Towards an Abstraction-Friendly Programming Model for High Productivity and High Performance Computing

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344
Programming and high level abstractions

- Best practice in software engineering:
  - High level abstractions $\rightarrow$ high productivity
    - expose interface, hide implementation details
    - + code reuse, - software complexity
  - Standard or customized
    - C++ STL containers, algorithms, iterators, …
    - User-defined classes, functions, libraries, …
Semantics of abstractions: an unexploited gold mine

- Semantics: any standard or user-defined meanings
  - `STL::vector<T>` elements stored contiguously
  - `a->foo(x)` read only
  - `STL::Set<mytype>` order does not matter

- Not fully exploited by traditional programming models:
  - Traditional pmodel: write code and throw it to a vendor compiler
  - Low level intermediate representation (IR)
  - Info. hiding mechanism
  - Semantics: too many and too diverse

- Performance is inversely proportional to the level of abstractions used
An abstraction-friendly HPC programming model

- Goal: encourage the best programming practice while maintaining high or even better performance
- Solution:
  - User intervention
    - A specification: abstractions + semantics
    - User-defined optimizations: eliminate the dependence on compiler experts
  - An extensible source-to-source compiler framework
    - Recognize abstractions
    - Semantics-aware optimizations
    - Complement vendor compilers
ROSE: making compiler technology accessible

Vendor Compiler

C/C++/Fortran/OpenMP/UPC

EDG Front-end/Open Fortran Parser

EDG /Fortran-to-ROSE Connector

IR (AST)

Program Analysis

Program Transformation/Optimization

ROSE Unparser

ROSE Compiler Framework

Analyzed/Transformed/Optimized Source Code

http://www.roseCompiler.org

2009 Winner
ROSE intermediate representation (IR)

- ROSE IR = AST + symbol tables + CFG ...
- Preserves all source level details
  - Token stream, source comments
  - C preprocessor control structure
  - C++ templates
- Rich interface
  - AST traversal, query, creation, copy, symbol lookup
  - Generic analyses, transformations, optimizations
- Fully support
  - Abstraction recognition and semantic analysis
Case 1: a vector computation loop

- `std::vector <double> v1(SIZE);`
- `...`
- `double sum = 0.0;`
- `std::vector <double>::iterator iter;`
- `for (iter= v1.begin(); iter!=v1.end(); iter++)`
  `sum = sum + *iter;`

- `std::vector` : better productivity than arrays
  - Dynamic allocated, automatic de-allocation
  - Easier resizing, boundary-check

- Impede optimizations
  - E.g. Auto parallelization: primitive arrays
  - Non-canonical loop: for (integer-init; test; increment) block
  - Obscure element accesses: dereferencing an iterator
Semantics can help

- Semantics of `std::vector <T>`
  - An array-like container
  - Element access methods: `[ ]`, `at()`, `*iterator`

- Loop normalization:
  - loops using iterators → loops using integers
  - `*iterator → container.at(i)`

- Dependence analysis:
  - `element_access_method(i) → subscript i`

```cpp
double v1[SIZE];
double sum = 0.0;
int i;
#pragma omp parallel for reduction (sum)
for (i = 0; i < SIZE; i++)
    sum = sum + v1.at(i);
```
Case 2: a domain-specific tree traversal

- Compass: A ROSE-based tool for static code analysis
  - A checker: detect a violation of MISRA* Rule 5-0-18

```c++
void CompassAnalyses::PointerComparison::Traversal::visit(SgNode* node){
    // Check binary operation nodes
    SgBinaryOp* bin_op = isSgBinaryOp(node);
    if (bin_op) {
        // Check relational operations
        if (isSgGreaterThanOp(node) || isSgGreaterOrEqualOp(node) ||
            isSgLessThanOp(node) || isSgLessOrEqualOp(node)) {
            SgType* lhs_type = bin_op->get_lhs_operand()->get_type();
            SgType* rhs_type = bin_op->get_rhs_operand()->get_type();
            // Check operands of pointer types
            if (isSgPointerType(lhs_type) || isSgPointerType(rhs_type))
                // output a violation
                output->addOutput(bin_op);
        }
    }
}
```

Semantics can help

- Enabling parallelization
  - Read-only semantics
    - Information retrieval functions: `get_*()`
    - Type casting functions: `isSg*()`
  - Order independent side effects
    - `output->addOutput(bin_op)`
    - Suitable for using `omp critical`

- Enabling customized optimization
  - Order-independent tree traversal
  - Nodes stored in memory pools
  - Recursive tree traversal → Loop over memory pools
#pragma omp parallel for
for (i=0; i<pool_size; i++)
{
    SgBinaryOp* bin_op = isSgBinaryOp(MEMPOOL[i]);
    if (bin_op)
    {
        if (isSgGreaterThanOp(node) || isSgGreaterOrEqualOp(node) ||
            isSgLessThanOp(node) || isSgLessOrEqualOp(node))  {

            SgType* lhs_type = bin_op->get_lhs_operand()->get_type();
            SgType* rhs_type = bin_op->get_rhs_operand()->get_type();

            if (isSgPointerType(lhs_type) || isSgPointerType(rhs_type))
            {
                #pragma omp critical
                output->addOutput(bin_op);
            }
        }
    }
}
Implementation: a semantics-aware parallelizer

An abstraction/semantics specification file

class std::vector<MyType> {
    alias none; overlap none; //elements are alias-free and non-overlapping
    is_fixed_sized_array { //semantic-preserving functions as a fixed-sized array
        length(i) = {this.size()};
        element(i) = {this.operator[](i); this.at(i);};
    };
};

SgXXX* isSgXXX(SgNode*node)
{ modify none; } // read-only functions

SgNode* SgNode::get_XXX()
{ modify none; } // read-only member functions

void Compass::OutputObject::addOutput(SgNode* node){
    read {node};
    //order-independent side effects
    modify {Compass::OutputObject::outputList<order_independent>};
}
Preliminary results

Platform: Dell Precision T5400, 3.16GHz quad-core Xeon X5460 dual processor, 8GB
Compilers: ROSE OpenMP translator + Omni 1.6 Runtime + GCC 4.1.2
Related Work

- Kennedy, et.al. Telescoping languages: a system for automatic generation of domain languages, proceedings of IEEE, 2005
  - High-level scripting languages, library preprocessing

- Gregor, Schupp, STLlint: lifting static checking from languages to libraries, Softw. Pract. Exper. 2006
  - Static analysis of error use of abstractions
  - C++ syntax for specification

- Kulkarni, Pingali, et.al. Optimistic parallelism requires abstractions. PLDI 2007
  - Abstraction: un-ordered set;
  - Semantics: commutativity, inverse
Conclusions and future work

- ROSE-based abstraction-friendly programming model:
  - High productivity (use of abstractions) + high performance (semantics-aware optimizations)
  - Source-to-source: complement vendor compilers
  - User intervention: less depend on compiler experts

- Future work
  - Better specification files
  - Classify and formalize more abstractions/semantics
  - Operations on semantics to generate new semantics?
Questions?