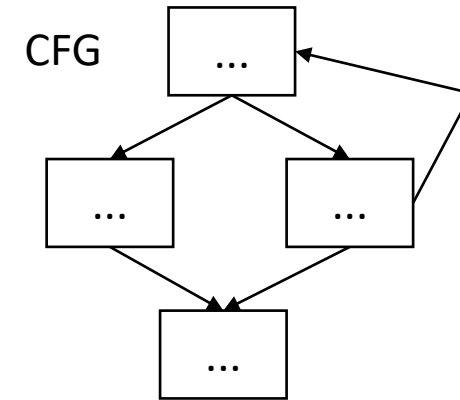
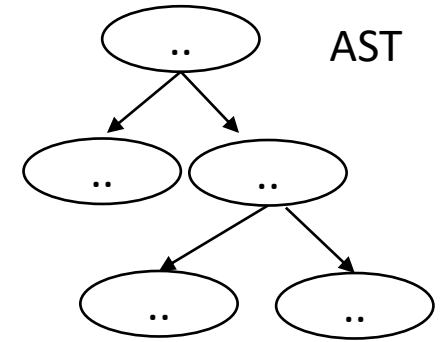


# CSE110A: Compilers

## Topics:

- *Module 3: Intermediate representations*
  - *Finishing up type checking*
  - *Linear lrs : 18*



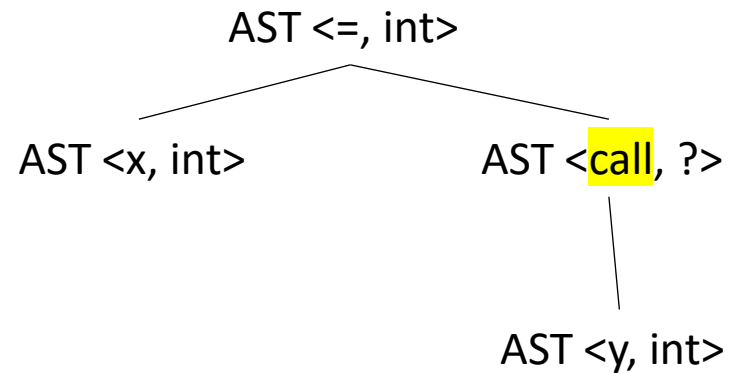
3 address code

```
store i32 0, ptr %2
%3 = load i32, ptr %1
%4 = add nsw i32 %3, 1,
store i32 %4, ptr %1
%5 = load i32, ptr %2
```

# Type Systems

# How are functions handled?

```
int x;  
int y;  
x = sqrt(y)
```



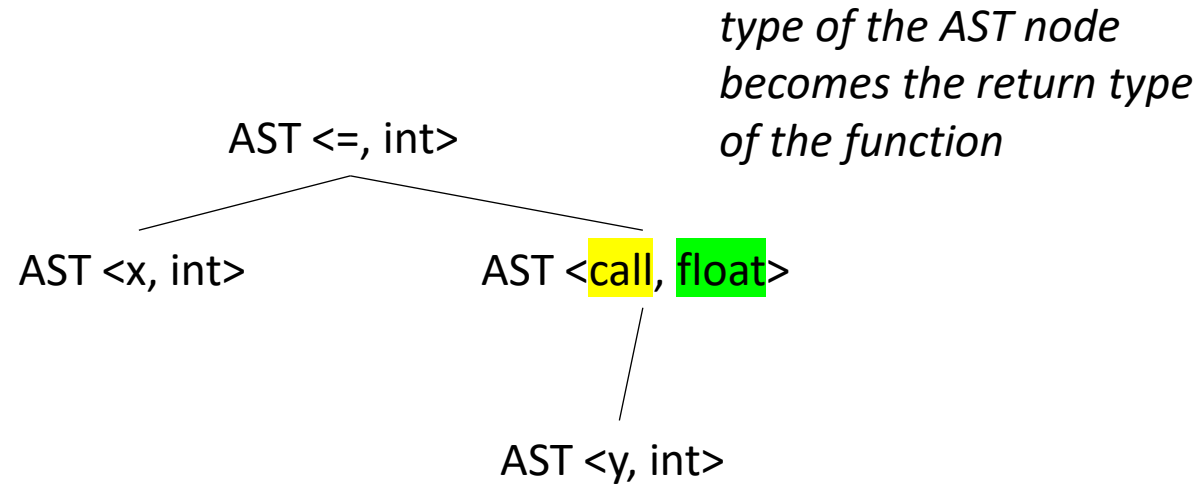
requires a function specification,  
using in the .h file:

```
float sqrt(float x) ;
```

stored in the symbol table before type checking - think about C. you have to declare a function before you use it

# How are functions handled?

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int x;  
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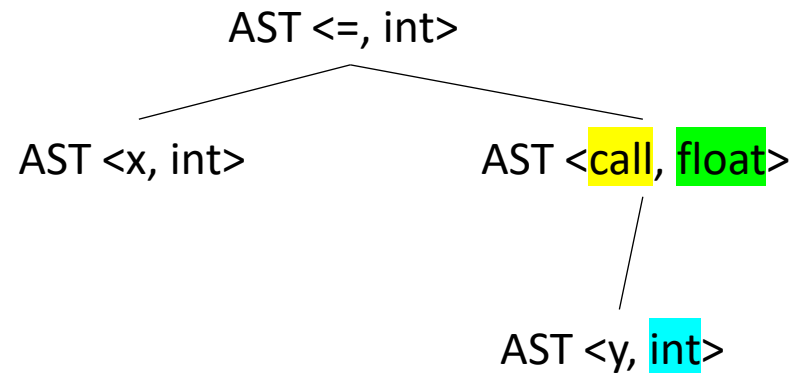
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int x;  
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*type inference must make sure arguments match types*

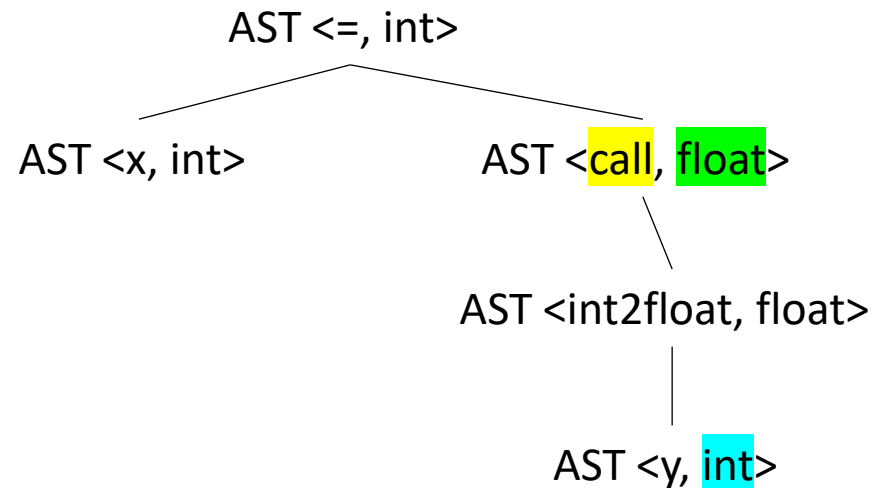
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# How are functions handled?

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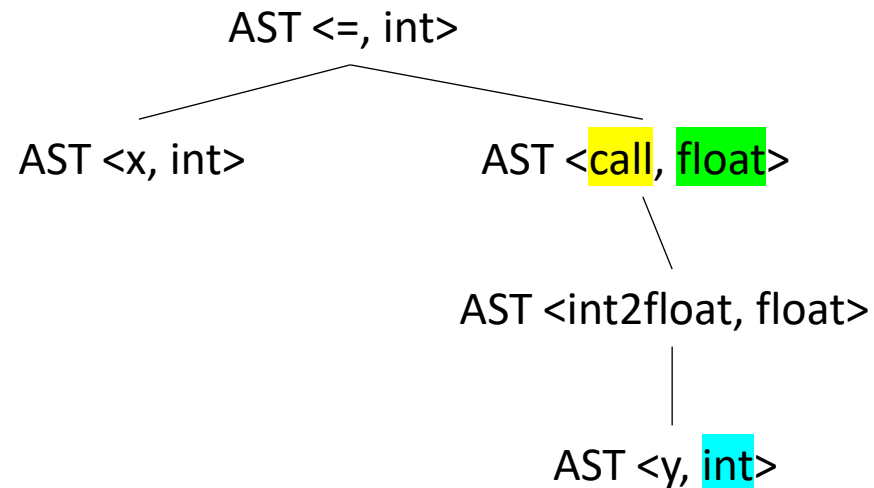
*type inference must make sure  
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stored in the symbol table before type checking - think about C. you have to declare a function before you use it

# How are functions handled?

```
int x;  
int y;  
x = sqrt(y)
```

*How would type inference finish this?*



requires a function specification,  
using in the .h file:

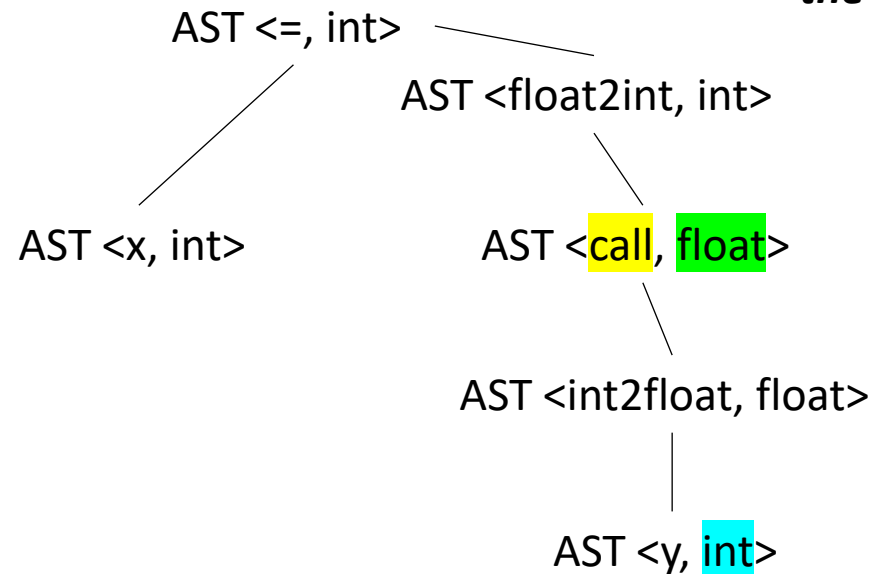
```
float sqrt(float x) ;
```

stored in the symbol table before type checking - think about C. you have to declare a function before you use it

# How are functions handled?

```
int x;  
int y;  
x = sqrt(y)
```

*How would type inference finish this?  
**remember that assignment converts to  
the lhs type***



requires a function specification,  
using in the .h file:

```
float sqrt(float x) ;
```

stored in the symbol table before type checking - think about C. you have to declare a function before you use it



# What about floats to ints?

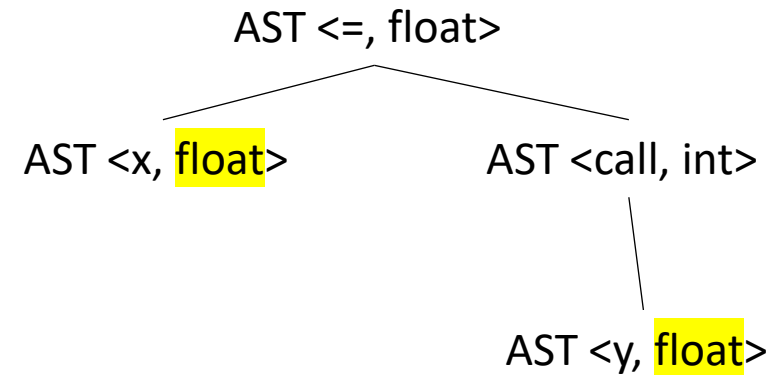
```
int int_sqrt(int input);
```

```
float x;
```

```
float y;
```

```
x = int_sqrt(y)
```

*Does this compile?*



# What about floats to ints?

```
int int_sqrt(int input);
```

```
float x;
```

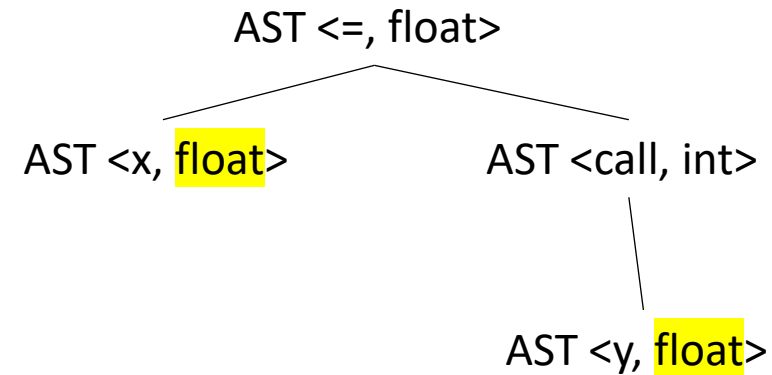
```
float y;
```

```
x = int_sqrt(y)
```

*Does this compile? Yes!*

*In this case the compiler will convert floats to an int.*

*Is that the right choice? ...*



# What about floats to ints?

```
int int_sqrt(int input);
```

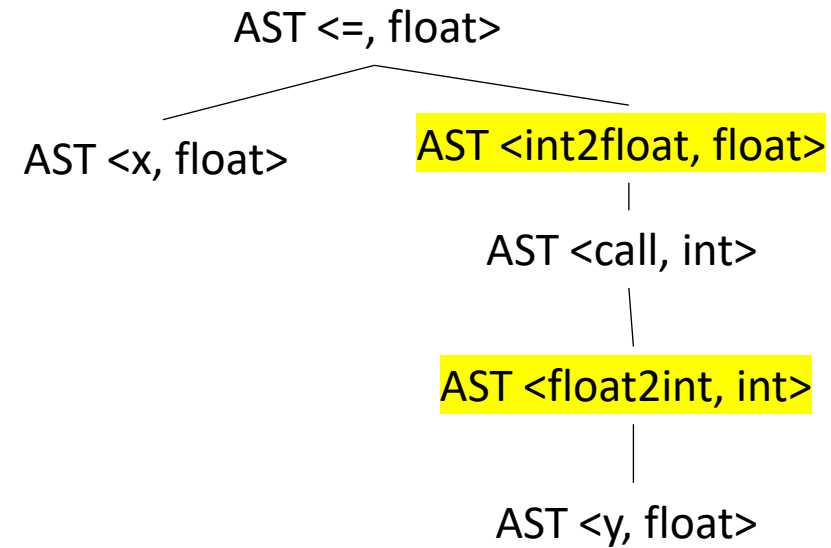
```
float x;
```

```
float y;
```

```
x = int_sqrt(y)
```

*Does this compile? Yes!*

*In this case the compiler will convert floats to an int.  
Is that the right choice? ...*



# Discussion

- Many languages (and styles) state that the programmer extends the type system through functions
- Other languages allow operator overloading
  - Controversial design pattern
  - But it can be really nice (e.g. it is used extensively in LLVM internals)

```

class Complex {
private:
    float real;
    float imag;
public:
    // Constructor to initialize real and imag to 0
    Complex() : real(0), imag(0) {}

    // Overload the + operator
    Complex operator + (const Complex& obj) {
        Complex temp;
        temp.real = real + obj.real;
        temp.imag = imag + obj.imag;
        return temp;
    }
}

```

Table for *plus* binary ops

left child	right child	result
int	int	int
int	float	float
float	int	float
float	float	float
Complex	Complex	Complex

```

class Complex {
private:
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        return temp;
    }

    Complex operator + (const float& i) {
        Complex temp;
        temp.real = real + i;
        temp.imag = imag;
        return temp;
    }
}

```

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        temp.real = real + i;
        temp.imag = imag;
        return temp;
    }
}

```

Table for *plus* binary ops

left child	right child	result
int	int	int
int	float	float
float	int	float
float	float	float
Complex	Complex	Complex
Complex	float	Complex

We can add extra rows

# Type systems finished

- Defined what a type system is and discussed various different design decisions
  - static vs. dynamic, choice of primitive types, size of primitive types
- Implemented type inference parameterized by type conversion tables on an AST.
  - identified common conversions (int to float) and when the opposite can happen
- Discussed how programmers can extend the type system
  - function calls
  - operator overloading



# Intermediate Representations

# Our next challenge, IR: 3 address code or linear IR

- We will specify our own that we will use in this class
  - Will be used in the next homeworks
- Similar to assembly
  - Untyped
  - Specialized operations for each type
- Similar to typical IRs (e.g. LLVM)
  - Unlimited virtual registers
- Patterned after RISC Machines, i.e. Load/Store, 3-address reg to reg Ops.

LES US SET DOWN SOME  
RULES FOR OUR IR

# Class-IR: The Players

**Inputs/outputs (IO):** 32-bit typed inputs

e.g.: `int x, int y, float z`     `// e.g. params to a function`

**Program Variables (Variables):** 32-bit untyped virtual register

given as `vrX` where `X` is an integer:

e.g. `vr0, vr1, vr2, vr3 ...`

**Constants (float or ints):** e.g. `3.5, 3e5, 6, 1024`

we will assume input/output names are disjoint from virtual register names

# Class-IR

## **binary operators:**

```
dst = operation(op0, op1);
```

operations can be one of these:

```
[add, sub, mult, div, eq, lt]
```

each operation is followed by an "i" or "f", which specifies how the bits in the registers are interpreted, eg **multi** for integers, **multf** for floating point.

# Class-IR

## **binary operators:**

```
dst = operation(op0, op1);
```

operations can be one of:

```
[add, sub, mult, div, eq, lt]
```

*all of `dst`, `op0`, and `op1` must be untyped virtual registers.*

# Class-IR: Examples

## **binary operators:**

```
dst = operation(op0, op1);
```

Examples:

```
vr0 = addi(vr1, vr2);
```

```
vr3 = subf(vr4, vr5);
```

```
x = multf(vr0, vr1); not allowed!
```

```
vr0 = addi(vr1, 1); not allowed!
```

*We'll talk about how to  
do this using other  
instructions*

# Class-IR: Control Flow

## Control flow

`branch(label);`

- branches unconditionally to the label

`bne(op0, op1, label)`

- if op0 is not equal to op1 then branch to label
- operands must be virtual registers!

`beq(op0, op1, label)`

- Same as bne except it is for equal



# Class-IR

## Assignment

```
vr0 = vr1
```

one virtual register can be assigned to another

# Class-IR

## Assignment

```
vr0 = vr1
```

one virtual register can be assigned to another

Examples:

```
vr0 = 1; not allowed
```

```
vr1 = x; not allowed
```

# Class-IR

**unary get untyped register**

```
dst = operation(op0);
```

operations are: [int2vr, float2vr]

Example:

*Given IO: int x*

```
vr1 = int2vr(x);
```

```
vr2 = float2vr(2.0);
```

# Class-IR

**unary get typed data for IO**

```
dst = operation(op0);
```

operations are: [vr2int, vr2float]

Example:

*Given IO: int x and float y*

```
x = vr2int(vr1);
```

```
y = vr2float(vr3);
```

# Class-IR

**unary conversion operators for VRs:**

```
dst = operation(op0);
```

operations can be one of:

```
[vr_int2float, vr_float2int]
```

**converts** the bits in a **virtual register** from **one type to another**. ***op0** and **dst** must be a **virtual register!***

# Class-IR: Examples

## **unary conversion operators:**

```
dst = operation(op0);
```

Examples:

```
vr0 = vr_int2float(vr1);
```

```
vr2 = vr_float2int(1.0); not allowed!
```

# Example

adding the values 1 - 9 to an input/output variable: `int x`

# Example

adding the values 1 - 9 to an input/output variable: int x

```
vr0 = int2vr(1);
```

```
vr1 = int2vr(1);
```

```
vr2 = int2vr(10);
```

```
loop_start:
```

```
vr3 = lti(vr0, vr2);
```

```
bne(vr3, vr1, end_label);
```

```
vr4 = int2vr(x);
```

```
vr5 = addi(vr4, vr0);
```

```
x = vr2int(vr5);
```

```
vr0 = addi(vr0, vr1);
```

```
branch(loop_start);
```

```
end_label:
```



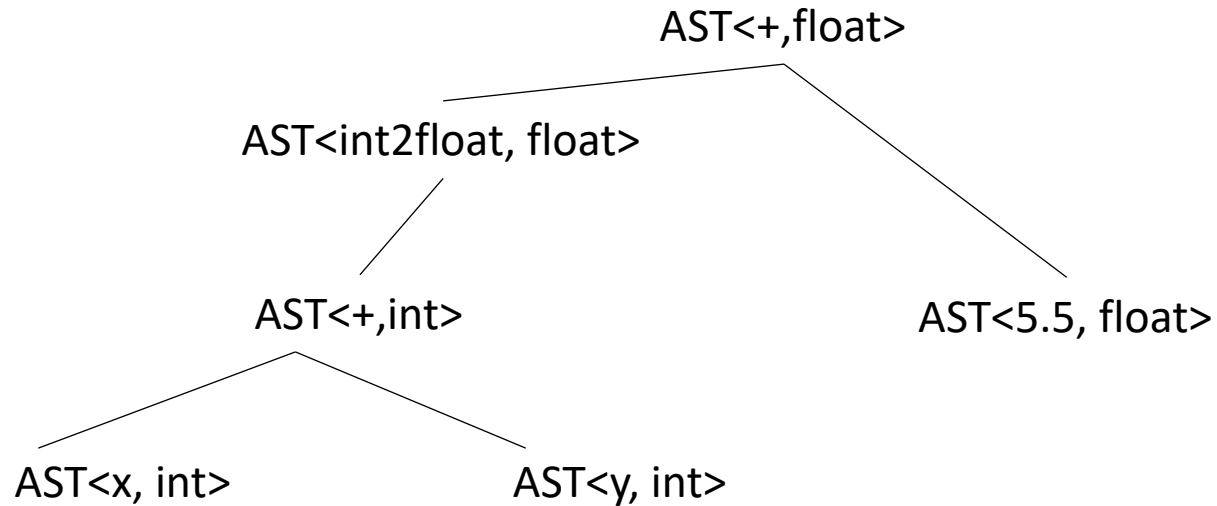
SO WE HAVE THE RULES

# Converting AST into Class-IR

# Converting AST into Class-IR

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```

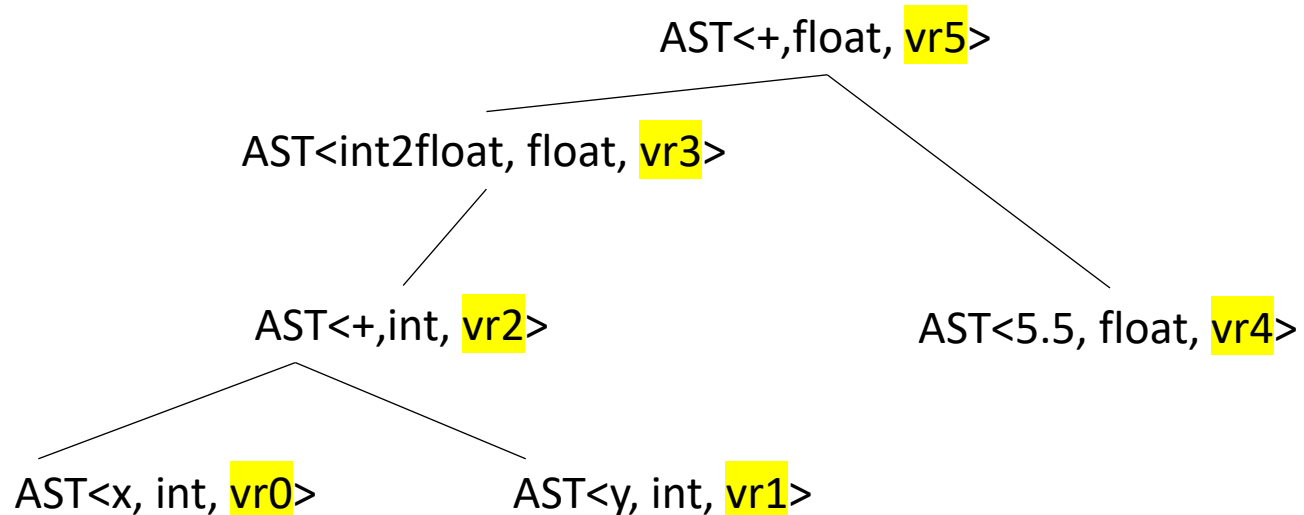
**After type inference**



# Converting AST into Class-IR

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```

**After type inference**



We will start by adding a new member to each AST node:

**A virtual register**

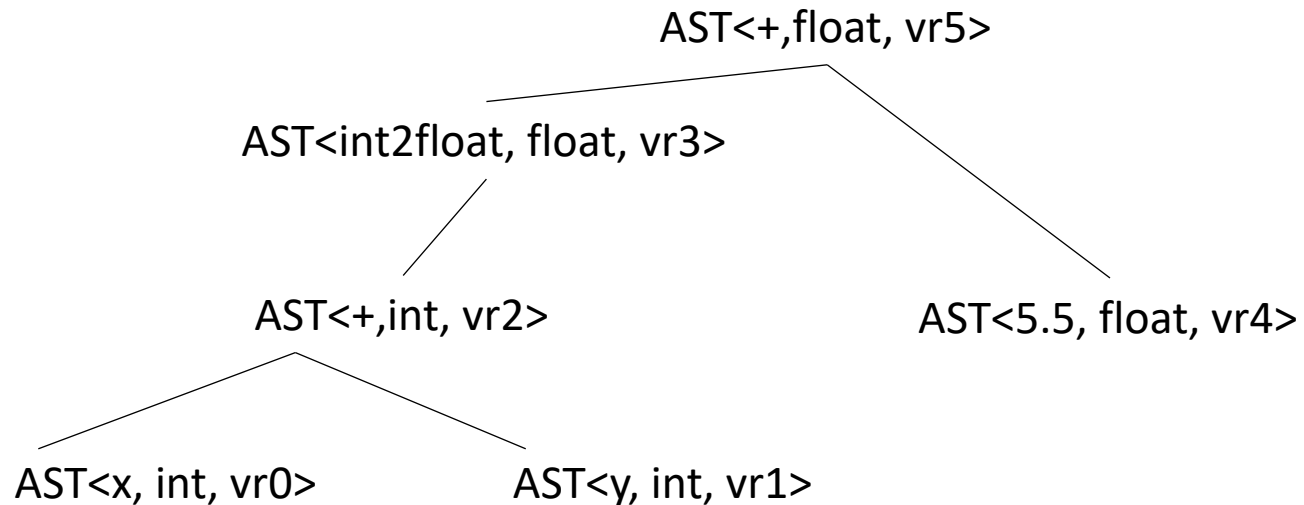
Each node needs a distinct virtual register

# Converting AST into Class-IR

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```

**After type inference**

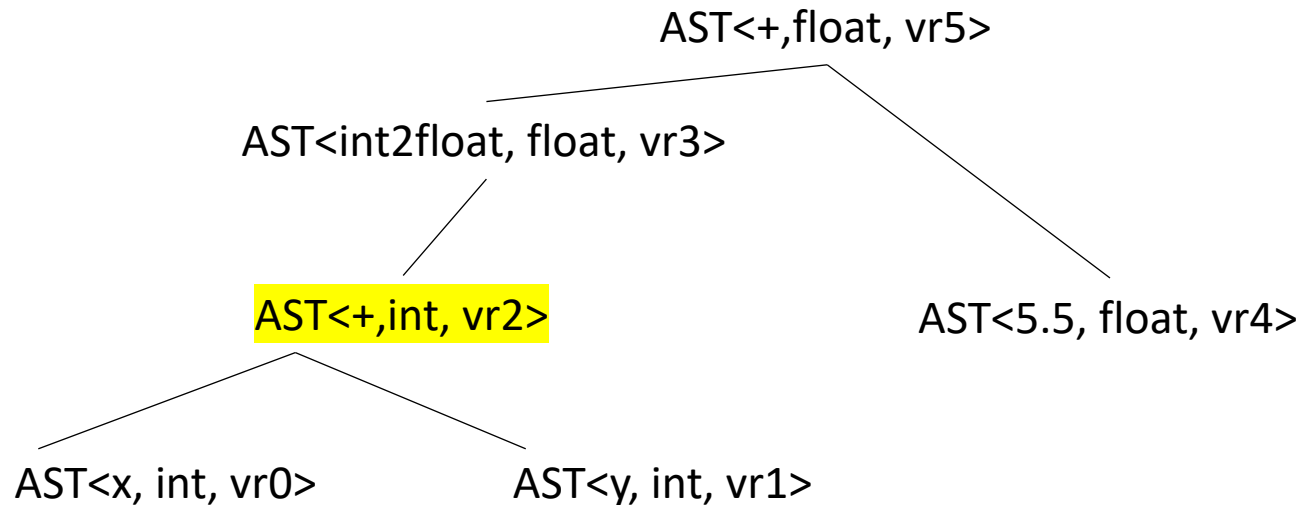
Next each AST node needs  
to know how to print a  
3 address instruction



# Converting AST into Class-IR

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```

**After type inference**



Next each AST node needs to know how to **print** a 3 address instruction

Let's look at add

```
class ASTPlusNode(ASTBinOpNode):
    def __init__(self, l_child, r_child):
        super().__init__(l_child, r_child)

    # return a string of the three address instruction
    # that this node encodes
    def three_addr_code(self):
        ??
```

```
return "%s = %s(%s,%s);" %
    (self.vr, self.get_op(), self.l_child.vr, self.r_child.vr)
```

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class ASTPlusNode(ASTBinOpNode):
    def __init__(self, l_child, r_child):
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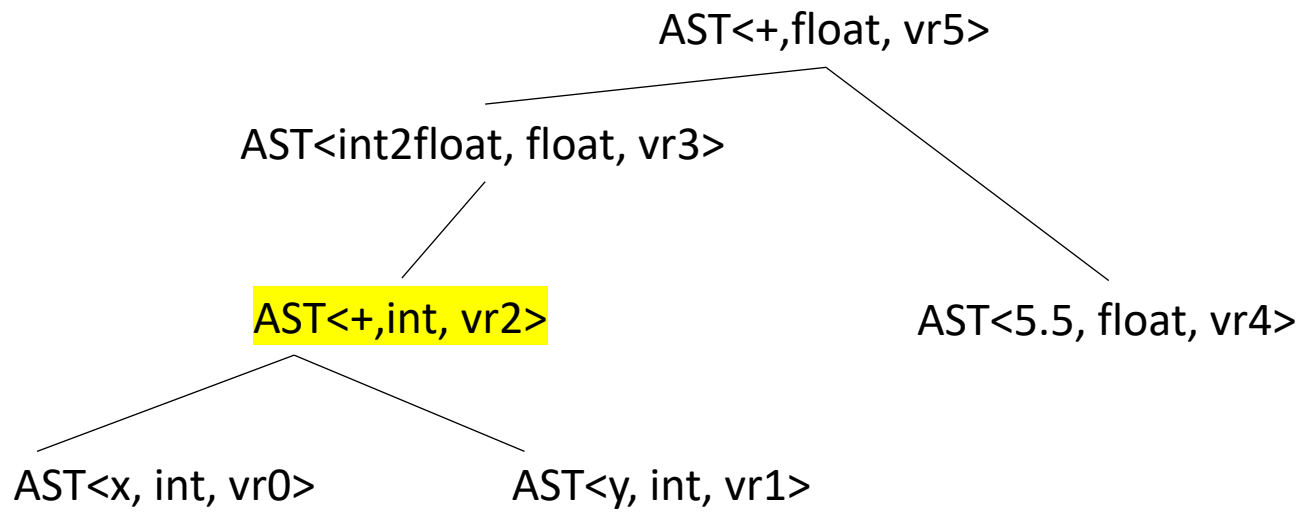
What is this one?



```
def get_op(self):  
    if self.node_type is Types.INT:  
        return "addi"  
    else:  
        return "addf"
```

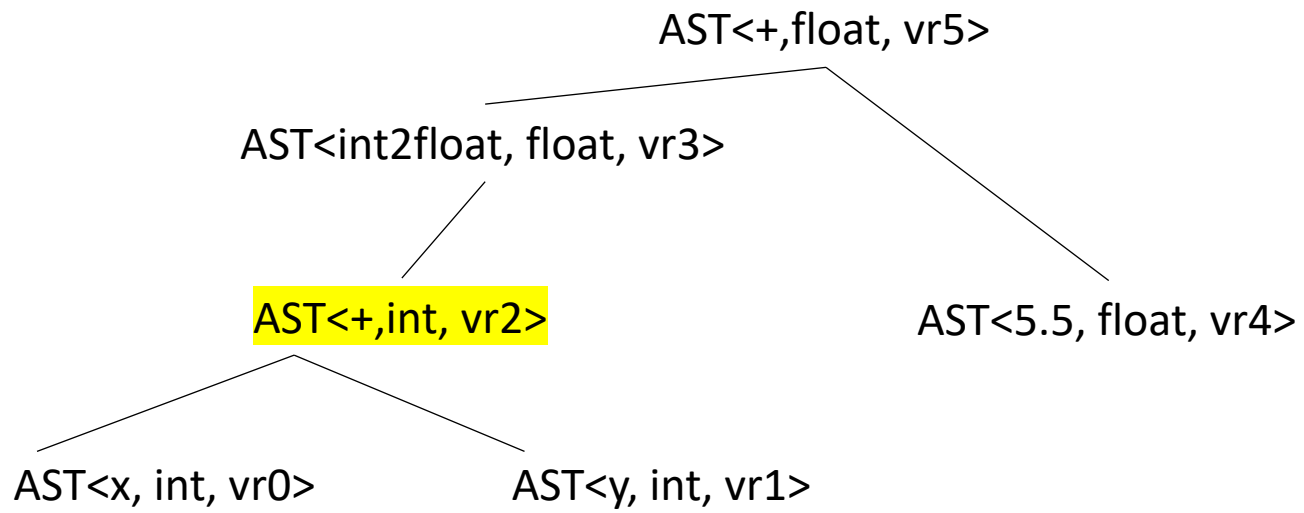
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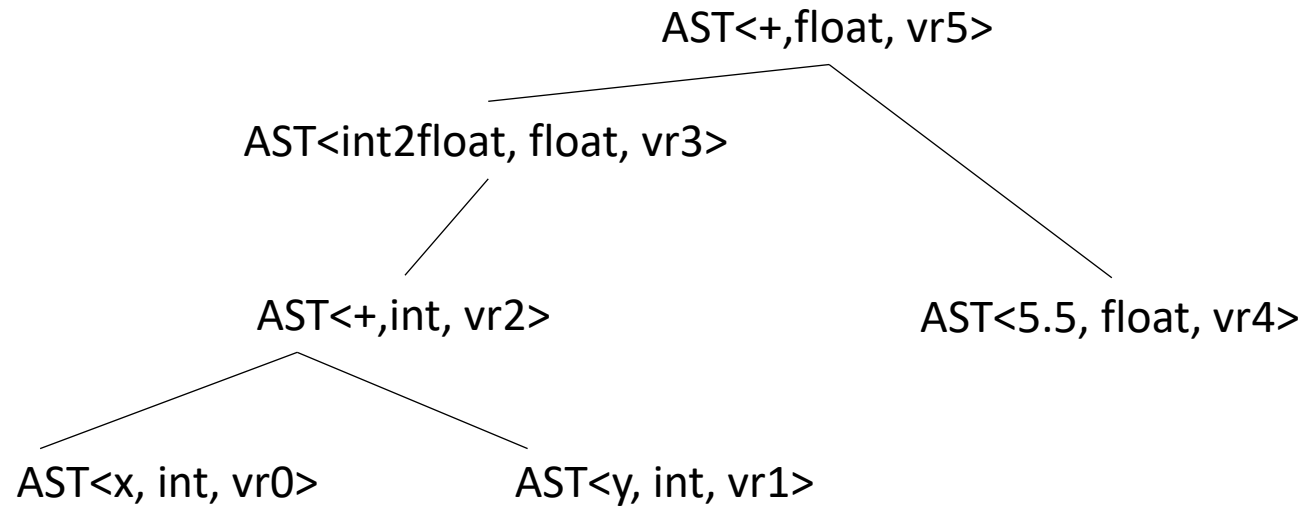


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```
return "%s = %s(%s,%s);" %  
    (self.vr, self.get_op(), self.l_child.vr, self.r_child.vr)
```

```
vr2 = addi(vr0, vr1);
```

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```



```
vr0 = int2vr(x);  
vr1 = int2vr(y);
```

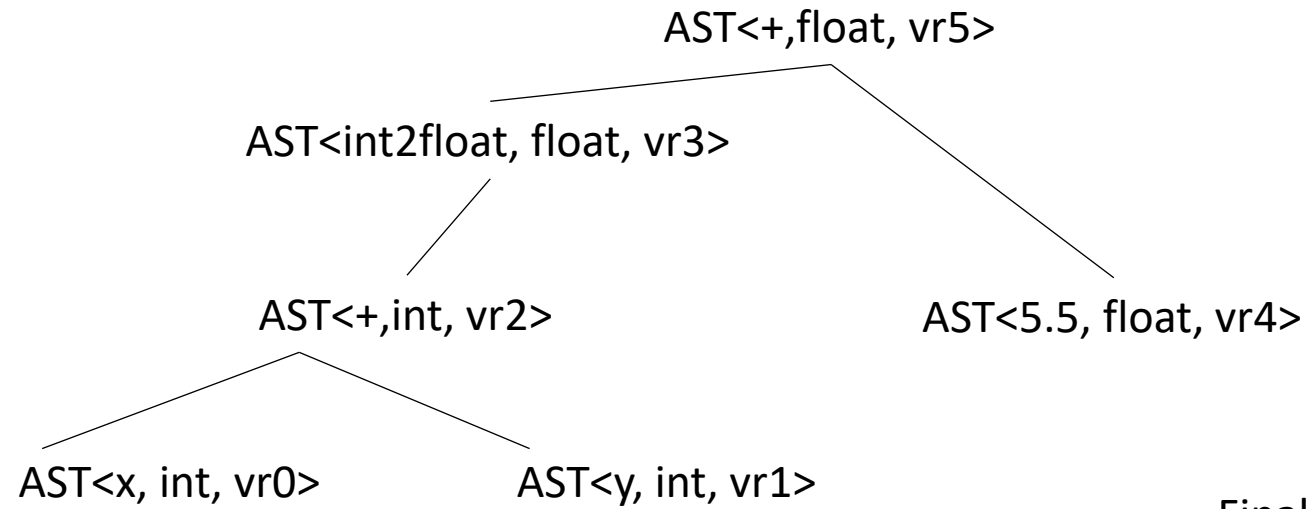
```
vr4 = float2vr(5.5);
```

```
vr2 = addi(vr0,vr1);
```

```
vr3 = vr_int2float(vr2);
```

```
vr5 = addf(vr3,vr4);
```

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```



We can create a 3 address program doing a post-order traversal

Final program

```
vr0 = int2vr(x);
```

```
vr1 = int2vr(y);
```

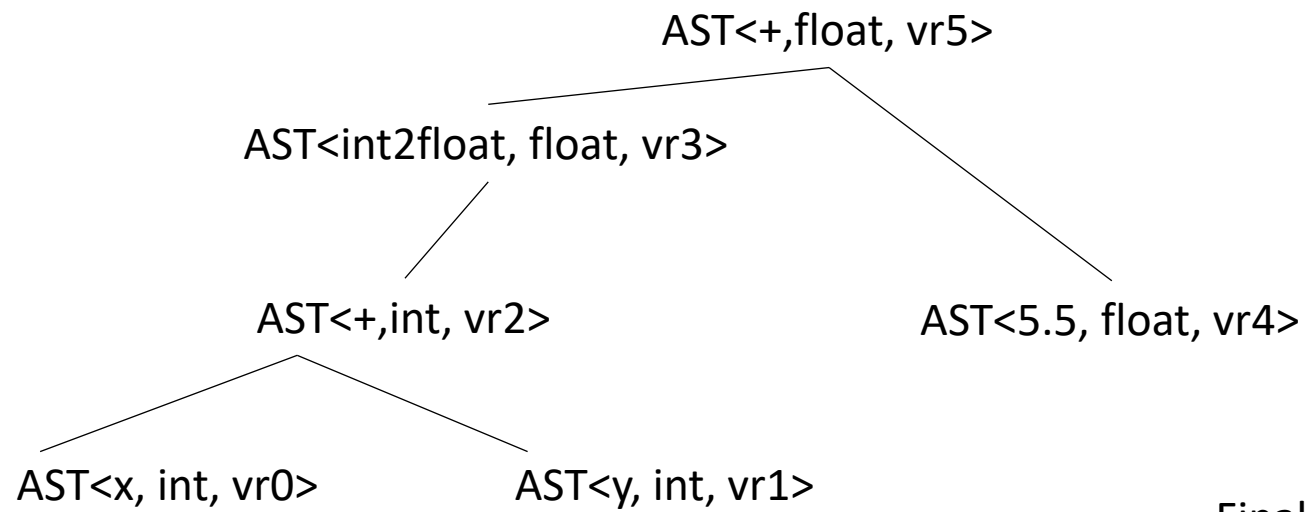
```
vr2 = addi(vr0, vr1);
```

```
vr3 = vr_int2float(vr2);
```

```
vr4 = float2vr(5.5);
```

```
vr5 = addf(vr3, vr4);
```

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```



We can create a 3 address program doing a post-order traversal

*Is this the only ordering?*

Final program

```
vr0 = int2vr(x);
```

```
vr1 = int2vr(y);
```

```
vr2 = addi(vr0, vr1);
```

```
vr3 = vr_int2float(vr2);
```

```
vr4 = float2vr(5.5);
```

```
vr5 = addf(vr3, vr4);
```

# Thinking at a higher level

## What we now know how to do:

- parse an expression: `parse_expr`
- create an AST during parsing
- do type inference on an AST
- convert a type-safe AST into 3 address code

# Backing up to an even higher level

- We can now define what our parser return as:
  - A list of 3 address code
- We can get 3 address code from parsing expressions,  
now we just need to get it from statements



# From our grammar

```
statement := declaration_statement
           | assignment_statement
           | if_else_statement
           | block_statement
           | for_loop_statement
```

Our top-down parser should have a function called `parse_statement`

This should return a list of 3 address code instructions that encode the statement

# From our grammar

```
statement := declaration_statement  
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```

Our top down parser should have a function called `parse_statement`

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```
int x;  
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float w;  
w = x + y + 5.5
```

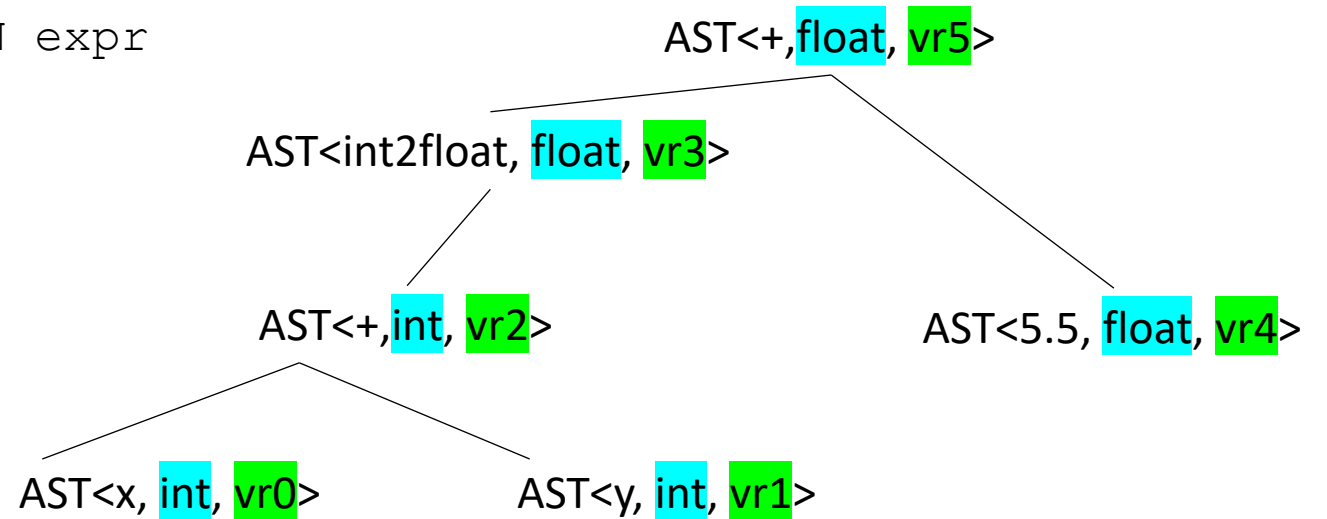
```
assignment_statement_base := ID ASSIGN expr
```

```
{  
    id_name = to_match.value  
    eat("ID");  
    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = %s" % ?  
    return program + [new_inst]  
}
```

```
int x;  
int y;  
float w;  
w = x + y + 5.5
```

assignment\_statement\_base := ID ASSIGN expr

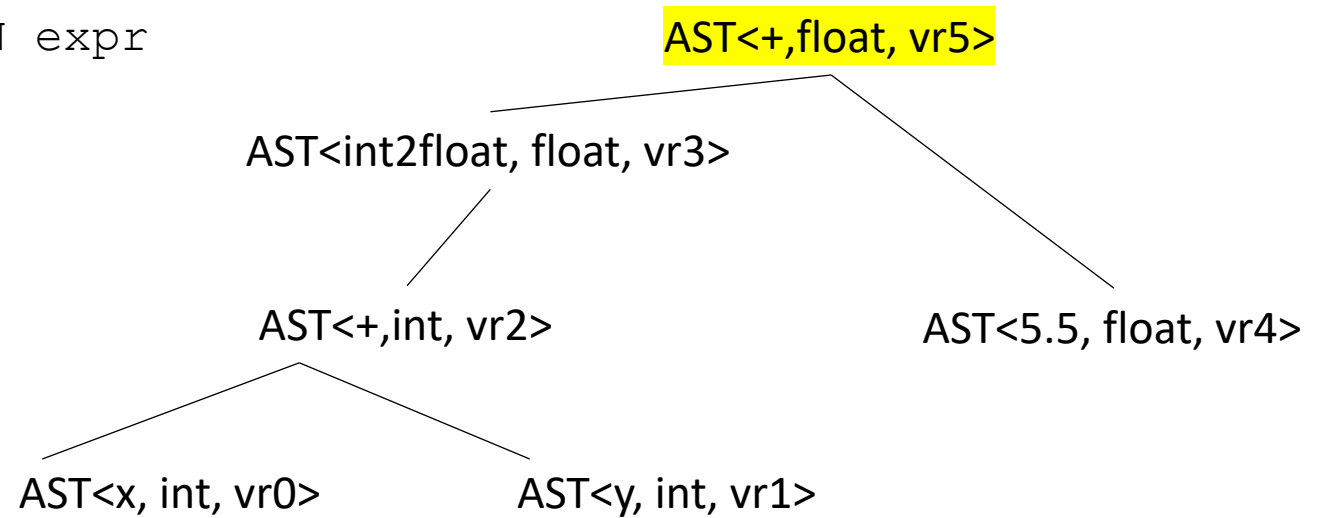
```
{  
    id_name = to_match.value  
    eat("ID");  
    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    assign_registers(ast)  
    program = ast.linearize() # 3-addr IR code of expr  
    new_inst = "%s = %s" % ?  
    return program + [new_inst]  
}
```



```
int x;  
int y;  
float w;  
w = x + y + 5.5
```

assignment\_statement\_base := ID ASSIGN expr

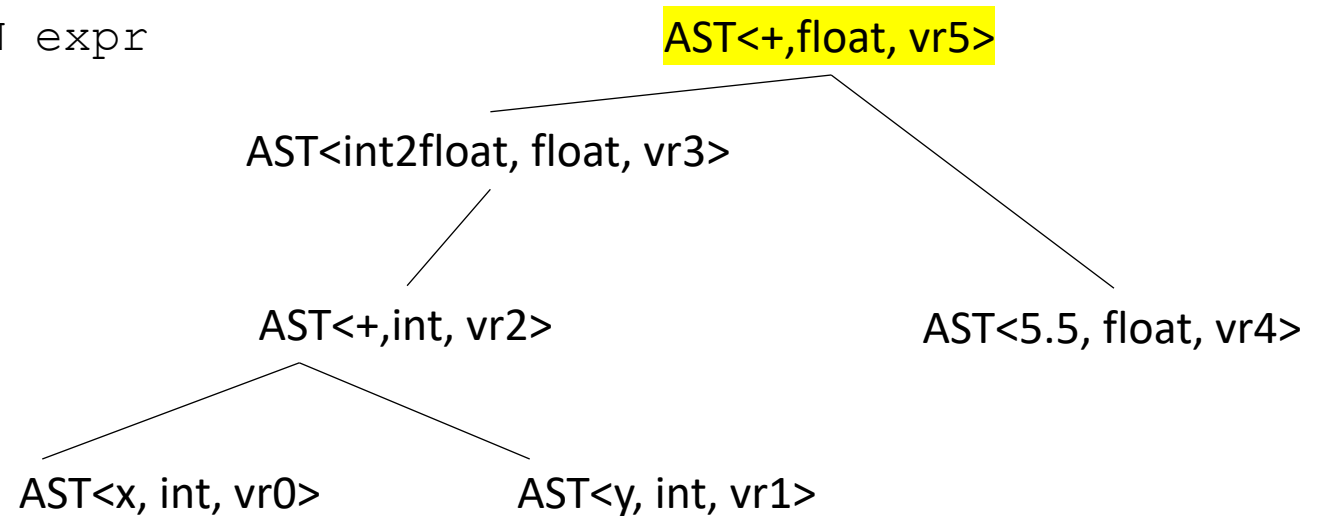
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```
int x;  
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    type_inference(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = %s" % (id_name, ast.vr)  
    return program + [new_inst]  
}
```



```
int x;
int y;
float w;
w = x + y + 5.5
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assignment\_statement\_base := ID ASSIGN expr

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    id_name = to_match.value
    eat("ID");
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    ast = parse_expr()
    type_inference(ast)
    assign_registers(ast)
    program = ast.linearize()
    new_inst = "%s = %s" % (id_name, ast.vr)
    return program + [new_inst]
}
```

program

```
vr0 = int2vr(x);
```

```
vr1 = int2vr(y);
```

```
vr2 = addi(vr0, vr1);
```

```
vr3 = vr_int2float(vr2);
```

```
vr4 = float2vr(5.5);
```

```
vr5 = addf(vr3, vr4);
```

new inst

```
w = vr5
```

```
int x;  
int y;  
float w;  
w = x + y + 5.5
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```
assignment_statement_base := ID ASSIGN expr
```

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{  
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    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = %s" % (id_name, ast.vr)  
    return program + [new_inst]  
}
```

*What are we missing for this assignment?*

1. If the type of ID doesn't match the type of the ast, then the ast needs to be converted.
2. ID should be checked if it is an input/output variable. which means it will need to be handled differently.
3. You need to check the ID in the symbol table

*it can get a little messy*



```
int x;  
int y;  
int w;  
w = x + y + 5.5
```

```
assignment_statement_base := ID ASSIGN expr
```

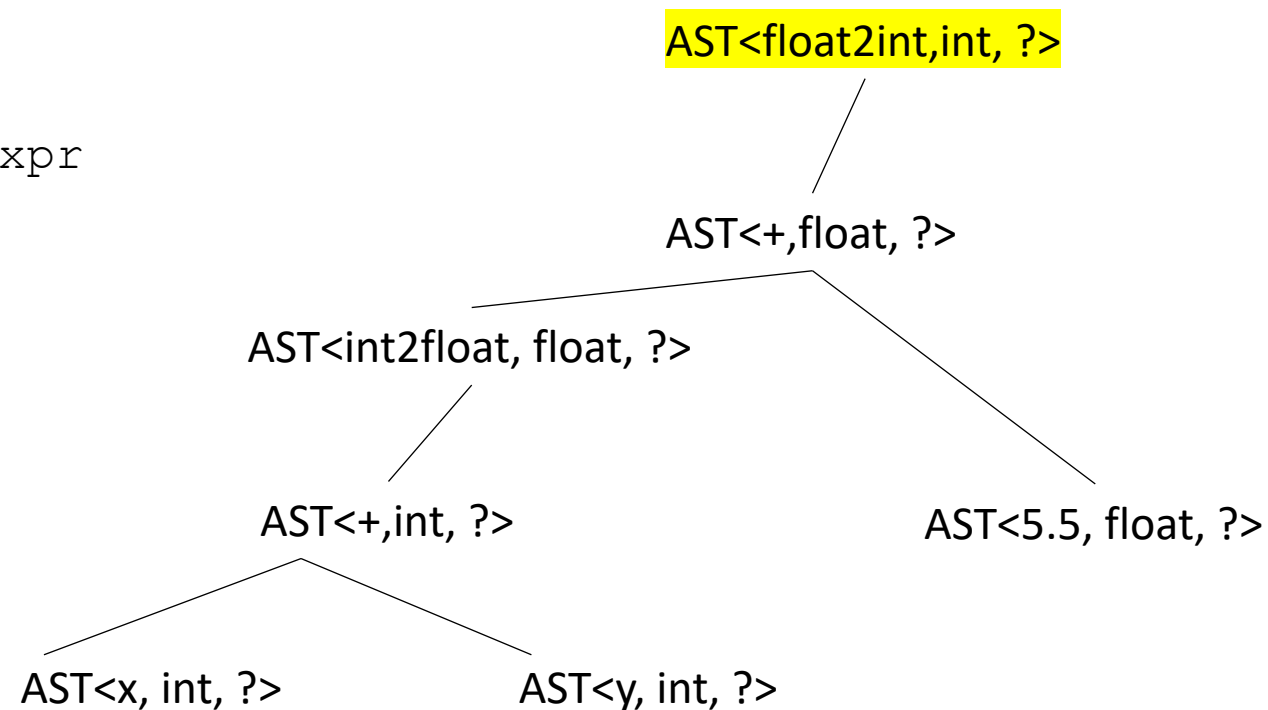
```
{  
    id_name = to_match.value  
    id_data_type = # get ID data type  
    eat("ID");  
    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    if id_data_type == INT and  
        ast.node_type == FLOAT:  
        ast = ASTFloatToInt(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = %s" % (id_name, ast.vr)  
    return program + [new_inst]  
}
```

one possible case

```
int x;  
int y;  
int w;  
w = x + y + 5.5
```

```
assignment_statement_base := ID ASSIGN expr
```

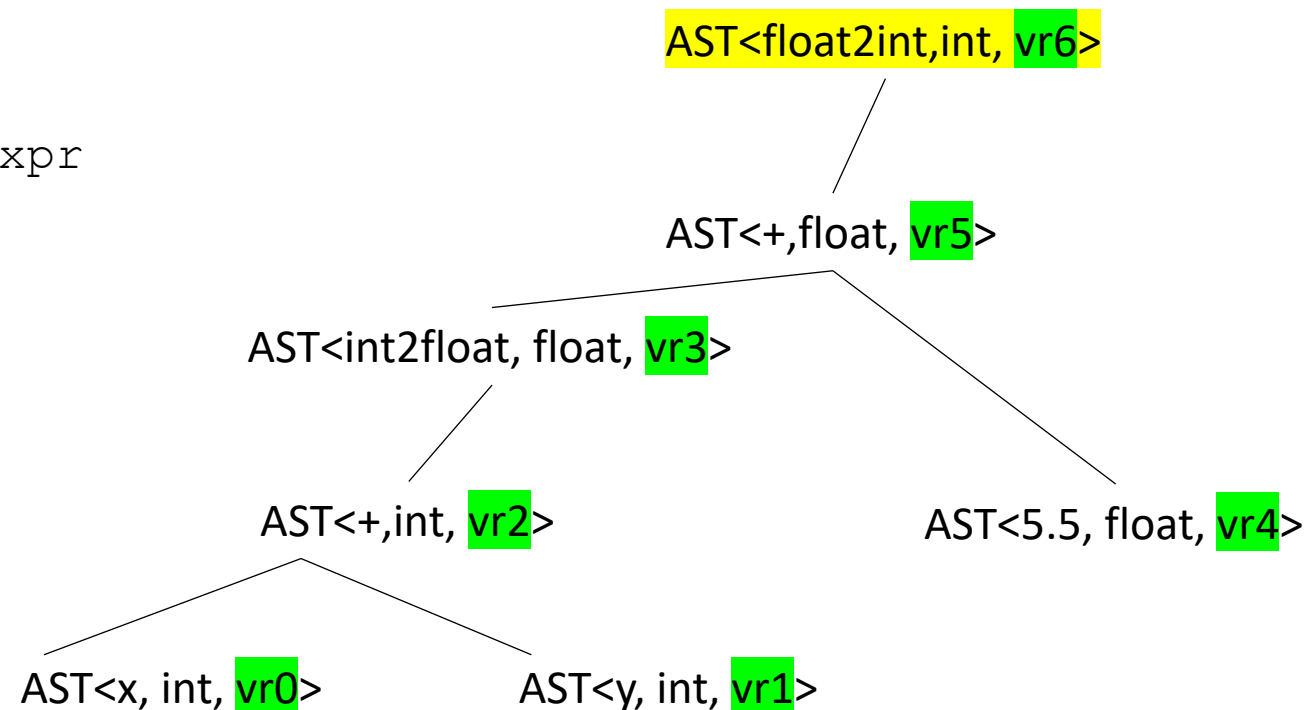
```
{  
    id_name = to_match.value  
    id_data_type = # get ID data type  
    eat("ID");  
    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    if id_data_type == INT and  
        ast.node_type == FLOAT:  
        ast = ASTFloatToInt(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = %s" % (id_name, ast.vr)  
    return program + [new_inst]  
}
```



```
int x;  
int y;  
int w;  
w = x + y + 5.5
```

```
assignment_statement_base := ID ASSIGN expr
```

```
{  
    id_name = to_match.value  
    id_data_type = # get ID data type  
    eat("ID");  
    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    if id_data_type == INT and  
        ast.node_type == FLOAT:  
        ast = ASTFloatToInt(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = %s" % (id_name, ast.vr)  
    return program + [new_inst]  
}
```



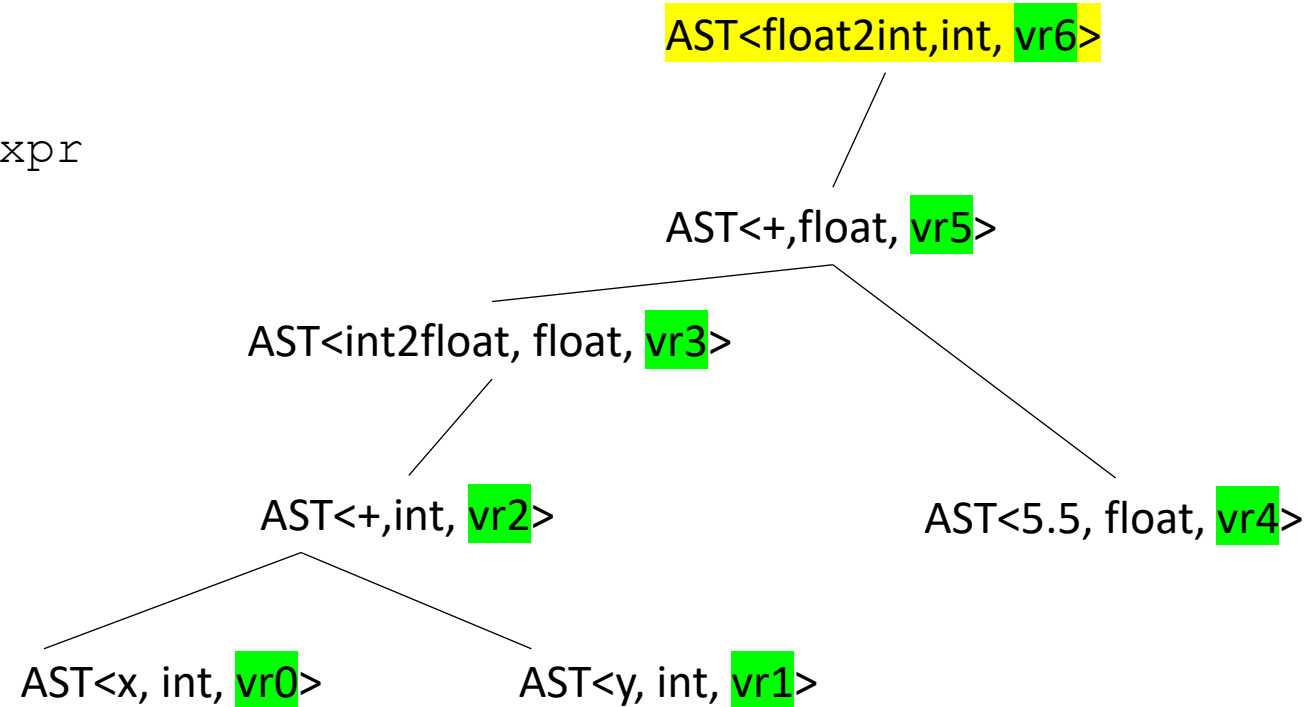
```
(IO: int w)
```

*How would we deal with w as an IO variable?*

```
int x;  
int y;  
w = x + y + 5.5
```

```
assignment_statement_base := ID ASSIGN expr
```

```
{  
  id_name = to_match.value  
  id_data_type = # get ID data type  
  eat("ID");  
  eat("ASSIGN");  
  ast = parse_expr()  
  type_inference(ast)  
  if id_data_type == INT and  
    ast.node_type == FLOAT:  
    ast = ASTFloatToInt(ast)  
  assign_registers(ast)  
  program = ast.linearize()  
  new_inst = "%s = %s" % (id_name, ast.vr)  
  return program + [new_inst]  
}
```



```
(IO: int w)
```

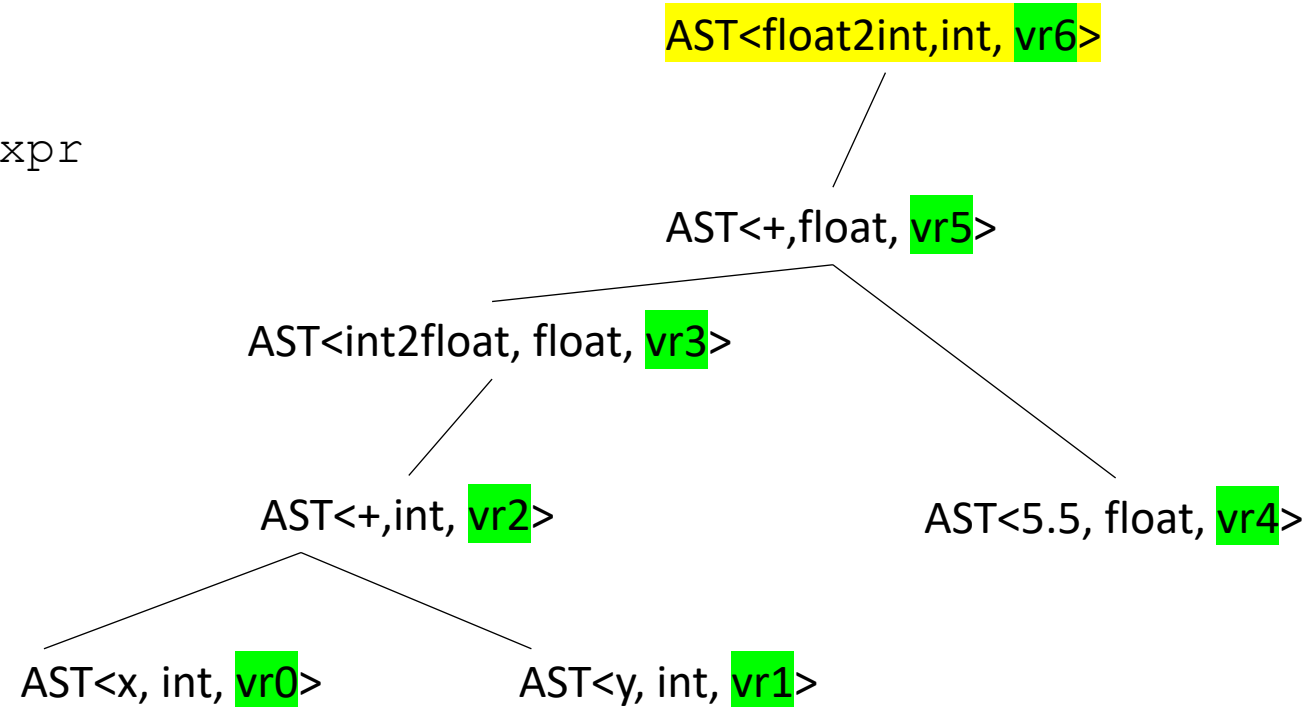
*How would we deal with w as an IO variable?*

```
int x;  
int y;  
w = x + y + 5.5
```

```
assignment_statement_base := ID ASSIGN expr
```

```
{  
    id_name = to_match.value  
    id_data_type = # get ID data type  
    eat("ID");  
    eat("ASSIGN");  
    ast = parse_expr()  
    type_inference(ast)  
    if id_data_type == INT and  
        ast.node_type == FLOAT:  
        ast = ASTFloatToInt(ast)  
    assign_registers(ast)  
    program = ast.linearize()  
    new_inst = "%s = vr2int(%s)" % (id_name, ast.vr)  
    return program + [new_inst]  
}
```

***Only if it is an IO variable!***



Let's do another one

```
statement := declaration_statement  
          | assignment_statement  
          | if_else_statement  
          | block_statement  
          | for_loop_statement
```

```

if_else_statement := IF LPAR expr RPAR statement ELSE statement

{
    eat("IF");
    eat("LPAR");
    expr_ast = parse_expr()
    ...
    program0 = # type safe and linearized ast
    eat("RPAR");
    program1 = parse_statement()
    eat("ELSE")
    program2 = parse_statement()
    ...
}

```

```

if (program0) {
    program1
}
else {
    program2
}

```

*We need to convert this  
to 3 address code*

```

if_else_statement := IF LPAR expr RPAR statement ELSE statement

{
    eat("IF");
    eat("LPAR");
    expr_ast = parse_expr()
    ...
    program0 = # type safe and linearized ast
    eat("RPAR");
    program1 = parse_statement()
    eat("ELSE")
    program2 = parse_statement()
    ...
}

```

```

if (program0) {
    program1
}
else {
    program2
}

```

*We need to convert this  
to 3 address code*

```

program0
program1
program2

```



```

if_else_statement := IF LPAR expr RPAR statement ELSE statement
{
    eat("IF");
    eat("LPAR");
    expr_ast = parse_expr()
    ...
    program0 = # type safe and linearized ast
    eat("RPAR");
    program1 = parse_statement()
    eat("ELSE")
    program2 = parse_statement()
    ...
}

```

```

if (program0) {
    program1
}
else {
    program2
}

```

*We need to convert this  
to 3 address code*

```

program0;
vrX = int2vr(0)
beq(expr_ast.vr, vrX, else_label);
program1
branch(end_label);
else_label:
program2
end_label:

```

<pre> if_else_statement := IF LPAR <b>expr</b> RPAR <b>statement</b> ELSE <b>statement</b> {     ...     # get resources     end_label  = mk_new_label()     else_label = mk_new_label()     vrX        = mk_new_vr()      # make instructions     ins0 = "%s = int2vr(0)" % vrX # create False     ins1 = "beq(%s, %s, %s);" %             (expr_ast.vr, vrX, else_label)     ins2 = "branch(%s)" % end_label      # concatenate all programs     return program0 + [ins0, ins1] + program1                     + [ins2, label_code(else_label)]                     + program2 + [label_code(end_label)] } </pre>	<pre> if (<b>program0</b>) {     <b>program1</b> } else {     <b>program2</b> }  <i>We need to convert this to 3 address code</i>  <b>program0;</b>     vrX = int2vr(0);    // a False     beq(expr_ast.vr, vrX, else_label); <b>program1</b>     branch(end_label); else_label:     <b>program2</b> end_label: </pre>
---	--

```
if_else_statement := IF LPAR expr RPAR statement ELSE statement
```

```
{  
    ...  
    # get resources  
    end_label  = mk_new_label()  
    else_label = mk_new_label()  
    vrX        = mk_new_vr()  
  
    # make instructions  
    ins0 = "%s = int2vr(0)" % vrX  
    ins1 = "beq(%s, %s, %s);" %  
           (expr_ast.vr, vrX, else_label)  
    ins2 = "branch(%s)" % end_label  
  
    # concatenate all programs  
    return program0 + [ins0, ins1] + program1  
        + [ins2, label_code(else_label)]  
        + program2 + [label_code(end_label)]  
}
```

```
class VRAllocator():  
    def __init__(self):  
        self.count = 0  
  
    def mk_new_vr(self):  
        vr = "vr" + str(self.count)  
        self.count += 1  
        return vr
```

```
if_else_statement := IF LPAR expr RPAR statement ELSE statement
```

```
{  
    ...  
    # get resources  
    end_label  = mk_new_label()  
    else_label = mk_new_label()  
    vrX        = mk_new_vr()  
  
    # make instructions  
    ins0 = "%s = int2vr(0)" % vrX  
    ins1 = "beq(%s, %s, %s);" %  
           (expr_ast.vr, vrX, else_label)  
    ins2 = "branch(%s)" % end_label  
  
    # concatenate all programs  
    return program0 + [ins0, ins1] + program1  
        + [ins2, label_code(else_label)]  
        + program2 + [label_code(end_label)]  
}
```

```
class LabelAllocator():  
    def __init__(self):  
        self.count = 0  
  
    def mk_new_label(self):  
        lb = "label" + str(self.count)  
        self.count += 1  
        return lb
```

```

if_else_statement := IF LPAR expr RPAR statement ELSE statement

{
    ...
    # get resources
    end_label  = mk_new_label()
    else_label = mk_new_label()
    vrX        = mk_new_vr()

    # make instructions
    ins0 = "%s = int2vr(0)" % vrX
    ins1 = "beq(%s, %s, %s);" %
            (expr_ast.vr, vrX, else_label)
    ins2 = "branch(%s)" % end_label

    # concatenate all programs
    return program0 + [ins0, ins1] + program1
        + [ins2, label_code(else_label)]
        + program2 + [label_code(end_label)]
}

```

**Need a :**

```

if_else_statement := IF LPAR expr RPAR statement ELSE statement

{
    ...
    # get resources
    end_label  = mk_new_label()
    else_label = mk_new_label()
    vrX        = mk_new_vr()

    # make instructions
    ins0 = "%s = int2vr(0)" % vrX
    ins1 = "beq(%s, %s, %s);" %
            (expr_ast.vr, vrX, else_label)
    ins2 = "branch(%s)" % end_label

    # concatenate all programs
    return program0 + [ins0, ins1] + program1
        + [ins2, label_code(else_label)]
        + program2 + [label_code(end_label)]
}

```

```

def label_code(l):
    return l + ":"

```

```

# return a well-formed label
# e.g.  else_label_2:

```

```
statement := declaration_statement  
          | assignment_statement  
          | if_else_statement  
          | block_statement  
          | for_loop_statement
```

We did these two

You do these two for your homework

*Draw out for loops just like how we did with the if statements!*

# Compiler pragmatics

- New terminology I learned recently:
  - **Pragmatics** gives you the *how and why* of how real compilers make trade-offs, handle edge cases, optimize code, or support language features not captured by formal models.
- We need to talk about different ID types (IO, VRs)
- We need to talk about scopes



# Class-IR

**Inputs/outputs (IO):** 32-bit typed inputs

e.g.: `int x, int y, float z`

**Program Variables (Variables):** 32-bit untyped virtual register

given as `vrX` where `X` is an integer:

e.g. `vr0, vr1, vr2, vr3 ...`

we will assume input/output names are disjoint from virtual register names

# Two different ID nodes

*Gets compiled into an untyped virtual register*

```
class ASTVarIDNode(ASTLeafNode):  
    def __init__(self, value, value_type):  
        super().__init__(value)  
        self.node_type = value_type
```

*Gets compiled into a typed IO variable*

```
class ASTIOIDNode(ASTLeafNode):  
    def __init__(self, value, value_type):  
        super().__init__(value)  
        self.node_type = value_type
```

# Two different ID nodes

What we are compiling

```
void test4(float &x) {  
    int i;  
    for (i = 0; i < 100; i = i + 1) {  
        x = i;  
    }  
}
```

# Class-IR

What we are compiling

```
void test4(float &x) {  
    int i;  
    for (i = 0; i < 100; i = i + 1) {  
        x = i;  
    }  
}
```

IO variables

program variables

```
int main() {  
    int a = 0;  
    test1(a);  
    cout << a << endl;  
    return 0;  
}
```

*What does this print?*

What we are compiling

IO variables

```
void test4(float &x) {  
    int i;  
    for (i = 0; i < 100; i = i + 1) {  
        x = i;  
    }  
}
```

program variables

*Every time you access an IO variable,  
you need to convert it to a vr first  
using float2vr or int2vr*

IO Node needs to account to  
convert according to the type of  
the IO variable

```
class ASTIOIDNode(ASTLeafNode):
```

```
...
```

```
def three_addr_code(self):
```

```
    if self.node_type == Types.INT:
```

```
        return "%s = int2vr(%s);" % (self.vr, self.value)
```

```
    if self.node_type == Types.FLOAT:
```

```
        return "%s = float2vr(%s);" % (self.vr, self.value)
```

<= Code generated

What we are compiling

IO variables

```
void test4(float &x) {  
    int i;  
    for (i = 0; i < 100; i = i + 1) {  
        x = i;  
    }  
}
```

program variables

*Every time you access a program variable, it does not need to be converted.*

*Because its value is a virtual register, you can even just use its value as its virtual register*

```
class ASTVarIDNode(ASTLeafNode):
```

```
...
```

```
def three_addr_code(self):  
    return "%s = %s;" % (self.vr, self.value)
```

<= Code generated

building an expression AST, we parse a unit at the base

```
unit := ID  
      | ...
```

*How do we know whether to make an IO node or a Var node?*

```
{  
  id_name = self.to_match[1]  
  data_type = # get type from symbol table  
  eat("ID")  
  return ASTIDNode(id_name, data_type)  
}
```

*Previously we had just one ID node*

building an expression AST, we parse a unit at the base

```
unit := ID  
      | ...
```

*How do we know whether to make an IO node or a Var node?*

```
{  
  id_name = self.to_match[1]  
  data_type = # get type from symbol table  
  eat("ID")  
  return ASTIDNode(id_name, data_type)  
}
```



building an expression AST, we parse a unit at the base

```
unit := ID  
      | ...
```

*How do we know whether to make an IO node or a Var node?*

```
{  
    id_name = self.to_match[1]  
    id_data = # get id_data from the symbol table  
    eat("ID")  
    return ASTIDNode(id_name, ...)  
}
```

*id\_data should contain:*

***id\_type**: IO or Var*

***data\_type**: int or float*

building an expression AST, we parse a unit at the base

```
unit := ID
      | ...           How do we know whether to make an IO node or a Var node?

{
    id_name = self.to_match[1]
    id_data = # get id_data from the symbol table
    eat("ID")
    if (id_data.id_type == IO)
        return ASTIOIDNode(id_name, id_data.data_type)
    else
        return ASTVarIDNode(id_name, id_data.data_type)
}
```

*id\_data should contain:*

***id\_type**: IO or Var*

***data\_type**: int or float*

Getting back to our statements:

```
statement := declaration_statement  
           | assignment_statement  
           | if_else_statement  
           | block_statement  
           | for_loop_statement
```

When we declare a variable, we need to mark it as a program variable in the symbol table

Getting back to our statements:

```
statement := declaration_statement  
           | assignment_statement  
           | if_else_statement  
           | block_statement  
           | for_loop_statement
```

*We need to use symbol table data for something else. What?*

Getting back to our statements:

```
statement := declaration_statement
           | assignment_statement
           | if_else_statement
           | block_statement
           | for_loop_statement
```

*We need to use symbol table data for something else. What?*

*Scopes! Class IR has no {}s, so we need to manage scopes*

# Scopes

```
int x;  
int y;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

What does y hold?

# Scopes

```
int x;  
int y;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

How can we get rid of the {}'s?

What does y hold?

# Scopes

Let's walk through it with a symbol table

```
int x;  
int y;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```



# Scopes

Let's walk through it with a symbol table

```
int x;  
int y;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

HT0



symbol table hash table stack

# Scopes

rename

Let's walk through it with a symbol table

```
int x_0;  
int y;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

make a new unique name for x

HT0

x: (INT, VAR, "x_0")
----------------------

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

HT0

x: (INT, VAR, "x_0")
----------------------

symbol table hash table stack

# Scopes

rename

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

make a new unique name for y

HT0

x:	(INT, VAR, "x_0")
y:	(INT, VAR, "y_0")

symbol table hash table stack

# Scopes

search

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

HT0

x:	(INT, VAR, "x_0")
y:	(INT, VAR, "y_0")

symbol table hash table stack

# Scopes

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

replace  
with  
new name

Let's walk through it with a symbol table

HT0

x:	(INT, VAR, "x_0")
y:	(INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x;  
  x = 6;  
  y = x;  
}
```

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x_1;  
  x = 6;  
  y = x;  
}
```

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack



# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x_1;  
  x = 6;  
  y = x;  
}
```

lookup

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x_1;  
  x_1 = 6;  
  y = x;  
}
```

lookup

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x_1;  
  x_1 = 6;  
  y = x;  
}
```

lookup

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x_1;  
  x_1 = 6;  
  y_0 = x_1;  
}
```

lookup

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
{  
  int x_1;  
  x_1 = 6;  
  y_0 = x_1;  
}
```

No more need for {}

new scope. Add x with a new name

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

Let's walk through it with a symbol table

```
int x_0;  
int y_0;  
x_0 = 5;  
int x_1;  
x_1 = 6;  
y_0 = x_1;
```

new scope. Add x with a new name

No more need for {}

HT1

x: (INT, VAR, "x_1")
----------------------

HT0

x: (INT, VAR, "x_0")
y: (INT, VAR, "y_0")

symbol table hash table stack

# Scopes

What happens with multiple scopes?

```
int x;  
int y;  
x = 5;  
{  
    int x;  
    x = 6;  
}  
{  
    int x;  
    x = 1;  
    y = x;  
}
```

# Scopes

What happens with multiple scopes?

```
int x;  
int y;  
x = 5;  
{  
    int x;  
    x = 6;  
}  
{  
    int x;  
x = 1;  
    y = x;  
}
```

What if x is uninitialized?



# Class-IR

Remind ourselves what we are compiling

```
void test4(float &x) {  
  int i;  
  for (i = 0; i < 100; i = i + 1) {  
    x = x + i;  
  }  
}
```

We only need new names for program variables, not for IO variables

building an expression AST, we parse a unit at the base

```
unit := ID
      | ...           How do we know whether to make an IO node or a Var node?

{
  id_name = self.to_match[1]
  id_data = # get id_data from the symbol table
  eat("ID")
  if (id_data.id_type == IO)
    return ASTIOIDNode(id_name, id_data.data_type)
  else
    return ASTVarIDNode(id_data.new_name, id_data.data_type)
}
```

*id\_data should contain:*

***id\_type**: IO or Var*

***data\_type**: int or float*

***new\_name**: new unique name*

# NEXT:

- Finish up talking about intermediate representations