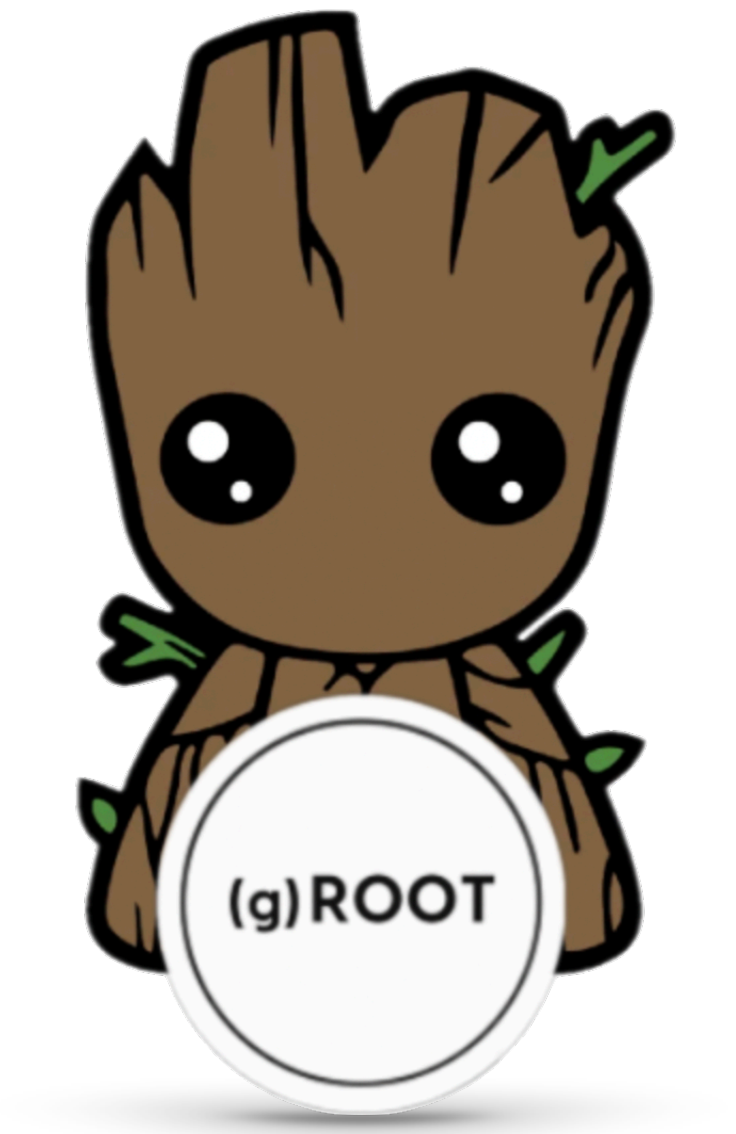
g(root)

Amy Bui
Eliza Encherman
Zach Goldstein
Sam Russo
Nickolas Gravel



start

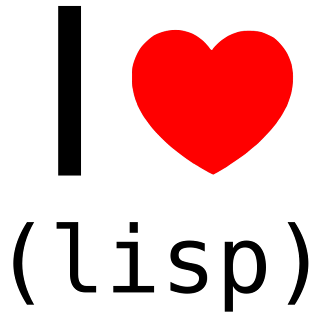
Table of Contents

(g)ROOT

Introduction

g(root)
Key Features

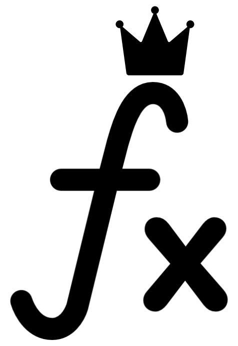
Functional Language
General-purpose functional language, all expressions return a value.



Lisp-like Syntax
Fully parenthesized pre-fixed notation.

Inferred Types

Utilizes the Hadley-Milner type system algorithm to infer various g(root) types

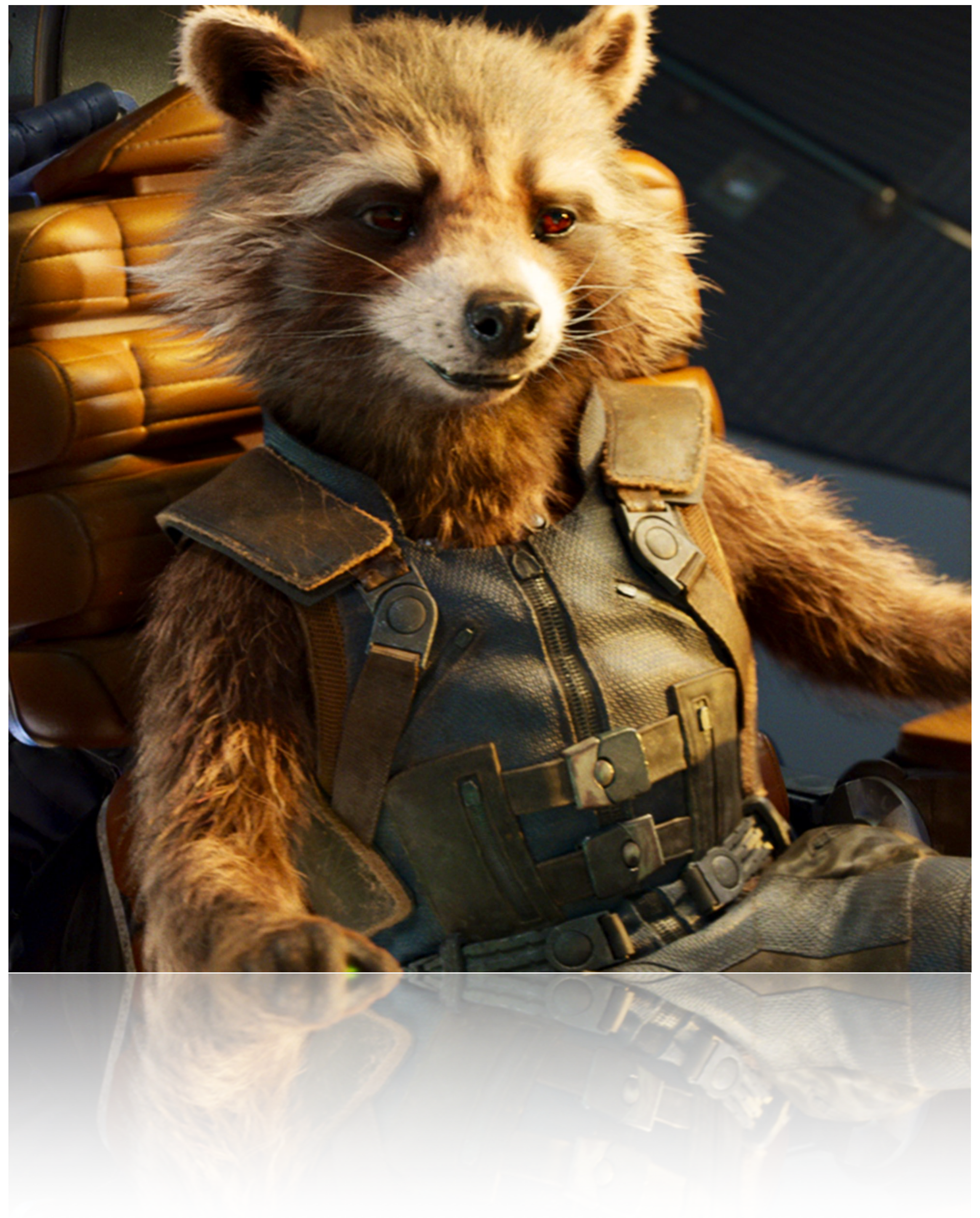


Higher-Order Functions
Functions can be *passed* and *returned* from functions.

Variable Redefinition
Top-level variable redefinition updates all previous references to the redefined value

"Finally a functional language the whole galaxy can enjoy!"

– Rocket Raccoon



next

Motivations...in the beginning.

A ***functional*** language that is ***intuitive*** and ***easy to use*** for first time functional programmers.

Minimalistic programming language – we only give you what you need, no bells and whistles.

Tree data structure as a **basic primitive type.**

But things change...

A ***functional*** language that is ***intuitive*** and ***easy to use*** for first time functional programmers.

Minimalistic programming language — we only give you what you need, no bells and whistles.

~~***Tree*** data structures as a **basic primitive type.**~~

next

g(root) Tutorial

(g)root grammar

$\langle def \rangle$ ::= (val *ident* *expr*)
| *expr*

$\langle expr \rangle$ ::= literal
| *ident*
| *unary-operator* *expr*
| (*binary-operator* *expr* *expr*)
| (*ident* (*expr*})
| (let ([*ident* *expr*] {[*ident* *expr*]}) *expr*)
| (if *expr* *expr* *expr*)
| (lambda ({*arguments*}) *expr*)

$\langle literal \rangle$ ::= *integer-literal* | *boolean-literal* | *character* | *leaf*

$\langle arguments \rangle$ ::= ϵ
| *ident* :: arguments

Code Snippets

```
(val x 4)
(print x)
                            (; prints 4 ;)
(val x (+ 2 x))
(printi (x))                (; prints 6 ;)

(printi if(> 0 x) x ~x)     (; prints -6 ;)
```

Assign *x* a value, modify the *x*, and print the *x*

- **Lisp-style** syntax
- Sequential Execution
- All expressions are literals and variables enclosed in parentheses
- **Redefinition** is allowed

Code Snippets

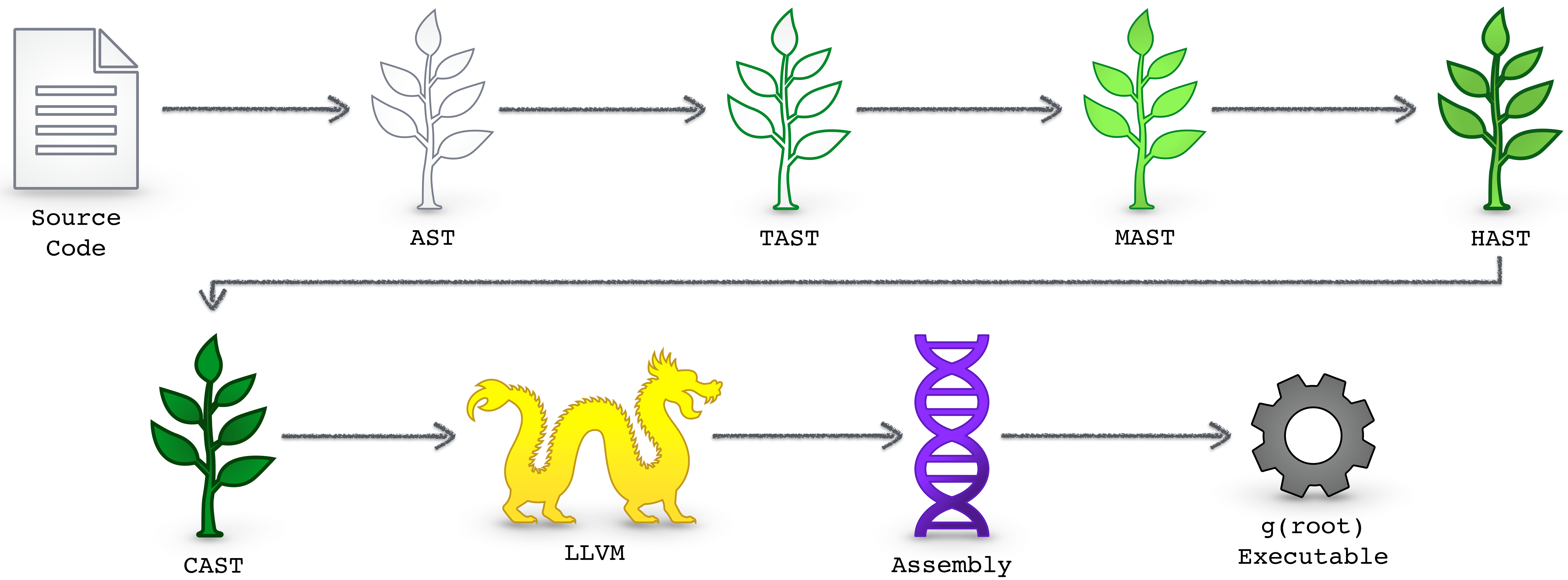
```
(val year 2021)
(print year)                    (; prints 2021 ;)

(val myYear (lambda () year))
(printi (myYear))               (; prints 2021 ;)

(val year 2022)
(printi (myYear))               (; prints 2021 ;)
```

Supports both named and anonymous functions using lambdas.

- Variable values remain **fixed** inside the closure at the time the closure was made
- **Redefinition** of the variable is still allowed

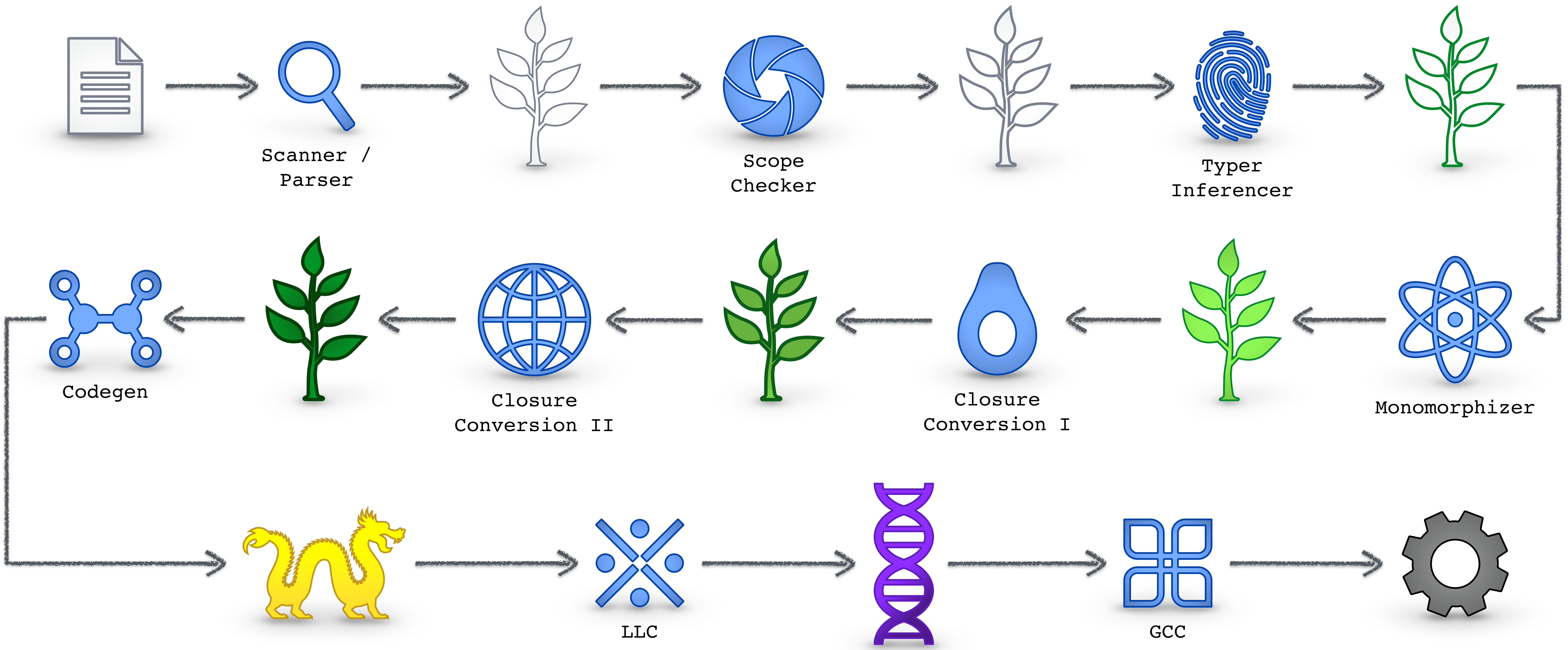
Compiler Architecture

(; src —> ir* —> exe ;)



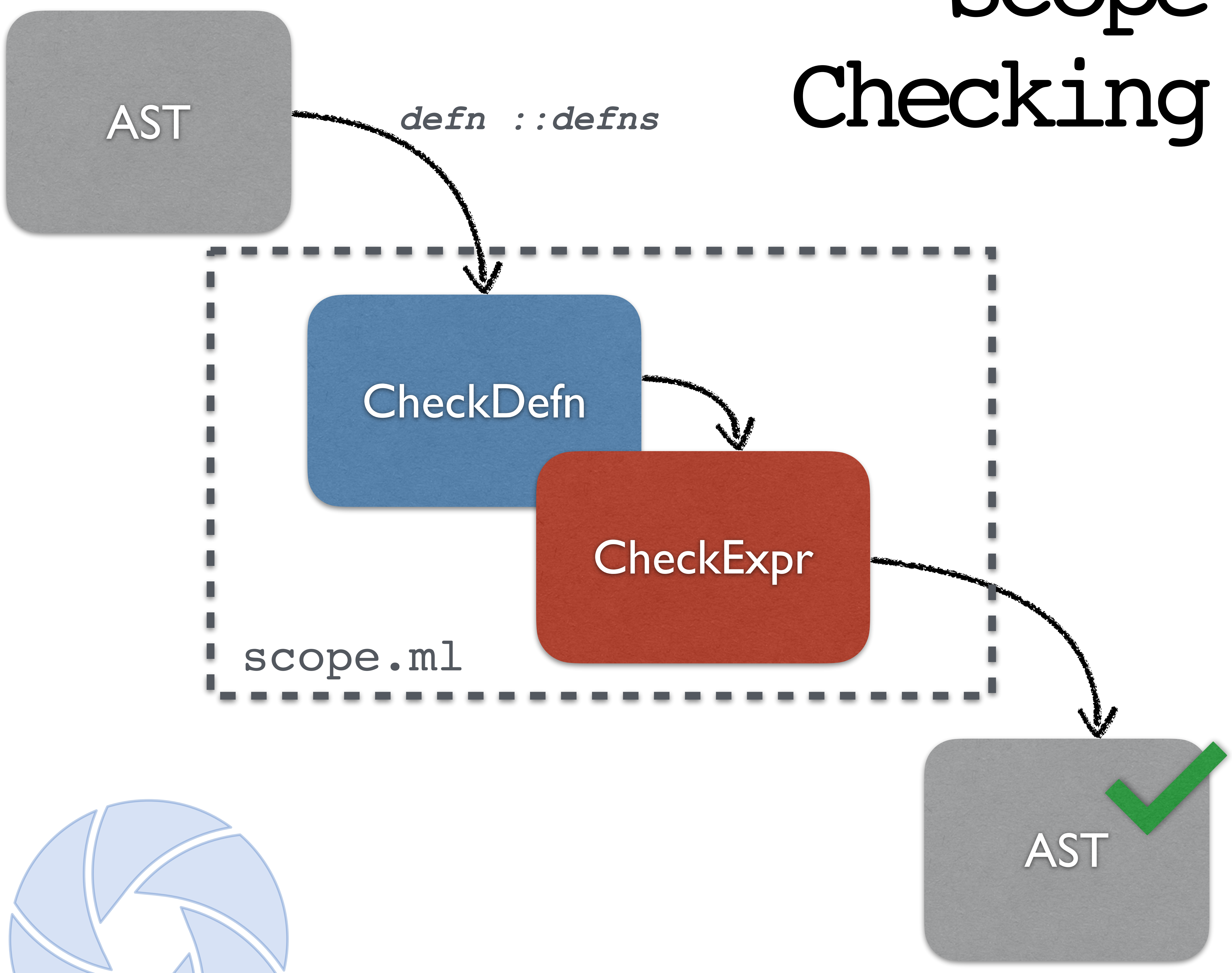
 next

Compiler Module Flow



next

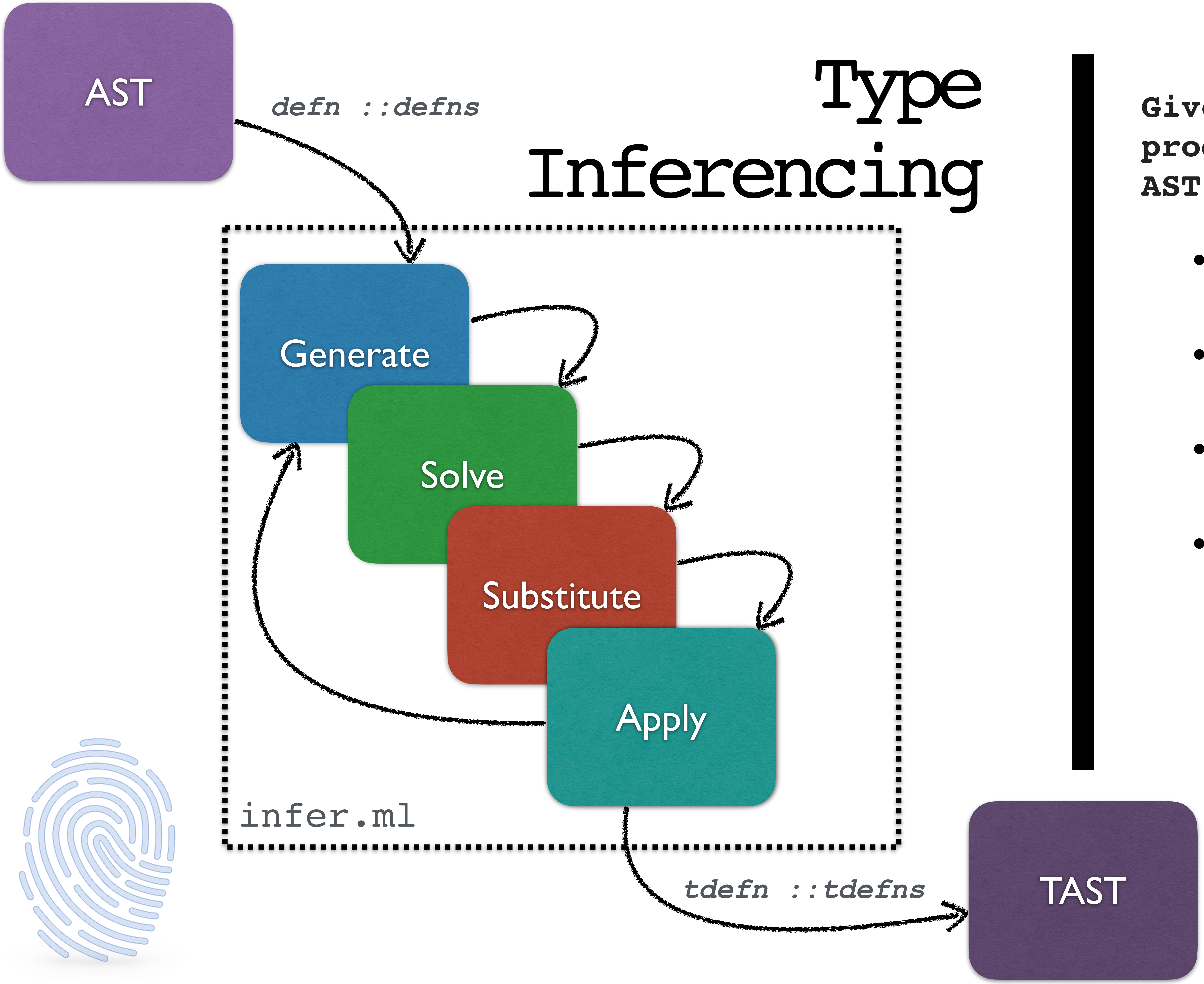
Scope Checking



Given an *AST*, this module performs a partial semantic check

- Ensures variables are used in **correct scope**
- **Unbound variable** checking
- Reports an *unbound error* if found
- Otherwise, this module returns the given AST

Type Inferencing



Given an *AST*, this module produces a *TAST*, or a "Typed" AST

- Utilizes **Hadley-Milner type system** algorithm
- Infers types utilizing **types of primitives** and **literals**
- **Type error** thrown if a type-mismatch is found
- Supports **polymorphism!**
  - ***Note:*** Use nested lambdas at your own risk!

Monomorphization

```
(; retn : 'a -> 'a ;)
(val retn (lambda (n) n))

(retn 13)   (; int ;)

(retn #f)   (; bool ;)

(retn 'c') (; char ;)
```

```
(; retn : int -> int ;)
(val retn (lambda (n) n))
(retn 13)

(; retn : bool -> bool ;)
(val retn (lambda (n) n))
(retn #f)

(; retn : char -> char ;)
(val retn (lambda (n) n))
(retn 'c')
```

Given an *TAST*, this module produces a *MAST*, or a "Monomorphized" AST

- Searches the TAST for any use of polymorphic expressions
- Injects a *mono-typed* definition to resolve all polymorphism
- **Bugs**:
  - **Int type** is inserted for any expression still bound to a type variable

Closure Conversion I

```
let partial_closure_type(id, retty, formaltys, freetys) =
   HTycon (HCls (id, retty, formaltys, freetys))
```

Given an *MAST*, this module produces a *HAST*, or "H for H" AST

- ***Partial* Closure Conversion for Lambda Expressions**
  - Re-types lambda expressions to newly defined **closure type**
  - **Unique name** – indicates a function call to execute, or which closure type to use
  - **Types** of **return**, **formals**, and **free variables**
- Detects uses of **higher-order functions**, and augments the types and expressions to refer to new closure type.

Closure Conversion II

```
let function_definition =
{
  bodyExpression;
  returnType;
  functionName;
  formals;
  freeVars;
}

```

Given an *HAST*, this module produces a *CAST*, or a “Closed” AST

- Redefined variables are tracked
- A **new function definition** is created for every lambda expression
- The new definition carries the lambda’s body

Closure Conversion II

```
closure _lambda0 {
  int (int, int)* ;        (;_func0;)
}                          (; retn ;)

int _func0 (int n, int m) {
  return n;
}
```

```
...
(val retn (lambda (n m) n))
(val x 42)
...



... lambda (a) (retn x a) ...
```

```
closure _lambda1 {
  int (int, _lambda0*, int)* ;   (;_func1;)
  _lambda0* ;
  int;
}

int _func1 (int a, _lambda0* retn, int x) {
  func = retn[0];
  result = func(x a);
  return result;
}
```

Putting the lid on lambda expressions.

- **Closed Lambda Expression**
  - *Unique name* - indicates function call to execute correct lambda body
  - *List of Free Variables - as Var expressions*
    - Names are modified with most recent occurrence number appended
- **Closure Type of Closed Lambdas:**
  - List of the types of the free variables
  - Augmented function type

Code Generation

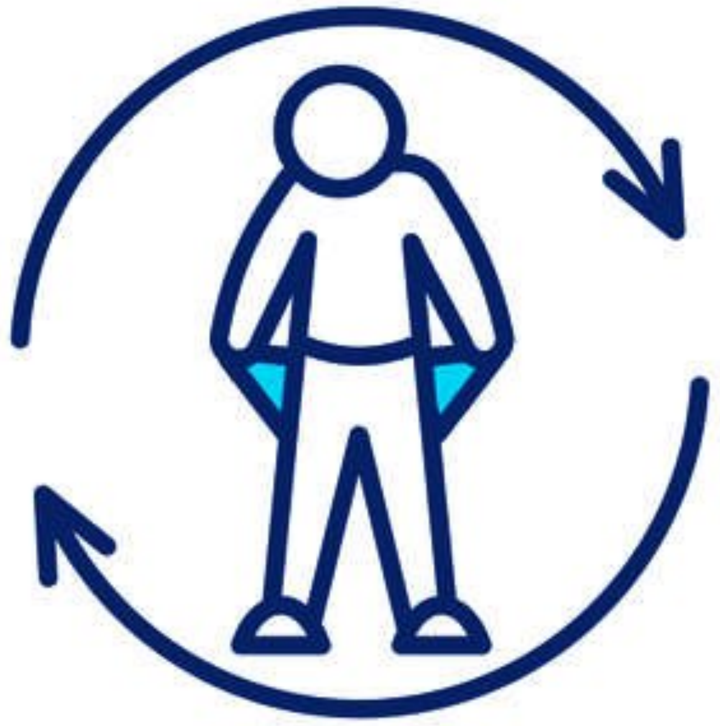
Int	i32
Bool	i1
Char	i8*
Closures	unique, named struct ptrs: { fptr; [frees] }

*abstract types become **lltypes***

Given a *CAST* this module translates expressions into *LLVM*

- Every *definition* is an *instruction* in main()
- Top-level val definitions assign values to **global variable names**
- Each lambda's body expression is a **uniquely** named function definition
- **Redefinitions** allowed by tagging variable with the **occurrence #**
  - This ensures closures use the **correct value of a free variable** even if that variable gets redefined

Conclusions



Writing a type inferencer took away a lot of resources.

Two out of our five members spent much of the time implementing this module. It took a lot of time and resources to complete.

Lesson learned:
Implement a working compiler without inferred typing, *then* introduce type inferencing.

Give g(root) roots, and branches, and leaves!

Initially, we planned to implement a primitive tree ADT for g(root). However, due to time, we decided to save this feature for later release.

Lookout for g(root) vol. 2!

Start with an interpreter when implementing a functional language,

Implementing an **interpreter** early in development would have helped **generate test cases**, and **flesh out ideas** early in the development process.

Demonstration

FIN.

Presenters:
Amy Bui
Eliza Encherman
Zach Goldstein
Sam Russo
Nickolas Gravel

close