Semantic-Driven Parallelization of Loops Operating on User-Defined Containers

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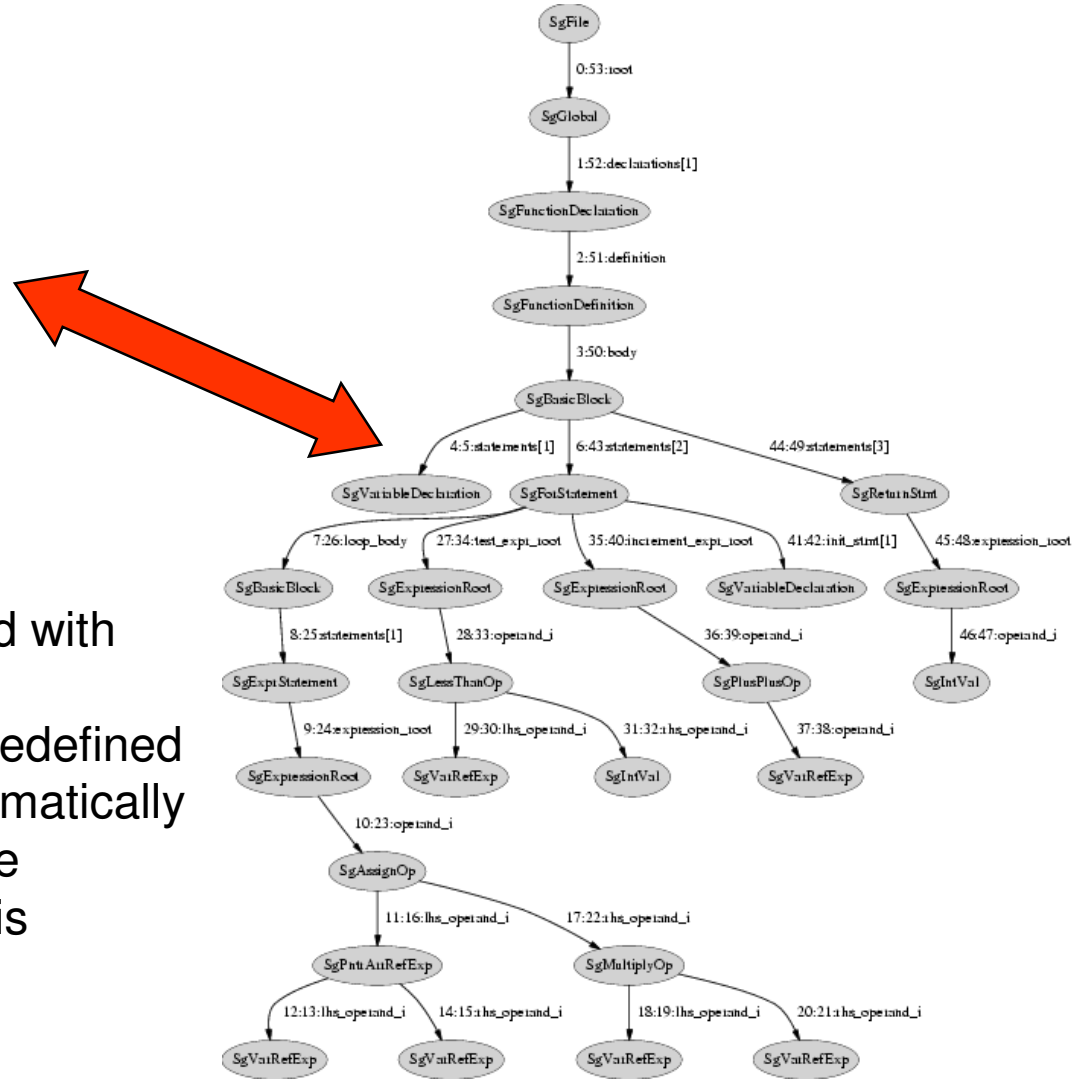
Outline of Talk

- **ROSE** Architecture
- AST Restructure Operations
- Building Domain Specific Languages from Libraries
- User-Defined Container Optimizations
  - Annotations
  - Analysis
- Example
- Related Work
- Conclusions

ROSE: Tool to Build Translators

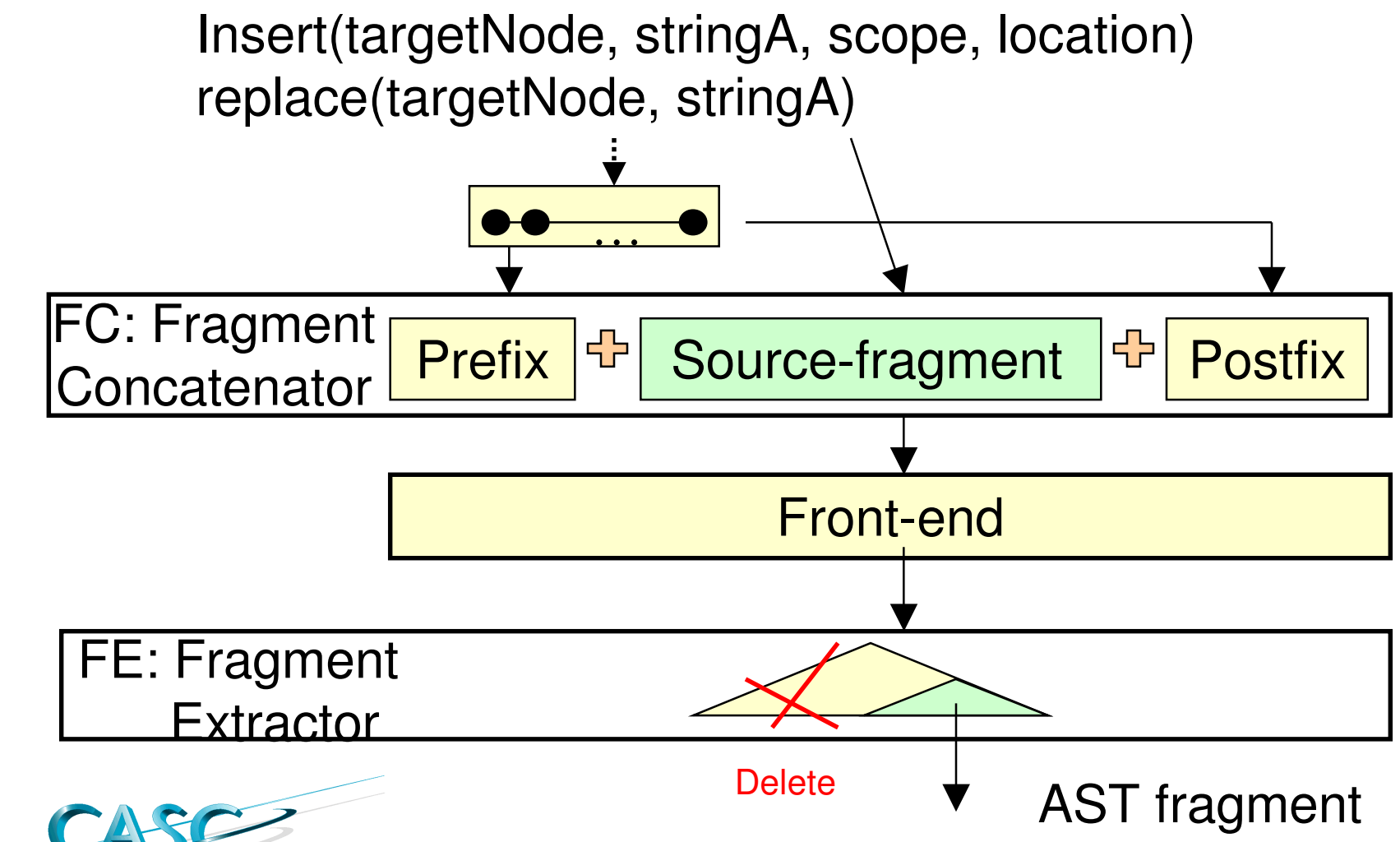
```
int main() {
  int a[10];

  for(int i=0;i<10;i++)
    a[i]=i*i;
  return 0;
}
```



- ROSE AST Features:
  - AST Query mechanisms
  - AST Rewrite mechanisms
  - Semantic actions associated with grammar rules
  - Abstract C++ grammar is predefined
  - Higher level grammars automatically generated from library source
  - Database for Global Analysis
  - Source code generation

String-Based Rewrite of AST



Domain Specific Languages

- Programming Languages exist to make programming productive
  - General purpose languages are *only generally* productive
  - Domain Specific Languages are *much more* productive
    - if used in their domain
    - if well designed
- Compilers have a role in automating the generation of Domain Specific Languages
- Observations:
  - Many Languages Support Abstractions
  - Libraries Define Abstractions
  - No Mechanism to Communicate *Semantics* of Abstractions

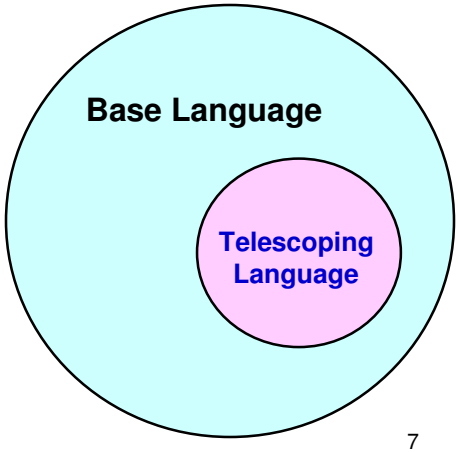
Constructive Definitions

- **Definition: Base Language is the language used to implement all libraries and the target applications that use them.**
- **Definition: Abstract Grammar is the set of product rules minus those specific to any syntax. I will use Abstract Grammar and Grammar interchangeably**
- **Definition: Domain Specific Grammar is the abstract grammar of the base language *plus* product rules specific to abstractions.**

- **Trick Question: What is a Domain Specific Language without a corresponding domain specific grammar?**

Domain Specific Languages

- Observations about this Domain Specific Grammar:
  - 1) We have defined a domain specific language
  - 2) Can't add syntax (no new keywords)
  - 3) Domain Specific Language build inside of base language
  - 4) Not a language Extension
    - Application and libraries are still written in the base language
  - 5) Parser front-end need not be modified (still use EDG)
  - 6) Process can be fully automated by processing the library's definition (found in it's header files)
- Language --> Grammar
  - Domain Specific Languages have a Domain Specific Grammar
  - Telescoping Languages have a *Telescoping Grammar*



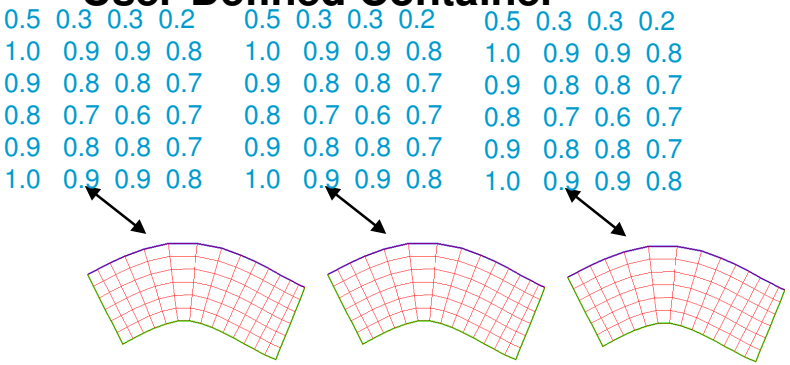
What Good is a Telescoping Grammar?

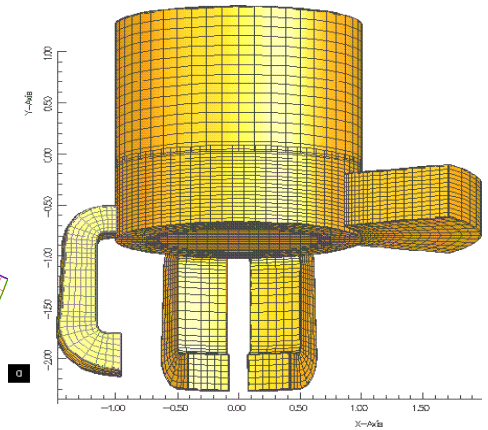
- **Can be automatically generated**
- **Don't extend the syntax of the base language**
- **Use same tools as base language**
- **Helps recognize abstractions at compile-time**
- **Simplifies transformations**
  - **High degree of resolution of language/library abstractions**
  - **Attach semantic actions to corresponding attribute grammars.**

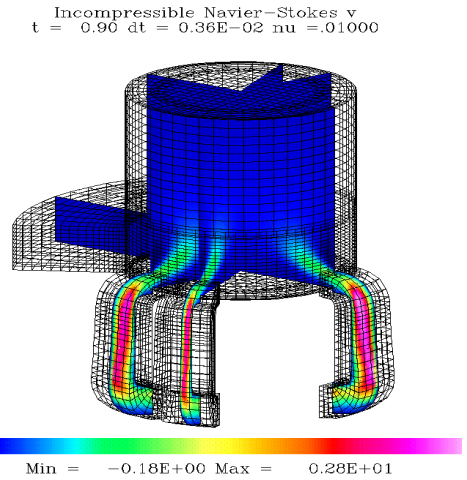
Equation: $u_{new} = u - \delta t \ ((u \bullet \nabla)u - \nu \Delta u)$

Code: uNew = u - dt*(u.convectiveDerivative() - nu*u.laplacian());

User-Defined Container







A++ Library: ~80 operators, **performance penalty: 3.6**

Simple Motivating Example

- Example Code:

```
Foo f; list mycontainer;
…
for (list::iterator i = mycontainer.begin(); i != mycontainer.end(); i++)
      f.foobar(*i);
```

- Can be parallel if:
  - *f.foobar* is safe (see safety analysis)
  - elements of *list* are not aliased
- After Transformation

```
Foo f; list mycontainer;
...
SupportingOmpContainer_list mycontainer2 (mycontainer);
#pragma omp parallel for
for (int i=0; i < mycontainer2.size(); i++)
      f.foobar(mycontainer2[i]);
```

Attached Semantic Action (Coco)

- Transformation (SgScopeStatement rule)

```
SgScopeStatement<unsigned int forNestingLevel>
  = SgForStatement
(.
   bool isOmpForQualified =
      ompTransUtil.isUserDefIteratorForStatement(astNode,forNestingLevel);
.)
"(" SgForInitStatementNT<forNestingLevel> SgExpressionRootNT
    SgExpressionRootNT SgBasicBlockNT<forNestingLevel+1>
")"
(.
    if (isOmpForQualified) {
       string iVarName = query.iteratorVariableName(astNode);
       string iContName = query.iteratorContainerName(astNode);
       string iContType = query.iteratorContainerType(astNode,iContName);
       string parTypeName = ompTransUtil.supportingParType(astNode,iContType);
       string parContName = ompTransUtil.uniqueVarName(astNode,iContName);
       string modifiedBodyString = ompTransUtil.derefToIndexBody(astNode,iVarName,iContName);
       string support = parTypeName+" "+parContName+"("+iContName+");\n";
       string beforeForStmt = "#pragma omp parallel for\n";
       string newForStmt = "for(int "+iVarName+"=0;"
                                     +iVarName+"<"+parContName+".size();"
                                     +iVarName+"++)"+modifiedBodyString;
       string subst.replace(astNode,support+beforeForStmt+newForStmt);
    }
.)
| ...
```

Evaluation of Inherited Attribute

Evaluation of Synthesized Attribute

Call AST Rewrite Mechanism

Transformation of Motivating Example

```
Foo f; list mycontainer;
...
SupportingOmpContainer_list mycontainer2 (mycontainer);
#pragma omp parallel for
for (int i=0; i < mycontainer2.size(); i++)
    f.foobar(mycontainer2[i]);
```

Annotation & Safety Analysis

- Summary of annotation Mechanism
  - Specification of qualified container classes (by type name)
  - Specification of functions side-effects
    - Function name
    - Names of modified global variables
    - Names of modified input parameters
- Summary of algorithm for safety analysis of parallelization
  - Check form of loop header:
    - *for (container::iterator p = l.begin(); p != l.end(); p++)*
  - Find modified variables in loop body
    - Check if locally declared or (*p)
  - Find function calls
    - Check if modifies global variables
    - Find modified arguments
      - Check if locally declared or (*p)

Related Work

- Large body of autoparallelizing Fortran compilers:
  - Dsystem, Fx, Vienna Fortran Compiler, Paradigm, Polaris, SUIF (F77, C, C++)
- Parallel STL like containers
  - STAPL (parallel STL library)
  - Parallel Standard Library
- Broadway Compiler (C compiler)
  - More sophisticated annotation language
- Telescoping Language work at RICE

Conclusions and Future Work

- Compile-Time optimization of a library abstraction
- Semantic-Driven parallelization of iterations over user-defined container similar to STL
- One possible approach to parallel STL?
- Demonstrates transformation specific annotation mechanism (not as powerful as that within the Broadway Compiler)
- Future Work:
  - More sophisticated annotation mechanism for function side-effects
    - automated support
    - combined with support in ROSE for global analysis
  - Specification of semantics
  - Less conservative, more precise analysis
  - Optimize performance of object-oriented scientific libraries