Project 6:
Semantic Checking (Part 2)

Due: Tuesday, November 29

Final: Monday, December 5, 10:15-12:05

Modify Checker.java
Catch all remaining errors
Fill in more fields in AST

PDF Files:
- **Assignment**
- **List of all Error Messages**

Need to insert "implicit coercions"

```
x := 1.2 + (i * 5);
```

⇓

```
x := 1.2 + intToReal(i * 5);
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Project 6 - Semantic Checking Part 2

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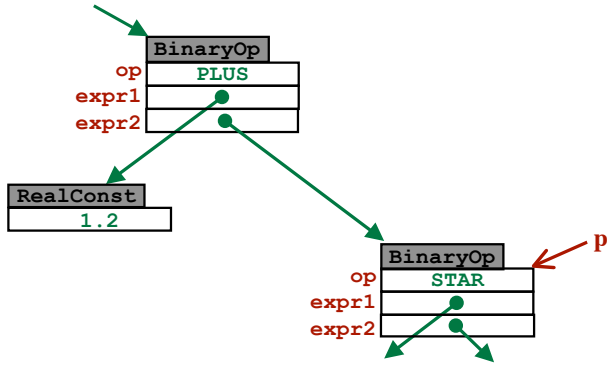
New Class: **IntToReal**



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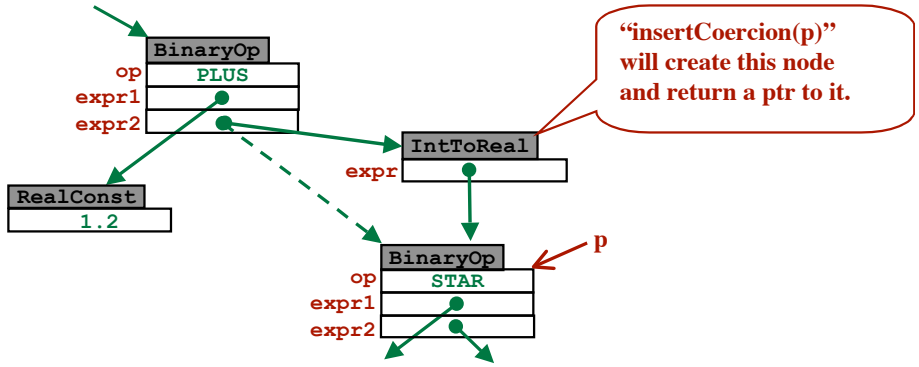
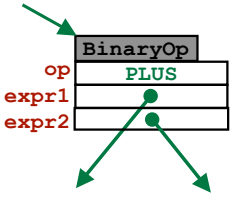
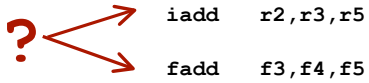


The "mode" field

What code to generate for:





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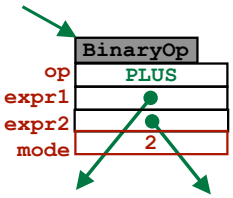
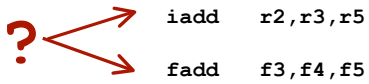




The "mode" field added to...

- `BinaryOp`
- `UnaryOp`
- `ReadArg`
- `Argument`

Possible Values:

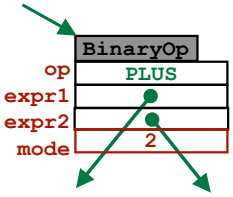
1 = `INTEGER_MODE`
2 = `REAL_MODE`
3 = `STRING_MODE`
4 = `BOOLEAN_MODE`

Add Java Constants...

```
static final int
   INTEGER_MODE = 1;
   REAL_MODE    = 2;
   STRING_MODE  = 3;
   BOOLEAN_MODE = 4;
```

The "mode" field

What code to generate for:



?

```
iadd   r2,r3,r5
fadd   f3,f4,f5
```

The "mode" field added to...

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```

`BOOLEAN_MODE` and `STRING_MODE` will only be used for **Argument**s of **WriteStmt**s.

```
write (a,b,c,d);
```

All values will be 32-bit binary values...
How shall we print each value?

Type Checking

Goal:

Check to make sure that the types are "correct"

```
x := y;
```

Need to check whether the type of `x` *is equal to the type of* `y`.

For the purposes of type checking...
we will need only the name of the type

`TypeName`

Modify the "`check`*" methods to return a* `TypeName`

`checkExpr`
`checkBinaryOp`
`...`
`checkValueOf`
`checkLValue`

} *Modify methods concerned with expressions and L-Values to return the type of the expression / L-Value.*

`...`
`checkIfStmt`
`checkTypeDecl`
`...`

} *Do not modify other methods*

Type Equivalence

```
type T1 is record
             f: integer;
             g: real;
           end;
     T2 is record
             f: integer;
             g: real;
           end;


var a: T1;
    b: T1;
    c: T2;
```

Is TypeOf (a) = TypeOf (b) ?
Is TypeOf (a) = TypeOf (c) ?

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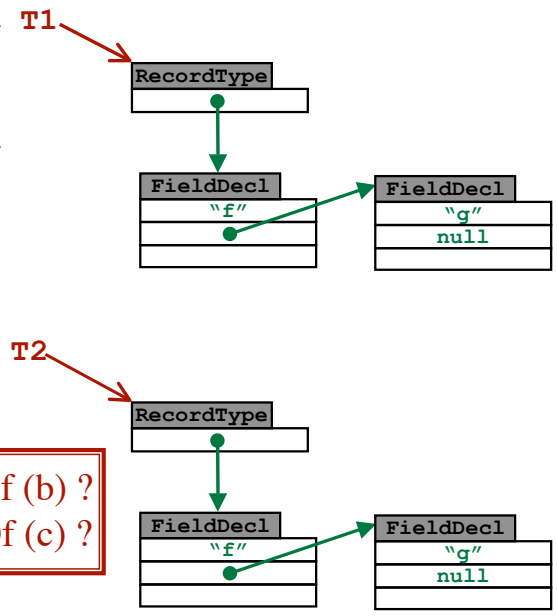

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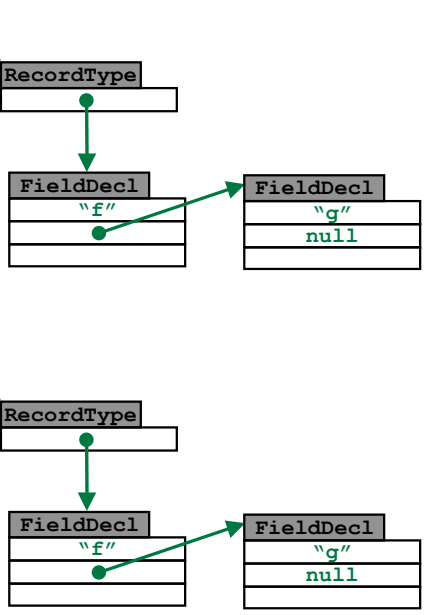

Name Equivalence

TypeOf (a) = TypeOf (b)
TypeOf (a) ≠ TypeOf (c)

Structural Equivalence

TypeOf (a) = TypeOf (b)
TypeOf (a) = TypeOf (c)

Project 6 - Semantic Checking Part 2

Type Equivalence

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type T1 is record
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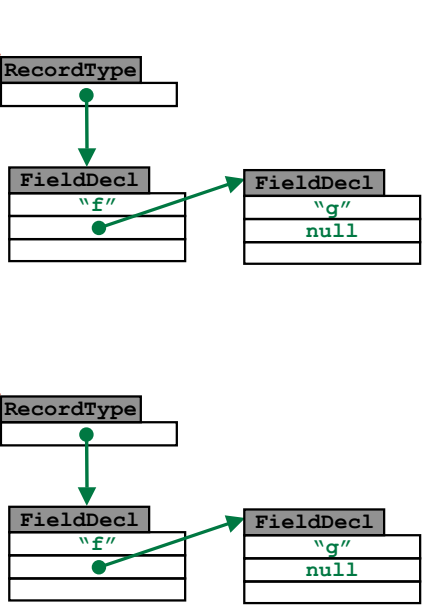

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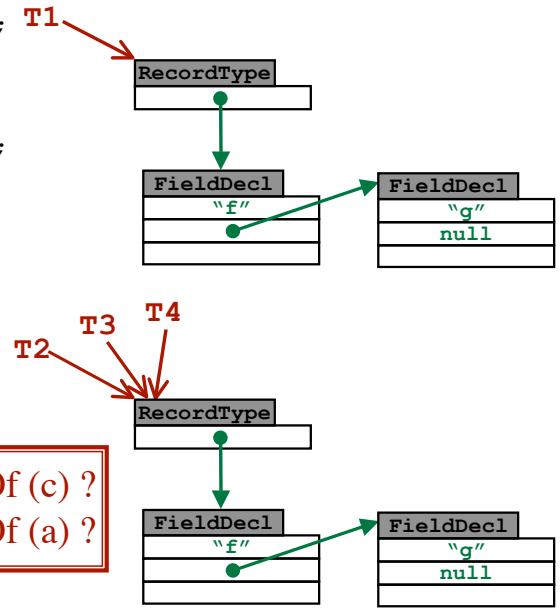
TypeOf (a) = TypeOf (b)
TypeOf (a) = TypeOf (c)

Many Languages have "Type Aliasing"

```
type T1 is record
             f: integer;
             g: real;
           end;
     T2 is record
             f: integer;
             g: real;
           end;
     T3 is T2;
     T4 is T3;
var a: T1;
    b: T1;
    c: T2;
    d: T4;
```



Is TypeOf (d) = TypeOf (c) ?
Is TypeOf (d) = TypeOf (a) ?

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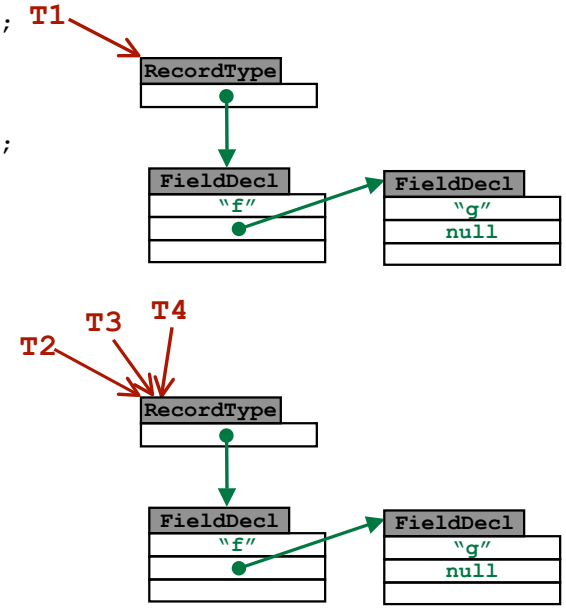

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How to Deal with "Type Aliasing"

```
program is
  type T1 is T2;
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  var x: T1 ...;
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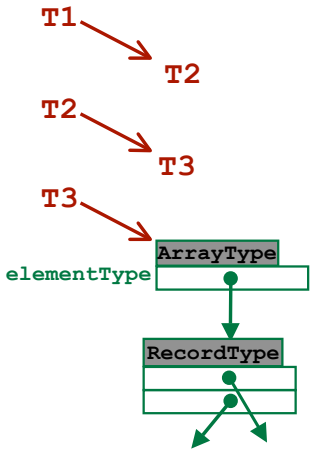
```

What is the "real" type of x?



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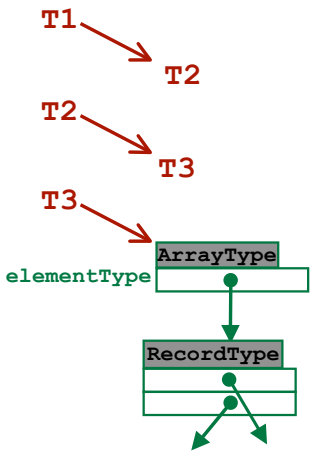

Note the distinction between

- **Names of Types**
- **Underlying "concrete" Types**

Types are represented by trees

```
array of record
            f: array of int;
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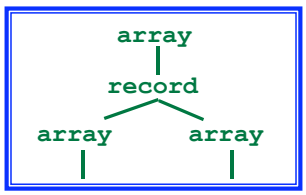

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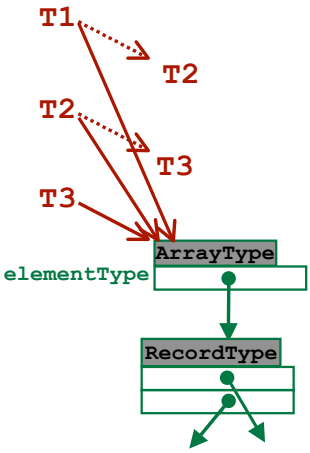

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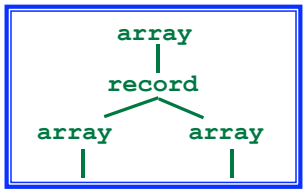

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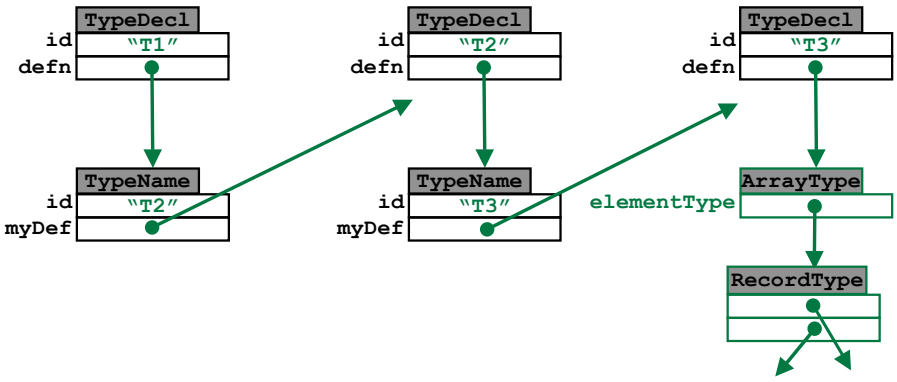

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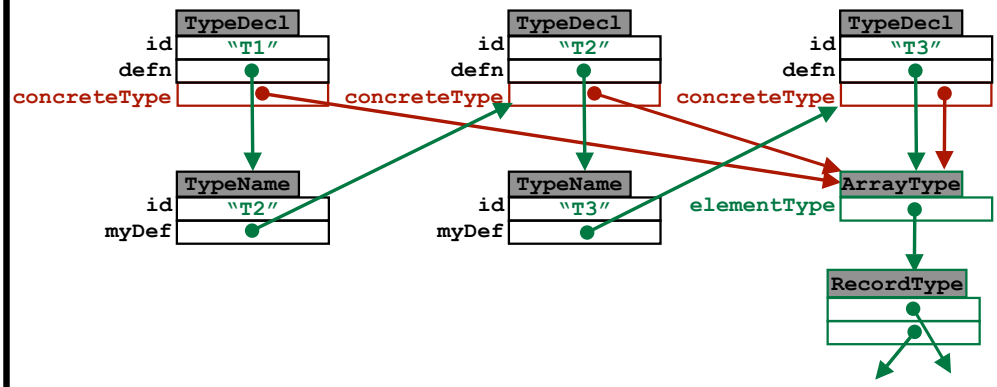
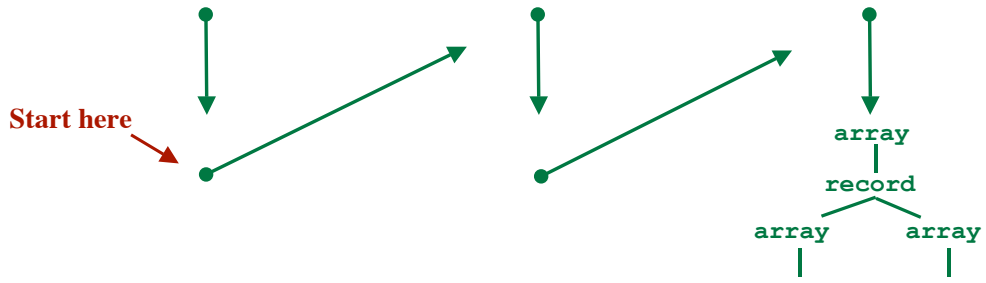


Finding the Underlying, Concrete Type

Goal:

Move through the definitions...
until we find a true, concrete type.
If we see another name, keep going.



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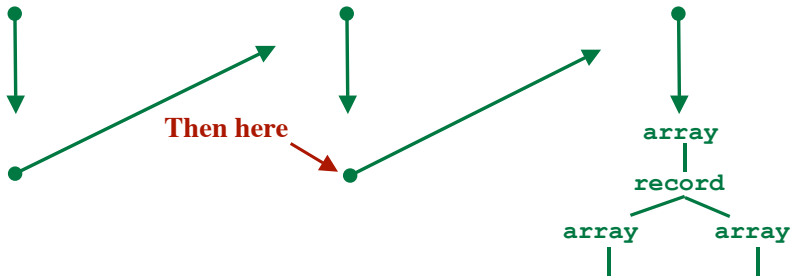

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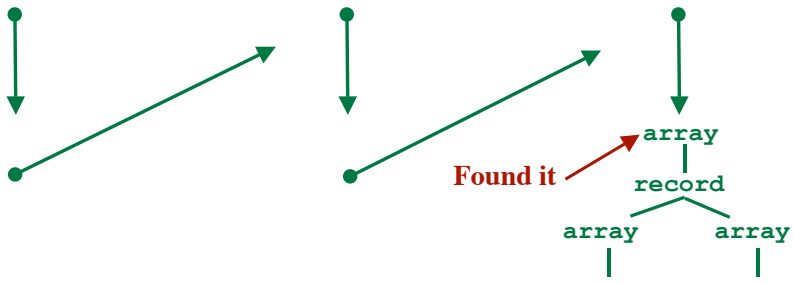

Problem: Cyclic Type Errors

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type T1 is T2;
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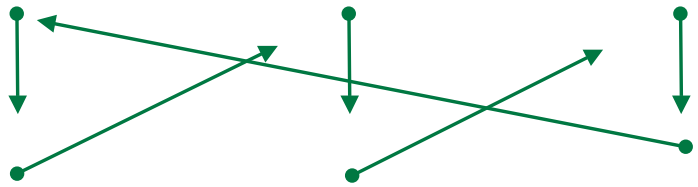

We don't want to get caught in a cycle
... going around in circles forever!

Cyclic Type Error

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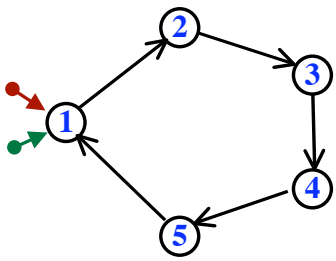
Languages that allow type aliasing must detect this error.

Algorithm to find cycles in a graph:



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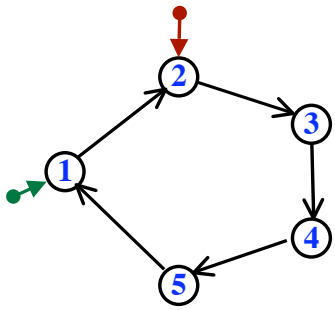

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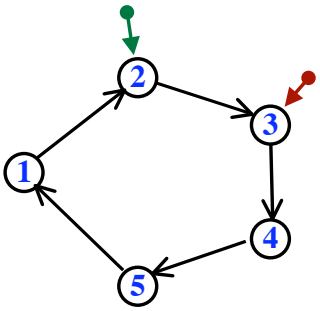

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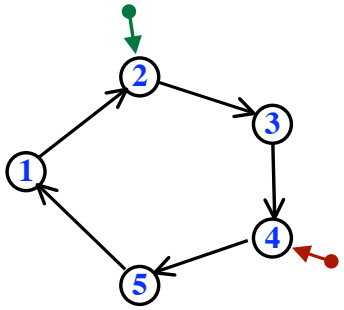

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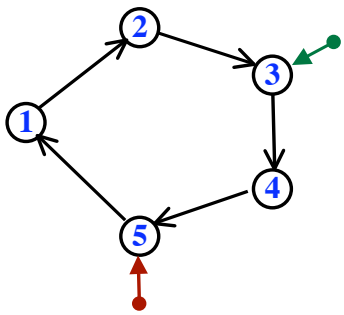

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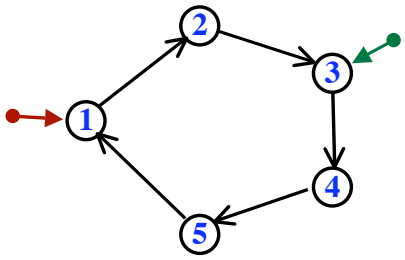

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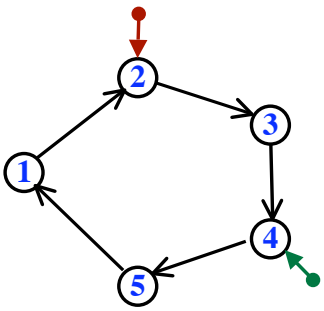

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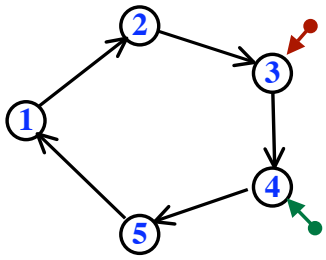

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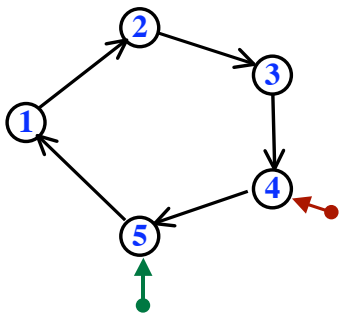

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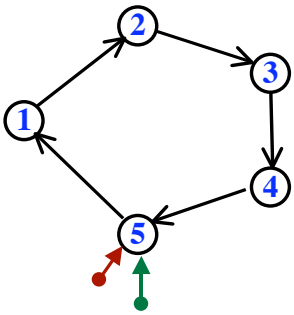


Pointer "p1" moves through the graph.
Pointer"p2" moves through the graph.
"p2 only moves every other time
Either:
"p1" reaches a concrete type
"p1" reaches "p2"
Finds the cycle in 2N steps.

Checking Type Equality

Example:

```
program is

  var x: integer;
  procedure foo (...) is

    var y: integer;
    begin
      ...
      x := y;
      ...
    end;
  begin
    ...
  end;
```

When the types are
integer
real
boolean
Then it is okay to
just compare the name IDs.

Checking Type Equality

Example:

```
program is
  type T1 is array of integer;
  var x: T1;
  procedure foo (...) is
    type T1 is array of boolean;
    var y: T1;
    begin
      ...
      x := y;
      ...
    end;
  begin
    ...
  end;
```

Is this assignment legal?
Must check whether
TypeOf(x) = TypeOf(y)
Can't just look at name of type!
When a type has a definition,
Must see if it is the same.

typeEquals

We often need to compare two types for equality.

Useful Routine: `typeEquals (Ast.TypeName t1, t2) returns boolean`

This method is passed two types .
Returns TRUE iff t1 and t2 are equal.
If *either* type name has a definition,
then we must compare definitions
"Name Equality": Compare pointers (TypeName.myDef)
"Structural Equality": Walk and compare the type trees
If both are undefined, then compare IDs.
Previous type errors during checking?
If either argument is NULL, just return TRUE

We want "Name Equality"

Example:

```
procedure foo (x: ...Error...) is begin ... end;
...
foo (7);
```

```
if !(typeEquals (__,__)) then
      semanticError ("Type of argument is wrong");
```

Checking Assignment

```
x := y;
```

Check expr and get its type. Call it "fromType."
Check l-value and get its type. Call it "toType."

Useful Routine: `assignOK (Ast.TypeName toType, fromType) returns boolean`

This method is passed two types .
Returns TRUE iff it is legal to assign from type "fromType" to type "toType".

When is this assignment legal?

- **$T_X = T_Y$** *(Types are equal; use typeEquals)*
- **T_X=Real, T_Y= Integer** *(We'll also need a coercion)*
- **T_X=NULL or T_Y= NULL** *(Due to previous errors)*
- **T_X=ArrayType and T_Y=NilType**
- **T_X=RecordType and T_Y=NilType**

Need to use getCompoundType here

getCompoundType

Useful Routine: `getCompoundType (TypeName t) returns CompoundType`

This method is passed the name of a type. If it has a definition, then return a pointer to the ArrayType or RecordType.
TypeName.myDef
If the type has no definition, then return NULL
"integer", "real", "boolean", or an undefined name
Errors? (the parameter may be NULL)
Return NULL
No error message

Example:

```
if (getCompoundType(t)) instanceof ArrayType) ....
```

Adding the "intToReal" Coercion

Example:

```
r := i*j;
```

"fromType" ... integer?
"toType" ... real?

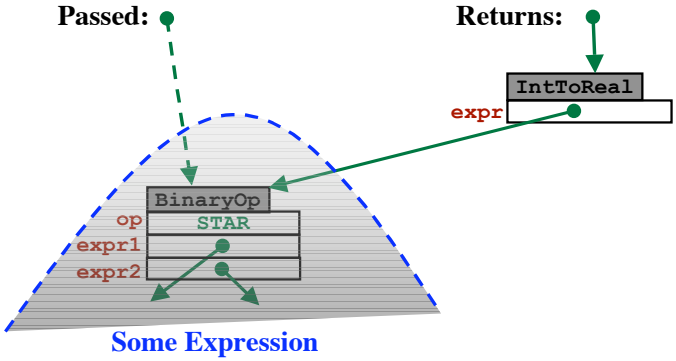
Useful Routine: `needCoercion (TypeName toType, fromType) returns boolean`

This method is passed two types.
It returns TRUE iff an integer-to-real coercion must be inserted.
This occurs when...

T_{FROM}**.id = "integer"**
T_{TO}**.id = "real"**

Adding the "intToReal" Coercion

Useful Routine: `insertCoercion (Ast.Expr t) returns Ast.IntToReal`



Example Code

```
void checkAssignStmt (Ast.AssignStmt t) {

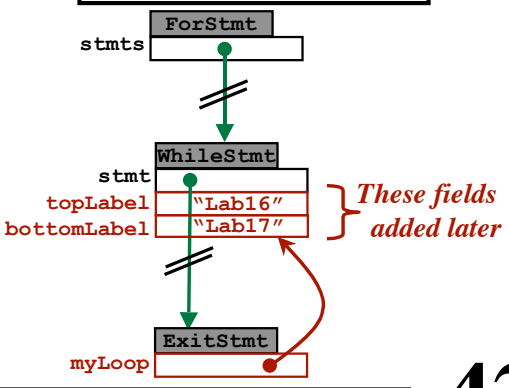
    toType = checkLValue (t.lValue);
    fromType = checkExpr (t.expr);

    if (assignOK (toType, fromType)) then
        if (needCoercion (toType, fromType)) then
            t.expr = insertCoercion (t.expr);
        endIf
    else
        semanticError (t.expr, "In assignment, type of
                  LHS is not compatible with type of RHS");
    endIf
}
```


New Field: myLoop

To generate code for EXIT statement
Will generate a branch to ... where?
Need to know which loop we are exiting from.

```
for ...
  ...
  while condition do
    ...
    exit;
    ...
  end;
  ...
end;
```

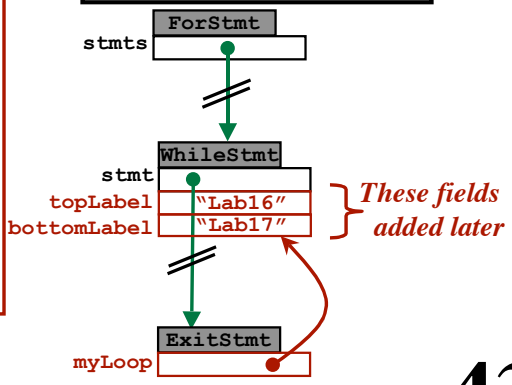


New Field: myLoop

Later, we'll generate this code:

```
Lab16:      } Code for top of WHILE
   xxx
   xxx...goto Lab17...      Code for condition
   xxx
   xxx
   xxx
   xxx                      Code for statements
   goto Lab17               Code for EXIT
   xxx
   xxx
   xxx
   goto Lab16
Lab17:      } Code for bottom of WHILE
```

```
for ...
  ...
  while condition do
    ...
    exit;
    ...
  end;
  ...
end;
```

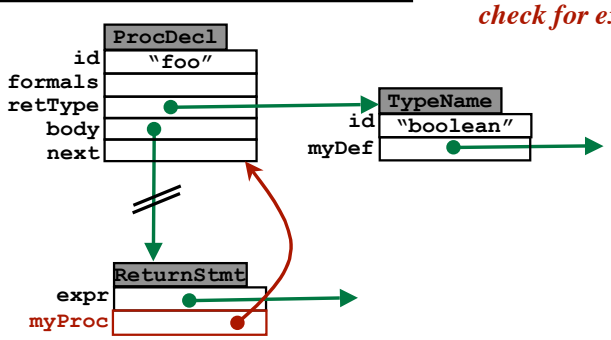


New Field: myProc

To generate code for the RETURN statement,
need info about the procedure we are returning from .

```
procedure foo (...): boolean is ...
  ...
  begin
    ...
    return [expression] ;
    ...
  end;
```

Is the expression requried?
Must check!
Is the expression "assignment compatible" with the return type?
If the procedure is void, check for expr == NULL.



Pass "currentLoop" and "currentProc" down through the check routines.

```
checkIfStmt (t, currentLoop, currentProc)
```

Pointer to innermost LoopStmt, WhileStmt, or ForStmt that encloses this statement. (NULL, if none)

Pointer to innermost ProcDecl that encloses this statement. (NULL, if none)

```
checkReturnStmt (t, _, currentProc)
   t.myProc = currentProc;
   if currentProc == NULL ... Error

checkExitStmt (t, currentLoop, _)
   t.myLoop = currentLoop;
   if currentLoop == NULL ... Error

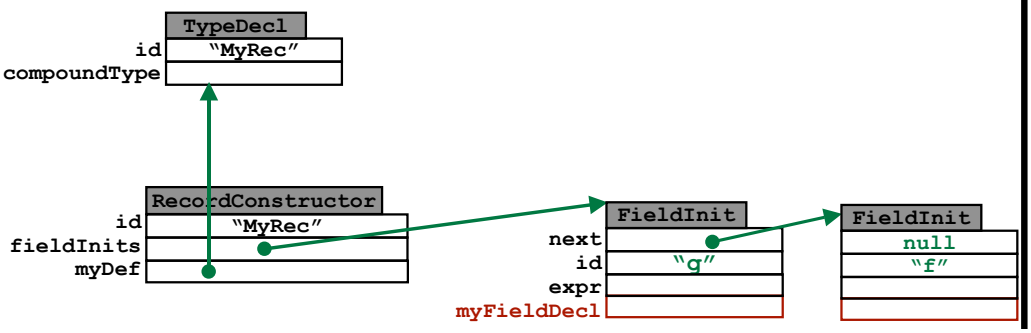
checkWhileStmt (t, _, currentProc)
   ...
   checkStmts (t.stmts, t, currentProc)
   ...
```

Come methods will not need currentLoop and/or currentProc.

For those methods, no need to pass it down.

New Field "myFieldDecl"

```
type MyRec is record
                  f: integer;
                  g: real;
               end;
var r: MyRec := nil;
...
r := MyRec { g := 1.2; f := 5 };
```



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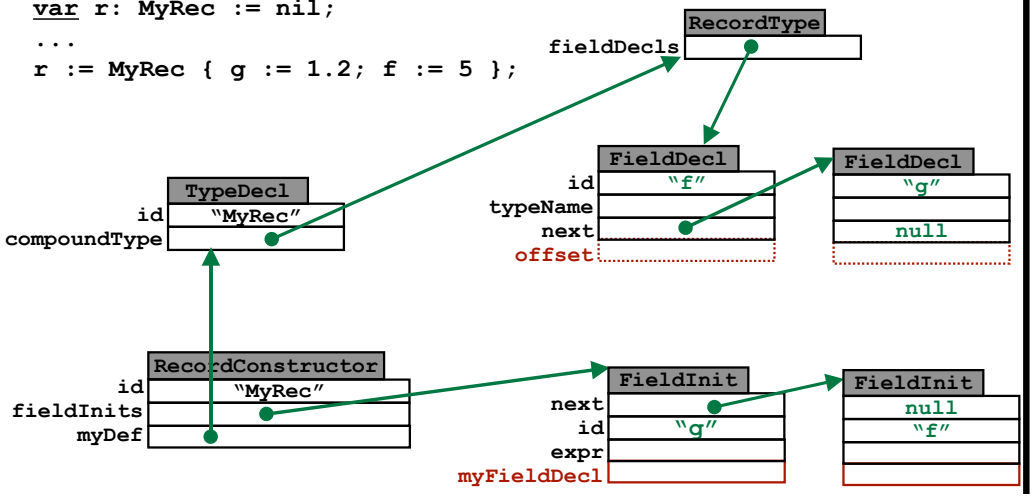

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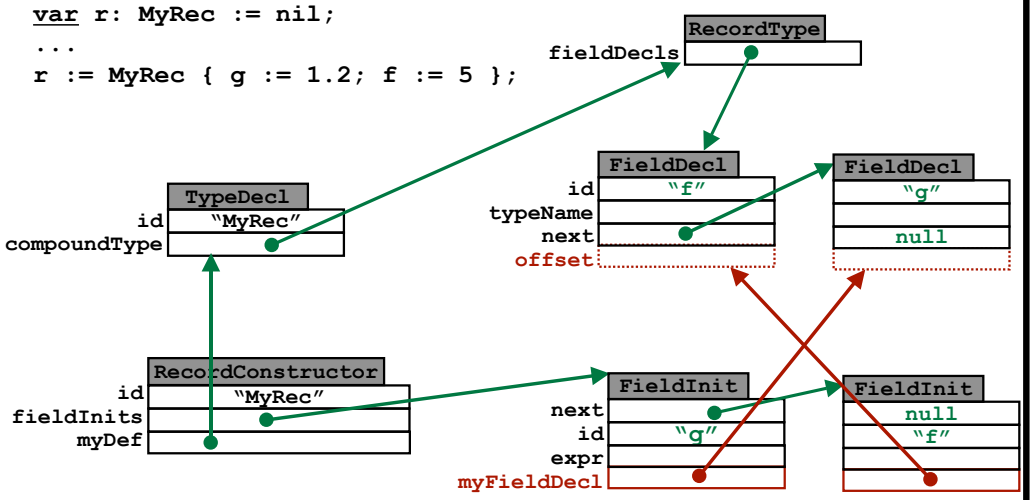

Testing

- **OK to modify PrettyPrint.java**
  Add code to print out "mode" or "myProc" or "myLoop"

- **OK to modify Main.java**
  Comment out the call to printAst

- **OK to use your Lexer and Parser**

- **We'll use the "standard" files in testing.**
  Make sure you test with standard files before submitting!

Testing

- **PCAT Source programs without errors...**
  All output must agree exactly.

- **PCAT Source program with errors...**
  ```
  arrayOK.pcat
  arrayErr.pcat
  ```
  Error messages (stderr) must agree exactly.
  AST (stdout) will be ignored.
  ```
  run
  runErr
  ```

- **Recommended Approach:**
  Get checker working with your own tests
  THEN run my test suite.
  If you pass them all... High confidence of program correctness!

Danger:
Writing code just to handle known example cases!