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Building Domain-Specific Languages

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Acknowledgments

A researcher once told me after a talk I had given that "It was clear there was a single mind behind these tools." In reality, there are many minds behind the ideas in my language tools and research, though I'm a benevolent dictator with specific opinions about how ANTLR should work. At the least, dozens of people let me bounce ideas off them, and I get a lot of great ideas from the people on the ANTLR interest list.[1]

Concerning the ANTLR v3 tool, I want to acknowledge the following contributors for helping with the design and functional requirements: Sriram Srinivasan (Sriram had a knack for finding holes in my *LL(*)* algorithm), Loring Craymer, Monty Zukowski, John Mitchell, Ric Klaren, Jean Bovet, and Kay Roepke. Matt Benson converted all my unit tests to use JUnit and is a big help with Ant files and other goodies. Juergen Pfundt contributed the ANTLR v3 task for Ant. I sing Jean Bovet's praises every day for his wonderful ANTLRWorks grammar development environment. Next comes the troop of hardworking ANTLR language target authors, most of whom contribute ideas regularly to ANTLR:[2] Jim Idle, Michael Jordan (no not that one), Ric Klaren, Benjamin Niemann, Kunle Odutola, Kay Roepke, and Martin Traverso.

I also want to thank (then Purdue) professors Hank Dietz and Russell Quong for their support early in my career. Russell also played a key role in designing the semantic and syntactic predicates mechanism.

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1. See http://www.antlr.org:8080/pipermail/antlr-interest/.
2. See http://www.antlr.org/wiki/display/ANTLR3/Code+Generation+Targets.

Preface

In August 1993, I finished school and drove my overloaded moving van to Minnesota to start working. My office mate was a curmudgeonly astrophysicist named Kevin, who has since become a good friend. Kevin has told me on multiple occasions that only physicists do real work and that programmers merely support physicists. Because all I do is build language tools to support programmers, I am at least two levels of indirection away from doing anything useful.[3] Now, Kevin also claims that Fortran 77 is a good enough language for anybody and, for that matter, that Fortran 66 is probably sufficient, so one might question his judgment. But, concerning my usefulness, he was right—I am fundamentally lazy and would much rather work on something that made other people productive than actually do anything useful myself. This attitude has led to my guiding principle:[4]

Why program by hand in five days what you can spend five years of your life automating?

Here's the point: The first time you encounter a problem, writing a formal, general, and automatic mechanism is expensive and is usually overkill. From then on, though, you are much faster and better at solving similar problems because of your automated tool. Building tools can also be much more fun than your real job. Now that I'm a professor, I have the luxury of avoiding real work for a living.

---

3. The irony is that, as Kevin will proudly tell you, he actually played solitaire for at least a decade instead of doing research for his boss—well, when he wasn't scowling at the other researchers, at least. He claimed to have a winning streak stretching into the many thousands, but one day Kevin was caught overwriting the game log file to erase a loss (apparently per his usual habit). A holiday was called, and much revelry ensued.

4. Even as a young boy, I was fascinated with automation. I can remember endlessly building model ships and then trying to motorize them so that they would move around automatically. Naturally, I proceeded to blow them out of the water with firecrackers and rockets, but that's a separate issue.

My passion for the last two decades has been ANTLR, ANother Tool for Language Recognition. ANTLR is a parser generator that automates the construction of language recognizers. It is a program that writes other programs.

From a formal language description, ANTLR generates a program that determines whether sentences conform to that language. By adding code snippets to the grammar, the recognizer becomes a translator. The code snippets compute output phrases based upon computations on input phrases. ANTLR is suitable for the simplest and the most complicated language recognition and translation problems. With each new release, ANTLR becomes more sophisticated and easier to use. ANTLR is extremely popular with 5,000 downloads a month and is included on all Linux and Mac OS X distributions. It is widely used because it:

- Generates human-readable code that is easy to fold into other applications
- Generates powerful recursive-descent recognizers using *LL(*)*, an extension to *LL(k)* that uses arbitrary lookahead to make decisions
- Tightly integrates StringTemplate,[5] a template engine specifically designed to generate structured text such as source code
- Has a graphical grammar development environment called ANTLRWorks[6] that can debug parsers generated in any ANTLR target language
- Is actively supported with a good project website and a high-traffic mailing list[7]
- Comes with complete source under the BSD license
- Is extremely flexible and automates or formalizes many common tasks
- Supports multiple target languages such as Java, C#, Python, Ruby, Objective-C, C, and C++

Perhaps most importantly, ANTLR is much easier to understand and use than many other parser generators. It generates essentially what you would write by hand when building a recognizer and uses technology that mimics how your brain generates and recognizes language (see Chapter 2, *The Nature of Computer Languages*, on page 36).

5. See http://www.stringtemplate.org.
6. See http://www.antlr.org/works.
7. See http://www.antlr.org:8080/pipermail/antlr-interest/.

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You generate and recognize sentences by walking their implicit tree structure, from the most abstract concept at the root to the vocabulary symbols at the leaves. Each subtree represents a phrase of a sentence and maps directly to a rule in your grammar. ANTLR's grammars and resulting top-down recursive-descent recognizers thus feel very natural. ANTLR's fundamental approach dovetails your innate language process.

Why a Completely New Version of ANTLR?

For the past four years, I have been working feverishly to design and build ANTLR v3, the subject of this book. ANTLR v3 is a completely rewritten version and represents the culmination of twenty years of language research. Most ANTLR users will instantly find it familiar, but many of the details are different. ANTLR retains its strong mojo in this new version while correcting a number of deficiencies, quirks, and weaknesses of ANTLR v2 (I felt free to break backward compatibility in order to achieve this). Specifically, I didn't like the following about v2:[8]

- The v2 lexers were very slow albeit powerful.
- There were no unit tests for v2.
- The v2 code base was impenetrable. The code was never refactored to clean it up, partially for fear of breaking it without unit tests.
- The linear approximate *LL(k)* parsing strategy was a bit weak.
- Building a new language target duplicated vast swaths of logic and print statements.
- The AST construction mechanism was too informal.
- A number of common tasks were not easy (such as obtaining the text matched by a parser rule).
- It lacked the semantic predicates hoisting of ANTLR v1 (PCCTS).
- The v2 license/contributor trail was loose and made big companies afraid to use it.

ANTLR v3 is my answer to the issues in v2. ANTLR v3 has a very clean and well-organized code base with lots of unit tests. ANTLR generates extremely powerful *LL(*)* recognizers that are fast and easy to read.

8. See http://www.antlr.org/blog/antlr3/antlr2.bashing.tml for notes on what people did not like about v2. ANTLR v2 also suffered because it was designed and built while I was under the workload and stress of a new start-up (jGuru.com).

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Many common tasks are now easy by default. For example, reading in some input, tweaking it, and writing it back out while preserving whitespace is easy. ANTLR v3 also reintroduces semantic predicates hoisting. ANTLR's license is now BSD, and all contributors must sign a "certificate of origin."[9] ANTLR v3 provides significant functionality beyond v2 as well:

- Powerful *LL(*)* parsing strategy that supports more natural grammars and makes it easier to build them
- Auto-backtracking mode that shuts off all grammar analysis warnings, forcing the generated parser to simply figure things out at runtime
- Partial parsing result memoization to guarantee linear time complexity during backtracking at the cost of some memory
- Jean Bovet's ANTLRWorks GUI grammar development environment
- StringTemplate template engine integration that makes generating structured text such as source code easy
- Formal AST construction rules that map input grammar alternatives to tree grammar fragments, making actions that manually construct ASTs no longer necessary
- Dynamically scoped attributes that allow distant rules to communicate
- Improved error reporting and recovery for generated recognizers
- Truly retargetable code generator; building a new target is a matter of defining StringTemplate templates that tell ANTLR how to generate grammar elements such as rule and token references

This book also provides a serious advantage to v3 over v2. Professionally edited and complete documentation is a big deal to developers. You can find more information about the history of ANTLR and its contributions to parsing theory on the ANTLR website.[10,11]

Look for *Improved in v3* and *New in v3* notes in the margin that highlight improvements or additions to v2.

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9. See http://www.antlr.org/license.html.
10. See http://www.antlr.org/history.html.
11. See http://www.antlr.org/contributions.html.

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Who Is This Book For?

The primary audience for this book is the practicing software developer, though it is suitable for junior and senior computer science undergraduates. This book is specifically targeted at any programmer interested in learning to use ANTLR to build interpreters and translators for domain-specific languages. Beginners and experts alike will need this book to use ANTLR v3 effectively. For the most part, the level of discussion is accessible to the average programmer. Portions of Part III, however, require some language experience to fully appreciate. Although the examples in this book are written in Java, their substance applies equally well to the other language targets such as C, C++, Objective-C, Python, C#, and so on. Readers should know Java to get the most out of the book.

What's in This Book?

This book is the best, most complete source of information on ANTLR v3 that you'll find anywhere. The free, online documentation provides enough to learn the basic grammar syntax and semantics but doesn't explain ANTLR concepts in detail. This book helps you get the most out of ANTLR and is required reading to become an advanced user. In particular, Part III provides the only thorough explanation available anywhere of ANTLR's *LL(*)* parsing strategy.

This book is organized as follows. Part I introduces ANTLR, describes how the nature of computer languages dictates the nature of language recognizers, and provides a complete calculator example. Part II is the main reference section and provides all the details you'll need to build large and complex grammars and translators. Part III treks through ANTLR's predicated-*LL(*)* parsing strategy and explains the grammar analysis errors you might encounter. Predicated-*LL(*)* is a totally new parsing strategy, and Part III is essentially the only written documentation you'll find for it. You'll need to be familiar with the contents in order to build complicated translators.

Readers who are totally new to grammars and language tools should follow the chapter sequence in Part I as is. Chapter 1, *Getting Started with ANTLR*, on page 23 will familiarize you with ANTLR's basic idea; Chapter 2, *The Nature of Computer Languages*, on page 36 gets you ready to study grammars more formally in Part II; and Chapter 3, *A Quick Tour for the Impatient*, on page 61 gives your brain something

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concrete to consider. Familiarize yourself with the ANTLR details in Part II, but I suggest trying to modify an existing grammar as soon as you can. After you become comfortable with ANTLR's functionality, you can attempt your own translator from scratch. When you get grammar analysis errors from ANTLR that you don't understand, then you need to dive into Part III to learn more about *LL(*)*.

Those readers familiar with ANTLR v2 should probably skip directly to Chapter 3, *A Quick Tour for the Impatient*, on page 61 to figure out how v3 differs. Chapter 4, *ANTLR Grammars*, on page 88 is also a good place to look for features that v3 changes or improves on.

If you are familiar with an older tool, such as YACC [Joh79], I recommend starting from the beginning of the book as if you were totally new to grammars and language tools. If you're used to JavaCC[12] or another top-down parser generator, you can probably skip Chapter 2, *The Nature of Computer Languages*, on page 36, though it is one of my favorite chapters.

I hope you enjoy this book and ANTLR v3 as much as I have enjoyed writing them!

Terence Parr
March 2007
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12. See https://javacc.dev.java.net.

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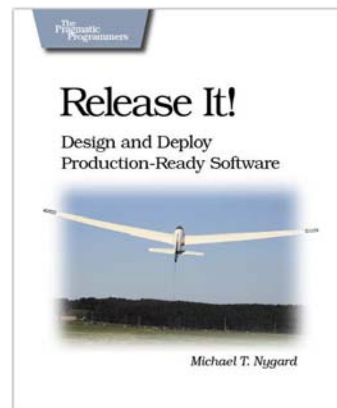

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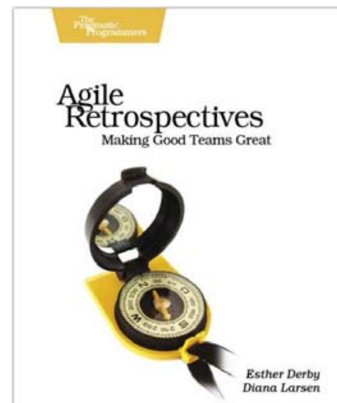

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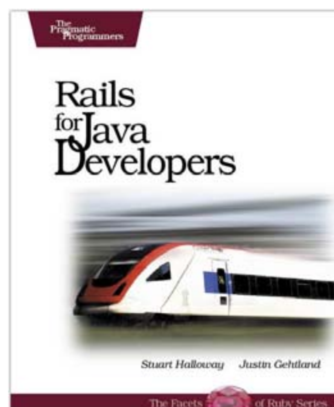

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