Compiler Construction

Chapter 4 – Type Checking

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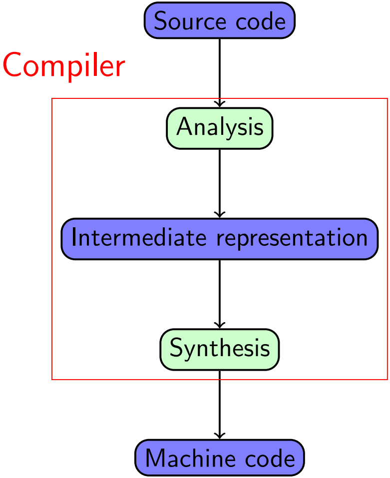
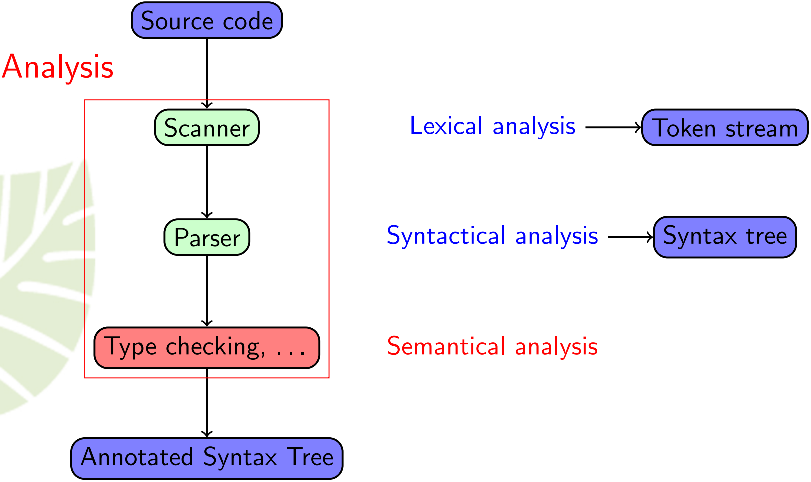
Compiler Overview




Source code
Analysis
Scanner
Parser
Type checking, ...
Annotated Syntax Tree
Lexical analysis
Token stream
Syntactical analysis
Syntax tree
Semantical analysis

Type Checking

- In most modern programming languages variables and functions are typed
- Examples
  - `int`
  - `void*`
  - `struct { int x; int y; }`
- Useful
  - Memory management
  - avoiding run-time errors
  - well-typed programs don't go wrong
- Types can be
  - declared and then checked
  - inferred

Type Expressions

- Types are defined by type expressions
- Type expressions
  1. base types like `int`, `float`
  2. type constructors applied to types
- Examples of type constructor expressions
  - record:
  - pointer: `t*`
  - arrays: `t[]`
  - functions: `t(t1,...,tk)`

Type Names

- Synonym for type expression
- Omitted from project
- Used as a short-hand notion

  ⇒ `typedef struct { int x; int y; } point_t`
- Used to define recursive types

Two definitions of singly-linked lists

```
struct list {
    int info;
    struct list* next;
}

struct list* head;
```

```
typedef struct list list_t;
struct list {
    int info;
    list_t* next;
}
list_t head;
```

Type Checking

Given: set of type declarations $\Gamma = [t_1\ x_1, \ldots, t_k\ x_k]$

Check: Can expression `e` have type `t`?

Random type expressions

```
struct list { int info; struct list* next; }
int f(struct list* l) { return 1; }
struct { struct list* c; }* b;
int* a[11];
```

Is the following expression type correct? `*a[f(b->c)]*2`

Type Checking the AST

Traverse the syntax tree bottom-up!

Variables	look up type in type environment Γ
Constants	determine type directly
Inner nodes	apply typing rules

Typing Rules

Formally we consider statements of the form

$$\Gamma \vdash e : t$$

In type environment Γ expression e has type t.

Axioms

$$\begin{array}{lll} \textsc{Const}: & \Gamma \vdash c : t_c & (t_c \text{ type of constant } c) \\ \textsc{Var}: & \Gamma \vdash x : \Gamma(x) & (x \text{ variable}) \end{array}$$

Rules

$$\textsc{Ref}: \quad \frac{\Gamma \vdash e : t}{\Gamma \vdash \&e : t*} \qquad\qquad \textsc{Deref}: \quad \frac{\Gamma \vdash e : t*}{\Gamma \vdash *e : t}$$

More C Rules

ARRAY1: $$\frac{\Gamma \vdash e_1 : t* \quad \Gamma \vdash e_2 : \texttt{int}}{\Gamma \vdash e_1[e_2] : t}$$

ARRAY2: $$\frac{\Gamma \vdash e_1 : t[] \quad \Gamma \vdash e_2 : \texttt{int}}{\Gamma \vdash e_1[e_2] : t}$$

STRUCT: $$\frac{\Gamma \vdash e : \texttt{struct}\{t_1\ a_1; \ldots ; t_m\ a_m\}}{\Gamma \vdash e.a_i : t_i}$$

APP: $$\frac{\Gamma \vdash e : t(t_1 \ldots t_k) \quad \Gamma \vdash e_1 : t_1 \ldots \Gamma \vdash e_k : t_k}{\Gamma \vdash e(e_1 \ldots e_k) : t}$$

OP: $$\frac{\Gamma \vdash e_1 : \texttt{int} \quad \Gamma \vdash e_2 : \texttt{int}}{\Gamma \vdash e_1 + e_2 : \texttt{int}}$$

CAST: $$\frac{\Gamma \vdash e : t_1 \quad t_1 \text{ converts to } t_2}{\Gamma \vdash (t_2)e : t_2}$$

Type Equality

- In order to apply typing rules, type equality needs to be checked
- In C: `struct A { }` and `struct B { }` are considered different types
- Extending a record works only by embedding it into a larger one
- Type synonmys are considered equal

⇒ `typedef int C;` means that `int` and `C` become equal types

Overloading

- Some operators like `+` are overloaded
- Possible types for $7+$ (non-exhaustive)
  - `int +(int,int)`
  - `float +(float,float)`
  - `float* +(float*, int)`
- Depending on its type, `+` may have different implementations
- Arguments determine which implementation

```
1 + 2.4
```

- Instead of defining all possible combinations of argument types, argument types are converted

⇒ Coercion

- Such a conversion may generate extra code
- Usually one converts to supertypes
  - → expression above will have type `float`

C features particular coercion rules for integer types: promotion

$$\begin{array}{c}\texttt{unsigned char}\\ \texttt{signed char}\end{array} \leq \begin{array}{c}\texttt{unsigned short}\\ \texttt{signed short}\end{array} \leq \texttt{int} \leq \texttt{unsigned int}$$

Integer promotion may lead to subtle mistakes

What's the output?

```
int si = -1;
unsigned int ui = 1;
printf("%d\n", si < ui);
```

Good for you: Project requires only ints.

Summary

- Why types?
- What are types (expressions, names)?
- Checking algorithm and typing rules
- C specific stuff