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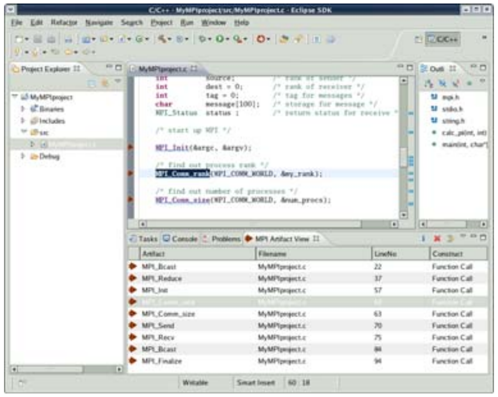


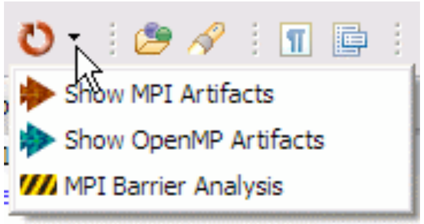
Static Analysis in PTP with CDT

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?



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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 :)

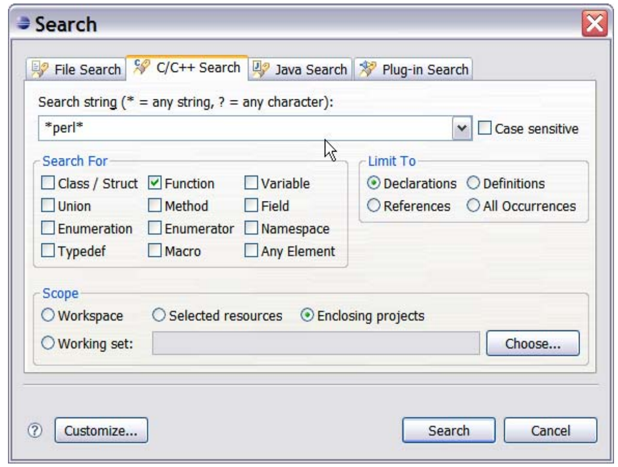
CDT Introspection Components

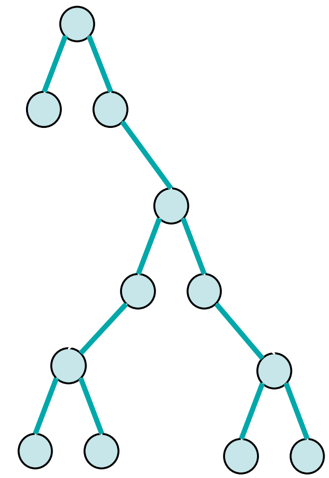
- Knowledge about the user's source code is stored in the CDT's DOM: Document Object Model
- Two components of DOM
  - DOM AST concentrate here
    - Abstract Syntax Tree that stores detailed structural information about the code
  - Index
    - Built from the AST
    - Provides the ability to perform fast lookups by name on elements
    - Persistent index called the PDOM (persistent DOM)

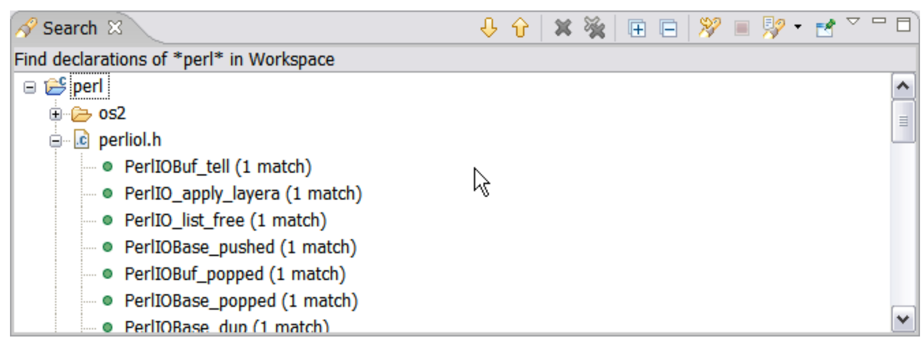
Ref: EclipseCon 2007, "C/C++ Source Code Introspection Using the CDT", Recoskie & Tibbitts

What is this information used for in CDT?

- Search
- Navigation
- Content Assist
- Call Hierarchy
- Type Hierarchy
- Include browsing
- Dependency scanning
- Syntax highlighting
- Refactoring

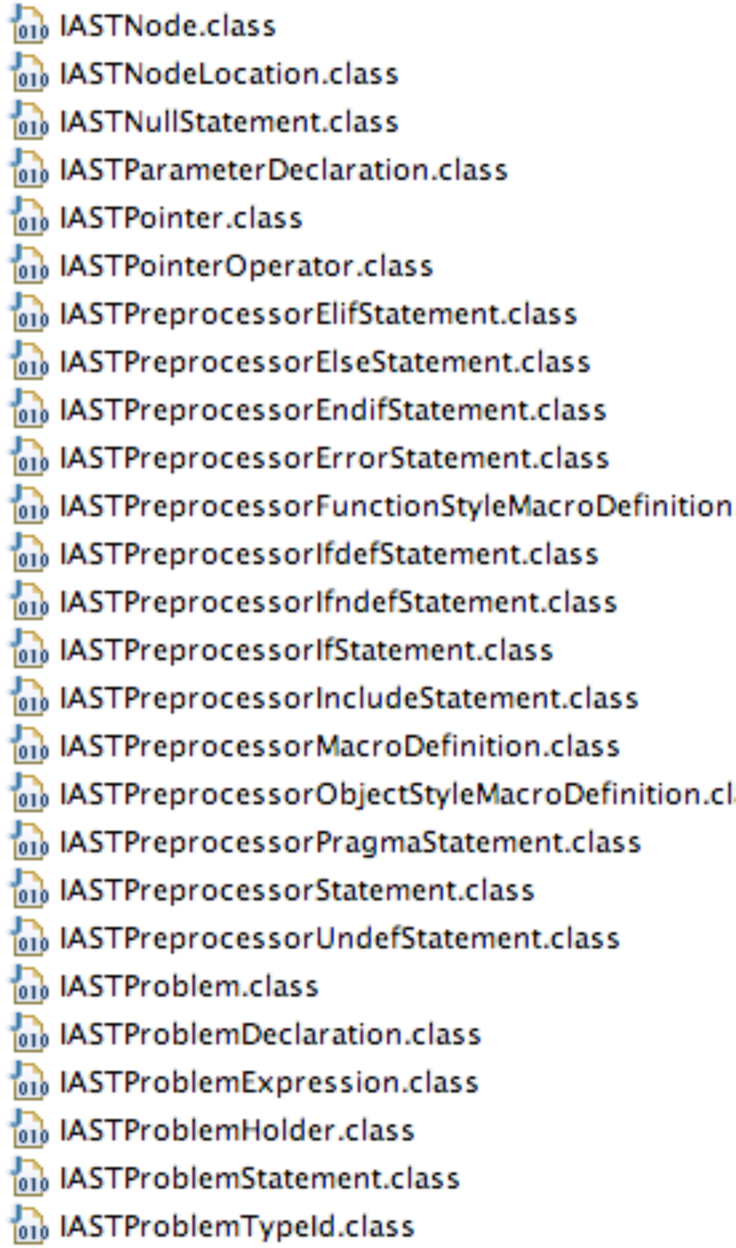






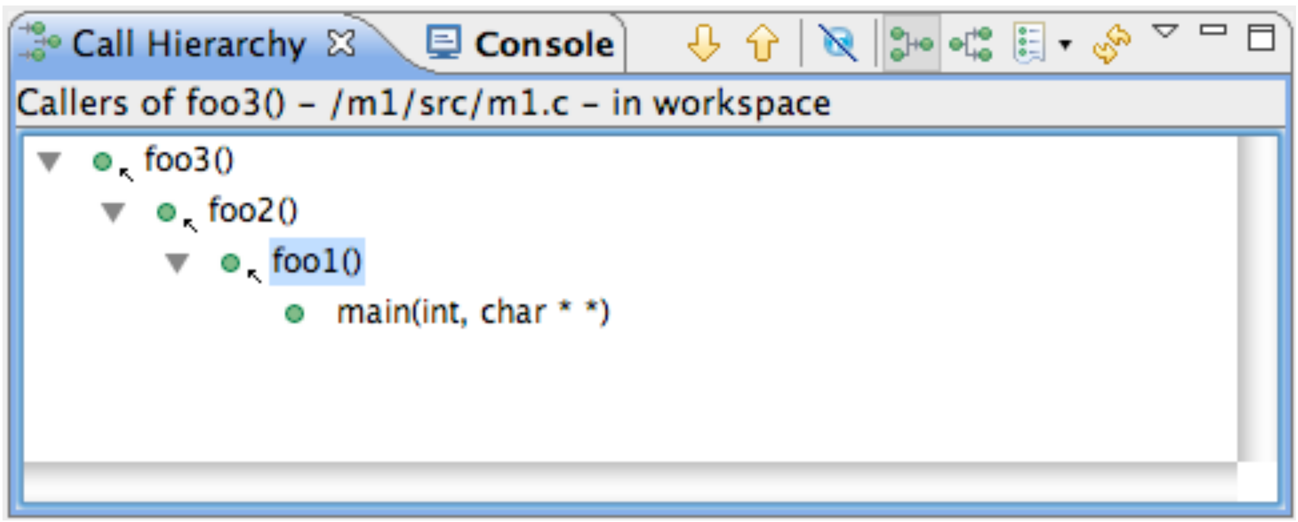
Abstract Syntax Tree: AST

- 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



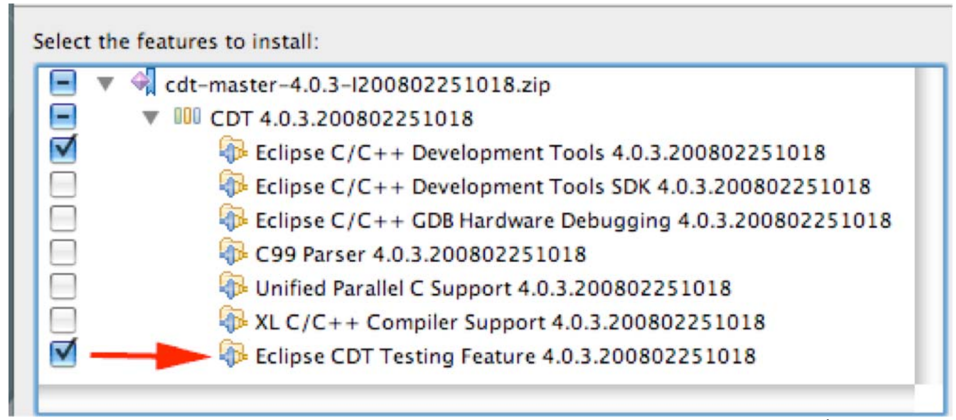
Existing CDT views that use structure include….

CDT Call Hierarchy view

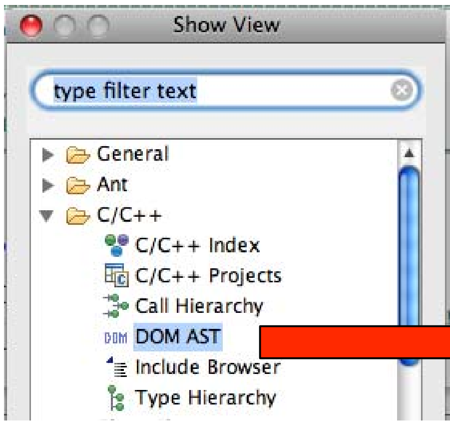


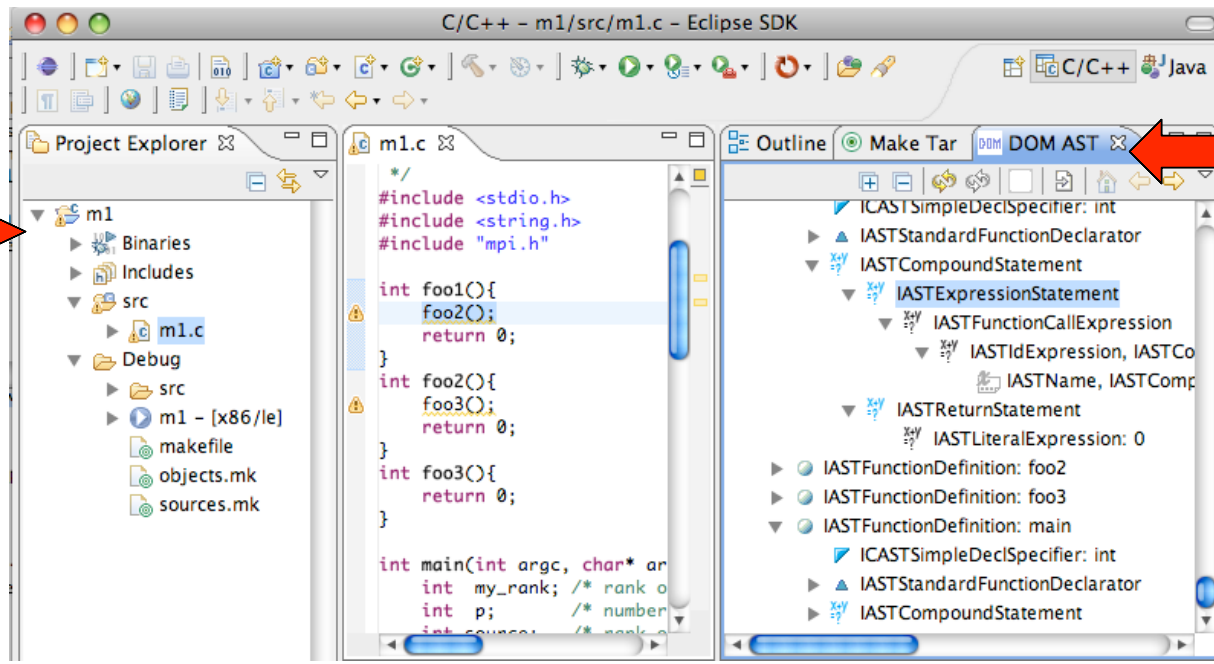
CDT DOM AST View

- 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.pldt.sampleCDTstaticAnalysis

Walk AST

Show Call Graph

Show Control Flow Graph

Creating an AST (1): get ITranslationUnit

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

```
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()

```
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);
  }
}
```

```
ast.
getAllPreprocessorStatements();
```

```
ast.getDeclarations();
```

```
ast.getDependencyTree();//includes
```

Creating an AST: (2) show “flat info”

- Source and Results: flat info

```
ws = complete path to workspace
```

```
//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

```
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
```

AST: (4) Walk AST nodes : walkITU_AST()

```
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

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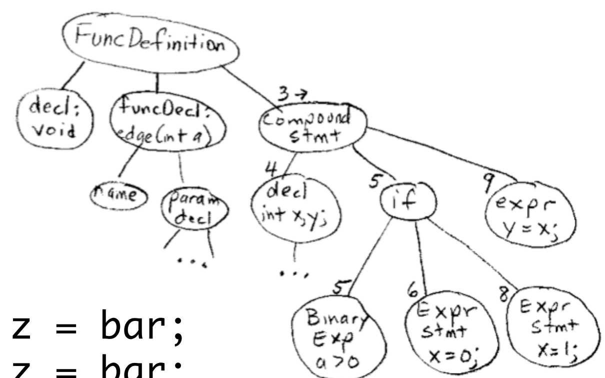
Watch AST walking: walkITU_AST()

- Source and Results:

```
// walkast_edge.c
1 #include <stdio.h>
2
3  void edge(int a) {
4    int x,y;
5    if(a>0)
6      x=0;
7    else
8      x=1;
9    y=x;
10  }
11  int foo(int bar){
12    int z = bar;
13    return z;
14  }
```

Note new example

```
AST visitor for walkast_edge.c
..Omit included stuff …
AST visitor for walkast_edge.c
Visiting decl: void edge(int a) {…}      3
Visiting stmt: { int x,y … y=x;}         3
Visiting stmt: int x,y;                  4
Visiting decl: int x,y;
Visiting stmt: if(a>0)  x=0;  else x=1;  5
Visiting stmt: x=0;                      5
Visiting stmt: x=1;                      8
Visiting stmt: y=x;                      9
Visiting decl: int foo(int bar){
  int z = bar;
  return z;
}
Visiting stmt: {
  int z = bar;
  return z;
}
Visiting stmt: int z = bar;
Visiting decl: int z = bar;
Visiting stmt: return z;
```



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

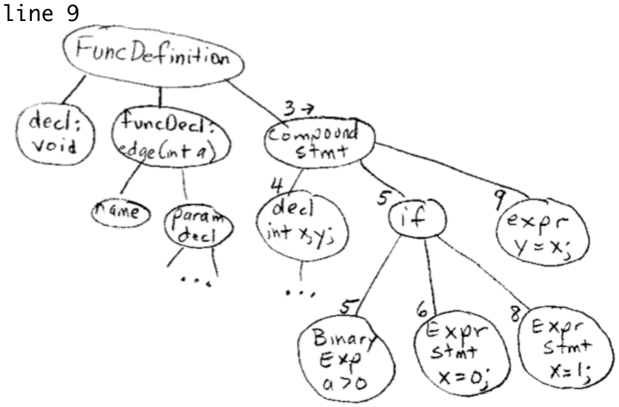
```
// walkast_edge.c
#include <stdio.h>

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

```
Visiting stmt: if(a>0)          line 5
                   x=0;
                 else
                   x=1;
Visiting name: a
 Leaving name: a
Visiting stmt: x=0;              line 6
    Visiting name: x
     Leaving name: x
     Leaving stmt: x=0;
      Visiting stmt: x=1;        line 8
      Visiting name: x
       Leaving name: x
       Leaving stmt: x=1;
Leaving stmt: if(a>0)
                x=0;
                else
                x=1;
Visiting stmt: y=x;                line 9
  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;
    }
```

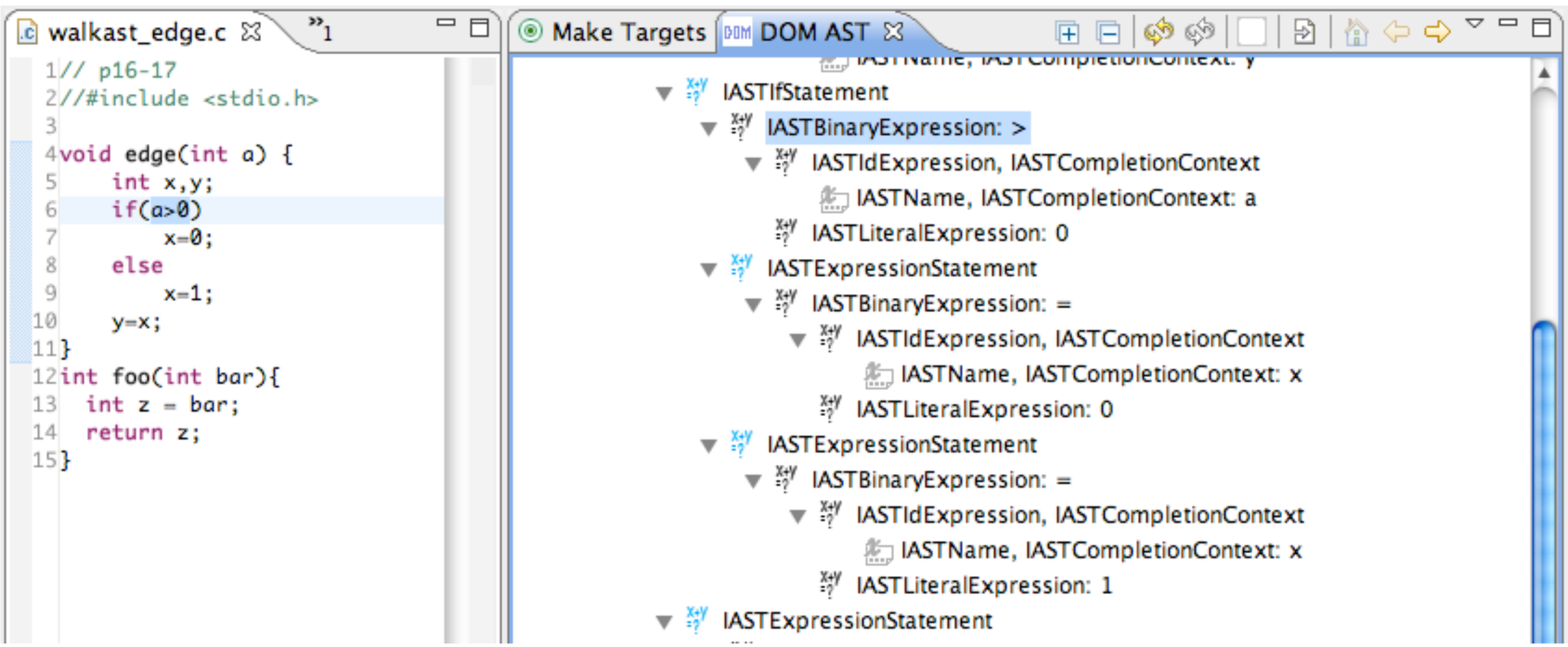
visit if stmt

leave if stmt



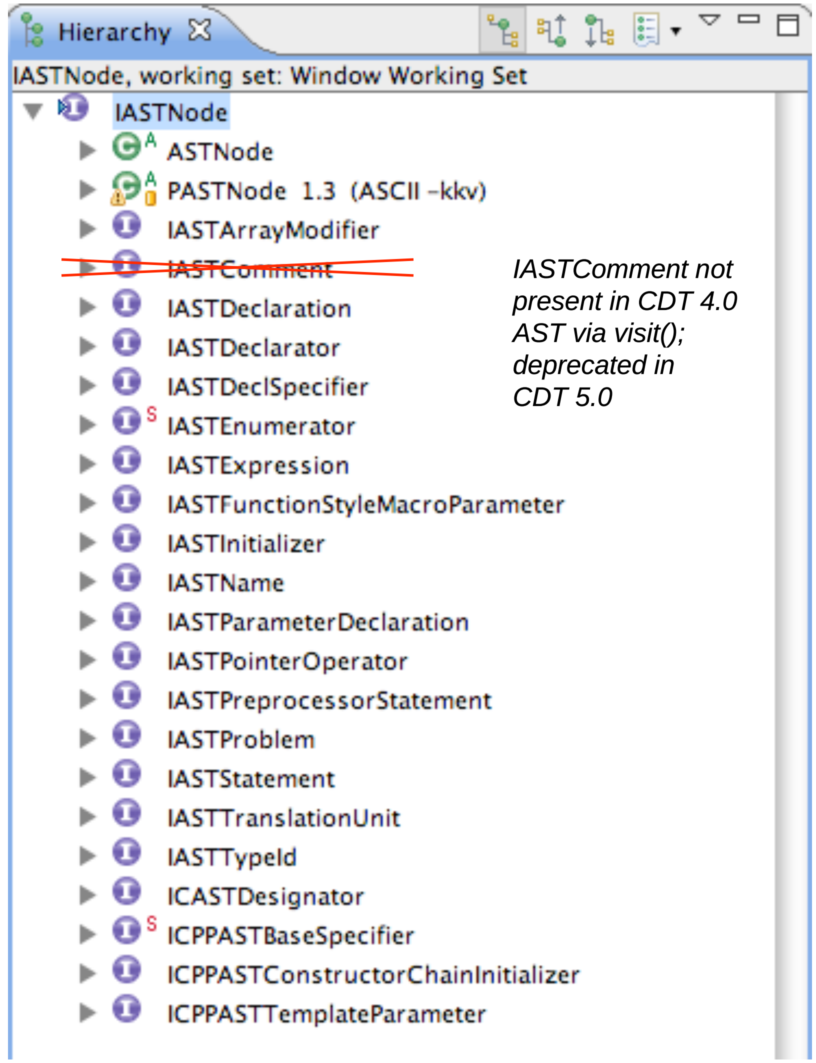
Relook at DOM AST View: see depth parsed

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

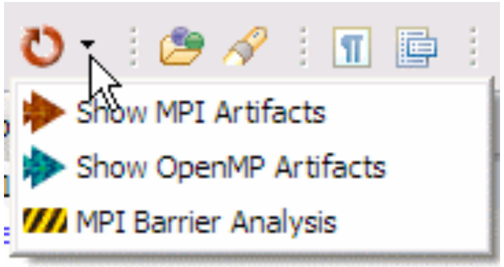


IASTNode hierarchy

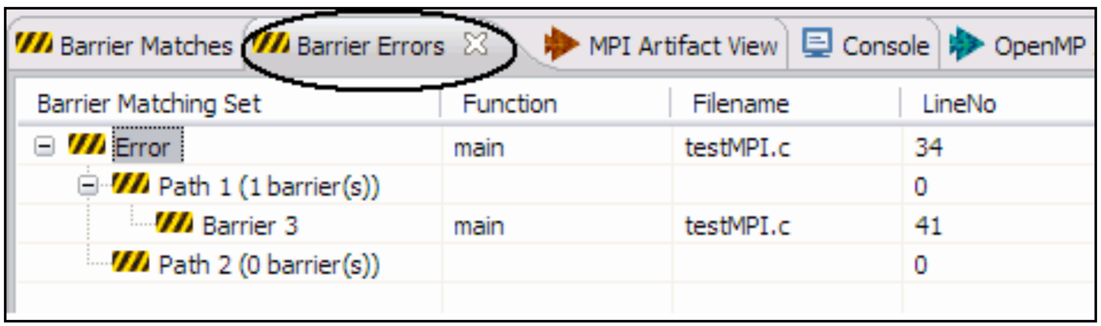
- Classes represent various language constructs

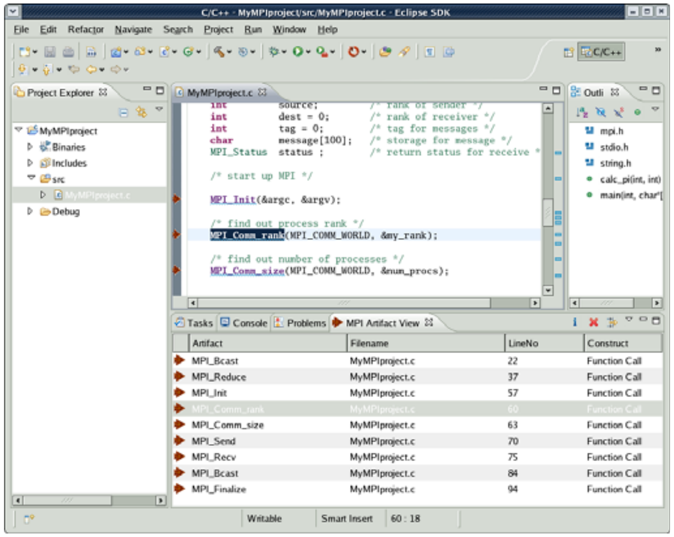


AST: what we do with it
PTP/PLDT provided structures



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





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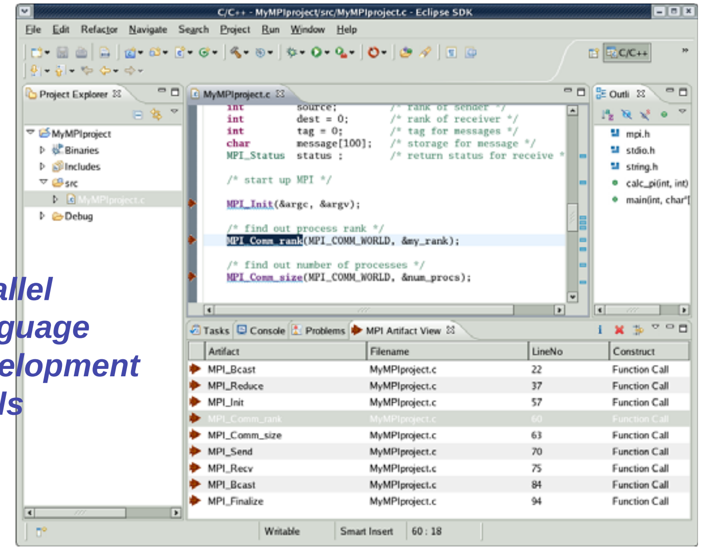
PLDT’s AST walking



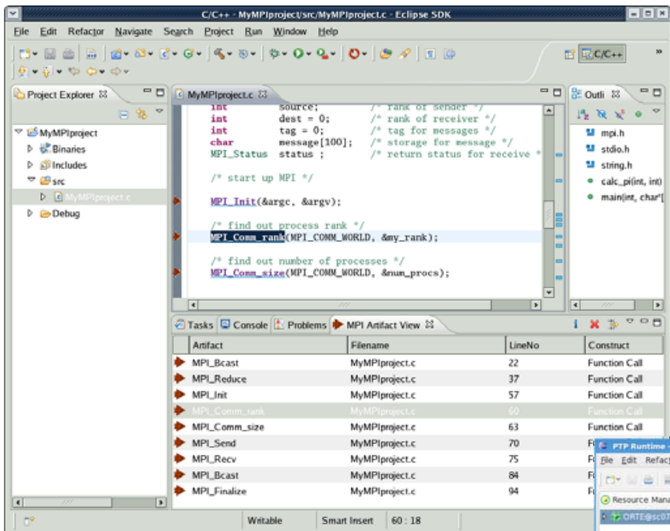
Parallel Language Development Tools

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

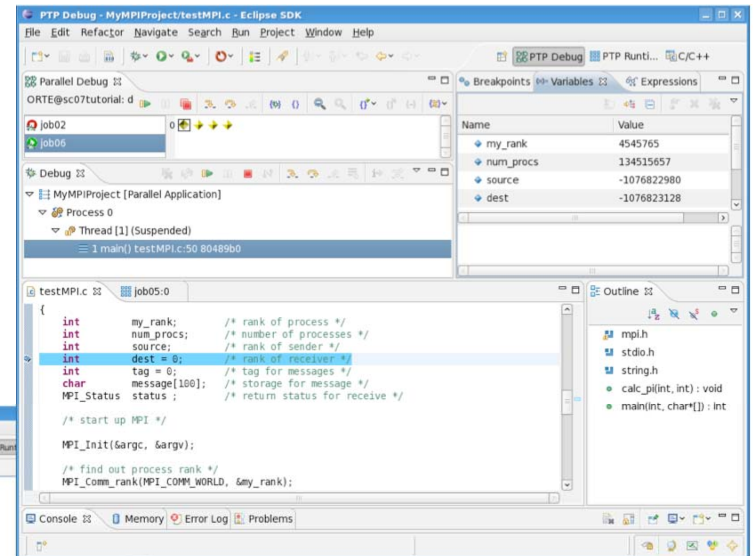
```
protected boolean isMPIArtifact(IASTName funcName) {
  IBinding binding = funcName.resolveBinding();
  String name=binding.getName();
  String rawSig=funcName.getRawSignature();
  //Sometimes names are empty (e.g. preprocessor change) or represented differently
  name = chooseName(name, rawSig);

  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;
}
```

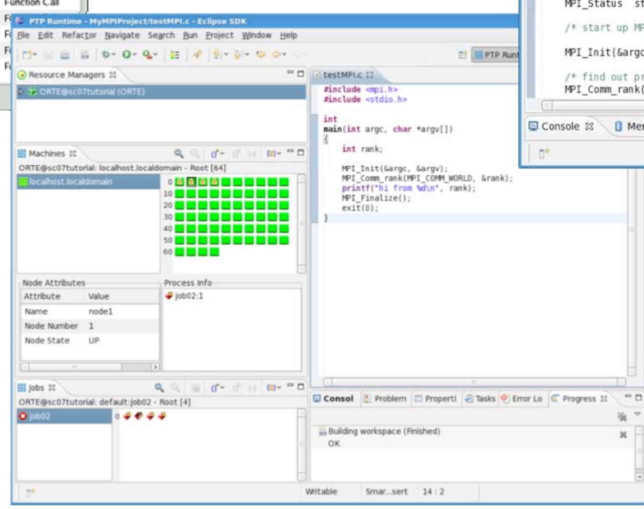
PTP from 30,000 feet
Parallel Tools Platform
http://eclipse.org/ptp

PTP BOF
Tues. 8:45 PM



Leverages
Eclipse CDT
& Photran
(eventually)





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

PTP Debugger

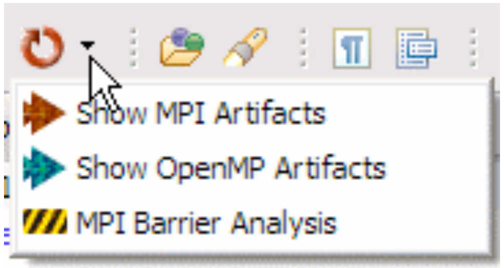
PTP Runtime

Constructed by PTP's PLDT:

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

In order to do:

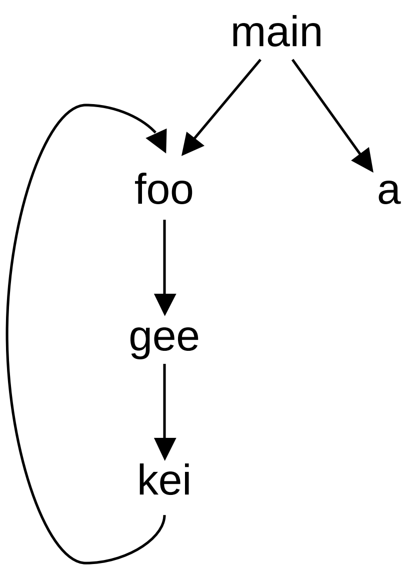
- MPI Barrier Analysis: detect deadlocks; find concurrently executed statements



Caveats:

- C only (not C++)
- No UI - structures used for analysis only

Call Graph - PLDT (example)



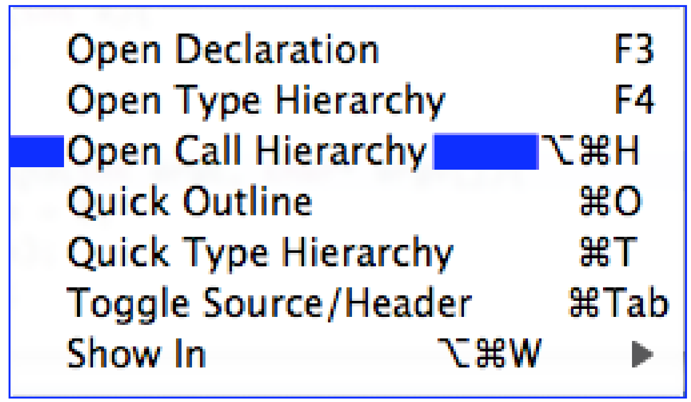
Recursive calls detected…

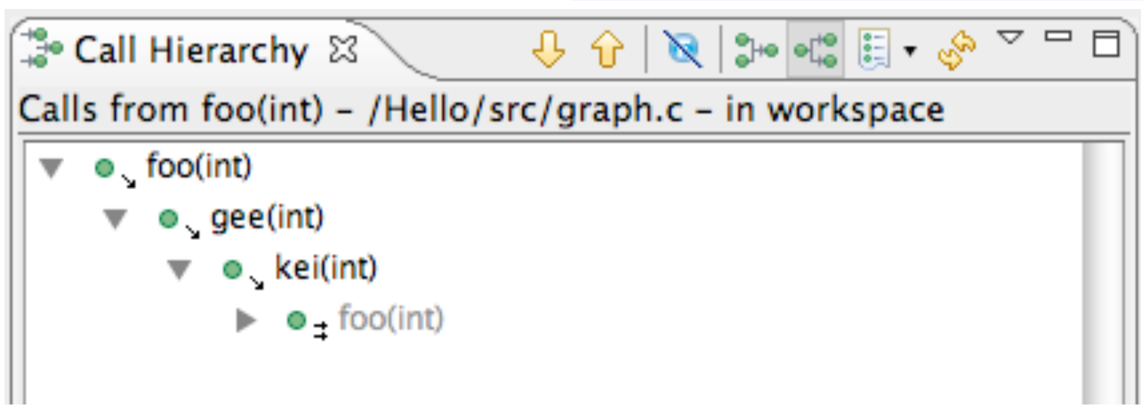
A cycle is detected on foo, gee and kei

```
#include "mpi.h"
#include "stdio.h"

void foo(int x);
void gee(int x);
void kei(int x);

void foo(int x){
  x ++;
  gee(x);
}

void gee(int x){
  x *= 3;
  kei(x);
}

void kei(int x){
  x = x % 10;
  foo(x);
}

void a(int x){
  x --;
}

int main3(int argc, char* argv[]){
  int x = 0;
  foo(x);
  a(x);
}
```

CDT’s Call Hierarchy view - partial call graph

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





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

```
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

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

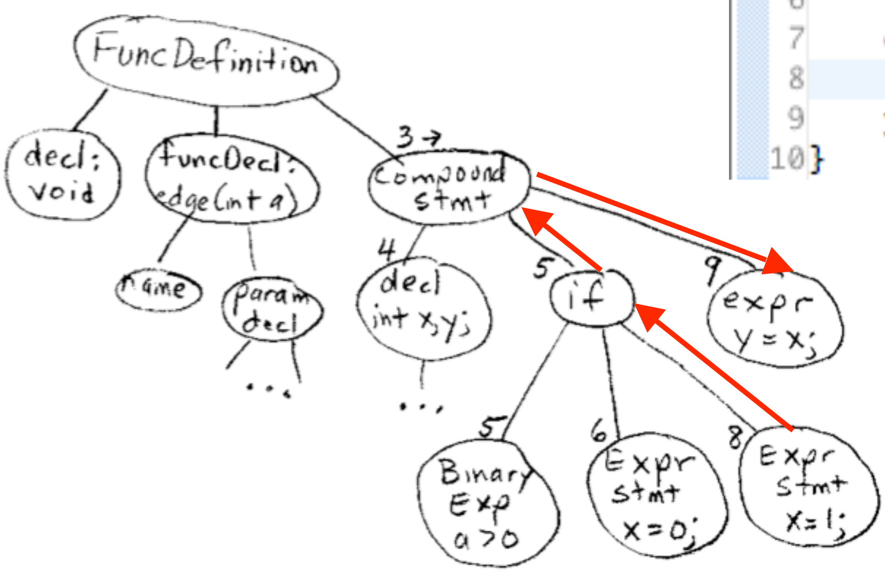
•*Live variables: still used in program (x)*

•*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)

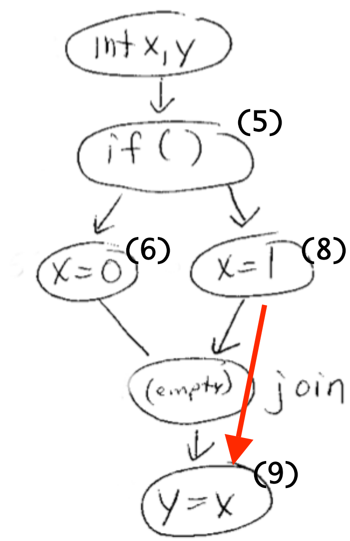
AST



CFGtest.c

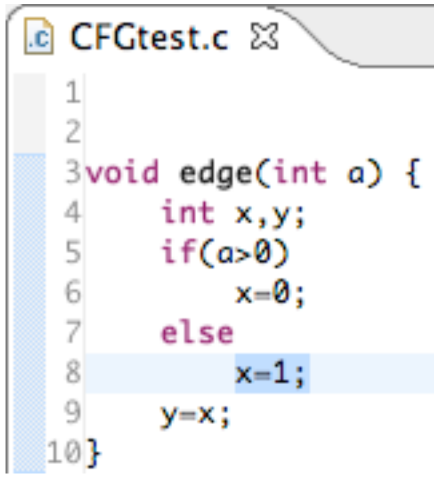
```
1
2
3 void edge(int a) {
4     int x,y;
5     if(a>0)
6         x=0;
7     else
8         x=1;
9     y=x;
10 }
```

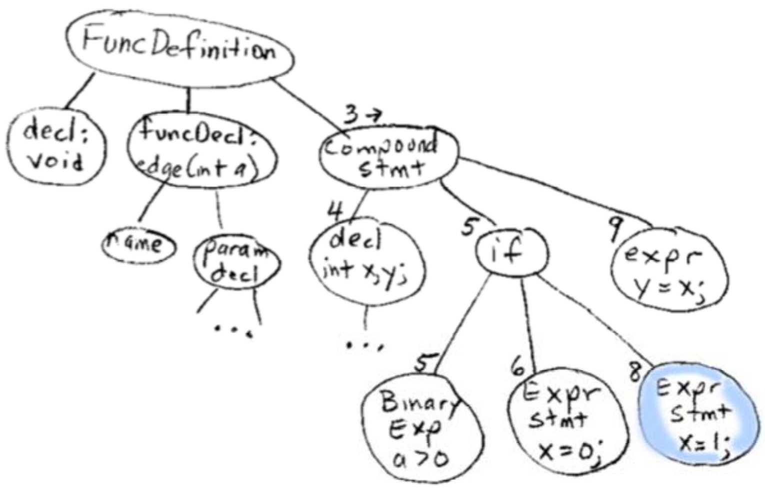
CFG

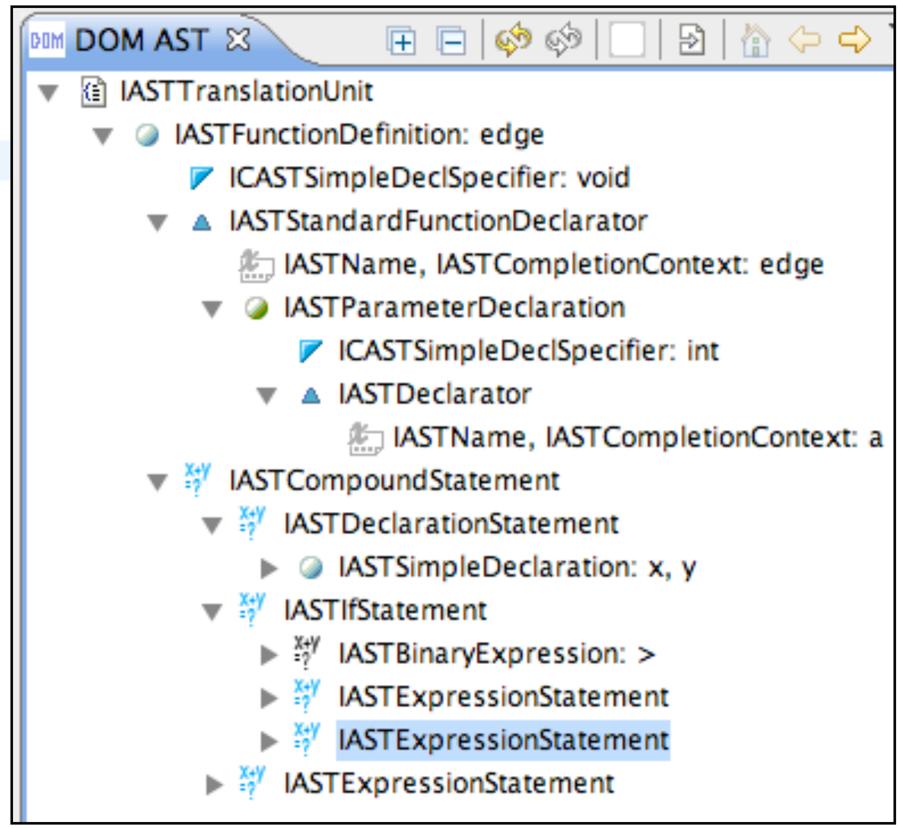


- To walk from line 8 to 9, in AST would have to walk backwards up tree to IASTIfStatement, then next to y=x expr on line 9
- Control Flow Graph (CFG) has direct edge from 8 to 9

AST Illustrated



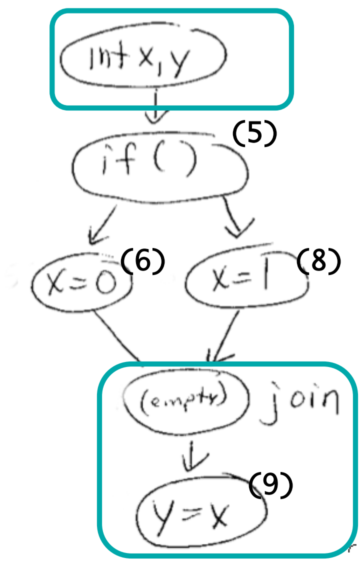


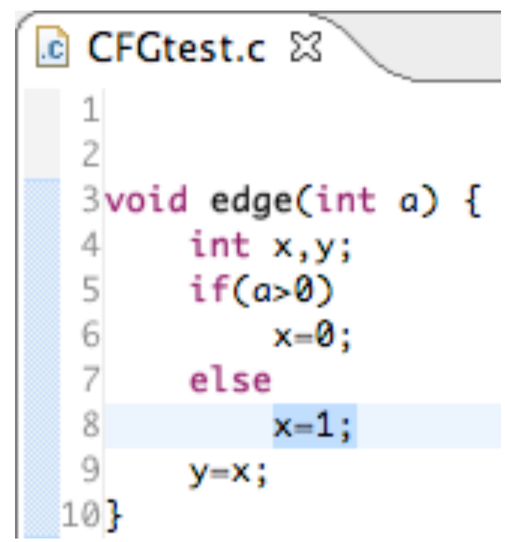


CFG illustrated

- 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)

```
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
```



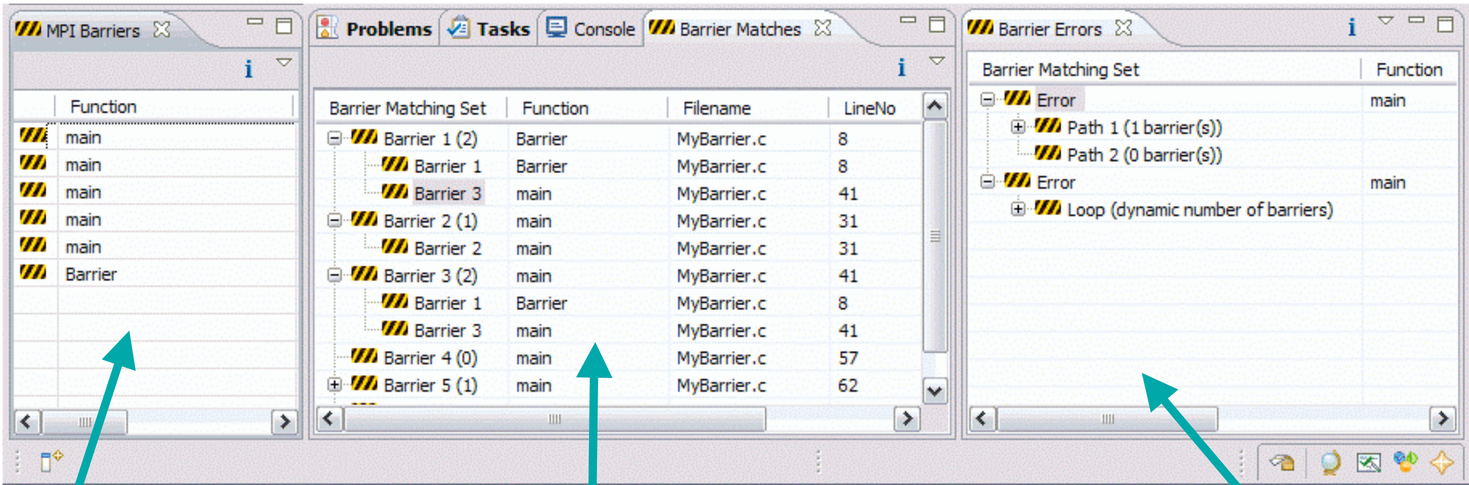


Basic Block

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

Use of CFG: MPI Barrier Analysis

Finds potential deadlocks in MPI code due to mismatched MPI_Barrier statements



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)

Static Analysis and related features
A peek at things to come

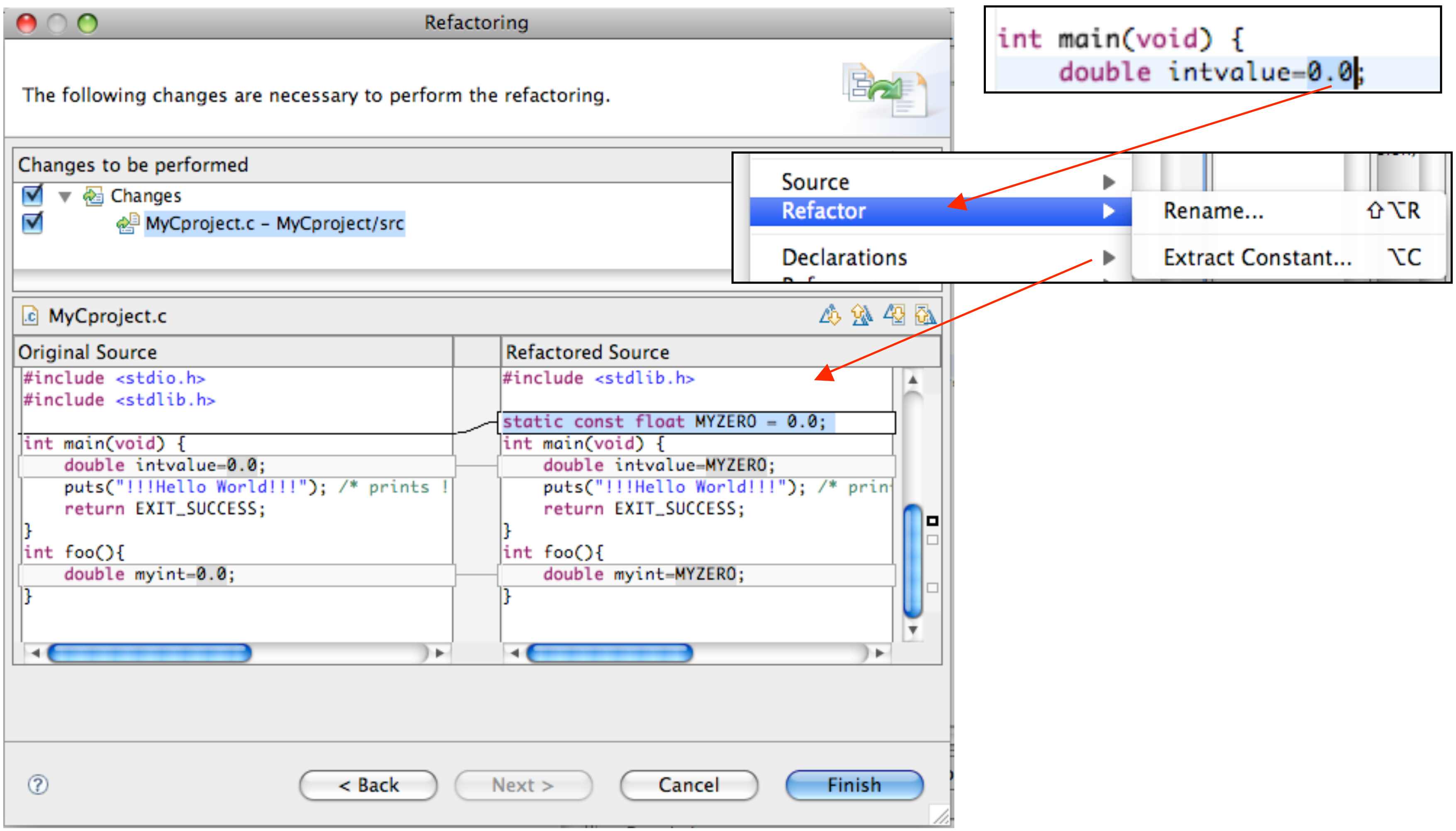
- Refactoring in CDT 5.0
  - New framework with AST Rewriter has potential for complex and useful refactorings
- PTP/PLDT integration of compiler information
- PTP/PLDT Source code instrumentation
  - Usable by Dynamic Instrumentation

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



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 xlC/xlC++, xlF (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

A Performance Analysis Framework For C/C++ and Fortran - Wyatt Spear (University of Oregon)
EclipseCon Short Talk Wednesday, 15:40,
10 minutes | Room 209/210 |

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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