CSL302: Compiler Design

Intermediate Code Generation

Vishwesh Jatala

Assistant Professor

Department of CSE

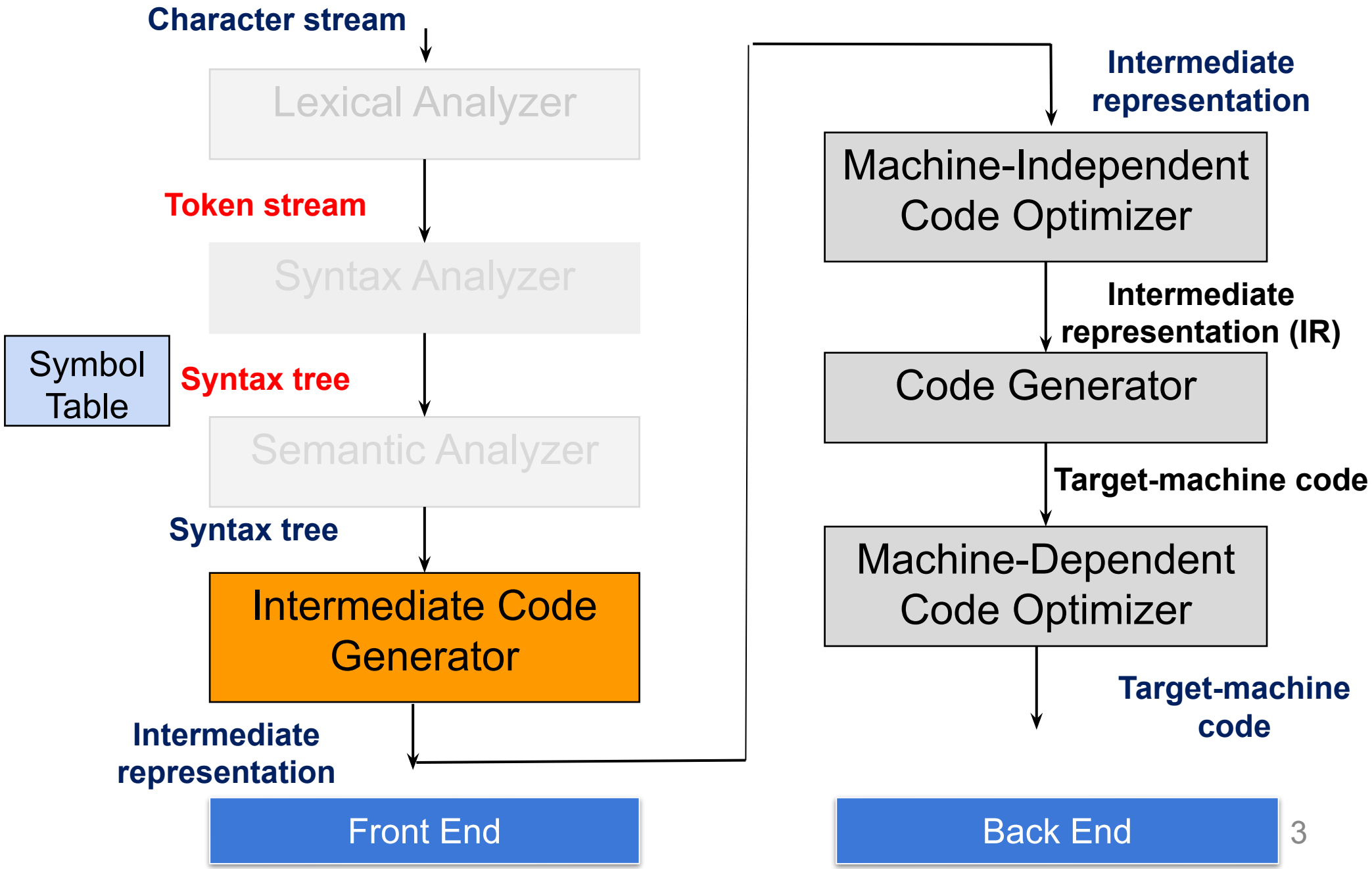
Indian Institute of Technology Bhilai

vishwesh@iitbhilai.ac.in

Acknowledgement

- References for today's slides
  - *Lecture notes of Prof. Amey Karkare (IIT Kanpur) and Late Prof. Sanjeev K Aggarwal (IIT Kanpur)*
  - *IIT Madras (Prof. Rupesh Nasre)*
    http://www.cse.iitm.ac.in/~rupesh/teaching/compiler/aug15
  - *Course textbook*

Compiler Design



Access to non-local names

```
{  var X: integer
    X=50
    procedure Bar
   begin
       print X ---> S
    end
    procedure Foo
   begin
       var X: integer
            X=10
            Bar()
       end
    end
    Foo ()
end
```

Output of X at S?

Access to non-local names

- Scope rules determine the treatment of non-local names
- A common rule is *lexical scoping* or *static scoping* (most languages use lexical scoping)
  - Most closely nested declaration
- Alternative is *dynamic scoping*
  - Most closely nested activation

Scope with nested procedures

```
{  var X: integer
    X=50
    procedure Bar
   begin
       print X ---> S
    end
    procedure Foo
   begin
       var X: integer
            X=10
            Bar()
       end
    end
    Foo ()
end
```

Output at S: 50

Scope with nested procedures

How to implement?

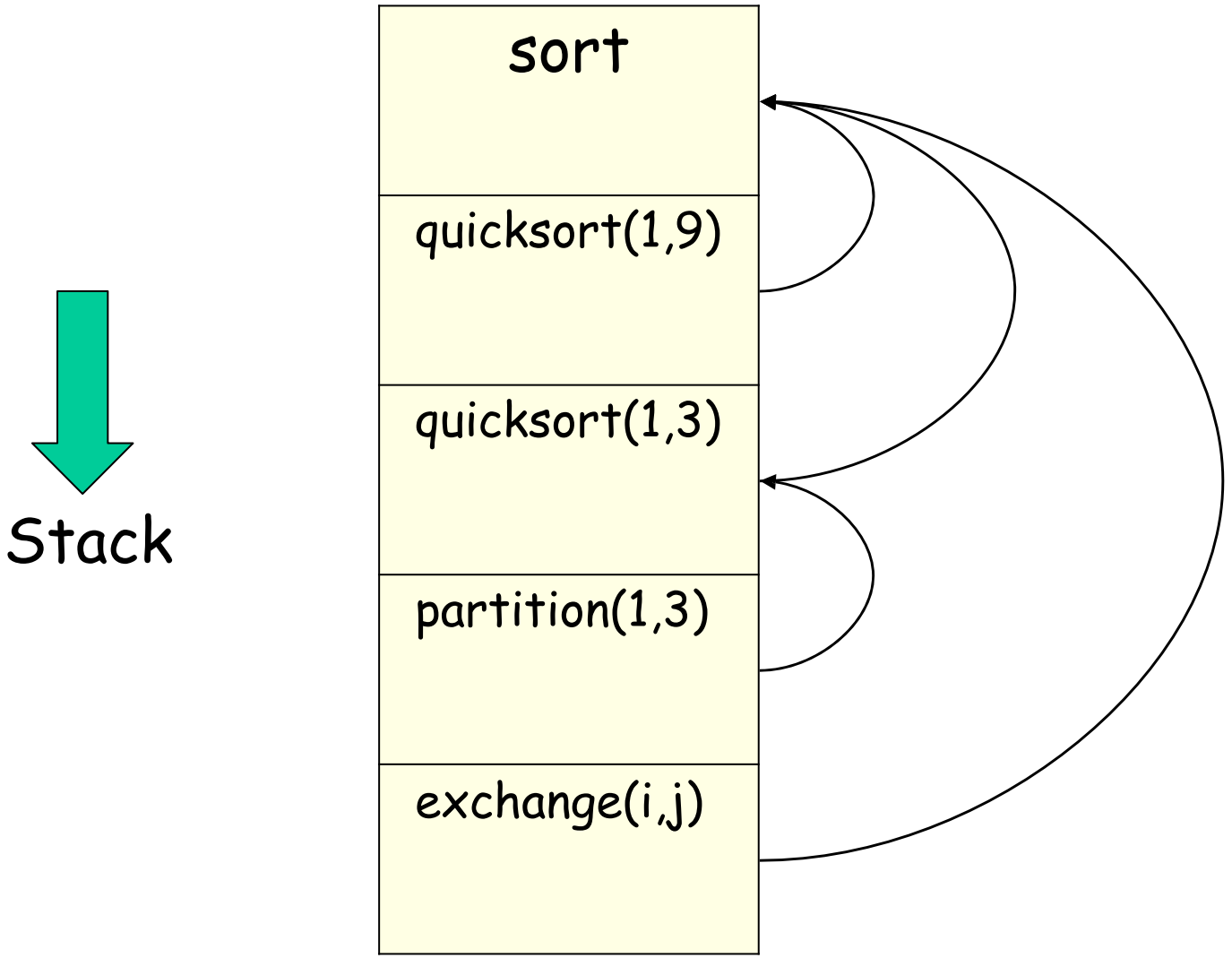
Access to non-local names

- Include a field ‘access link’ in the activation record
- If p is nested in q then access link of p points to the access link in most recent activation of q

Scope with nested procedures

```
Program sort;
 var a: array[1..n] of integer;
        x: integer;
 procedure readarray;
    var i: integer;
    begin

    end;
 procedure exchange(i,j:integer)
    begin

    end;
```

```
procedure quicksort(m,n:integer);
   var k,v : integer;

   function partition(y,z:integer): integer;
      var i,j: integer;
      begin

      end;
   begin
                        .
   end;
begin
            .
end.
```


Stack
sort
quicksort(1,9)
quicksort(1,3)
partition(1,3)
exchange(i,j)

Dynamic Scoping

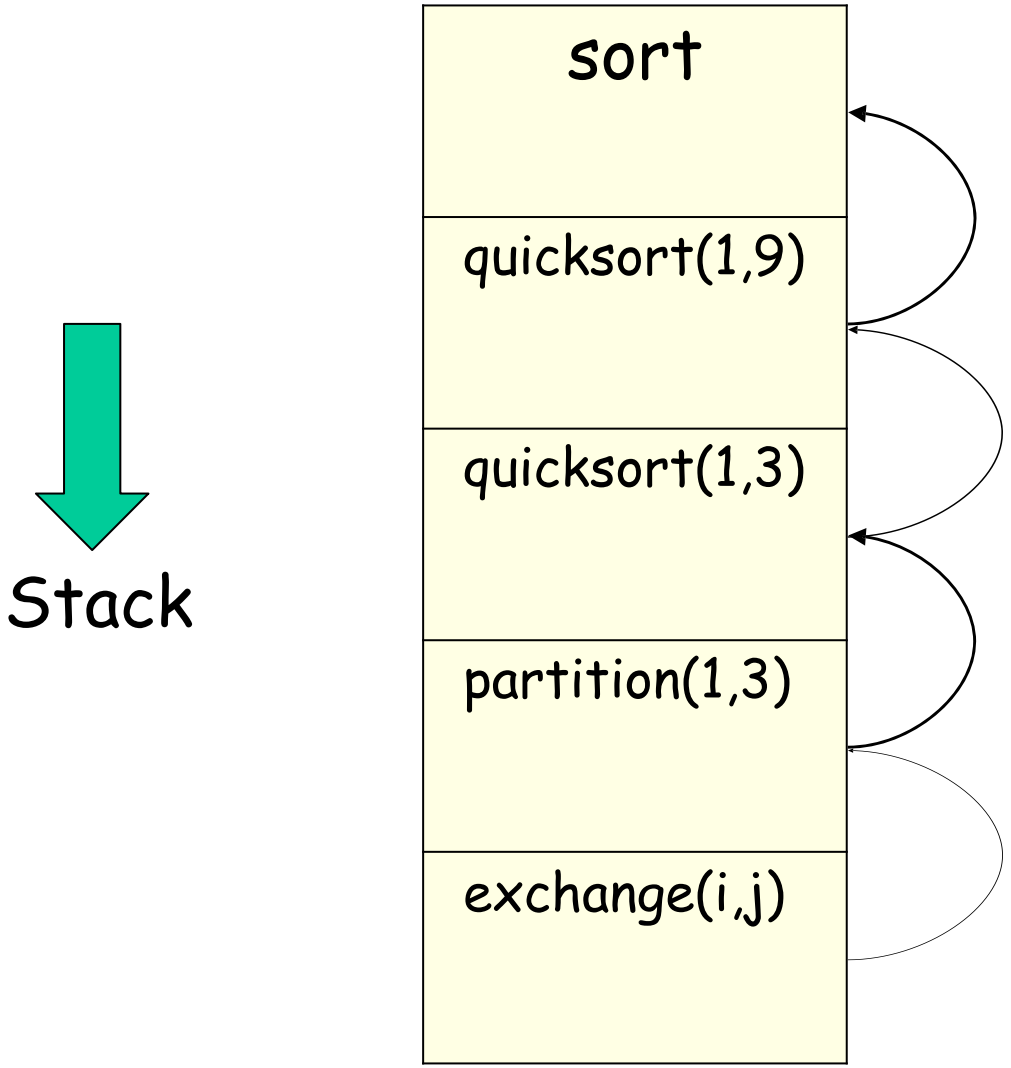
- Dynamic scoping:
  - The declaration of an identifier (v) is determined by the most recent declaration that is seen during the execution leading the occurrence of v

Dynamic Scoping: Example

```
{  var X: integer
    X=50
    procedure Bar
   begin
       print X ---> S
    end
    procedure Foo
   begin
       var X: integer
            X=10
            Bar()
       end
    end
    Foo ()
end
```

Output at S: 10

Implementing Dynamic Scope



Summary

- Intermediate code generation
  - Procedure
    - Three address code
    - Runtime environment
    - Static scoping
    - Dynamic scoping

Type system

- What is a type in the programming language?

Type system

- A type is a set of values and operations on those values
- A language's type system specifies which operations are valid for a type
- The aim of type checking is to ensure that operations are used on the variable/expressions of the correct types

Type system

- Languages of three categories w.r.t type:
  - "untyped"
    - No type checking needs to be done
    - Assembly languages
  - Statically typed
    - All type checking is done at compile time
    - Algol class of languages
    - Also, called strongly typed
  - Dynamically typed
    - Type checking is done at run time
    - Mostly functional languages like Lisp, Scheme etc.

Type systems

- Static typing
  - Catches most common programming errors at compile time
  - Avoids runtime overhead
- Most code is written using static types languages
- In fact, developers for large/critical system insist that code be strongly type checked at compile time even if language is not strongly typed.

Type expression

- Type of a language construct is denoted by a type expression
  - It is either a basic type OR
  - it is formed by applying operators called *type constructor* to other type expressions

Type expression

- **Basic types:**
  - integer, char, float, boolean
- **Constructed type:**
  - array, record, pointers, functions
- **Enumerated type:** (violet, indigo, red)

Type Constructors

- Array: if T is a type expression then array(I, T) is a type expression denoting the type of an array with elements of type T and index set I

  int A[10];

  A can have type expression array(0 .. 9, integer)

- Product: if T1 and T2 are type expressions then their Cartesian product T1 * T2 is a type expression
  - Pair/tuple

Type constructors

- Records: it applies to a tuple formed from field names and field types. Consider the declaration

```
type student = record
          id:   integer;
          name:  array [1 .. 15] of char
         end;

var s: student;
```

Type constructors

- Pointer: if T is a type expression then pointer(T) is a type expression denoting type pointer to an object of type T

Specifications of a type checker

- Consider a language which consists of a sequence of declarations followed by a single expression

  $P \rightarrow D\ ;\ E$

  $D \rightarrow D\ ;\ D \mid id : T$

  $T \rightarrow char \mid integer \mid T[num] \mid\ T*$

  $E \rightarrow literal \mid num \mid E\%E \mid E\ [E] \mid *E$

Specifications of a type checker …

- A program generated by this grammar is

  key : integer;
  key %1999

- Assume following:
  - basic types are char, int, etc
  - all arrays start at 0
  - char[256] has type expression
    array(0 .. 255, char)

Rules for Symbol Table entry

$D \rightarrow id : T$	addtype(id.entry, T.type)
$T \rightarrow char$	T.type = char
$T \rightarrow integer$	T.type = int
$T \rightarrow T_1 *$	T.type = pointer(T_1.type)
$T \rightarrow T_1 [num]$	T.type = array(0..num-1, T_1.type)

Type checking for expressions

$E \rightarrow$ literal	E.type = char
$E \rightarrow$ num	E.type = integer
$E \rightarrow$ id	E.type = lookup(id.entry)
$E \rightarrow E_1 \% E_2$	E.type = if E_1.type == integer and E_2.type==integer then integer else type_error

Type conversion

- Consider expression like x + i where x is of type real and i is of type integer
- Internal representations of integers and reals are different in a computer
  - different machine instructions are used for operations on integers and reals
- The compiler has to convert both the operands to the same type
- Language definition specifies what conversions are necessary.

Type conversion

- Type checker is used to insert conversion operations:

  x + i

  x + inttoreal(i)

- Type conversion is called implicit/coercion if done by compiler.
- It is limited to the situations where no information is lost
- Conversions are explicit if programmer has to write something to cause conversion

Type checking for expressions

$E \rightarrow$ num E.type = int

$E \rightarrow$ num.num E.type = real

$E \rightarrow$ id E.type = lookup(id.entry)

$E \rightarrow E_1$ op E_2 E.type =

if E_1.type == int && E_2.type == int
then int
elif E_1.type == int && E_2.type == real then real
elif E_1.type == real && E_2.type == int
then real
elif E_1.type == real && E_2.type==real
then real

Compiler Design