Optimization of X10 Programs with ROSE Compiler Infrastructure

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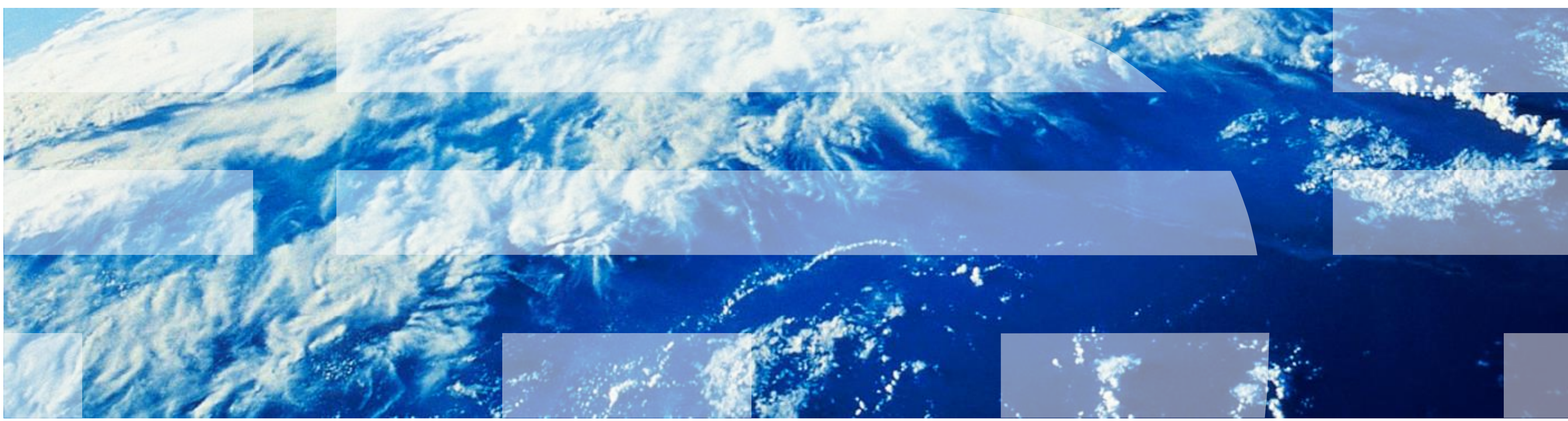

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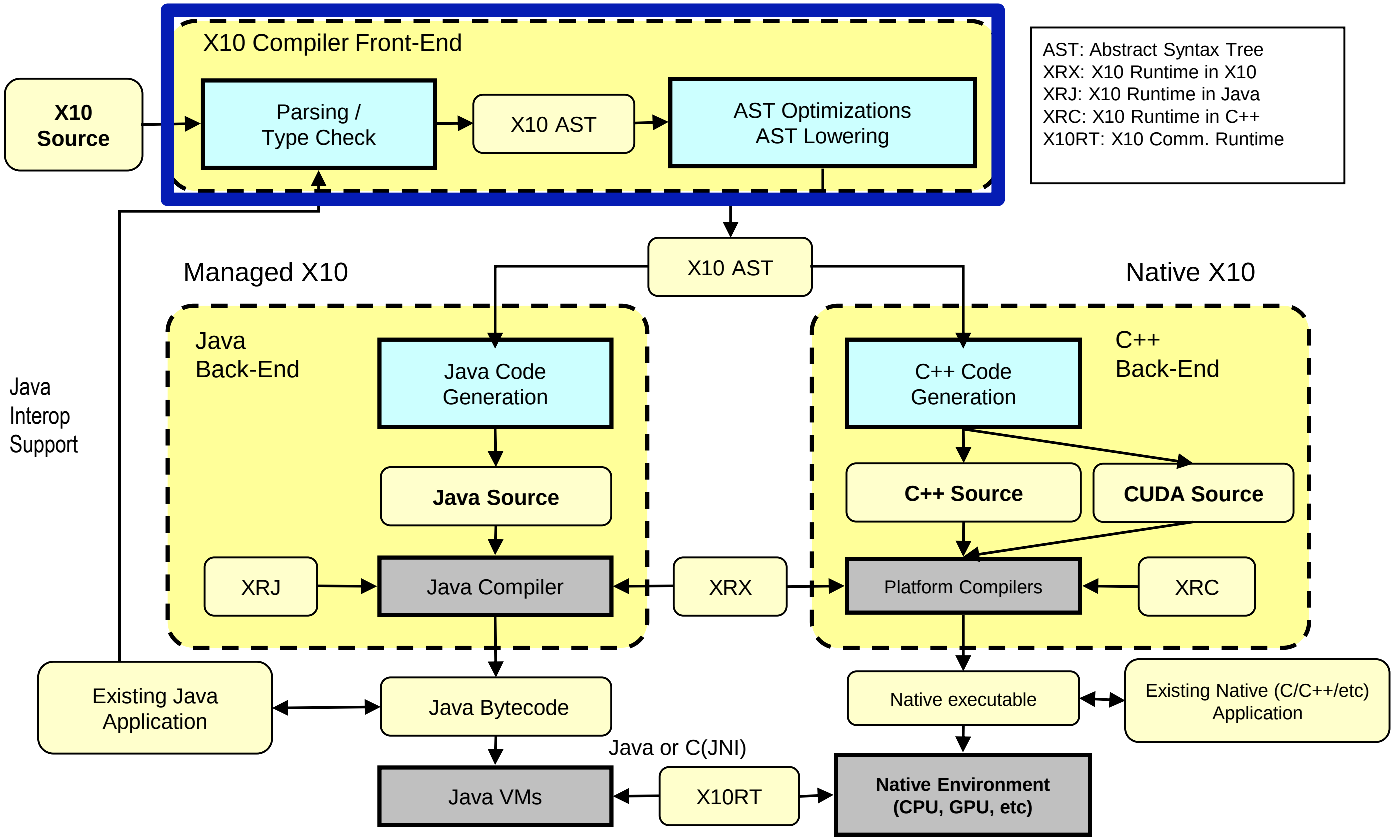
X10 compiler

- Front-end executes type checking and AST optimizations
- Back-end generates either C++ or Java source programs
  - Vendor compilers are available for compiling C++ or Java programs



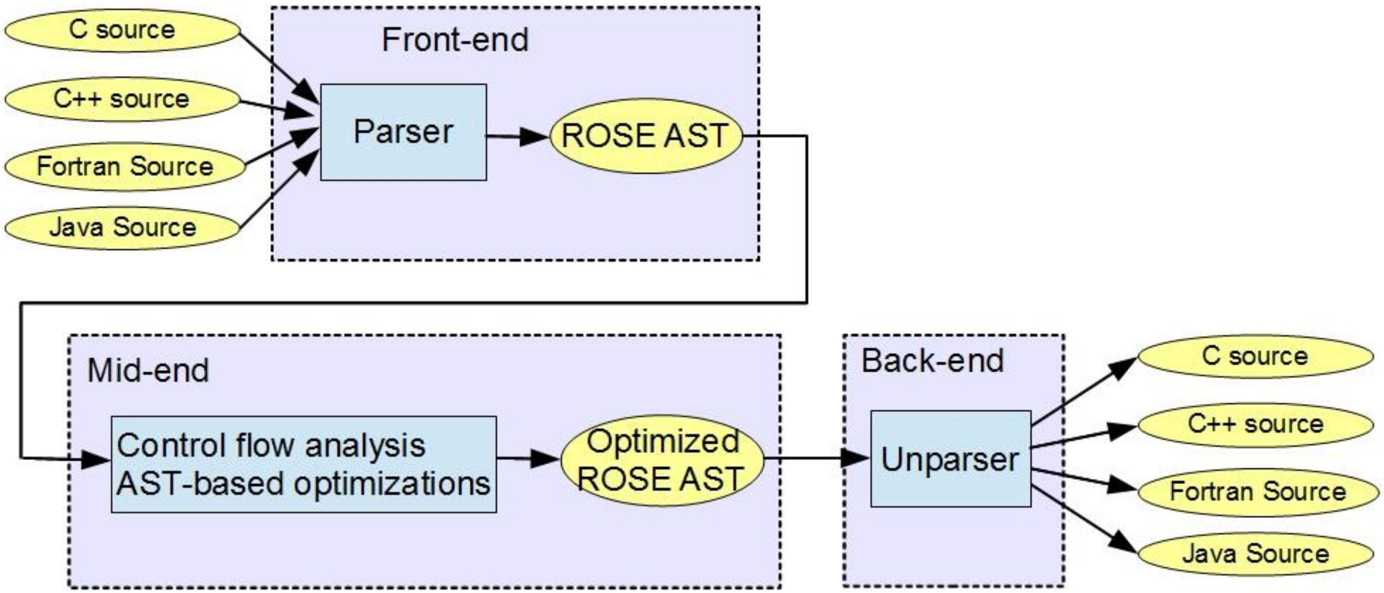
Our goal

- To apply standard optimizations at the front-end and get better performance

- We want to use another compiler that already has the rich set of optimization tools
  - Implementing optimization tools from scratch is a high cost

ROSE compiler infrastructure

- Source-to-source translator
  - Developed in the LLNL
  - Support C/C++/Fortran/Java, MPI/OpenMP, etc.
    - High-level IR optimizations
      - The same level of abstraction as source programs
    - AST consists of both language-common and language-specific IRs
    - Currently there is no mechanism to unify language-specific IRs
      - ROSE unparses back to the same language as the original input language



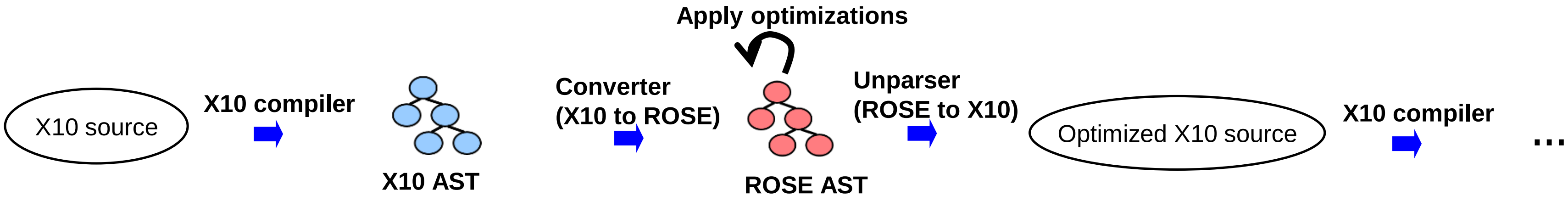
How to use ROSE's source-to-source translation

- Users can invoke basic functions such as *frontend()*, *backend()*, etc.
- Also, users need to choose the ordering of ROSE optimizations by invoking their APIs
- Process inherited/synthesized attributes in AST

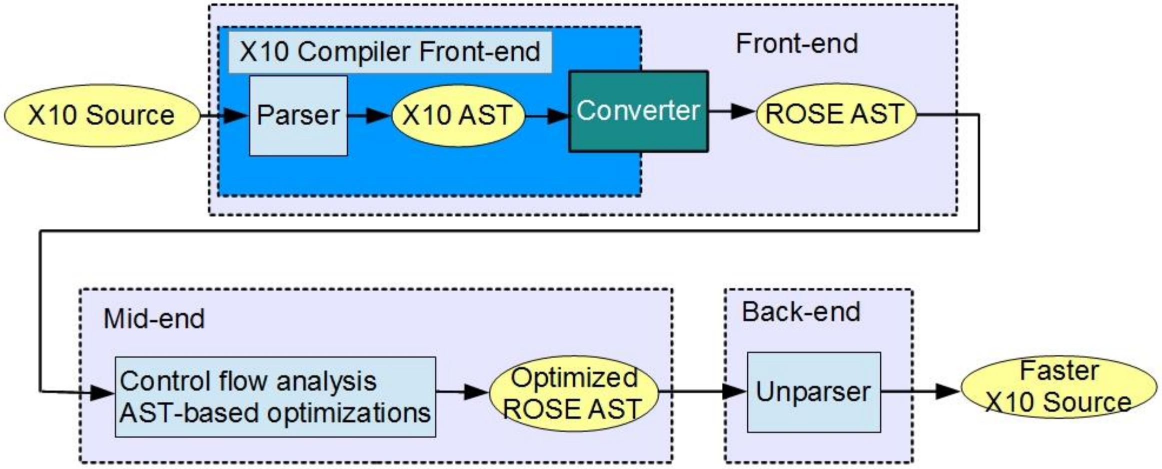
```
int main (int argc, char** argv )
{
        SgProject* sageProject = frontend(…);     // starts parsing input source files

        PRE::partialRedundancyElimination(sageProject);     // applies PRE

        ConstantFolding::constantFoldingOptimization(sageProject);    // applies constant folding

        SgFunctionCallExp* functionCall = …
        bool isSucess = doInline(functionCall, true);    // executes inlining for the target function

        generateDOT(*sageProject);            // generates dot file to check generated AST

        return backend(sageProject);          // unparses to source files from the generated AST
}
```

Combining X10 compiler and ROSE

- To enrich optimizations in X10 front-end, we reuse the ROSE optimizations
  - To create a ROSE AST, we convert once-created X10 AST by traversing it



  - Extended ROSE front-end, mid-end, and back-end
    - Reused existing ROSE AST nodes as many as possible to represent X10 code
    - Applied small changes to ROSE optimizations
    - Introduced X10 unparser based on Java unparser



Front-end

- Defined new ROSE AST nodes for representing APGAS constructs
  - *Finish, async, at, etc.*
  - Reused the AST nodes common with Java
  - Reused the AST nodes common with C++ for closure, struct, etc.

- Valid AST conversion was necessary to pass ROSE semantic analyses
  - Constructed type hierarchies also in ROSE

- Only the library classes that are directly referenced in input classes are parsed

Preparation for the mid-end

- Type conversion was necessary to use ROSE optimizations
  - X10 uses object types to represent arithmetic types, while ROSE uses C++ types inside each corresponding ROSE AST nodes
    - *x10.lang.Long* ➔ *long*
    - *x10.lang.Rail[Long]* ➔ *long[]*
  - They are all final classes

- Also replaced the method invocations of converted types to the one of static helper functions, which has no method body
  - *Rail.size()* ➔ X10_ROSE_Helper_Rail.size()

- In the unparser, the converted types and helper functions changed back to X10 data types

Mid-end

- Loop optimizations worked as-is
  - ROSE's mid-end mainly supports C or C++
  - AST representation for loop blocks does not change among X10 and C/C++

- Some optimizations were needed to change its strategy to align with X10
  - ROSE's default inliner uses *goto* statements for return-statements. Instead, we changed not to use goto.

```
def cond(a:Long):Boolean {
      return a < 8;
}

public static def main(args:Rail[String]) {
   val o = new InliningExample();
   var i:Long = 0;
   for (; o.cond(i) ; ++i) {
      // loop body
   }
}
```

```
val o = ...;
var i:long = 0L;
for (; true; ++i) {
   var rose_temp__4:boolean;
   val this__1 = o;
   var a__2:long = i;
   rose_temp__4 = a__2 < 8L;
   goto rose_inline_end__3__1;
   rose_inline_end__3__1:
   var rose__temp:boolean = (rose_temp__4) as boolean;
   if (!(rose__temp))
      break;
   else {
     // loop body
   }
}
```

An example of using the mid-end API

```
SgJavaClassDeclarationList *class_list = file -> get_class_list();
vector<SgClassDeclaration *> &type_list = class_list -> get_java_class_list();
for (int i = 0; i < type_list.size(); i++) {
    SgClassDeclaration *class_declaration = type_list[i];
    SgClassDefinition *class_definition = class_declaration->get_definition();
    AstSgNodeListAttribute *attribute = (AstSgNodeListAttribute *) class_definition -> getAttribute("class_members");
    for (int j = 0; j < attribute->size(); ++j) {
        SgFunctionDefinition *method_definition = isSgFunctionDefinition(attribute -> getNode(j));
                :
        SgBasicBlock *stmts = method_definition->get_body();
        SgStatementPtrList &stmts2 = stmts->get_statements();
        for (SgStatementPtrList::iterator m = stmts2.begin(); m != stmts2.end(); ++m) {
            if (isSgBasicBlock(*m)) {
                SgBasicBlock *bb = (SgBasicBlock *)*m;
                SgStatementPtrList &stmts3 = bb->get_statements();
                for (SgStatementPtrList::iterator l = stmts3.begin(); l != stmts3.end(); ++l) {
                    if (isSgForStatement(*l)) {
                        SageInterface::loopUnrolling((SgForStatement *)*l, (size_t)4);
                                :
                    }
                }
            }
        }
    }
}
```

Available as OSS

- ROSE side support on Github
  - https://github.com/rose-compiler/edg4x-rose/tree/master/src/frontend/X10_ROSE_Connection

- X10 side support in X10 sourceforge
  - http://sourceforge.net/p/x10/code/HEAD/tree/trunk/x10.compiler/src/x10rose

- ROSE installation became much easier by using our installation scripts on the Github
  – A week for trial and error ➔ a few hours, just waiting!

- We confirmed that our system works on
  – CentOS 6.5
  – Red Hat Enterprise Linux 6.1
  – Red Hat Enterprise Linux 5.11

Benchmarks

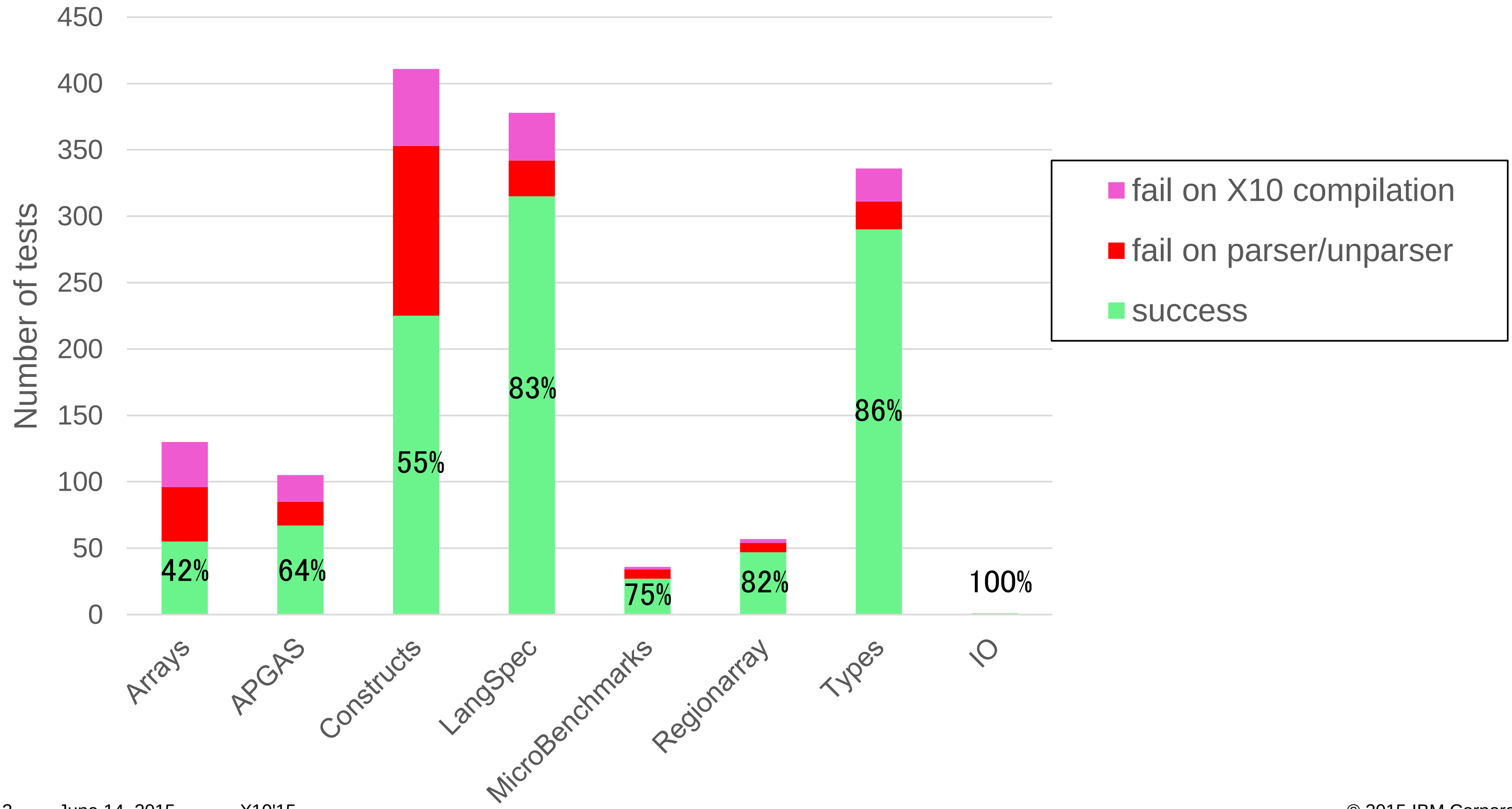
- X10 tests in http://sourceforge.net/p/x10/code/HEAD/tree/trunk/x10.tests/tests/
  - More than 2,000 files
  - To see the coverage of current parser and unparser

- Proxy applications
  - HPC applications that are developed in the research projects of U.S. Department of Energy（DoE）
  - Implemented in C/C++, Fortran with MPI, OpenMP, etc.
    - LULESH：Lagrangian hydrodynamics
    - MCCK: neutronics, investigating the communication cost
    - CoMD: molecular dynamics
  - We have X10 port of these proxy applications
    - See http://sourceforge.net/p/x10/code/HEAD/tree/applications/trunk
    - Also we have a publication:

Porting MPI based HPC Applications to X10,
Hiroki Murata, Michihiro Horie, Koichi Shirahata, Jun Doi, Hideki Tai, Mikio Takeuchi, and Kiyokuni Kawachiya.
In *Proceedings of the 2014 X10 Workshop (X10 '14), co-located with PLDI '14*, 7 pages (2014/06/12).

Coverage on parser and unparser (without optimizations)

- Currently 73% on average
  - Success : unparsed X10 code was able to compile without an error



Applying ROSE optimizations to LULESH

- X10 port of LULESH revision 28354

- Currently, we tried to apply basic optimizations
  - Loop unrolling
  - Method inlining
  - Stack allocation
  - Loop Invariant Hoisting

- Estimated how much execution performance can improve by using ROSE optimizations

Loop unrolling

- ROSE provides an API:
  - *loopUnrolling(SgForStatement *loop, size_t factor)*
- We found 6 targets in LULESH

Before optimization

```
protected def calcForceForNodes(domain : Domain) {
    for (var i : Long = 0; i <= (domain.numNode-1); ++i) {
        domain.fx(i) = 0.0;
        domain.fy(i) = 0.0;
        domain.fz(i) = 0.0;
    }
        :
}
```

After optimization

```
protected def calcForceForNodes(domain : Domain) {
    var i_nom_5 : long;
    val _lu_fringe_6 = domain.numNode - 1 -
                        ((domain.numNode == 0 ? domain.numNode :
                         (domain.numNode + 1)) % 4 == 0 ? 0 : 4);
    for (i_nom_5 = 0L; i_nom_5 <= _lu_fringe_6; i_nom_5 += 4) {
        domain.fx(i_nom_5) = 0.0;
        domain.fy(i_nom_5) = 0.0;
        domain.fz(i_nom_5) = 0.0;
        domain.fx(i_nom_5 + 1) = 0.0;
        domain.fy(i_nom_5 + 1) = 0.0;
        domain.fz(i_nom_5 + 1) = 0.0;
        domain.fx(i_nom_5 + 2) = 0.0;
        domain.fy(i_nom_5 + 2) = 0.0;
        domain.fz(i_nom_5 + 2) = 0.0;
        domain.fx(i_nom_5 + 3) = 0.0;
        domain.fy(i_nom_5 + 3) = 0.0;
        domain.fz(i_nom_5 + 3) = 0.0;
    }
    for (; i_nom_5 <= (domain.numNode - 1L); i_nom_5 += 1) {
        domain.fx(i_nom_5) = 0.0;
        domain.fy(i_nom_5) = 0.0;
        domain.fz(i_nom_5) = 0.0;
    }
        :
}
```

Inlining (@*Inline*)

- ROSE provides an API:
  - *doInline(SgFunctionCallExp* funcall, bool allowRecursion)*
- We found 16 targets in LULESH

Before optimization

```
def calcVolumeForceForElems(domain : Domain)  {
    val hgcoef = domain.hgcoef;
    val determ = new Rail[double](numElem);
        :
    calcHourglassControlForElems(domain,determ,hgcoef);
}

def calcHourglassControlForElems(domain : Domain,
                        determ : Rail[double], hgcoef : double)  {
    val numElem = domain.numElem;
    val numElem8 = numElem * 8L;
    if (dvdx == null) {
        dvdx = new Rail[double](numElem8);
        dvdy = new Rail[double](numElem8);
        dvdz = new Rail[double](numElem8);
           :
    }
        :
}
```

After optimization

```
def calcVolumeForceForElems(domain : Domain)  {
    val hgcoef = domain.hgcoef;
    val determ = new Rail[double](numElem);
        :
    {
    val numElem = domain.numElem;
    val numElem8 = numElem * 8L;
    if (dvdx == null) {
        dvdx = new Rail[double](numElem8);
        dvdy = new Rail[double](numElem8);
        dvdz = new Rail[double](numElem8);
           :
    }
        :
    }
}

def calcHourglassControlForElems(domain : Domain,
                        determ : Rail[double], hgcoef : double)  {
    val numElem = domain.numElem;
    val numElem8 = numElem * 8L;
    if (dvdx == null) {
        dvdx = new Rail[double](numElem8);
        dvdy = new Rail[double](numElem8);
        dvdz = new Rail[double](numElem8);
           :
    }
        :
```

Stack allocation

- ROSE does not provide optimization API for applying stack allocation
- Instead, we would like to attach *@StackAllocate* of X10 automatically
  - We check whether attaching *@StackAllocate* is valid
    - Reusing pointer analysis that ROSE provides
- In LULESH, 26 variables were found to be stack-allocatable
  - These variables were all *Rail* objects, and they were declared within the main loop of calculation

Before optimization

```
val x1 = new Rail[double](8L);
```

After optimization

```
@StackAllocate val x1 = @StackAllocate new Rail[double](8L);
```

Loop invariant hoisting

- Althogugh ROSE does not provide optimization API, we can realize by using primitive ROSE APIs
  - *insertStatement()*
  - *removeStatement()*
- We found 1 target in LULESH
- To decide whether hoisting loop invariants is valid or not, we can use ROSE's analyses:
  - Use-Definition analysis
  - Liveness analysis

Before optimization

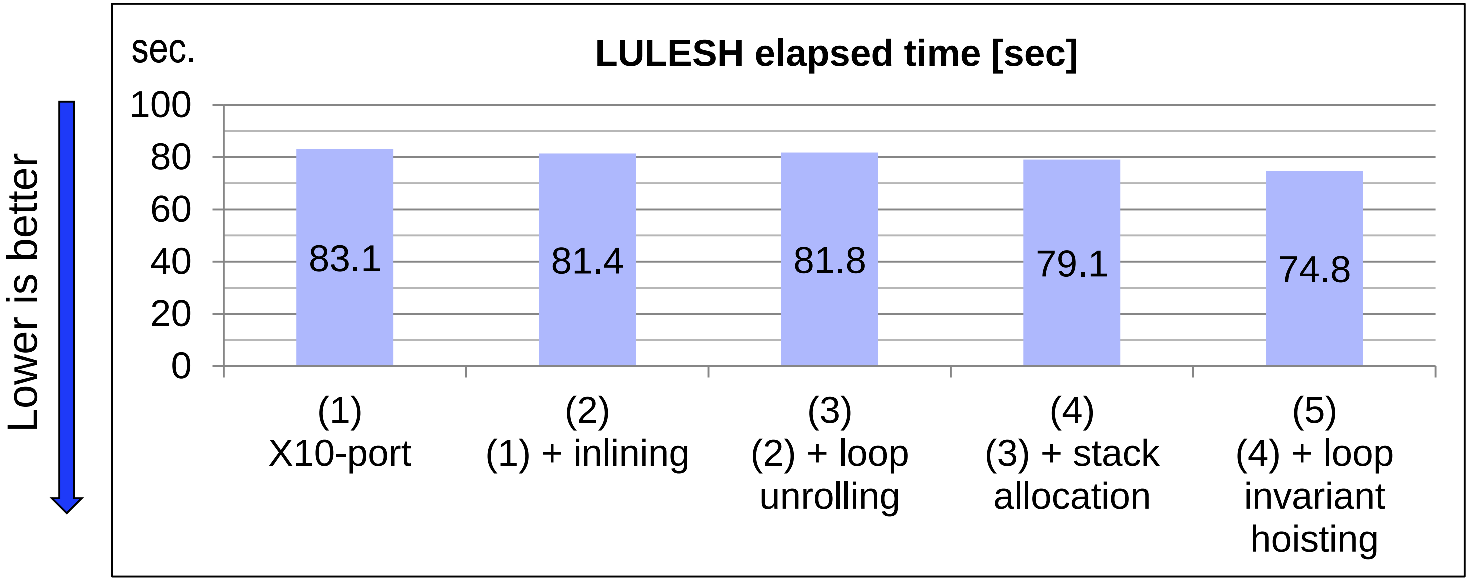
```
    :
val numElem = domain.numElem;
val numElem8 = numElem * 8L;
while ((domain.time < domain.stopTime) &&
                 (domain.cycle < Lulesh.this.opts.its)) {
   dvdx = new Rail[double](numElem8);
   dvdy = new Rail[double](numElem8);
   dvdz = new Rail[double](numElem8);
          :
}
```

After optimization

```
val numElem = domain.numElem;
val numElem8 = numElem * 8L;
dvdx = new Rail[double](numElem8);
dvdy = new Rail[double](numElem8);
dvdz = new Rail[double](numElem8);
while ((domain.time < domain.stopTime) &&
                 (domain.cycle < Lulesh.this.opts.its)) {
      :
}
```

Execution performance in a single place and single process

- By incrementally applying optimizations, we observed a 10% performance improvement
  - This is also a 2% improvement compared to the C++ original



P7IH: (32 Power7 cores 3.84 GHz, 128 GB memory, peak: 982 Gflops) * 1 nodes
Red Hat Enterprise Linux Server release 6.4 (Santiago)
X10 2.5.1 native backend (compile option: -X10rt pami –O –NO_CHECKS)
C/C++ compiler : XL C V12.1 (compile option: -O3 -qinline)

Conclusion

- Applying standard optimizations at the front-end and getting better performance
  - We want to use a different compiler that already has the rich set of optimization tools
  - To implement optimization tools from scratch is a high cost

- We estimated the execution performance of LULESH in a single place and single process
  - Improved by 10% compared to the X10-port

- Future works
  - We have to extend ROSE because it is not APGAS-oriented
  - Also, we should support APGAS-specific optimizations in ROSE