Improving the Gnu Compiler Collection

Uday Khedker

(www.cse.iitb.ac.in/~uday)

GCC Resource Center,
Department of Computer Science and Engineering,
Indian Institute of Technology, Bombay

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Outline

- Introduction and motivation
- Understanding GCC
- Improving machine independent optimizations in GCC
- Improving machine descriptions and intruction selection in GCC

Part 1

Introduction and Motivation

Why GCC?

- An Informal Group

- A Desire

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  - CSE faculty members at IITB: Uday Khedker
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  Performing research grounded in theory and corroborated by empirical evidence
  - Exploring research issues in real compilers
  - Demonstrating the relevance and effectiveness of our research in real compilers

A Modest Start in 2003...

- Our Tool of Experiment

- Our Guinea Pigs

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- Our Tool of Experiment The Gnu Compiler Collection
  - Compiler generation framework
    Stable compiler generated for several dozen targets
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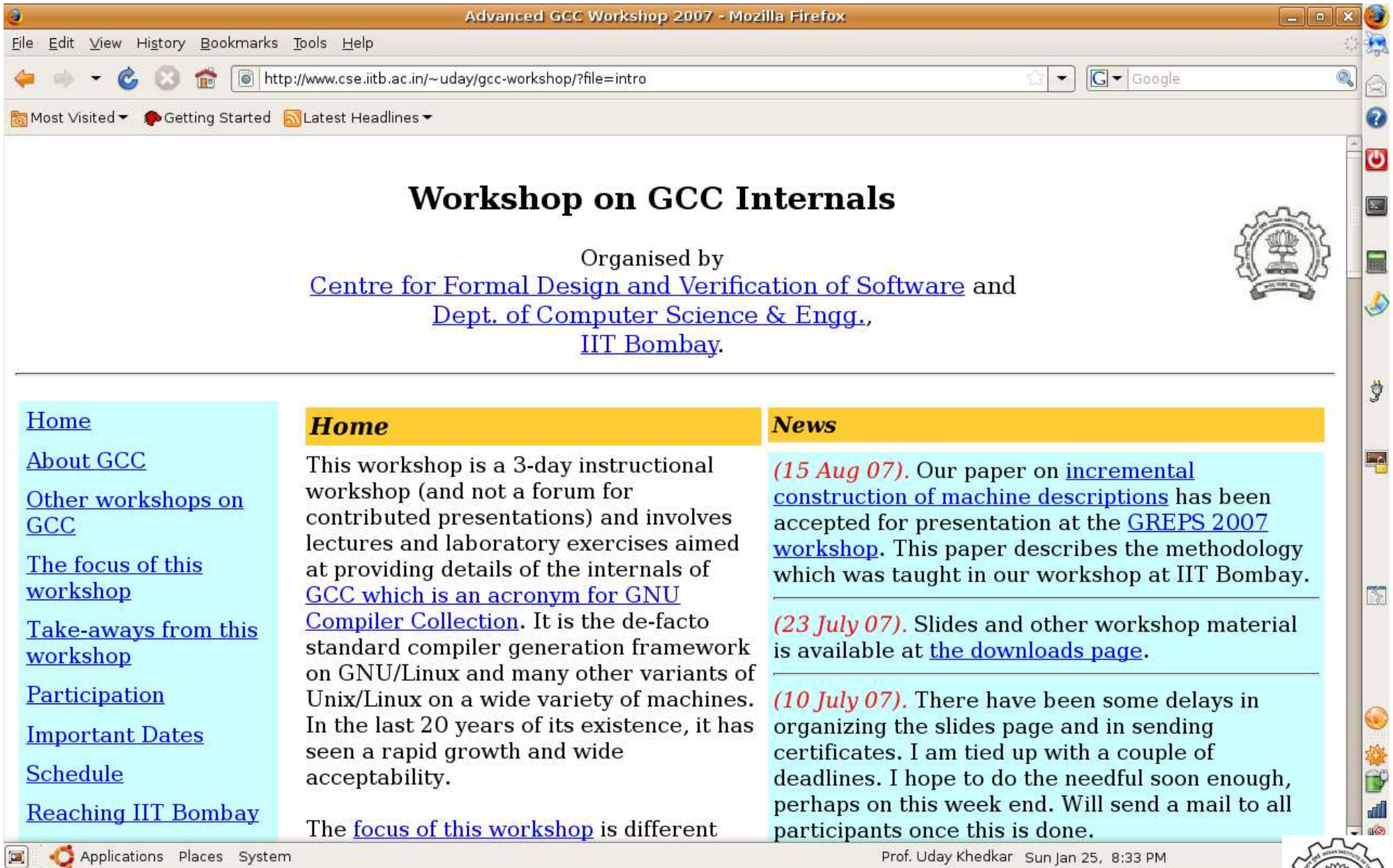
- Our Guinea Pigs
  - Several unsuspecting M.Tech. students, external B.E. students, and project engineers

And Then in 2007...



And then in 2008...

Thanks to small seed grants from IITB and IBM Faculty Award...

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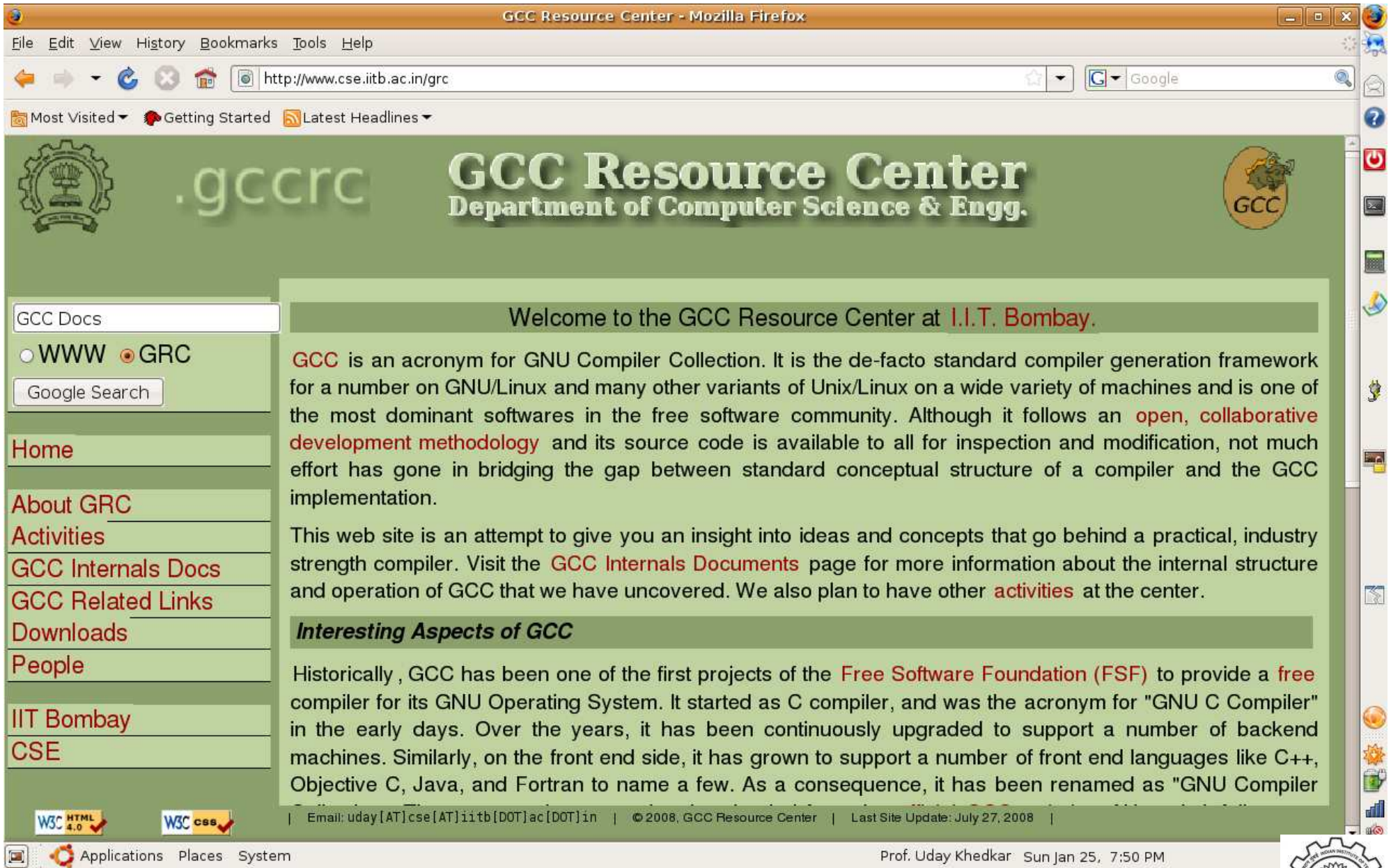

Finally in 2009...

- A generous grant from the Department of Information Technology, Ministry of Communication and Information Technology, Government of India

July 2009...


Essential Abstractions in GCC '09, Workshop on GCC Internals - Konqueror
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Essential Abstractions in GCC '09
A Workshop on GCC Internals by GCC Resource Center
Department of Computer Science & Engineering
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This workshop is a 3-day instructional workshop (and not a forum for contributed presentations) and involves lectures and laboratory exercises aimed at providing details of the internals of GCC which is an acronym for GNU Compiler Collection. It is the de-facto standard compiler generation framework on GNU/Linux and many variants of Unix. In the last 20 years of its existence, it has seen a rapid growth and wide acceptability.
Take-aways from the Workshop
After attending this workshop
A teacher of compiler construction will be able to take examples of real compilation processes to illustrate the difference phases of compilation
A compiler developer wanting to retarget GCC to a new machine will know how to write machine descriptions systematically
A researcher exploring retargetable compilation will be exposed to real issues in an industry strength compiler
A researcher exploring machine independent optimizations will be able to add data flow analysis based optimization passes to GCC
A software engineer will be exposed to the architecture of a very large and very successful software
Who should attend this workshop?
Anybody who has done at least a first level undergraduate course in compiler construction and has some experience of either working in compilers or teaching compilers. A sound understanding of the process of compilation is a must. Familiarity with Unix/Linux (particularly, the command line style of working) is absolutely necessary.
About GCC
GCC, an acronym for GNU Compiler Collection, is a compiler generation framework which generates production quality optimizing compilers from descriptions of target platforms. It follows an open development model whereby its source is available for all for inspection and modification. It supports a wide variety of source languages and target machines (including operating system specific variants) in a ready-to-deploy form. Besides, new machines can be added by describing instruction set architctures and some other information (eg. calling conventions).
Novices may want to see the Wikipedia introduction to GCC. For experts, the GCC page contains a wealth of information including installation instructions, reference manuals (which include users' guides as well as details of GCC internals), a set of frequently asked questions, a wiki page for
Applications Places System
Prof. Uday Khedkar Sat May 23, 9:20 AM

Objectives of GCC Resource Center

1. To support the open source movement
   Providing training and technical know-how of the GCC framework to academia and industry
2. To include better technologies in GCC
   Whole program optimization, Optimizer generation, Tree tiling based instruction selection.
3. To facilitate easier and better quality deployments/enhancements of GCC
   Restructuring GCC and devising methodologies for systematic construction of machine descriptions in GCC
4. To bridge the gap between academic research and practical implementation
   Designing suitable abstractions of GCC architecture

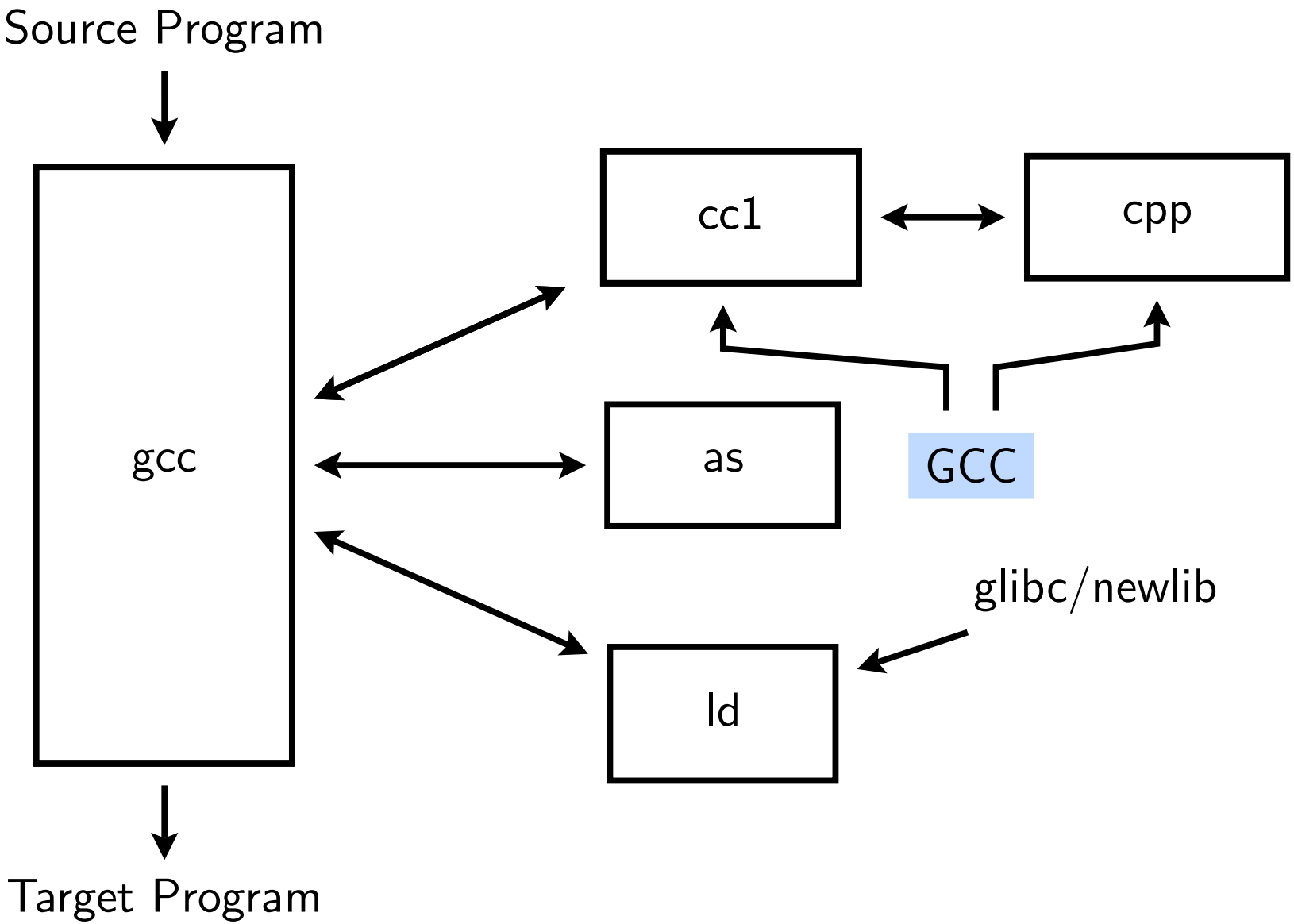
Broad Research Goals of GCC Resource Center

- Using GCC as a means
  - Adding new optimizations to GCC
  - Adding flow and context sensitive analyses to GCC (In particular, pointer analysis)
- Using GCC as an end in itself
  - Changing the retargetability mechanism of GCC
  - Cleaning up the machine descriptions of GCC
  - Systematic construction of machine descriptions
  - Facilitating optimizer generation in GCC

Part 2

Understanding GCC

The Gnu Tool Chain



Why is Understanding GCC Difficult?

Some of the obvious reasons:

- Comprehensiveness

  GCC is a production quality framework in terms of completeness and practical usefulness

- Open development model

  Could lead to heterogeneity. Design flaws may be difficult to correct

- Rapid versioning

  GCC maintenance is a race against time. Disruptive corrections are difficult

Comprehensiveness of GCC 4.3.1: Wide Applicability

- Input languages supported:
  C, C++, Objective-C, Objective-C++, Java, Fortran, and Ada
- Processors supported in standard releases:
  - Common processors: Alpha, ARM, Atmel AVR, Blackfin, HC12, H8/300, IA-32 (x86), x86-64, IA-64, Motorola 68000, MIPS, PA-RISC, PDP-11, PowerPC, R8C/M16C/M32C, SPU, System/390/zSeries, SuperH, SPARC, VAX
  - Lesser-known target processors: A29K, ARC, ETRAX CRIS, D30V, DSP16xx, FR-30, FR-V, Intel i960, IP2000, M32R, 68HC11, MCORE, MMIX, MN10200, MN10300, Motorola 88000, NS32K, ROMP, Stormy16, V850, Xtensa, AVR32
  - Additional processors independently supported: D10V, LatticeMico32, MeP, Motorola 6809, MicroBlaze, MSP430, Nios II and Nios, PDP-10, TIGCC (m68k variant), Z8000, PIC24/dsPIC, NEC SX architecture

Comprehensiveness of GCC 4.3.1: Size

Source Lines	Number of lines in the main source	2,029,115
	Number of lines in libraries	1,546,826
Directories	Number of subdirectories	3527
Files	Total number of files	57825
	C source files	19834
	Header files	9643
	C++ files	3638
	Java files	6289
	Makefiles and Makefile templates	163
	Configuration scripts	52
	Machine description files	186

(Line counts estimated by the program `sloccount` by David A. Wheeler)

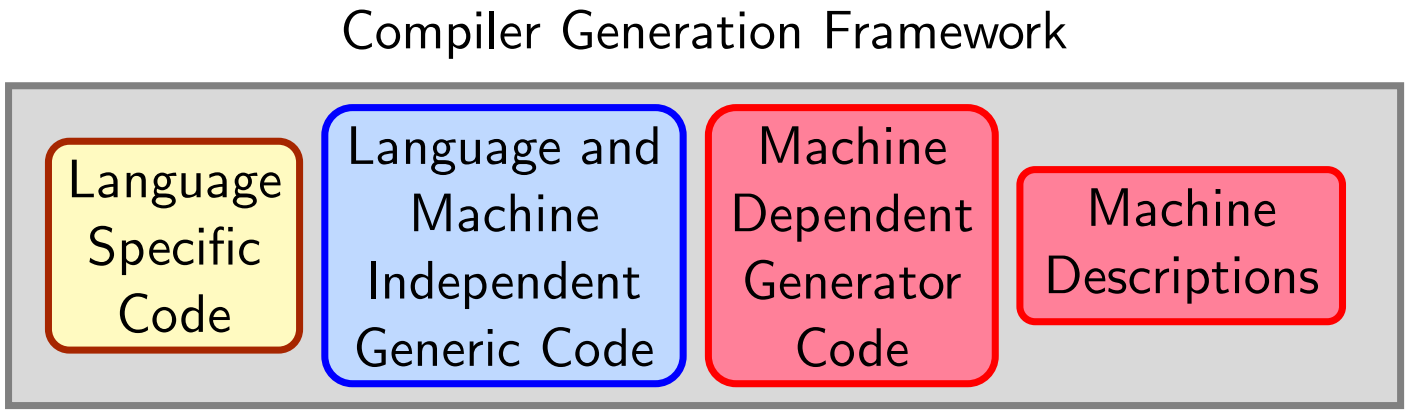
Why is Understanding GCC Difficult?

Deeper reason: GCC is not a *compiler* but a *compiler generation framework*

There are two distinct gaps that need to be bridged:

- Input-output of the generation framework: The target specification and the generated compiler
- Input-output of the generated compiler: A source program and the generated assembly program

The Architecture of GCC



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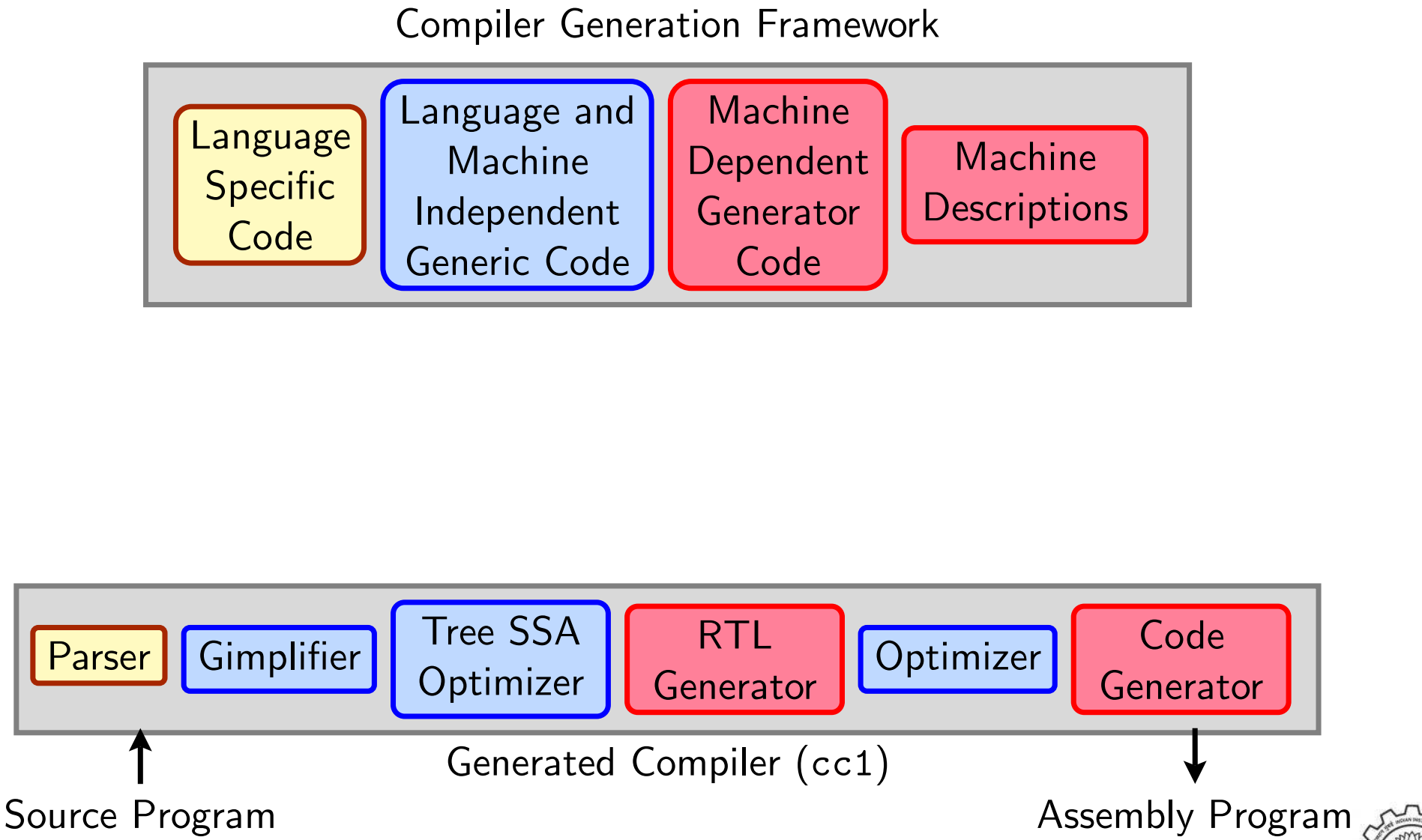

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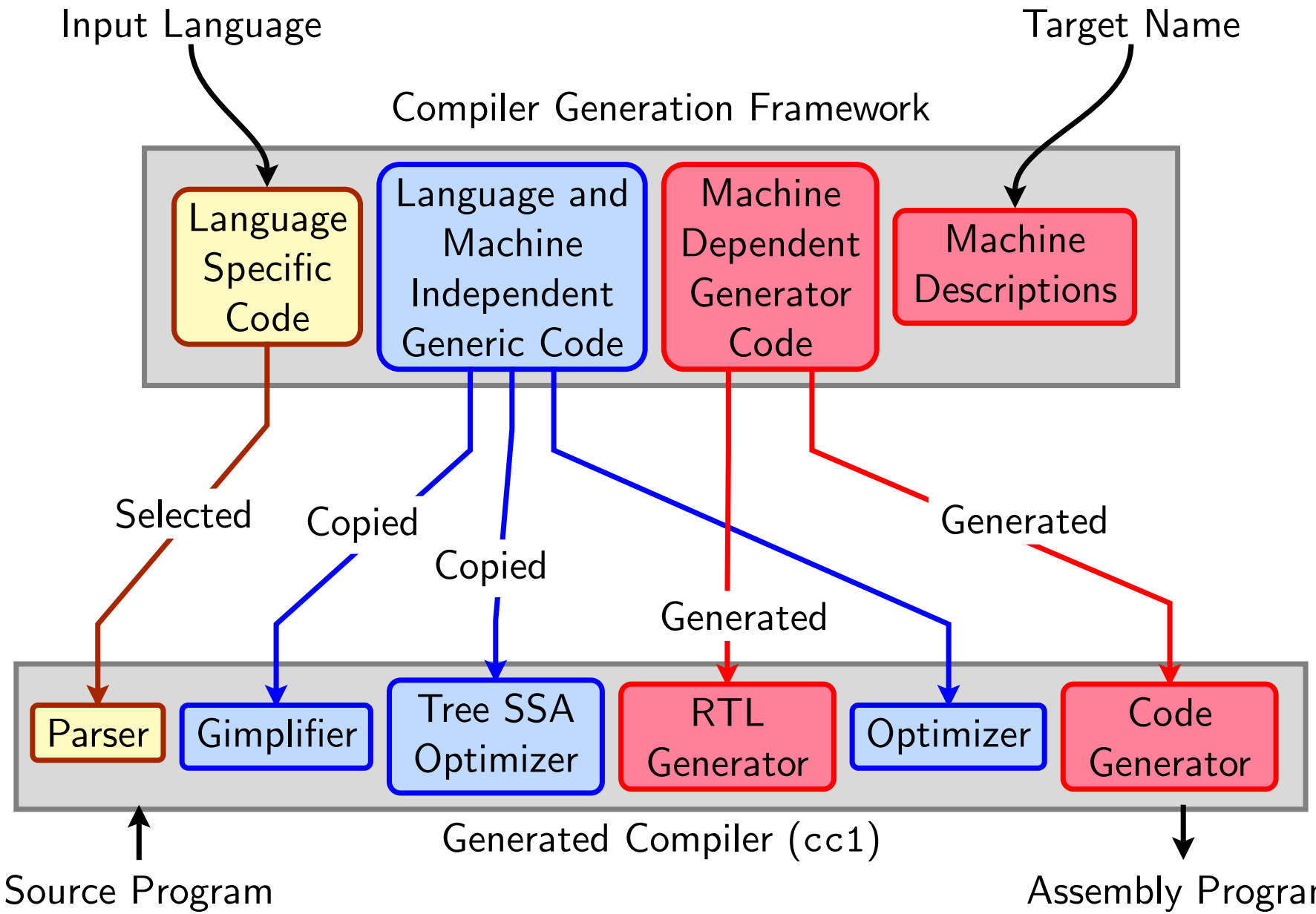

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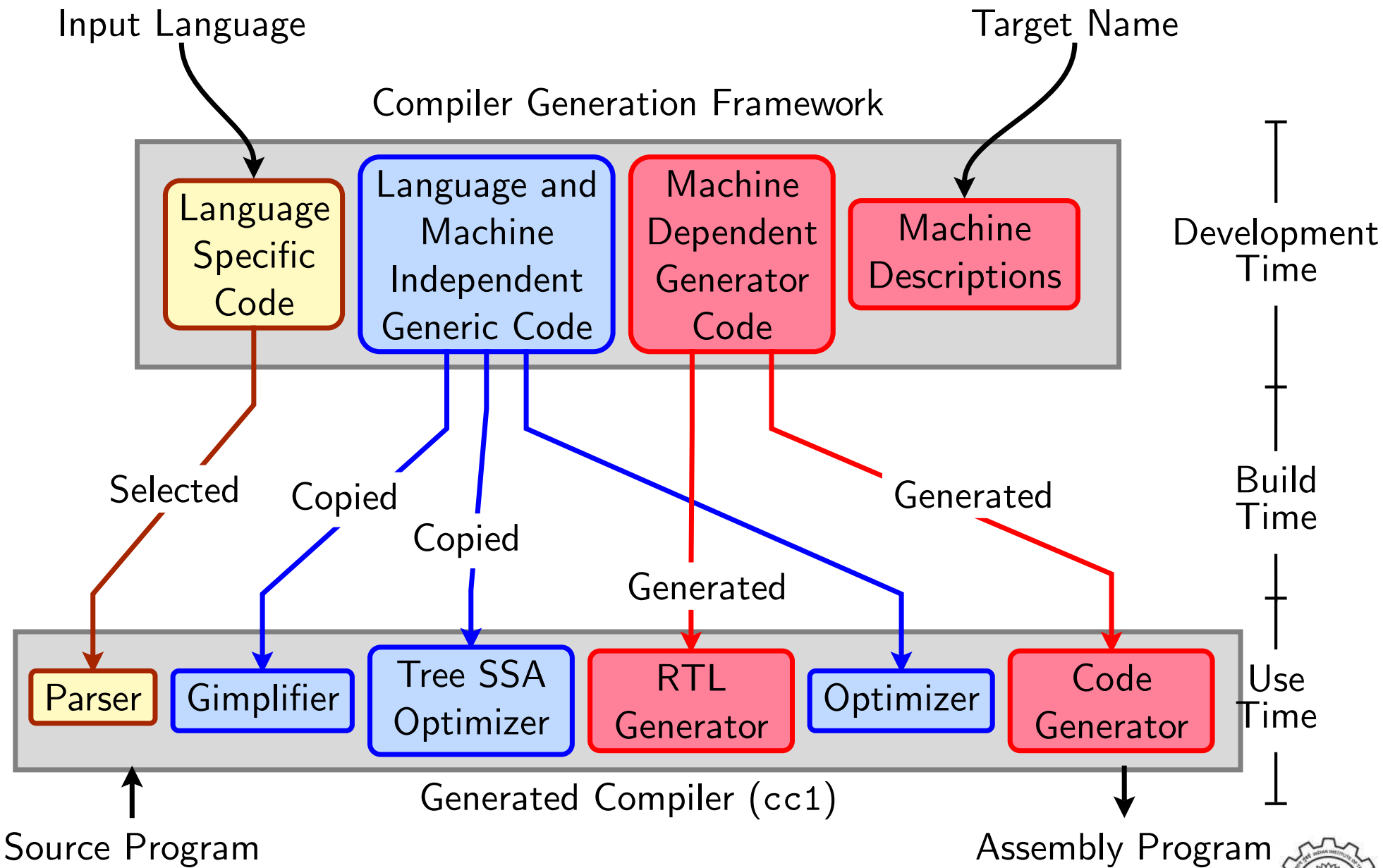
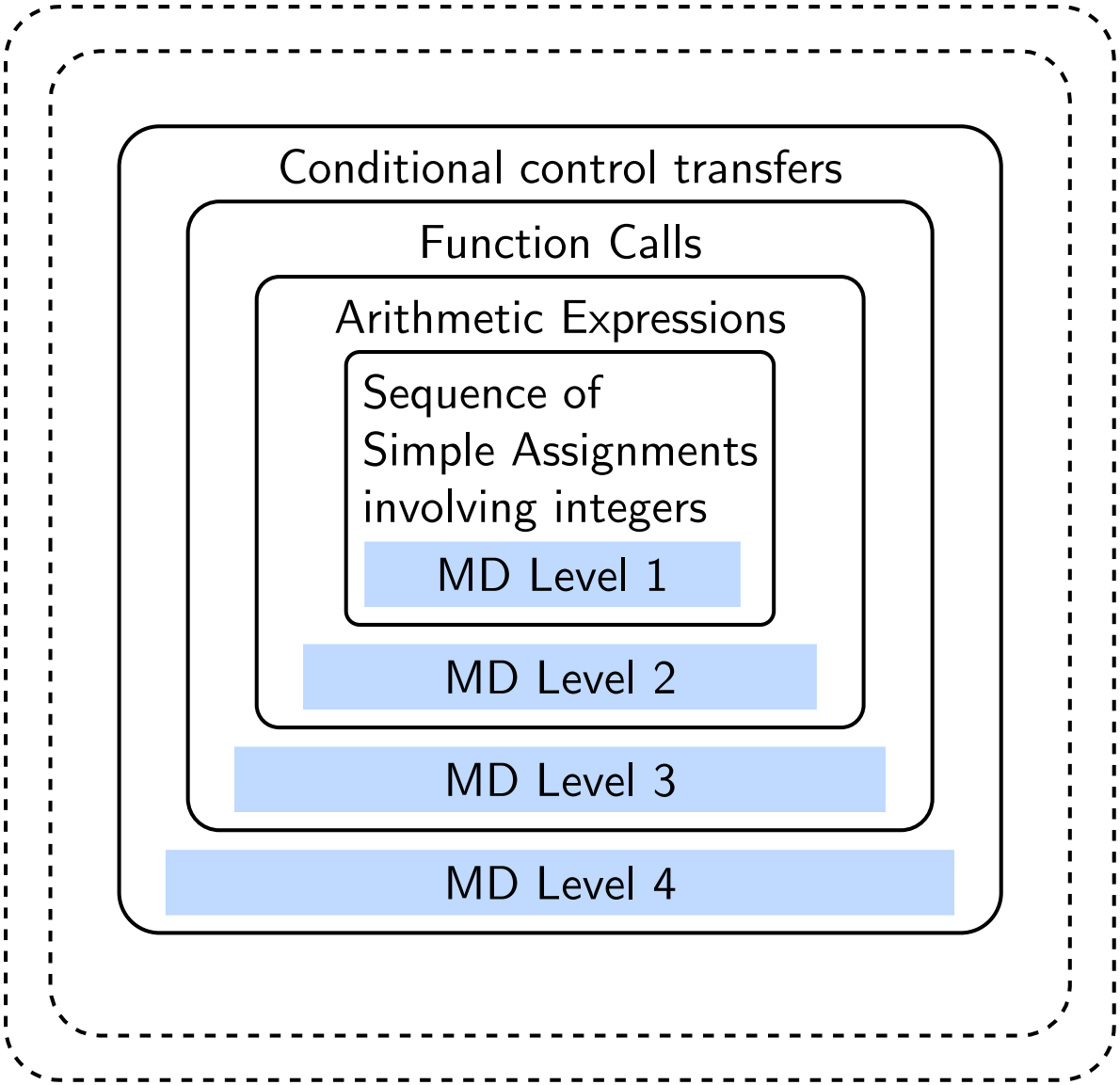


Systematic Development of Machine Descriptions [GREPS 2007]



Systematic Development of Machine Descriptions

- Define different levels of source language
- Identify the minimal information required in the machine description to support each level
  - Successful compilation of any program, and
  - correct execution of the generated assembly program
- Interesting observations
  - It is the increment in the source language which results in understandable increments in machine descriptions rather than the increment in the target architecture
  - If the levels are identified properly, the increments in machine descriptions are monotonic

Systematic Development of Machine Descriptions

- Consequence

  The usual ramp up period into GCC machine descriptions has been brought down from over six months to a couple of weeks

- Current Status
  - Has been used for GCC 4.0.2 for mips target
  - Many people the world over have found it very useful
  - Has been extended to GCC 4.3.1
  - Has been extended to floating point operations

- Further Work
  - Extending it to optimizations specified in machine descriptions
  - Adapting it to possible simplifications in machine descriptions

Part 3

Improving Optimizations in GCC

Improving Machine Independent Optimizations in GCC

- The Problems:
- Our Goals:
- Current Status:

Improving Machine Independent Optimizations in GCC

- The Problems:
  - Primitive algorithms and adhoc designs (too many passes, repetitive work in passes, inappropriateness of IR)
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  - Facilitate generation of optimizers from specifications
    - Clean specifications
    - Systematic local, global, and interprocedural analysis
    - Simple, efficient, generic, and precise algorithms
    - Incremental analyses for aggressive optimizations
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  - Algorithms and formal theory required further is in place

Interprocedural Data Flow Analysis [TOPLAS2007, CC2008]

- Objectives:
- Main Challenge:
- The State of Art:
- Our Breakthrough:
- The Consequences:
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- Further Goal: Design a scalable variant to analyze a million lines of code in a few minutes

Heap Reference Analysis [TOPLAS 2007]

- The Problem:
- Our Objectives:
- Main Challenge:
- Our Key Idea:
- Current status:
- Further Work:

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- Further Work:
  - Improve alias analysis
  - Interprocedural implementation and Performance tuning

Part 4

Improving Machine Descriptions and Instruction Selection

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- The specification mechanism for Machine descriptions is quite adhoc
- Adhoc design decisions

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    When required during gimple to RTL translation, a lot of C code is required
  - Choice of insertion of NOPs

Improving Machine Descriptions and Instruction Selection

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- The machine descriptions are difficult to construct, understand, maintain, and enhance
- GCC has become a hacker's paradise instead of a clean, production quality compiler generation framework

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Current Status:

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  - Fewer rules
  - Simple rules

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- Prototype of new code generator generator (cgg) is being tested in a toy compiler set up

Part 5

Translation Validation of GCC

Translation Validation of GCC

- Problem:
- Our Objectives:
- Our approach:
- Current Status:
- Further work:

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- Current Status:
  - Formal theory and prototype implementation exists
  - Soundness has been shown
- Further work:
  - Cleaning up the theory to systematize the termination criteria
  - Ensuring completeness (more optimizations, more programs)

Linear Types in GCC

- The Problems:
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Linear Types in GCC

- The Problems:
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  - Synchronization and correctness problems in threads
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  - An initial draft of the type system is in place

Part 6

Conclusions

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- GCC is a strange paradox
  - Practically very successful but quite adhoc.
  - Needs significant improvements
- GCC Resource Center at IIT Bombay
  - Synergy from group activities
  - Long term commitment to challenging research problems
  - A desire to explore real issues in real compilers
    A dream to improve GCC

Last but not the least . . .

Thank You!