Faculty of Science

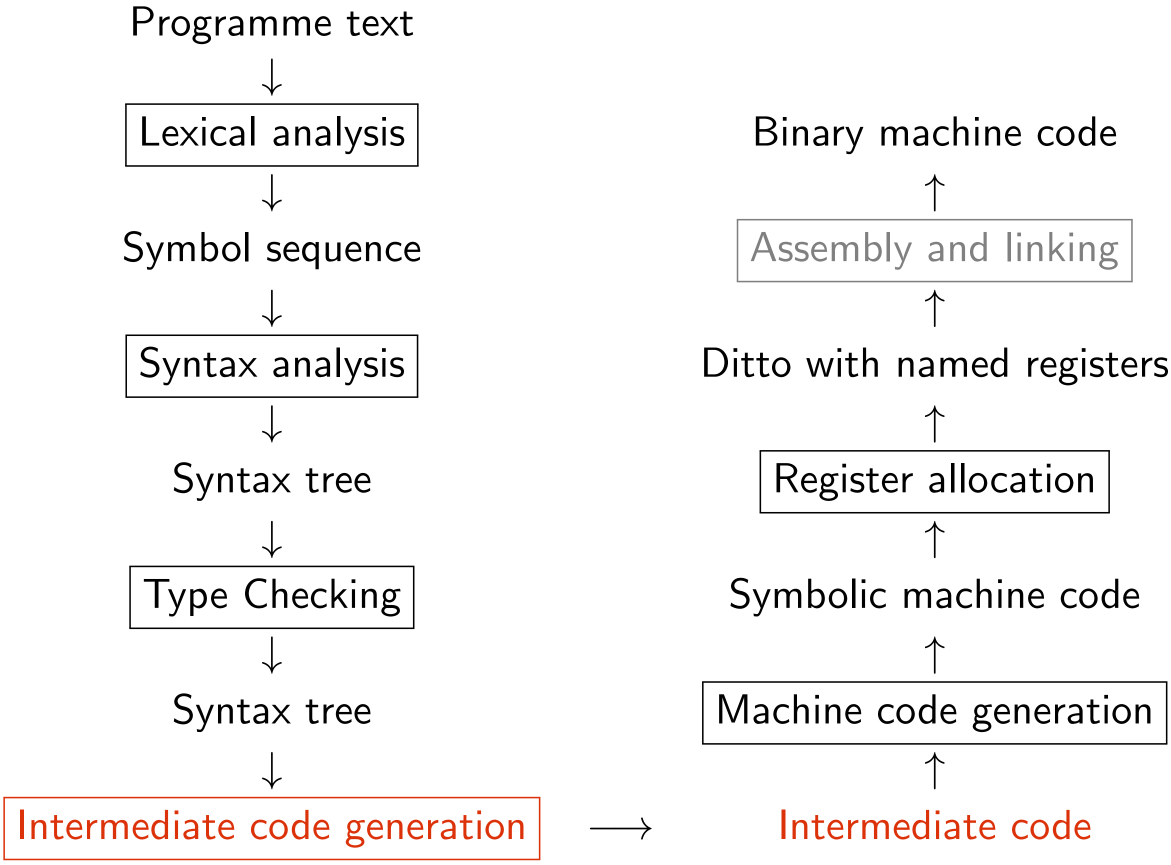
Intermediate-Code Generation

Cosmin E. Oancea
`cosmin.oancea@diku.dk`

Department of Computer Science
University of Copenhagen

December 2012

Structure of a Compiler

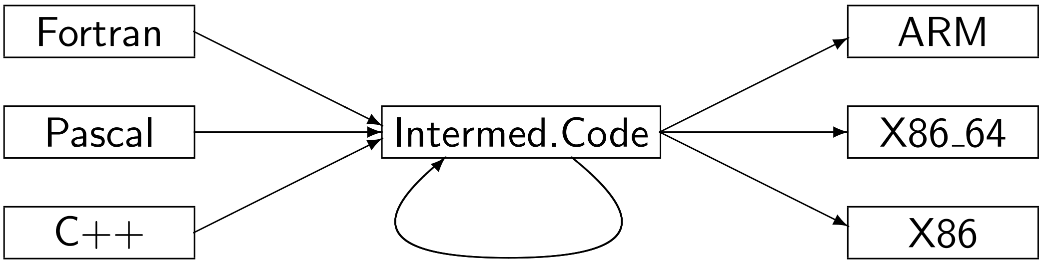


Programme text
↓
Lexical analysis
↓
Symbol sequence
↓
Syntax analysis
↓
Syntax tree
↓
Type Checking
↓
Syntax tree
↓
Intermediate code generation ⟶ Intermediate code
↑
Machine code generation
↑
Symbolic machine code
↑
Register allocation
↑
Ditto with named registers
↑
Assembly and linking
↑
Binary machine code

1. Why Intermediate Code?
    - Intermediate Language
    - To-Be-Translated Language
2. Syntax-Directed Translation
    - Arithmetic Expressions
    - Statements
    - Boolean Expressions, Sequential Evaluation
3. Translating More Complex Structures
    - More Control Structures
    - Arrays and Other Structured Data
    - Role of Declarations in the Translation

Why Intermediate Code

- Compilers for different platforms and languages can share parts



- Machine-independent optimisations are possible
- Also enables interpretation. . .

Intermediate Language IL

- Machine Independent: no limit on register and memory, no machine-specific instructions.

- Mid-level(s) between source and machine languages (tradeoff): simpler constructs, easier to generate machine code

- What features/constructs should IL support?
  - every translation loses information;
  - use the information before losing it!

- How complex should IL's instruction be?
  - complex: good for interpretation (amortizes instruction-decoding overhead),
  - simple: can more easily generate optimal machine code.

Intermediate Language

Here: Low-level language, but keeping functions (procedures).
Small instructions:

- 3-address code: one operation per expression.
- Memory read/write (`M`) (address is atom).
- Jump labels, `GOTO` and conditional jump (`IF`).
- Function calls and returns

Prg → *Fcts*
Fcts → *Fct Fcts* | *Fct*
Fct → *Hdr Bd*
Hdr → **functionid**(*Args*)
Bd → [*Instrs*]

Instrs → *Instr* ; *Instrs* | *Instr*
Instr → **id** := *Atom* | **id** := **unop** *Atom*
| **id** := **id binop** *Atom*
| **id** := *M*[*Atom*] | *M*[*Atom*] := **id**
| `LABEL` **label** | `GOTO` **label**
| `IF` **id relop** *Atom*
`THEN` **label** `ELSE` **label**
| **id** := `CALL` **functionid**(*Args*)
| `RETURN` **id**
Atom → **id** | **num**
Args → **id** , *Args* | **id**

The To-Be-Translated Language

We shall translate a simple procedural language:

- Arithmetic expressions and function calls, boolean expressions,
- conditional branching (`if`),
- two loops constructs (`while` and `repeat until`).

Syntax-directed translation:

- In practice we work directly on the abstract-syntax tree AbSyn (but here we use a generic-grammar notation)
- Implement each syntactic category via a translation function: Arithmetic expressions, Boolean expressions, Statements.
- Code for subtrees is generated independent of context (i.e., context is a parameter to the translation function)

Translating Arithmetic Expressions

Expressions in Source Language

- Variables and number literals,
- unary and binary operations,
- function calls (with argument list).

$$\begin{array}{lcl} \mathit{Exp} & \rightarrow & \mathbf{num} \mid \mathbf{id} \\ & & \mid \mathbf{unop}\ \mathit{Exp} \\ & & \mid \mathit{Exp}\ \mathbf{binop}\ \mathit{Exp} \\ & & \mid \mathbf{id}(\mathit{Exps}) \\ \mathit{Exps} & \rightarrow & \mathit{Exp} \mid \mathit{Exp}\ ,\ \mathit{Exps} \end{array}$$

Translation function:

$\mathit{Trans}_{\mathit{Exp}}$ `:: (Exp, VTable, FTable, Location) -> [ICode]`

- Returns a list of intermediate code instructions `[ICode]` that . . .
- . . . upon execution, computes `Exp`'s result in variable `Location`.
- Case analysis on `Exp`'s abstract syntax tree (ABSYN).

Symbol Tables and Helper Functions

Translation function:

$\mathit{Trans}_{\mathit{Exp}}$ `:: (Exp, VTable, FTable, Location) -> [ICode]`

Symbol Tables

vtable : variable names to intermediate code variables

ftable : function names to function labels (for `call`)

Helper Functions

`lookup`: retrieve entry from a symbol table

`getvalue`: retrieve value of source language literal

`getname`: retrieve name of source language variable/operation

`newvar`: make new intermediate code variable

`newlabel`: make new label (for jumps in intermediate code)

`trans_op`: translates an operator name to the name in IL.

Generating Code for an Expression

$Trans_{Exp}$: `(Exp, VTable, FTable, Location) -> [ICode]`
$Trans_{Exp}\ (exp, vtable, ftable, place) =$ case exp of

num	$v =$ getvalue(**num**) $[place := v]$
id	$x =$ lookup($vtable, getname$(**id**)) $[place := x]$
unop Exp_1	$place_1 =$ newvar() $code_1 = Trans_{Exp}(Exp_1, vtable, ftable, place_1)$ $op =$ trans_op($getname$(**unop**)) $code_1$ @ $[place := op\ place_1]$
Exp_1 **binop** Exp_2	$place_1 =$ newvar() $place_2 =$ newvar() $code_1 = Trans_{Exp}(Exp_1, vtable, ftable, place_1)$ $code_2 = Trans_{Exp}(Exp_2, vtable, ftable, place_2)$ $op =$ trans_op($getname$(**binop**)) $code_1$ @ $code_2$ @ $[place := place_1\ op\ place_2]$

Generating Code for a Function Call

$Trans_{Exp}\ (exp, vtable, ftable, place) =$ case exp of ...

id$(Exps)$	$(code_1, [a_1, \ldots, a_n]) = Trans_{Exps}(Exps, vtable, ftable)$ $fname =$ lookup($ftable, getname$(**id**)) $code_1$ @ $[place :=$ CALL $fname(a_1, \ldots, a_n)]$

$Trans_{Exps}$ returns the code that evaluates the function's parameters, *and* the list of new-intermediate variables (that store the result).

$Trans_{Exps}$: `(Exps, VTable, FTable) -> ([ICode], [Location])`
$Trans_{Exps}(exps, vtable, ftable) =$ case $exps$ of

Exp	$place = newvar()$ $code_1 = Trans_{Exp}(Exp, vtable, ftable, place)$ $(code_1, [place])$
Exp , $Exps$	$place = newvar()$ $code_1 = Trans_{Exp}(Exp, vtable, ftable, place)$ $(code_2, args) = Trans_{Exps}(Exps, vtable, ftable)$ $code_3 = code_1$ @ $code_2$ $args_1 = place :: args$ $(code_3, args_1)$

Translation Example

Assume the following symbol tables:

- vtable $= [x \mapsto v0,\ y \mapsto v1,\ z \mapsto v2]$
- ftable $= [f \mapsto \_F\_1]$

Translation of `Exp` with place $= t0$:

- `Exp=x-3`

```
t1 := v0
t2 := 3
t0 := t1 - t2
```

- `Exp=3+f(x-y,z)`

```
  t1 := 3
      t4 := v0
      t5 := v1
    t3 := t4 - t5
    t6 := v2
  t2 := CALL _F_1(t3, t6)
t0 := t1 + t2
```

---

1. Why Intermediate Code?
   - Intermediate Language
   - To-Be-Translated Language
2. Syntax-Directed Translation
   - Arithmetic Expressions
   - Statements
   - Boolean Expressions, Sequential Evaluation
3. Translating More Complex Structures
   - More Control Structures
   - Arrays and Other Structured Data
   - Role of Declarations in the Translation

Translating Statements

Statements in Source Language

- Sequence of statements
- Assignment
- Conditional Branching
- Loops: `while` and `repeat` (simple conditions for now)

Stat → *Stat* ; *Stat*
| **id** := *Exp*
| `if` *Cond* `then` { *Stat* }
| `if` *Cond* `then` { *Stat* } `else` {*Stat*}
| `while` *Cond* `do` { *Stat* }
| `repeat` { *Stat* } `until` *Cond*
Cond → *Exp* **relop** *Exp*

We assume relational operators translate directly (using `trans_op`).

Translation function:

Trans$_{Stat}$ `:: (Stat, VTable, FTable) -> [ICode]`

- As before: syntax-directed, case analysis on `Stat`
- Intermediate code instructions for statements

Generating Code for Sequences, Assignments,. . .

Trans$_{Stat}$ `: (Stat, Vtable, Ftable) -> [ICode]`
Trans$_{Stat}$(*stat*, *vtable*, *ftable*) = `case` *stat* `of`

Stat$_1$; *Stat*$_2$	*code*$_1$ = *Trans*$_{Stat}$(*Stat*$_1$, *vtable*, *ftable*) *code*$_2$ = *Trans*$_{Stat}$(*Stat*$_2$, *vtable*, *ftable*) *code*$_1$ `@` *code*$_2$
id := *Exp*	*place* = `lookup`(*vtable*, *getname*(**id**)) *Trans*$_{Exp}$(*Exp*, *vtable*, *ftable*, *place*)
. . .	(rest coming soon)

- Sequence of statements, sequence of code.
- Symbol tables are inherited attributes.

Generating Code for Conditional Jumps: Helper

- Helper function for loops and branches
- Evaluates `Cond`, i.e., a boolean expression, then jumps to one of two labels, depending on result

```
Trans_cond : (Cond, Label, Label, Vtable, Ftable) -> [ICode]
Trans_Cond(cond, label_t, label_f, vtable, ftable) = case cond of
    Exp_1 relop Exp_2    t_1 = newvar()
                         t_2 = newvar()
                         code_1 = Trans_Exp(Exp_1, vtable, ftable, t_1)
                         code_2 = Trans_Exp(Exp_2, vtable, ftable, t_2)
                         op = trans_op(getname(relop))
                         code_1 @ code_2 @ [IF t_1 op t_2 THEN label_t ELSE label_f]
```

- Uses the `IF` of the intermediate language
- Expressions need to be evaluated before (restricted `IF`: only variables and atoms can be used)

Generating Code for If-Statements

- Generate new labels for branches and following code
- Translate `If` statement to a conditional jump

```
Trans_Stat(stat, vtable, ftable) = case stat of
    if Cond          label_t = newlabel()
    then Stat_1      label_f = newlabel()
                     code_1 = Trans_Cond(Cond, label_t, label_f, vtable, ftable)
                     code_2 = Trans_Stat(Stat_1, vtable, ftable)
                     code_1 @ [LABEL label_t] @ code_2 @ [LABEL label_f]
    ---------------------------------------------------------------------------
    if Cond          label_t = newlabel()
    then Stat_1      label_f = newlabel()
    else Stat_2      label_e = newlabel()
                     code_1 = Trans_Cond(Cond, label_t, label_f, vtable, ftable)
                     code_2 = Trans_Stat(Stat_1, vtable, ftable)
                     code_3 = Trans_Stat(Stat_2, vtable, ftable)
                     code_1 @ [LABEL label_t] @ code_2 @ [GOTO label_e]
                            @ [LABEL label_f] @ code_3 @ [LABEL label_e]
```

Generating Code for Loops

- `repeat-until` loop is the easy case:
  Execute body, check condition, jump back if false.
- `while` loop needs check before body, one extra label needed.

```
Trans_Stat(stat, vtable, ftable) = case stat of
---------------------------------------------------------------------------
  repeat Stat    label_f = newlabel()
  until Cond     label_t = newlabel()
                 code_1 = Trans_Stat(Stat, vtable, ftable)
                 code_2 = Trans_Cond(Cond, label_t, label_f, vtable, ftable)
                 [LABEL label_f] @ code_1 @ code_2 @ [LABEL label_t]
---------------------------------------------------------------------------
  while Cond     label_s = newlabel()
  do Stat        label_t = newlabel()
                 label_f = newlabel()
                 code_1 = Trans_Cond(Cond, label_t, label_f, vtable, ftable)
                 code_2 = Trans_Stat(Stat, vtable, ftable)
                 [LABEL label_s] @ code_1
                  @ [LABEL label_t] @ code_2 @ [GOTO label_s]
                      @ [LABEL label_f]
---------------------------------------------------------------------------
```

Translation Example

- Symbol table vtable: $[x \mapsto v_0,\ y \mapsto v_1,\ z \mapsto v_2]$
- Symbol table ftable: [`getInt` ↦ `libIO_getInt`]

```
x := 3;
y := getInt();
z := 1;
while y > 0
    y := y - 1;
    z := z * x
```

```
v_0 := 3
v_1 := CALL libIO_getInt()
v_2 := 1
 LABEL l_s
  t_1 := v_1
  t_2 := 0
  IF t_1 > t_2 THEN l_t else l_f
  LABEL l_t
   t_3 := v_1
   t_4 := 1
   v_1 := t_3 - t_4
   t_5 := v_2
   t_6 := v_0
   v_2 := t_5 * t_6
  GOTO l_s
 LABEL l_f
```

1. Why Intermediate Code?
   - Intermediate Language
   - To-Be-Translated Language
2. Syntax-Directed Translation
   - Arithmetic Expressions
   - Statements
   - Boolean Expressions, Sequential Evaluation
3. Translating More Complex Structures
   - More Control Structures
   - Arrays and Other Structured Data
   - Role of Declarations in the Translation

More Complex Conditions, Boolean Expressions

Boolean Expressions as Conditions

- Arithmetic expressions used as Boolean
- Logical operators (not, and, or)
- Boolean expressions used in arithmetics

$$
\begin{array}{lcl}
\mathit{Cond} & \rightarrow & \mathit{Exp}\ \textbf{relop}\ \mathit{Exp} \\
 & & \mid \mathit{Exp} \\
 & & \mid \textbf{not}\ \mathit{Cond} \\
 & & \mid \mathit{Cond}\ \textbf{and}\ \mathit{Cond} \\
 & & \mid \mathit{Cond}\ \textbf{or}\ \mathit{Cond} \\
\mathit{Exp} & \rightarrow & \ldots \mid \mathit{Cond}
\end{array}
$$

We extend the translation functions $\mathit{Trans}_{\mathit{Exp}}$ and $\mathit{Trans}_{\mathit{Cond}}$:

- Interpret numeric values as Boolean expressions: 0 is **false**, all other values **true**.
- Likewise: truth values as arithmetic expressions

Numbers and Boolean Values, Negation

Expressions as Boolean values, negation:

$Trans_{Cond}$: `(Cond, Label, Label, Vtable, Ftable) -> [ICode]`
$Trans_{Cond}(cond, label_t, label_f, vtable, ftable) =$ `case` $cond$ `of`

. . .	
Exp	$t = \texttt{newvar}()$ $code = Trans_{Exp}(Exp, vtable, ftable, t)$ $code$ @ [IF $t \neq 0$ THEN $label_t$ ELSE $label_f$]
not $Cond$	$Trans_{Cond}(Cond, label_f, label_t, vtable, ftable)$
. . .	

Conversion of Boolean values to numbers (by jumps):

$Trans_{Exp}$: `(Exp, Label, Label, Vtable, Ftable) -> [ICode]`
$Trans_{Exp}(exp, vtable, ftable, place) =$ `case` exp `of`

. . .	
$Cond$	$label_1 = \texttt{newlabel}()$ $label_2 = \texttt{newlabel}()$ $t = \texttt{newvar}()$ $code = Trans_{Cond}(Cond, label_1, label_2, vtable, ftable)$ $[t := 0]$ @ $code$ @ [LABEL $label_1$, $t := 1$] @ [LABEL $label_2$, $place := t$]

Fasto Implementation for Conditionals/Comparisons

Fasto Implementation

```
fun compileExp e vtable place = case e of
      ...
    | Fasto.If (e1,e2,e3,pos) =>
        let val thenLab="..." val elseLab="..." val endLab="..."
            val code1 = compileCond e1 vtable thenLab elseLab
            val code2 = compileExp  e2 vtable place
            val code3 = compileExp  e3 vtable place
        in code1 @ [Mips.LABEL thenLab] @ code2  @ [Mips.J endLab] @
             [Mips.LABEL elseLab] @ code3 @ [Mips.LABEL endLab]  end


and compileCond c vtable tlab flab = case c of
      Fasto.Equal (e1,e2,pos) =>
        let val t1 = "..."   val t2 = "..."
            val code1 = compileExp e1 vtable t1
            val code2 = compileExp e2 vtable t2
        in code1 @ code2 @ [Mips.BEQ (t1,t2,tlab), Mips.J flab]  end
```

Sequential Evaluation of Conditions

```
Moscow ML version 2.01 (January 2004)
Enter `quit();' to quit.
- fun f l = if (hd l = 1) then "one" else "not one";
> val f = fn : int list -> string
- f [];
! Uncaught exception:
! Empty
```

In most languages, logical operators are evaluated sequentially.

- If $B_1 = \mathit{false}$, do not evaluate B_2 in $B_1 \&\& B_2$ (anyway *false*).
- If $B_1 = \mathit{true}$, do not evaluate B_2 in $B_1 || B_2$ (anyway *true*).

```
- fun g l = if not (null l) andalso (hd l = 1) then "one" else "not one";
> val g = fn : int list -> string
- g [];
> val it = "not one" : string
```

Sequential Evaluation by “Jumping Code”

$Trans_{Cond}$: `Cond, Label, Label, Vtable, Ftable) -> [ICode]`
$Trans_{Cond}(cond, label_t, label_f, vtable, ftable) =$ `case` $cond$ `of`
...

$Cond_1$ **and** $Cond_2$	$label_{next}$ = `newlabel()` $code_1 = Trans_{Cond}(Cond_1, label_{next}, label_f, vtable, ftable)$ $code_2 = Trans_{Cond}(Cond_2, label_t, label_f, vtable, ftable)$ $code_1$ @ [LABEL $label_{next}$] @ $code_2$
$Cond_1$ **or** $Cond_2$	$label_{next}$ = `newlabel()` $code_1 = Trans_{Cond}(Cond_1, label_t, label_{next}, vtable, ftable)$ $code_2 = Trans_{Cond}(Cond_2, label_t, label_f, vtable, ftable)$ $code_1$ @ [LABEL $label_{next}$] @ $code_2$

- Note: No logical operations in intermediate language! Logics of **and** and **or** encoded by jumps.
- Alternative: Logical operators in intermediate language
  $$Cond \Rightarrow Exp \Rightarrow Exp\ \mathbf{binop}\ Exp$$
  Translated as an arithmetic operation. Evaluates both sides!

1. Why Intermediate Code?
   - Intermediate Language
   - To-Be-Translated Language
2. Syntax-Directed Translation
   - Arithmetic Expressions
   - Statements
   - Boolean Expressions, Sequential Evaluation
3. Translating More Complex Structures
   - More Control Structures
   - Arrays and Other Structured Data
   - Role of Declarations in the Translation

More Control Structures

- Control structures determine control flow: which instruction to execute next
- A **while**-loop is enough . . . but . . . languages usually offer more.
- Explicit jumps: *Stat* → **label** :
  | **goto label**

  . . . considered harmful (Dijkstra 1968)

  Necessary instructions in the intermediate language.
  Need to build symbol table of labels.
- Case/Switch: *Stat* → **case** *Exp* **of** [*Alts*]
  Alts → **num** : *Stat* | **num** : *Stat*, *Alts*

  When exited after each case: chain of `if-then-else`
  When "falling through" (f.ex. in C): `if-then-else` and `goto`.
- Break and Continue: *Stat* → **break** | **continue**

  (`break`: jump behind loop, `continue`: jump to end of loop body).
  Needs two jump target labels used only inside loop bodies
  (parameters to translation function `trans_stat`)

1. Why Intermediate Code?
   - Intermediate Language
   - To-Be-Translated Language
2. Syntax-Directed Translation
   - Arithmetic Expressions
   - Statements
   - Boolean Expressions, Sequential Evaluation
3. Translating More Complex Structures
   - More Control Structures
   - Arrays and Other Structured Data
   - Role of Declarations in the Translation

Translating Arrays (of `int` elements)

Extending the Source Language

- Array elements used as an expression
- Assignment to an array element
- Array elements accessed by an index (expression)

$$\begin{array}{lcl} \mathit{Exp} & \rightarrow & \ldots \mid \mathit{Idx} \\ \mathit{Stat} & \rightarrow & \ldots \mid \mathit{Idx} \;:=\; \mathit{Exp} \\ \mathit{Idx} & \rightarrow & \mathbf{id}[\ \mathit{Exp}\ ] \end{array}$$

Again we extend $Trans_{Exp}$ and $Trans_{Stat}$.

- Arrays stored in pre-allocated memory area, generated code will use memory access instructions.
- Static (compile-time) or dynamic (run-time) allocation.

Generating Code for Address Calculation

- *vtable* contains the base address of the array.
- Elements are `int` here, so 4 bytes per element for address.

$Trans_{Idx}(index, vtable, ftable) = \texttt{case}\ index\ \texttt{of}$	
$\textbf{id}[Exp]$	$base = \texttt{lookup}(vtable, getname(\textbf{id}))$ $addr = \texttt{newvar}()$ $code_1 = Trans_{Exp}(Exp, vtable, ftable, addr)$ $code_2 = code_1$ @ $[addr := addr*4, addr := addr+base]$ $(code_2, addr)$

Returns:

- Code to calculate the absolute address . . .
- of the array element in memory (corresponding to `index`), . . .
- . . . and a new variable ($addr$) where it will be stored.

Generating Code for Array Access

Address-calculation code: in expression and statement translation.

- Read access inside expressions:

  $Trans_{Exp}(exp, vtable, ftable, place) = \texttt{case}\ exp\ \texttt{of}$

  . . .

Idx	$(code_1, address) = Trans_{Idx}(Idx, vtable, ftable)$ $code_1$ @ $[place := M[address]]$

- Write access in assignments:

  $Trans_{Stat}(stat, vtable, ftable) = \texttt{case}\ stat\ \texttt{of}$

  . . .

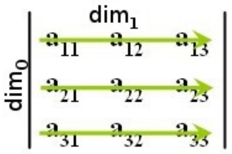
$Idx := Exp$	$(code_1, address) = Trans_{Idx}(Index, vtable, ftable)$ $t = \texttt{newvar}()$ $code_2 = Trans_{Exp}(Exp, vtable, ftable, t)$ $code_1$ @ $code_2$ @ $[M[address] := t]$

Multi-Dimensional Arrays

Arrays in Multiple Dimensions

- Only a small change to previous grammar: *Idx* can now be recursive.
- Needs to be mapped to an address in one dimension.

$$\begin{array}{lcl} Exp & \rightarrow & \ldots \mid Idx \\ Stat & \rightarrow & \ldots \mid Idx := Exp \\ Idx & \rightarrow & \textbf{id}[Exp] \mid Idx[Exp] \end{array}$$



- Arrays stored in row-major or column-major order. Standard: row-major, index of `a[k][l]` is $k \cdot dim_1 + l$ (Index of `b[k][l][m]` is $k \cdot dim_1 \cdot dim_2 + l \cdot dim_2 + m$)
- Address calculation need to know sizes in each dimension. symbol table: base address and list of array-dimension sizes.
- Need to change $Trans_{Idx}$, i.e., add recursive index calculation.

Address Calculation in Multiple Dimensions

```
Trans_Idx(index, vtable, ftable) =
    (code_1, t, base, []) = Calc_Idx(index, vtable, ftable)
    code_2 = code_1 @ [t := t * 4, t := t + base]
    (code_2, t)
```

Recursive index calculation, multiplies with dimension at each step.

```
Calc_Idx(index, vtable, ftable) = case index of
    id[Exp]        (base, dims) = lookup(vtable, getname(id))
                   addr = newvar()
                   code = Trans_Exp(Exp, vtable, ftable, addr)
                   (code, addr, base, tail(dims))
    Index[Exp]     (code_1, addr, base, dims) = Calc_Idx(Index, vtable, ftable)
                   d = head(dims)
                   t = newvar()
                   code_2 = Trans_Exp(Exp, vtable, ftable, t)
                   code_3 = code_1 @ code_2 @ [addr := addr * d, addr := addr + t]
                   (code_3, addr, base, tail(dims))
```

1. Why Intermediate Code?
    - Intermediate Language
    - To-Be-Translated Language
2. Syntax-Directed Translation
    - Arithmetic Expressions
    - Statements
    - Boolean Expressions, Sequential Evaluation
3. Translating More Complex Structures
    - More Control Structures
    - Arrays and Other Structured Data
    - Role of Declarations in the Translation

Declarations in the Translation

Declarations are necessary

- to allocate space for arrays,
- to compute addresses for multi-dimensional arrays,
- . . . and when the language allows local declarations (scope).

Declarations and scope

- Statements following a declarations can see declared data.
- Declaration of variables and arrays
- Here: Constant size, one dimension

$$\begin{array}{lcl} \mathit{Stat} & \rightarrow & \mathit{Decl};\ \mathit{Stat} \\ \mathit{Decl} & \rightarrow & \texttt{int}\ \mathbf{id} \\ & & \mid \texttt{int}\ \mathbf{id}[\mathbf{num}] \end{array}$$

Function `trans_decl : (Decl, VTable) -> ([ICode], VTable)`

- translates declarations to code and new symbol table.

Translating Declarations to Scope and Allocation

Code with local scope (extended symbol table):

$Trans_{Stat}(stat, vtable, ftable) = \texttt{case}\ stat\ \texttt{of}$

$Decl\ ;\ Stat_1$	$(code_1, vtable_1) = Trans_{Decl}(Decl, vtable)$ $code_2 = Trans_{Stat}(Stat_1, vtable_1, ftable)$ $code_1$ `@` $code_2$

Building the symbol table and allocating:

$Trans_{Decl}$ `: (Decl, VTable) -> ([ICode], VTable )`

$Trans_{Decl}(decl, vtable) = \texttt{case}\ decl\ \texttt{of}$

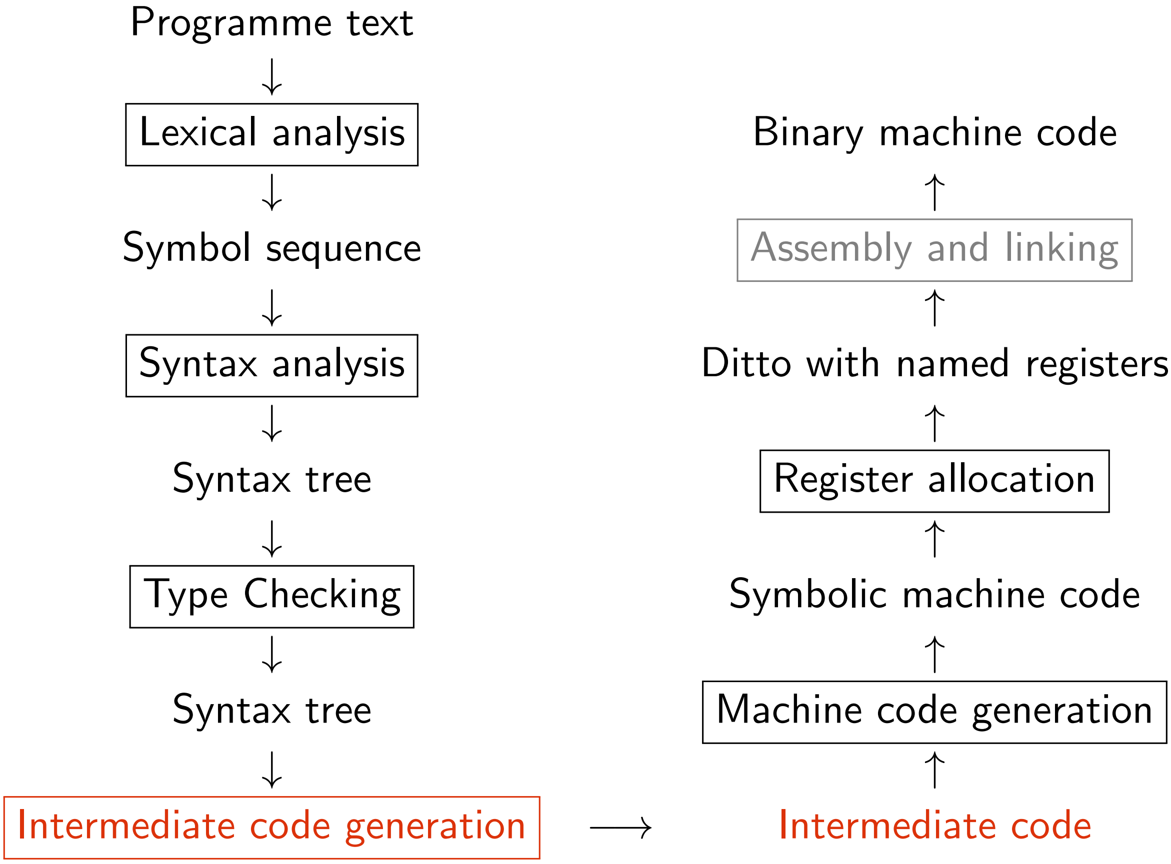
`int` **id**	$t_1 = \texttt{newvar}()$ $vtable_1 = \texttt{bind}(vtable, \texttt{getname}(\mathbf{id}), t_1)$ $([],\ vtable_1)$
`int` **id**[**num**]	$t_1 = \texttt{newvar}()$ $vtable_1 = \texttt{bind}(vtable, \texttt{getname}(\mathbf{id}), t_1)$ $([t_1 := HP,\ HP := HP + (4 * \texttt{getvalue}(\mathbf{num}))],\ vtable_1)$

...where `HP` is the heap pointer, indicating first free space in a managed heap at runtime, to provide memory to the running programme.

Other Structures that Require Special Treatment

- Floating-Point values:
  Often stored in different registers
  Always require different machine operations
  Symbol table needs type information when creating variables in intermediate code.
- Strings
  Sometimes just arrays of (1-byte) `char` type, but variable length.
  In modern languages/implementations, elements can be `char` or `unicode` (UTF-8 and UTF-16 variable size!)
  Usually handled by library functions.
- Records and Unions
  Linear in memory. Field types and sizes can be different.
  Field selector known at compile time: compute offset from base.

Structure of a Compiler



Programme text
↓
Lexical analysis
↓
Symbol sequence
↓
Syntax analysis
↓
Syntax tree
↓
Type Checking
↓
Syntax tree
↓
Intermediate code generation ⟶

Binary machine code
↑
Assembly and linking
↑
Ditto with named registers
↑
Register allocation
↑
Symbolic machine code
↑
Machine code generation
↑
Intermediate code