Framework for Separation of Concerns Between Application Requirements and System Requirements

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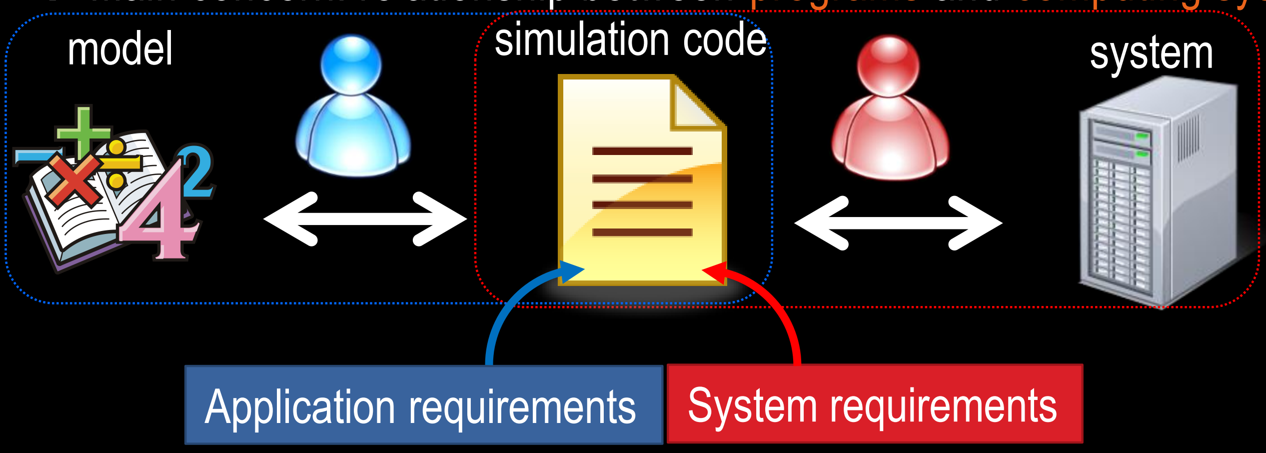
BACKGROUND

- HPC programming = team work of programmers with different concerns
  - **Application developers** (= computational scientists)
    - write a program so as to get correct results
    - → Main concern: relationship between simulation models and programs.
  - **Performance tuners** (= computer scientists/engineers)
    - write a program so as to get high performance
    - → Main concern: relationship between programs and computing systems.



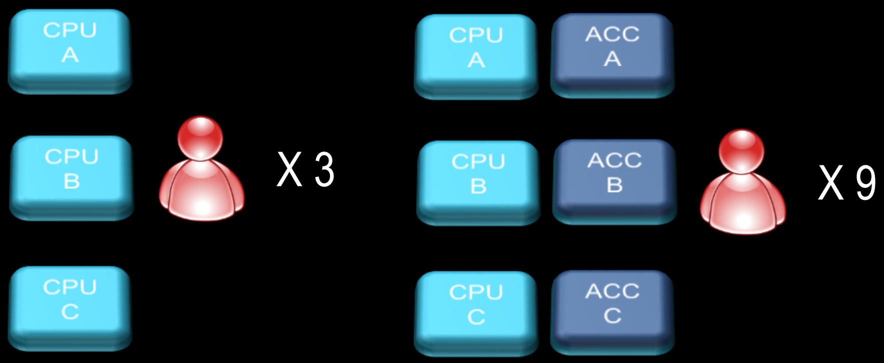
WHAT'S THE PROBLEM?

- **System complexity is increasing**
  - Need to consider both parallelism and heterogeneity
  - Also need to manage deeper memory/storage hierarchy, power, fault tolerance, …

  System-aware performance optimizations are needed for high performance

  → An HPC application is specialized for a particular system

- **System diversity is also increasing**
  - Different processor combinations
  - Different system scales
  - Different interconnect network topologies
  - Different system operation policies



What can we do to achieve high performance on various systems?

XEVOLVER PROJECT

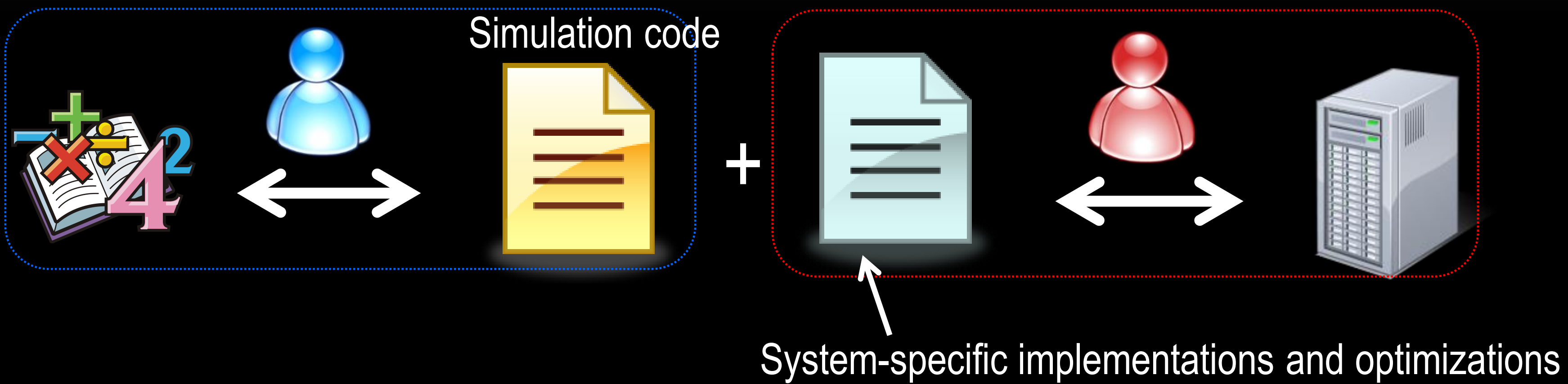
How can we help legacy application migration?

It is difficult because system-specific optimizations are tightly interwoven with application codes.

- **System-aware Code Optimizations in Existing Applications**
  - Egawa@Tohoku-U
    - The code patterns should be refactored because they potentially (likely) degrade the performance portability across different systems.
- **System-aware Code Optimizations for “PostPeta” Systems**
  - Suda@U-Tokyo and Takahashi@U-Tsukuba
    - New optimization techniques and algorithms for future systems
      - Communication-avoiding algorithms, etc (Suda)
      - Highly-optimized implementations for GPU clusters, etc (Takahashi).
- **Representation of System-awareness**
  - Takizawa@Tohoku-U (PI)
    - How to separate system-awareness from application codes

OUR GOAL = APPROPRIATE DIVISION OF LABOR

- **Separation of system-awareness from application programs**



There are many approaches to abstraction of system-awareness

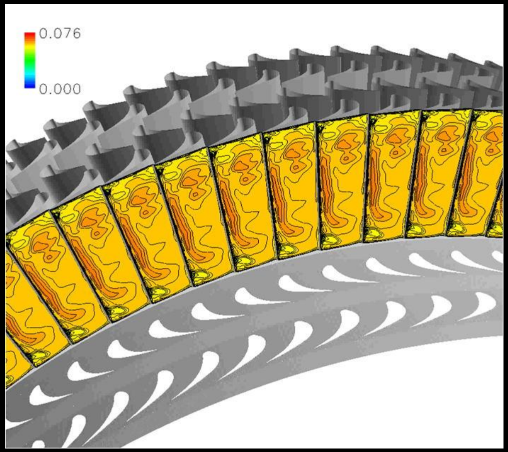
- System-aware implementations with a common interface = Numerical libraries
- Standardized programming models and languages = MPI, OpenMP, OpenACC …

In reality, we still need to manually modify a code for high performance.

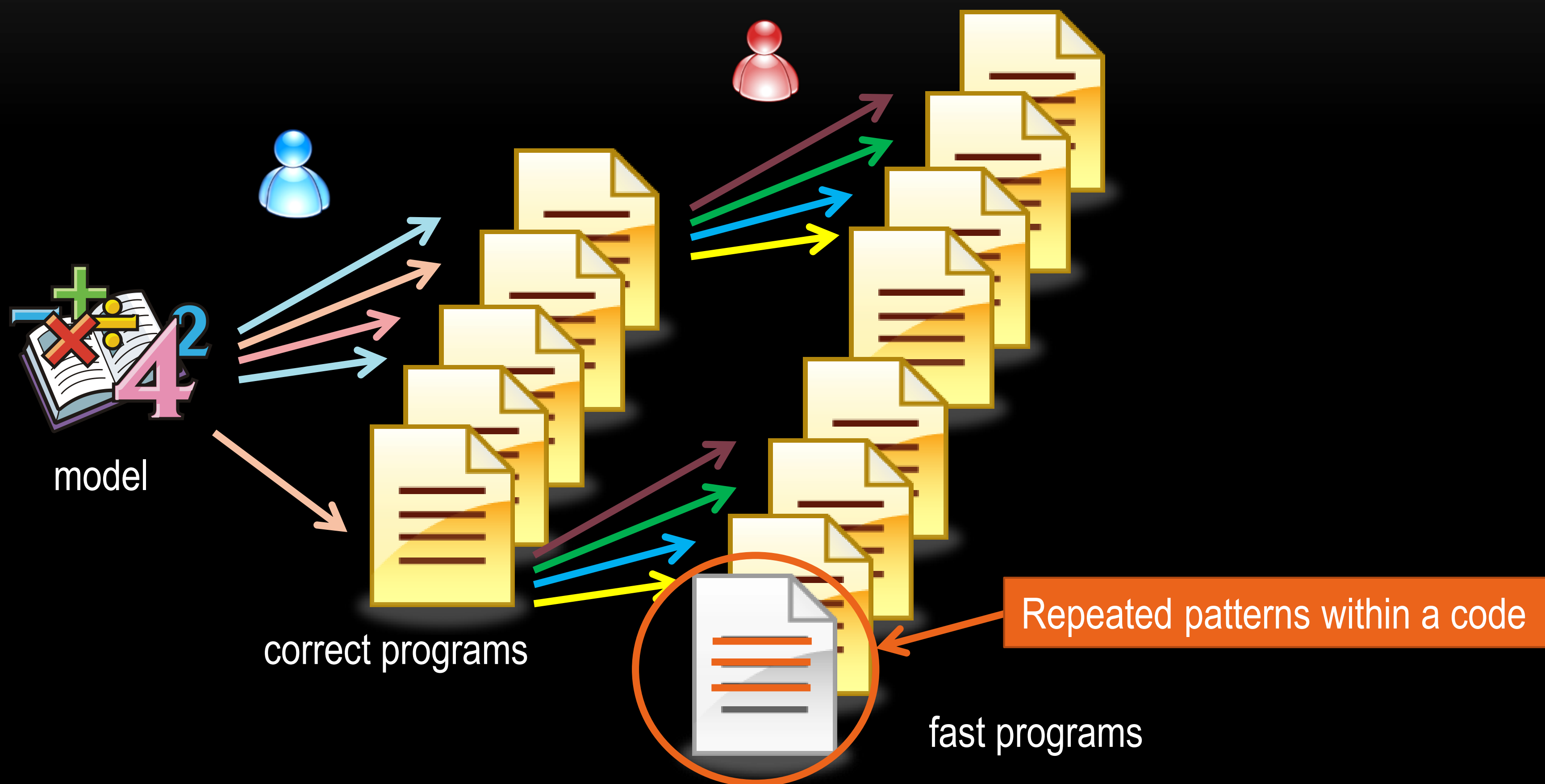
→ How can we abstract such code modifications?

A MOTIVATING EXAMPLE

- Numerical Turbine (NT)
  - Developed by Prof. Yamamoto (Tohoku U.)
    - 44 loop nests of the code have the same loop structure.
      - The loop nests are optimized for NEC SX-9 system.
      - OpenACC compiler cannot vectorize the loop nests for GPUs.
    - Because of the same loop structure, all the loop nests need to be modified in the same way for GPUs.



REPETITIVE PATTERNS IN CODE MODIFICATIONS

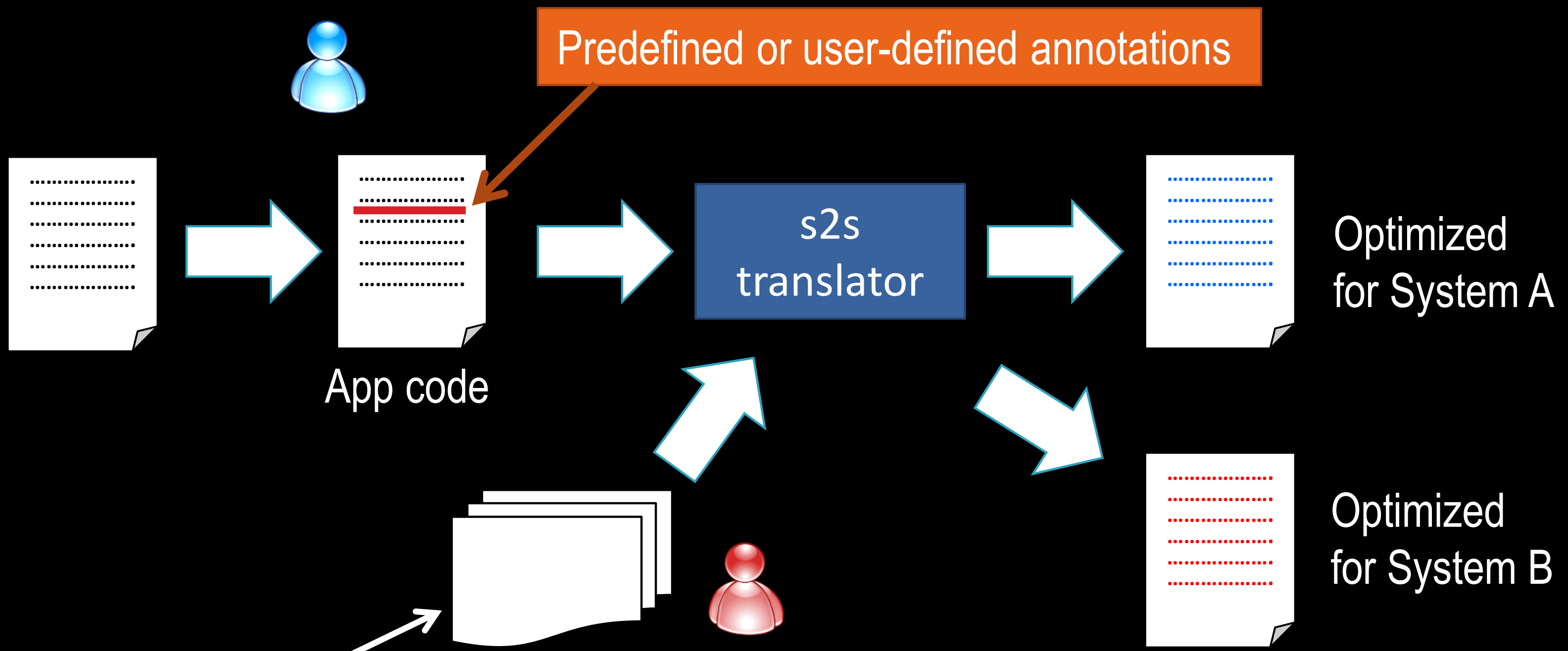


Manual code modifications can be replaced with a smaller number of mechanical code transformations.

XEVOLVER FRAMEWORK

Various transformations are required for replacing arbitrary code modifications.
= cannot be expressed by combining predefined transformations.

→ Xevolver : a framework for custom code transformations

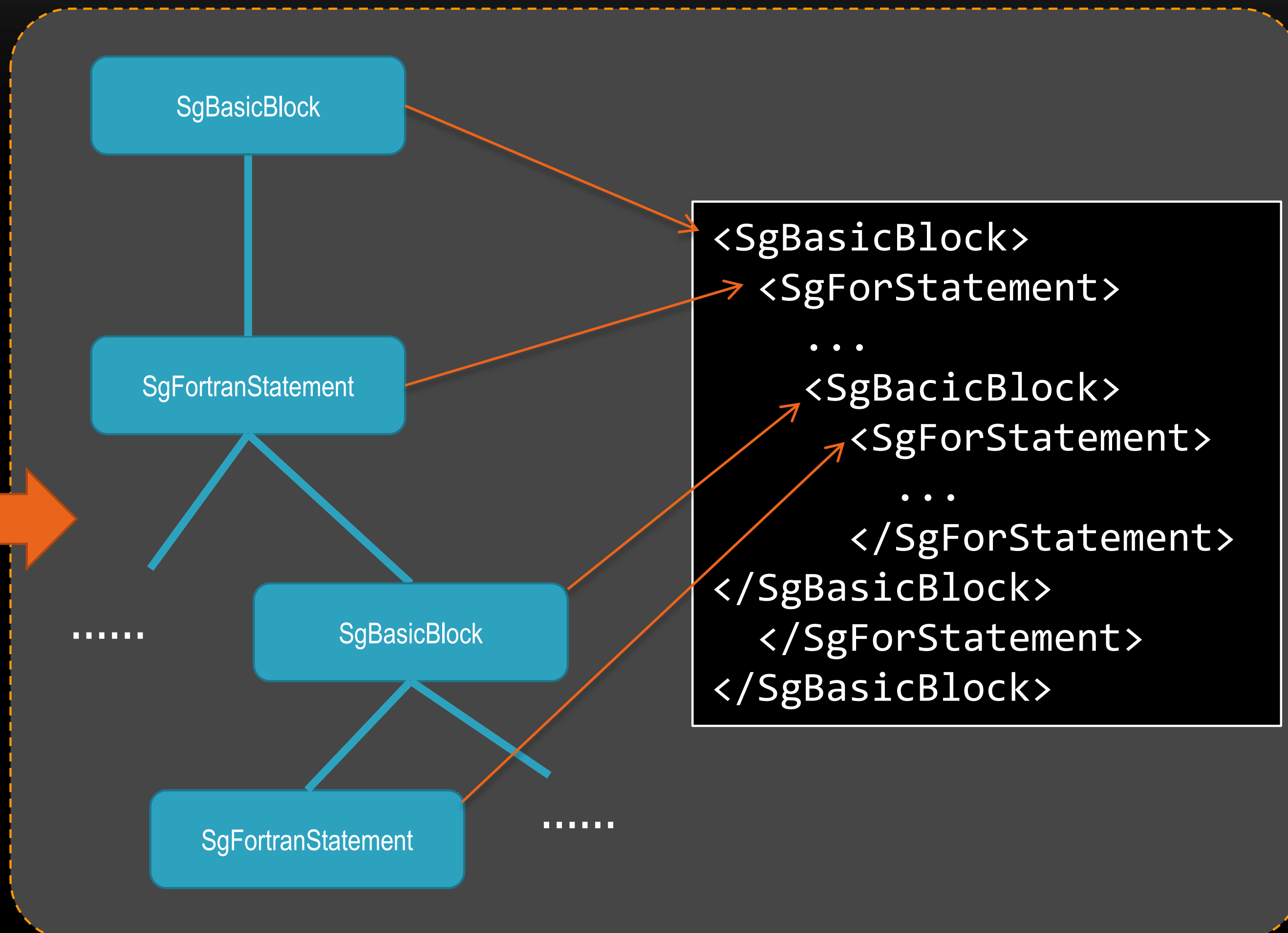


Translation rules

- Define the code transformation of each annotation
- Different systems can use different rules
- Users can define their own code transformations

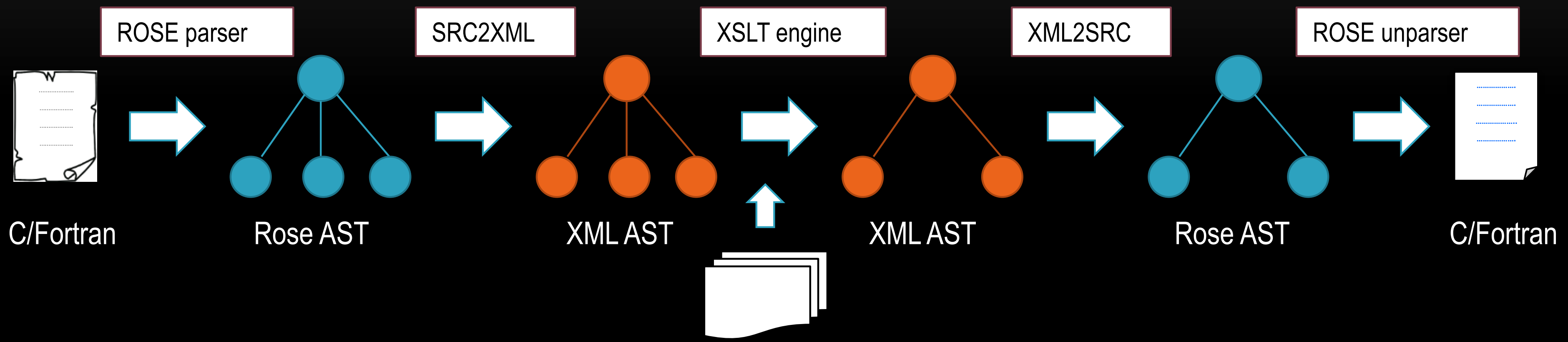
XML AST

```
{
  for(i=0;i<N;i++){
    for(j=0;j<M;j++){
      ...
    }
  }
}
```



An AST is a data tree and naturally represented as an XML document.

PROOF-OF-CONCEPT IMPLEMENTATION



- On top of the ROSE compiler infrastructure
  - ✓ **Interconversion between ROSE ASTs and XML ASTs.**
- **XSLT** is employed to describe translation rules
  - ✓ XSLT rules can be written in a text format.
  - ✓ In the framework, other XML-related technologies are also available for translation, analysis, and visualization of ASTs.
- Apache Xerces and Xalan libraries are used for XML data representation and translation.

CUSTOM CODE TRANSFORMATION

Application code is just annotated with a user-defined mark (directive/comment).

```
!$xev loop_tag
do k=1,n-1
  do j=1,n-1
    do i=1,n-1
      B(i,j,k)=A(i,j,k)
    end do
  end do
end do
```

Application code

```
{
    "xev loop_tag":{
        "target":"SgFortranDo",
        "rules":[
           {"chill_unroll_jam":{"var":"k","max":4}},
            {"chill_unroll":{"var":"i","max":2}}
        ]
    }
}
```

Unroll and jam

Loop Unroll

The translation rule is defined in an external file

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  end do
end do
```

Application code

```
<xsl:template match= "SgFortranDo">
<xsl:choose>
<xsl:when test= "preceding-sibling::*[1]/SgPragma/@pragma = 'xev loop_tag'">
<xsl:comment>
test-3.xsl xev loop_tag
</xsl:comment>

<xsl:variable name= "step1">
<xsl:apply-templates select= "." mode="chill_unroll_jam">
<xsl:with-param name= "max" select="4" />
<xsl:with-param name= "var" select="'k'" />
</xsl:apply-templates>
</xsl:variable>

<xsl:apply-templates select= "exslt:node-set($step1)"
mode= "find_loop_and_unroll" />
</xsl:when>

<xsl:otherwise>
<xsl:copy>
<xsl:copy-of select= "@*" />

</xsl:choose>
</xsl:template>
```

Unroll and jam

Loop unrolling

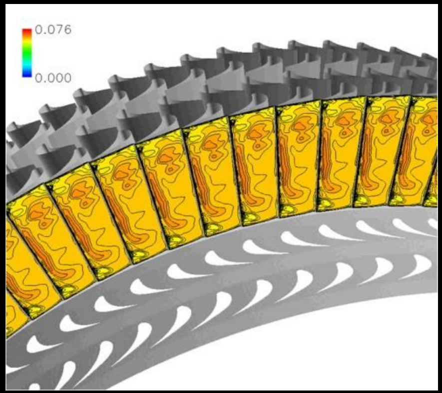
Every translation rule is written declaratively in XML (XSLT).
Users can customize it without developing their own code translators.

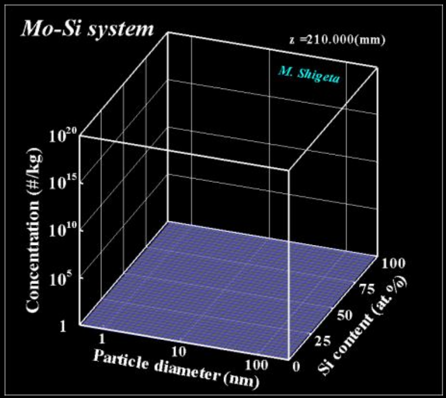
The translation rule is defined in an external file

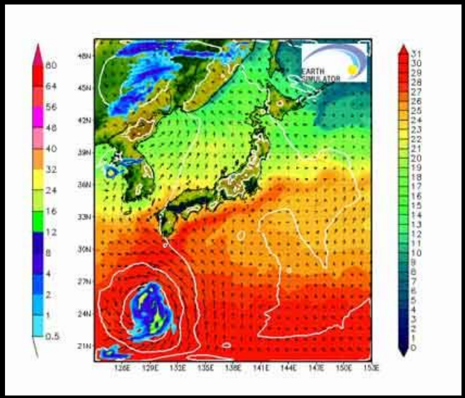
*1 Takizawa et al@HiPC2014.

RECENT PUBLICATION *1

- Real-world applications originally developed for NEC SX-9 have been ported to OpenACC.
  - Numerical Turbine (Yamamoto et al@Tohoku-U)
  - Nano-Powder Growth Simulation (Shigeta@Osaka-U)
  - MSSG-A (Takahashi et al@JAMSTEC)

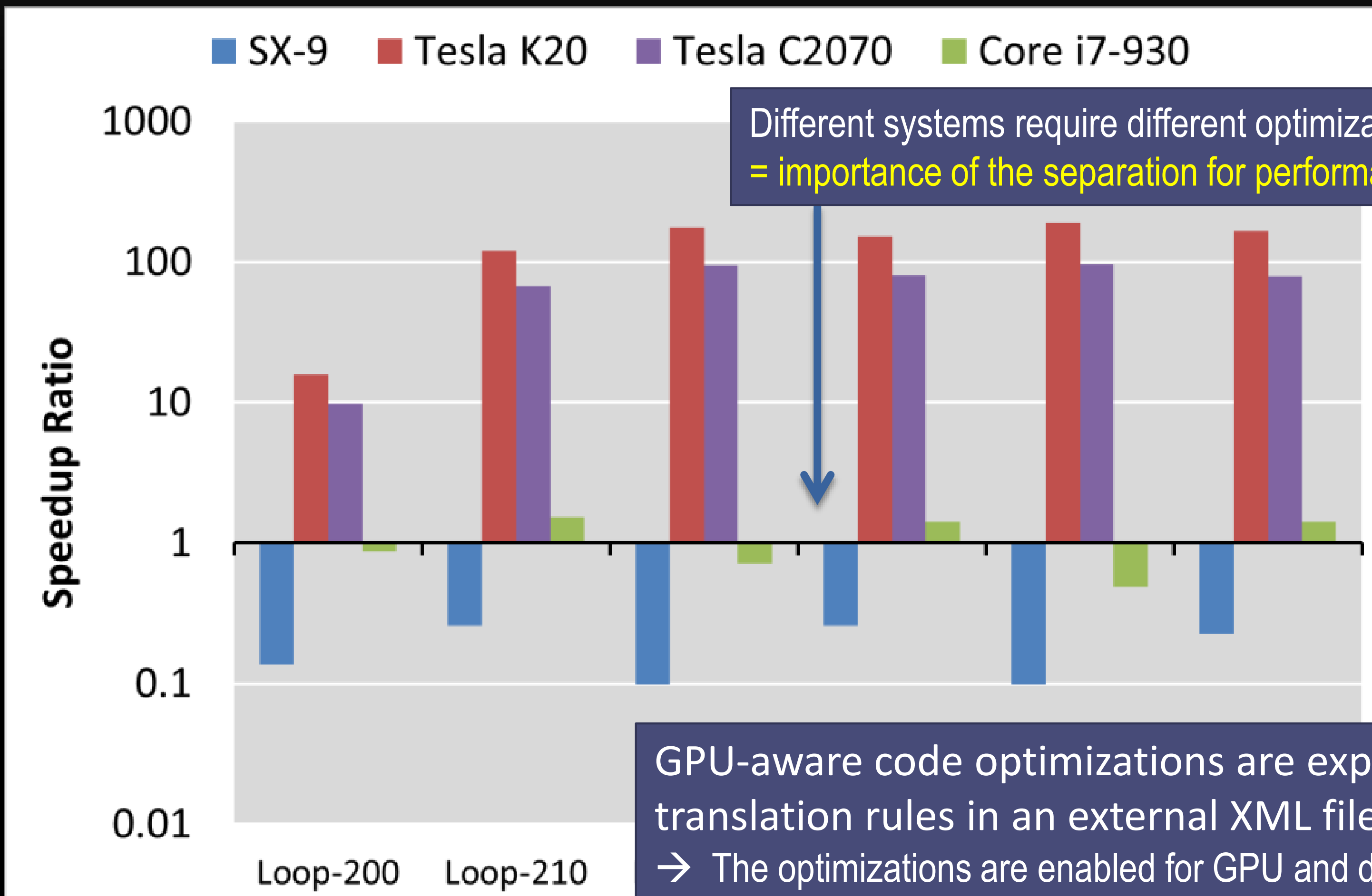






Xevolver can express system-awareness in an XML data format for migrating all the applications to OpenACC platform without major modifications.

PERFORMANCE EVALUATION RESULTS (NT)



Different systems require different optimizations
= importance of the separation for performance portability

GPU-aware code optimizations are expressed as code translation rules in an external XML file.
→ The optimizations are enabled for GPU and disabled for SX-9
= High performance portability between GPU and SX-9

Speedup due to code transformations
(Main kernels of Numerical Turbine)

Suda@U-Tokyo

DEMOCRATIZING CODE TRANSFORMATIONS!

Ongoing

```
program loop_inv0

!$xev tgen variable(i_, i0_, i1_)
!$xev tgen list(stmt_)

!$xev tgen src begin
!$xev(.) loop inv
  do i_ = i0_, i1_
    call xev_exec(stmt_)
  end do
!$xev tgen src end

!$xev tgen dst begin
  do i_ = i1_, i0_, -1
    call xev_exec(stmt_)
  end do
!$xev tgen dst end

end program loop_inv0
```

Automatic generation of translation rules

- A list variable catches multiple things
- Directive that drives transform
- The code pattern before transformation
- Special form to catch arbitrary statement
- Loop is reversed
- The code pattern after transformation
- Reproduces the caught statement

CONCLUSIONS

- Xevolver Framework

  = No new languages and models = incremental migration

  - AST is converted to a text format (XML) and exposed to programmers.
  - System-specific optimizations are separated from app.
    - Computational scientists can maintain the original code
    - Performance tuners describe system-specific optimizations in an external file

    → Helpful for long-term software evolution.

We need a standard way to describe system-awareness to fight against never-ending system changes.

→ Standardized Optimization Programming Interface

ACKNOWLEDGEMENTS

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Xevolver with some sample translation rules is online available at http://xev.arch.is.tohoku.ac.jp.

Your feedbacks (and bug reports) are welcome!