Programming Languages and Techniques (CIS120)

Lecture 2
Value-Oriented Programming
If you are joining us today...

• Read the course syllabus/lecture notes on the website
  – www.cis.upenn.edu/~cis120
• Sign yourself up for Piazza
  – piazza.com/upenn/spring2019/cis120
• Try out Codio
  – www.cis.upenn.edu/~cis120/current/codio.shtml
• Sign yourself up for Poll Everywhere
  – Details are in Piazza

• If you aren’t registered for the class yet, please fill out the Waitlist Form
• If you are registered, but want to switch the lecture/recitation section, please fill out the “Switch Recitations or Lectures” Form

• No laptops, tablets, smart phones, etc., during lecture (except for participating in PollEverywhere quizzes)
Announcements

• Please read:
  – Chapter 2 of the course notes
  – OCaml style guide on the course website
    (http://www.seas.upenn.edu/~cis120/current/programming_style.shtml)

• Homework 1: OCaml Finger Exercises
  – Available from Schedule page on course website
  – Practice using OCaml to write simple programs
  – Due: January 29, at 11:59:59pm (midnight)
  – Start early!
  – Start with first 4 problems (lists will be introduced next week!)
Homework Policies

• Projects will be (mostly) automatically graded with immediate feedback
  – We’ll give you some tests, as part of the assignment
  – You’ll write your own tests to supplement these
  – Our grading script will apply additional tests
  – Your score is based on how many of these you pass
  – 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
  – Your final grade is determined by the best raw score

• 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:
  – manual grading of non-testable properties
  – feedback on style from your TAs
Important Dates

• Homework:
  – Homework due dates will be listed on course calendar
  – Tuesdays at midnight: see schedule on web

• Exams:
  – 12% First midterm: Friday, March 1 in class
  – 12% Second midterm: Friday, April 5th in class
  – 18% Final exam: TBA
  – Contact instructor well in advance if you have a conflict

  – Make-up Exam Times will be announced beforehand
Where to ask questions

• Course material
  – Piazza Discussion Boards
  – TA office hours, on webpage calendar
  – Tutoring
  – Prof office hours:
    Fouh: Tuesday from 2:00 to 4:00 PM
    Pierce: Tuesday from 1:00 to 3:00 PM
    or by appointment (changes will be announced on Piazza)

• HW/Exam Grading: see webpage

• About CIS majors & Registration
  – Desirae Cesar or Laura Fox, Levine 309
    CIS Undergraduate coordinators
Poll Everywhere
Poll Everywhere Basics

• Beginning today, we’ll use Poll Everywhere in each lecture
  – Grade recording starts Monday 1/28
• You can use your phone, laptop, etc. to go the website.
• You can also use your phone to text directly

• Polls will be restricted to registered participants
• Register with your Penn Email Address if you haven’t already

<table>
<thead>
<tr>
<th>In what language do you have the most significant programming experience?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java or C#</td>
</tr>
<tr>
<td>C, C++, or Objective-C</td>
</tr>
<tr>
<td>Python, Ruby, Javascript, or MATLAB</td>
</tr>
<tr>
<td>Clojure, Scheme, or LISP</td>
</tr>
<tr>
<td>OCaml, Haskell, or Scala</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Options</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>CIS 110</td>
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<tr>
<td>High School course (incl. AP CS)</td>
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<tr>
<td>Camp or other extra-curricular</td>
</tr>
<tr>
<td>Self-taught</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>
Programming in OCaml

Read Chapter 2 of the CIS 120 lecture notes, available from the course web page
What is an OCaml module?

```ocaml
;; 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**: `open Assert` is used to import the `Assert` module.
- **Function declarations**: `let attendees` and `let test` are function declarations, using the `let` keyword.
- **Identifier declarations**: `let x` is an identifier declaration, also using the `let` keyword.
- **Commands**: `;; print_int x` and `;; print_endline "end of demo"` are commands in the OCaml code.
To know what will be printed we need to know the value of each expression.

```
;; 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 be a bit challenging at first

• But it often leads to code that is much more beautiful
### Values and Expressions

<table>
<thead>
<tr>
<th>Types</th>
<th>Values</th>
<th>Operations*</th>
<th>Expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>int</td>
<td>-1 0 1 2</td>
<td>+ * - /</td>
<td>3 + (4 * x)</td>
</tr>
<tr>
<td>float</td>
<td>0.12 3.1415</td>
<td>+. * . - . / .</td>
<td>3.0 *. (4.0 *. a)</td>
</tr>
<tr>
<td>string</td>
<td>“hello” “CIS120”</td>
<td>^ (concatenation)</td>
<td>“Hello,” ^ s</td>
</tr>
<tr>
<td>bool</td>
<td>true false</td>
<td>&amp;&amp;</td>
<td></td>
</tr>
</tbody>
</table>

- Each type corresponds to a set of well-typed values.

*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.*
Types

• Every *identifier* has a unique associated type.

• "Colon" notation associates an identifier with its type:

  \[ x : \text{int} \quad a : \text{float} \]
  \[ s : \text{string} \quad b1 : \text{bool} \]

• Every OCaml *expression* has a unique type determined by its constituent *subexpressions*:

\[ x + (\text{int_of_float} (a +. 2.3)) \]

\[ : \text{int} \]
\[ : \text{float} \]
\[ : \text{float} \]
\[ : \text{float} \]
\[ : \text{int} \]
\[ : \text{int} \]
Type Errors

- OCaml will use *type inference* to check that your program to ensure that it uses types consistently.
  - It will give you an error if not

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

```
x : int
(string_of_float (a +. 2.3)) : float
```

**ERROR**: expected `int` but found `string`

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

\[(+) : \text{int} \to \text{int} \to \text{int}\]  \textit{function types}

\[\text{string}_\text{of}_\text{int} : \text{int} \to \text{string}\]

\[() : \text{unit}\]

\[(1, 3.0) : \text{int} \ast \text{float}\]  \textit{tuple types}

\[[1;2;3] : \text{int list}\]  \textit{list types}

We will see all of these (and how to define our own brand new types) in upcoming lectures...
Calculating Expression Values

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 *calculation* or *simplification* steps that eventually lead to this value

• (By 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 *implicit, pervasive* state of the machine)
Calculating with Expressions

OCaml programs mostly consist of *expressions*.

Expressions *simplify* to values:

\[
\begin{align*}
3 & \Rightarrow 3 \\
3 + 4 & \Rightarrow 7 \\
2 \times (4 + 5) & \Rightarrow 18 \\
\text{attendees 500} & \Rightarrow 120
\end{align*}
\]

(values compute to themselves)

The notation `<exp> ⇒ <val>` means that the expression `<exp>` computes to the final value `<val>.

Note that the symbol ‘⇒’ is not OCaml syntax. We’re using it to *talk* about the way OCaml programs behave.
Step-wise Calculation

• We can break down ⇒ in terms of single step calculations, written ⟷

• For example:
  
  \[(2+3) \times (5-2)\]
  
  ⟷ 5 \times (5-2)  \quad \text{because } 2+3 \longrightarrow 5
  
  ⟷ 5 \times 3  \quad \text{because } 5-2 \longrightarrow 3
  
  ⟷ 15  \quad \text{because } 5\times3 \longrightarrow 15
Conditional Expressions

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

  ```
  if s = "positive" then 1 else -1
  
  if day >= 6 && day <= 7 then "weekend" else "weekday"
  
  (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:

  \[(\text{if } 3 > 0 \text{ then } 2 \text{ else } -1) \times 100\]

  \[\Rightarrow (\text{if true then } 2 \text{ else } -1) \times 100\]

  \[\Rightarrow 2 \times 100\]

  \[\Rightarrow 200\]

• The type of a conditional expression is the (single!) type shared by \emph{both} of its branches.

• It doesn’t make sense to leave out the ‘else’ branch in an ‘if’. (What would be the result if the test was ‘false’?)
Top-level Let Declarations

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

```plaintext
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.

“scope” of a name = “the region of the program in which it can be used”
Immutability

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

Java / C / C++ / ... imperative update

'int x = 3; x = 4;' is a command that means 'update the contents of location x to be 3'

Ocaml named expressions

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

'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
Local Let Expressions

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

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

- Local (nested) let declarations are followed by ‘in’
  - e.g. attendees, revenue, and cost
- Top-level let declarations do not use ‘in’
  - e.g. profit_500
- The scope of a local identifier is just the expression after the ‘in’
Typing Let Expressions

- 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:

```plaintext
let x : int = ... ((x + 3) : int) ...
```
Multiple declarations of the same variable or function name are allowed. The later declaration *shadows* the earlier one for the rest of the program.

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

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```
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

```plaintext
let total : int =
  let x = 1 in
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  let x = 1000 in
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```
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```plaintext
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

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```plaintext
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
- then substitute the resulting value for the identifier in its scope
- drop the ‘let...in’ part
- simplify what's left

```plaintext
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

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```plaintext
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.
```
Simplifying Let Expressions

- To calculate the value of a `let` expression:
  - first calculate the value of the right hand side
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let total : int =
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Simplifying Let Expressions

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```plaintext
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:
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  - 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
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let total : int =
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  let x = 1000 in
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```
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- To calculate the value of a let expression:
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```let total : int =
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let total : int =
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Simplifying Let Expressions

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let total : int =

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let z = 1000 + 2 in
1000 + 2 + z
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let total : int =
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  let z = 1000 + 2 in
  1000 + 2 + z
```
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  - then *substitute* the resulting value for the identifier in its scope
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  - simplify what's left

```plaintext
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
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```
let total : int =

let z = 1000 + 2 in
1000 + 2 + z
```
Simplifying Let Expressions

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```let total : int = 
  let z = 1000 + 2 in
  1000 + 2 + z```
Simplifying Let Expressions

- To calculate the value of a let expression:
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  - simplify what's left

```
let total : int =
  let z = 1002 in
  1000 + 2 + z
```
Simplifying Let Expressions

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  – then substitute the resulting value for the identifier in its scope
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  – 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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```plaintext
let total : int =

let z = 1002 in
1000 + 2 + 1002
```
Simplifying Let Expressions

- To calculate the value of a let expression:
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  - simplify what's left

```plaintext
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
```
Things (for you) to do...

• Sign up for Piazza if necessary

• Sign up for Codio

• 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!