Parallel GCC: Status and Expectations

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Introduction

- **FLUSP – Floss at USP**
  - Student extension group
  - Aims to Contribute to FLOSS
  - Projects we currently contribute: Linux Kernel, GCC, Git, Debian
  - Promote Contribution Events, such as the KernelDevDay

Overview

1. Introduction
2. Where to Start?
3. Parallel Architecture
4. Results
5. TODOs
6. References

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Introduction

- **How many of you have seen a compiler running in parallel?**

Introduction

- **Parallelization of GCC Internals**
  - Exploring parallelism in a single file

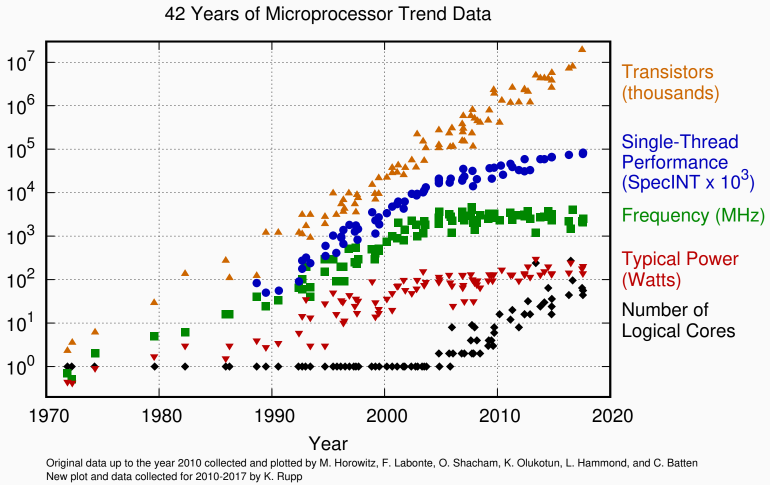
- **Main objectives**
  - Reduction of compilation time
  - Highlight GCC global states

Motivation

- **Compilers are really complex programs**
  - GCC dates from 1987
  - Still sequential
- **Automatic Generation of big files**
  - `gimple-match.c`: 100358 lines of C++ (GCC 10.0.0)
- **Exponencial growth in number of cores of a CPU**

Motivation

Growth of Computational Power (Rupp, 2018)

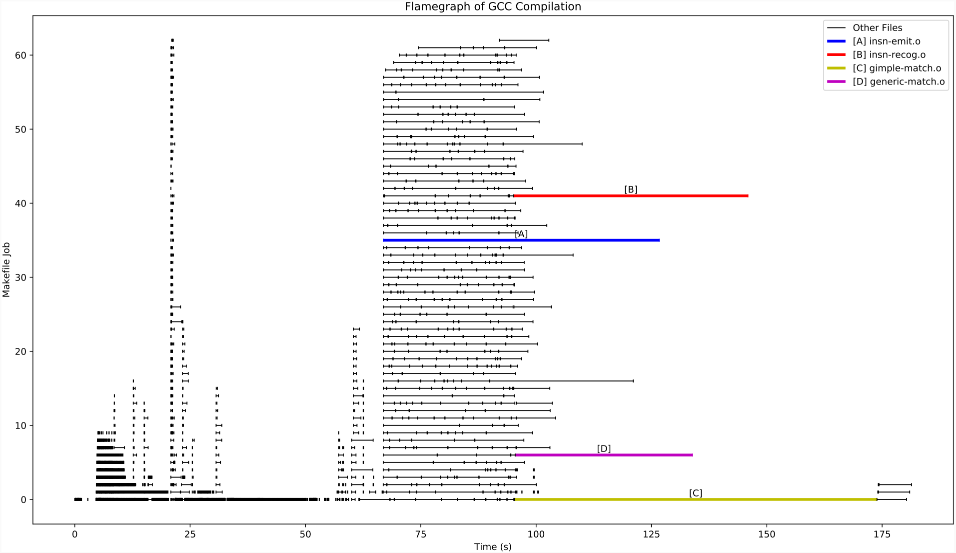


Motivation

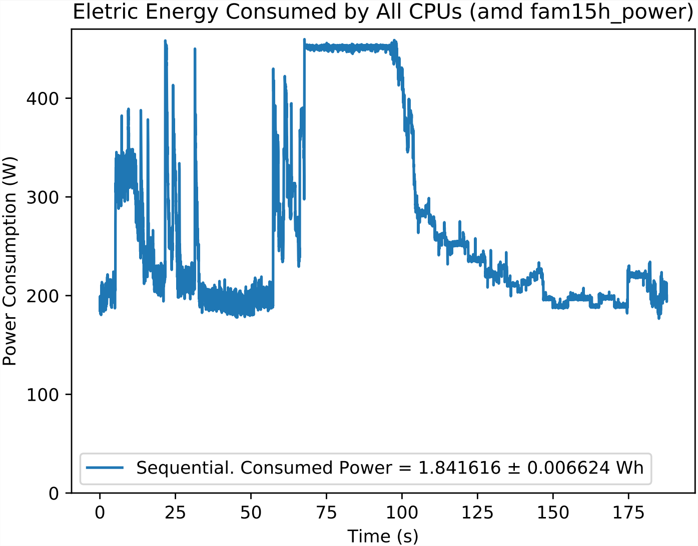
- **Where can we use these parallel processors in a compiler?**
- **How much the improvement is?**
- **Is there projects that can be benefited from this?**

Introduction

- **Experiment 1**
  - GCC compilation on a machine with $4\times$ AMD Opteron 6376
    - $4 \times 16 = 64$ *cores*
  - No *bootstrap* (`--disable-bootstrap`)
  - `$ make -j64`
  - Collected Compilation Time of each file
  - Collected Consumed Energy of all CPUs



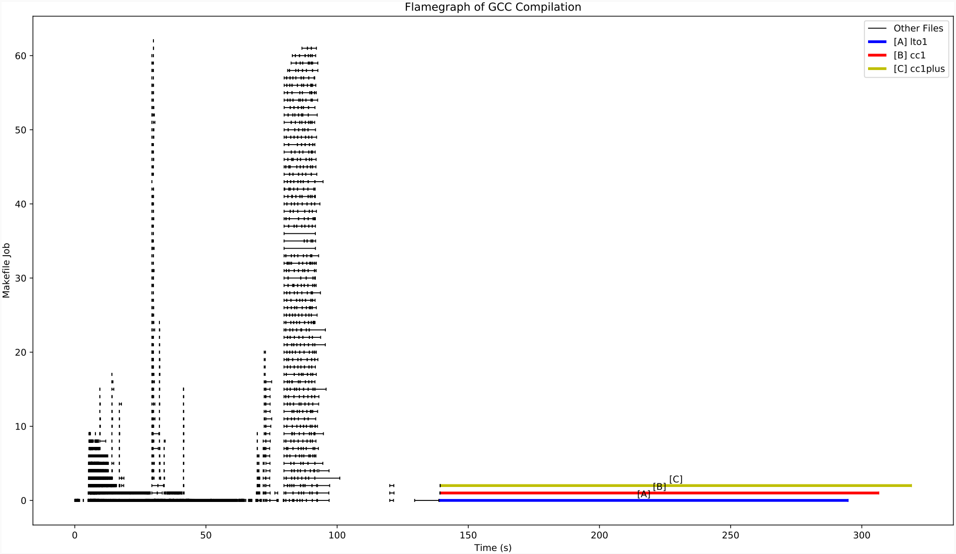
Flamegraph of GCC Compilation
Other Files
[A] insn-emit.o
[B] insn-recog.o
[C] gimple-match.o
[D] generic-match.o
[A]
[B]
[C]
[D]
Makefile Job
Time (s)
0
10
20
30
40
50
60
0
25
50
75
100
125
150
175


Eletric Energy Consumed by All CPUs (amd fam15h_power)
Power Consumption (W)
0
100
200
300
400
0
25
50
75
100
125
150
175
Time (s)
Sequential. Consumed Power = 1.841616 ± 0.006624 Wh

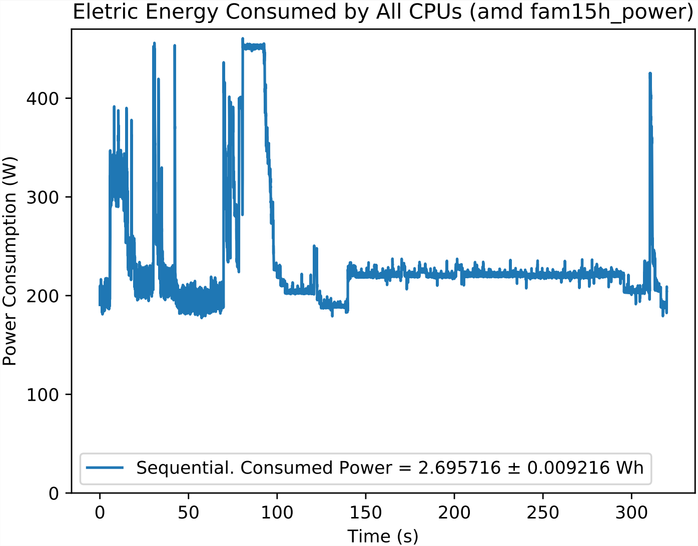
Introduction

- **How about LTO?**

- **Experiment 2**
  - GCC compilation on a machine with $4\times$ AMD Opteron 6376
    - » $4 \times 16 = 64$ *cores*
  - No *bootstrap* (`--disable-bootstrap`)
  - Enabled LTO (`CFLAGS=-flto=64 CXXFLAGS=-flto=64`)
  - `$ make -j64`
  - Collected Compilation Time of each file
  - Collected Consumed Energy of all CPUs



Flamegraph of GCC Compilation
Other Files
[A] lto1
[B] cc1
[C] cc1plus
[A]
[B]
[C]
Makefile Job
0
10
20
30
40
50
60
Time (s)
0
50
100
150
200
250
300



Eletric Energy Consumed by All CPUs (amd fam15h_power)
Power Consumption (W)
0
100
200
300
400
0
50
100
150
200
250
300
Time (s)
Sequential. Consumed Power = 2.695716 ± 0.009216 Wh

Introduction

- **There is a parallelism bottleneck in GCC project**
  - And the compilation uses more electrical power as a consequence

- **Could we improve it by parallelizing GCC?**

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Where to Start?

GCC structure is divided in three parts.

- ***Front End***
  - Parsing
- ***Middle End***
  - Hardware-Independent Optimization
- ***Back End***
  - Hardware-Dependent Optimization
  - Code Generation

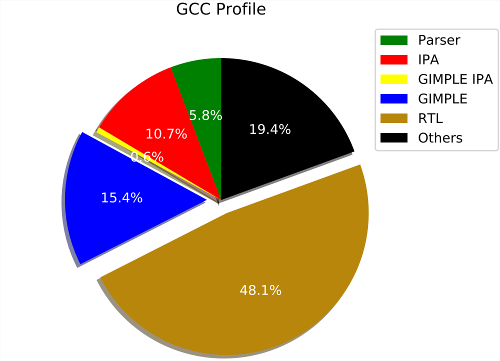
Where to Start?

- **Selected Part: Middle End**
  - Applies Hardware-Independent Optimizations in the code
  - Why? Because it looked easier to start rather than RTL

- **Optimization can be broken into two disjoint sets**
  - Intra Procedural
    - » *Can be applied into a function without observing the interactions with other functions*
  - Inter Procedural
    - » *Interaction with other functions must be considered*
    - » *GCC calls this Inter Process Analysis (IPA)*

GCC Profile

- **We used `gimple-match.c` to profile the compiler**
  - Intel Core i5-8250U (4 cores)
  - 5400RPM 1TB Hard Drive



GCC Profile

- **We used `gimple-match.c` to profile the compiler**
  - 48s is spent compiling this file
  - 63% is spent in Intra Procedural Optimization
  - This can be parallelized
  - Maximum speedup: $2.7\times$ according to Amdahl's Law

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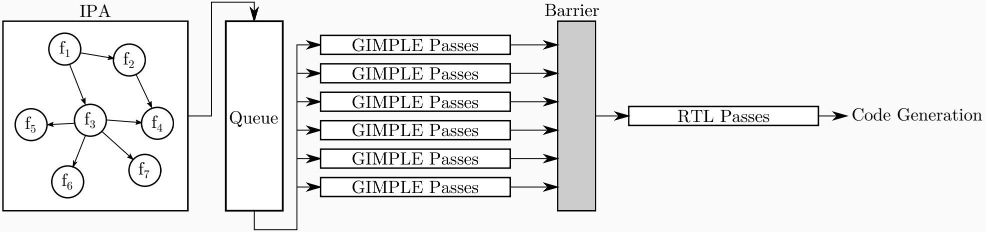
Parallel Architecture

- **Parallelize Intra Procedural Optimizations**
  - By per-function
  - Similarly to Wortman and Junkin (1992)
  - With arbitrary number of threads

Parallel Architecture

- **Architecture of Parallel GCC**
  - The Inter Process Analysis inserts functions into a Producer Consumer Queue
  - Each thread is responsible to remove their work from the Queue
  - When Queue is empty, threads are blocked until work is inserted into it
  - The threads die when the `EMPTY` token is inserted
  - Measured overhead: 0.1s for 2000 functions



Parallel Architecture

- **Advantages**
  - Best candidate to Linear speedup
  - Worst case: A single big function
- **Disadvantage**
  - Map per-pass global states in the compiler

Implementation

- **Split `cgraph_node::expand` into three methods:**
  1. `expand_ipa_gimple`
  2. `expand_gimple` ⟵ Parallelization effort in GSoC 2019
  3. `expand_rtl`
- **Serialized the Garbage Collector**
- **Serialized memory related structures**

Implementation

Memory Pools:

- **Problems:**
  - Linked List of several object instances
  - Can be allocated/released upon request
  - Most race conditions were there
- **Solution:**
  - Create an instance for every thread
  - Merge the memory pools when all threads join
  - Implementing merge feature: Just append the two Linked List

Implementation

Garbage Collection:

- **Problem:**
  - GCC implements a garbage collector
  - Variables can be marked to be watched by it
  - Collection can also be done upon request
- **Partial Solution:**
  - Serialize the entire Garbage Collector
  - Disable collection between passes
- **Research is needed to:**
  - Map the race conditions in the Garbage Collector
  - Make it thread safe

Implementation

`rtl_data` Structure:

- **Problem:**
  - This class represents the current function being compiled in RTL
  - GCC only has a single instance of this class
  - GIMPLE uses it to decide optimization related to instruction costs
- **Solution**
  - Have one copy of this structure for each thread
  - Make GIMPLE not rely on this?

Implementation

tree-ssa.address.c: `mem_addr_template_list`

- **Problem:**
  - Race condition in this structure
- **Partial Solution:**
  - Serialize with a mutex
- **Solution**
  - Replicate for each thread?

Implementation

Integer to Tree Node hash

- **Problem:**
  - Race condition in this structure
- **Partial Solution:**
  - Serialize with a mutex
- **Solution**
  - Replicate for each thread?

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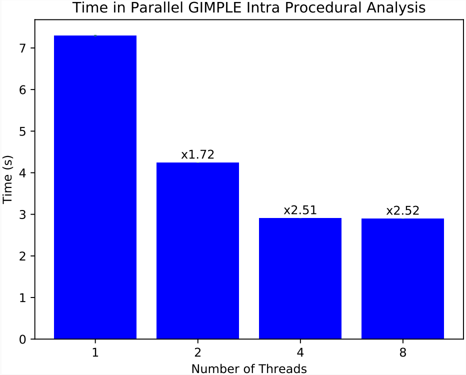
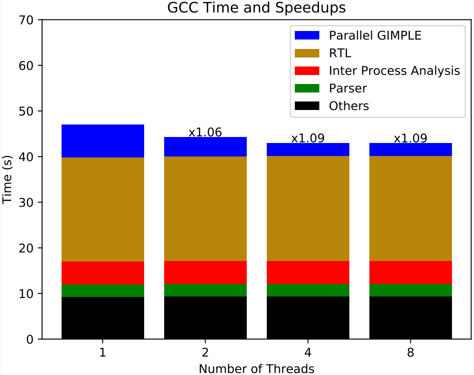
Results

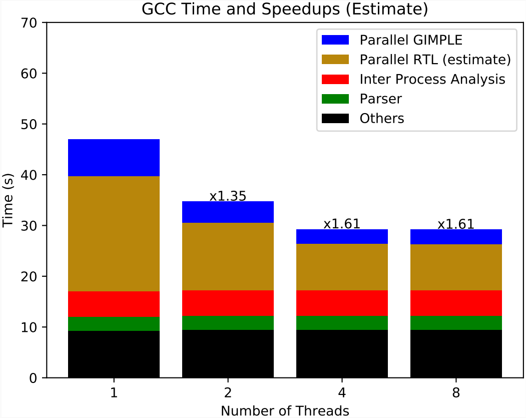
- **Results by parallelizing GIMPLE**
- **Mean of 30 samples**





Results

- The same approach can be used to parallelize RTL
- Using the GIMPLE results



Motivation

- **Where can we use these parallel processors in a compiler?**
  - Intra Process Analysis is a easy answer
- **How much the improvement is?**
  - Without much optimization, $1.6\times$ using 4 threads
  - Better results will require more effort
- **Is there projects that can be benefited from this?**
  - GCC
  - ...What else?

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TODOs

- **What is left to do:**
  - Fix all race conditions in GIMPLE
  - Fix all C11 `__thread` occurrences
    - *Initialize Inter-Pass objects at* `::execute` *time*
    - *Per-thread attributes initialized at spawn time*
  - Make this build pass the testsuite
  - Parallelize RTL
  - Parallelize IPA (useful for LTO?)
  - Communicate with Make for automatic threading

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References i

- Karl Rupp (2018). *42 Years of Microprocessor Trend Data.* URL: https://github.com/karlrupp/microprocessor-trend-data.
- D.B. Wortman and M.D. Junkin (Jan. 1992). "A Concurrent Compiler for Modula-2+". In: 27, pp. 68–81. DOI: 10.1145/143103.120025.

Repositories

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https://github.com/giulianobelinassi/gcc-timer-analysis

https://gitlab.com/flusp/gcc/tree/giulianob_parallel

https://gcc.gnu.org/wiki/ParallelGcc

Thank you!