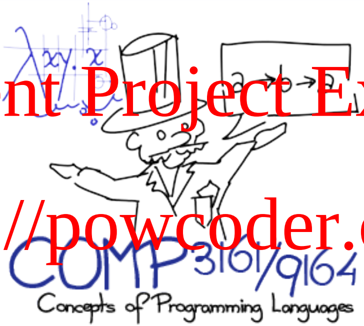

Introduction

Dr. Liam O'Connor
University of Edinburgh LFCS
UNSW, Term 3 2020

Who are we?

I am Liam O'Connor, a lecturer at the University of Edinburgh, and former convenor of this course. I am pre-recording the first 5 weeks of lectures for this iteration, to ensure a smooth hand-over to..

Dr. Christine Rizkallah, who is the new lecturer in charge. She is a lecturer at UNSW who works on, among other things, trustworthy systems and formal methods projects with data61.

Vivian Dang and Matthew Di Meglio are the tutors for this year. Vivian works with Christine on security type systems, and Matthew will be imminently starting his PhD at Edinburgh.

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Contacting Us

http://www.cse.unsw.edu.au/~cs3161

Forum

There is a Piazza forum available on the website. Questions about course content should typically be made there. You can ask us private questions to avoid spoiling solutions to other students.

I highly recommend disabling the Piazza Careers rubbish.

Administrative questions should be sent to cs3161@cse.unsw.edu.au.

What do we expect?

Maths

This course uses a significant amount of *discrete mathematics*. You will need to be reasonably comfortable with *logic*, *set theory* and *induction*. MATH1081 is neither necessary nor sufficient for aptitude in these skills.

Programming

We expect you to be familiar with C and at least one other programming language. Course assignments 1 and 2 are in Haskell. Only very simple Haskell is required, but some self-study may be needed.

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Assessment

Assignment 0	15%
Assignment 1	17.5%
Assignment 2	17.5%
Final Exam	50%

Tutorials

- Start this week on Thursday and Friday.
- You may change tutorials, just seek approval first.
- Please attempt some of the questions beforehand.

Assignment 0

- Focuses on theory and proofs.
- It will be released in Week 3 and due in Week 4.
- Aim to have marks back by census date (not guaranteed).
- 10% penalty for one day late, 25% for two, 50% for three and 100% for four+.

Assignments

- Given a formal specification, implement in Haskell.
- Released around Week 5 and Week 8

- Approximately 2 weeks to complete each assignment.
- 10% penalty for one day late, 25% for two, 50% for three and 100% for four+.

Lectures

- My lectures (Weeks 1-5) will be pre-recorded, Christine's delivered through Blackboard Collaborate in the lecture time slot.
- We may use the lecture time slot for consultations in Weeks 1-5.
- All board-work will be done digitally and made available to you.
- Separate lecture notes are also published.

Books

There is no textbook for this course. Regular written lecture notes are made available throughout the semester, along with challenge exercises.

Much of the course material is covered in these two excellent books, however their explanations may differ and the usual disclaimers apply — this course does not follow these books exactly:

- *Types and Programming Languages* by Benjamin Pierce, MIT Press. `https://www.cis.upenn.edu/~bcpierce/tapl/`
- *Practical Foundations for Programming Languages* by Bob Harper, Cambridge University Press. `http://www.cs.cmu.edu/~rwh/pfpl.html`

Course Content

This is a programming language *appreciation* course. This means we focus on the three R's of computer science, giving you the skills to:

Read and understand new programming languages;

Write your own programming languages; and

Reason about programming languages in a rigorous way.

Why Read?

The choice of programming language affects nearly every aspect of a system:

- Design
- Development Costs and Productivity
- Safety and Security
- Performance

The Obvious

Learning to read and understand new programming languages is a vital skill in any computing discipline.

Why Write?

You may not implement a general-purpose programming language like C or Haskell in your career.

However..

Every company has its own hand-rolled *domain-specific* language for accomplishing some task, often *embedded* in another language in a very ad-hoc and ugly way.

Example

XSLT, Perl scripts for processing text files, CSE's give system, etc.

Learn how to make a PL properly and save yourself and your colleagues from headaches.

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Why Reason?

Programming languages are formal languages. Formal specification and proof allows us to:

- Design languages *better*, avoiding *undefined behaviour* and other goblins.
- Make languages easier to process and parse. COMP3131
- Give a mathematical meaning to programs, allowing for *formal verification* of programs. COMP4161, COMP2111, COMP6721
- Develop algorithms to find bugs automatically. COMP3153
- Rigorously analyse optimisations and other program transformations.

These tools are also very important for the pursuit of research in programming languages.

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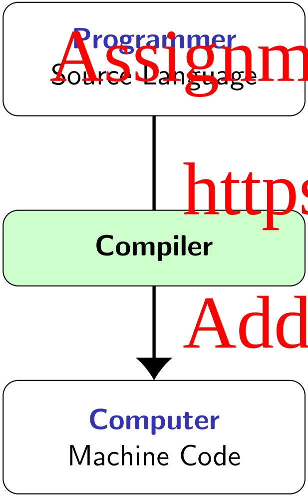
Bridging the Gap

Programmer
Source Language

Computers can't typically execute source code directly.

Computer
Machine Code

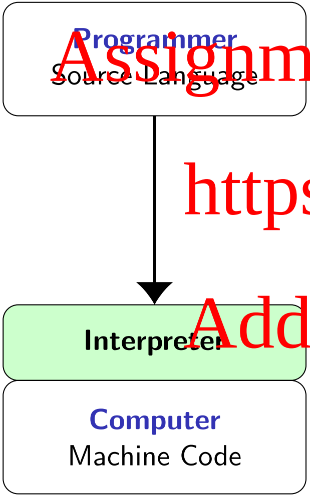
Bridging the Gap



A compiler translates from source code to a target language, typically machine code.

Example: C, C++, Haskell, Rust

Bridging the Gap

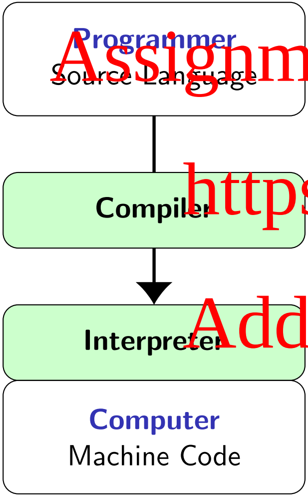


An interpreter executes a program as it reads the source code.

Examples: Perl, Python, JavaScript

JIT compilers complicate this picture somewhat.

Bridging the Gap



Some languages make use of a hybrid approach. First translating the source language to an intermediate language (abstract or virtual machine), then interpreting that.

Examples: Java, C#

Stages of a Compiler

The first stage of a compiler is called a *lexer*, which, given an input string of source code, produces a stream of *tokens* or *lexemes*, discarding irrelevant information like whitespace or comments.

Example (C)

```
int foo () {
  int i;
  i = 11;
  if (i > 5) {
    i = i - 1;
  }
  return i;
}
```

lexer →

```
Ident "int"  Ident "foo"
LParen  RParen  LBrace
Ident "int"  Ident "i"  Semi
Ident "i"  . . .
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Stages of a Compiler

A *parser* converts the stream of tokens from the lexer into a *parse tree* or *abstract syntax tree*:

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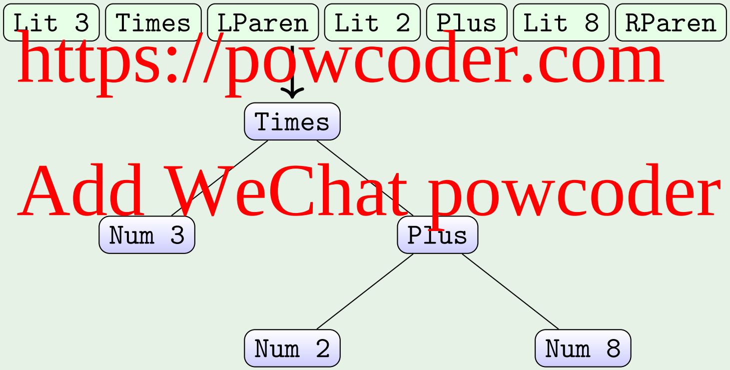

Grammars

The structure of lexemes expected to produce certain parse trees is called a *grammar*.

Example (Informal grammar for C)

C function definitions consist of:

- an identifier (return type), followed by
- an identifier (function name), followed by
- a possibly empty sequence of arguments, enclosed in parentheses, then
- a statement (function body).

Conclusions

This kind of definition is way too verbose and too imprecise to specify an implementation.

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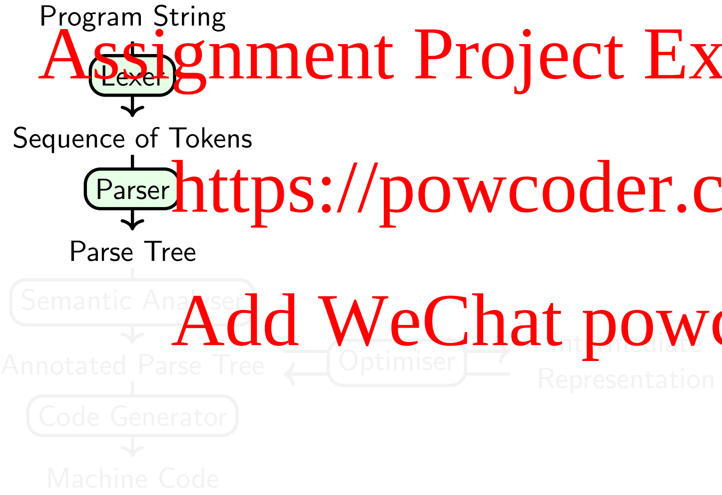
Backus-Naur Form

Specify grammatical productions by using a bare-bones recursive notation. *Non-terminals* are in *italics* whereas *terminals* are in **this typeface**.

Example (C subset)

$$
\begin{array}{lcl}
\mathit{funDef} & ::= & \mathit{Ident}_1\ \mathit{Ident}_2\ \mathbf{(}\ \mathit{args}\ \mathbf{)}\ \mathit{stmt} \\
\mathit{stmt} & ::= & \mathit{expr}\ \mathbf{;}\ \mid\ \mathbf{if}\ \mathbf{(}\ \mathit{expr}\ \mathbf{)}\ \mathit{stmt}\ \mathbf{else}\ \mathit{stmt} \\
 & \mid & \mathbf{return}\ \mathit{expr}\ \mathbf{;}\ \mid\ \mathbf{\{}\ \mathit{locDec}\ \mathit{stmts}\ \mathbf{\}} \\
 & \mid & \mathbf{while}\ \mathbf{(}\ \mathit{expr}\ \mathbf{)}\ \mathit{stmt} \\
\mathit{stmts} & ::= & \varepsilon\ \mid\ \mathit{stmt}\ \mathit{stmts} \\
\mathit{expr} & ::= & \mathit{Number}\ \mid\ \mathit{Ident}\ \mid\ \mathit{expr}_1\ \mathbf{+}\ \mathit{expr}_2 \\
 & \mid & \mathit{Ident}\ \mathbf{=}\ \mathit{expr}\ \mid\ \mathit{Ident}\ \mathbf{(}\ \mathit{expr}\ \mathbf{)} \\
\mathit{locDec} & ::= & \mathit{Ident}_1\ \mathit{Ident}_2\ \mathbf{;} \\
\mathit{args} & ::= & \varepsilon\ \mid\ \cdots
\end{array}
$$

Stages of a Compiler



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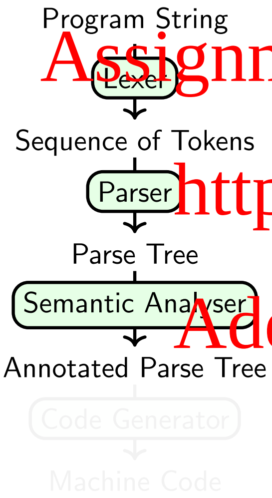
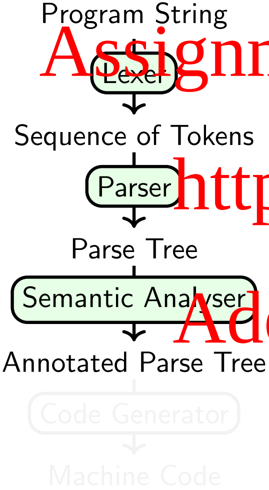


Optimiser
Intermediate Representation

Semantic Analysis

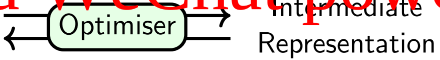
- Checks variable scoping
- Static semantics checks: most notably type checking
- Adds extra information to the tree.

Stages of a Compiler



Optimisation

- Loop unrolling, loop fusion
- Inlining, specialisation
- Sometimes transforms the tree dramatically.



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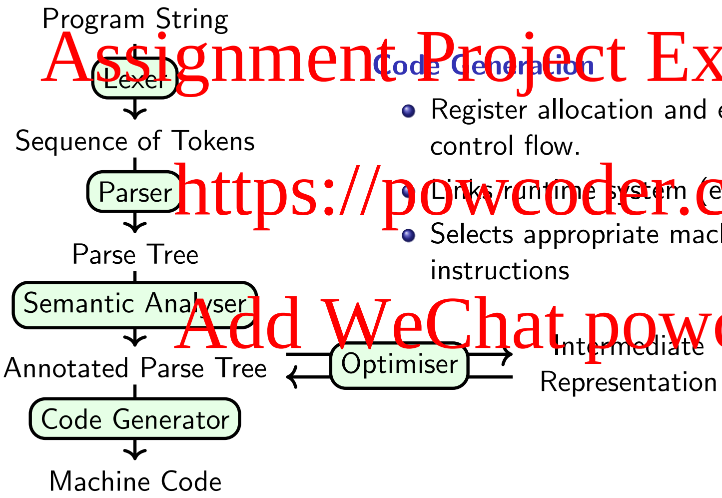

Code Generation

- Register allocation and explicit control flow.
- Links runtime system (e.g. GC)
- Selects appropriate machine instructions