Type Checking

Outline

1. Introduction
2. The *j*-- Types
3. *j*-- Symbol Tables
4. Pre-analysis of *j*-- Programs
5. Analysis of *j*-- Programs

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Semantic analysis of *j--* programs involves all of the above

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j-- code may interact with classes from the Java library but it must be able to do so using only these types

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1. Java types are represented by objects of (Java) type `java.lang.Class`; since *j*-- is a subset of Java, why not use `Class` objects to represent its types?
2. Define an abstract class (or interface) `Type`, and concrete sub-classes (or implementations) `PrimitiveType`, `ReferenceType`, and `ArrayType`

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For example, reconsider the simple `Factorial` program. In this version we mark two locations in the program using comments: `position 1` and `position 2`

```
package pass;

import java.lang.System;

public class Factorial {
    public static int factorial(int n) {
        // position 1:
        if (n <= 0) {
            return 1;
        } else {
            return n * factorial(n - 1);
        }
    }

    public static void main(String[] args) {
        // position 2:
        int x = n;
        System.out.println(n + "! = " + factorial(x));
    }

    static int n = 5;
}
```

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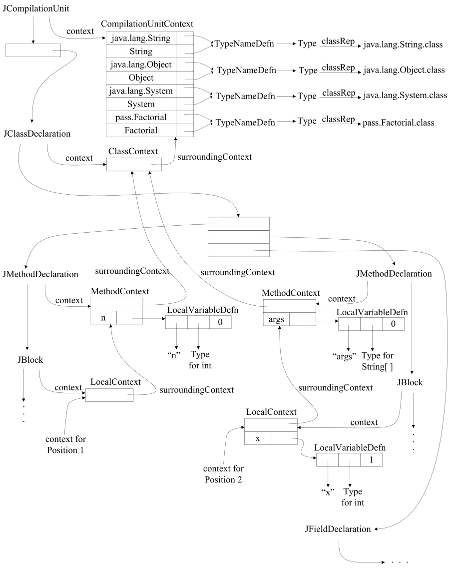
The symbol table for the `Factorial` program, and its relationship to the AST, is illustrated in figure below



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Each `surroundingContext` link back towards the `CompilationUnitContext` points to the context representing the surrounding lexical scope

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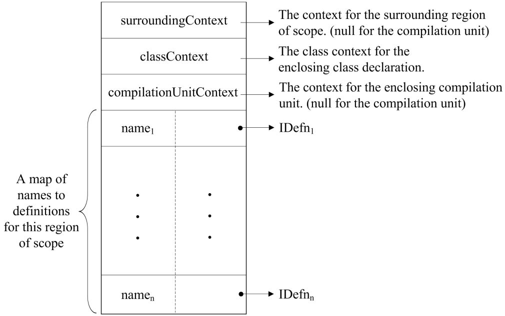
Type names are looked up in the `CompilationUnitContext`; to facilitate this, each context maintains three pointers to surrounding contexts, as illustrated in the following figure



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A `LocalContext` represents the scope within a block, which includes the block defining the body to a method; local variables are declared here

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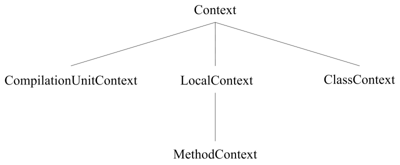

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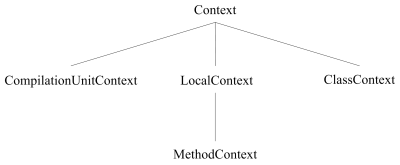

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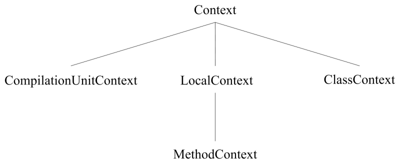

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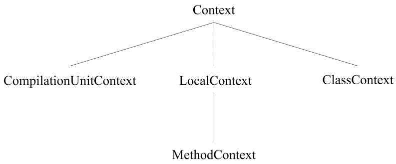

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1. A `TypeNameDefn`, which defines a type name; an `IDefn` of this sort encapsulates the `Type` that it denotes
2. A `LocalVariableDefn` defines a local variable and encapsulates the name, its `Type` and an offset in the current run-time stack frame

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For example, `Type` supports a method `fieldFor()` which, when given a name returns a `Field` with the given name that is defined for that type

```
public Field fieldFor(String name) {
    Class<?> cls = classRep;
    while (cls != null) {
        java.lang.reflect.Field[] fields = cls.getDeclaredFields();
        for (java.lang.reflect.Field field:fields) {
            if (field.getName().equals(name)) {
                return new Field(field);
            }
        }
        cls = cls.getSuperclass();
    }
    return null;
}
```

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The traversals are accomplished by the method `preAnalyze()` for the first traversal and the method `analyze()` for the second, which invoke themselves at the child nodes for recursively descending the AST

The `preAnalyze()` method must traverse down the AST only far enough for:

- Declaring imported type names
- Declaring user-defined class names
- Declaring fields
- Declaring methods (including their signatures - the types of their parameters)

Therefore, `preAnalyze()`need be defined only in the following types of AST nodes:

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- `JClassDeclaration`

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- `JCompilationUnit`
- `JClassDeclaration`
- `JFieldDeclaration`
- `JMethodDeclaration`
- `JConstructorDeclaration`

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

For the `JCompilationUnit` node at the top of the AST, `preAnalyze()` does the following:

Pre-analysis of j-- Programs

For the `JCompilationUnit` node at the top of the AST, `preAnalyze()` does the following:

1. It creates a `CompilationUnitContext`

Pre-analysis of j-- Programs

For the `JCompilationUnit` node at the top of the AST, `preAnalyze()` does the following:

1. It creates a `CompilationUnitContext`
2. It declares the implicit *j*-- types, `java.lang.String` and `java.lang.Object`

Pre-analysis of j-- Programs

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1. It creates a `CompilationUnitContext`
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3. It declares any imported types

Pre-analysis of j-- Programs

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1. It creates a `CompilationUnitContext`
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3. It declares any imported types
4. It declares the types defined by class declaration, ie, creates a `Type` for each declared class, whose `classRep` refers to a `Class` object for an empty class; for example, in the pre-analysis phase of our `Factorial` program above, the `Type` for `Factorial` would have a `classRep`, the `Class` object for the class

```
class Factorial {}
```

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```
class Factorial {}
```

5. Finally, `preAnalyze()` invokes itself for each of the type declarations in the compilation unit

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

```
public void preAnalyze() {
    context = new CompilationUnitContext();

    // Declare the two implicit types java.lang.Object and
    // java.lang.String
    context.addType(0, Type.OBJECT);
    context.addType(0, Type.STRING);

    // Declare any imported types
    for (TypeName imported: imports) {
        try {
            Class<?> classRep =
                Class.forName(imported.toString());
            context.addType(imported.line(),
                Type.typeFor(classRep));
        }
        catch (Exception e) {
            JAST.compilationUnit.reportSemanticError(
                imported.line(),
                "Unable to find %s", imported.toString());
        }
    }

    // Declare the locally declared type(s)
    CLEmitter.initializeByteClassLoader();
    for (JAST typeDeclaration: typeDeclarations) {
        ((JTypeDecl)
            typeDeclaration).declareThisType(context);
    }

    // Pre-analyze the locally declared type(s). Generate
    // (partial) Class instances, reflecting only the member
    // interface type information
    CLEmitter.initializeByteClassLoader();
    for (JAST typeDeclaration: typeDeclarations) {
        ((JTypeDecl)
          typeDeclaration).preAnalyze(context);
    }
```

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

In a class declaration, `preAnalyze()` does the following:

Pre-analysis of j-- Programs

In a class declaration, `preAnalyze()` does the following:

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Pre-analysis of j-- Programs

In a class declaration, `preAnalyze()` does the following:

1. It firstly creates a new `ClassContext`, whose `surroundingContext` points to the `CompilationUnitContext`
2. It resolves the class's super type

Pre-analysis of j-- Programs

In a class declaration, `preAnalyze()` does the following:

1. It firstly creates a new `ClassContext`, whose `surroundingContext` points to the `CompilationUnitContext`
2. It resolves the class's super type
3. It creates a new `CLEmitter` instance, which will eventually be converted to the `Class` object for representing the declared class

Pre-analysis of j-- Programs

In a class declaration, `preAnalyze()` does the following:

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4. It adds a class header, defining a name and any modifiers, to this `CLEmitter` instance

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4. It adds a class header, defining a name and any modifiers, to this `CLEmitter` instance
5. It recursively invokes `preAnalyze()` on each of the class's members, which causes field declarations, constructors and method declarations (but with empty bodies) to be added to the `CLEmitter` instance

Pre-analysis of j-- Programs

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6. If there is no explicit constructor (having no arguments) in the set of members, it adds the implicit constructor to the `CLEmitter` instance; for example, for the `Factorial` program above, the following implicit constructor is added

```
public Factorial() {
    super();
}
```

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   ```
   public Factorial() {
       super();
   }
   ```

7. Finally, the `CLEmitter` instance produces a `Class` object, and that replaces the `classRep` for the `Type` of the declared class name in the (parent) `ClassContext`

Pre-analysis of j-- Programs

Here is the code for `preAnalyze()` in `JClassDeclaration`

```
public void preAnalyze(Context context) {
    // Construct a class context
    this.context = new ClassContext(this, context);

    // Resolve superclass
    superType = superType.resolve(this.context);

    // Creating a partial class in memory can result in a
    // java.lang.VerifyError if the semantics below are
    // violated, so we can't defer these checks to analyze()
    thisType.checkAccess(line, superType);
    if (superType.isFinal()) {
        JAST.compilationUnit.reportSemanticError(line,
            "Cannot extend a final type: %s",
            superType.toString());
    }

    // Create the (partial) class
    CLEmitter partial = new CLEmitter();

    // Add the class header to the partial class
    String qualifiedName =
        JAST.compilationUnit.packageName() == "" ? name :
            JAST.compilationUnit.packageName() + "/" + name;
    partial.addClass(mods, qualifiedName, superType.jvmName(),
        null, false);
```

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

```
    // Pre-analyze the members and add them to the partial class
    for (JMember member: classBlock) {
        member.preAnalyze(this.context, partial);
        if (member instanceof JConstructorDeclaration &&
             ((JConstructorDeclaration) member).
                 params.size() == 0) {
            hasExplicitConstructor = true;
        }
    }

    // Add the implicit empty constructor?
    if (!hasExplicitConstructor) {
        codegenPartialImplicitConstructor(partial);
    }

    // Get the Class rep for the (partial) class and make it the
    // representation for this type
    Type id = this.context.lookupType(name);
    if (id != null &&
         !JAST.compilationUnit.errorHasOccurred()) {
        id.setClassRep(partial.toClass());
    }
}
```

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

In a method declaration, `preAnalyze()` does the following:

Pre-analysis of j-- Programs

In a method declaration, `preAnalyze()` does the following:

1. It resolves the types of the formal parameters

Pre-analysis of j-- Programs

In a method declaration, `preAnalyze()` does the following:

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3. It checks proper use of the `abstract` modifier

Pre-analysis of j-- Programs

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4. It computes the method descriptor

Pre-analysis of j-- Programs

In a method declaration, `preAnalyze()` does the following:

1. It resolves the types of the formal parameters
2. It resolves the return type
3. It checks proper use of the `abstract` modifier
4. It computes the method descriptor
5. It generates (partial) code for the method

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

Here is the code for `preAnalyze()` in `JMethodDeclaration`

```
public void preAnalyze(Context context, CLEmitter partial) {
    // Resolve types of the formal parameters
    for (JFormalParameter param: params) {
        param.setType(param.type().resolve(context));
    }

    // Resolve return type
    returnType = returnType.resolve(context);

    // Check proper local use of abstract
    if (isAbstract && body != null) {
        JAST.compilationUnit.reportSemanticError(line(),
            "abstract method cannot have a body");
    }
    else if (body == null && ! isAbstract) {
        JAST.compilationUnit.reportSemanticError(line(),
            "Method with null body must be abstract");
    }
    else if (isAbstract && isPrivate ) {
        JAST.compilationUnit.reportSemanticError(line(),
            "private method cannot be declared abstract");
    }
    else if (isAbstract && isStatic ) {
        JAST.compilationUnit.reportSemanticError(line(),
            "static method cannot be declared abstract");
    }

    // Compute descriptor
    descriptor = "(";
    for (JFormalParameter param: params) {
        descriptor += param.type().toDescriptor();
    }
    descriptor += ")" + returnType.toDescriptor();

    // Generate the method with an empty body (for now)
    partialCodegen(context, partial);
}
```

Pre-analysis of j-- Programs

The code for `partialCodegen()` is as follows:

```java
public void partialCodegen(Context context, CLEmitter partial) {
    // Generate a method with an empty body; need a return to
    // make the class verifier happy.
    partial.addMethod(mods, name, descriptor, null, false);

    // Add implicit RETURN
    if (returnType == Type.VOID) {
        partial.addNoArgInstruction(RETURN);
    }
    else if (returnType == Type.INT ||
             returnType == Type.BOOLEAN ||
             returnType == Type.CHAR) {
        partial.addNoArgInstruction(ICONST_0);
        partial.addNoArgInstruction(IRETURN);
    }
    else {
        // A reference type.
        partial.addNoArgInstruction(ACONST_NULL);
        partial.addNoArgInstruction(ARETURN);
    }
}
```

Pre-analysis of j-- Programs

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Pre-analysis of j-- Programs

Pre-analysis for a `JFieldDeclaration` is similar to that for a `JMethodDeclaration`, and does the following:

1. Enforces the rule that fields may not be declared `abstract`
2. Resolves the field's declared type
3. Generates the JVM code for the field declaration, via the `CLEmitter` created for the enclosing class declaration

Pre-analysis for a `JFieldDeclaration` is similar to that for a `JMethodDeclaration`, and does the following:

1. Enforces the rule that fields may not be declared `abstract`
2. Resolves the field's declared type
3. Generates the JVM code for the field declaration, via the `CLEmitter` created for the enclosing class declaration

The code itself is rather simple

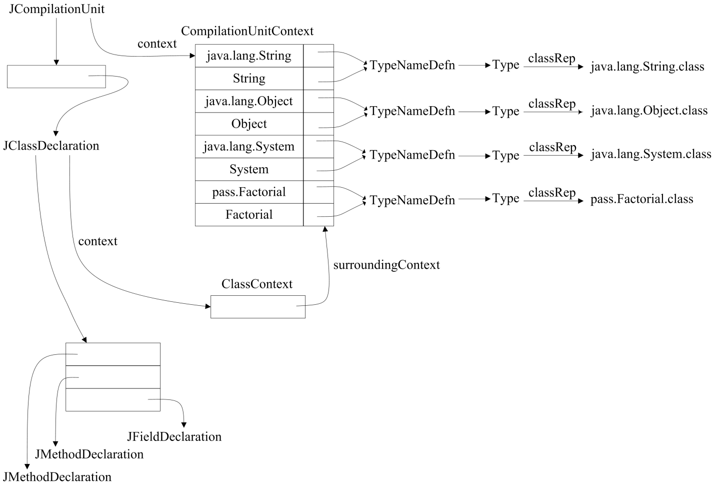
```
public void preAnalyze(Context context, CLEmitter partial) {
    // Fields may not be declared abstract.
    if (mods.contains("abstract")) {
        JAST.compilationUnit.reportSemanticError(line(),
            "Field cannot be declared abstract");
    }

    for (JVariableDeclarator decl: decls) {
        // Add field to (partial) class
        decl.setType(decl.type().resolve( context));
        partial.addField(mods, decl.name(),
            decl.type().toDescriptor(), false);
    }
}
```

Pre-analysis of j-- Programs

Pre-analysis of j-- Programs

The following figure illustrates how much of the symbol table is constructed for our `Factorial` program once pre-analysis is complete



Analysis of j-- Programs

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The analysis phase, ie, the `analyze()` method, recursively descends throughout the AST all the way to its leaves:

- Re-writing field and local variable initializations as assignments
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- Computing the types of expressions and enforcing the language type rules

Analysis of j-- Programs

The analysis phase, ie, the `analyze()` method, recursively descends throughout the AST all the way to its leaves:

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- Reclassifying ambiguous names

Analysis of j-- Programs

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Analysis of j-- Programs

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- Computing the types of expressions and enforcing the language type rules
- Reclassifying ambiguous names
- Doing a limited amount of tree surgery

At the top of the AST, `analyze()` simply recursively descends into each of the type (class) declarations, delegating analysis to one class declaration at a time

```
public JAST analyze(Context context) {
    for (JAST typeDeclaration : typeDeclarations) {
        typeDeclaration.analyze(this.context);
    }
    return this;
}
```

Analysis of j-- Programs

Analysis of j-- Programs

In `JFieldDeclaration`, `analyze()` rewrites the field initializer as an explicit assignment statement, analyzes that and then stores it in the `JFieldDeclaration`'s initializations list

```
public JFieldDeclaration analyze(Context context) {
    for (JVariableDeclarator decl : decls) {
        // All initializations must be turned into assignment
        // statements and analyzed
        if (decl.initializer() != null) {
            JAssignOp assignOp = new JAssignOp(decl.line(),
                                          new JVariable(decl.line(),
                                              decl.name()), decl.initializer());
            assignOp.isStatementExpression = true;
            initializations.add(new JStatementExpression(decl.line(),
                                    assignOp).analyze(context));
        }
    }
    return this;
}
```

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        if (decl.initializer() != null) {
            JAssignOp assignOp = new JAssignOp(decl.line(),
                                     new JVariable(decl.line(),
                                         decl.name()), decl.initializer());
            assignOp.isStatementExpression = true;
            initializations.add(new JStatementExpression(decl.line(),
                                    assignOp).analyze(context));
        }
    }
    return this;
}
```

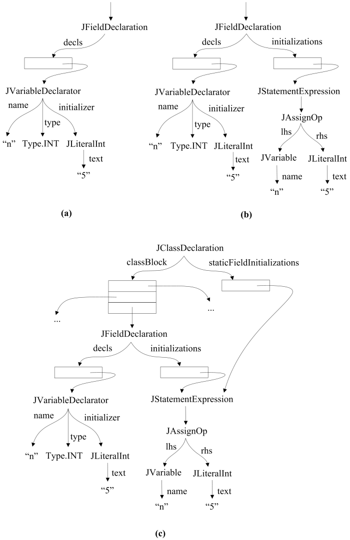
In `JClassDeclaration`, `analyze()` separates the assignment statements into two lists: one for the static fields and one for the instance fields

```
// Copy declared fields for purposes of initialization.
for (JMember member : classBlock) {
    if (member instanceof JFieldDeclaration) {
        JFieldDeclaration fieldDecl = (JFieldDeclaration) member;
        if (fieldDecl.mods().contains("static")) {
            staticFieldInitializations.add(fieldDecl);
        } else {
            instanceFieldInitializations.add(fieldDecl);
        }
    }
}
```

Analysis of j-- Programs

Analysis of j-- Programs

The following figure shows how the static field declaration (`static int n = 5;`) in the `Factorial` program is rewritten



Analysis of j-- Programs

Both formal parameters and local variables are declared in the symbol table and allocated locations within a method invocation's run-time stack frame

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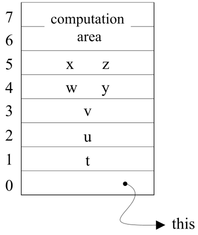
For example, consider the following class declaration

```
public class Locals {
    public int foo(int t, String u) {
        int v = u.length();
        {
            int w = v + 5, x = w + 7;
            v = w + x;
        }
        {
            int y = 3;
            int z = v + y;
            t = t + y + z;
        }
        return t + v;
    }
}
```

Analysis of j-- Programs

The stack frame allocated for an invocation of `foo()` at run time by the JVM is shown below



Analysis of j-- Programs

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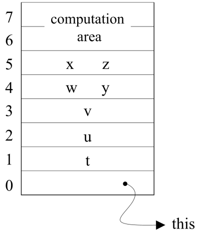

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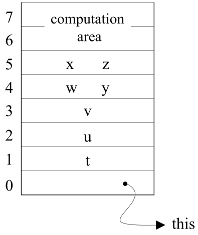

The code for analyzing a `JMethodDeclaration` performs four steps:

1. It creates a new `MethodContext`, whose `surroundingContext` points back to the previous `ClassContext`

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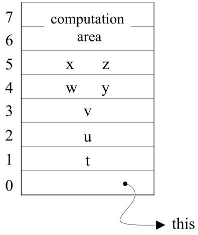

The code for analyzing a `JMethodDeclaration` performs four steps:

1. It creates a new `MethodContext`, whose `surroundingContext` points back to the previous `ClassContext`
2. The first stack frame offset is 0; but if this is an instance method then offset 0 must be allocated to `this`, and the `nextOffset` is incremented to 1

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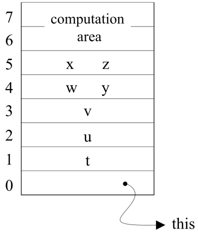

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3. The formal parameters are declared as local variables and allocated consecutive offsets in the stack frame

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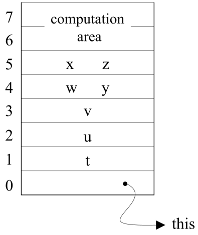

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1. It creates a new `MethodContext`, whose `surroundingContext` points back to the previous `ClassContext`
2. The first stack frame offset is 0; but if this is an instance method then offset 0 must be allocated to `this`, and the `nextOffset` is incremented to 1
3. The formal parameters are declared as local variables and allocated consecutive offsets in the stack frame
4. It analyzes the method's body

Analysis of j-- Programs

```
public JAST analyze(Context context) {
    this.context = new MethodContext(context, returnType);

    if (!isStatic) {
        // Offset 0 is used to addr "this".
        this.context.nextOffset();
    }

    // Declare the parameters
    for (JFormalParameter param : params) {
        this.context.addEntry(param.line(), param.name(),
                new LocalVariableDefn(param.type(), this.context
                        .nextOffset(), null));
    }

    if (body != null) {
        body = body.analyze(this.context);
    }
    return this;
}
```

Analysis of j-- Programs

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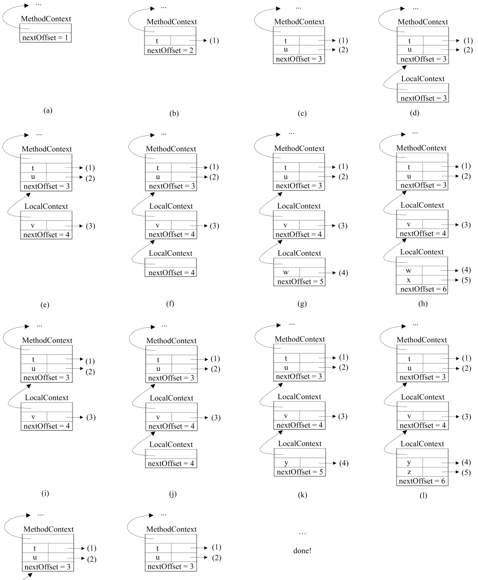
```
public JBlock analyze(Context context) {
    // { ... } defines a new level of scope.
    this.context = new LocalContext(context);

    for (int i = 0; i < statements.size(); i++) {
        statements.set(i, (JStatement) statements.get(i).analyze(
                this.context));
    }
    return this;
}
```

Analysis of j-- Programs

Analysis of j-- Programs

The stages of the symbol table in analyzing `Locals.foo()`



Analysis of j-- Programs

A local variable declaration is represented in the AST with a `JVariableDeclaration`; for example, consider the local variable declaration from `Locals`

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int w = v + 5, x = w + 7;
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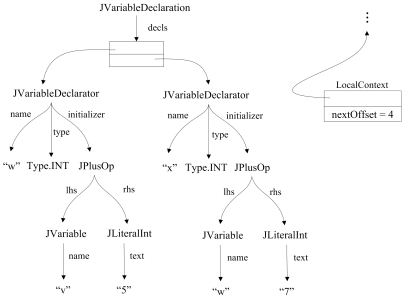
Before the `JVariableDeclaration` is analyzed, it appears exactly as it was created by the parser, as is illustrated below



Analysis of j-- Programs

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1. `LocalVariableDefn`s and their corresponding stack frame offsets are allocated for each of the declared variables
2. The code checks to make sure that the declared variables do not shadow existing local variables
3. The variables are declared in the local context
4. Any initializations are rewritten as explicit assignment statements; those assignments are re-analyzed and stored in an `initializations` list

Analysis of j-- Programs

```
public JStatement analyze(Context context) {
    for (JVariableDeclarator decl : decls) {
        // Local variables are declared here (fields are
        // declaredin preAnalyze())
        int offset = ((LocalContext) context).nextOffset();
        LocalVariableDefn defn = new LocalVariableDefn(decl
            .type().resolve(context), offset);

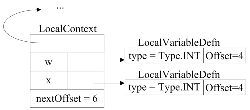
        // First, check for shadowing
        IDefn previousDefn = context.lookup(decl.name());
        if (previousDefn != null
            && previousDefn instanceof LocalVariableDefn) {
            JAST.compilationUnit.reportSemanticError(decl.line(),
                "The name " + decl.name()
                    + " overshadows another local variable.");
        }

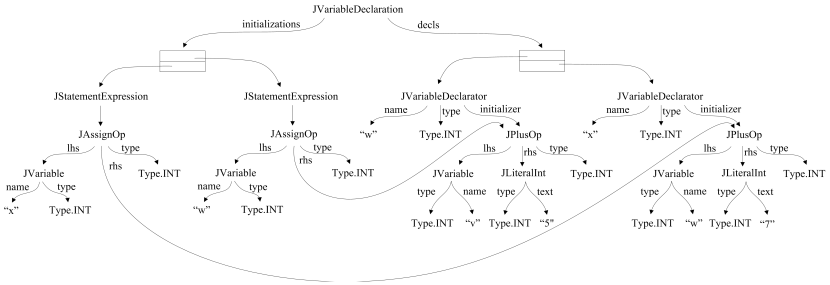
        // Then declare it in the local context
        context.addEntry(decl.line(), decl.name(), defn);

        // All initializations must be turned into assignment
        // statements and analyzed
        if (decl.initializer() != null) {
             defn.initialize();
            JAssignOp assignOp = new JAssignOp(decl.line(),
                new JVariable(decl.line(), decl.name()), decl
                    .initializer());
            assignOp.isStatementExpression = true;
            initializations.add(new JStatementExpression(decl
                .line(), assignOp).analyze(context));
        }
    }
    return this;
}
```

Analysis of j-- Programs

The sub-tree for `int w = v + 5, x = w + 7;` after analysis is shown below





Analysis of j-- Programs

Analysis of j-- Programs

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If a variable is not found in the symbol table, we examine the `Type` for the surrounding class (in which the variable appears) to see if it is a field; if it is a field, then the field selection is made explicit by rewriting the tree as a `JFieldSelection`

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```
public JExpression analyze(Context context) {
    iDefn = context.lookup(name);
    if (iDefn == null) {
        // Not a local, but is it a field?
        Type definingType = context.definingType();
        Field field = definingType.fieldFor(name);
        if (field == null) {
            type = Type.ANY;
            JAST.compilationUnit.reportSemanticError(line,
                "Cannot find name: " + name);
        } else {
            // Rewrite a variable denoting a field as an
            // explicit field selection
            type = field.type();
            JExpression newTree = new JFieldSelection(line(),
                field.isStatic() ||
                (context.methodContext() != null &&
                 context.methodContext().isStatic()) ?
                        new JVariable(line(),
                            definingType.toString()) :
                            new JThis(line), name);
            return (JExpression) newTree.analyze(context);
        }
```

Analysis of j-- Programs

Analysis of j-- Programs

```
    } else {
        if (!analyzeLhs && iDefn instanceof LocalVariableDefn &&
            !((LocalVariableDefn) iDefn).isInitialized()) {
            JAST.compilationUnit.reportSemanticError(line,
                "Variable " + name + " might not have been
                    initialized");
        }
        type = iDefn.type();
    }
    return this;
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Analysis of j-- Programs

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    } else {
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                "Variable " + name + " might not have been
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        type = iDefn.type();
    }
    return this;
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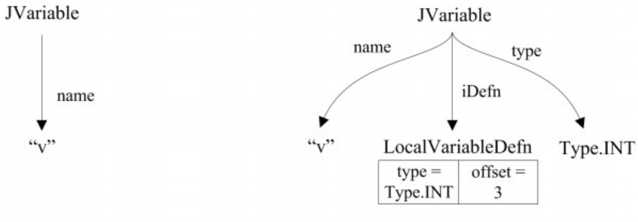
```

For example, the AST node for the local variable `v` in the statement `return t + v;` in `Locals.foo()`, before and after analysis, is shown below



Analysis of j-- Programs

As another example, consider the analysis of the static field `n`, when it appears in the `main()` method of our `Factorial` class; the AST node for the field, before and after analysis, is shown below

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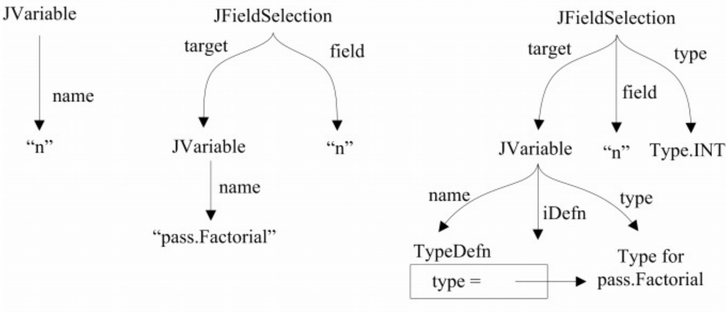

Analysis of j-- Programs

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For this reason, the parser packages up the string `"w.x.y"` in an `AmbiguousName` object, attached to either the `JFieldSelection` or `JMessageExpression`, deferring the decision until analysis

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The `reclassify()` method in `AmbiguousName` is based on the rules in the Java Language Specification for reclassifying an ambiguous name

Analysis of j-- Programs

Analysis of j-- Programs

```java
public JExpression reclassify(Context context) {
    // Easier because we require all types to be imported.
    JExpression result = null;
    StringTokenizer st = new StringTokenizer(name, ".");

    // Firstly, find a variable or Type.
    String newName = st.nextToken();
    IDefn iDefn = null;

    do {
        iDefn = context.lookup(newName);
        if (iDefn != null) {
            result = new JVariable(line, newName);
            break;
        } else if (!st.hasMoreTokens()) {
            // Nothing found. :(
            JAST.compilationUnit.reportSemanticError(line,
                "Cannot find name " + newName);
            return null;
        } else {
            newName += "." + st.nextToken();
        }
    } while (true);

    // For now we can assume everything else is fields.
    while (st.hasMoreTokens()) {
        result = new JFieldSelection(line, result, st.nextToken());
    }
    return result;
}
```

Analysis of j-- Programs

For example, consider the message expression

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java.lang.System.out.println(...);
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5. Thus the target is a field selection whose target is `java.lang.System` and whose field name is `out`

Analysis of j-- Programs

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Analysis of j-- Programs

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4. Otherwise, it checks to make sure the field is accessible to this region, a non-static field is not referenced from a static context, and then returns the analyzed field selection sub-tree

Analysis of j-- Programs

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```
public JExpression analyze(Context context) {
    // Reclassify the ambiguous part.
    ...

    target = (JExpression) target.analyze(context);
    Type targetType = target.type();

    // We use a workaround for the "length" field of arrays.
    if ((targetType instanceof ArrayTypeName) && fieldName.equals("length")) {
        type = Type.INT;
    } else {
        // Other than that, targetType has to be a
        // ReferenceType
        if (targetType.isPrimitive()) {
            JAST.compilationUnit.reportSemanticError(line(),
                "Target of a field selection must be a defined type");
            type = Type.ANY;
            return this;
        }
```

Analysis of j-- Programs

```
        field = targetType.fieldFor(fieldName);
        if (field == null) {
            JAST.compilationUnit.reportSemanticError(line(),
                "Cannot find a field: " + fieldName);
            type = Type.ANY;
        } else {
            context.definingType().checkAccess(line,
                (Member) field);
            type = field.type();

            // Non-static field cannot be referenced from a
            // static context.
            if (!field.isStatic()) {
                if (target instanceof JVariable &&
                    ((JVariable) target).iDefn() instanceof
                       TypeNameDefn) {
                     JAST.compilationUnit.
                        reportSemanticError(line(),
                        "Non-static field " + fieldName +
                           " cannot be referenced from a static
                             context");
                }
            }
        }
    }
    return this;
}
```

Analysis of j-- Programs

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After reclassifying any `AmbiguousName`, analyzing a `JMessageExpression` proceeds as follows:

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Analysis of j-- Programs

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4. It takes the message name and the array of argument types and looks for a matching method defined in the target's type (in *j*--, argument types must match exactly), and if no such method is found, it reports an error

After reclassifying any `AmbiguousName`, analyzing a `JMessageExpression` proceeds as follows:

1. It analyzes the arguments to the message and constructs an array of their types
2. It determines the surrounding, defining class (for determining access)
3. It analyzes the target to which the message is being sent
4. It takes the message name and the array of argument types and looks for a matching method defined in the target's type (in *j--*, argument types must match exactly), and if no such method is found, it reports an error
5. Otherwise, the target class and method are checked for accessibility, a non-static method is now allowed to be referenced from a static context, and the method's return type becomes the type of the message expression

```
public JExpression analyze(Context context) {
    // Reclassify the ambiguous part


    // Then analyze the arguments, collecting
    // their types (in Class form) as argTypes
    argTypes = new Type[arguments.size()];
    for (int i = 0; i < arguments.size(); i++) {
        arguments.set(i, (JExpression) arguments.get(i).analyze(
            context));
        argTypes[i] = arguments.get(i).type();
    }
```

Analysis of j-- Programs

```
// Where are we now? (For access)
Type thisType = ((JTypeDecl) context.classContext
    .definition()).thisType();

// Then analyze the target
if (target == null) {
             // Implied this (or, implied type for statics)
    if (!context.methodContext().isStatic()) {
        target = new JThis(line()).analyze(context);
    }
    else {
        target = new JVariable(line(),
                    context.definingType().toString()).
                        analyze(context);
    }
} else {
    target = (JExpression) target.analyze(context);
    if (target.type().isPrimitive()) {
        JAST.compilationUnit.reportSemanticError(line(),
            "cannot invoke a message on a primitive type:"
                + target.type());
    }
}
```

Analysis of j-- Programs

```
    // Find appropriate Method for this message expression
    method = target.type().methodFor(messageName, argTypes);
    if (method == null) {
        JAST.compilationUnit.reportSemanticError(line(),
            "Cannot find method for: "
                + Type.signatureFor(messageName, argTypes));
        type = Type.ANY;
    } else {
        context.definingType().checkAccess(line,
                                           (Member) method);
        type = method.returnType();

        // Non-static method cannot be referenced from a
        // static context.
        if (!method.isStatic()) {
            if (target instanceof JVariable &&
                ((JVariable) target).iDefn() instanceof
                    TypeNameDefn) {
                 JAST.compilationUnit.reportSemanticError(line(),
                  "Non-static method " +
                  Type.signatureFor(messageName, argTypes) +
                  "cannot be referenced from a static context");
            }
        }
    }
    return this;
}
```

Analysis of j-- Programs

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Analysis of `JIfStatement`

```
public JStatement analyze(Context context) {
    test = (JExpression) test.analyze(context);
    test.type().mustMatchExpected(line(), Type.BOOLEAN);
    consequent = (JStatement) consequent.analyze(context);
    if (alternate != null) {
        alternate = (JStatement) alternate.analyze(context);
    }
    return this;
}
```

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    }
    return this;
}
```

Analysis of `JSubtractOp`

```
public JExpression analyze(Context context) {
     lhs = (JExpression) lhs.analyze(context);
     rhs = (JExpression) rhs.analyze(context);
     lhs.type().mustMatchExpected(line(), Type.INT);
     rhs.type().mustMatchExpected(line(), Type.INT);
     type = Type.INT;
     return this;
 }
```

Analysis of j-- Programs

Analysis of j-- Programs

Analysis of JPlusOp

```
public JExpression analyze(Context context) {
    lhs = (JExpression) lhs.analyze(context);
    rhs = (JExpression) rhs.analyze(context);
    if (lhs.type() == Type.STRING || rhs.type() == Type.STRING) {
        return (new JStringConcatenationOp(line, lhs, rhs))
            .analyze(context);
    } else if (lhs.type() == Type.INT && rhs.type() == Type.INT){
        type = Type.INT;
    } else {
        type = Type.ANY;
        JAST.compilationUnit.reportSemanticError(line(),
            "Invalid operand types for +");
    }
    return this;
}
```

Analysis of j-- Programs

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        type = Type.INT;
    } else {
        type = Type.ANY;
        JAST.compilationUnit.reportSemanticError(line(),
            "Invalid operand types for +");
    }
    return this;
}
```

Analysis of `JStringConcatenateOp`

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public JExpression analyze(Context context) {
    type = Type.STRING;
    return this;
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Analysis of j-- Programs

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        type = Type.INT;
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            "Invalid operand types for +");
    }
    return this;
}
```

Analysis of `JStringConcatenateOp`

```
public JExpression analyze(Context context) {
    type = Type.STRING;
    return this;
}
```

Analysis of `JLiteralInt`

```
public JExpression analyze(Context context) {
    type = Type.INT;
    return this;
}
```

Analysis of j-- Programs

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This does not exclude polymorphism; for example if type `Bar` extends type `Foo`, if `bar` is a variable of type `Bar` and `foo` is a variable of type `Foo`, we can say

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foo = (Foo) bar;
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```

must determine two things:

1. That an expression of type `Type1` can be cast to `Type2`, ie, that the cast is valid
2. The type of the result, which is simply `Type2`

Analysis of j-- Programs

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3. The following table summarizes other casts, and says whether or not (and how) a type labeling a row may be cast to a type labeling a column

	`boolean`	`char`	`int`	`Boolean`	`Character`	`Integer`
`boolean`	Identity	Error	Error	Boxing	Error	Error
`char`	Error	Identity	Widening	Error	Boxing	Error
`int`	Error	Narrowing	Identity	Error	Error	Boxing
`Boolean`	Unboxing	Error	Error	Identity	Error	Error
`Character`	Error	Unboxing	Error	Error	Identity	Error
`Integer`	Error	Error	Unboxing	Error	Error	Identity

Analysis of j-- Programs

Analysis in JCastOp

```
public JExpression analyze(Context context) {
    expr = (JExpression) expr.analyze(context);
    type = cast = cast.resolve(context);
    if (cast.equals(expr.type())) {
        converter = Converter.Identity;
    } else if (cast.isJavaAssignableFrom(expr.type())) {
        converter = Converter.WidenReference;
    } else if (expr.type().isJavaAssignableFrom(cast)) {
        converter = new NarrowReference(cast);
    } else if ((converter =
        conversions.get(expr.type(), cast)) != null) {
    } else {
        JAST.compilationUnit.reportSemanticError(line,
            "Cannot cast a " + expr.type().toString() + " to a "
                + cast.toString());
    }
    return this;
}
```

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    expr = (JExpression) expr.analyze(context);
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                + cast.toString());
    }
    return this;
}
```

A converter for narrowing one reference type to another (more specific) reference sub-type

```
class NarrowReference implements Converter {
    private Type target;

    public NarrowReference(Type target) {
        this.target = target;
    }

    public void codegen(CLEmitter output) {
        output.addReferenceInstruction(CHECKCAST, target.jvmName());
    }
}
```

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Our JVM to MIPS translator performs data-flow analysis as part of computing live intervals for register allocation