Parallelization of the AliRoot event-reconstruction by using a source-to-source transformation

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Introduction

ALICE need to exploit all available computing resources and facilities.

Multi-processing (PROOF-lite)

- Grid and Cloud computing
- Computer cluster
- Socket parallelism (SMP)
- Multi-core CPUs (CMP)
- Hardware threads (SMT)
- Data parallelism (SIMD)
- Super scalability
- Pipeline
Introduction

ALICE need to exploit all available computing resources and facilities.

Multi-processing (PROOF-lite)  Multi-threading

Benefit from multi-threading:
• Fast context switch
• Sharing memory by nature
• Benefit from SMT

Utilization of thread-level parallelism is unaffordable to gain further performance!

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- Computer cluster
- Socket parallelism (SMP)
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- Data parallelism (SIMD)
- Super scalability
- Pipeline
Objectives

Remaining issues:
• Thread-safety is difficult to introduce
• Parallel programming is labor intensive

A semi-automatic source-to-source transformation.

(as investigated from the Geant4-MT Project)
Objectives

Remaining issues:
• Thread-safety is difficult to introduce
• Parallel programming is labor intensive

A semi-automatic source-to-source transformation.
(as investigated from the Geant4-MT Project)

Benefits:
• Faster development process
• No additional development branch
• Without expert knowledge
• User maintain only their sequential code
Objectives

Parallel design:

- Full reconstruction per thread
- No interference amongst threads
- Event-level parallelism
Source-to-Source Transformation

Scheme of the source-to-source transformation:

- Source-code files
- Abstract-Syntax-Tree
- Parsing
- AST
- Static Analysis
- Rewriting Rules
- User specific Transformation

Original Tool:
- Augmented GCC parser to return positioning information.
- Case-based fact extraction from a token-stream generated by ELSAs parser.
Source-to-Source Transformation

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Source-code files → Abstract-Syntax-Tree

No access to AST during rewriting!

Error prone for heterogeneous source-code like in ROOT and AliRoot and hard to fix.

Original Tool:
- Source-code files
- Abstract-Syntax-Tree
- Rewriting (PrettyPrinting)
- Static Analysis
- Rewriting Rules
- User specific Transformation

Case-based fact extraction from a token-stream generated by ELSAs parser.
Scheme of the source-to-source transformation:

Source-code files → Parsing → AST → Abstract-Syntax-Tree → User specific Transformation → Rewriting Rules → Static Analysis → Rewriting (PrettyPrinting)

Original Tool:
Augmented GCC parser to return positioning information
Case-based fact extraction from a token-stream generated by ELSAs parser.

Missing Information:
- Kind of types (POD or complex)
- Function decl. with access to globals
- Scope (class, namespace)
**Source-to-Source Transformation**

**Static Analysis & Rewriting with Clang**
(Clang is the front-end of the LLVM project)

- Analysis and rewriting by the same software
- Access to AST during rewriting
- Fixes all bugs mentioned and further small problems

**Features:**

- Source-code (basis)
- Lexer (Preprocessing)
- Syntax Analysis (Parsing)
- Static Analysis (Walk AST Nodes)
- Source-code Generation
- Rewriting (Pretty Printing)

**Position Information**

- Decl* Position and Offset
- FunctionDecl* Position and Offset

1) TTS

The source-code adaption follows 4 important steps:

<table>
<thead>
<tr>
<th>Manual Intervention</th>
<th>Automated</th>
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<tbody>
<tr>
<td>1) TTS</td>
<td>Privatization of global and static declaration</td>
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<td>2) TMR</td>
<td>Source-code adaption</td>
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<td>3) Verification</td>
<td>Protection for unintended write access to read-only data</td>
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<td>4) Optimization</td>
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Manual intervention is following a specific procedure to adapt source-code. If it is conducted once, it can be automated for further transformations.
Thread-safety: Access to resources do not lead to unintended interference amongst threads. The strongest kind is *unconditional thread-safety*, where there is no interference at all.

1. Recognize concerned declarations:
The *recognition* phase is part of the static analysis. The aim is to detect global and static declarations and to collect position information.

2. Privatize recognized declarations:
For *privatization* the thread-specifier is used to allocate the recognized declarations into thread-local storage (TLS) and to make them private to threads.
1) TTS for ROOT & AliRoot

Can we run in parallel now?

<table>
<thead>
<tr>
<th>Found (Changed)</th>
<th>Statics</th>
<th>Globals</th>
<th>Extern</th>
</tr>
</thead>
<tbody>
<tr>
<td>AliRoot</td>
<td>2023 (417)</td>
<td>138 (11)</td>
<td>159 (31)</td>
</tr>
<tr>
<td>ROOT</td>
<td>3652 (620)</td>
<td>191 (150)</td>
<td>125 (46)</td>
</tr>
<tr>
<td>CINT</td>
<td>228 (0)</td>
<td>69 (0)</td>
<td>308 (0)</td>
</tr>
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Only involved source-code has been addressed.

In practice: **Violations** by

1. source-code generation (global decl. in CInt)
2. external libraries and non re-entrant functions.
3. common accessible resources.
2) TMR

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2) TMR

Scheme of the transformation for memory footprint reduction (TMR):

Sharing Classes: Since it is uncertain to find whole classes with static content that can be shared, single member fields can be classified as transitory and will become thread-local in the transformed source-code. Resting members are assumed to be relative read-only.

Manual
1. Run memory profiling to find interesting objects. (e.g. Memory graph of massif)
2. Classify and select member fields as transitory.
3. Must not necessarily be correct => Verification later.
2) TMR to share Clnt

**TROOT**
- fBrowsables : Tlist*
- fRootFolder : Tfolder*
- fTasks : TSeqCollection*
- ...

GetRootFolder()  
GetListOfBrowsable()  
GetListOfTasks()  
...

**Initialization of TLS data**

**Access from Threads**

**Constructor initializes TCint**
- Ctrol init. List of Classes  
- Ctrol init. List of Types

**Ctrol init. ROOT Folders**
- Ctrol init. List of Browsables  
- Ctrol init. List of Tasks

 Shall become relative read-only  
 Shall become transitory

Involved: TClass, TClassTable and others.

And: Type information (reflex information) has to be *loaded in advance*. Resting write access must be serialized.

**Now:**
1. TROOT stay a singleton  
2. Type information are shared  
3. TCInt is shared
3) Verification

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Manual intervention is following a specific procedure to adapt source-code. If it is conducted once, it can be automated for further transformations.
Which violation of correctness can occur?

1) Race condition, because of resting global state
2) Race condition, if read-only data are written
3) Access to common resources (process resources, e.g. files, sockets, locks)
4) Semantic relations between resources and global decl.

Solutions:
• 1) & 2) can be detected using dynamic data-race detection tools like helgrind.
• 2) can easier be detected with the MWP Tool
• 3) can whether be detected by race detection or by static analysis
• Semantic relations can be detected by Bisimulation
3) Verification

Verification of TMR:

Class member

Memory Write Protection Tool (MWPT):

Unintended write op.

Legal read op.

Single thread

Heap

Protected memory

Read-only data

Actual

False classification

read-only

transitory

transitory

read-only

No violation

Violation!
3) Verification

**Verification** of TMR:

<table>
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Class member

Memory Write Protection Tool (MWPT):

Unintended write op.  Legal read op.

- Remove protection and re-execute last function.
- Single thread

SIGUSR

Protected memory

Read-only data

SIGV

Print ptrace report

Heap

3) Verification

**Misbehaviour:**

A: Sequential (original) code  
B: Multi-threaded (adapted) code

**Bisimulation:**

Gdb with A

Brakpoint: Call2

Compare behavior

Gdb with B

Breakpoint: Call2

Where is 2nd (2.2) call?
What about performance?
Testing Event Reconstruction

**Initialization**: Divided into 4 steps
1. Creation of reflex data in advance.
2. Preparation of data for shared classes.
4. Per thread: Initialization of Reconstruction.

**Extraction & Merging**: Prepare data by loading, extracting and distributing them to the reconstruction threads. Merge the resulting files per threads in the end.

**Termination & Exit**: During exit objects are going to be deleted, object in container must be cleaned, what is now executed during termination for thread dedicated resources.

**Concurrent Processing**: Parallel event reconstruction. Currently no master-worker paradigm used.
Testing Event Reconstruction

200 p-p events (red) vs. 20 Pb-Pb events (blue)

ITS only, no QA

Max. Speedup of parallel processing only:
4.9 (p-p), 5.6 (Pb-Pb)

Test machine: 12 core Intel Westmere. 2.6 GHz, 12 MB LL cache.

Synchronization avoids scalability. Led-Led processing is more computing intensive and uses less synchronization. Hence it scales better.
Performance characteristic:
1. 3,95 M calls of _tls_get_addr per pp-event. 1.45% of runtime.
2. 350k mutexes acquired per event, thereof around 90k Tstorage::Alloc*
3. Around 360k times malloc/free per event, 1.16% of runtime.

- The parallel initialization is locked and affects performance.
- Local reconstruction is the slowest task, due to intense IO.
200 p-p events vs. 20 led-led events

ITS only, no QA

Memory per thread:
- 400 MB (pp), 800 MB (PbPb)

Only Cint & TROOT shared.

Test machine: 12 core Intel Westmere. 2.6 GHz, 12 MB LL cache.

Each thread has an opened set of files for reading raw data and writing down results. For a Led-Led run these consume 200 MB and for a p-p run 133 MB virtual memory.
Conclusions

Transformation:
1. Introducing multi-threading without expert knowledge is possible.
2. Rewriting with the current tool is sophisticated and error-prone. It can be improved by using a new Clang front-end.

Performance:
1. Speedup of a Led-Led run rose to 5.6 with 8 threads.
2. Memory consumption is reduced by around 100 MB. Led-led reconstruction footprint still rises to 600 MB virtual memory per thread.
3. More memory can be shared, e.g. Geometry and CDB data.
4. Prototype can be used to evaluate performance for first design

Correctness:
1. With helgrind and MWPT, practical concerns can be evaluated.
2. All concerns of correctness have been addressed by provided tool.
3. Since validation and the corresponding tools are hard to apply, many items are not jet fixed appropriate, leading to instability.
Questions?