Static Analysis in PTP with CDT

Parallel Tools Platform   eclipse.org/ptp
C/C++ Development Tools   eclipse.org/cdt

What can I find out about my C/C++ program?
How do I do it? Why is it useful?

Beth R. Tibbitts   IBM Research
tibbitts@us.ibm.com

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Outline

- **Basics of static analysis**
- **What CDT provides today:**
  - AST: how to inspect it; how to walk it
- Additional info built by PTP/PLDT for analysis
  - Call graph (incl recursion)
  - Control flow graph
  - Data dependency (partial)
- Upcoming features
  - Refactoring & potential in CDT 5.0
  - Using external info for analysis: e.g. compiler info
  - Source Code instrumentation

PLDT = Parallel Language Development Tools: “the analysis part of PTP”
What is static analysis?

- **Static code analysis** is analysis of a computer program that is performed without actual execution - analysis performed on executing programs is known as **dynamic analysis**.
  - Usually performed on some intermediate representations of the **source code**.
  - Routinely done by compilers in order to *generate and optimize* object code.

- Motivation:
  - Deriving properties of execution behavior or program structure
  - Various forms of analysis and refactoring
  - Lots more in JDT :)

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CDT Introspection Components

• Knowledge about the user’s source code is stored in the CDT’s DOM: Document Object Model

• Two components of DOM
  - DOM AST
    - Abstract Syntax Tree that stores detailed structural information about the code
  - Index
    - Built from the AST
    - Provides the ability to perform fast lookups by name on elements
    - Persistent index called the PDOM (persistent DOM)

Ref: EclipseCon 2007, “C/C++ Source Code Introspection Using the CDT”, Recoskie & Tibbitts
What is this information used for in CDT?

- Search
- Navigation
- Content Assist
- Call Hierarchy
- Type Hierarchy
- Include browsing
- Dependency scanning
- Syntax highlighting
- Refactoring
Abstract Syntax Tree: AST

• Maps C/C++ source code info onto a tree structure
  ❖ A tree of nodes, all subclasses of
    ▪ org.eclipse.cdt.core.dom.ast.IASTNode
  ❖ Nodes for: functions, names, declarations, arrays, expressions, statements/compound statements, etc.
  ❖ Src file root: IASTTranslationUnit
    ▪ Correlates to a source file: myfile.c
  ❖ Tree structure eases analysis
  ❖ Knows relationships (parent/child)
  ❖ Easy traversal (ASTVisitor)
  ❖ … etc
Existing CDT views that use structure include….

CDT Call Hierarchy view
CDT DOM AST View

- Graphical inspection of AST

Available in CDT Testing feature:
org.eclipse.cdt.ui.tests package
Creating an AST: steps to create and use

1. Get ITranslationUnit - from e.g. source file “foo.c”
2. From ITranslationUnit, Show some “flat info” - lists preprocessor stmts, declarations, include dependencies
3. Walk the ITranslationUnit’s tree: CElements
4. Create AST and walk it

Code for tree walking is in sample plugin
On dev.eclipse.org: org.eclipse.ptp/tools/samples/
Project org.eclipse.ptp.ptdt.sampleCDTstaticAnalysis
Creating an AST (1): get ITranslationUnit

- From a source file in Projects view - Example: Plugin with an Action which gets current selection:

```java
public void runSelectionExample(ISelection selection) {
    if (selection instanceof IStructuredSelection) {
        IStructuredSelection ss = (IStructuredSelection) selection;
        for (Iterator iter = ss.iterator(); iter.hasNext();) {
            Object obj = (Object) iter.next();
            // It can be a Project, Folder, File, etc...
            if (obj instanceof IAdaptable) {
                IAdaptable iad = (IAdaptable) obj;
                IResource res = (IResource) iad.getAdapter(IResource.class);
                System.out.println("got resource: " + res);
                // ICElement covers folders and translation units
                ICElement ce = (ICElement) iad.getAdapter(ICElement.class);
                System.out.println("got ICElement: " + ce);

                ITranslationUnit tu = (ITranslationUnit) iad.getAdapter(ITranslationUnit.class);
                System.out.println("got ITranslationUnit: " + tu);
                listFlatInfo(tu);
                walkITU(tu);
            }
        }
    }
}
```
Creating an AST: (2) get AST and listFlatInfo()

```java
void listFlatInfo(ITranslationUnit tu) throws CoreException {
    IASTTranslationUnit ast = tu.getAST();

    System.out.println("AST for: "+ast.getContainingFilename());
    IASTPreprocessorStatement[] ppss= ast.getAllPreprocessorStatements();
    System.out.println("PreprocessorStmts: (omit /usr/...)");
    for (int i = 0; i < ppss.length; i++) {
        IASTPreprocessorStatement pps = ppss[i];
        String fn = pps.getContainingFilename();
        if(!fn.startsWith("/usr")) System.out.println(i+" PreprocessorStmt: "+fn+" "+pps.getRawSignature());
    }
    IASTDeclaration[] decls = ast.getDeclarations();
    System.out.println("Declarations: (omit /usr/...)");
    for (int i = 0; i < decls.length; i++) {
        IASTDeclaration decl = decls[i];
        String fn = decl.getContainingFilename();
        if(!fn.startsWith("/usr")) System.out.println(i+" Declaration: "+fn+" "+decl.getRawSignature());
    }
    IDependencyTree dt=ast.getDependencyTree();
    IASTInclusionNode[] ins = dt.getInclusions();
    System.out.println("Include statements: ");
    for (int i = 0; i < ins.length; i++) {
        IASTInclusionNode in = ins[i];
        IASTPreprocessorIncludeStatement is = in.getIncludeDirective();
        System.out.println(i+" include stmt: "+is);
    }
}
```
Creating an AST: (2) show “flat info”

- Source and Results:

  flat info

```
//walkast.c
#include <stdio.h>
#define MYVAR 42

int main(void) {
    int a,b;
    a=0;
    b=MYVAR; // use defined
    b = b + a;
    return b;
}

int foo(int bar){
    int z = bar;
    return z;
}
```

SampleAction.selectionChanged()
  got resource: L/Hello/src/Hello.c
  got ICElement: Hello.c
  got ITranslationUnit: Hello.c

AST for: ws/Hello/src/Hello.c
PreprocessorStmts: (omit /usr/...)
  0 PreprocessorStmt: ws/Hello/src/Hello.c #include <stdio.h>
  357 PreprocessorStmt: ws/Hello/src/Hello.c #define MYVAR 42
Declarations: (omit /usr/...)
  154 Declaration: ws/Hello/src/Hello.c int main(void) ...
  155 Declaration: ws/Hello/src/Hello.c int foo(int bar){
    int z = bar;
    return z;
  }
Include statements:
  0 include stmt: /usr/include/stdio.h

Demo: this plus DOMAST
AST: (3) walkITU: Walk ICElement tree

```java
private void walkITU(ITranslationUnit tu) {
    String tuName = tu.getElementName();
    System.out.println("ITranslationUnit name: " + tuName);
    tu.accept(new ICElementVisitor() {
        public boolean visit(ICElement element) {
            boolean visitChildren = true;
            System.out.println("Visiting: " + element.getElementName());
            return visitChildren;
        }
    });
}
```

Visitor pattern:

Your Visitor code gets called at each node

tree.accept(visitor)

Exception handling omitted for brevity
Watch the walking: walkITU - ICElement Visitor

- Source and Results:
  walkITU()

```c
#include <stdio.h>
define MYVAR 42

int main(void) {
    int a,b;
    a=0;
    b=MYVAR; // use defined
    b = b + a;
    return b;
}

int foo(int bar){
    int z = bar;
    return z;
}
```

ITranslationUnit name: Hello.c
Visiting: Hello.c
Visiting: stdio.h
Visiting: MYVAR
Visiting: main
Visiting: foo
private void walkITU_AST(ITranslationUnit tu) throws CoreException {
    System.out.println("AST visitor for "+tu.getElementName());
    IASTTranslationUnit ast = tu.getAST();
    ast.accept(new MyASTVisitor());
}

class MyASTVisitor extends ASTVisitor {
    MyASTVisitor() {
        this.shouldVisitStatements=true; // lots more
        this.shouldVisitDeclarations=true;
    }
    public int visit(IASTStatement stmt) { // lots more
        System.out.println("Visiting stmt: "+stmt.getRawSignature());
        return PROCESS_CONTINUE;
    }
    public int visit(IASTDeclaration decl) {
        System.out.println("Visiting decl: "+decl.getRawSignature());
        return PROCESS_CONTINUE;
    }
}

Visitor pattern:
Your Visitor code gets called at each node

tree.accept(visitor)

Note: simple visitor only visits statements and declarations
Watch AST walking: walkITU_AST()

- Source and Results:

```c
// walkast_edge.c
#include <stdio.h>

void edge(int a) {
    int x,y;
    if(a>0)
        x=0;
    else
        x=1;
    y=x;
}

int foo(int bar){
    int z = bar;
    return z;
}
```

Note new example
MyASTVisitor2

- More details in the visit() methods....
- Implements leave() methods too... showing depth
- See tree on next slide

Adds:

1. New type of construct visited (IASTName)
2. leave() methods as well as visit() methods

visit(IASTName stmt){...}
leave(IASTName stmt){...}
AST: More complex Visitor exposes more AST

leave() indicates nesting

// walkast_edge.c
#include <stdio.h>

3 void edge(int a) {
4   int x, y;
5   if(a>0)      x=0;
6   else      x=1;
7   y=x;
8   }
9
10 void foo(int bar) {
11   int z = bar;
12   return z;
13   }

Visiting stmt: if(a>0)  
   x=0;  
   else  
      x=1;

Visiting name: a
Leaving name: a
Visiting stmt: x=0;
   
Visiting name: x  
Leaving name: x
Visiting stmt: x=1;

Leaving stmt: if(a>0)  
   x=0;  
   else  
      x=1;

Leaving stmt: y=x;
Visiting name: y
Leaving name: y
Visiting name: x
Leaving name: x
Leaving stmt: y=x;
Leaving stmt: {  
    int x,y;
    if(a>0)  
      x=0;  
    else  
      x=1;
    y=x;
  }
Relook at DOM AST View: see depth parsed

- Relook at DOM AST View: see “descending into structure”
IASTNode hierarchy

• Classes represent various language constructs
AST: what we do with it
PTP/PLDT provided structures

- Find Location of: MPI, OpenMP artifacts; MPI Barriers with AST walking
- Analysis: MPI barrier deadlock detection, OpenMP concurrency
PLDT’s AST walking

- Location of “MPI Artifacts”
- Not a simple text location
- During tree walking, expressions are located for function calls, and tested for viability:

```java
protected boolean isMPIArtifact(IASTName funcName) {
    IBinding binding = funcName.resolveBinding();
    String name = binding.getName();
    String rawSig = funcName.getRawSignature();
    // Sometimes names are empty (e.g. preprocessor change) or represented differently
    name = chooseName(name, rawSig);

    IASTName[] decls = funcName.getTranslationUnit().getDeclarationsInAST(binding);
    for (int i = 0; i < decls.length; ++i) {
        // IASTFileLocation is file and range of lineNos
        IPath includeFilePath = new Path(decls[i].getFileLocation().getFileName());
        // See if it's in the list of known (MPI) Include paths
        for (String knownMPIincludePath : includes_) {
            IPath includePath = new Path(knownMPIincludePath);
            if (includePath.isPrefixOf(includeFilePath))
                return true;
        }
    }
    return false;
}
```
PTP from 30,000 feet
Parallel Tools Platform
http://eclipse.org/ptp

Leverages Eclipse CDT & Photran (eventually)

PLDT:
Parallel Lang. Dev. Tools (Analysis Tools)

PTP Debugger

PTP Runtime
Constructed by PTP’s PLDT:

- Call Graph
- Control Flow Graph
- Dependency Graph (Defined/Use Chain: partial)

In order to do:
- MPI Barrier Analysis: detect deadlocks; find concurrently executed statements

Caveats:
- C only (not C++)
- No UI - structures used for analysis only
Recursive calls detected...

A cycle is detected on foo, gee and kei
CDT’s Call Hierarchy view - partial call graph

• Call Hierarchy view shows info for a selected function
  • From context menu within CDT editor:

![Call Hierarchy view](image)
Call Graph - PLDT - how to

• As part of the PLDT analysis, call graphs are constructed.

• `org.eclipse.ptp.pldt.mpi.analysis.cdt`
  Project isolates generic analysis code

• `org.eclipse.ptp.pldt.mpi.analysis.cdt.graphs.GraphCreator`
  class has several convenience methods

```java
GraphCreator graphCreator = new GraphCreator();
Iresource resource = ...
// Initialize call graph with function info
ICallGraph cg = graphCreator.initCallGraph(resource);
// Compute callers & callees
graphCreator.computeCallGraph(callGraph);
// print call graph to console
graphCreator.showCallGraph(callGraph);
```

Sample plugin

Shows call graph
- text only
Control Flow Graph

• A control flow graph (CFG) is a representation of all paths that might be traversed through a program during its execution. Each node in the graph represents a basic block, i.e. a straight-line piece of code with a single point of entry and a single point of exit.

• A Statement Level CFG is a CFG with individual statements instead of larger basic blocks.
  - PLDT builds a statement level CFG as described here
Control Flow Graph creation

// get the first node in the CallGraph
ICallGraphNode node = callGraph.topEntry();
IASTStatement funcBody = node.getFuncDef().getBody();
// create CFG from a statement
IControlFlowGraph cfg = new ControlFlowGraph(funcBody);
cfg.buildCFG();

// print CFG
IBlock entryBlock = cfg.getEntry();
for (IBlock block= cfg.getEntry(); block!=null; 
    block = block.getTopNext()) {
    block.print();
}
Motivation: AST vs. CFG (Control Flow Graph)

- What can CFG provide that AST cannot?
- AST alone is not the right representation to do all static analysis

```plaintext
5 if(..)  
6   x=0; 
7 else  
8   x=1;  
9   y=x;
```

- **Live variables: still used in program (x)**
- **Data flow: need to determine what values could flow into x at 9**
- **CFG has direct edge from 8 to 9; using AST would have to walk tree backwards**
Motivation: AST vs. CFG (Control Flow Graph)

- To walk from line 8 to 9, in AST would have to walk backwards up tree to IASTIfStatement, then next to y=x expr on line 9
- Control Flow Graph (CFG) has direct edge from 8 to 9
CFG illustrated

Block 0: Empty block (Line No)
   flows to: 2,
Block 2: CASTDeclarationStatement int x,y;
   flows to: 3,
Block 3: CASTIdExpression true (5)
   flows to: 5, 6,
Block 6: CASTExpressionStatement x=1; (8)
   flows to: 4,
Block 5: CASTExpressionStatement x=0; (6)
   flows to: 4,
Block 4: Empty block
   flows to: 7,
Block 7: CASTExpressionStatement y=x; (9)
   flows to: 1,
Block 1: Empty block

Direct flow from line (8) --Block 6 to line (9) --Blocks 4-7

- To walk from line (8) to (9), in AST would have to walk backwards up tree to IASTIfStatement, then back down to y=x expr on line 9
- Control Flow Graph (CFG) has direct edge from (8) to (9)
Use of CFG: MPI Barrier Analysis

MPI Barriers view
Simply lists the barriers
Like MPI Artifacts view, double-click to navigate to source code line (all 3 views)

Barrier Matches view
Groups barriers that match together in a barrier set – all processes must go through a barrier in the set to prevent a deadlock

Barrier Errors view
If there are errors, a counter-example shows paths with mismatched number of barriers

Demo (if time)

Finds potential deadlocks in MPI code due to mismatched MPI_Barrier statements
Static Analysis and related features
A peek at things to come

- Refactoring in CDT 5.0
  - New framework with AST Rewriter has potential for complex and useful refactorings
- PTP/PLDT integration of compiler information
- PTP/PLDT Source code instrumentation
  - Usable by Dynamic Instrumentation
Refactoring (CDT 5.0)

• New refactoring framework in CDT 5.0
  ✷ Leverages Platform refactoring framework in LTK

• Current refactorings:
  ✷ Rename (class, variable, etc)
  ✷ Extract Constant - example of new framework use
  ✷ In org.eclipse.cdt.ui: See
    org.eclipse.cdt.internal.ui.refactoring.extractconstant.ExtractConstantRefactoring
    1. checkInitialConditions(..)
    2. createChange()...
    3. checkFinalConditions().
CDT 5.0 Refactoring: Extract Constant

int main(void) {
    double intvalue = 0.0;
}

Source

Refactor

Extract Constant...
Future: Integrating Analysis information from Compilers

- Compilers have stronger tools for analysis than what we have in CDT! And more years of experience generating the info.

- Compiler information offered to expose to PTP users:
  - IBM xIC/xIC++, xIF (C, C++, and Fortran)
  - HP compilers (C, C++, and Fortran)
  - U.Houston

- Compiler output supplied in various forms
- Exposed to use in Eclipse view, mapped to source line
- Expected types of output:
  - Parallelization attempts, hindrances
  - May assist user in manual parallelization of code, for example
Future: Source Code instrumentation

• Instrumentation of Java code is being done for IBM’s TuningFork, and extensions to do this for C/C++ code as well are planned.
• Summary: use AST and pgm info to make decisions about how to instrument code (add statements for gathering information during dynamic analysis / performance tuning)
• Planned to be part of PTP Perf. Analysis Framework
Summary

• CDT has the basics for Static Analysis, including AST (Abstract Syntax Tree)
• Other useful graphs are built by PTP’s PLDT
  ❖ PLDT=Parallel Language Development Tools
  ❖ Call Graph, Control Flow Graph, etc.
  ❖ These graphs make analysis more straightforward
• Other features are in the works
  ❖ CDT 5.0: Refactoring framework + refactorings
  ❖ PLDT:
    ▪ Integration of external tools’ analysis findings (e.g. compilers)
    ▪ Source Code Instrumentation uses AST to find instrumentation points

http://eclipse.org/ptp  Parallel Tools Platform
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