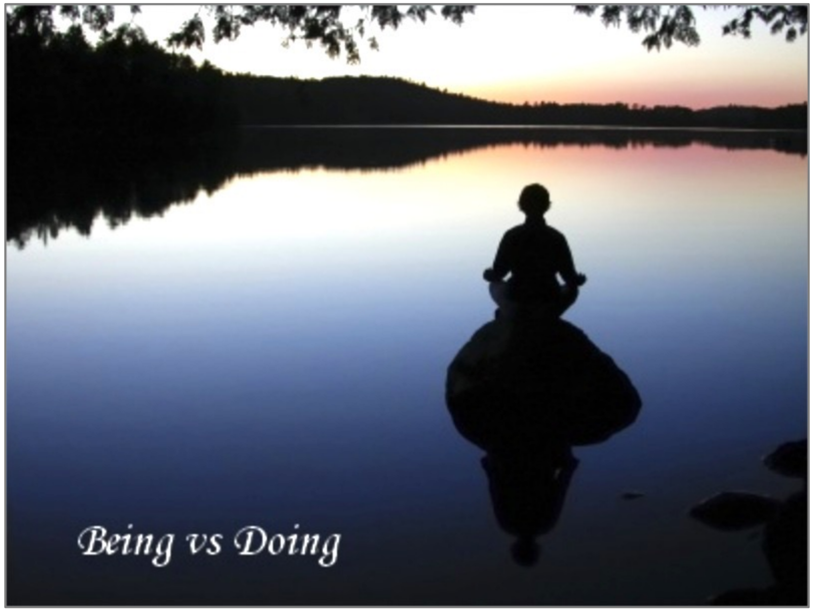
    … but these are used rarely
  - Most of what we write is *expressions* denoting *values*

Metaphorically, we might say that

imperative programming is about ***doing***

while

value-oriented programming is about ***being***



Programming with Values

Programming in *value-oriented* (a.k.a. *pure* or *functional*) style can feel a bit challenging at first

But it often leads to code that is much more beautiful

Types, Values, and Expressions

Types	Values	Operations	Expressions
`int`	`-1 0 1 2`	`+ * - /`	`(3 + y) * x`

- Each *type* corresponds to a set of *values*
- Each *expression* is built from *operations* on values, and it simplifies to a value (or already is a value)
- Use parentheses to associate nested expressions

Types, Values, and Expressions

Types	Values	Operations*	Expressions
int	-1 0 1 2	+ * - /	(3 + y) * x
float	0.12 3.1415	+. *. -. /.	3.0 *. (4.0 *. a)
string	"hello" "CIS120"	^ *(concatenation)*	"Hello, " ^ s
bool	true false	&& || not	(not b1) || b2

- Each *type* corresponds to a set of *values*
- Each *expression* is built from *operations* on values, and it simplifies to a value (or already is a value)
- Use parentheses to associate nested expressions

*Note that there is no automatic conversion from float to int, etc., so you must use explicit conversion operations like `string_of_int` or `float_of_int`

Static vs. Dynamic

The term '*static*' indicates something that happens *before* the program is run

OCaml (like Java) has a static type system: the compiler checks that the program is *well typed* before the program is run

The term '*dynamic*' refers to something that happens *while* the program is running

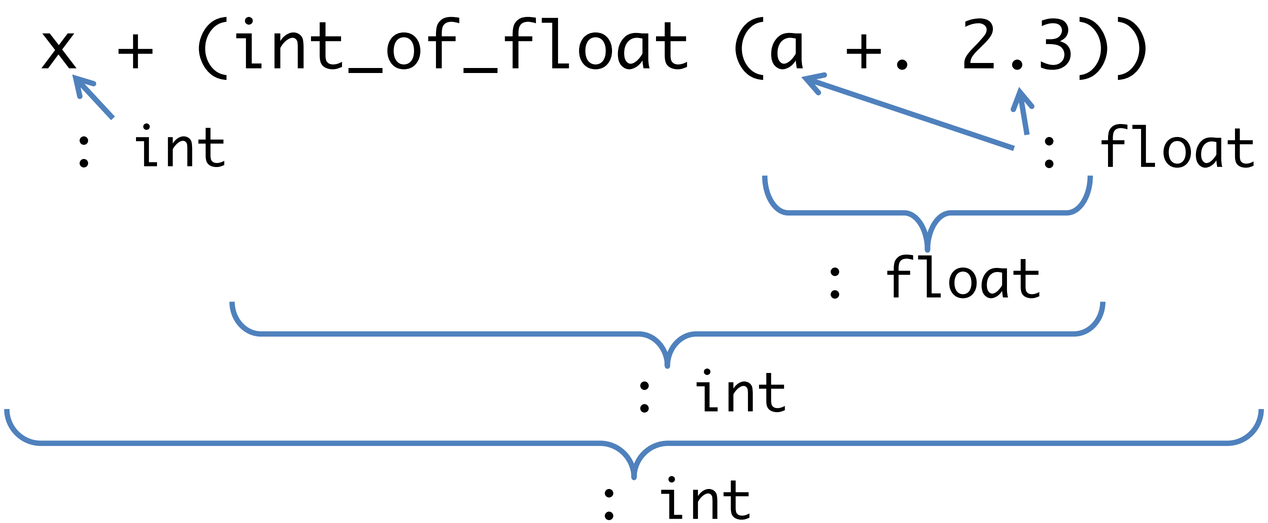
(E.g., we will learn about Java's "dynamic dispatch" later)

Static Type System

- Every *identifier* has a unique associated type
- "Colon" notation associates an identifier with its type

```
x : int        a : float
s : string     b1 : bool
```

- Every OCaml *expression* has a unique type determined by its *subexpressions*



Static Type Errors

- OCaml uses *type inference* to check that your program uses types consistently

```
x + (string_of_float (a +. 2.3))
```

x : int

a, 2.3 : float

(a +. 2.3) : float

string_of_float (a +. 2.3) : string

`ERROR: expected int but found string`

Because + expects both of its inputs to be of type `int`.

NOTE: Every time OCaml points out a type error, it is indicating a likely bug. Well-typed OCaml programs often "just work"!

Calculating the Values of Expressions

OCaml’s model of computation

Simplification vs. Execution

- We can think of an OCaml expression as just a way of writing down a *value*
- We can visualize running an OCaml program as a sequence of *simplification* steps that lead to this value

```
2 * (4 + 5) ⇒ 18
```

- In contrast, a running Java program is best thought of as performing a sequence of *actions* or *commands*
  - *… a variable named x gets created*
  - *… then we put the value 3 in x*
  - *… then we test whether y is greater than z*
  - *… the answer is true, so we put the value 4 in x*

  Each command modifies the *state* of the machine

Calculating with Expressions

- OCaml expressions *simplify* to values

```
3 ⇒ 3        (values simplify to themselves)
3 + 4 ⇒ 7
(2+3) * (5-2) ⇒ 15
attendees 500 ⇒ 120
```

> Note that the symbols '⇒' and '⟼' are *not* OCaml syntax. We're using them to *talk* about the way OCaml programs behave.

- The notation <exp> ⇒ <val> means that the expression <exp> computes to the final value <val>
- We can break down ⇒ in terms of *single step* calculations, written <exp> ⟼ <exp>

```
  (2+3) * (5-2)
⟼ 5 * (5-2)          because 2+3 ⟼ 5
⟼ 5 * 3              because 5-2 ⟼ 3
⟼ 15                 because 5*3 ⟼15
```

Conditional Expressions

```
if s = "positive" then 1 else -1
```

```
if day >= 6 && day <= 7
then "weekend" else "weekday"
```

OCaml *conditionals* are also expressions: they can be used inside of other expressions

```
(if 3 > 0 then 2 else -1) * 100
```

```
if x > y then "x is bigger"
else (if x < y
then "y is bigger"
else "same")
```

Simplifying Conditional Expressions

- A conditional expression yields the value of either its ‘then’-branch or its ‘else’-branch, depending on whether the test is ‘true’ or ‘false’
- For example

```
  (if 3 > 0 then 2 else -1) * 100
⟼ (if true then 2 else -1) * 100
⟼ 2 * 100
⟼ 200
```

- It doesn’t make sense to leave out the ‘else’ branch in an ‘if’ (What would the value be if the test was ‘false’?)

Typing Conditional Expressions

```
if s = "positive" then 1 else -1
```

: string

: int

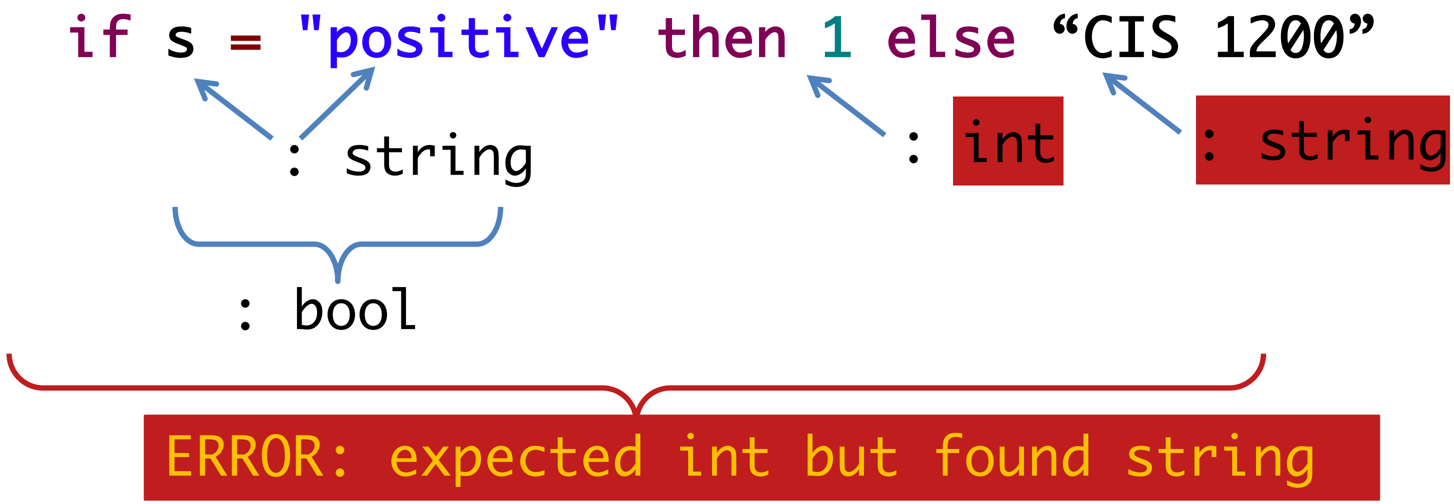
: int

: bool

: int

NOTE: both branches must have the same type!

Type Errors



if s = "positive" then 1 else “CIS 1200”
: string
: int
: string
: bool
ERROR: expected int but found string

Let Declarations

naming, not “assigning”

Top-level Let Declarations

- A let declaration gives a *name* (a.k.a. *identifier*) to the value denoted by some expression

```
let pi : float = 3.14159
let seconds_per_day : int = 60 * 60 * 24
```

- The *scope* of a top-level identifier is the rest of the file after the declaration

The "*scope*" of a name is "the region of the program in which it can be used"

Local Let Expressions

- Let declarations can appear both at top level and *nested* within other expressions.

```
let profit_500 : int =
  let attendees = 120 in
  let revenue = attendees * 500 in
  let cost = 18000 + 4 * attendees in
  revenue - cost
```

The scope of attendees is only the expression after the 'in'

- Local let declarations are followed by 'in'
  - e.g. attendees, revenue, and cost
- Top-level let declarations are not followed by 'in'
  - e.g., profit_500 itself
- The scope of a local identifier is just the expression after the 'in', not the rest of the file

Immutability

- Once defined by `let`, the *binding* between an identifier and a value cannot be changed!

```
int x = 3;
x = 4;
```

Java / C / C++ / python /…

imperative update

'`x = 4`' is a *command* that means 'update the contents of *location* x to be 4'

The state associated with 'x' *changes* as the program runs

```
let x : int = 3 in
x = 4
```

Ocaml

named expressions

'`let x : int = 3`' simply gives the value 3 the *name* 'x'

'`x = 4`' asks `does x equal 4?' (a boolean value, false)

Once defined, the value bound to 'x' never changes

Typing Local Let Expressions

```
let x = 3 + 5 in string_of_int (x * x)
```

: int

: string

: int

: string

- A let-bound identifier has the type of the expression it is bound to.
- The type of the whole local let expression is the type of the expression after the ‘in’
- Recall: type annotations are written using colon:

```
let x : int = … ((x + 3) : int) …
```

Shadowing

Multiple declarations of the same identifier or function name are allowed. The later declaration *shadows* the earlier one for the rest of the scope.

```
let total : int =
  let x = 1 in
  let y = x + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

scope of x

scope of y

scope of x (shadows earlier x)

scope of z

scope of total is the rest of the file

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =
  let x = 1 in
  let y = x + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
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```
let total : int =
  let x = 1 in
  let y = x + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

First, we simplify the right-hand side of the declaration for identifier total.

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the 'let…in' part
  - simplify what's left

```
let total : int =
  let x = 1 in
  let y = x + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

This r.h.s. is already a value.

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
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  - drop the 'let...in' part
  - simplify what's left

```
let total : int =
  let x = 1 in
  let y = 1 + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Substitute 1 for x here.

But not here because the second x shadows the first.

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =
  let x = 1 in
  let y = 1 + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Discard the local let since it’s been “substituted away”: There are no more uses of (this) x

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the 'let…in' part
  - simplify what's left

```
let total : int =

  let y = 1 + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =

  let y = 1 + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Simplify the expression remaining in scope.

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =

  let y = 1 + 1 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Repeat!

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =

  let y = 2 in
  let x = 1000 in
  let z = x + 2 in
    x + y + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =

  let y = 2 in
  let x = 1000 in
  let z = x + 2 in
    x + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =

  let y = 2 in
  let x = 1000 in
  let z = x + 2 in
    x + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =


  let x = 1000 in
  let z = x + 2 in
    x + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
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  - simplify what's left

```
let total : int =

   let x = 1000 in
   let z = x + 2 in
     x + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
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```
let total : int =


  let x = 1000 in
  let z = x + 2 in
    x + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =


    let x = 1000 in
    let z = 1000 + 2 in
      1000 + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =


  let x = 1000 in
  let z = 1000 + 2 in
    1000 + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =



  let z = 1000 + 2 in
    1000 + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =


    let z = 1000 + 2 in
      1000 + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the 'let…in' part
  - simplify what's left

```
let total : int =



  let z = 1000 + 2 in
    1000 + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =



  let z = 1002 in
    1000 + 2 + z
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the ‘let…in’ part
  - simplify what's left

```
let total : int =



  let z = 1002 in
    1000 + 2 + 1002
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
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```
let total : int =



    let z = 1002 in
      1000 + 2 + 1002
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
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  - simplify what's left

```
let total : int =



    1000 + 2 + 1002
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the 'let...in' part
  - simplify what's left

```
let total : int =



    1000 + 2 + 1002      ⇒     2004
```

Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
  - then *substitute* the resulting value for the identifier in its scope
  - drop the 'let...in' part
  - simplify what's left

```
let total : int = 2004
```

Lexical Scopes

When reading code: a variable refers to the nearest enclosing let-binding.

– Be sure to account for nested expressions

```
let answer : int =
  let x = 1 in
  let y = let x = 2 in x + x in
  x + y
```

For example:
answer = 5

With explicit parentheses:

```
let answer : int =
  let x = 1 in
  let y = (let x = 2 in x + x) in
  x + y
```

These occurrences of ‘x’ refer to ‘x = 2’

This ‘x’ refers to ‘x = 1’. (The other let binding doesn’t enclose this x!)

Things (for you) to do…

- Sign up for Codio

- Check Ed for announcements

- Homework 1: OCaml Finger Exercises
  – Practice using OCaml to write simple programs
  – Start with first 4 problems
    - (needed background on lists coming next week!)
  – Start early!