Strings

- All string operations performed by run-time system functions.
- In Tiger, C, string literal is constant address of memory segment initialized to characters in string.
  - In assembly, label used to refer to this constant address.
  - Label definition includes directives that reserve and initialize memory.

`''foo''`:

1. Translate module creates new label l.
2. `Tree.NAME(`l`)` returned: used to refer to string.
3. String *fragment* "foo" created with label l. Fragment is handed to code emitter, which emits directives to initialize memory with the characters of "foo" at address l.

Strings

String Representation:

Pascal fixed-length character arrays, padded with blanks.

C variable-length character sequences, terminated by ‘/000’

Tiger any 8-bit code allowed, including ‘/000’

"foo"

label:	3
	f
	o
	o

Strings

- Need to invoke run-time system functions
  - string operations
  - string memory allocation
- `Frame.externalCall: string * Tree.exp -> Tree.exp`

  `Frame.externalCall("stringEqual", [s1, s2])`

  - Implementation takes into account calling conventions of external functions.
  - Easiest implementation:

```
fun externalCall(s, args) =
    T.CALL(T.NAME(Temp.namedlabel(s)), args)
```

Array Creation

```
type intarray = array of int
var a:intarray := intarray[10] of 7
```

Call run-time system function `initArray` to malloc and initialize array.

```
Frame.externalCall("initArray", [CONST(10), CONST(7)])
```

Record Creation

```
type rectype = { f1:int, f2:int, f3:int }
var a:rectype := rectype{f1 = 4, f2 = 5, f3 = 6}

ESEQ(SEQ( MOVE(TEMP(result),
            Frame.externalCall("allocRecord",
                               [CONST(12)])),
     SEQ( MOVE(BINOP(PLUS, TEMP(result), CONST(0*w)),
               CONST(4)),
     SEQ( MOVE(BINOP(PLUS, TEMP(result), CONST(1*w)),
               CONST(5)),
     SEQ( MOVE(BINOP(PLUS, TEMP(result), CONST(2*w)),
               CONST(6)))))),
     TEMP(result))
```

- `allocRecord` is an external function which allocates space and returns address.
- `result` is address returned by `allocRecord`.

While Loops

One layout of a **while loop**:

```
while CONDITION do BODY

test:
    if not(CONDITION) goto done
    BODY
    goto test
done:
```

A **break** statement within body is a `JUMP` to label `done`.
`transExp and transDec` need formal parameter “break”:

- passed done label of nearest enclosing loop
- needed to translate breaks into appropriate jumps
- when translating while loop, `transExp` recursively called with loop done label in order to correctly translate body.

For Loops

Basic idea: Rewrite AST into let/while AST; call transExp on result.

```
for i := lo to hi do
  body
```

Becomes:

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

Complication:
If `limit == maxint`, then increment will overflow in translated version.

Function Calls

```
f(a1, a2, ..., an) =>
   CALL(NAME(l_f), sl::[e1, e2, ..., en])
```

- `sl` static link of `f` (computable at compile-time)
- To compute static link, need:
  - `l_f` : level of f
  - `l_g` : level of g, the calling function
- Computation similar to simple variable access.

Declarations

Consider type checking of "let" expression:

```
fun transExp(venv, tenv) =
  ...
  | trexp(A.LetExp{decs, body, pos}) =
      let
        val {venv = venv', tenv = tenv'} =
          transDecs(venv, tenv, decs)
      in
        transExp(venv', tenv') body
      end
```

- Need `level`, `break`.
- What about variable initializations?

Declarations

Need to modify code to handle IR translation:

1. `transExp`, `transDec` require `level` to handle variable references.
2. `transExp`, `transDec` require `break` to handle breaks in loops.
3. `transDec` must return Translate.exp list of assignment statements corresponding to variable initializations.
   - Will be prepended to body.
   - Translate.exp will be empty for function and type declarations.

Function Declarations

- Cannot specify function headers with IR tree, only function bodies.
- Special "glue" code used to complete the function.
- Function is translated into assembly language segment with three components:
  - prologue
  - body
  - epilogue

Function Prologue

Prologue precedes body in assembly version of function:

1. Assembly directives that announce beginning of function.
2. Label definition for function name.
3. Instruction to adjust stack pointer (SP) - allocate new frame.
4. Instructions to save escaping arguments into stack frame, instructions to move non-escaping arguments into fresh temporary registers.
5. Instructions to store into stack frame any *callee-save* registers used within function.

Function Epilogue

Epilogue follows body in assembly version of function:

6. Instruction to move function result (return value) into return value register.
7. Instructions to restore any *callee-save* registers used within function.
8. Instruction to adjust stack pointer (SP) - deallocate frame.
9. Return instructions (jump to return address).
10. Assembly directives that announce end of function.

- Steps 1, 3, 8, 10 depend on exact size of stack frame.
- These are generated late (after register allocation).
- Step 6:

```
MOVE(TEMP(RV), unEx(body))
```

Fragments

```
signature FRAME = sig
  ...
  datatype frag = STRING of Temp.label * string
                | PROC of {body:Tree.stm, frame:frame}
end
```

- Each function declaration translated into fragment.
- Fragment translated into assembly.
- `body` field is instruction sequence: 4, 5, 6, 7
- `frame` contains machine specific information about local variables and parameters.

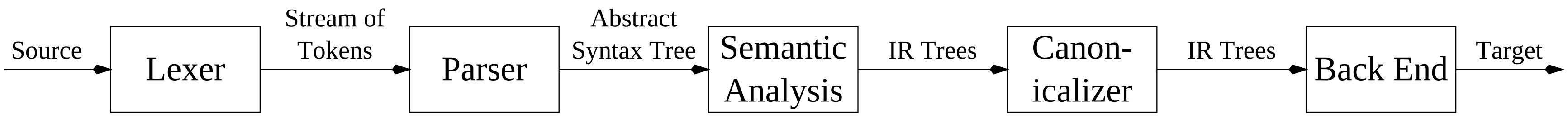
Problem with IR Trees

Problem with IR trees generated by the `Translate` module:

- Certain constructs don't correspond exactly with real machine instructions.
- Certain constructs interfere with optimization analysis.
- `CJUMP` jumps to either of two labels, but conditional branch instructions in real machine only jump to *one* label. On false condition, fall-through to next instruction.
- `ESEQ, CALL` nodes within expressions force compiler to evaluate subexpression in a particular order. Optimization can be done most efficiently if subexpressions can proceed in any order.
- `CALL` nodes within argument list of `CALL` nodes cause problems if arguments passed in specialized registers.

Solution: Canonicalizer

Canonicalizer



Canonicalizer takes `Tree.stm` for each function body, applies following transforms:

1. `Tree.stm` becomes `Tree.stm list`, list of canonical trees. For each tree:
   - No `SEQ, ESEQ` nodes.
   - Parent of each `CALL` node is `EXP(...)` or `MOVE(TEMP(t), ...)`
2. `Tree.stm list` becomes `Tree.stm list list`, statements grouped into *basic blocks*
   - A *basic block* is a sequence of assembly instructions that has one entry and one exit point.
   - First statement of basic block is `LABEL`.
   - Last statement of basic block is `JUMP, CJUMP`.
   - No `LABEL, JUMP, CJUMP` statements in between.

Canonicalizer

3. `Tree.stm list list` becomes `Tree.stm list`
   - Basic blocks reordered so every `CJUMP` immediately followed by false label.
   - Basic blocks flattened into individual statements.