Course Introduction

Concepts of Programming Languages
Lecture 1

CAS CS 320

Outline

» Discuss the logistics of the course

» Give an overview of what PL is about

» Take a first look at OCaml

Course Logistics

Minutiae

Instructor: Nathan Mull

Teaching Fellows: Zachery Casey and Jared Pincus

Teaching Assistant: Vishesh Jain

Course Webpage: https://nmmull.github.io/CS320/landing/Spring-2025/index.html

Midterm Date: February 27

Grade Breakdown

30%	Assignments	(6 total, 1 dropped, 6% each)
30%	Mini-Projects	(3 total, no drops, 10% each)
20%	Midterm Exam	(February 27 during class)
20%	Final Exam	(Date TBD, Cumulative)

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» We will automatically drop your lowest assignment score

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- Barring technical issues, lectures will be **recorded**

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» All lab material is fair game for exams

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- You must chose the correct pages on Gradescope
- We reserve the right to dock points for not following these instructions

Course Communication

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- We will not respond to any material-related questions by email
- If you have logistical questions (e.g., about disability accommodations) send me an email directly

Course Webpage

https://nmmull.github.io/CS320/landing/Spring-2025/index.html

The webpage contains readings, assignments and labs.
Please check it frequently for updates

Course Repository

https://github.com/BU-CS320/cs320-spring-2025

The course repo contains starter code and lecture material

In **Lab 1**, you'll set up a mirror of this repository for assignment submission

Course Standard Library

https://nmmull.github.io/CS320/landing/Spring-2025/Specifications/Stdlib320/index.html

We'll assume a barebones standard library during the first half of the course

You'll need to familiarize yourself with what's there during this first half

You'll install it during Lab 1 (Tomorrow)

Questions?

If I missed anything, ask on Piazza

Make sure you're on Piazza and Gradescope, checking the course webpage, and pulling down the course repo frequently

By continuing in this course you're agreeing to all these conditions

One Last Thing

Remember to be kind. This is a difficult course. Don't take it out on other students

We care about your success in this course. We're not out to get you, we're here to help

Use your best judgment, you're adults

What is a PL?

Fair Question

How would you define a PL?

How would you explain it to your roommate?

How would you answer if you were asked during an interview?

Discuss this with the people around you for 1min

Programmer's view of a PL

```
42  def subtraction():
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50      if int(choice) == num_1 - num_2:
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» A text-based way of interacting with hardware/a computer

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» A way of organizing and working with data

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» A text-based way of interacting with hardware/a computer

» A way of organizing and working with data

These are not what the course is about

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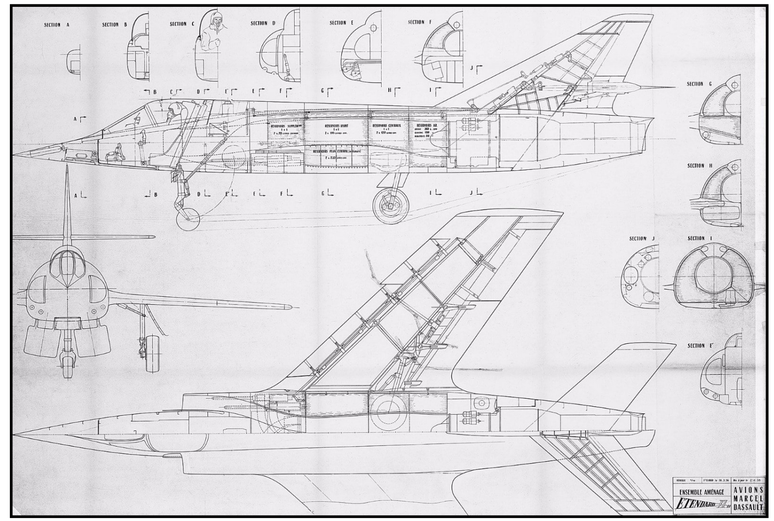
Aside: Users vs. Designers

VS



Aside: Users vs. Designers

Programmers *use* PLs. We're interested in **designing** PLs

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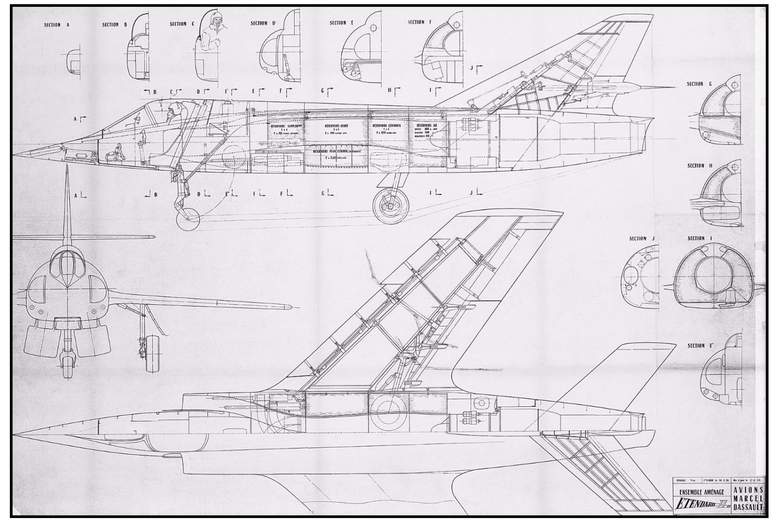

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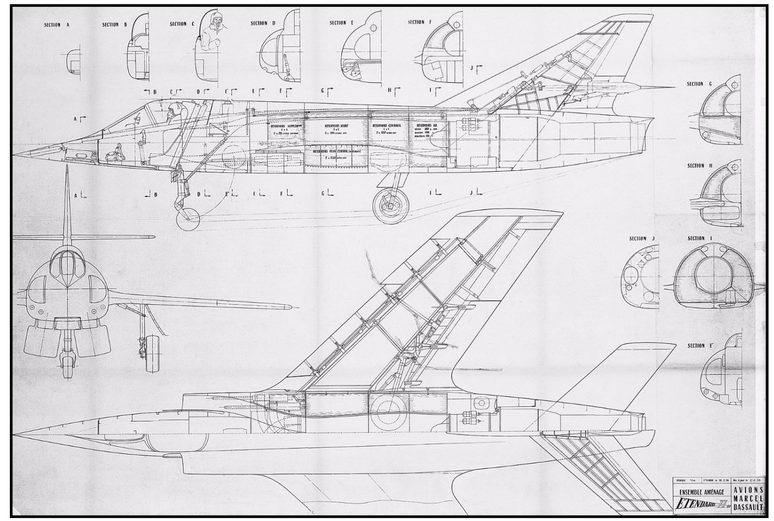

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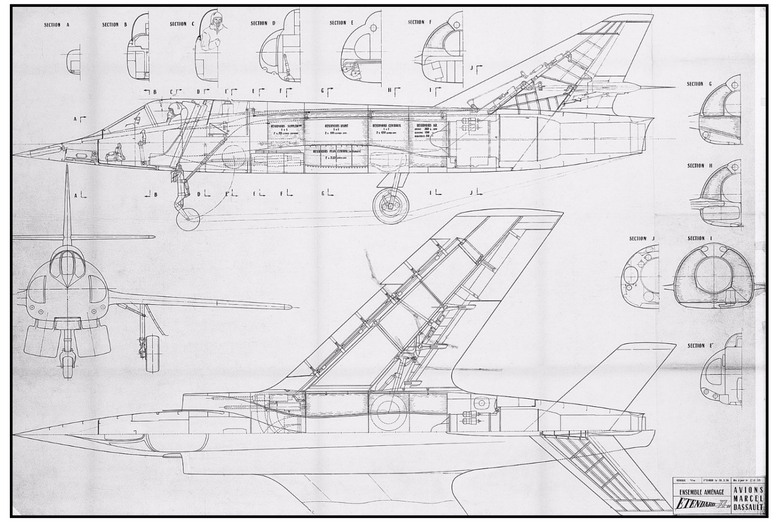

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(CS320 is secretly a math class)

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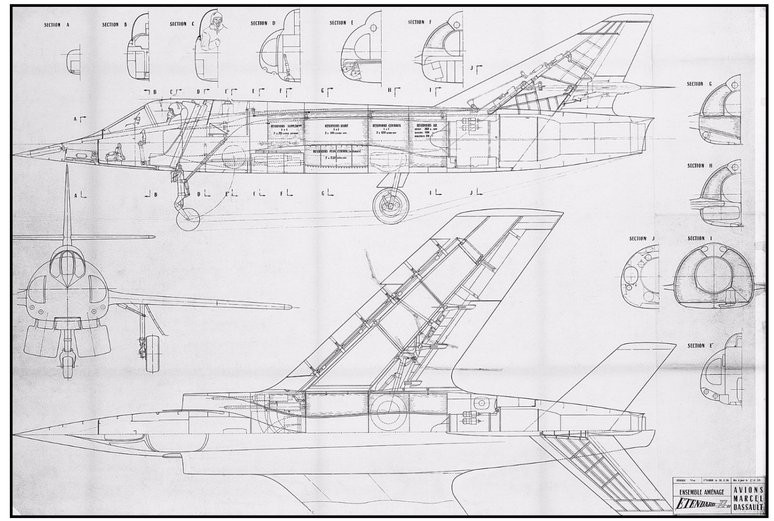

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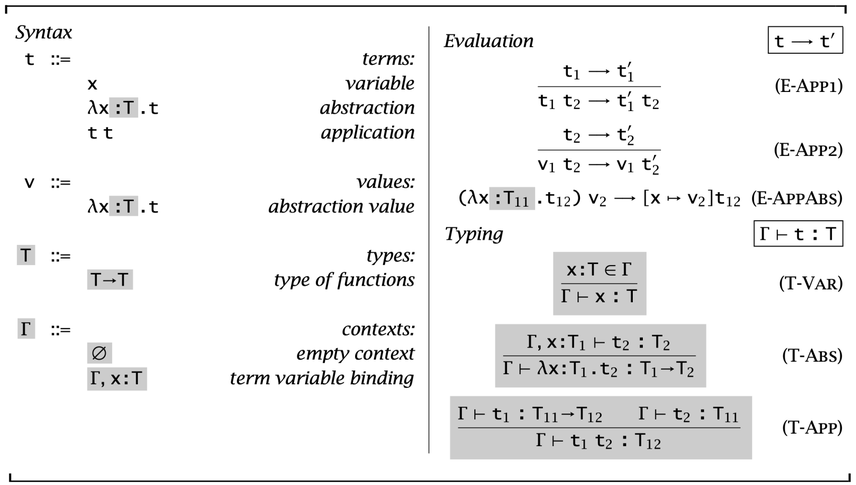

Syntax

t	::=		*terms:*
		x	*variable*
		$\lambda x{:}T.t$	*abstraction*
		$t\ t$	*application*
v	::=		*values:*
		$\lambda x{:}T.t$	*abstraction value*
T	::=		*types:*
		$T \to T$	*type of functions*
Γ	::=		*contexts:*
		$\varnothing$	*empty context*
		$\Gamma, x{:}T$	*term variable binding*

Evaluation $t \longrightarrow t'$

$$\frac{t_1 \longrightarrow t_1'}{t_1\ t_2 \longrightarrow t_1'\ t_2} \quad \text{(E-App1)}$$

$$\frac{t_2 \longrightarrow t_2'}{v_1\ t_2 \longrightarrow v_1\ t_2'} \quad \text{(E-App2)}$$

$$(\lambda x{:}T_{11}.t_{12})\ v_2 \longrightarrow [x \mapsto v_2]t_{12} \quad \text{(E-AppAbs)}$$

Typing $\Gamma \vdash t : T$

$$\frac{x{:}T \in \Gamma}{\Gamma \vdash x : T} \quad \text{(T-Var)}$$

$$\frac{\Gamma, x{:}T_1 \vdash t_2 : T_2}{\Gamma \vdash \lambda x{:}T_1.t_2 : T_1 \to T_2} \quad \text{(T-Abs)}$$

$$\frac{\Gamma \vdash t_1 : T_{11} \to T_{12} \qquad \Gamma \vdash t_2 : T_{11}}{\Gamma \vdash t_1\ t_2 : T_{12}} \quad \text{(T-App)}$$

(from T&PL by Pierce)

Mathematician's View of PL

» a mathematical object, like a polynomial or a vector

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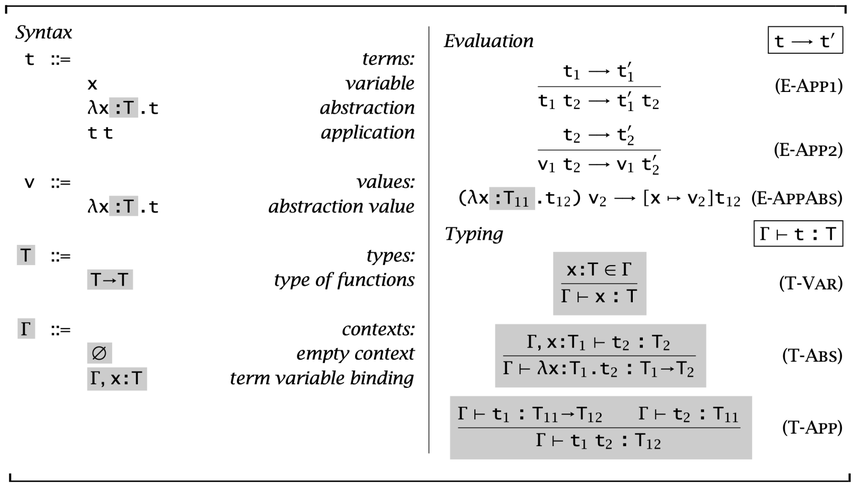

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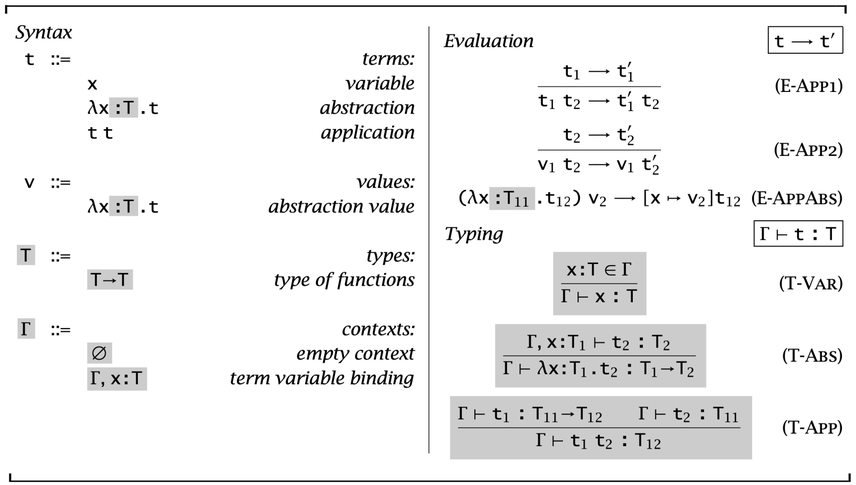

(from T&PL by Pierce)

Mathematician's View of PL

» a mathematical object, like a polynomial or a vector

» a formal specification

» composed of exactly three things:

- Syntax
- Type System
- Semantics

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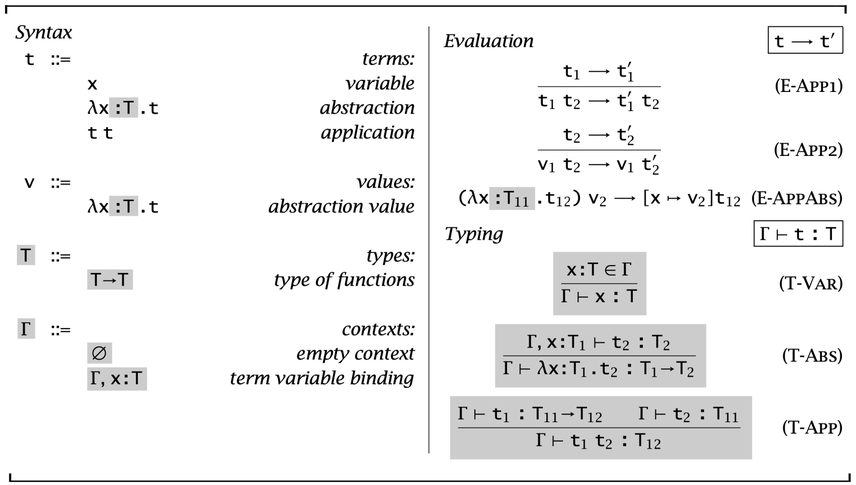

(from T&PL by Pierce)

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This course is about finding out **what makes a PL good**

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We want ***good*** PLs

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(correction: what I think makes a PL good)

A Couple Notes to the Skeptical

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» There are jobs you can only get by knowing a functional PL, and there are more jobs in PL right now than you might expect (DSLs, compilers, verification, security)

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» If you think PL is useless, at least learn the language to tell people why you think so...

Formal PL

The Three Components

The Three Components

Syntax: What a *well-formed* program in your PL?

```
def f():
    return 3
```

```
define f():
    3 return
```

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Type System (Static Semantics): What is a *valid* program in your PL?

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x = 2 + 2
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x = 2 + "two"
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```
x = 2 + "two"
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Semantics (Dynamic Semantics): What is the *output* of a (valid) program?

```
>>> 2 + 2
4
```

```
>>> 2 + 2
False
```

For everything we do from now on, we'll define the **syntax rules**, the **typing rules**, and the **semantic rules**

Syntax Rules

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A syntax rule will almost always be of the form:

If ***<such-and-such>*** *is a well-formed expression and* ***<some-other-things>*** *are a well-formed expression, then* ***<some-combination-of-such-and-such-and-some-other-things>*** *is a well-formed expression*

Example: Integer Addition Syntax

is called production rule

2 + "two" is w.f.

BNF grammar

```
<expr> ::= <expr> + <expr>
```

foo + #x ?

If e_1 is a well-formed expression and e_2 is a well-formed expression, then e_1 + e_2 is a well-formed expression

2 + 42 is w.f.

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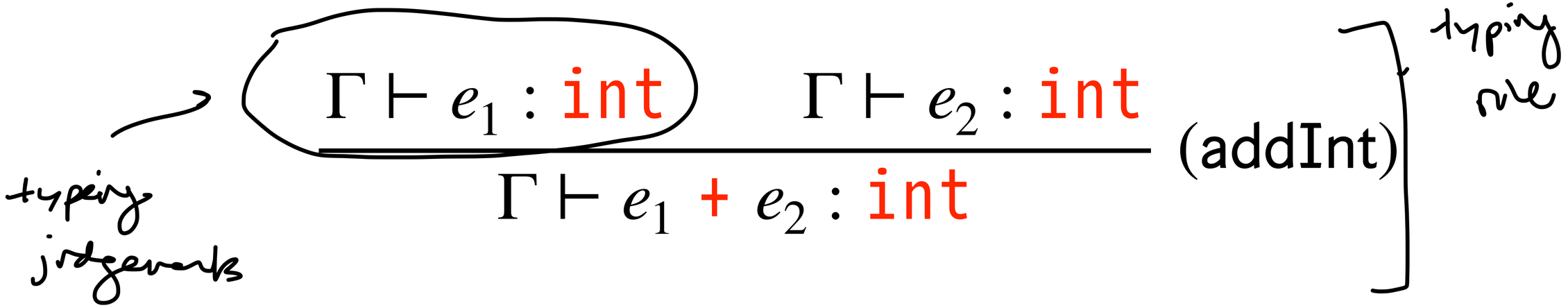
If **<such-and-such>** *is of* **<such-and-such-type>** *and* **<some-other-things>** *are of* **<some-other-types>**, *then* **<some-combination-of-such-and-such-and-some-other-things>** *is of* **<some-different-type>**

Example: Integer Addition Typing



If e_1 is an `int` (in any context Γ) and e_2 is an `int` then (in any context Γ) e_1 `+` e_2 is an `int` (in any context Γ)

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Think of a context in the English sense like the "computational setting" or the "environment"

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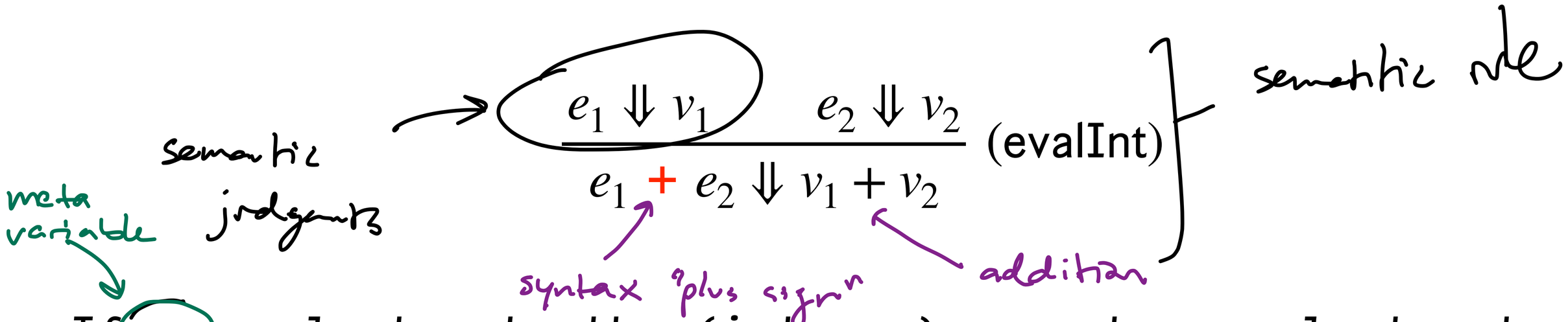
If **<such-and-such>** evaluates to **<such-and-such-value>** and **<some-other-things>** evaluate to **<some-other-values>** then **<some-combination-of-such-and-such-and-some-other-things>** evaluates to **<some-other-value-computed-based-on-such-and-such-value-and-some-other-values>**

Example: Integer Addition Semantics



If e_1 evaluates to the (integer) v_1 and e_2 evaluates to the (integer) v_2, then $e_1 + e_2$ evaluates to the (integer) $v_1 + v_2$

$$\frac{2+3 \Downarrow 5 \qquad 4+6 \Downarrow 10}{(2+3)+(4+6) \Downarrow 15}$$

$$\frac{e_1 \Downarrow 7 \qquad e_2 \Downarrow 4}{e_1 + e_2 \Downarrow 11}$$

We'll come back to all this soon...

OCaml: First Look

Preamble

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A lot of people have a lot to say about OCaml...it's fun but also a bit difficult, it's a very different game then we're probably used to:

» **Minimality:** The language is simple, there's very little to it

» **Functional:** A completely different paradigm. We're not writing procedures via commands/statements, we're defining values via expressions

Preamble (Continued)

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Okay, let's get started...

Overview

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- It was developed at Inria (smart researchers in France) in the 90s
- It won the ACM SIGPLAN Programming Languages Software Award in 2023
- It's used/developed heavily by Jane Street (and too a lesser degree by facebook, Microsoft, docker, Wolfram)

Functional vs. Imperative

OCaml is a functional language. This means a couple things:

- No state (which means no loops!)
- We don't think of a program as describing a procedure, but as defining a value

Anatomy of an OCaml Program

```
let x = 3

let y = "string"

(* function definition *)
let square x = x * x

(* recursive function definition *)
let rec f x = if x = 0 then 0 else x + f (x - 1)

(* We can't just print , we assign to wildcard *)
let _ = print_endline("Hello world")
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The values we assign are gotten by *evaluating* the expressions on the RHS of the '=' sign

Expressions

Expressions are syntactic objects which describe values in a program

Mneumonic: ***E****xpressions are* ***EV****aluated to* ***V****alues*

They appear in both functional and imperative PLs, but in functional PLs we *only* have expressions

$$2 + (2 * 3)$$

```
if x = 3 then 3 else 4
```

$$H(f(f(f(x, y), 2), g(z)))$$

A Note on State

```python
def fact(n):
    acc = 1
    for i in range(1, n + 1): # i is "stateful"
        acc *= i
    return acc
```

In Python, we can define variables that change throughout the evaluation of the program

We can't do this in OCaml. Instead we use **recursion**(!)

If you can write recursive functions in Python, then you can program in OCaml

Free yourself from Pythonic thinking...

demo

(learning by doing)

The Point

Imperative programs define how to update state by a sequence of commands

Function programs define what the output is for a given input

Every imperative program can be made functional by "simulating" loops using recursion

One Last Point: Building Interpreters

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```
parse : string -> expr
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» **Type system** is implemented by a **type checker**

```
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» **Syntax** is implemented by a **parser**

```
parse : string -> expr
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» **Type system** is implemented by a **type checker**

```
type_check : expr -> bool (* valid or not *)
```

» **(Dynamic) semantics** is implemented by an **evaluator**

```
eval : expr -> value
```

Next Steps

- Make sure you're on Piazza and Gradescope, keep an eye on announcements
- Bookmark the course webpage and course repo
- Install opam, VSCode, the course standard library, etc. *(go to lab tomorrow)*
- **Do the reading listed on the course webpage**

Summary

A PL is a mathematical object given by its **syntax**, **type system** and **semantics**

There is **no state** in functional programming. Programs define the output for a given input

Practice, practice, practice. Functional programming takes time to learn, but once you get it, it's as easy as programming in any other PL