# Overview of Compilation

**Readings: EAC2 Chapter 1**

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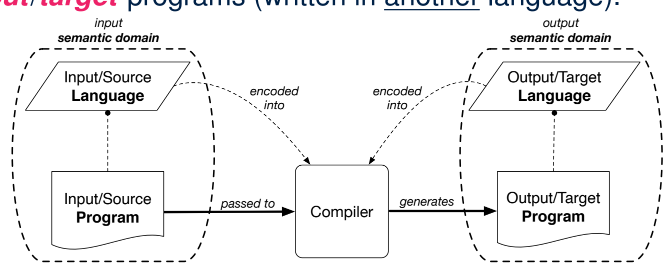
## What is a Compiler? (1)

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




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



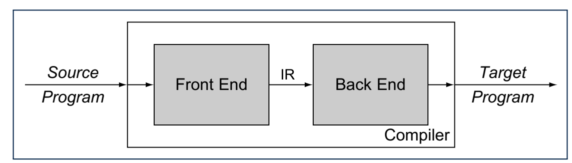
## What is a Compiler? (2)

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

  <u>**Mental Exercise.**</u> Let's consider an A+ challenge.
- A compiler <u>should</u> be constructed with good *SE principles*.
  - ***Modularity*** [ interacting components ]
  - ***Information Hiding*** [ <u>hiding</u> 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)



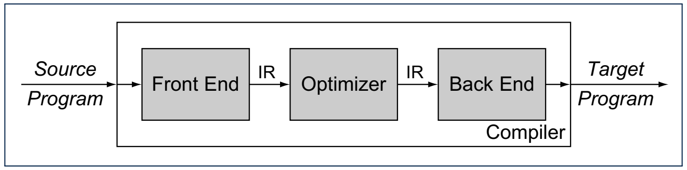

- FRON END:
  - Encodes: knowledge of the **source** language
  - Transforms: from the **source** to some ***IR*** (*intermediate representation*)
  - Principle: ***meaning*** of the source must be *preserved* in the ***IR***.
- BACK END:
  - Encodes knowledge of the **target** language
  - Transforms: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

⇒ 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?

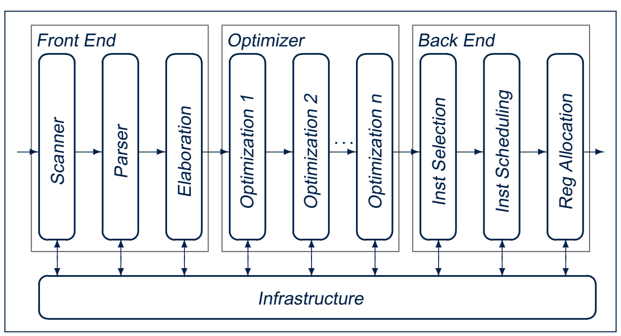
1. ***Meaning*** of the **source** preserved in ***IR***?
2. ***IR**-to-**IR*** transformation of the optimizer ***semantics-preserving***?
3. ***Meaning*** of ***IR*** preserved in the generated **target**?

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



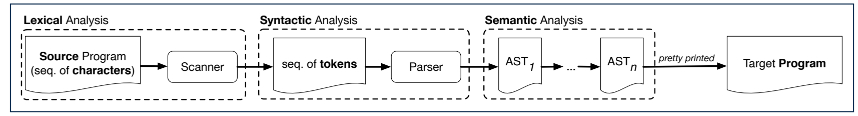
# Example Compiler 1

- 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 perceived 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.

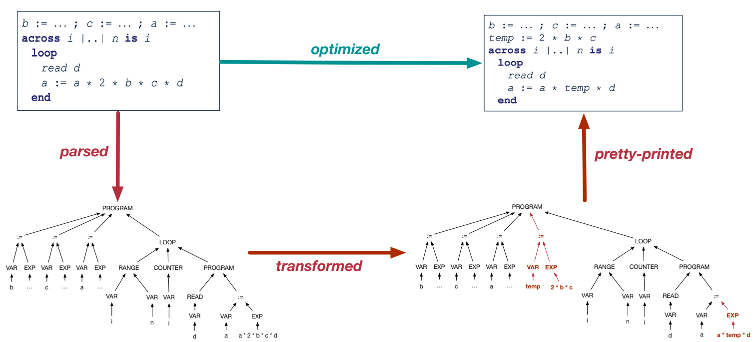
- An ***optimizer*** may *transform* AST like above into:

```
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.






## 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?

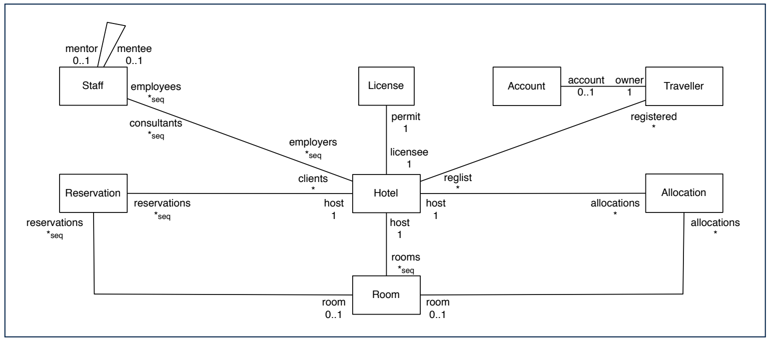
  **Hint.** Which semantic domain is better for high-level specification?
  **Hint.** Which semantic domain is better for data management?

| | 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)





## Index (2)