Overview of Compilation

Readings: EAC2 Chapter 1

EECS4302 A:
Compilers and Interpreters
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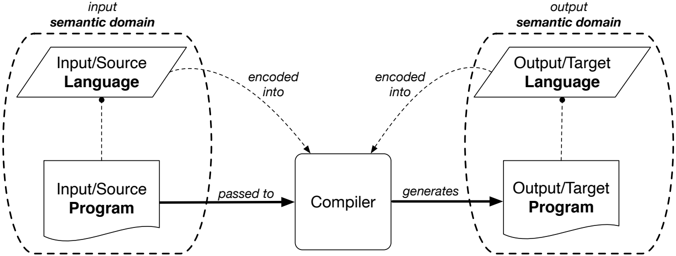
What is a Compiler? (1)

A **software system** that **automatically** ***translates/transforms*** ***input/source*** programs (written in one language) to ***output/target*** programs (written in another language).



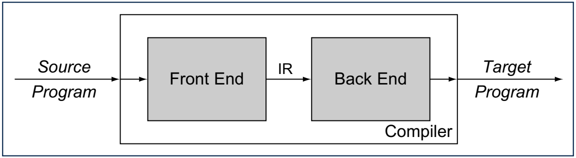
- *Semantic Domain* : Context with its own vocabulary & meanings
  e.g., OO (EECS1022/2030/2011), database (3421), predicates (1090)
- ***Source*** and ***target*** may be in **different** ***semantic domains***.
  e.g., Java programs to SQL relational database schemas/queries
  e.g., C procedural programs to MISP assembly instructions

What is a Compiler? (2)

- The idea about a ***compiler*** is extremely powerful:
  You can turn anything to anything else,
  as long as the following are ***clear*** about these two things:
  - SYNTAX [***specifiable*** as CFGs]
  - SEMANTICS [***programmable*** as mapping functions]

  Mental Exercise. Let's consider an A+ challenge.
- A compiler should be constructed with good *SE principles*.
  - ***Modularity*** [interacting components]
  - ***Information Hiding*** [hiding unstable, revealing stable]
  - ***Single Choice Principle*** [a change only causing minimum impact]
  - ***Design Patterns*** [polymorphism & dynamic binding]
  - ***Regression Testing*** [e.g., unit-level, acceptance-level]

Compiler: Typical Infrastructure (1)



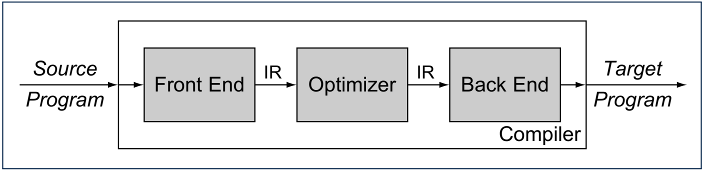
- **FRON END**:
  - Encodes: knowledge of the **source** language
  - Transforms: from the **source** to some ***IR*** (*intermediate representation*)
  - Principle: ***meaning*** of the source must be *preserved* in the ***IR***.
- **BACK END**:
  - Encodes knowledge of the **target** language
  - Transforms: from the ***IR*** to the **target**
  - Principle: ***meaning*** of the ***IR*** must be *reflected* in the **target**.

Q. How many ***IRs*** needed for building a number of compilers: JAVA-TO-C, C#-TO-C, JAVA-TO-PYTHON, C#-TO-PYTHON?

A. Two ***IRs*** suffice: One for ***OO***; one for ***procedural***.

$\Rightarrow$ IR should be as *language-independent* as possible.

Compiler: Typical Infrastructure (2)



OPTIMIZER:

- An ***IR****-to-****IR*** transformer that aims at "improving" the **output** of front end, before passing it as **input** of the back end.
- Think of this transformer as attempting to discover an "***optimal***" solution to some computational problem.
  e.g., runtime performance, static design

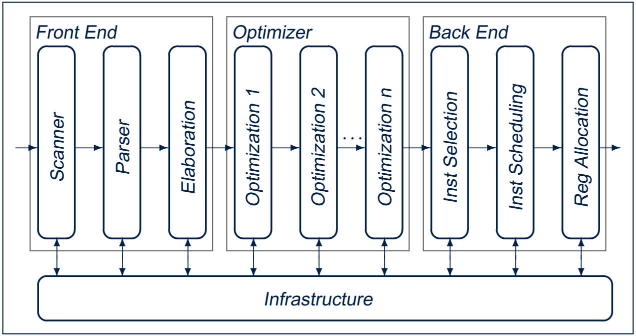
Q. Behaviour of the **target** program depends upon?

1. ***Meaning*** of the **source** preserved in ***IR***?
2. ***IR****-to-****IR*** transformation of the optimizer ***semantics-preserving***?
3. ***Meaning*** of ***IR*** preserved in the generated **target**?

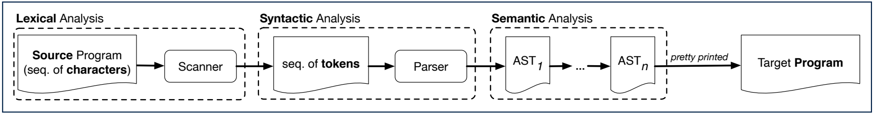
   (1) – (3) necessary & sufficient for the *soundness* of a compiler.

Example Compiler 1

- Consider a conventional compiler which turns a ***C-like program*** into executable ***machine instructions***.
- The ***source*** and ***target*** are at different levels of *abstractions*:
  - C-like program is like "high-level" ***specification***.
  - Macine instructions are the low-level, efficient ***implementation***.



Compiler Infrastructure: Scanner vs. Parser vs. Optimizer



- The same input program may be <u>perceived</u> differently:
  1. As a ***character sequence*** [subject to ***lexical*** analysis]
  2. As a ***token sequence*** [subject to ***syntactic*** analysis]
  3. As a *abstract syntax tree (AST)* [subject to *semantic* analysis]
- ***(1)*** & ***(2)*** are routine tasks of lexical/grammar rule specification.
- *(3)* is where the most creativity is used to a compiler:

  A series of ***semantics-preserving*** ***AST***-to-***AST*** transformations.

Compiler Infrastructure: Scanner

- The source program is perceived as a sequence of ***characters***.
- A scanner performs *lexical analysis* on the input character sequence and produces a sequence of ***tokens***.
- ANALOGY: Tokens are like individual ***words*** in an essay.

  ⇒ Invalid tokens ≈ Misspelt words

  e.g., a token for a useless delimiter: e.g., space, tab, new line

  e.g., a token for a useful delimiter: e.g., `(`, `)`, `{`, `}`, `,`

  e.g., a token for an identifier (for e.g., a variable, a function)

  e.g., a token for a keyword (e.g,. `int`, `char`, `if`, `for`, `while`)

  e.g., a token for a number (for e.g., `1.23`, `2.46`)

  Q. How to specify such ***pattern of characters***?

  A. ***Regular Expressions*** (***REs***)

  e.g., RE for keyword `while` [`while`]

  e.g., RE for an identifier [`[a-zA-Z][a-zA-Z0-9_]*`]

  e.g., RE for a white space [`[ \t\r]+`]

Compiler Infrastructure: Parser

- A parser's input is a sequence of ***tokens*** (by some scanner).
- A parser performs *syntactic analysis* on the input token sequence and produces an ***abstract syntax tree (AST)***.
- ANALOGY: ASTs are like individual ***sentences*** in an essay.

  ⇒ Tokens not ***parseable*** into a valid AST ≈ Grammatical errors

  Q. An essay with no speling and grammatical errors good enough?
  A. No, it may talk about non-sense (sentences in wrong contexts).

  ⇒ An input program with no lexical/syntactic errors should still be subject to *semantic analysis* (e.g., type checking, code optimization).

Q.: How to specify such ***pattern of tokens***?

A.: ***Context-Free Grammars*** (***CFGs***)

e.g., CFG (with **terminals** and **non-terminals**) for a while-loop:

WhileLoop	::=	`WHILE LPAREN` *BoolExpr* `RPAREN LCBRAC` *Impl* `RCBRAC`
Impl	::=	
	|	*Instruction* `SEMICOL` *Impl*

Compiler Infrastructure: Optimizer (1)

- Consider an input *AST* which has the pretty printing:

```
b := ... ; c := ... ; a := ...
across i |..| n is i
  loop
    read d
    a := a * 2 * b * c * d
  end
```

Q. AST of above program ***optimized*** for performance?
A. No ∵ values of `2`, `b`, `c` stay invariant within the loop.

- An ***optimizer*** may *transform* AST like above into:

```
b := ... ; c := ... ; a := ...
temp := 2 * b * c
across i |..| n is i
  loop
    read d
    a := a * temp * d
  end
```

Compiler Infrastructure: Optimizer (2)

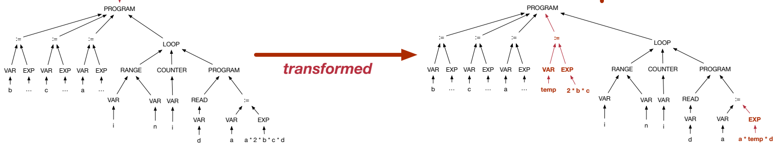
Problem: Given a user-written program, ***optimize*** it for best runtime performance.

```
b := ... ; c := ... ; a := ...
across i |..| n is i
  loop
    read d
    a := a * 2 * b * c * d
  end
```

optimized →

```
b := ... ; c := ... ; a := ...
temp := 2 * b * c
across i |..| n is i
  loop
    read d
    a := a * temp * d
  end
```

parsed ↓ ↑ ***pretty-printed***



Example Compiler 2

- Consider a compiler which turns an object-based ***Domain-Specific Language (DSL)*** into a **SQL *database***.
- Why is an ***object-to-relational compiler*** valuable?

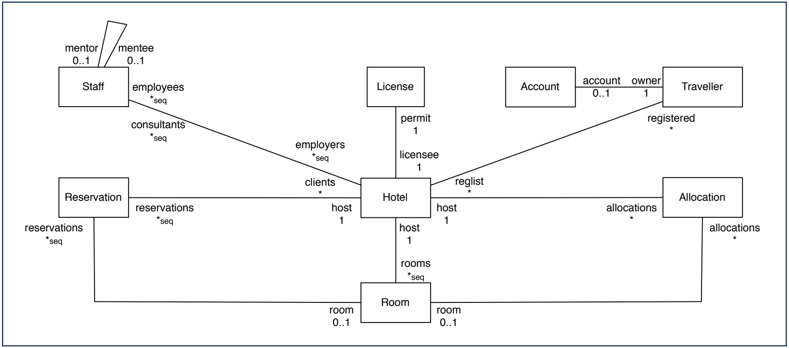
  Hint. Which semantic domain is better for high-level specification?
  Hint. Which semantic domain is better for data management?

	managing big data	specifying data & updates
object-oriented environment	×	✓
relational database	✓	×

- *Challenge* : ***Object-Relational Impedance Mismatch***

Example Compiler 2

- The input/source contains 2 parts:
  - **DATA MODEL**: ***classes*** & ***associations***
    e.g., data model of a Hotel Reservation System:



  - **BEHAVIOURAL MODEL**: update methods specified as ***predicates***

Example Compiler 2: Transforming Data

```
class A {
  attributes
    s: string
    bs: set(B . a) [*] }
```

```
class B {
  attributes
    is: set (int)
    a: A . bs }
```

- Each class is turned into a ***class table***:
  - Column `oid` stores the object reference. [PRIMARY KEY]
  - Implementation strategy for attributes:

	SINGLE-VALUED	MULTI-VALUED
PRIMITIVE-TYPED	column in ***class table***	***collection table***
REFERENCE-TYPED	***association table***	

- Each ***collection table***:
  - Column `oid` stores the context object.
  - 1 column stores the corresponding primitive value or `oid`.
- Each ***association table***:
  - Column `oid` stores the association reference.
  - 2 columns store `oid`'s of both association ends. [FOREIGN KEY]

Example Compiler 2: Input/Source

- Consider a **valid** input/source program:

```
class Account {
  attributes
    owner: Traveller . account
    balance: int
}
```

```
class Traveller {
  attributes
    name: string
    reglist: set(Hotel . registered)[*]
}
```

```
class Hotel {
  attributes
    name: string
    registered: set(Traveller . reglist)[*]
  methods
    register {
        t? : extent(Traveller)
      & t? /: registered
      ==>
          registered := registered \/ {t?}
      || t?.reglist := t?.reglist \/ {this}
    }
}
```

- How do you specify the ***scanner*** and ***parser*** accordingly?

Example Compiler 2: Output/Target

- Class ***associations*** are transformed to ***database schemas***.

```
CREATE TABLE `Account`(
  `oid` INTEGER AUTO_INCREMENT,`balance` INTEGER,
  PRIMARY KEY (`oid`));
CREATE TABLE `Traveller`(
  `oid` INTEGER AUTO_INCREMENT,`name` CHAR(30),
  PRIMARY KEY (`oid`));
CREATE TABLE `Hotel`(
  `oid` INTEGER AUTO_INCREMENT,`name` CHAR(30),
  PRIMARY KEY (`oid`));
CREATE TABLE `Account_owner_Traveller_account`(
  `oid` INTEGER AUTO_INCREMENT, `owner` INTEGER, `account` INTEGER,
  PRIMARY KEY (`oid`));
CREATE TABLE `Traveller_reglist_Hotel_registered`(
  `oid` INTEGER AUTO_INCREMENT, `reglist` INTEGER, `registered` INTEGER,
  PRIMARY KEY (`oid`));
```

- Method ***predicates*** are compiled into ***stored procedures***.

```
CREATE PROCEDURE `Hotel_register`(IN `this?` INTEGER, IN `t?` INTEGER)
  BEGIN
    ...
  END
```

Example Compiler 2: Transforming Updates

Challenge : Transform ***dot notations*** into ***relational queries***.

e.g., The AST corresponding to the following dot notation (in the context of class `Account`, retrieving the owner's list of registrations)

```
this.owner.reglist
```

may be transformed into the following (nested) table lookups:

```
SELECT (VAR `reglist`)
       (TABLE `Hotel_registered_Traveller_reglist`)
       (VAR `registered` = (SELECT (VAR `owner`)
                           (TABLE `Account_owner_Traveller_account`)
                           (VAR `owner` = VAR `this`)))
```

Beyond this lecture . . .

- Read Chapter 1 of EAC2 to find out more about Example Compiler 1
- Read this paper to find out more about Example Compiler 2:

  `http://dx.doi.org/10.4204/EPTCS.105.8`

Index (1)

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