Lero THE IRISH SOFTWARE RESEARCH CENTRE

LLVM LEON Backend Final Presentation

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Outline

Introduction

- Project Objectives
- LLVM & Problem Statement

Results of the Development Activities

- Software Requirements
- Software Design
- Implementation
- Unit Tests
- Test Suite
- Code Check-ins

Conclusion

- Overall Assessment
- Challenges
- Future Improvements

LLVM LEON Backend: Project Objectives

Build an LLVM Backend for LEON2/3/4-FT :

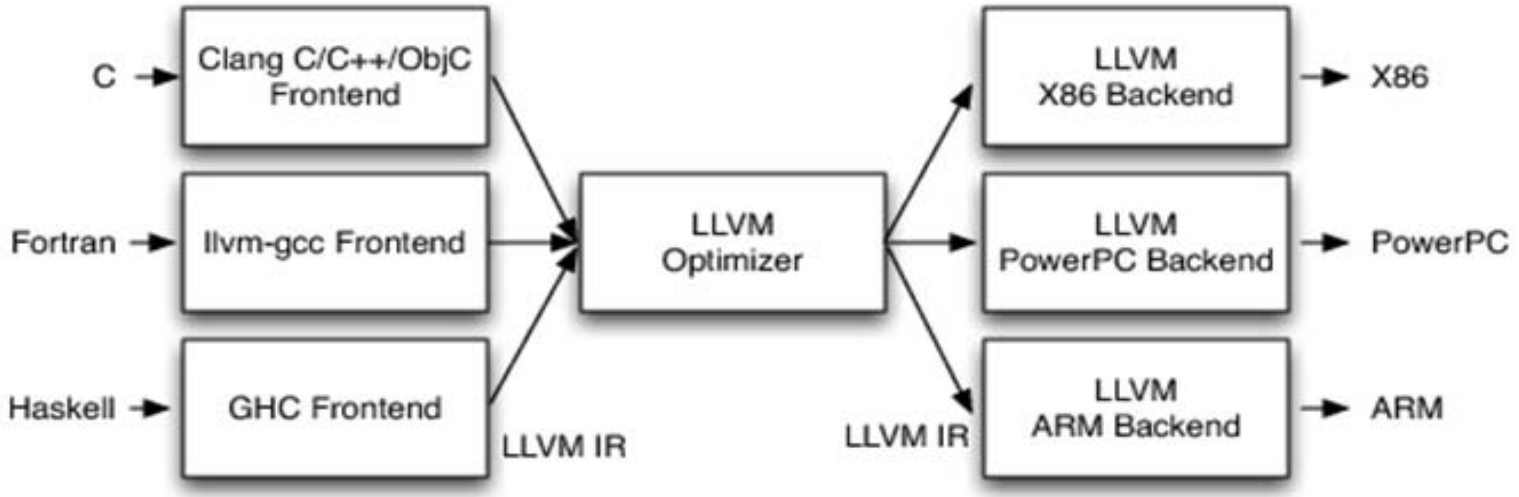
- ✓ specify the upgrades needed in the LLVM SPARC backend to support the LEON2/3/4-FT processors
- ✓ design and develop the LLVM backend for LEON2/3/4-FT processors
- ✓ implement a test suite running on the LEON3/4-FT architecture - comparison between LLVM and GNU GCC with respect to performance, accuracy, etc.
- ✓ study and prototype novel techniques to improve the determinism of application execution and WCET reduction
- ✓ identification of new use cases enabled by the LLVM LEON backend

LLVM Framework

Compiler stages:

- ✓ parse source language to an IR
- ✓ transformations of the IR
- ✓ generation of machine code from IR

LLVM - modular and reusable libraries built around the LLVM IR



LLVM LEON Backend: Problem Statement

LLVM LEON Backend:

- × cope with existing LLVM Framework and LLVM SPARC backend
- × open source, code needs to be checked-in
- × support to LEON 2 FT, LEON 3 FT, LEON 4 FT
- × different LEON instruction latencies, errata, SPARC architecture

Solution:

- ✓ subtargets for the current SPARC backend
- ✓ processor itineraries (LEON 2/3/4) and extended instruction set
- ✓ subtarget features to parameterize the LEON backend
- ✓ erratum fixes and optimizations

LEON Backend Results: Software Requirements

Elicitation and specification of backend requirements:

- ✓ multiple iterations – 80 refined requirements
- ✓ all requirements are addressed by the backend design and unit test plan
- ✓ traceability b
- ✓ traceability b

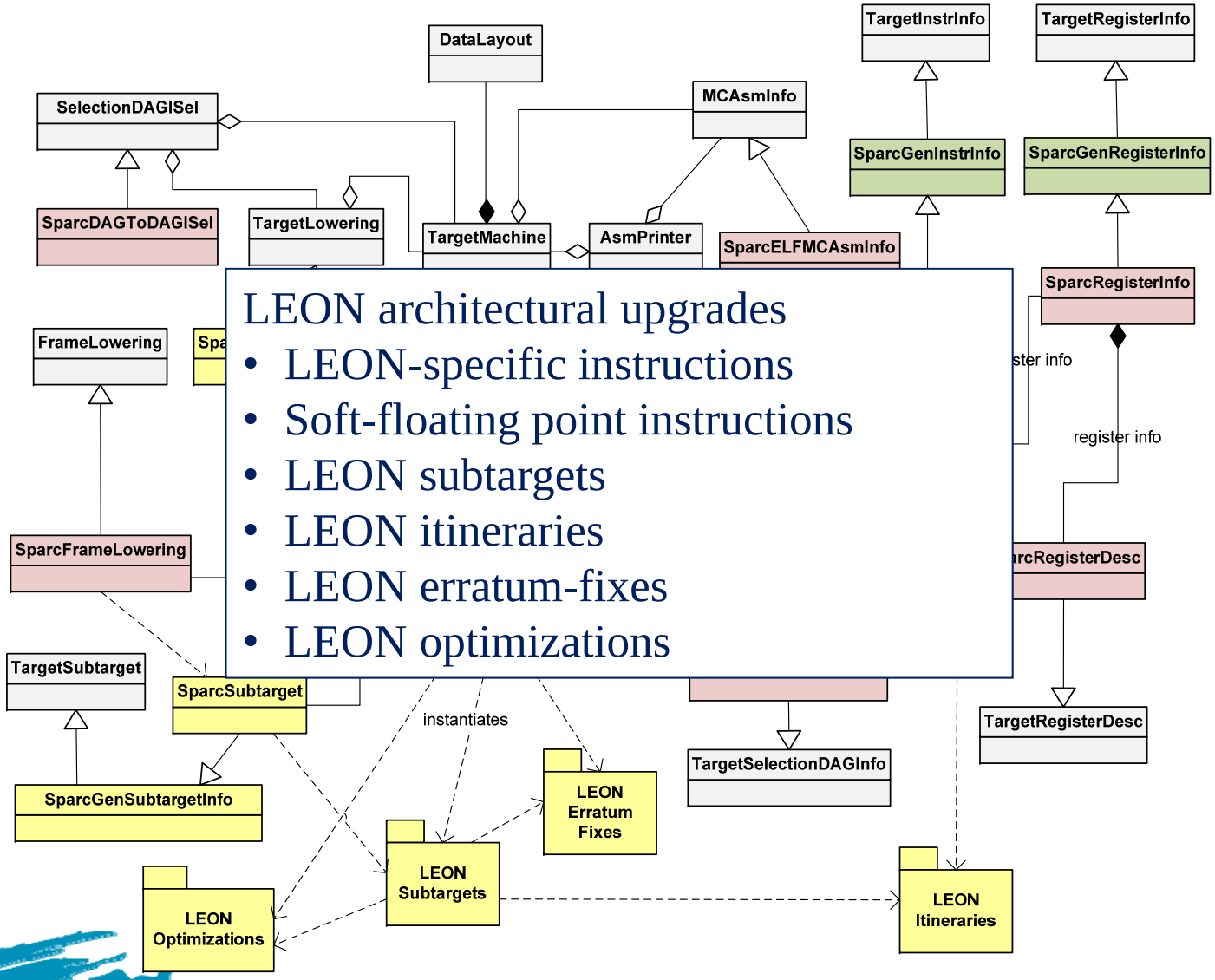
Performed studies:

- Implementation trade-off
- SPARC backend
- SPARC lowering
- SPARC ABI
- LEON Errata
- Cache and multicore optimization

Requirement #LBR21

- *Description*: For … e %i0 (the caller's %o0) to return the result.
- *Exception condition*: This is not required where a procedure is implemented as an optimized lead procedure.
- *Responsible*: Task 120, Task 210
- *Verification*: code inspection, empirical study

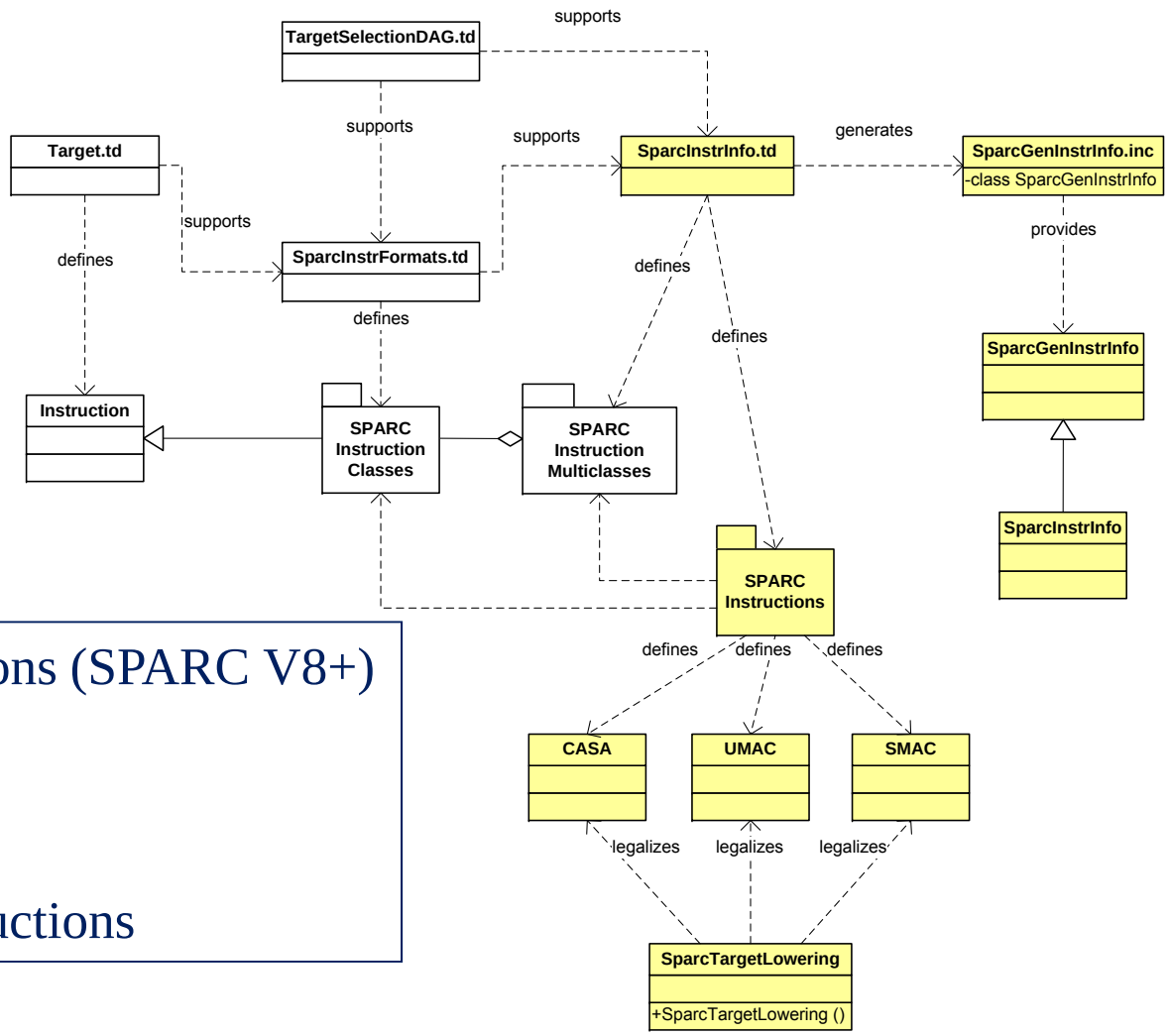
LEON Backend Results – Software Design



LEON architectural upgrades

- LEON-specific instructions
- Soft-floating point instructions
- LEON subtargets
- LEON itineraries
- LEON erratum-fixes
- LEON optimizations

LEON Backend Results – Software Design



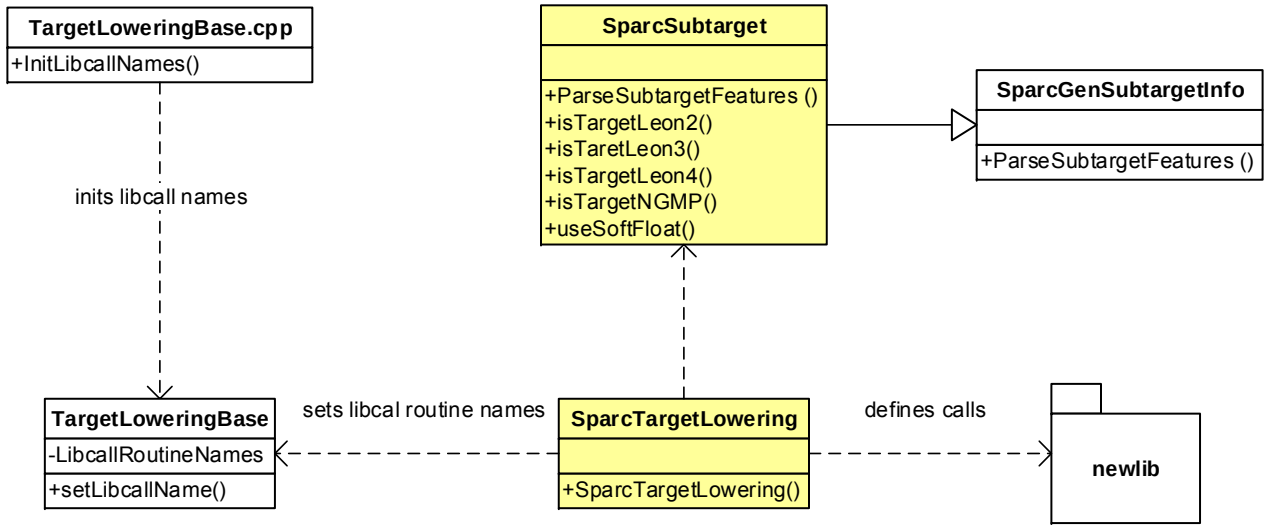
LEON specific instructions (SPARC V8+)

- UMAC/SMAC
- CASA

- + all SPARC V8 instructions

LEON Backend Results – Software Design

Software FP instructions
- software FP library calls
- mathematical library (libm), e.g, Newlib



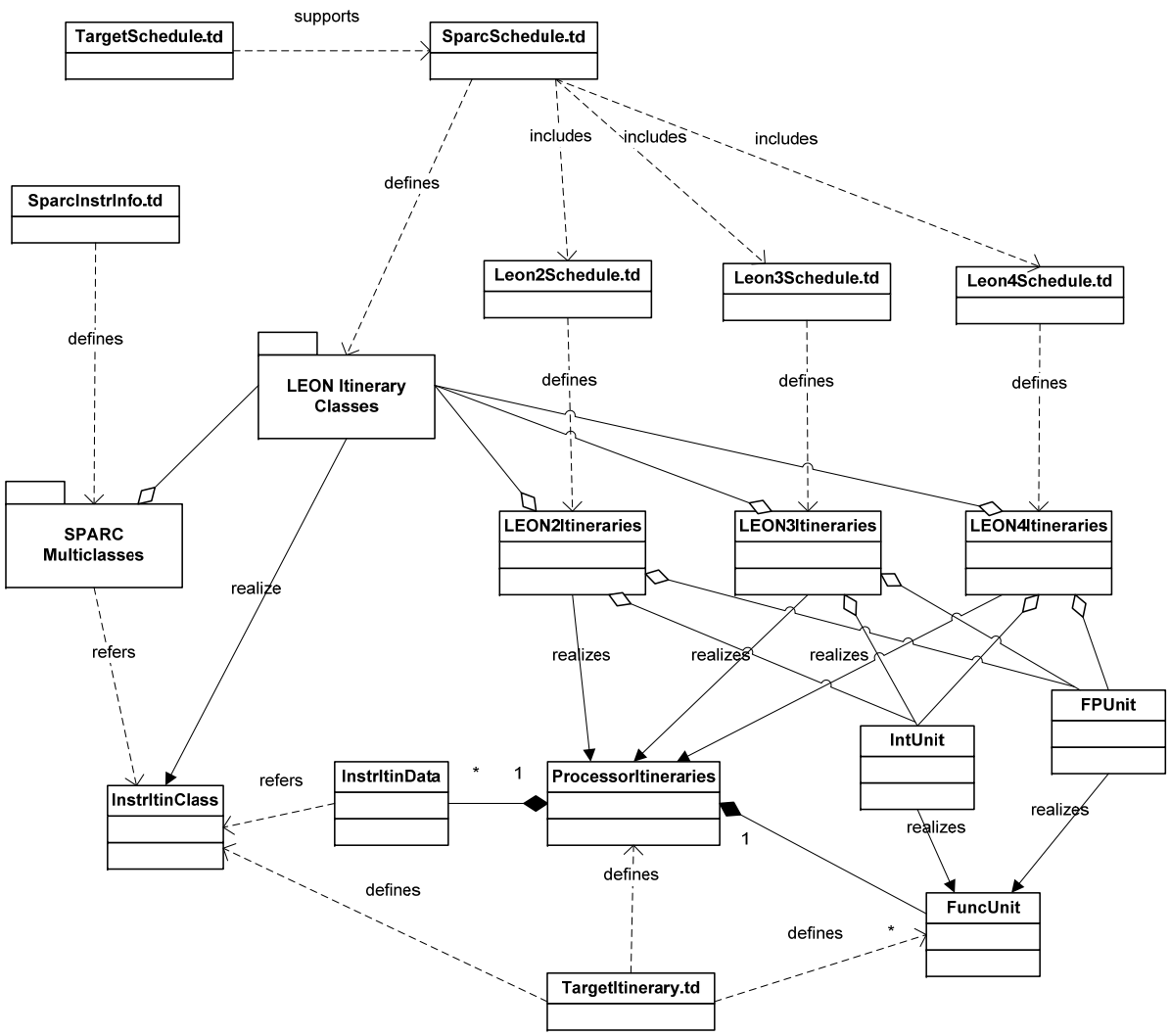
LEON Backend Results: Software Design

LEON subtargets

- ✓ leon2 - generic LEON 2 FT, LEON 2 itineraries, no erratum fixes
- ✓ at697e - AT697E / LEON 2 FT, LEON 2 itineraries, erratum fixes for LEON 2 AT697E
- ✓ at697f - AT697F / LEON 2 FT, LEON 2 itineraries, erratum fixes for LEON 2 AT697F
- ✓ leon3 – generic LEON 3 FT, LEON 3 itineraries, UMAC and SMAC instructions, no erratum fixes
- ✓ ut699 - UT699 / LEON 3 FT, LEON 3 itineraries, UMAC and SMAC instructions, erratum fixes for LEON 3 UT699
- ✓ gr712rc - GR712RC / LEON 3 FT, LEON 3 itineraries, UMAC and SMAC instructions, no erratum fixes, CASA instruction
- ✓ leon4 - generic LEON 4 FT, LEON 4 itineraries, UMAC and SMAC instructions, no erratum fixes, CASA instruction
- ✓ gr740 - GR740 / LEON 4 FT, LEON 4 itineraries, UMAC and SMAC instructions, no erratum fixes, CASA instruction

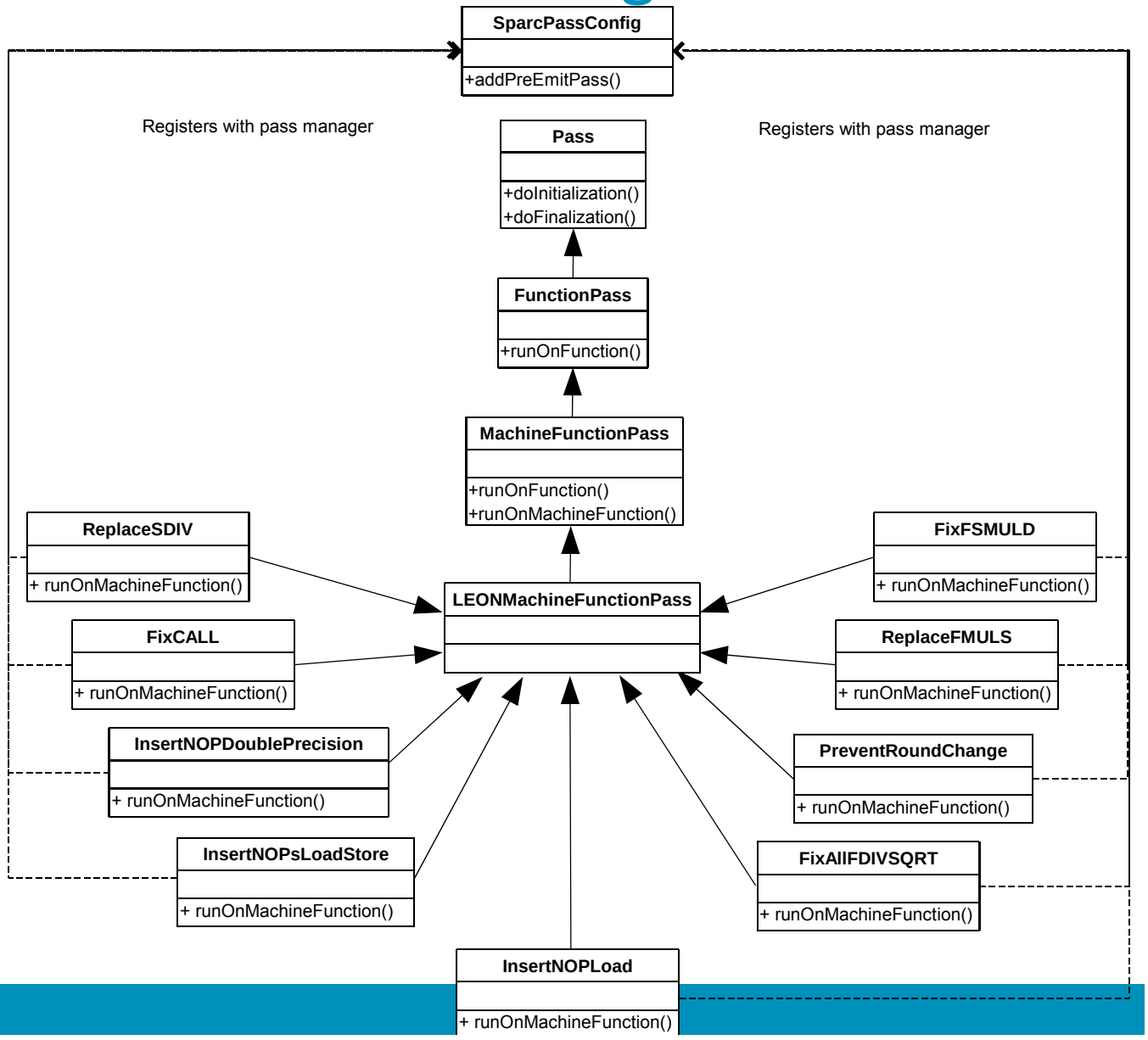
LEON Backend Results – Software Design

LEON itineraries



LEON Backend Results – Software Design

LEON erratum fixes



LEON Backend Results: Software Design

LEON Optimizations

New optimizations:

- ✓ Delay Slots Optimization

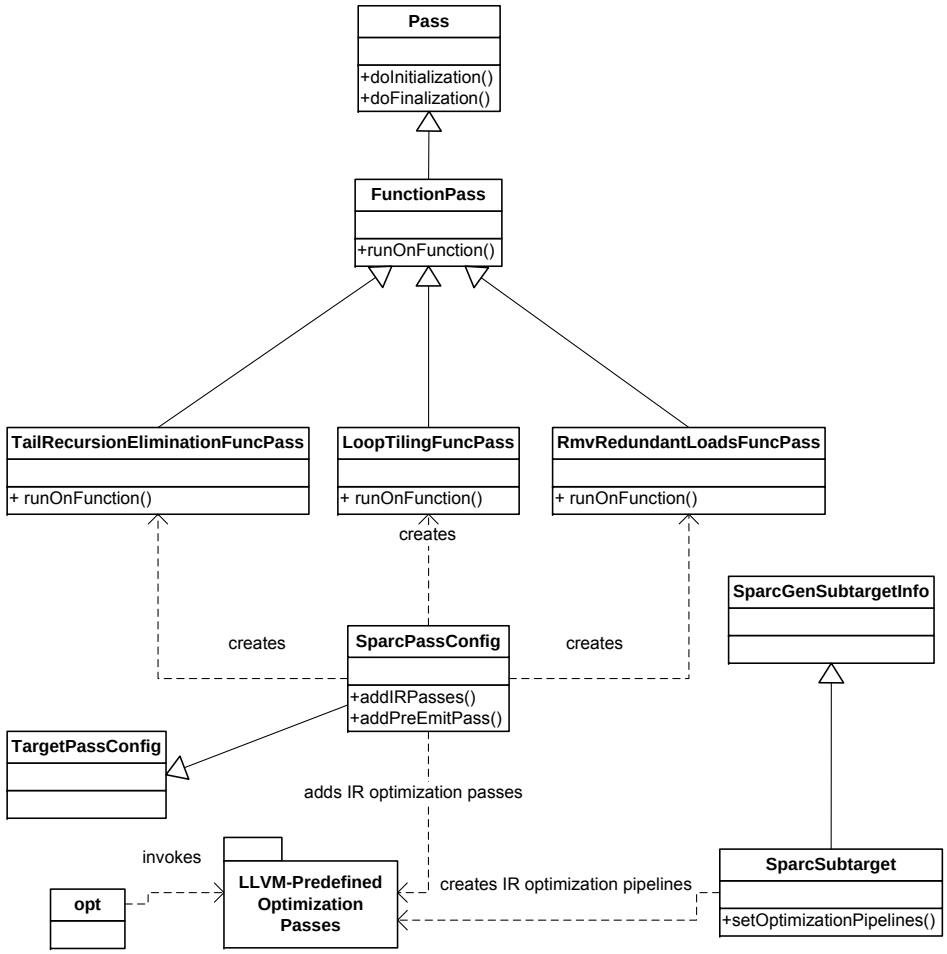
  (partially realized by DelaySlotFiller)

- ✓ Delay Slot after Unused Modified Register Optimization

  (realized for FixAllFDIVSQRTPass erratum fix)

Note:

Initially planned optimizations were not implemented: the focus was on the correctness of the generated code.

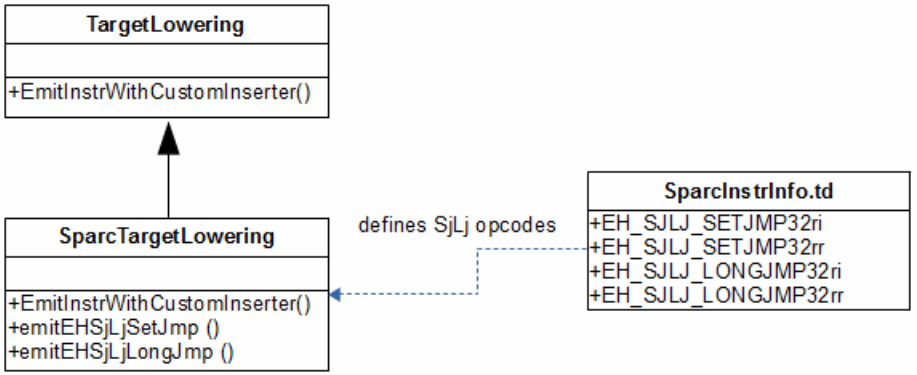


LEON Backend Results: Software Design

SPARC backend patches/fixes

Builtin intrinsics:

- ✓ __builtin_setjmp
- ✓ __builtin_longjmp



LEON Backend Results: Implementation

LEON backend implementation:
- multiple iterations (impl-UT-testing)
- followed and changed the design
- impacted by code check-in

- ✓ LEON subtargets
- ✓ Missing instructions (LEON-specific, coprocessor instr., etc.)
- ✓ LEON itineraries
- ✓ LEON subtarget features
- ✓ LEON erratum fixes
- ✓ LEON optimizations
- ✓ SjLj inrinsics
- ✓ Unplanned fixes and patches

LEON Backend Results: Unit Tests

LLVM UTs developed to test particular backend features:
-UT plan
-UT implementation

UTs – sc

UTs targ

- ✓ lower
- ✓ imple proce
- ✓ genel
- ✓ encoc

every sing

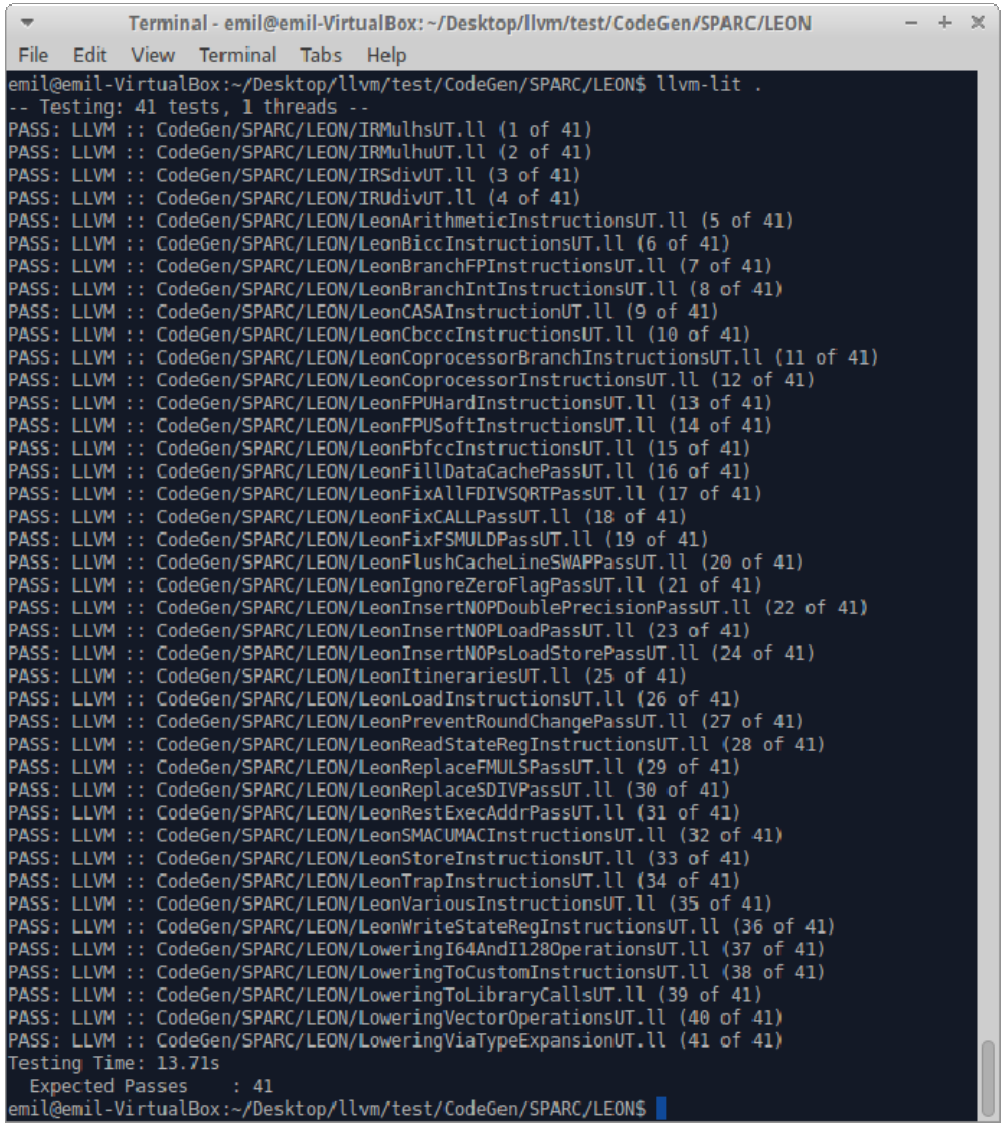
```
; RUN: llc < %s -march=sparc -mcpu=leon2    | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=at697e   | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=at697f   | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=leon3    | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=ut699    | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=gr712rc  | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=leon4    | FileCheck %s
; RUN: llc < %s -march=sparc -mcpu=gr740    | FileCheck %s

; testing ADD - Add
; CHECK-LABEL: test_add
; CHECK:       add
define i8 @test_add(i8 %a, i8 %b) nounwind {
  %1 = and i8 %a, %b

  ret i8 %1
}
```

nd LEON 3

LEON Backend Results: Unit Tests

UT Results – over 1000 test cases in 39 UT files

- ✓ developed and executed in multiple iterations
- ✓ final result: all the unit tests passed, confirming the correctness of the tested features



LEON Backend Results: Test Suite

Cobham Gaisler Test Suite:
- test the correctness of the LLVM LEON backend
- measure performance compared to GCC LEON backend

Includes over 6600 tests written in C/C++

Over 6500 tests coming from GCC

Targets LEON 3 and LEON 4:

- ✓ instruction generation
- ✓ erratum fixes

Tests executed on two LEON systems:

- ✓ LEON 3
- ✓ quad core LEON 4 with a L2 cache

LEON Backend Results: Test Suite

Test Suite Results

- ✓ Testing performed in multiple iterations
- ✓ Final result: only 11 GCC-specific tests do not pass out of over 6600 tests (over 1100 were not passing at the start of the project)
- ✓ The 11 non-passing tests are mostly related:
  - to the use of the GCC's __vector language extension of C++
  - to the use of inline assembly code with GCC syntax
- ✓ All errata-related tests successfully passed

LLVM LEON backend is a competitive alternative of GCC LEON backend

LEON Backend Results: Code Check-ins

Upload the LEON backend code into the LLVM Repository

Significant check-ins in the project:

- ✓ multiple iterations – upload-review-modification
- ✓ over 15 check-ins for the LEON backend implementation:
  - ➢ planned implementation
  - ➢ code fixes and patches
- ✓ problems mainly related to processing inline assembly and erratum fixes

LEON Backend Overall Assessment

LEON backend - complete solution and good competitor of GCC LEON backend

Multiple-iteration software process:

- ✓ comprehensive requirements specifications
- ✓ efficient and comprehensive backend design and implementation
- ✓ comprehensive and effective unit test plan
- ✓ efficient and exhaustive integration testing

Comprehensive and regular reporting

Three major review meetings

LEON Backend Challenges

LEON backend – extremely challenging project

- ✓ initial learning curve
  - ➢ learning about the SPARC instruction set
  - ➢ learning curve for the LLVM system
- ✓ TableGen language
- ✓ IR language
- ✓ coding support
- ✓ coding cycle time:
  - ➢ LLVM compilation time
  - ➢ test cycle time

LEON Backend Future Improvements

LEON backend – good solution with only few possible improvements

- ✓ LLVM LEON backend:
  - implement LEON itineraries following the NEW way of implementation
  - improvements in efficiency of the generated code
- ✓ Test suite:
  - categorization of the different test programs
  - by measuring the coverage of the compiler code
  - gathering more information from the execution environment
  - using the TSIM simulator
  - new runtimes (currently RTEMS)

LEON Backend Future Improvements

Improvements based on enabled use cases

- ✓ visual modeling for LLVM
- ✓ automatic code generation for LLVM
- ✓ automatic verification with model checking for LLVM
- ✓ static code analysis for LLVM
- ✓ automatic generation of unit tests for LLVM
- ✓ requirements specification for LLVM
- ✓ software design for LLVM
- ✓ visual modeling and code generation to C++/LLVM's IR
- ✓ formal specification, verification and code generation to C++/LLVM's IR
- ✓ specifying autonomy behavior and code generation to C++/LLVM's IR
- ✓ programming by mixing different programming languages and code generation to LLVM's IR

Summary

LLVM LEON backend

- LLVM Backend for LEON 2, LEON 3, and LEON 4
- Upgrade to LLVM SPARC backend
- Extensive set of various features
- Unit testing with LLVM UTs and LIT
- Integration testing with Cobham Gaisler test suite (6600+ tests)
- Code check-ins to LLVM repository

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