COS320: Compiling Techniques

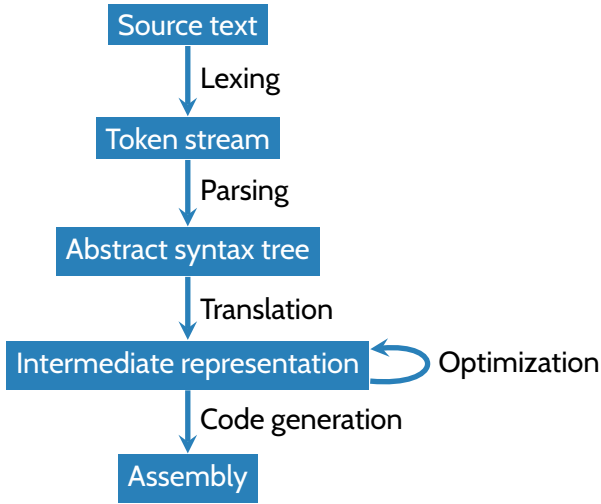
Zak Kincaid

April 30, 2020

- HW5 is due on **Dean's date, 5pm**.
- After this week, drop in office hours 3-4pm on Wednesday, appointments on WASE.
- Final exam
  - Released 9am on May 14, must be submitted by 5pm on May 15th.
  - No time limit. Expected time is 2 hours
  - Open book, open notes, computer allowed. **No collaboration.**
  - Some programming questions – make sure to have a working OCaml installation.
  - Ask questions using private posts on Piazza
  - *Mostly* material since the midterm. Topics:
    - Type systems (be comfortable reading inference rules, writing proof trees)
    - Data flow analysis (translate a global specification into local constraints)
    - Register allocation (graph coloring, coalescing)
    - Control flow analysis (dominators, loops, SSA conversion)

Review

Compiler phases (simplified)

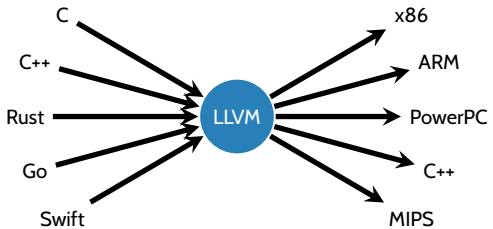


Software engineering

- Compilers are large software projects
  - Decompose the problem into lots of small phases, each of which accomplishes one thing
  - E.g., the optimization phase is also a large piece of software – it too is composed of lots of small individual phases
- Many problems do not have a "right" answer: pick a *convention*, document it well, and adhere to it.
  - E.g., calling conventions, pass environment as first argument to a closure, …

Intermediate representations

- An IR breaks code generation up into two phases. Simpler & easier to implement
- IRs (such as SSA) can drastically simplify optimization
- Makes compiler back-end re-usable



Lexing and parsing

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- Useful tool to have in your toolbox!
  - Parsing useful for programming languages, domain specific languages, custom data formats, ...
  - Lexer generators: lex, flex, **ocamllex**, jflex
  - Parser generators: Yacc, Bison, ANTLR, **menhir**

Type Systems

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$$\frac{J_1 \qquad J_2 \qquad \cdots \qquad J_n}{J} \textsc{Side-condition}$$

  - Succinct way to communicate a precise specification
  - Pervasive in formal logic and programming language theory. Can be used to specify
    - the semantics of programming languages
    - logics for reasoning about programs
    - program analyses
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- Type theory is a large subject and an active area of research
  - Close ties to logic (Curry-Howard correspondence: formulas are types, programs are proofs)
  - More in COS 510

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- Idea: can sometimes transform a global specification into a system of local constraints, which can be solved iteratively

LL parsing revisited

- LL(1) parser can be constructed from *nullable*, *first*, and *follow*, which have the following **global specifications**
  - Fix a grammar $G = (N, \Sigma, R, S)$
  - For any word $\gamma \in (N \cup \Sigma)^*$, define **first**$(\gamma) = \{a \in \Sigma : \gamma \Rightarrow^* aw\}$
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Current research

Conferences

- Programming Language Design and Implementation (PLDI)
- Principles of Programming Languages (POPL)
- Object Oriented Programming Systems, Languages & Applications (OOPSLA)
- Principles and Practice of Parallel Programming (PPoPP)
- Code Generation and Optimization (CGO)
- Compiler Construction (CC)
- International Conference on Functional Programming (ICFP)
- European Symposium on Programming (ESOP)
- Architectural Support for Programming Languages and Operating Systems (ASPLOS)

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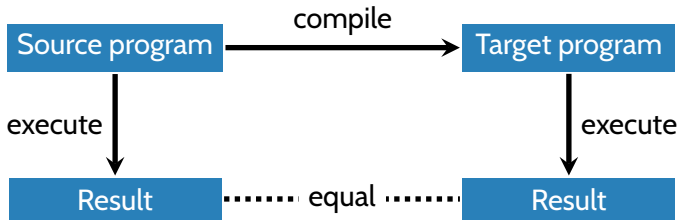

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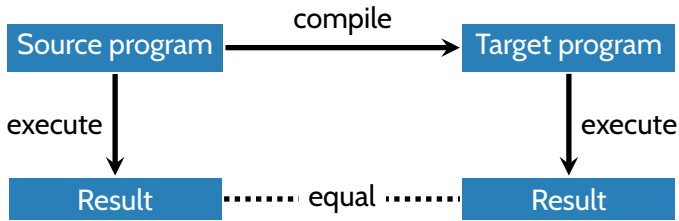

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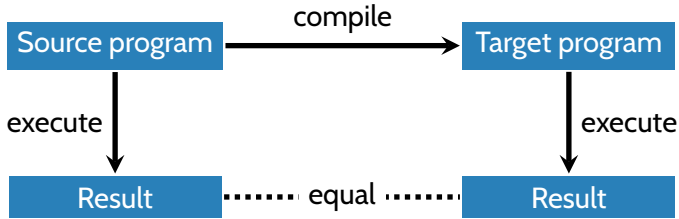

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- Compilers tend to be well-engineered and well-tested, but that does not mean bug-free

Bug-finding in compilers

- CSmith[1]: randomized differential testing of C compilers
  - Randomly generate a C program *without undefined behavior*
    - Integrates program analysis to find interesting test cases
  - Compile with several different compilers
  - Compare the results
- Over 3 years found several real bugs
  - 79 bugs in GCC (25 maximum-priority/release-blocking)
  - 202 bugs in LLVM

[1] Yang et al. Finding and Understanding Bugs in C Compilers, PLDI 2011

Verified compilation

- *CompCert*: (Xavier Leroy, primary developer of OCaml)
  - Optimizing C compiler, implemented and proved correct in the Coq proof assistant
  - Coq proof assistant an (essentially) implementation of a sophisticated type system (CoIC)

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- At Princeton: *CertiCoq* (Andrew Appel)
  - CompCert is implemented the proof assistant Coq… but why should we trust the Coq compiler?
  - CertiCoq is an optimizing compiler for Coq, implemented and verified in Coq.

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- Need new compiler technology to take advantage of multi-core – automatically find and exploit opportunities for parallel execution
- At Princeton: David August's parallelization project

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- At Princeton: Synthesizing Lenses (David Walker), synthesis via logical games (Z)

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  - Numerical analyses – e.g., find geometric regions that contain reachable values for integer variables. Can be used to verify absence of buffer overflows, divide-by-zero, ….
  - Shape analyses – determine whether a data structure in the heap is a list, a tree, a graph, … Can be used to verify memory safety.
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- Industrial program analysis
  - Static Driver Verifier (Microsoft): finds bugs in device driver code
  - Infer (Facebook): proves memory safety & finds race conditions
  - Astrée (AbsInt): static analyzer for safety-critcal embedded code (e.g., automotive & aerospace applications)
  - Several commerical static analyzers: Codesonar, Coverity, PVS-Studio, Fortify, …

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- My work:
  - *Compositional* program analysis
    - Program analyses typically work by propagating information forwards through a program
    - Compositional analysis: Analyze the program by breaking it into parts, analyzing each part, and then combining the results
  - *Understandable* program analysis
    - Program analyzers rely on *heuristics* for predicting program behavior. Can be brittle and have unexpected behavior.
    - Software developers should be able to predict how a change in their program affects the results of an analysis

What next?

- COS 375: Computer Architecture and Organization
- COS 326: Functional Programming
- COS 510: Programming Languages
- COS 516: Automated Reasoning about Software

Thanks!