Programming Languages and Compilers (CS 421)

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https://courses.engr.illinois.edu/cs421/sp2023

Based in part on slides by Mattox Beckman, as updated by Vikram Adve and Gul Agha

Programming Languages & Compilers

Three Main Topics of the Course

I

New Programming Paradigm

II

Language Translation

III

Language Semantics

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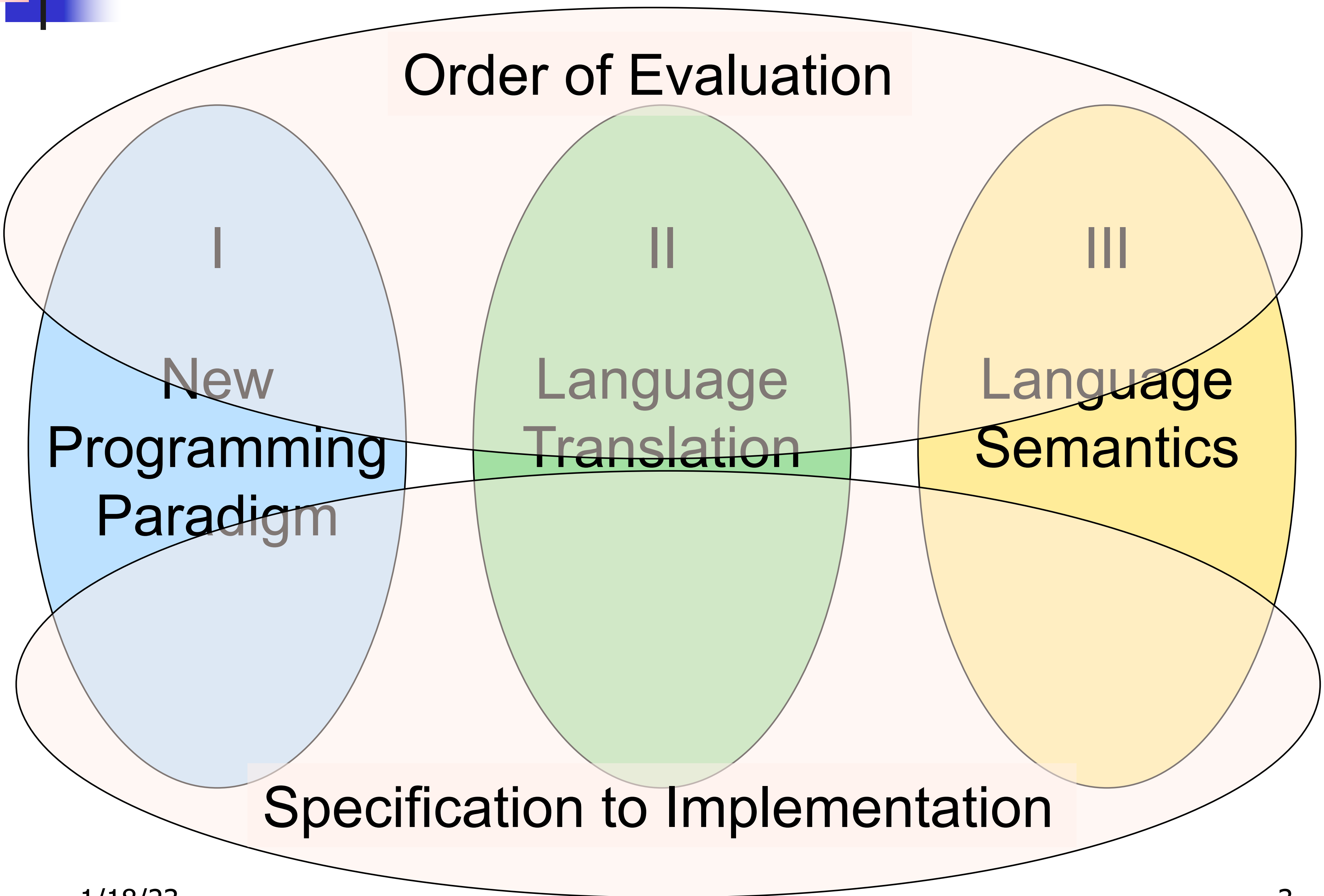

I : New Programming Paradigm

- Functional Programming
- Environments and Closures
- Patterns of Recursion
- Continuation Passing Style

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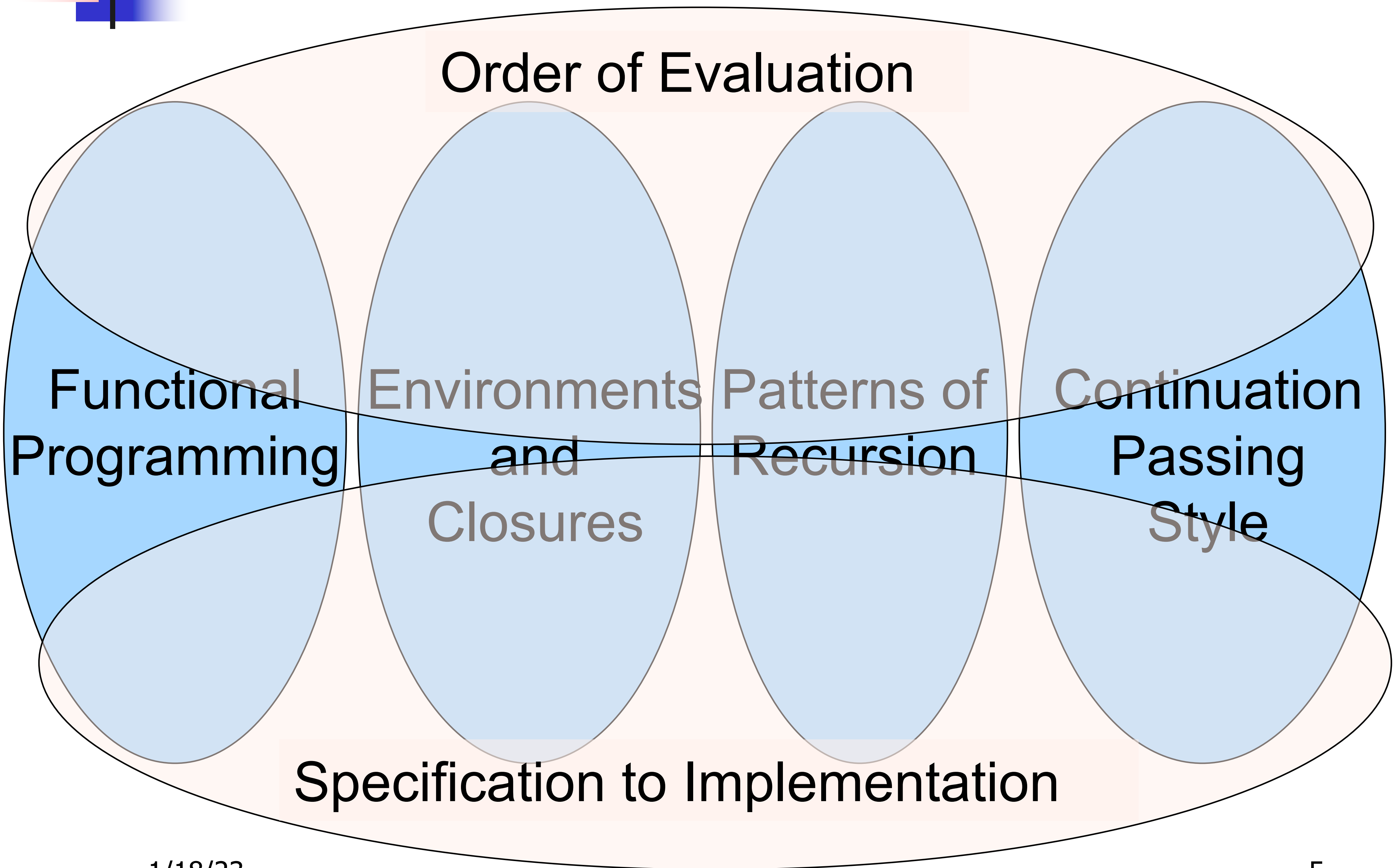

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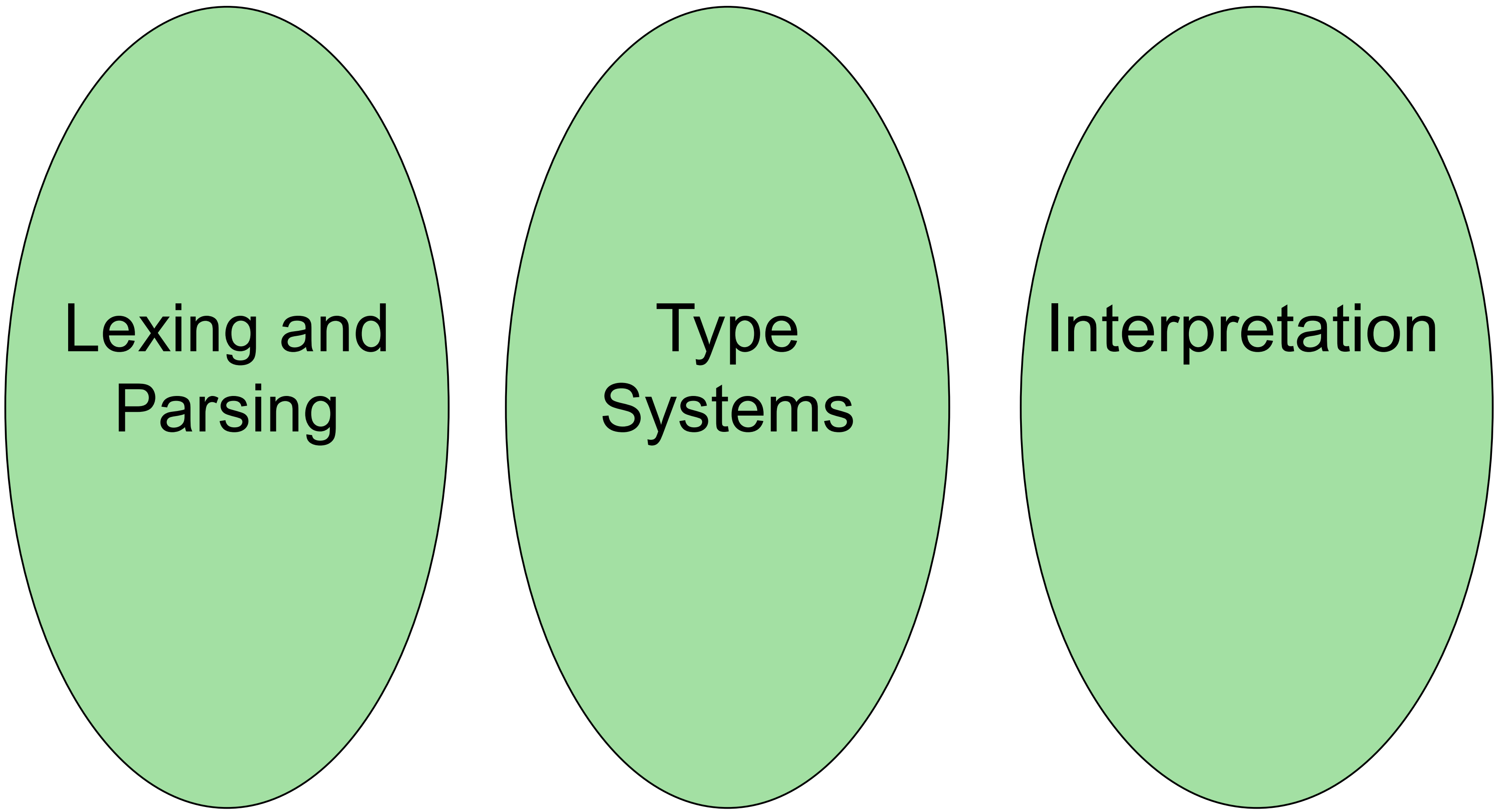
II : Language Translation



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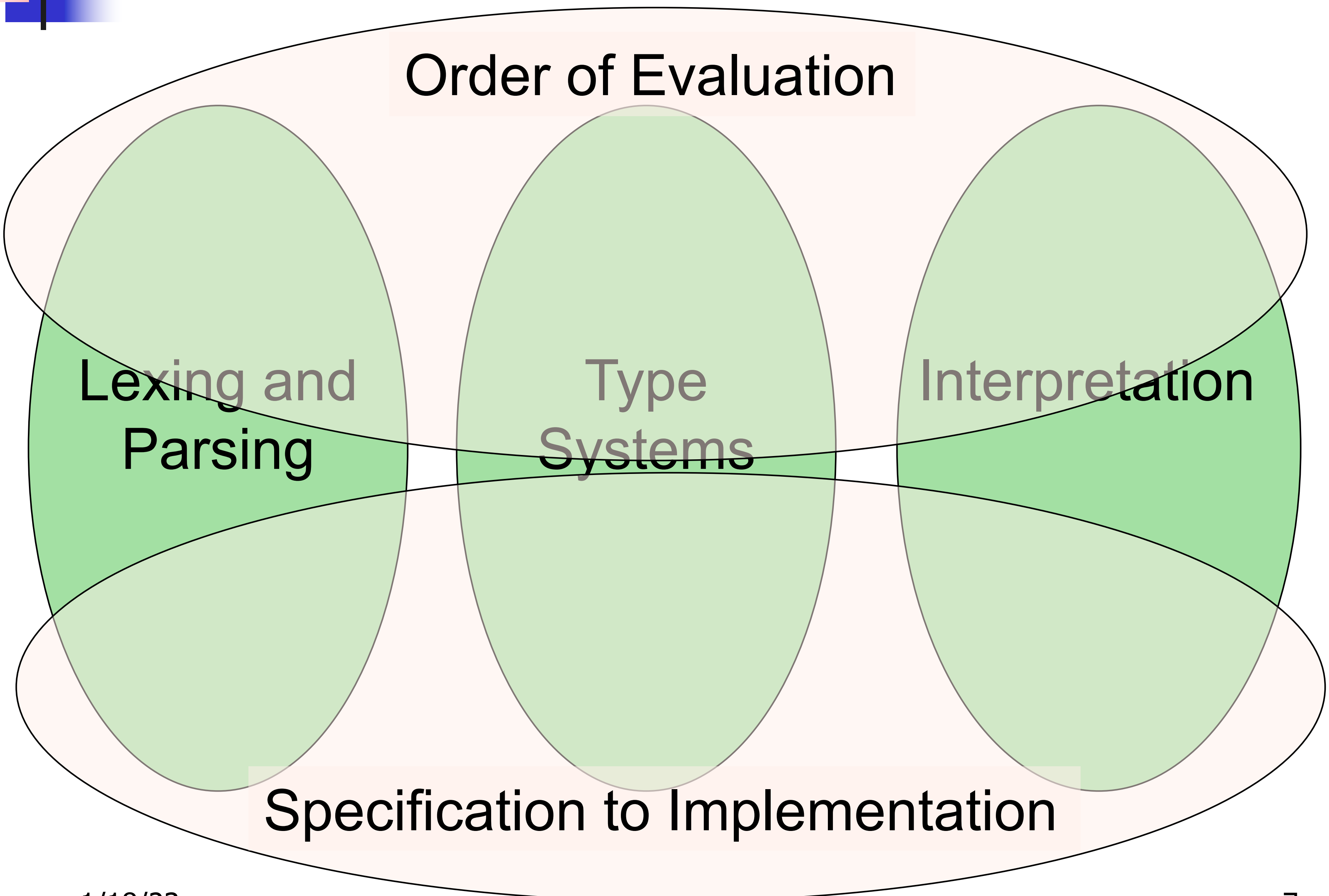

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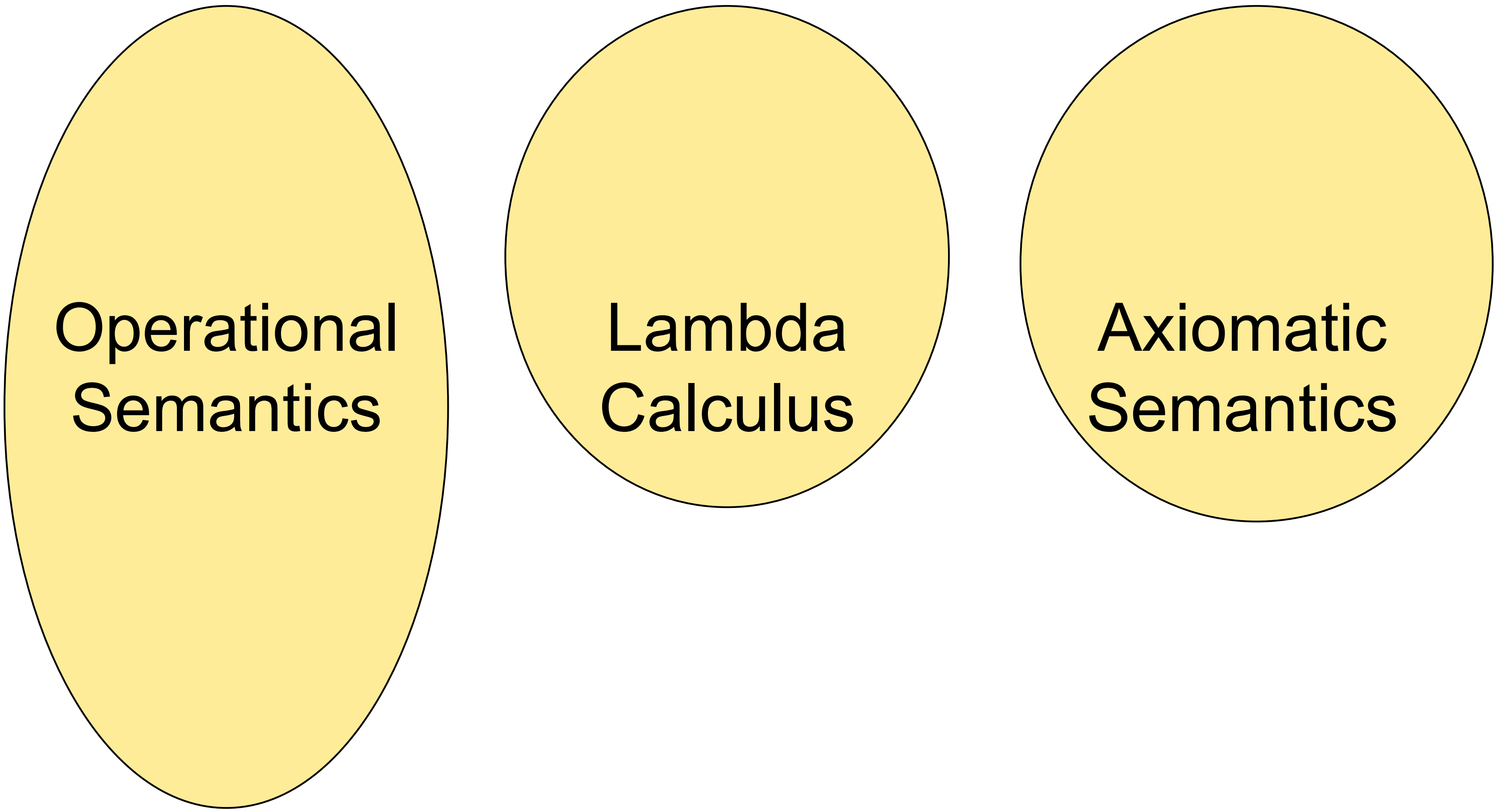
III : Language Semantics



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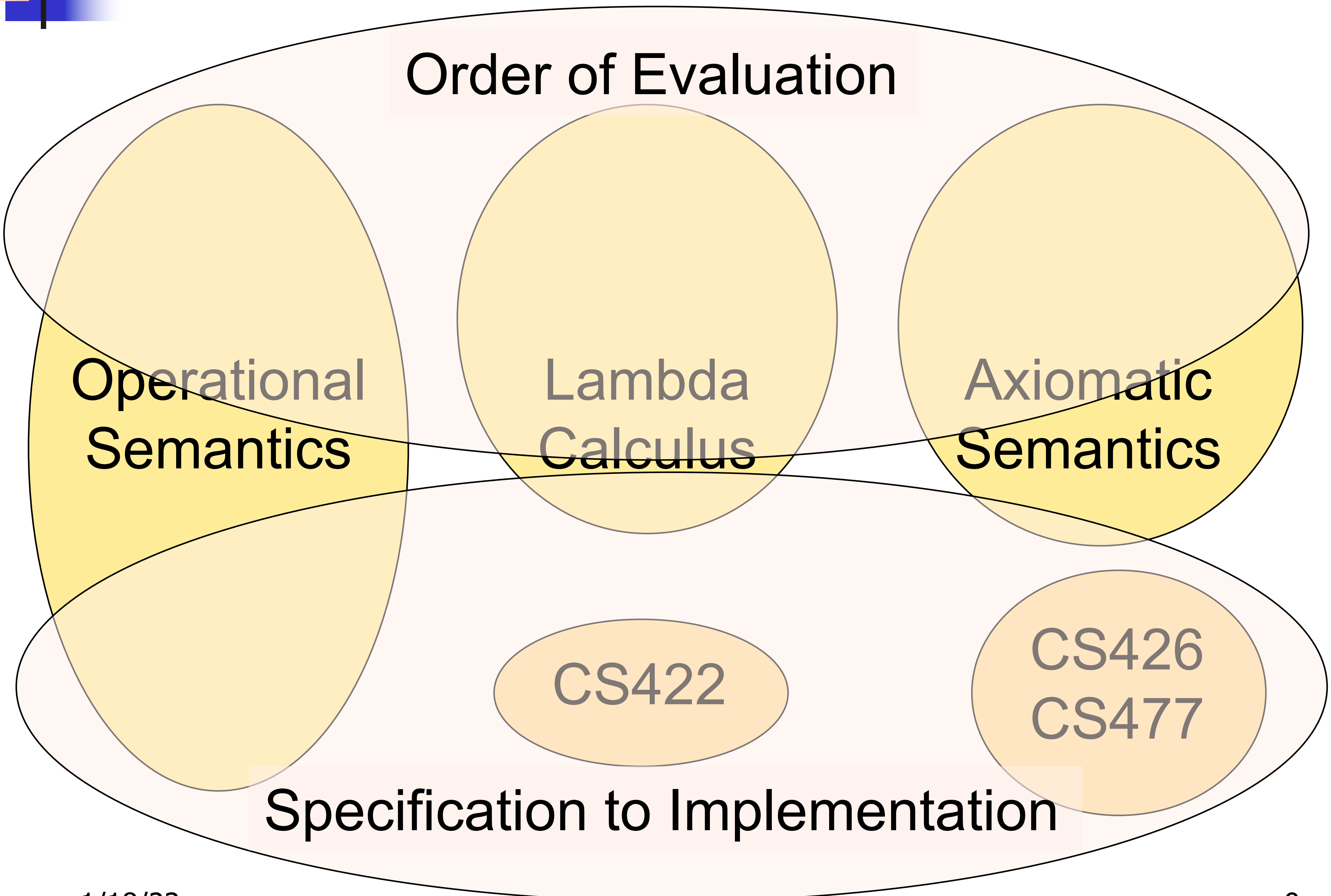
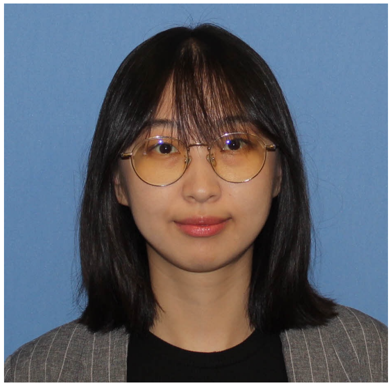


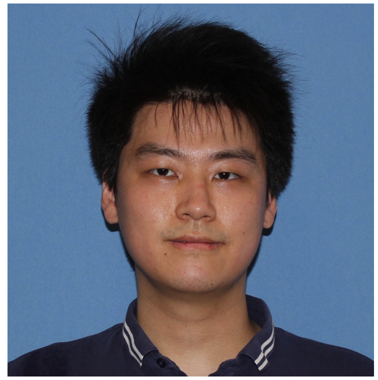
Contact Information - Elsa L Gunter

- Office: 2112 SC
- Office hours:
  - TBD
  - Today 11:00am – 11:50 pm
  - Also by appointment
- Email: eguntér@illinois.edu
  - Do not use DM in Campuswir if you want a timely response. It does not email me notifications of that and it make take days for a response.

Course TAs


Aruhan


Shaurya Gomber


Sizhuo Li

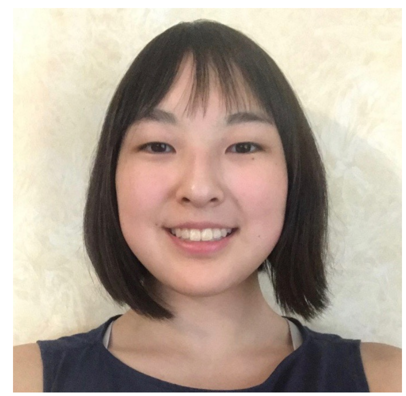

Mike Qin


Jun Yang


Amrith Balachander


Paul Krogmeier


Yerong Li

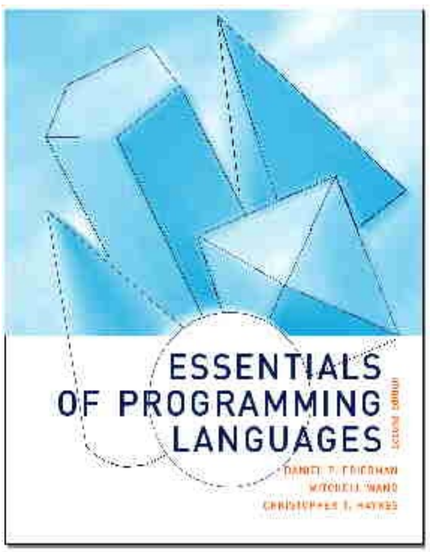

Tomoko Sakurayama

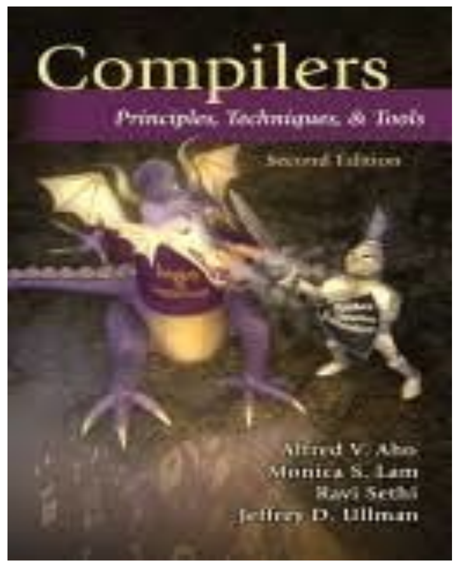
Course Website

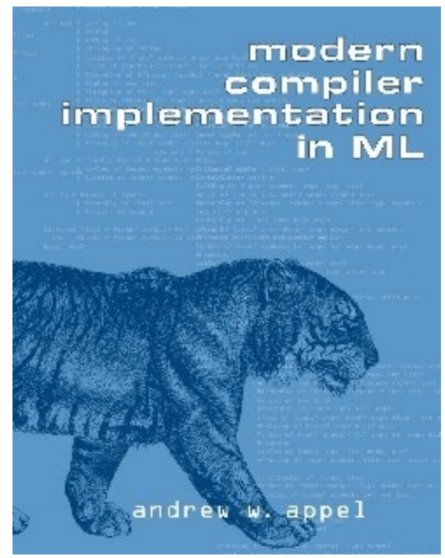
- https://courses.engr.illinois.edu/cs421/sp2023
- Main page - summary of news items
- Policy - rules governing course
- Lectures - syllabus and slides
- MPs - information about assignments
- Exams – Syllabi and review material for Midterms and finals
- Unit Projects - for 4 credit students
- Resources - tools and helpful info
- FAQ

Some Course References

- No required textbook
- Some suggested references







Some Course References

- No required textbook.
- Pictures of the books on previous slide
- Essentials of Programming Languages (2nd Edition) by Daniel P. Friedman, Mitchell Wand and Christopher T. Haynes, MIT Press 2001.
- Compilers: Principles, Techniques, and Tools, (also known as "The Dragon Book"); by Aho, Sethi, and Ullman. Published by Addison-Wesley. ISBN: 0-201-10088-6.
- Modern Compiler Implementation in ML by Andrew W. Appel, Cambridge University Press 1998
- Additional ones for Ocaml given separately

Course Grading

- Assignments 10%
  - Web Assignments (WA) (~3-6%)
  - MPs (in Ocaml) (~4-7%)
  - All WAs and MPs Submitted in **PrairieLearn**
  - **May include necessary reading material**
  - Late submission:
    - 48 hours, unless otherwise specified
    - capped at 80% of total

Course Grading

- Four quizzes, in class - 10%
- 3 Midterms - 15% each
  - Taken in the Computer Based Testing Facility (CBTF)
  - Self-scheduled from a four-day period
- Final: 35%, May 9, 7:00pm – 10:00pm
- Percentages are approximate

Course Assingments – WA & MP

- You may discuss assignments and their solutions with others
- You may work in groups, but you must **list members with whom you worked** if you share solutions or detailed solution outlines
- **Each student must write up and turn in their own solution separately**
  - **No direct copy-paste – type it yourself from your understanding**
- You may look at examples from class and other similar examples from any source – **cite appropriately**
  - Note: University policy on plagiarism still holds - cite your sources if not the sole author of your solution
  - Do not have to cite course notes or me

OCAML

- Locally:
  - Will use ocaml inside VSCode inside PrairieLearn problems this semester
- Globally:
  - Main OCAML home: http://ocaml.org
  - To install OCAML on your computer see: http://ocaml.org/docs/install.html
  - To try on the web: https://try.ocamlpro.com
  - More notes on this later

References for OCaml

- Supplemental texts (not required):
- The Objective Caml system release 4.05, by Xavier Leroy, online manual
- Introduction to the Objective Caml Programming Language, by Jason Hickey
- Developing Applications With Objective Caml, by Emmanuel Chailloux, Pascal Manoury, and Bruno Pagano, on O’Reilly
  - Available online from course resources

Features of OCAML

- Higher order applicative language
- Call-by-value parameter passing
- Modern syntax
- Parametric polymorphism
  - Aka structural polymorphism
- Automatic garbage collection
- User-defined algebraic data types

Why learn OCAML?

- Many features not clearly in languages you have already learned
- Assumed basis for much research in programming language research
- OCAML is particularly efficient for programming tasks involving languages (eg parsing, compilers, user interfaces)
- Industrially Relevant:
  - Jane Street trades billions of dollars per day using OCaml programs
  - Major language supported at Bloomberg
- Similar languages: Microsoft F#, SML, Haskell, Scala

Session in OCAML

% ocaml

Objective Caml version 4.07.1

(* Read-eval-print loop; expressions and declarations *)

2 + 3;; (* Expression *)

- : int = 5

3 < 2;;

- : bool = false

Declarations; Sequencing of Declarations

```
# let x = 2 + 3;;   (* declaration *)
val x : int = 5
# let test = 3 < 2;;
val test : bool = false
# let a = 1 let b = a + 4;; (* Sequence of dec
  *)
val a : int = 1
val b : int = 5
```

Functions

```
# let plus_two n = n + 2;;
val plus_two : int -> int = <fun>
# plus_two 17;;
- : int = 19
```

Functions

```
let plus_two n = n + 2;;

plus_two 17;;
- : int = 19
```

Extra Material

No Overloading for Basic Arithmetic Operations

```
# 15 * 2;;
- : int = 30
# 1.35 + 0.23;;  (* Wrong type of addition *)
Characters 0-4:
  1.35 + 0.23;;  (* Wrong type of addition *)
  ^^^^
Error: This expression has type float but an
    expression was expected of type
       int
# 1.35 +. 0.23;;
- : float = 1.58
```

No Implicit Coercion

```
# 1.0 * 2;; (* No Implicit Coercion *)
Characters 0-3:
  1.0 * 2;; (* No Implicit Coercion *)
  ^^^
Error: This expression has type float but an
    expression was expected of type
      int
```

Booleans (aka Truth Values)

```
# true;;
- : bool = true
# false;;
- : bool = false
```

// $\rho_7 = \{c \to 4, test \to 3.7, a \to 1, b \to 5\}$

```
# if b > a then 25 else 0;;
- : int = 25
```

Booleans and Short-Circuit Evaluation

```
# 3 > 1 && 4 > 6;;
- : bool = false
# 3 > 1 || 4 > 6;;
- : bool = true
# (print_string "Hi\n"; 3 > 1) || 4 > 6;;
Hi
- : bool = true
# 3 > 1 || (print_string "Bye\n"; 4 > 6);;
- : bool = true
# not (4 > 6);;
- : bool = true
```

Sequencing Expressions

```
# "Hi there";;  (* has type string *)
- : string = "Hi there"
# print_string "Hello world\n";;  (* has type unit *)
Hello world
- : unit = ()
# (print_string "Bye\n"; 25);;  (* Sequence of exp *)
Bye
- : int = 25
```

Recursive Functions

```
# let rec factorial n =
    if n = 0 then 1 else n * factorial (n - 1);;
  val factorial : int -> int = <fun>
# factorial 5;;
- : int = 120
# (* rec  is needed for recursive function
   declarations *)
```

Recursion Example

Compute n^2 recursively using:

$$n^2 = (2 * n - 1) + (n - 1)^2$$

```
# let rec nthsq n =          (* rec for recursion *)
    match n                  (* pattern matching for cases *)
    with 0 -> 0              (* base case *)
    | n -> (2 * n -1)        (* recursive case *)
        + nthsq (n -1);;     (* recursive call *)
val nthsq : int -> int = <fun>
# nthsq 3;;
- : int = 9
```

Structure of recursion similar to inductive proof

Recursion and Induction

```
# let rec nthsq n = match n with 0 -> 0
      | n -> (2 * n - 1) + nthsq (n - 1) ;;
```

- Base case is the last case; it stops the computation
- Recursive call must be to arguments that are somehow smaller - must progress to base case
- **if** or **match** must contain base case
- Failure of these may cause failure of termination

End of Extra Material

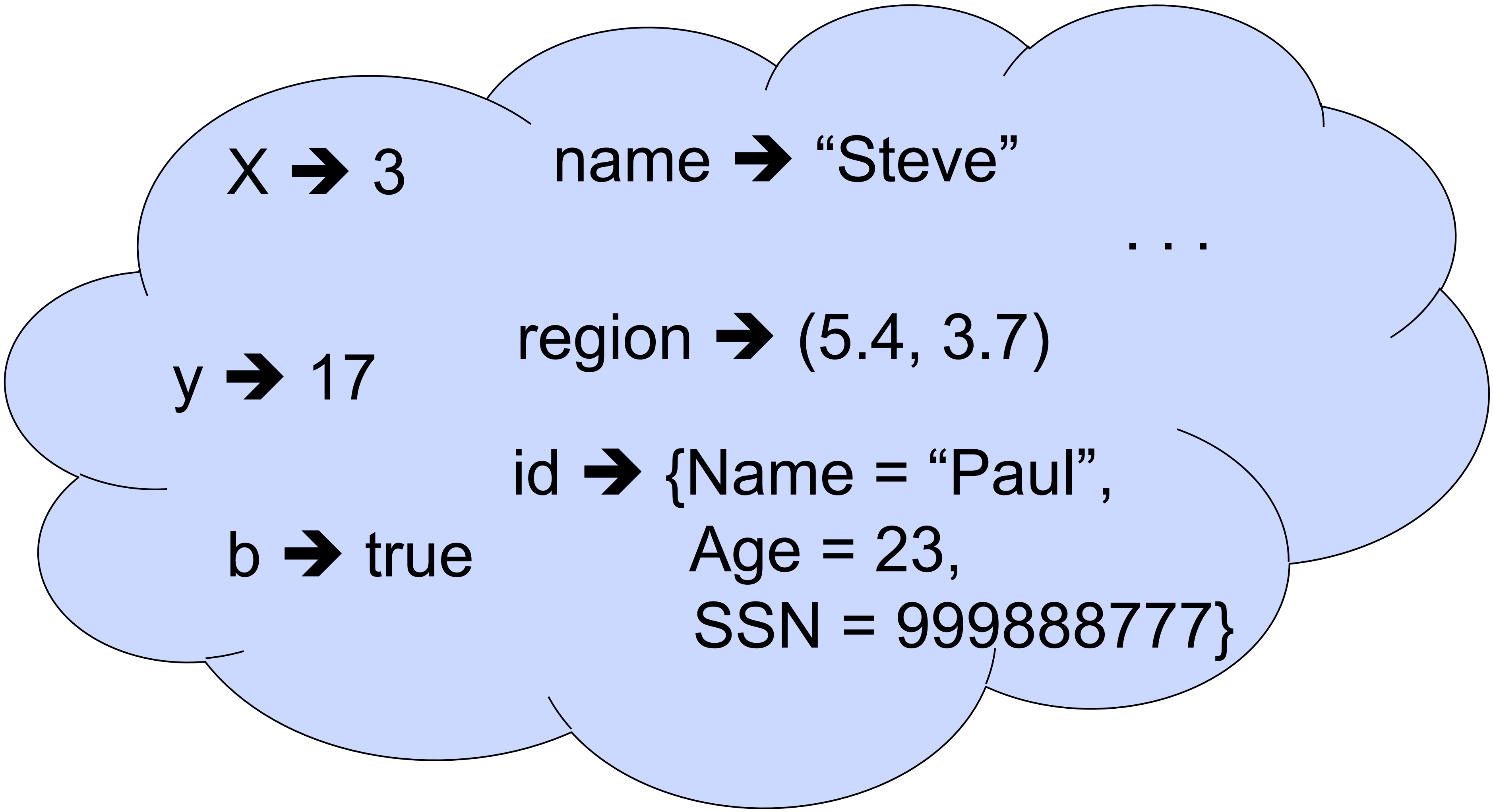
Environments

- *Environments* record what value is associated with a given identifier
- Central to the semantics and implementation of a language
- Notation

  $$\rho = \{name_1 \rightarrow value_1,\ name_2 \rightarrow value_2,\ \ldots\}$$

  Using set notation, but describes a partial function
- Often stored as list, or stack
  - To find value start from left and take first match

Environments



Global Variable Creation

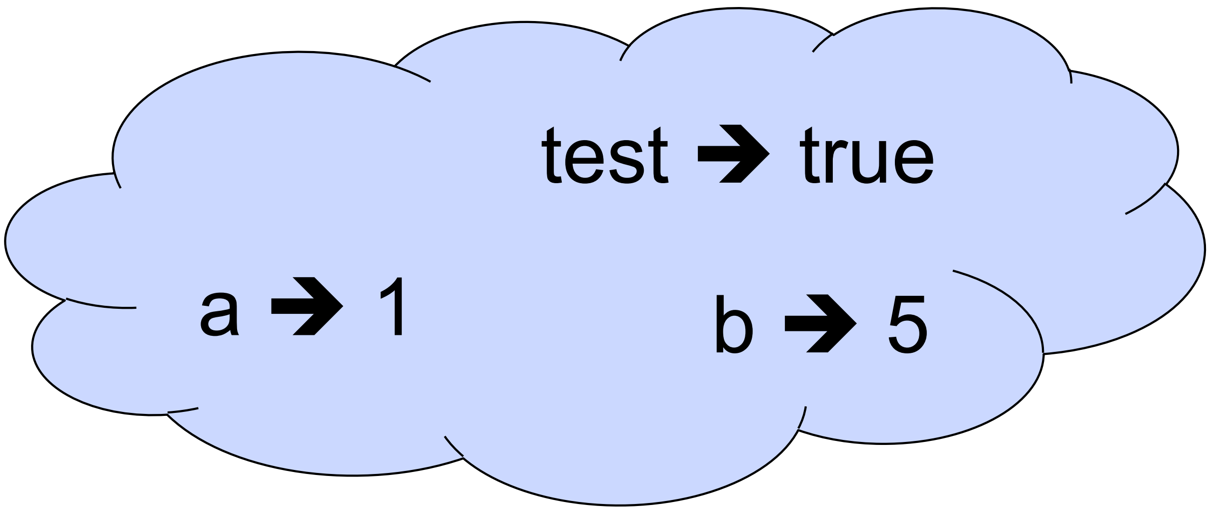
```
# 2 + 3;;     (* Expression *)
// doesn't affect the environment
# let test = 3 < 2;;        (* Declaration *)
val test : bool = false
```

// ρ_1 = {test → false}

```
# let a = 1 let b = a + 4;; (* Seq of dec *)
```

// ρ_2 = {b → 5, a → 1, test → false}

Environments



New Bindings Hide Old

// $\rho_2 = \{b \rightarrow 5, a \rightarrow 1, test \rightarrow false\}$

let test = 3.7;;

- What is the environment after this declaration?

New Bindings Hide Old

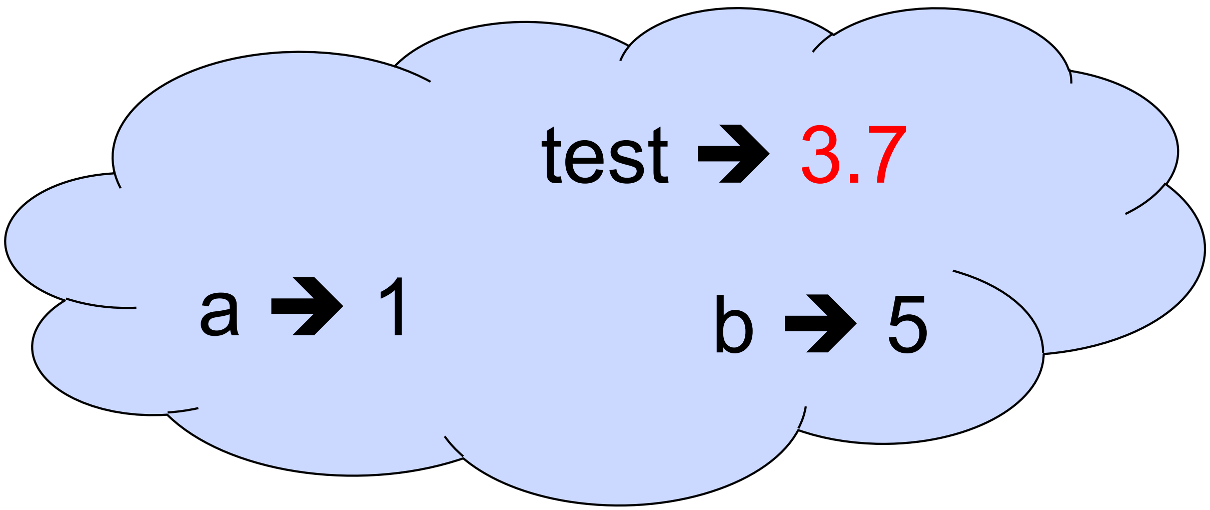
// $\rho_2 = \{b \to 5, a \to 1, test \to false\}$

```
let test = 3.7;;
```

- What is the environment after this declaration?

// $\rho_3 = \{test \to 3.7, a \to 1, b \to 5\}$

Environments



Now it’s your turn

You should be able to do WA1-IC Problem 1 , parts (* 1 *) - (* 3 *)