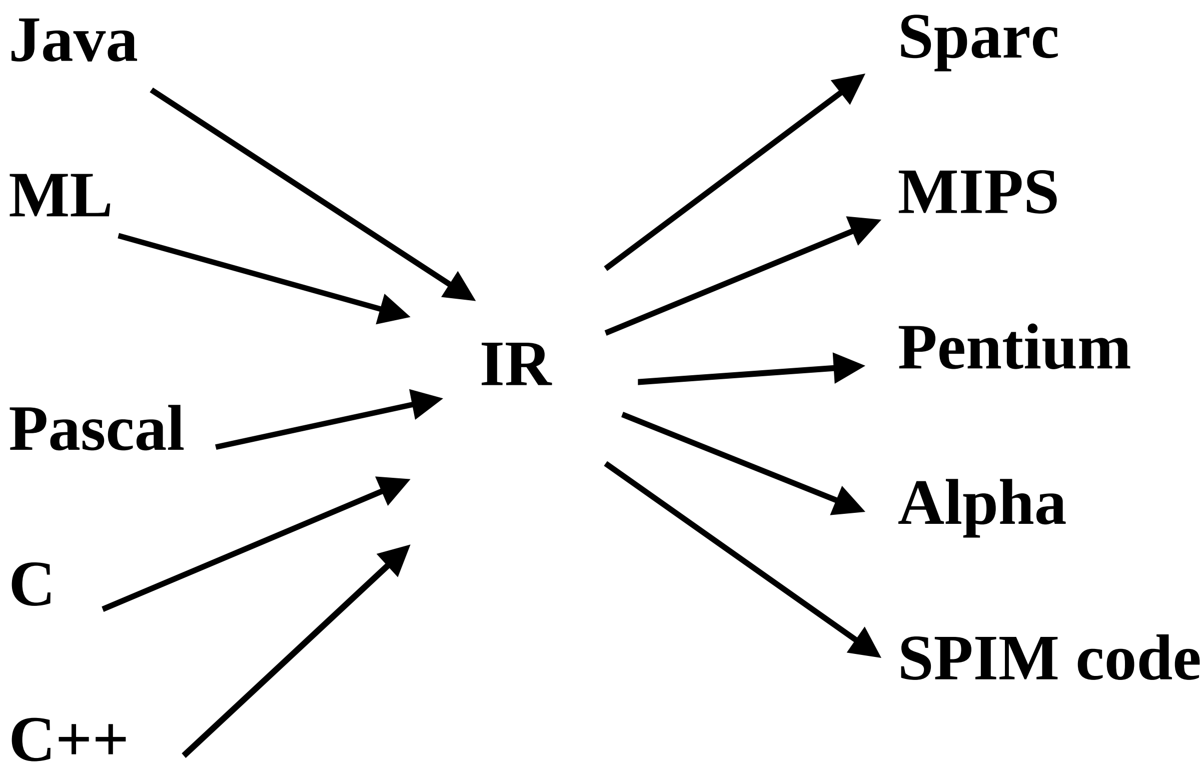
Intermediate Representations

- **Machine independent translation**
  - **Keep independent of target architecture for as long as possible**
- **Intermediate forms**
  - **3 address code (triples, quads)**
  - **Expression trees**
- **Some examples of Tiger intermediate code**

Why an intermediate representation?

- **Need representation closer to actual instructions for ease of translation**
- **Compiler**
  - ***Front end* does lexical analysis, parsing, semantic analysis, translation to IR**
  - ***Back end* does optimization of IR, translation to machine instructions**
- **Try to keep machine dependences out of IR for as long as possible**

How IR is useful?



Three Address Code

- ***Result, operand, operand, operator***
  - **x := y op z,** **where op is a binary operator and x, y, z can be variables, constants or compiler-generated temporaries (intermediate results)**
- **Can write this as a shorthand**
  - ***<op, arg1, arg2, result >*** **-- quadruples**
  - **Let line number of instruction stand for the result**
    - ***<op, arg1, arg2>*** **-- triples (saves space)**

Three Address Code

- **Set of statements allowed**
  - **Assignment   x := y op z**
  - **Copy stmts x := y**
  - **Goto L**
  - **if x relop y goto L**
  - **Indexed assignments x := y[j] or s[j] := z**
  - **Address and pointer assignments (for C)**

    x := &y, x := *p; *x := y
  - **Parm x; call p, n; return y; (for calls)**

How this works?

S ::= *id* := E
E ::= T R
R ::= *or* T R | ε
T ::= D Relop D

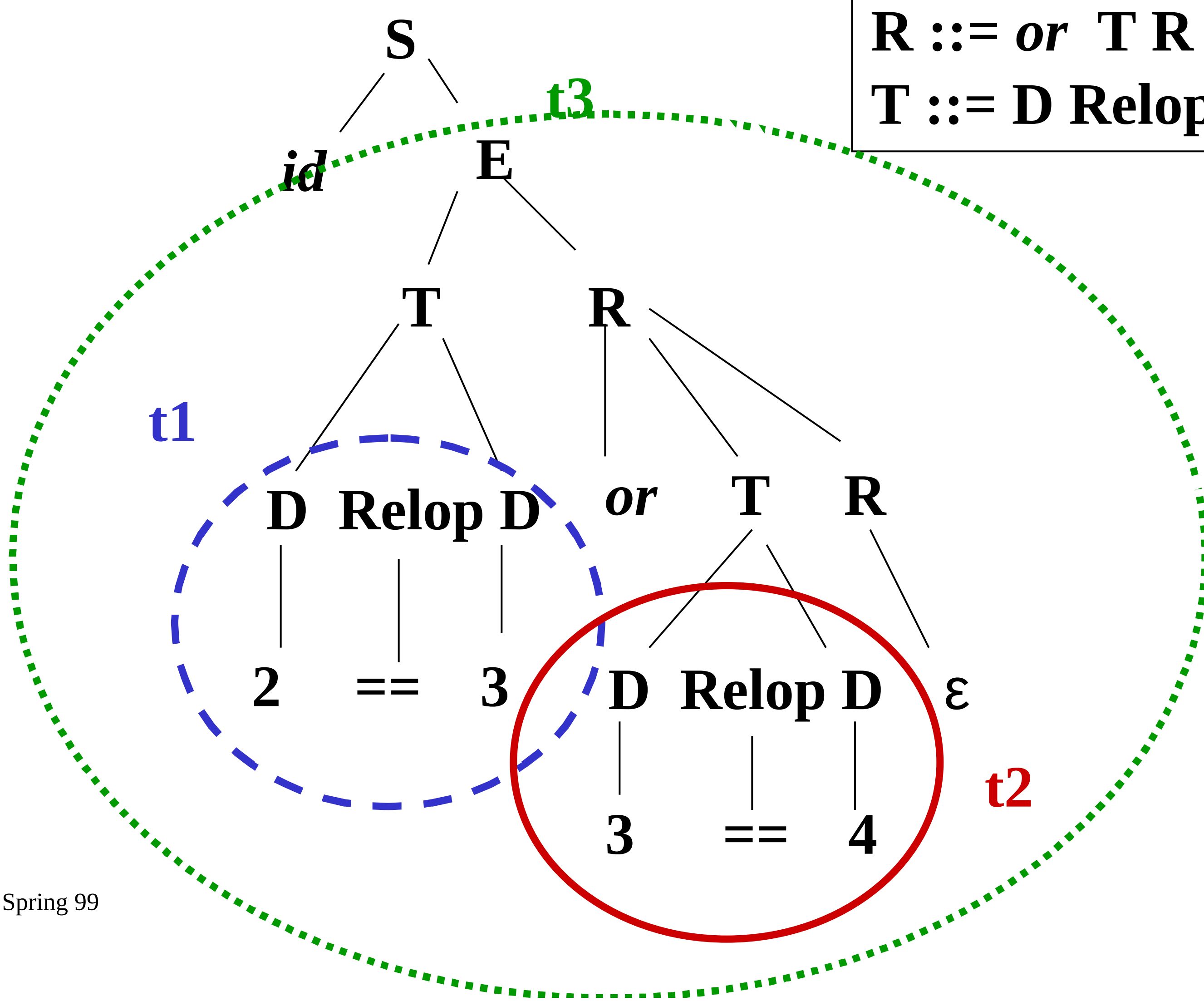
z := 2==3 or
3==4;

t1 := 2 == 3

t2 := 3 == 4

t3 := t1 or t2

z := t3



Expression Trees (Tiger)

- **Simple intermediate representation (IR)**
- **Convenient to translate into actual machine instructions for several target machines**
- **Convenient to produce from abstract syntax**
- **Each construct must have a clear meaning**
- **Take "big" pieces of abstract syntax and translate them into many small pieces of abstract machine instructions**

Tiger IR - Exp's

- ***Const(j)*, integer constant j**
- ***Name(n)*, symbolic constant n (to correspond to assembly language label)**
- ***Temp(t)*, temporary t (unlimited in number)**
- ***Binop(o, e1,e2)*, application of binary operator o to operands e1 and e2. (Appel, p 157)**
- ***Mem(e)*, contents of *wordSize* bytes of memory**

Tiger IR- Exp's

- ***Call(f,l)*, application of function f to argument list l**
- ***Eseq(s,e)* statement s evaluated for side effects and then e is evaluated for a result**

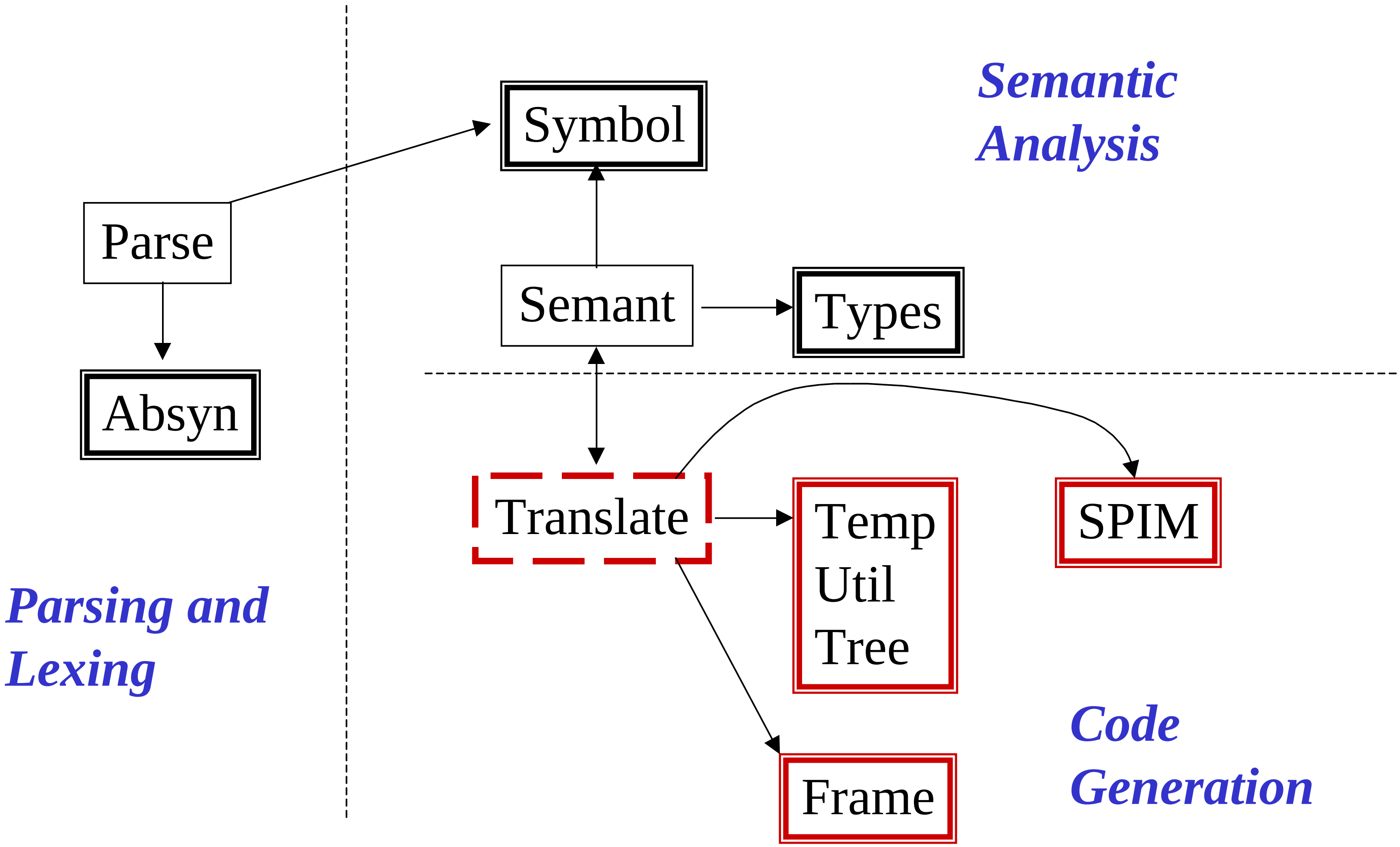
Tiger IR - Stm's

- ***Move(Temp t, e)*****, evaluate e and move it into t**
- ***Move (Mem(e1,k),e2)*****, evaluate e1 yielding address *a*. then evaluate e2 and store result into k bytes of memory starting at *a*.**
- ***Exp(e)*****, evaluate e and discard result**
- ***Jump (e,labs)*****, transfer control to address e; *labs* tells all possible locations that e can evaluate to**

Tiger IR - Stm's

- ***Cjump(o, e1, e2, t, f)*, evaluate e1, then e2, yielding values of a,b. now compare a to b using relational operator o. if result is true, jump to t, else jump to f.**
- ***Seq(s1,s2)*, statement s1 follows statement s2**
- ***Label(n)*, define the constant value of name n to be the current machine code address**
- **No abstract instructions for procedure entry or exit**

Project Organization: Packages



Package Absyn

- **Class Exp**
  - **ArrayExp,AssignExp, BreakExp, CallExp, ForExp, IfExp, IntExp, LetExp, NilExp, OpExp, RecordExp, SeqExp, StringExp, VarExp**
- **Class Dec**
  - **TypeDec, VarDec**
- **Class Ty**
  - **ArrayTy, NameTy, RecordTy**
- **Class FieldList**
- **Class FieldExpList**

Package Tree

- **Class Exp**
  - **BINOP ,CALL, CONST, ESEQ, MEM, NAME, TEMP**
- **Class Stm**
  - **SEQ, EXP, JUMP, CJUMP, LABEL, MOVE**
- **ExpList**
- **StmList**
- **Print**

Essentially, the job of assignment 5 is to translate Absyn trees to sequences of Tree trees.

IR vs AST (Appel,p 103,157)

package Tree	**package Absyn**
abstract class Exp	**abstract class Exp**
CONST (int value)	**IntExp(int pos, int value)**
NAME(Label label)	
TEMP (Temp.Temp temp)	
BINOP (Int binop, Exp left, Exp right)	**OpExp(int pos, Exp left, int oper, Exp right)**
MEM(Exp exp)	**VarExp(int pos, Var var)**
CALL(Exp func, ExpList args)	**CallExp(int pos, Symbol func, Explist args)**
ESEQ(Stm stm, Exp exp)	

Translating Expressions

- **Translation discussed in Chapter 7 talks about 3 sorts of expressions, pp 159ff:**
  - **unExp - a single valued expression**
  - **unNx - an expression that is a statement (yields no value)**
  - **unCx - a conditional expression (that jumps to t or f)**

package Translate: ***abstract class Exp***

class Ex   *class Nx*   *abstract class Cx*

Translating Expressions

- **Use simpler translation scheme (Appel, p 178)**
- **Translate all expressions as values**
  - **Can think of translating these using one *Translate.Exp* class without subclasses with a member *Tree.Exp* and only an *unEx()* method**
    - **unExp translated as usual to an Ex (an expression returning a value)**
    - **an Nx(s) is translated as Ex(ESEQ(s, CONST(0)))**
    - **For conditionals, use a value expression that evaluates to 0(false) or 1(true) --more later**

ExpTy transExp(Absyn.Exp e)

- **Use as a dispatcher method which calls other methods particularized to translation of a specific expression's Absyn AST**
  - **In class *Translate.Exp*, *Exp(Tree.Exp)* encapsulates its parameter object in a *Translate.Exp* object which can be stored in the first field of an *ExpTy* object (the field we had been leaving *null* in assignment 4)**
  - **Every *ExpTy* object has one each *Translate.Exp*, *Types.Type* members for intermediate code and type respectively**

What about conditional exprs?

/ if input is Absyn.IfExpr with else clause */*

1. generate 3 jump labels - one for true, other for false, one for end of if

2. generate a temp to hold the numerical result

3. create a code sequence which first calculates the test as a value expression, compares its value versus 0 and then jumps to true label or false label.

4. associate the true label with the code for the thenclause and jump to end of if

5. associate the false label with the code for the elseclause and fall through to end of if.

/* you will probably use JUMP, ESEQ, CONST, CJUMP from Tree package in combination to translate an IfExpr*/

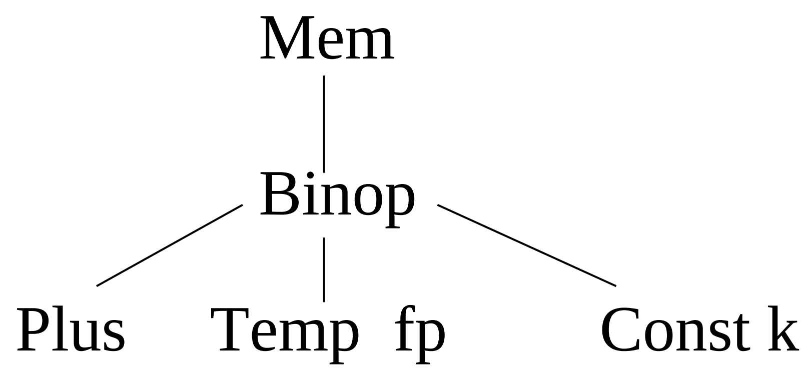
Memory

- **Any intermediate instructions that contain simple variables will involve accesses to memory through a frame**
  - ***Frame*** **interface to be provided**
  - **Access should be frame_pointer+offset through a Mem instruction**
- **Array elements will be addressed as base_address + subscript*elementsize**
  - **base_address is contents of Frame element corresponding to the array**
  - **elementsize is assumed same for all data**
  - **subscript is calculated as value of a temp**

Memory

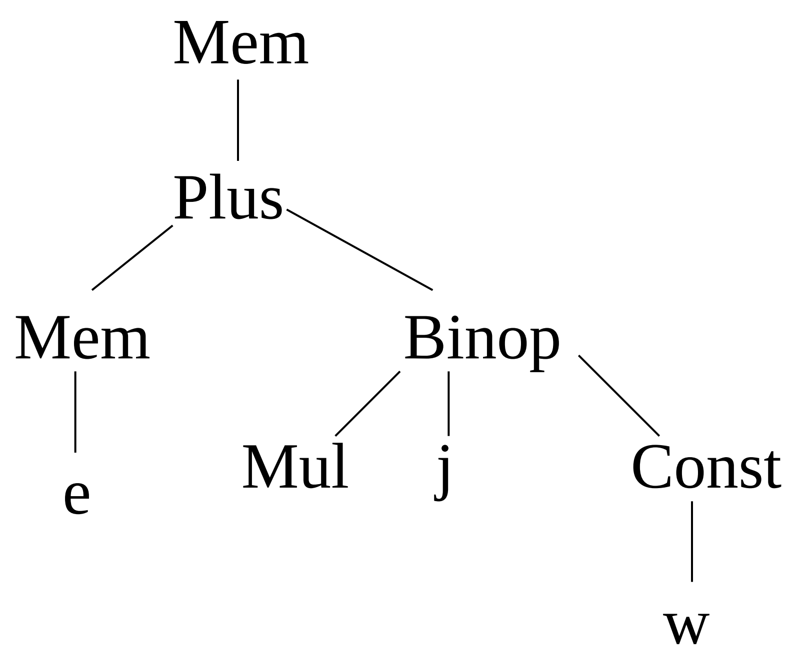
- **Simple variable**

(in frame)



- **Array element**

(memory-resident array variable a[j])



Translations

- **Arithmatic expressions**
  - **Unary negation implemented as subtraction from 0**
  - **Can be translated at first using just CONSTs as operands to check out transExp() driver and a small subset of translator routines**

Translations - Loops

- **While code**

  test: *if not(condition) goto done*

  body

  goto test

  done:

  - **Have to identify break statements with the** ***done*** **label for the closest enclosing loop**
  - **But this has to happen during transExp() recursive processing of a program expression**

Translations - Loops

- **For loop - most easily translated by considering as a form of while**

for *j* := *lo* to *hi* do *body* **becomes**

```
let var j := lo
    var limit := hi
in while j <= limit
      do (body ; j := j+1)
end
```

Translations - Declarations

- **Variables**
  - **Must reserve space for variables on frame**
  - **May need to emit code for intializations using assignments**

Fragments

- **Overall program expression is translated into a list of Fragment objects, one per function**
  - **Also translate String literal pool as a Fragment**
- **Necessary Fragments package to be supplied**