CS4200-B: Summary & Further Study

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TU Delft

CS4200 | Compiler Construction | January 13, 2022

Grading

Weights

- Project: 50%
- Exam: 50%

All grades >= 5.0

Final grade

- weighted average
- >= 5.8

Exam and Resit

January 21: Resit CS4200-A

- 13:30-16:30

January 28: Exam CS4200-B

- 13:30-16:30

April 8: Resit CS4200-B

- 13:30-16:30

Topics

- Everything we studied in the lectures
- Example exam questions: homework assignments

Outline

Compiler Components

- What did we study?

Meta-Linguistic Abstraction

- Another perspective

Further Study & Research

- Courses and conferences

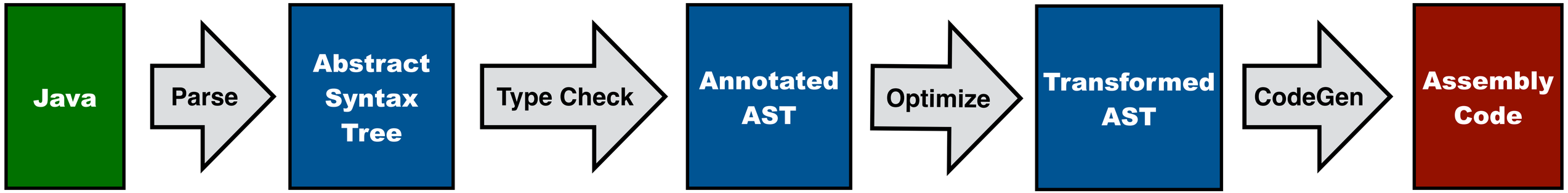
Research Challenges

- Including topics for master thesis projects

Compiler Components

What is a Compiler?

A bunch of components for translating programs



Compiler Components

Parser

- Reads in program text, checks that it complies with the syntactic rules of the language, and produces an abstract syntax tree, which represents the underlying (syntactic) structure of the program.

Type checker

- Consumes an abstract syntax tree and checks that the program complies with the static semantic rules of the language. To do that it needs to perform name analysis, relating uses of names to declarations of names, and checks that the types of arguments of operations are consistent with their specification.

Optimizer

- Consumes a (typed) abstract syntax tree and applies transformations that improve the program in various dimensions such as execution time, memory consumption, and energy consumption.

Code generator

- Transforms the (typed, optimized) abstract syntax tree to instructions for a particular computer architecture. (aka instruction selection)

ChocoPy Compiler

Syntax definition

- Parser through generation, design of abstract syntax

Static semantic analysis

- Name analysis
  - Lexical scoping, type-dependent name resolution
- Type checking
  - Class-based object-oriented language with sub-typing

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Desugaring

- Simple rewrite rules and strategies

Code generation

- Generation of Risc V instructions
- AST-to-AST transformation

Data-flow analysis

- Optimization

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Further Study

More Compiler Components

- Static analyses
- Optimization
- Register allocation
- Code generation for register machines
- Garbage collection

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Other Object Languages

- Functional programming: first-class functions, laziness
- Domain-specific languages: less direct execution models
- Data (description) languages
- Query languages
- ...

Meta-Linguistic Abstraction

Separation of Concerns

Language design

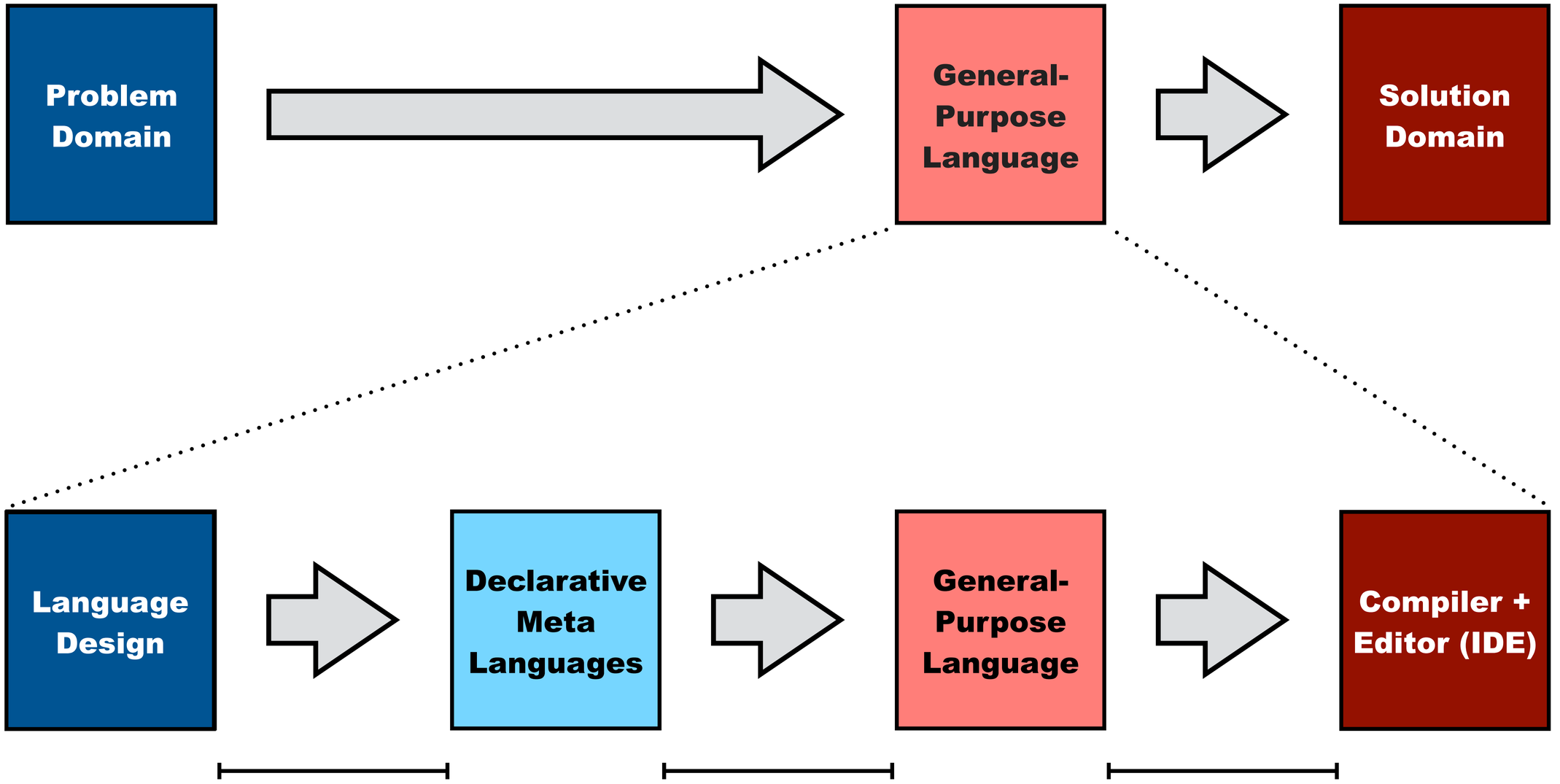
- Define the properties of a language
- Done by a language designer

Language implementation

- Implement tools that satisfy properties of the language
- Done by a language implementer

Can we automate the language implementer?

- That is what language workbenches attempt to do



That also applies to the definition of (compilers for) general purpose languages

Declarative Language Definition

Objective

- A workbench supporting design and implementation of programming languages

Approach

- Declarative multi-purpose domain-specific meta-languages

Meta-Languages

- Languages for defining languages

Domain-Specific

- Linguistic abstractions for domain of language definition (syntax, names, types, …)

Multi-Purpose

- Derivation of interpreters, compilers, rich editors, documentation, and verification from single source

Declarative

- Focus on what not how; avoid bias to particular purpose in language definition

Spoofax Meta-Languages

SDF3: Syntax definition

- context-free grammars + disambiguation + constructors + templates
- derivation of parser, formatter, syntax highlighting, …

Statix: Names & Types

- name resolution with scope graphs
- type checking/inference with constraints
- derivation of name & type resolution algorithm

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Stratego: Program Transformation

- term rewrite rules with programmable rewriting strategies
- derivation of program transformation system

FlowSpec: Data-Flow Analysis

- extraction of control-flow graph and specification of data-flow rules
- derivation of data-flow analysis engine

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DynSem: Dynamic Semantics

- specification of operational (natural) semantics
- derivation of interpreter

Course Evaluation

What do you think of the course, organization, project, etc.?

Research Challenges in Compiler Back-Ends

Transformation

New Transformation Language

- Operating on richer program model
- Generic (traversal) strategies
- Statically typed
- Type-preserving transformations
  - intrinsically or extrinsically verified?
- Semantics-preserving transformations
  - intrinsically or extrinsically verified?

Transformation Algorithms

- Refactorings, Optimizations

Code Generation / Instruction Selection

- BURS: Bottom-up rewrite system: Find cheapest / best mapping to code

Analysis

FlowSpec

- Declarative specification of data-flow analyses
- Increase expressiveness to cover more analyses
- High-performance execution of analyses
- Incremental execution of analyses (during transformation)

Data-flow Dependent Static Semantics

- Definite assignment in Java
- Borrow checking in Rust

Language Engineering

- Better integration in language workbench
- Program model

Dynamics

Interpreters from dynamic semantic specification

- Prototype for DynSem [RTA15] applied to Grace [DLS17], Tiger

Frame-based interpreters

- Scope graph describes memory model [ECOOP16]
- Define in DynSem applied to realistic languages
- Correct-by-construction [POPL18] => dependently-typed DynSem
- Language-independent garbage collection

Partial evaluation

- Specialize DynSem interpreter to language-specific set of semantic rules
- Specialize language-specific rules to specific program

Compiler generation

- Derive compiler from dynamic semantics specification

Verification

Intrinsically Typed Definitional Interpreters

- For Middle Weight Java (MJ) in Agda [POPL18]
- Extend to more sophisticated type systems (generics, System F)
- Extend to more sophisticated effect systems (continutations, algebraic effects)
- Extend approach to other operations: transformation, code generation

Extrinsic Proofs

- Generation of extrinsic type soundness proof
- Other properties

Other Verification Challenges

- Semantics preservation of DSL code generators
- Correctness of meta-DSLs

Theme: Incremental Compilation

Make all (meta) language processing incremental

- Effort proportional to size of change

Modular analysis out of the box

- Static analysis incremental based on (scope graph) dependencies

Compiler = build system

- Use PIE to glue together language processing pipelines

In progress

- Incremental parsing (Beta in Spoofax)
- Incremental compilation for Stratego (Beta in Beta)
- Incremental compilation for WebDSL

Research Challenges in Compiler Front-Ends

Vision: Language Designer's Workbench

High-Level Declarative Language Definition

- Human readable / understandable definition
- Serves as reference documentation

Verification

- Automatically verify properties of language definition
- Type soundness of interpretation
- Type preservation of transformations
- Semantics preservation of transformation

Implementation

- Generate production quality tools from language definition
- Interpreter, compiler, IDE with refactoring, completion, …
- Correct-by-construction, high performance

Syntax

High-Performance Parsing

- JSGLR2: 2x to 10x speed-up compared to JSGLR
- More speed-up possible?
- Explore effects of different parse table formats (LR, SLR, LALR)

Error Recovery & Error Messages

- Apply error recovery approach of [TOPLAS12] to JSGLR2
- Generate high quality error messages

Incremental Parsing

- Re-parse effort proportional to change of program text
- Approach: adapt Graham/Wagner algorithm to SGLR

Extensible Syntax

- Extend syntax during parsing to support extensible languages

Workbench / Editor Services

Code Completion

- Semantic code completion based on static semantics

Refactoring

- Sound refactoring scripts
- Refactoring based on scope graph program model
- New NWO MasCot project: programming and validating software restructurings

Live Language Development

- Immediate response after edit of language definition
- Requires: incremental evaluation of all compiler components
- Ongoing work: PIE DSL for interactive software development pipelines

Language Deployment

- Generate stand-alone language implementation: PIE partial evaluation

Workbench / Editor Services

Portable Editors

- Portable editor bindings based on AESI model (Pelsmaeker)
- Case study: bindings for Visual Studio, IntelliJ, LSP

Web Editors

- Generate language-specific editors for use in web browser
- Architectural questions
  - All processing client-side? Stateful back-end on server? Scalability?
  - Performance of Web Assembly (WASM) better than JS?
- Collaborative editing (operational transform)

Interactive Notebooks

- Combine documents with code in several languages and results of execution

Statics with Statix

Specification of type systems with Statix

- Subset of CHR (Constraint Handling Rules) + domain-specific constraints for scope graphs and relations
- Support more advanced type systems
- Structural types, polymorphism (generics), sub-typing [OOPSLA'18]
  - Better encoding?
  - Generalization (for parametric polymorphism)?

Solver

- Parallel solver for multi-module analysis
- Matrix-based name resolution algorithm?
- Correctness wrt resolution calculus?
- Scalability: modular and incremental analysis?

Exploring Type System Design Landscape

Substructural Type Systems

- Linear types
- Rust

Gradual Type Systems

- Gradual type theory: encode calculi and experiment
- Implement existing gradual type checkers
  - Python, TypeScript, Dart, Hack
- Design gradual type system for Stratego

Dependent Types

- Agda, Idris

Syntax + Statics

Program Model

- Extend term data model to incorporate scopes and types
- Persistent storage
- Query: retrieve information based on scope graph model
  - All methods in class A
- Construction
  - well-formed wrt static semantics

Random Program Generation

- Generation of well-formed and well-typed programs
- based on syntax + static semantics
- for testing compilers and other language processing tools

Theme: Error Localization and Diagnosis

Error Localization

- What program element is responsible for the failure?
- Minimal unsatisfiable core
  - What is the smallest set of constraints that correspond to failure?

Error Diagnosis

- Generate good (understandable) explanation of error
- Based on unsat core

Studying Programming Languages

Courses

Software Verification (Q3)

- Learn the basics of mechanised verification with Agda dependently typed programming language

Web Programming Languages (Q3)

Language-Based Software Security (Q4)

Language Engineering Project (Q4)

- Develop a Spoofax language definition for an interesting language

Seminar Programming Languages (Q1)

- Read and discuss papers from the PL literature

System Validation (Q1)

- Check properties of (concurrent) software with model checking

Master Thesis Project in PL group

Industrial Internships

Oracle Labs (Zürich)

- Applications of Spoofax: GreenMarl, PGQL
- Other projects (Truffle/Graal)

Canon (Venlo)

- Designs and manufactures digital printers
- New project to investigate design of DSLs in digital printing domain

Philips (Best)

- Software restructuring

Other

- Opportunities for language design and implementation projects at other companies

Conferences

ACM Special Interest Group on Programming Languages

- http://sigplan.org/

Key SIGPLAN Conferences

- POPL: Principles of Programming Languages
- PLDI: Programming Language Design and Implementation
- ICFP: International Conference on Functional Programming
- OOPSLA/SPLASH: Systems, Programming Languages, and Applications
- SLE: Software Language Engineering
- GPCE: Generative Programming

Other Conferences

- ECOOP: European PL conference
- ESOP: European Symposium on Programming

Summer Schools

PLMW: Programming Languages Mentoring Workshop

- technical sessions on cutting-edge research in programming languages, and mentoring sessions on how to prepare for a research career
- At ICFP, POPL, PLDI, SPLASH

OPLSS: Oregon Programming Languages Summer School

- Foundational work on semantics and type theory
- Adanced program verification techniques
- Experience with applying the theory

DSSS: DeepSpec Summer School

- Formal verification

PLISS: Programming Language Implementation Summer School

- Programming language systems, implementation, analysis

After the Master

PhD

- Dive into PL research for four years
- Develop new PL theory, designs, and implementations
- Write research papers and a dissertation
- ~~Present your work at conferences around the world~~

PL in industry

- Develop compilers, analyses, run-time systems
- Contribute to development of industrial programming languages
  - Oracle Labs (PGX), Google (Dart), Amazon (Cloud9), Canon (OIL)

Wanted: PhD Students in PL

Software Restructuring

- A principled approach to programming refactorings/restructurings
- Application: Transforming C++ code

Language Engineering

- Static semantics and type checking
- Deriving interpreters, compilers from dynamic semantics

Wanted: Research Assistants

Goal

- help with an ongoing research project
- often: programming work

Research Assistant

- 4 - 8 hours per week (flexible)
- Appointment per project (language)

Wanted: Java Performance Engineer

Goal

- Work on speeding up JSGLR2

Experience

- Java programming, performance engineering

Research Assistant

- 4 - 8 hours per week (flexible)
- Appointment per project (language)

Wanted: Grammar Engineer

Goal

- A collection of high quality syntax definitions for key languages
- Spoofax with `batteries included’
- Speeding up research case studies

Developing Syntax Definitions

- High quality
- High coverage

Research Assistant

- 4 - 8 hours per week (flexible)
- Appointment per project (language)

Wanted: Web Programmer

Academic Workflow Engineering

- Make university work better with web apps that automate workflows
- Education
  - WebLab, mystudyplanning, EvaTool
- Research
  - conf.researchr.org, researchr.org
- Administration

Combine with PL research

- Use high-level web PLs (WebDSL, IceDust)
- Contribute to better abstractions for web programming