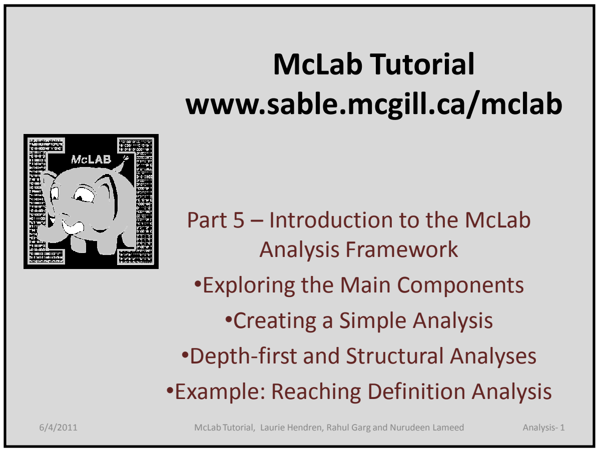


McLab Tutorial
www.sable.mcgill.ca/mclab

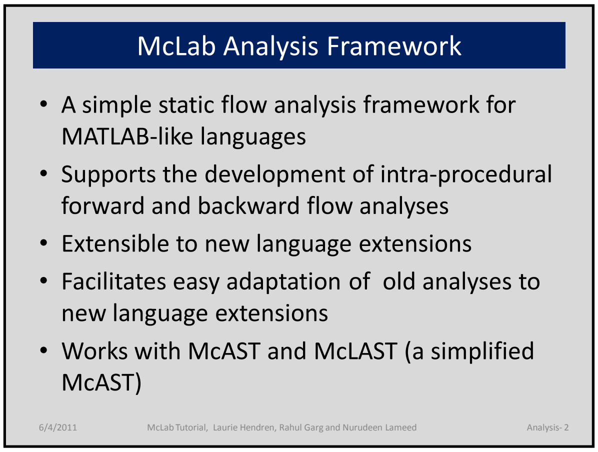
Part 5 – Introduction to the McLab Analysis Framework

•Exploring the Main Components

•Creating a Simple Analysis

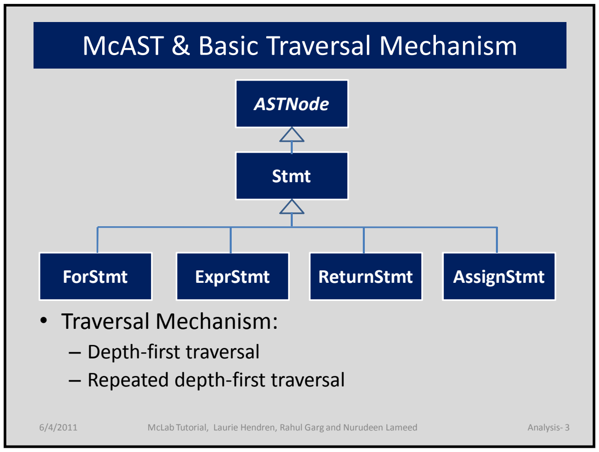
•Depth-first and Structural Analyses

•Example: Reaching Definition Analysis



McLab Analysis Framework

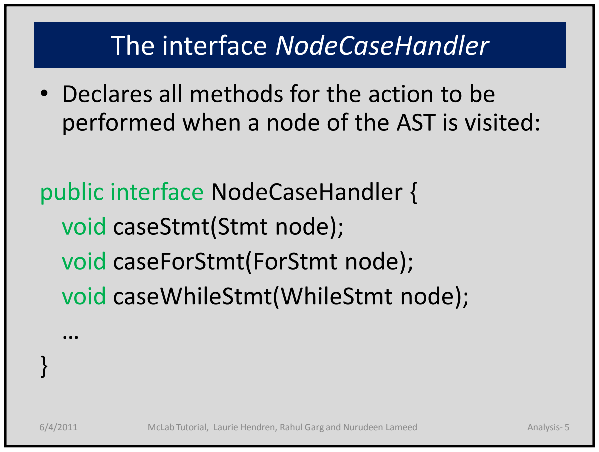
- A simple static flow analysis framework for MATLAB-like languages
- Supports the development of intra-procedural forward and backward flow analyses
- Extensible to new language extensions
- Facilitates easy adaptation of old analyses to new language extensions
- Works with McAST and McLAST (a simplified McAST)



McAST & Basic Traversal Mechanism

- Traversal Mechanism:
  - Depth-first traversal
  - Repeated depth-first traversal

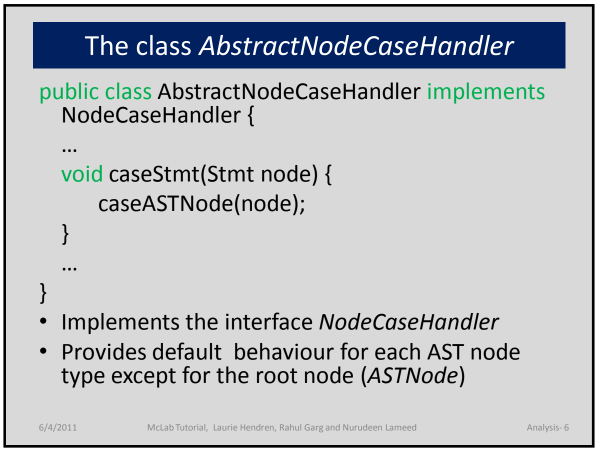
Exploring the main components for developing analyses



The interface *NodeCaseHandler*

- Declares all methods for the action to be performed when a node of the AST is visited:

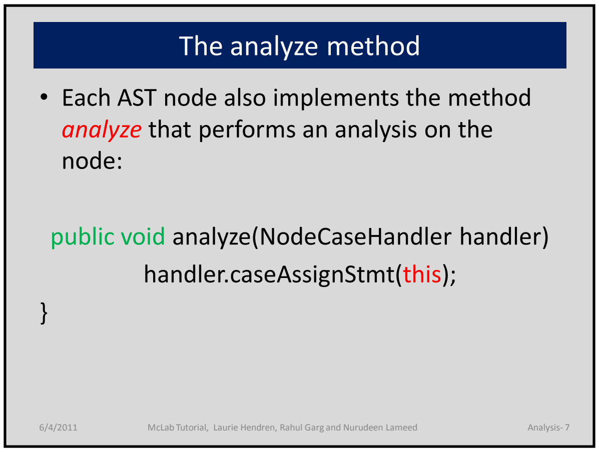
```
public interface NodeCaseHandler {
   void caseStmt(Stmt node);
   void caseForStmt(ForStmt node);
   void caseWhileStmt(WhileStmt node);
   …
}
```



The class *AbstractNodeCaseHandler*

```
public class AbstractNodeCaseHandler implements
   NodeCaseHandler {
   …
   void caseStmt(Stmt node) {
       caseASTNode(node);
   }
   …
}
```

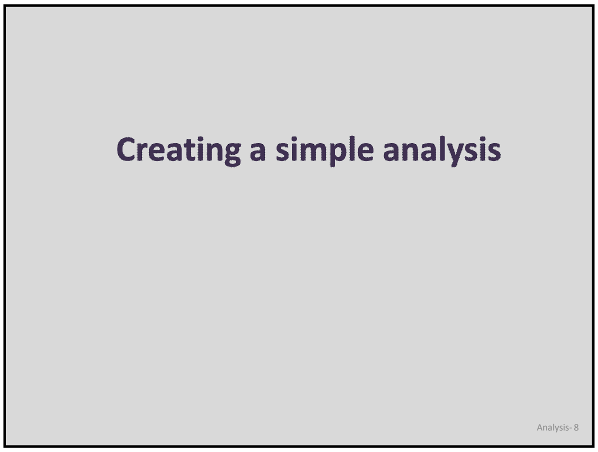
- Implements the interface *NodeCaseHandler*
- Provides default behaviour for each AST node type except for the root node (*ASTNode*)



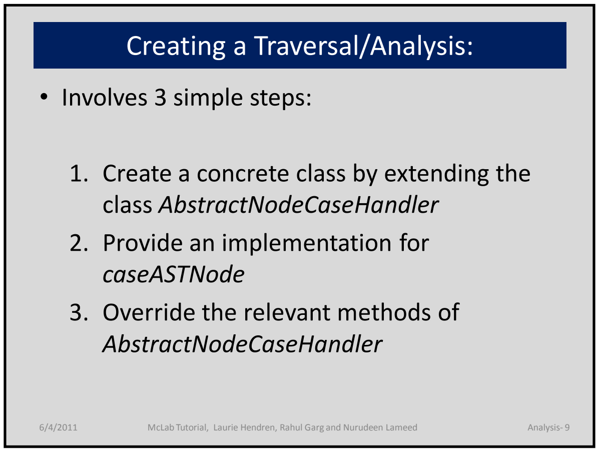
The analyze method

- Each AST node also implements the method *analyze* that performs an analysis on the node:

```
public void analyze(NodeCaseHandler handler)
        handler.caseAssignStmt(this);
}
```



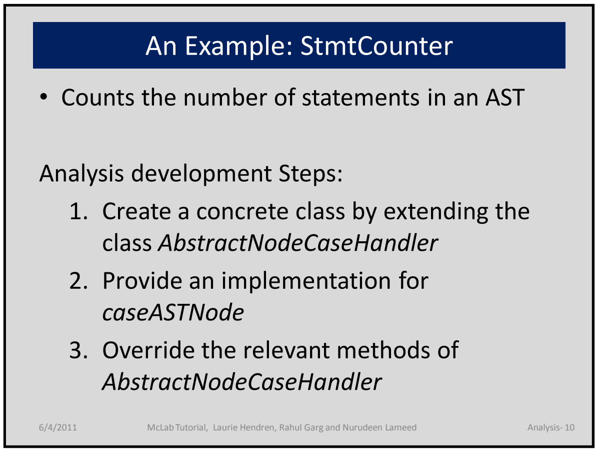
Creating a simple analysis



Creating a Traversal/Analysis:

- Involves 3 simple steps:

1. Create a concrete class by extending the class *AbstractNodeCaseHandler*
2. Provide an implementation for *caseASTNode*
3. Override the relevant methods of *AbstractNodeCaseHandler*

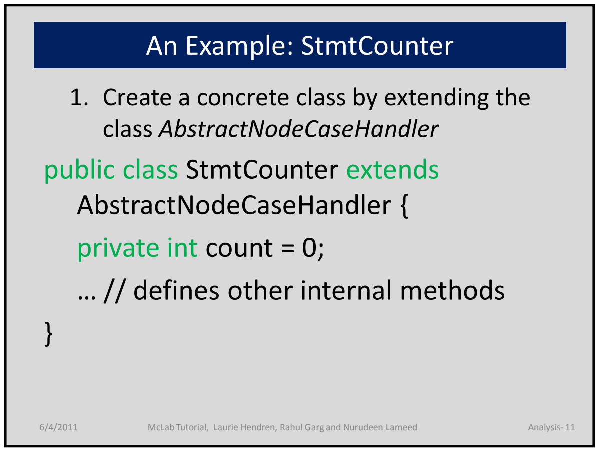


An Example: StmtCounter

- Counts the number of statements in an AST

Analysis development Steps:

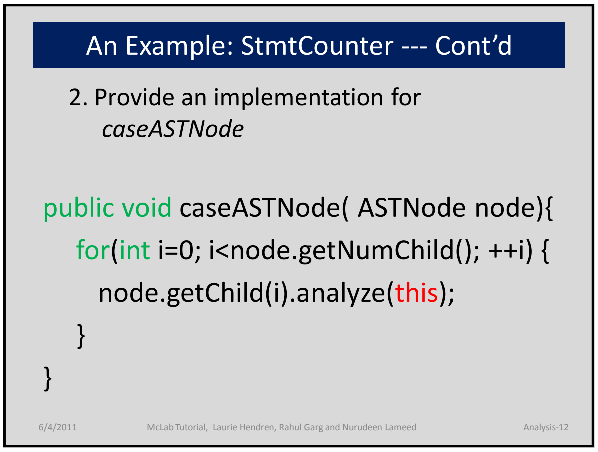
1. Create a concrete class by extending the class *AbstractNodeCaseHandler*
2. Provide an implementation for *caseASTNode*
3. Override the relevant methods of *AbstractNodeCaseHandler*



An Example: StmtCounter

1. Create a concrete class by extending the class *AbstractNodeCaseHandler*

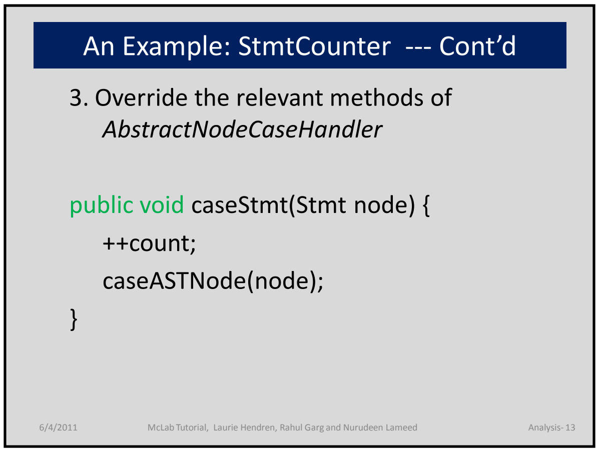
```
public class StmtCounter extends
    AbstractNodeCaseHandler {
    private int count = 0;
    … // defines other internal methods
}
```



An Example: StmtCounter --- Cont’d

2. Provide an implementation for *caseASTNode*

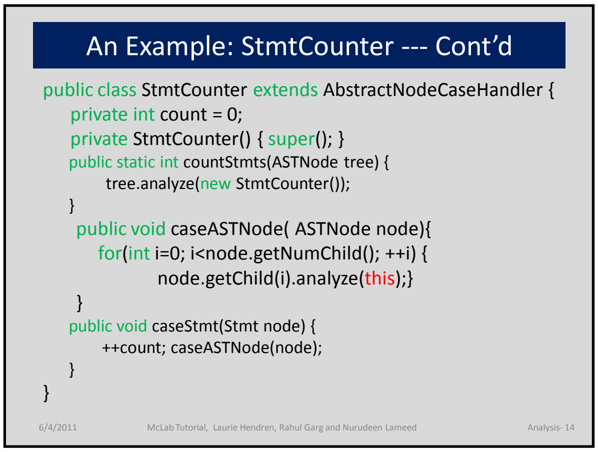
```
public void caseASTNode( ASTNode node){
   for(int i=0; i<node.getNumChild(); ++i) {
     node.getChild(i).analyze(this);
   }
}
```



An Example: StmtCounter --- Cont'd

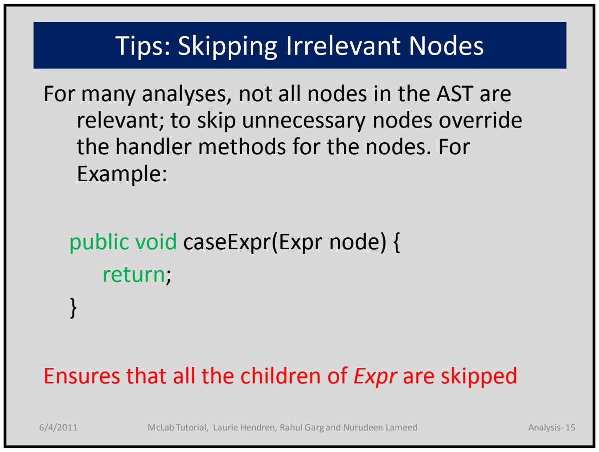
3. Override the relevant methods of *AbstractNodeCaseHandler*

```
public void caseStmt(Stmt node) {
    ++count;
    caseASTNode(node);
}
```



An Example: StmtCounter --- Cont'd

```
public class StmtCounter extends AbstractNodeCaseHandler {
    private int count = 0;
    private StmtCounter() { super(); }
    public static int countStmts(ASTNode tree) {
        tree.analyze(new StmtCounter());
    }
     public void caseASTNode( ASTNode node){
        for(int i=0; i<node.getNumChild(); ++i) {
                node.getChild(i).analyze(this);}
     }
    public void caseStmt(Stmt node) {
        ++count; caseASTNode(node);
    }
}
```

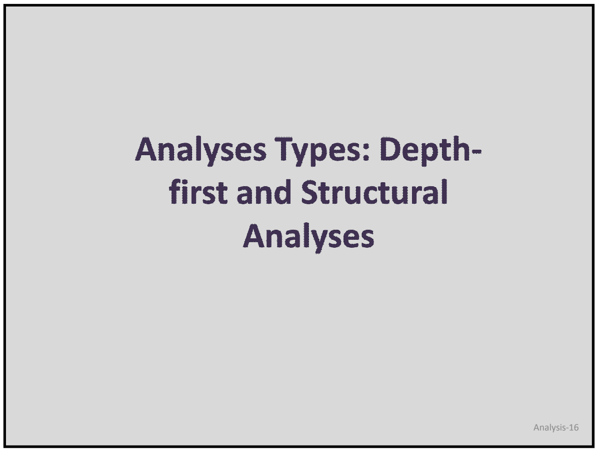


Tips: Skipping Irrelevant Nodes

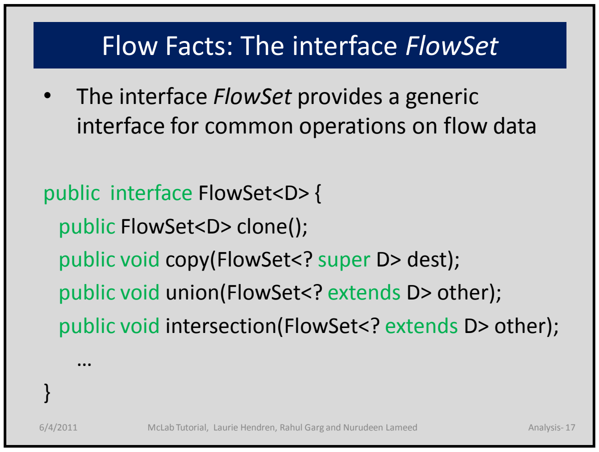
For many analyses, not all nodes in the AST are relevant; to skip unnecessary nodes override the handler methods for the nodes. For Example:

```
public void caseExpr(Expr node) {
    return;
}
```

Ensures that all the children of *Expr* are skipped



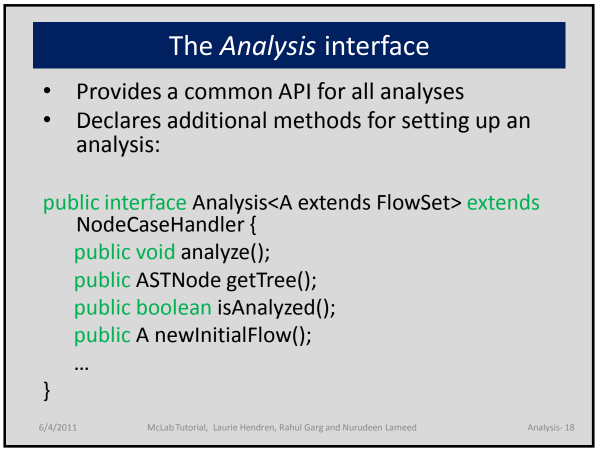
Analyses Types: Depth-first and Structural Analyses



Flow Facts: The interface *FlowSet*

- The interface *FlowSet* provides a generic interface for common operations on flow data

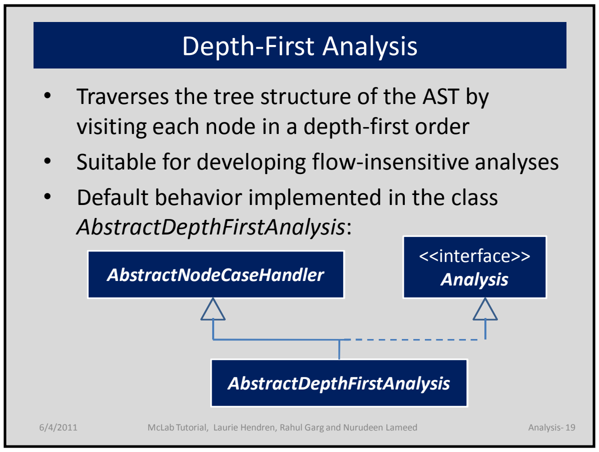
```
public  interface FlowSet<D> {
  public FlowSet<D> clone();
  public void copy(FlowSet<? super D> dest);
  public void union(FlowSet<? extends D> other);
  public void intersection(FlowSet<? extends D> other);
     …
}
```



The *Analysis* interface

- Provides a common API for all analyses
- Declares additional methods for setting up an analysis:

```
public interface Analysis<A extends FlowSet> extends
    NodeCaseHandler {
    public void analyze();
    public ASTNode getTree();
    public boolean isAnalyzed();
    public A newInitialFlow();
    …
}
```



Depth-First Analysis

- Traverses the tree structure of the AST by visiting each node in a depth-first order
- Suitable for developing flow-insensitive analyses
- Default behavior implemented in the class *AbstractDepthFirstAnalysis*:

AbstractNodeCaseHandler
<<interface>>
Analysis
AbstractDepthFirstAnalysis

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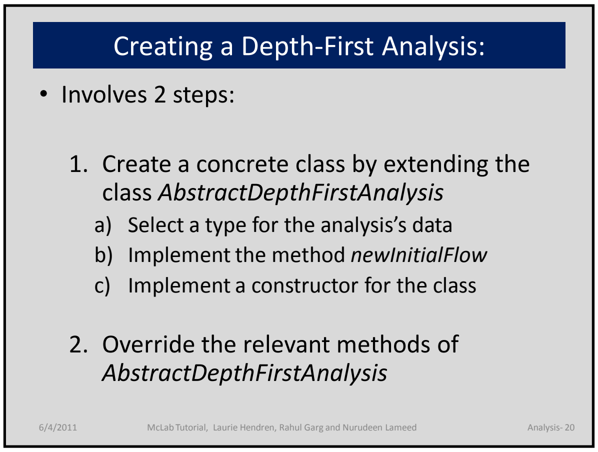

Creating a Depth-First Analysis:

- Involves 2 steps:

1. Create a concrete class by extending the class *AbstractDepthFirstAnalysis*
   a) Select a type for the analysis's data
   b) Implement the method *newInitialFlow*
   c) Implement a constructor for the class

2. Override the relevant methods of *AbstractDepthFirstAnalysis*

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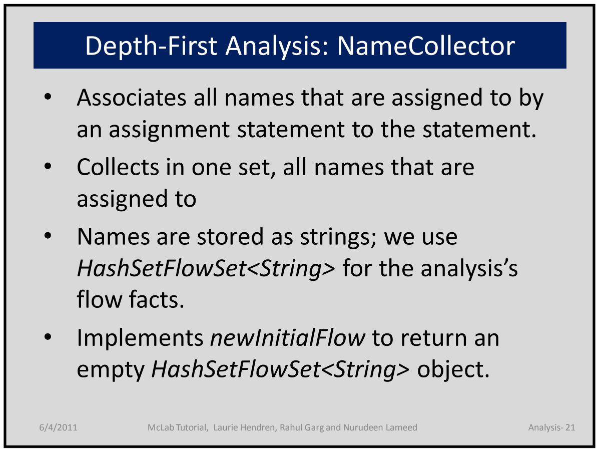

Depth-First Analysis: NameCollector

- Associates all names that are assigned to by an assignment statement to the statement.
- Collects in one set, all names that are assigned to
- Names are stored as strings; we use *HashSetFlowSet<String>* for the analysis's flow facts.
- Implements *newInitialFlow* to return an empty *HashSetFlowSet<String>* object.

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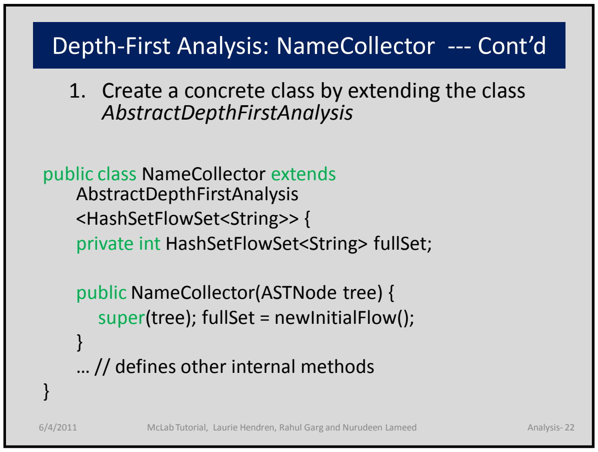

Depth-First Analysis: NameCollector --- Cont'd

1. Create a concrete class by extending the class *AbstractDepthFirstAnalysis*

```
public class NameCollector extends
     AbstractDepthFirstAnalysis
     <HashSetFlowSet<String>> {
     private int HashSetFlowSet<String> fullSet;

     public NameCollector(ASTNode tree) {
        super(tree); fullSet = newInitialFlow();
     }
     … // defines other internal methods
}
```

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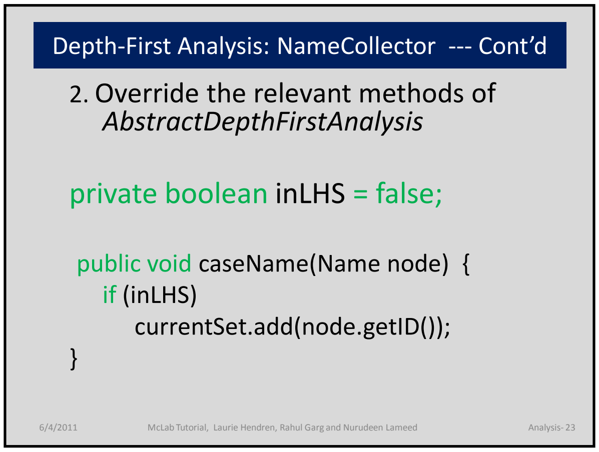

Depth-First Analysis: NameCollector --- Cont'd

2. Override the relevant methods of *AbstractDepthFirstAnalysis*

```
private boolean inLHS = false;

 public void caseName(Name node)  {
    if (inLHS)
         currentSet.add(node.getID());
}
```

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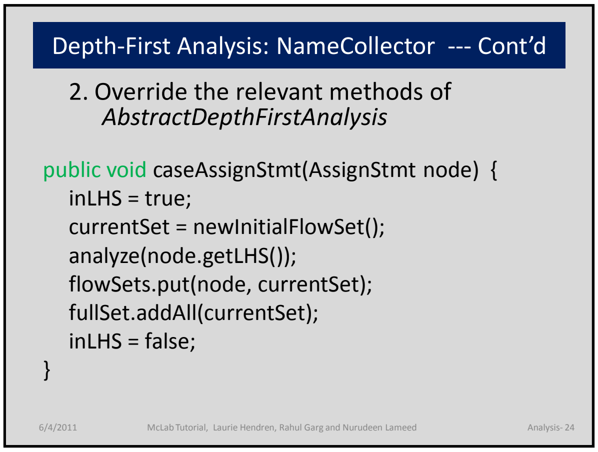

Depth-First Analysis: NameCollector --- Cont'd

2. Override the relevant methods of *AbstractDepthFirstAnalysis*

```
public void caseAssignStmt(AssignStmt node)  {
   inLHS = true;
   currentSet = newInitialFlowSet();
   analyze(node.getLHS());
   flowSets.put(node, currentSet);
   fullSet.addAll(currentSet);
   inLHS = false;
}
```

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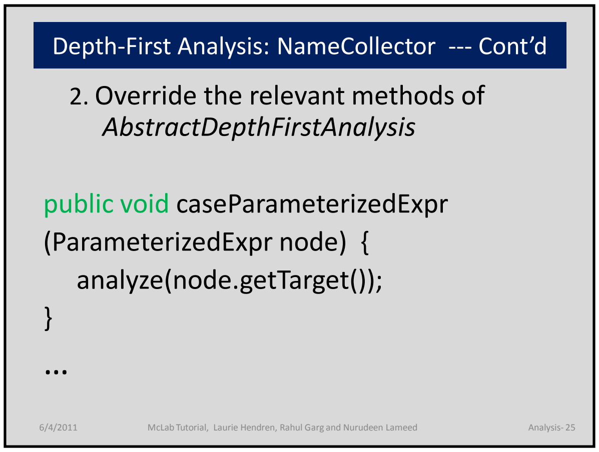
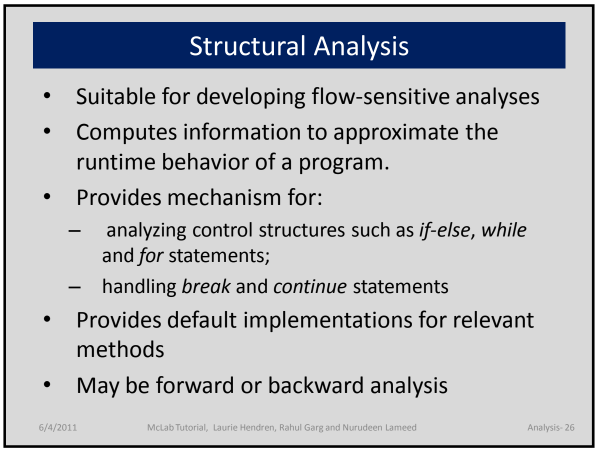


Depth-First Analysis: NameCollector --- Cont'd

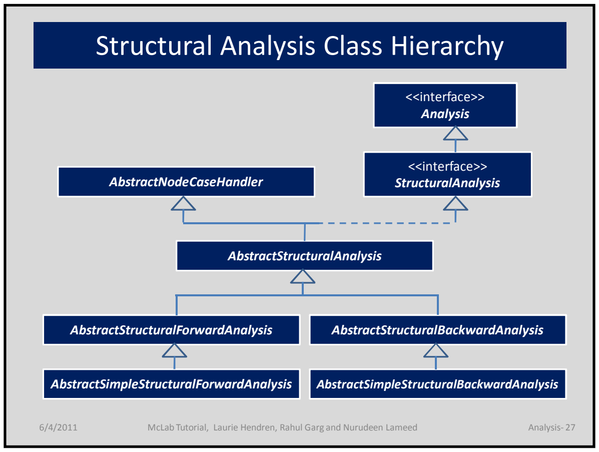
2. Override the relevant methods of *AbstractDepthFirstAnalysis*

```
public void caseParameterizedExpr
(ParameterizedExpr node)  {
    analyze(node.getTarget());
}

…
```



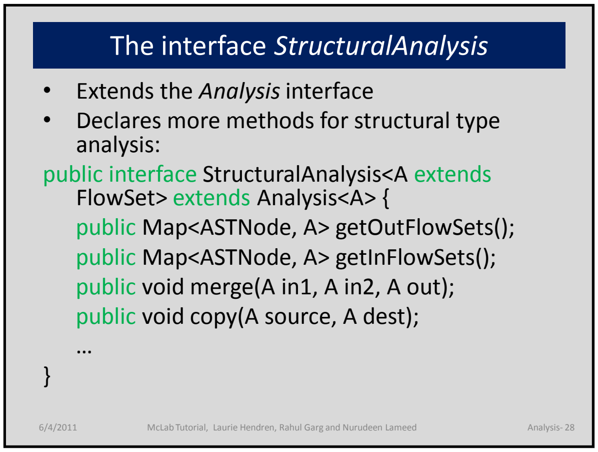
Structural Analysis

- Suitable for developing flow-sensitive analyses
- Computes information to approximate the runtime behavior of a program.
- Provides mechanism for:
  - analyzing control structures such as *if-else*, *while* and *for* statements;
  - handling *break* and *continue* statements
- Provides default implementations for relevant methods
- May be forward or backward analysis



Structural Analysis Class Hierarchy

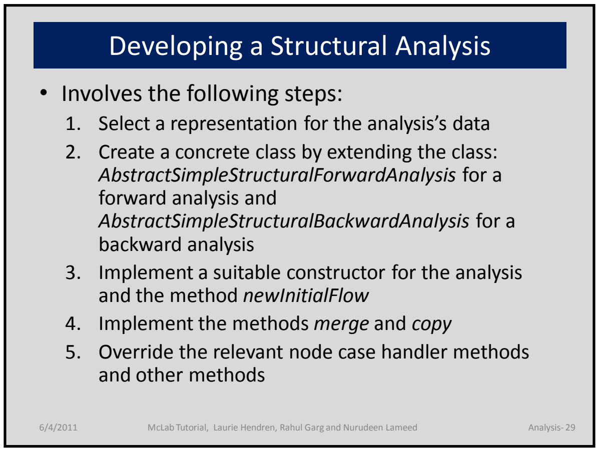
<<interface>> *Analysis*
<<interface>> *StructuralAnalysis*
AbstractNodeCaseHandler
AbstractStructuralAnalysis
AbstractStructuralForwardAnalysis
AbstractStructuralBackwardAnalysis
AbstractSimpleStructuralForwardAnalysis
AbstractSimpleStructuralBackwardAnalysis



The interface *StructuralAnalysis*

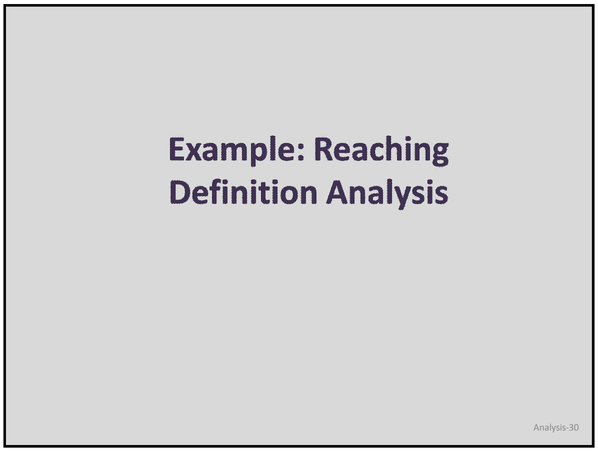
- Extends the *Analysis* interface
- Declares more methods for structural type analysis:

```
public interface StructuralAnalysis<A extends
    FlowSet> extends Analysis<A> {
    public Map<ASTNode, A> getOutFlowSets();
    public Map<ASTNode, A> getInFlowSets();
    public void merge(A in1, A in2, A out);
    public void copy(A source, A dest);
    …
}
```

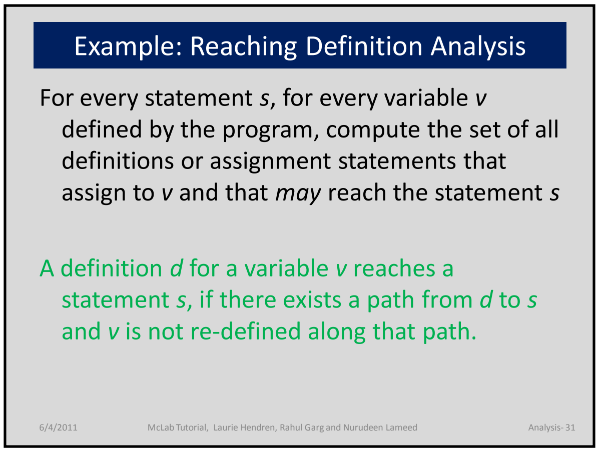


Developing a Structural Analysis

- Involves the following steps:
  1. Select a representation for the analysis's data
  2. Create a concrete class by extending the class: *AbstractSimpleStructuralForwardAnalysis* for a forward analysis and *AbstractSimpleStructuralBackwardAnalysis* for a backward analysis
  3. Implement a suitable constructor for the analysis and the method *newInitialFlow*
  4. Implement the methods *merge* and *copy*
  5. Override the relevant node case handler methods and other methods



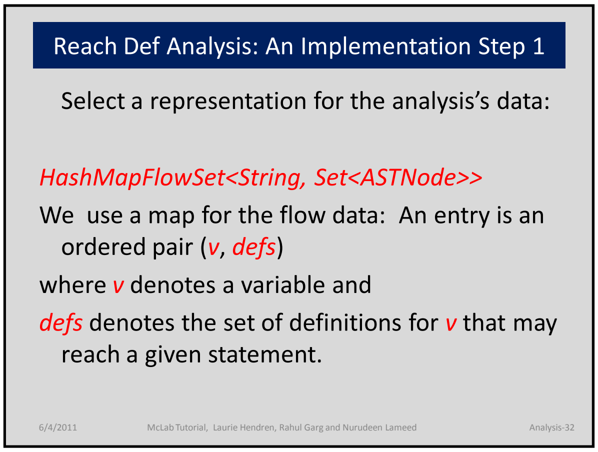
Example: Reaching Definition Analysis



Example: Reaching Definition Analysis

For every statement *s*, for every variable *v* defined by the program, compute the set of all definitions or assignment statements that assign to *v* and that *may* reach the statement *s*

A definition *d* for a variable *v* reaches a statement *s*, if there exists a path from *d* to *s* and *v* is not re-defined along that path.



Reach Def Analysis: An Implementation Step 1

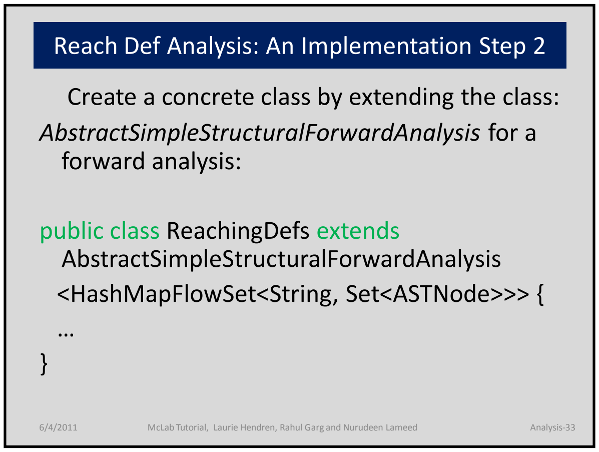
Select a representation for the analysis's data:

HashMapFlowSet<String, Set<ASTNode>>

We use a map for the flow data: An entry is an ordered pair (*v*, *defs*)

where *v* denotes a variable and

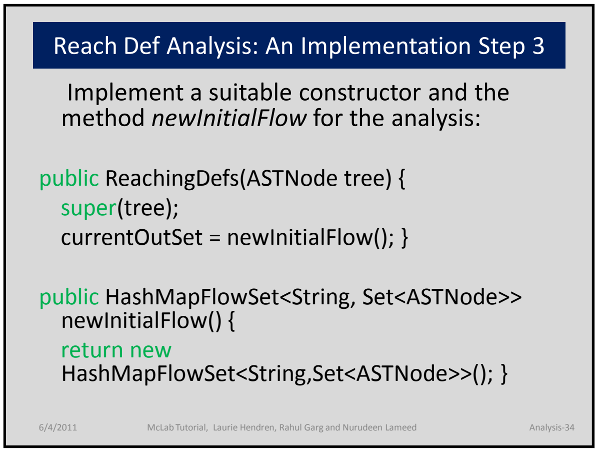
defs denotes the set of definitions for *v* that may reach a given statement.



Reach Def Analysis: An Implementation Step 2

Create a concrete class by extending the class: *AbstractSimpleStructuralForwardAnalysis* for a forward analysis:

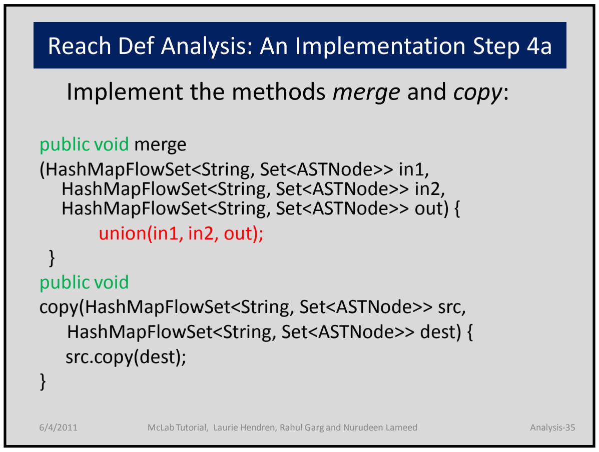
```
public class ReachingDefs extends
   AbstractSimpleStructuralForwardAnalysis
  <HashMapFlowSet<String, Set<ASTNode>>> {
  …
}
```



Reach Def Analysis: An Implementation Step 3

Implement a suitable constructor and the method *newInitialFlow* for the analysis:

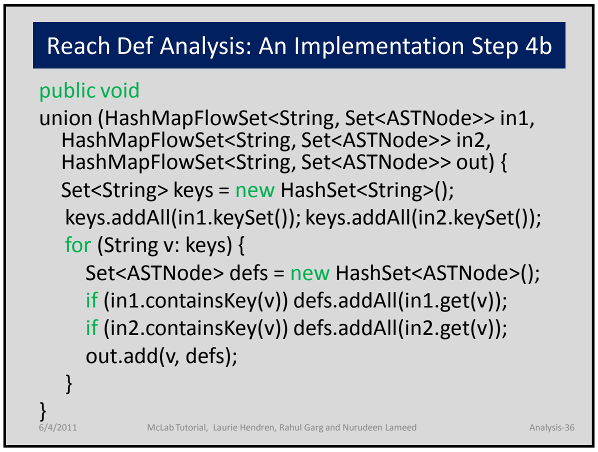
```
public ReachingDefs(ASTNode tree) {
   super(tree);
   currentOutSet = newInitialFlow(); }

public HashMapFlowSet<String, Set<ASTNode>>
   newInitialFlow() {
   return new
   HashMapFlowSet<String,Set<ASTNode>>(); }
```



Reach Def Analysis: An Implementation Step 4a

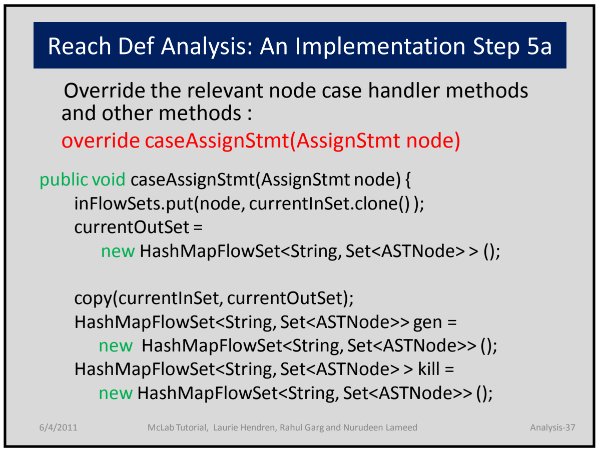
Implement the methods *merge* and *copy*:

```
public void merge
(HashMapFlowSet<String, Set<ASTNode>> in1,
   HashMapFlowSet<String, Set<ASTNode>> in2,
   HashMapFlowSet<String, Set<ASTNode>> out) {
        union(in1, in2, out);
 }
public void
copy(HashMapFlowSet<String, Set<ASTNode>> src,
    HashMapFlowSet<String, Set<ASTNode>> dest) {
    src.copy(dest);
}
```



Reach Def Analysis: An Implementation Step 4b

```
public void
union (HashMapFlowSet<String, Set<ASTNode>> in1,
   HashMapFlowSet<String, Set<ASTNode>> in2,
   HashMapFlowSet<String, Set<ASTNode>> out) {
   Set<String> keys = new HashSet<String>();
    keys.addAll(in1.keySet()); keys.addAll(in2.keySet());
    for (String v: keys) {
      Set<ASTNode> defs = new HashSet<ASTNode>();
      if (in1.containsKey(v)) defs.addAll(in1.get(v));
      if (in2.containsKey(v)) defs.addAll(in2.get(v));
      out.add(v, defs);
   }
}
```

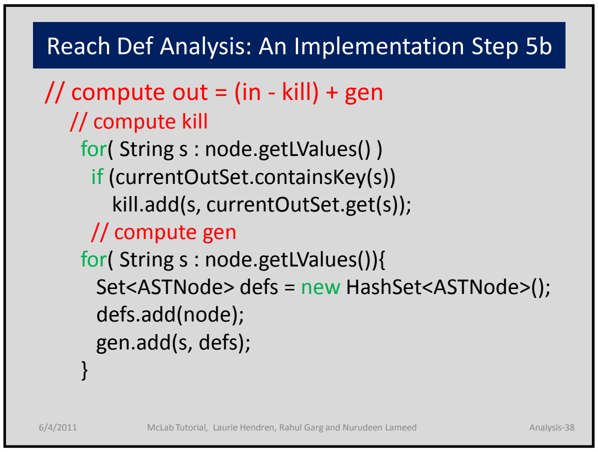


Reach Def Analysis: An Implementation Step 5a

Override the relevant node case handler methods and other methods :

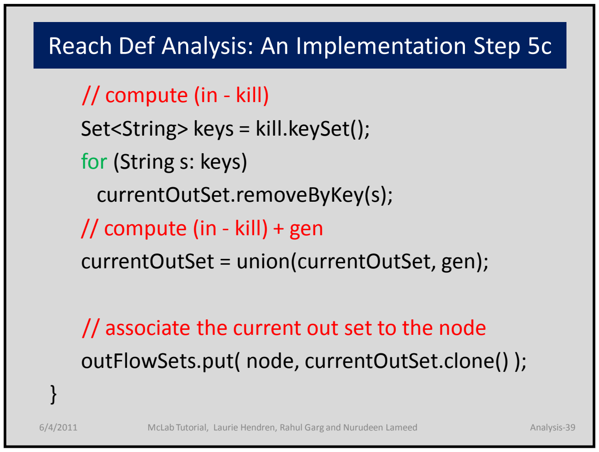
override caseAssignStmt(AssignStmt node)

```
public void caseAssignStmt(AssignStmt node) {
    inFlowSets.put(node, currentInSet.clone() );
    currentOutSet =
        new HashMapFlowSet<String, Set<ASTNode> > ();

    copy(currentInSet, currentOutSet);
    HashMapFlowSet<String, Set<ASTNode>> gen =
        new  HashMapFlowSet<String, Set<ASTNode>> ();
    HashMapFlowSet<String, Set<ASTNode> > kill =
        new HashMapFlowSet<String, Set<ASTNode>> ();
```



Reach Def Analysis: An Implementation Step 5b

```
// compute out = (in - kill) + gen
  // compute kill
   for( String s : node.getLValues() )
    if (currentOutSet.containsKey(s))
       kill.add(s, currentOutSet.get(s));
    // compute gen
   for( String s : node.getLValues()){
     Set<ASTNode> defs = new HashSet<ASTNode>();
     defs.add(node);
     gen.add(s, defs);
   }
```



Reach Def Analysis: An Implementation Step 5c

```
    // compute (in - kill)
    Set<String> keys = kill.keySet();
    for (String s: keys)
      currentOutSet.removeByKey(s);
    // compute (in - kill) + gen
    currentOutSet = union(currentOutSet, gen);

    // associate the current out set to the node
    outFlowSets.put( node, currentOutSet.clone() );
}
```