# INF5110 – Compiler Construction

## Introduction

Spring 2016

UNIVERSITAS OSLOENSIS • MDCCCXI •

# Outline

1. Introduction
   - Introduction
   - Compiler architecture & phases
   - Bootstrapping and cross-compilation

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1. Introduction

   Introduction

   Compiler architecture & phases

   Bootstrapping and cross-compilation

# Course info

## Course presenters:

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## Course's web-page

http://www.uio.no/studier/emner/matnat/ifi/INF5110

- overview over the course, pensum (watch for updates)
- various announcements, beskjeder, etc.

# Course material and plan

- The material is based largely on [Louden, 1997], but also other sources will play a role. A classic is "the dragon book" [Aho et al., 1986]
- see also Errata list at `http://www.cs.sjsu.edu/~louden/cmptext/`
- approx. 3 hours teaching per week
- mandatory assignments (= "obligs")
  - O1 published mid-February, deadline mid-March
  - O2 published beginning of April, deadline beginning of May
- group work up-to 3 people recommended. Please inform us about such planned group collaboration
- slides: see updates on the net
- exam: *8th June, 14:30*, 4 hours.

# Motivation: What is CC good for?

- not everyone is actually building a full-blown compiler, but
    - fundamental concepts and techniques in CC
    - most, if not basically all, software reads, processes/transforms and outputs "data"

  ⇒ often involves techniques central to CC
    - Understanding compilers ⇒ deeper understanding of programming language(s)
    - new language (domain specific, graphical, new language paradigms and constructs. . . )

  ⇒ CC & their principles will *never* be "out-of-fashion".

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# Architecture of a typical compiler

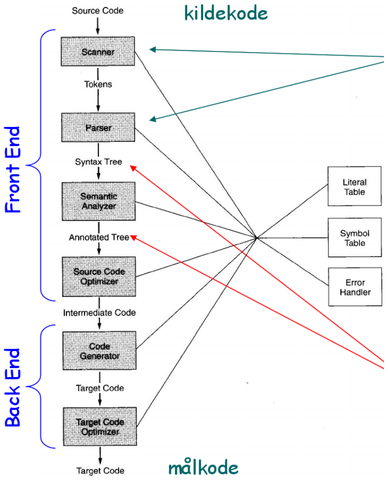
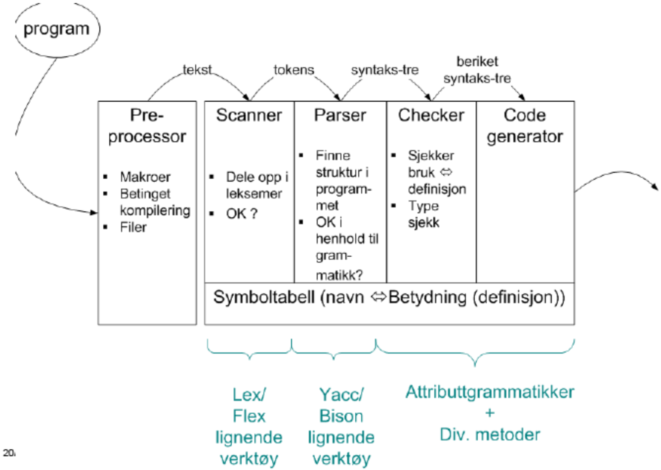


Figure: Structure of a typical compiler

# Anatomy of a compiler



program

tekst

tokens

syntaks-tre

beriket syntaks-tre

Pre-processor

- Makroer
- Betinget kompilering
- Filer

Scanner

- Dele opp i leksemer
- OK ?

Parser

- Finne struktur i programmet
- OK i henhold til grammatikk?

Checker

- Sjekker bruk ⇔ definisjon
- Type sjekk

Code generator

Symboltabell (navn ⇔Betydning (definisjon))

Lex/ Flex lignende verktøy

Yacc/ Bison lignende verktøy

Attributtgrammatikker + Div. metoder

20

# Pre-processor

- either separate program or integrated into compiler
- nowadays: C-style preprocessing mostly seen as "hack" grafted on top of a compiler.[1]
- examples (see next slide):
  - file inclusion[2]
  - macro definition and expansion[3]
  - conditional code/compilation: Note: `#if` is *not* the same as the `if`-programming-language construct.
- problem: often messes up the line numbers

[1] C-preprocessing is still considered sometimes a *useful* hack, otherwise it would not be around ... But it does not naturally encourage elegant and well-structured code, just quick fixes for some situations.

[2] the single most primitive way of "composing" programs split into separate pieces into one program.

[3] Compare also to the `\newcommand`-mechanism in LaTeX or the analogous `\def`-command in the more primitive TeX-language.

# C-style preprocessor examples

```
#include <filename>
```

Listing 1: file inclusion

```
#vardef #a = 5; #c = #a+1
 ...
#if (#a < #b)
      ..
#else
    ...
#endif
```

Listing 2: Conditional compilation

# C-style preprocessor: macros

```
#macrodef hentdata(#1,#2)
    ——— #1————
      #2———(#1)———
#enddef


 ...
#hentdata(kari, per)
```

Listing 3: Macros

```
 ——— kari ————
per———(kari)———
```

# Scanner (lexer . . . )

- input: “the program text” ( = string, char stream, or similar)
- task
  - *divide* and *classify* into *tokens*, and
  - remove blanks, newlines, comments ..
- theory: finite state automata, regular languages

# Scanner: illustration

```
a[index]␣=␣4␣+␣2
```

| lexeme | token class | value |
|---|---|---|
| `a` | *identifier* | `"a"` |
| `[` | *left bracket* | |
| `index` | *identifier* | `"index"` |
| `]` | *right bracket* | |
| `=` | *assignment* | |
| `4` | *number* | `"4"` |
| `+` | *plus sign* | |
| `2` | *number* | `"2"` |

# Scanner: illustration

```
a[index]␣=␣4␣+␣2
```

| lexeme | token class | value |
|---|---|---|
| a | *identifier* | 2 |
| [ | *left bracket* | |
| index | *identifier* | 21 |
| ] | *right bracket* | |
| = | *assignment* | |
| 4 | *number* | 4 |
| + | *plus sign* | |
| 2 | *number* | 2 |

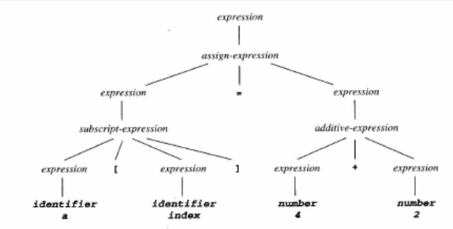
| | |
|---|---|
| 0 | |
| 1 | |
| 2 | "a" |
| | ⋮ |
| 21 | "index" |
| 22 | |
| | ⋮ |

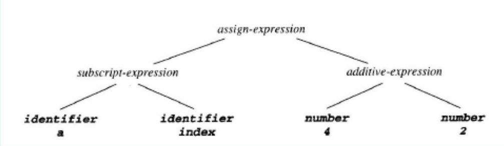
# Parser

parserings-tre
(syntaks-tre)

resultat av parsering

```
a[index] = 4 + 2
```

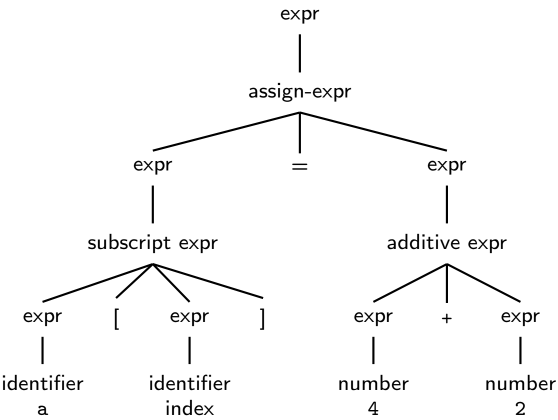




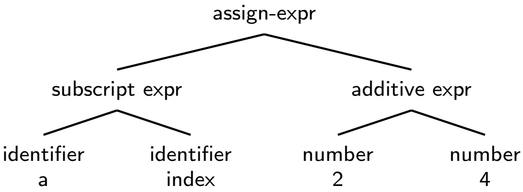
abstrakt
syntaks-tre

"syntaktisk
sukker"
fjernet

# a[index] = 4 + 2: parse tree/syntax tree

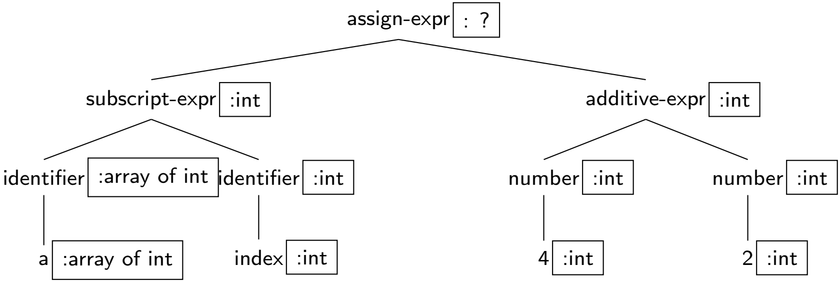


# a[index] = 4 + 2: abstract syntax tree



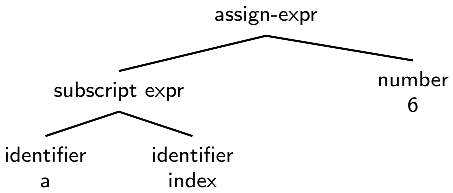
# (One typical) Result of semantic analysis

- one standard, general outcome of semantic analysis: “annotated” or “decorated” AST
- additional info (non context-free):
  - *bindings* for declarations
  - (static) *type* information



- here: *identifiers* looked up wrt. declaration
- 4, 2: due to their form, basic types.

# Optimization at source-code level



```
t = 4+2;
a[index] = t;
```

```
t = 6;
a[index] = t;
```

```
a[index] = 6;
```

# Code generation & optimization

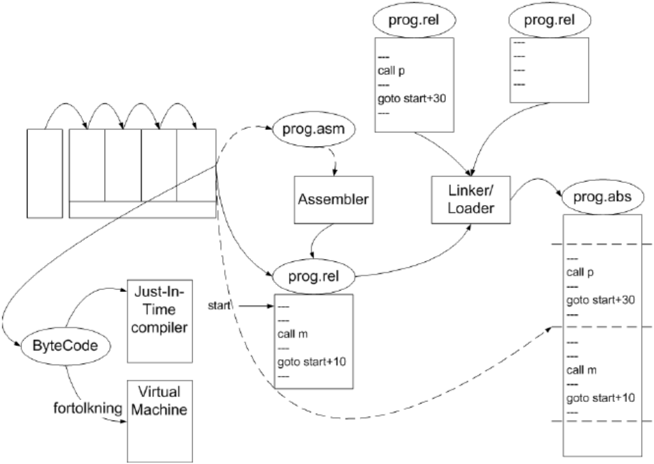
```
MOV  R0, index  ;;  value of index -> R0
MUL  R0, 2      ;;  double value of R0
MOV  R1, &a     ;;  address of a -> R1
ADD  R1, R0     ;;  add R0 to R1
MOV *R1, 6      ;;  const 6 -> address in R1
```

```
MOV R0, index        ;; value of index -> R0
SHL R0               ;; double value in R0
MOV &a[R0], 6        ;; const 6 -> address a+R0
```

- *many* optimizations possible
- potentially difficult to automatize[4], based on a formal description of language and machine
- platform dependent

[4] not that one has much of a choice. Difficult or not, *no one* wants to optimize generated machine code by hand . . . .

# Anatomy of a compiler (2)



# Misc. notions

- front-end vs. back-end, analysis vs. synthesis
- separate compilation
- how to handle *errors*?
- "data" handling and management at run-time (static, stack, heap), garbage collection?
- language can be compiled in *one pass*?
  - E.g. C and Pascal: declarations must *precede* use
  - no longer too crucial, enough memory available
- compiler assisting tool and infra structure, e.g.
  - debuggers
  - profiling
  - project management, editors
  - build support
  - ...

# Compiler vs. interpeter

## Compilation

- classically: source code $\Rightarrow$ machine code for given machine
- different "forms" of machine code (for 1 machine):
  - executable $\Leftrightarrow$ relocatable $\Leftrightarrow$ textual assembler code

## full interpretation

- directly executed from program code/syntax tree
- often used for command languages, interacting with OS etc.
- speed typically 10–100 slower than compilation

## compilation to intermediate code which is interpreted

- used in e.g. Java, Smalltalk, . . . .
- intermediate code: designed for efficient execution (byte code in Java)
- executed on a simple interpreter (JVM in Java)
- typically 3–30 times slower than direct compilation

# More recent compiler technologies

- *Memory* has become cheap (thus comparatively large)
  - keep whole program in main memory, while compiling
- OO has become rather popular
  - special challenges & optimizations
- Java
  - "compiler" generates byte code
  - part of the program can be *dynamically* loaded during run-time
- concurrency, multi-core
- graphical languages (UML, etc), "meta-models" besides grammars

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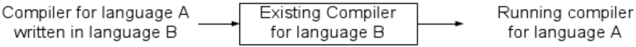
# Compiling from source to target on host

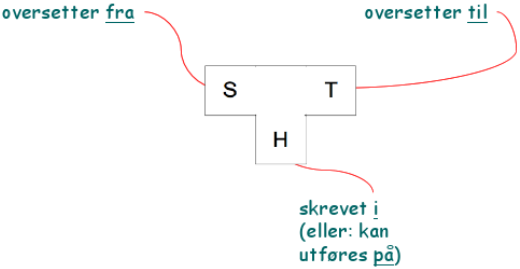
“tombstone diagrams” (or T-diagrams). . . .



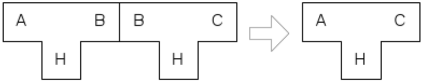
Compiler for language A written in language B

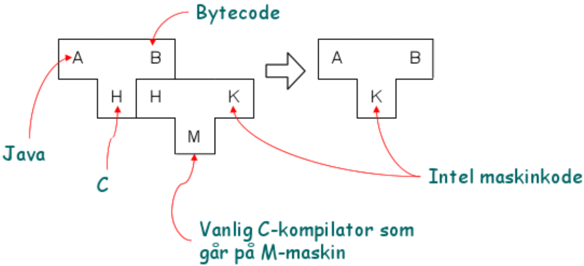
Existing Compiler for language B

Running compiler for language A

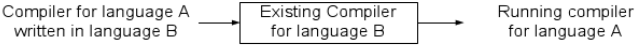


# Two ways to compose “T-diagrams”





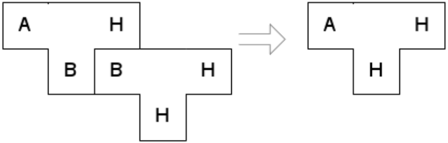
# Using an "old" language and its compiler for write a compiler for a "new" one



Compiler for language A written in language B

Existing Compiler for language B

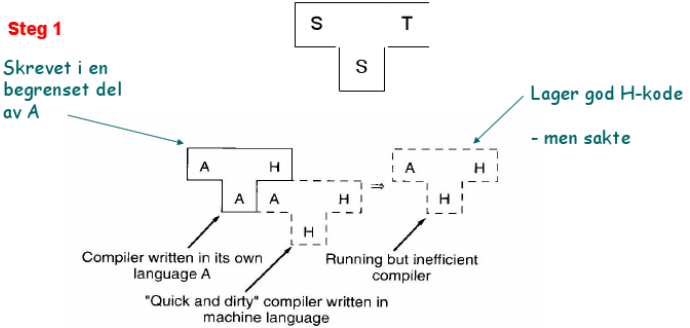
Running compiler for language A



# Pulling oneself up on one's own bootstraps

*bootstrap (verb, trans.): to promote or develop . . . with little or no assistance*
*— Merriam-Webster*

Lage en kompilator som er skrevet i eget språk, går fort og lager god kode

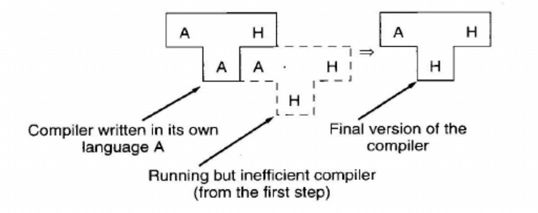

Steg 1
S
T
S
Skrevet i en begrenset del av A
Lager god H-kode
- men sakte
A
H
A
A
H
H
⇒
A
H
H
Compiler written in its own language A
"Quick and dirty" compiler written in machine language
Running but inefficient compiler

# Bootstrapping 2

**Steg 2**

Lager god H-kode

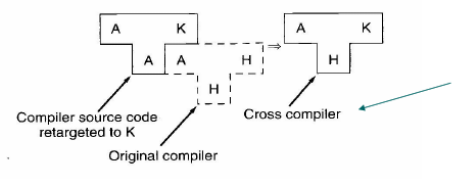
- og fort


A
H
A
A
H
H
⇒
A
H
H
Compiler written in its own language A
Running but inefficient compiler (from the first step)
Final version of the compiler

# Porting & cross compilation

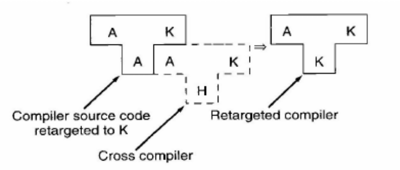
- Har: A kompilator som oversetter til H-maskinkode
- Ønsker: A-kompilator som oversetter til K-maskin kode

Steg 1: Skriv kompilator slik at den produserer K-kode (f.eks. vha ny back-end)



går på H-maskin, produserer K-kode (kryss-kompilator)

Steg 2: Oversetter den nye kompilatoren til K-kode. Gjøres på en H-maskin vha krysskompilatoren



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# References I

[Aho et al., 1986] Aho, A. V., Sethi, R., and Ullman, J. D. (1986).
*Compilers: Principles, Techniques and Tools*.
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