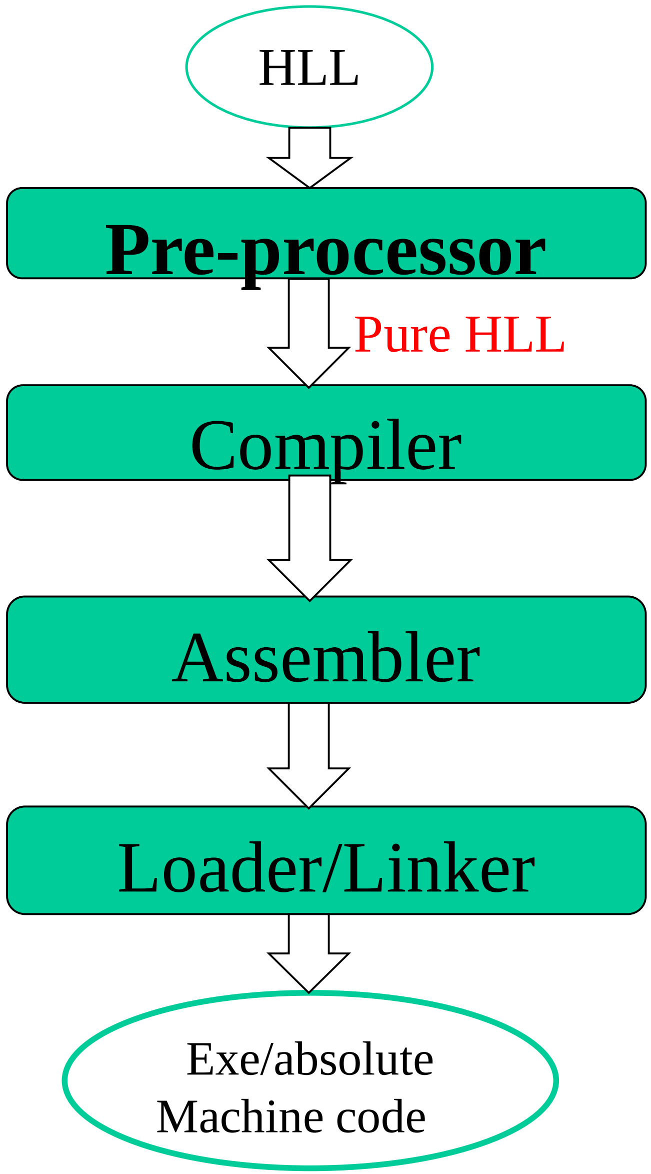
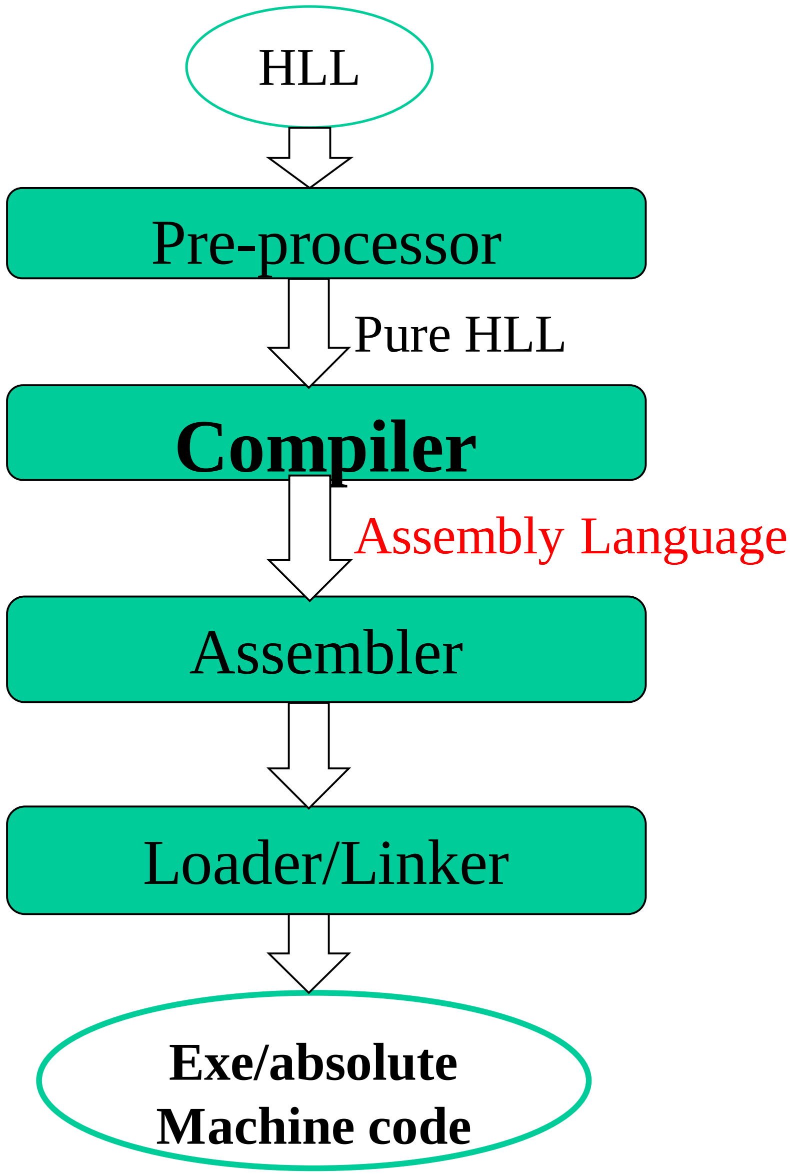
Execution of a Program



Execution of a Program



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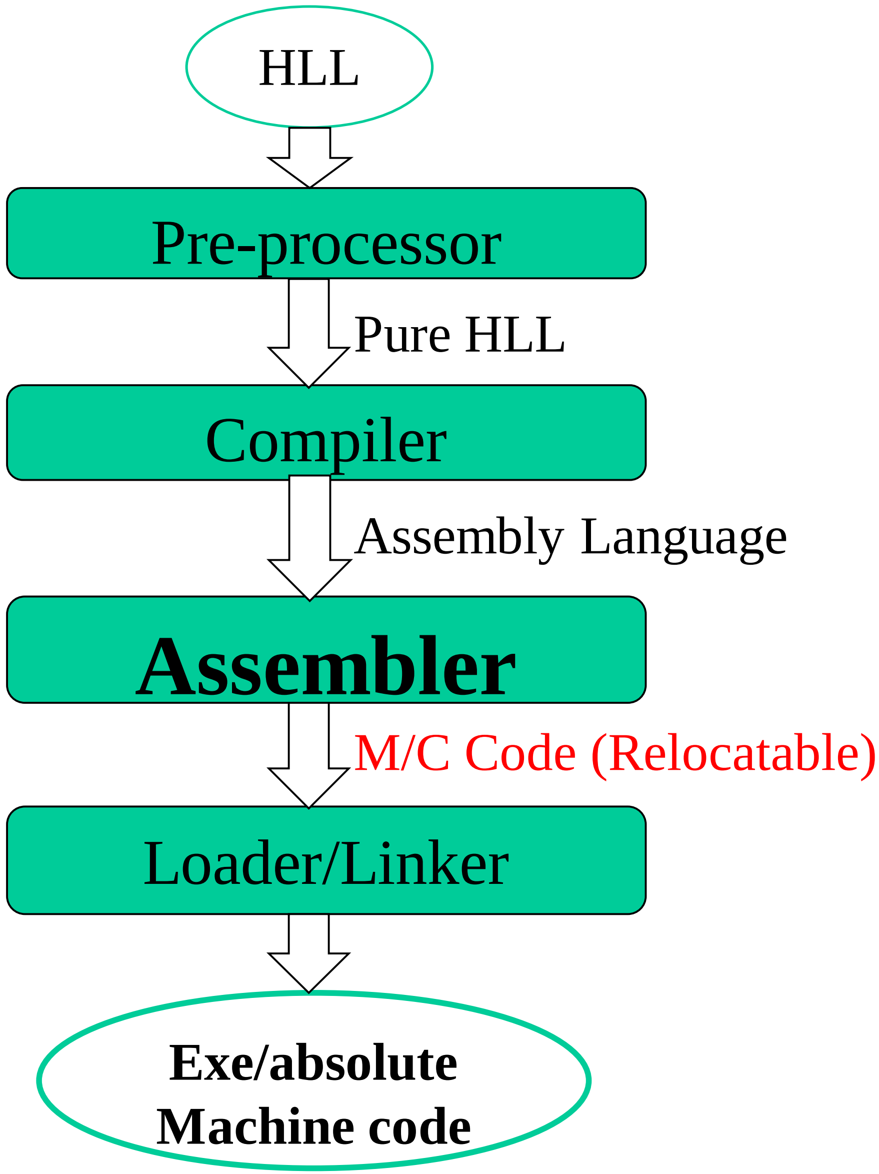

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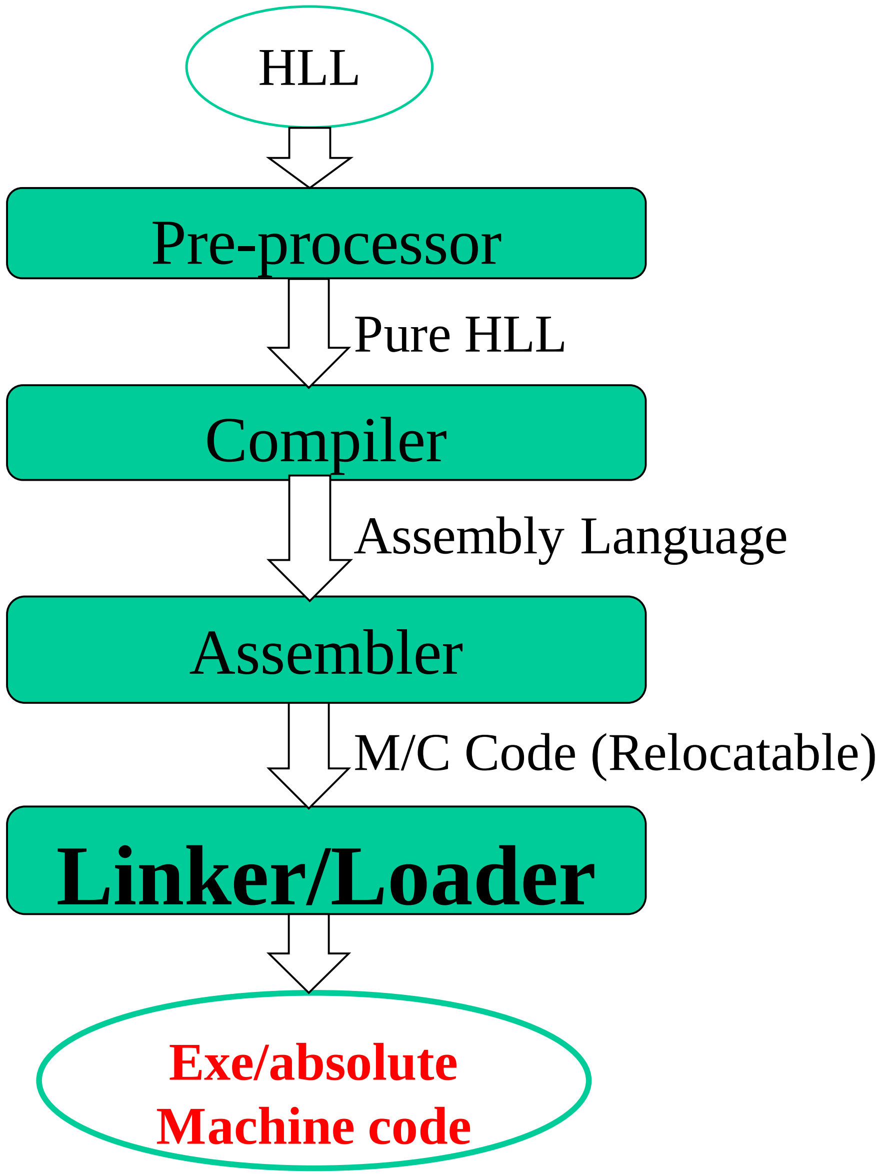

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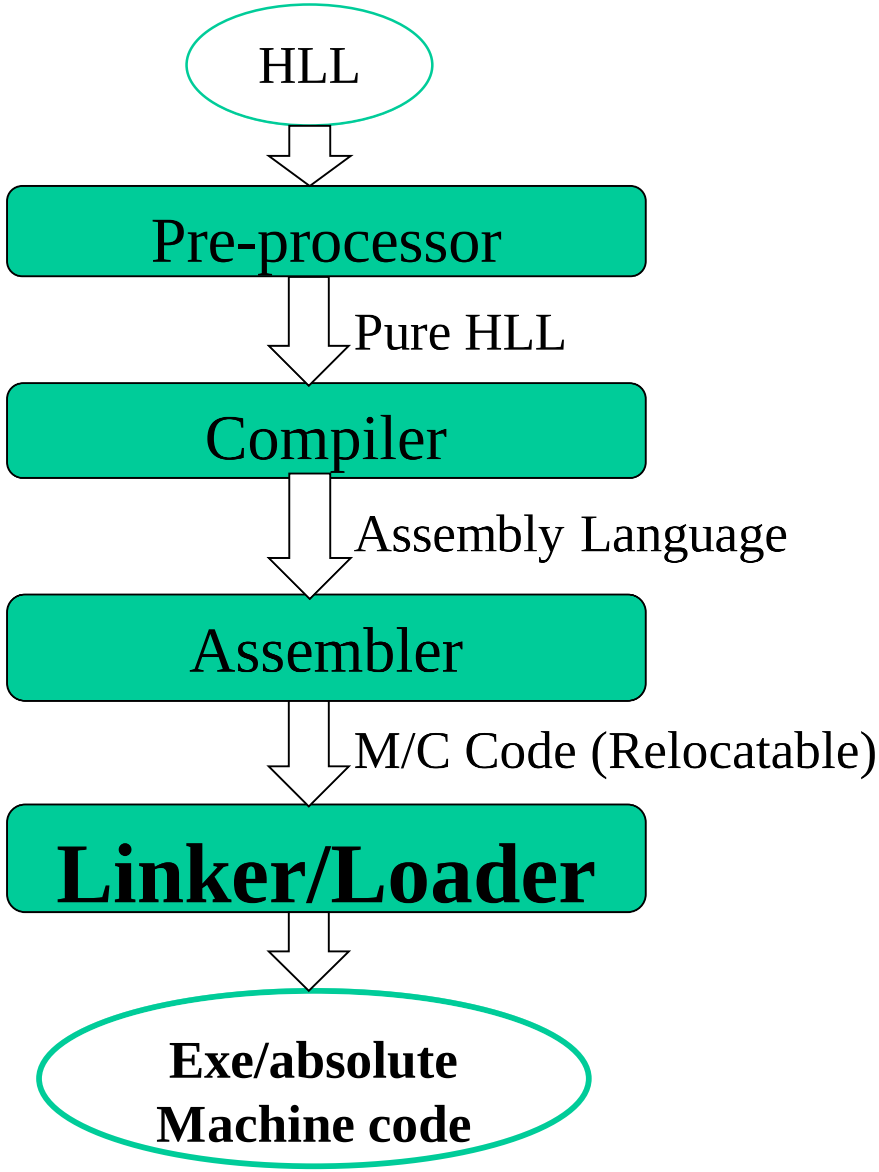
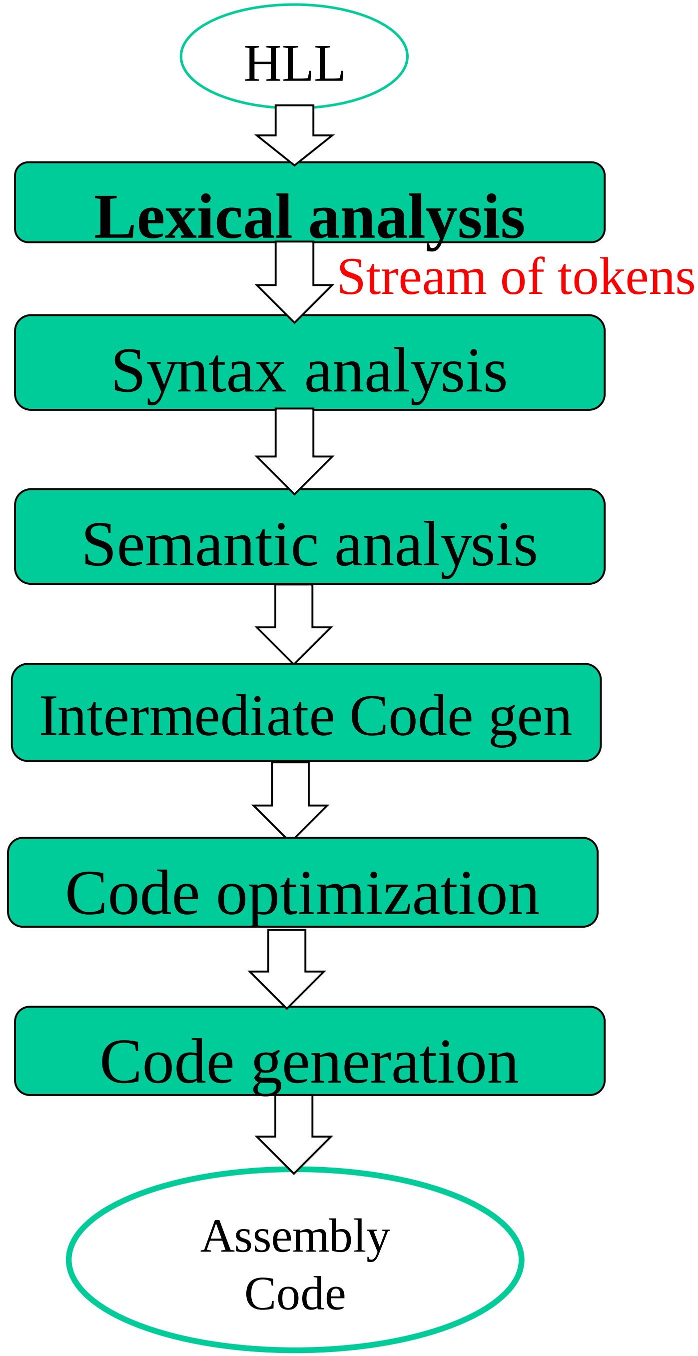
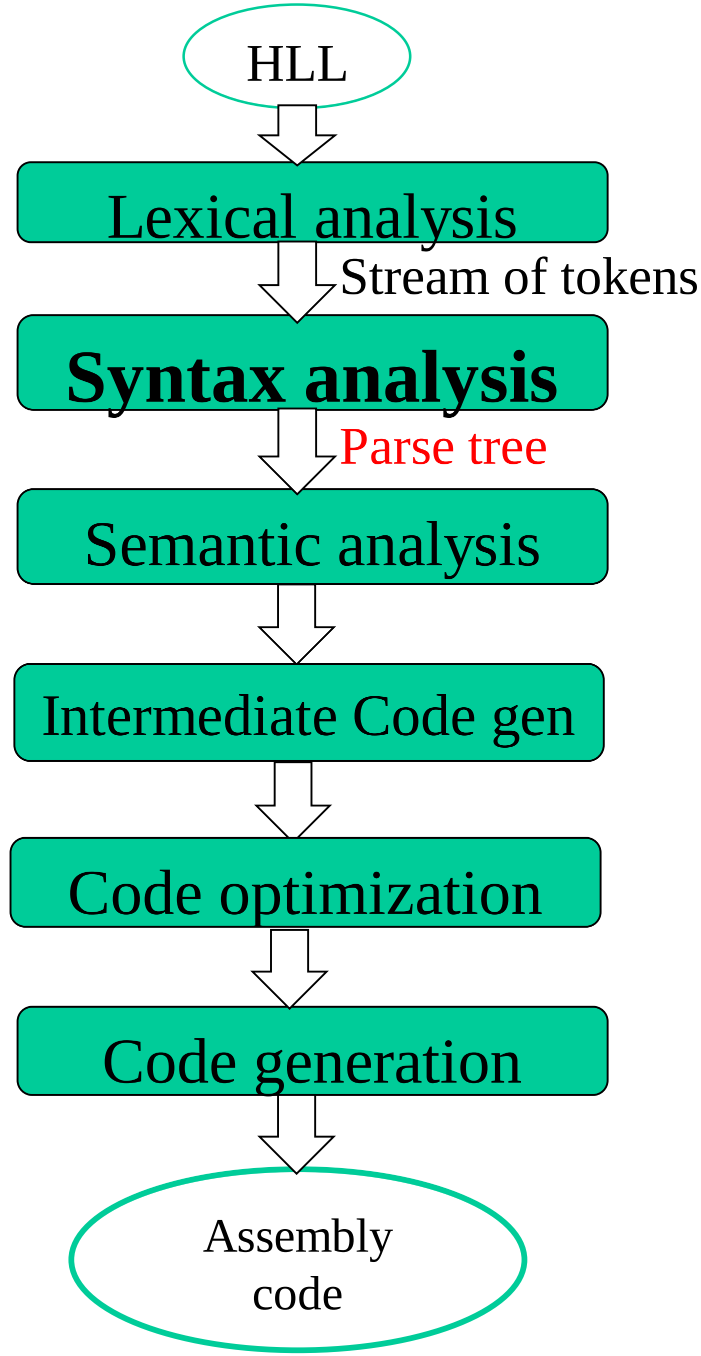


Phases (or structure) of Compiler


HLL
Lexical analysis
Stream of tokens
Syntax analysis
Semantic analysis
Intermediate Code gen
Code optimization
Code generation
Assembly Code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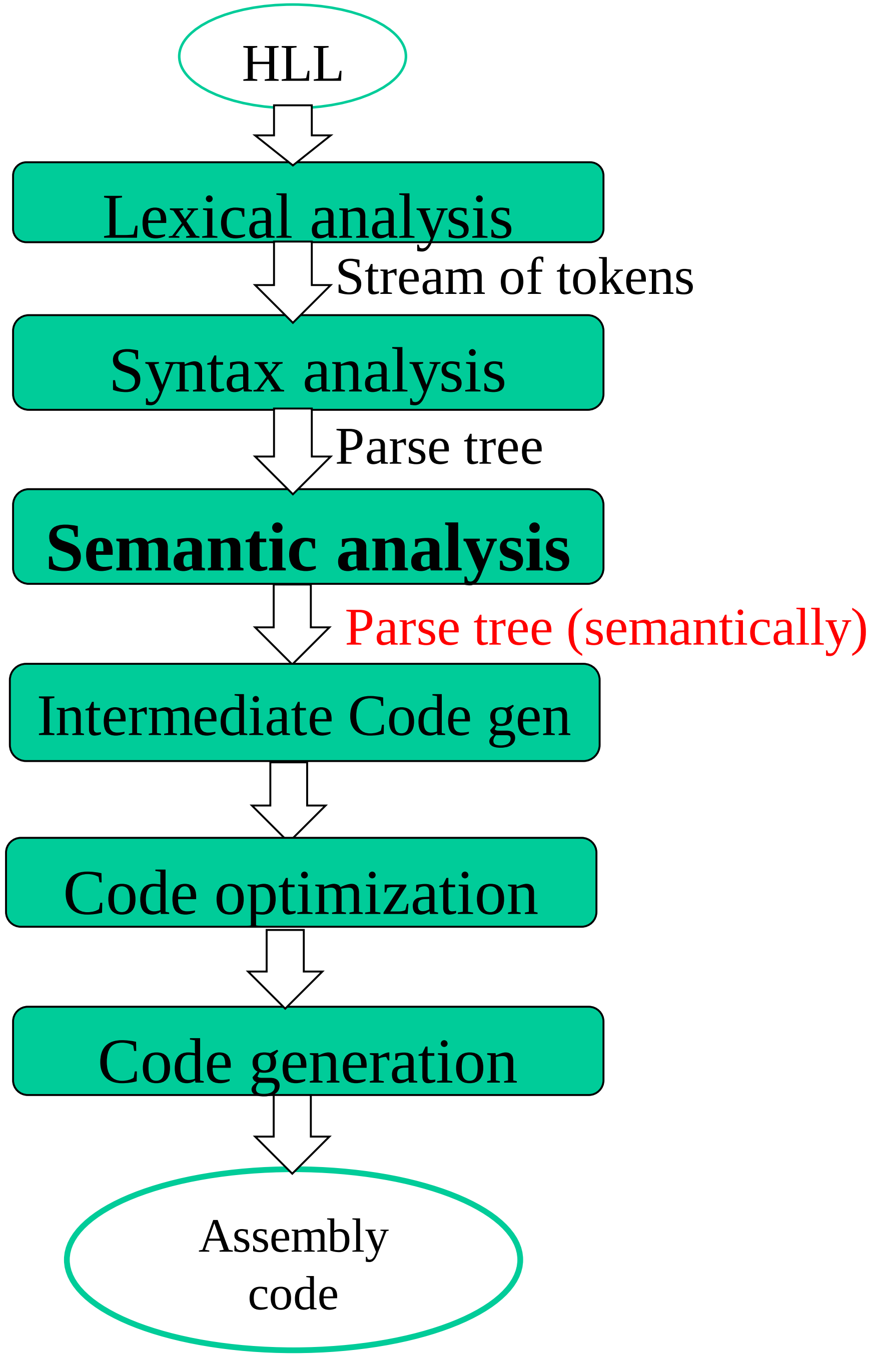
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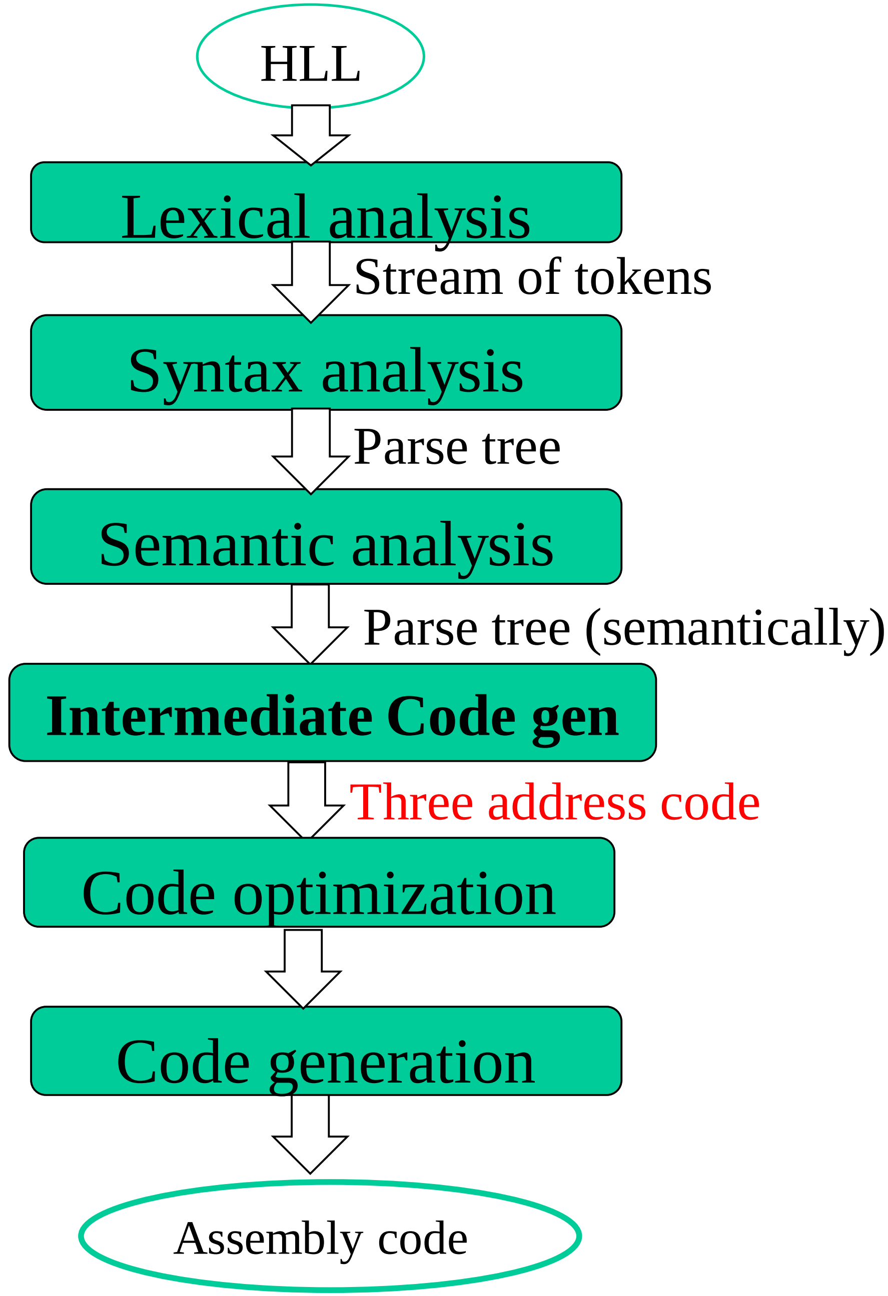
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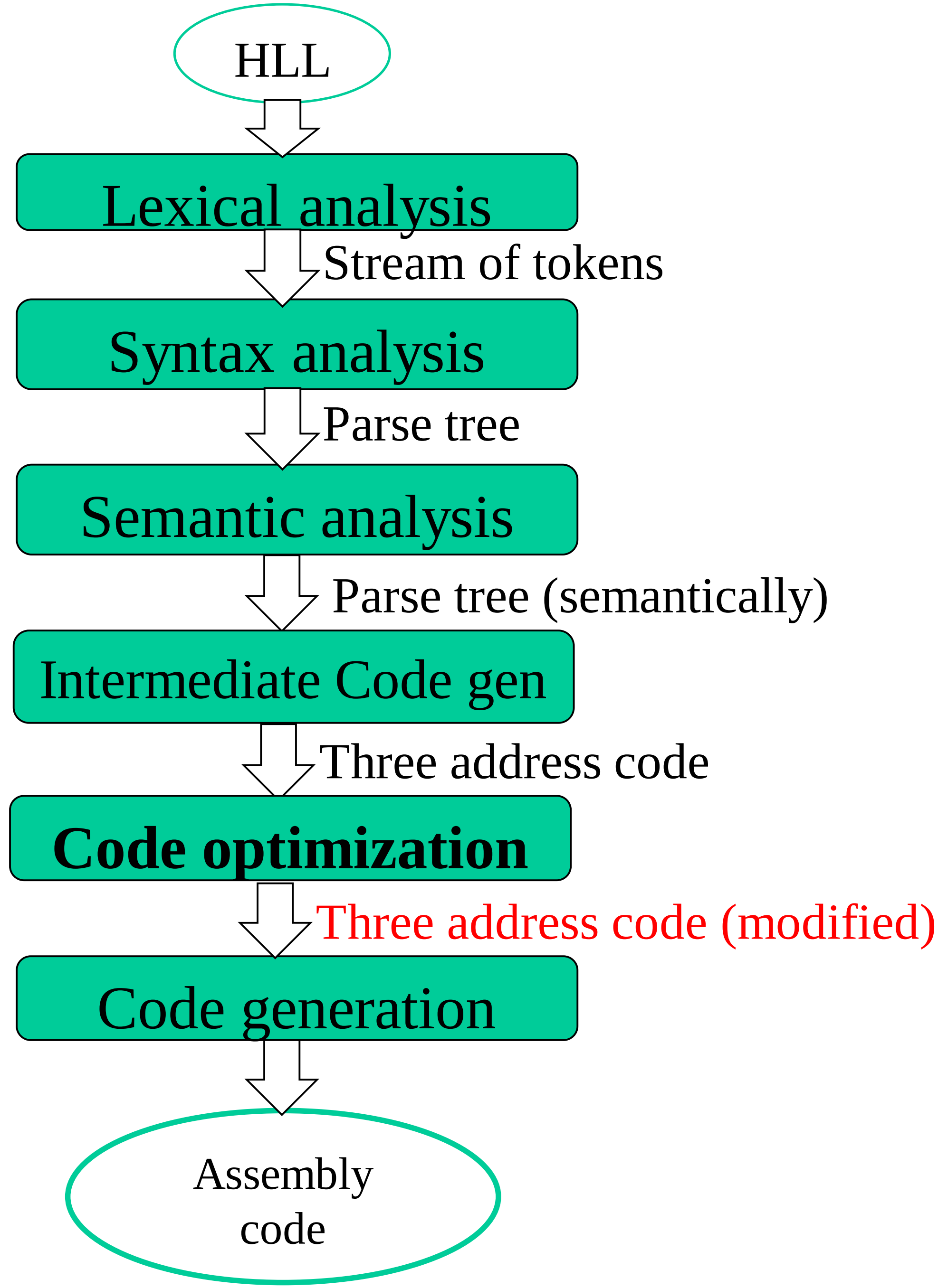
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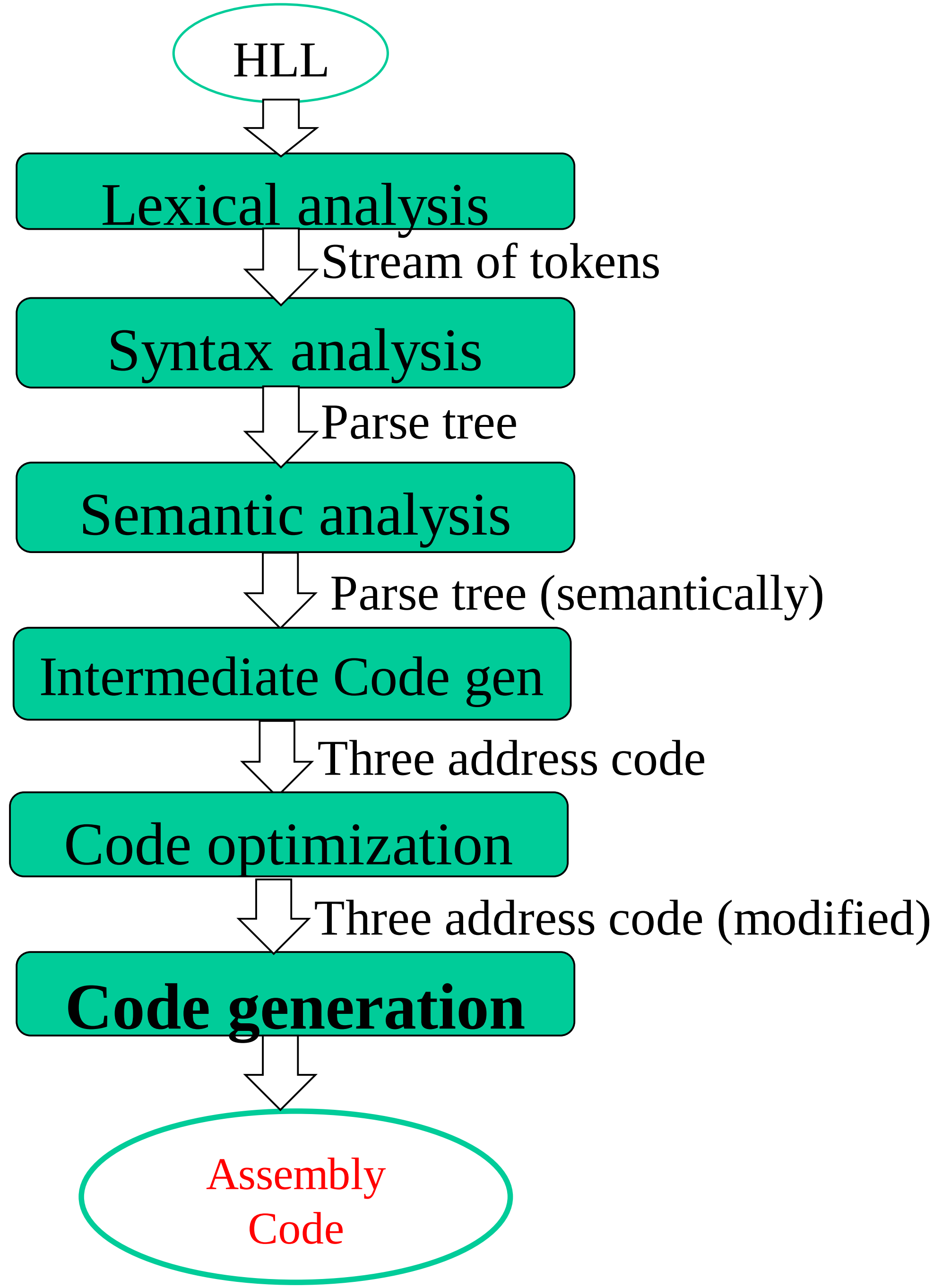
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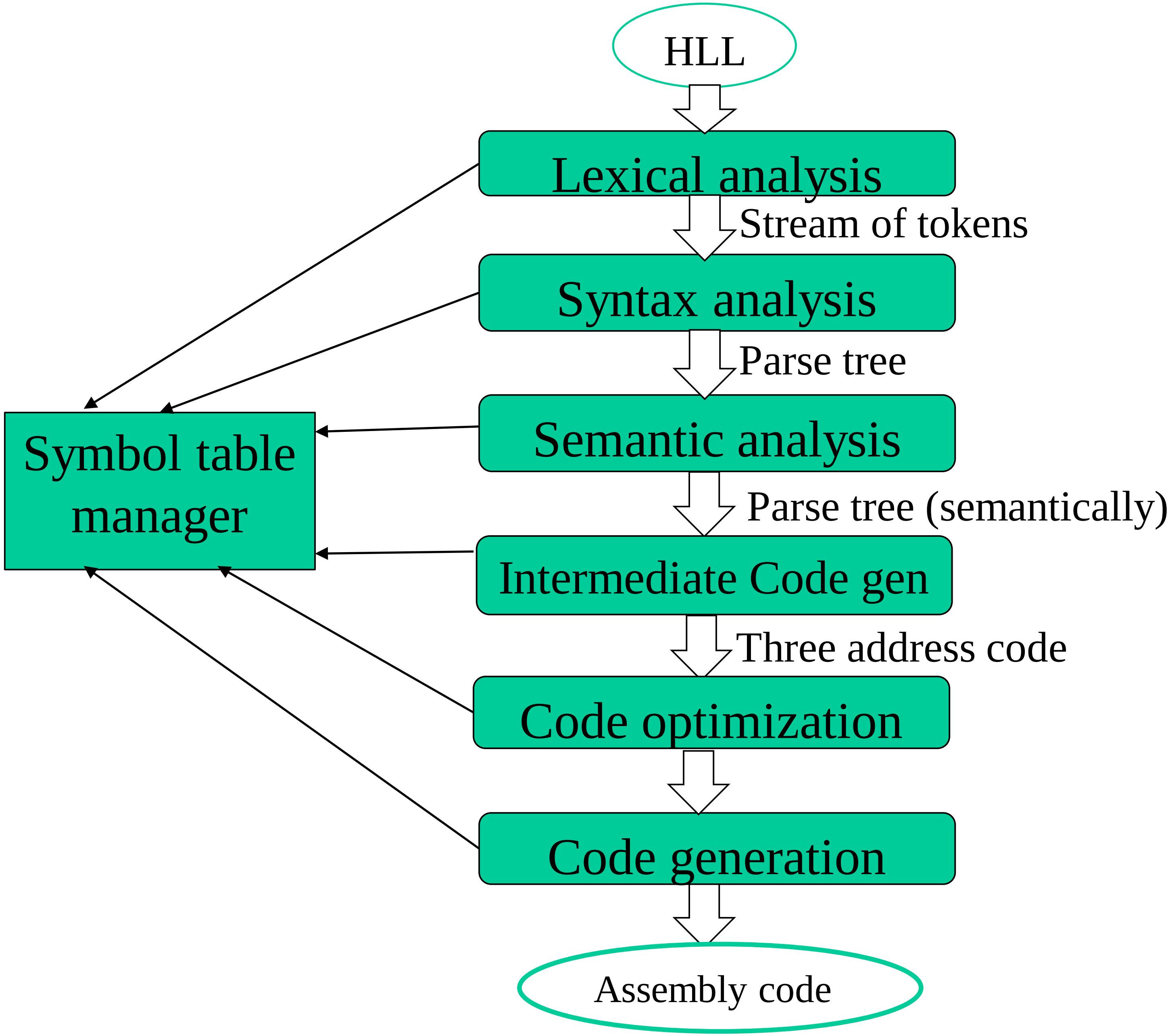
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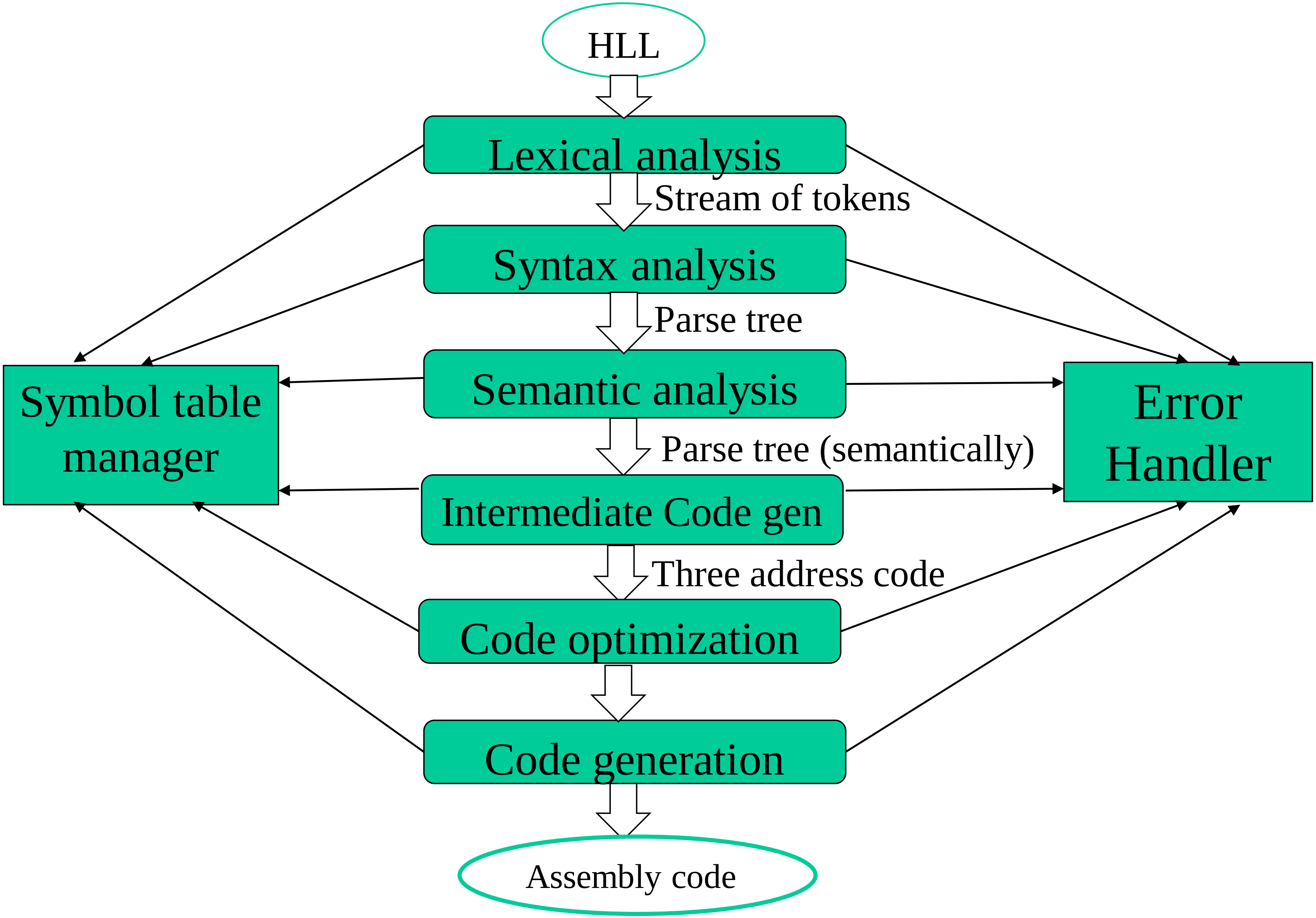
Assembly code
Symbol table manager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Symbol table manager
Error Handler

Lexical Analysis (Scanning)

- Reads characters in the source program and groups them into words (basic unit of syntax)
- Produces words and recognises what sort they are.
- The output is called token and is a pair of the form <*type*, *lexeme*> or <*token_class*, *attribute*>
- E.g.: **`a=b+c`** becomes <id,**`a`**> <=,> <id,**`b`**> <+,> <id,**`c`**>
- Needs to record each id attribute: keep a **symbol table**.
- Lexical analysis eliminates white space, etc…
- Speed is important - use a specialised tool: e.g., flex - a tool for generating <u>**scanners**</u>: programs which recognise lexical patterns in text; for more info: **`% man flex`**

Syntax (or syntactic) Analysis (Parsing)

- Imposes a hierarchical structure on the token stream.
- This hierarchical structure is usually expressed by recursive rules.
- Context-free grammars formalise these recursive rules and guide syntax analysis.
- Example:

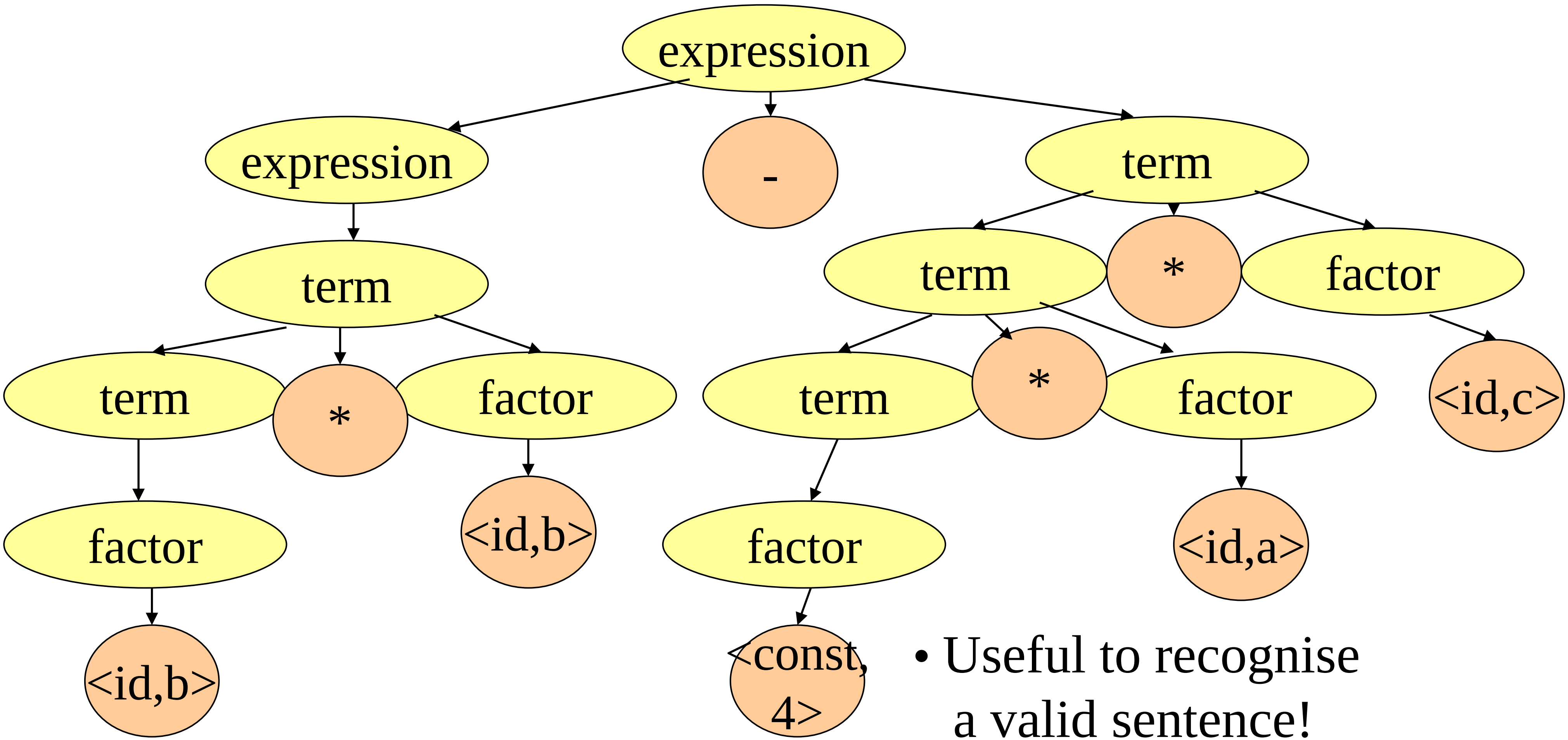
expression → expression '+' term | expression '-' term | term

term → term '*' factor | term '/' factor | factor

factor → identifier | constant | '(' expression ')'

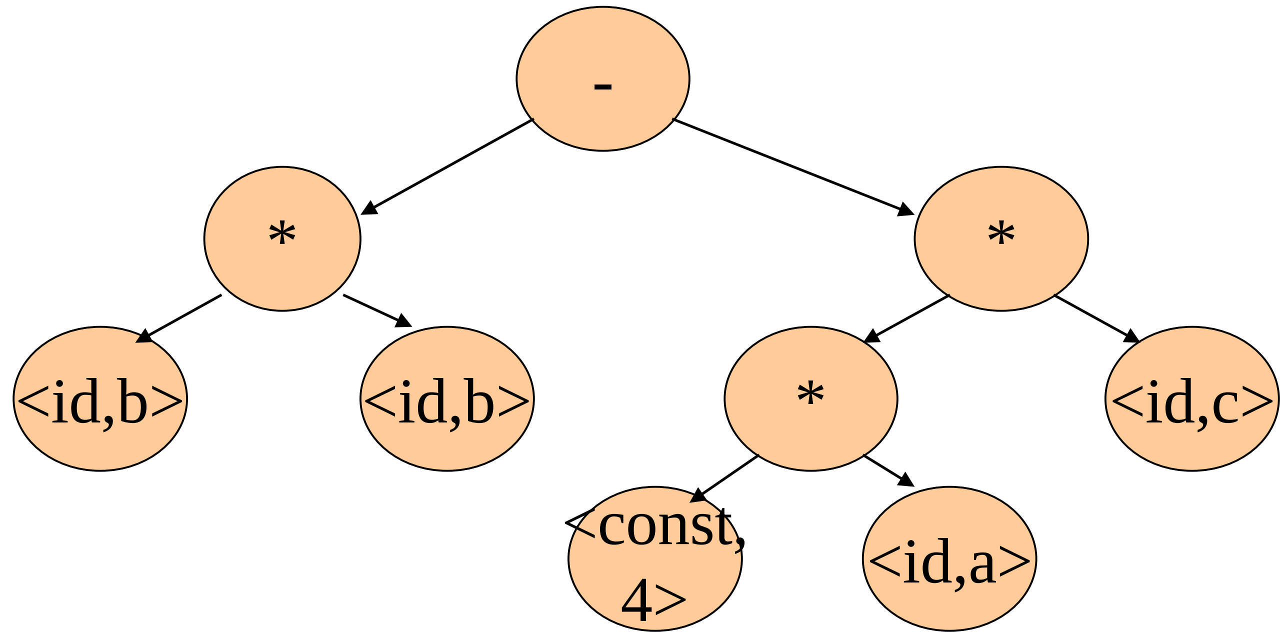
(this grammar defines simple algebraic expressions)

Parsing: parse tree for *b*b-4*a*c*



- Useful to recognise a valid sentence!
- Contains a lot of unneeded information!

AST for *b*b-4*a*c*



- An Abstract Syntax Tree (AST) is a more useful data structure for internal representation. It is a compressed version of the parse tree (summary of grammatical structure without details about its derivation)
- ASTs are one form of IR

Semantic Analysis (context handling)

- Collects context (semantic) information, checks for semantic errors, and annotates nodes of the tree with the results.
- Examples:
  - type checking: report error if an operator is applied to an incompatible operand.
  - check flow-of-controls.
  - uniqueness or name-related checks.

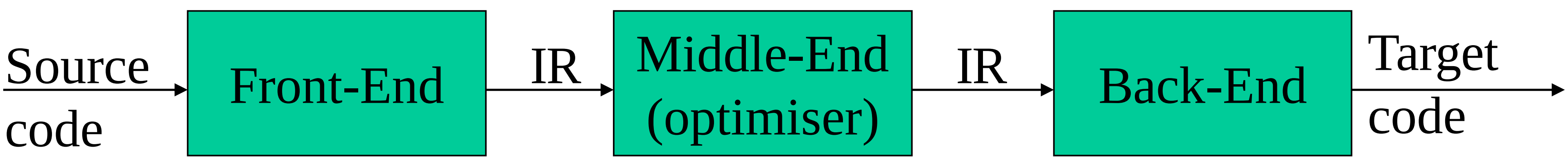
Intermediate code generation

- Translate language-specific constructs in the AST into more general constructs.
- A criterion for the level of "generality": it should be straightforward to generate the target code from the intermediate representation chosen.
- Example of a form of IR (3-address code):

```
tmp1=4
tmp2=tmp1*a
tmp3=tmp2*c
tmp4=b*b
tmp5=tmp4-tmp3
```

Code Optimisation

- The goal is to improve the intermediate code and, thus, the effectiveness of code generation and the performance of the target code.
- Optimisations can range from trivial (e.g. constant folding) to highly sophisticated (e.g, in-lining).
- For example: replace the first two statements in the example of the previous slide with: **`tmp2=4*a`**
- Modern compilers perform such a range of optimisations, that one could argue for:



Code Generation Phase

- Map the AST onto a linear list of target machine instructions in a symbolic form:
  - Instruction selection: a pattern matching problem.
  - Register allocation: each value should be in a register when it is used (but there is only a limited number): NP-Complete problem.
  - Instruction scheduling: take advantage of multiple functional units: NP-Complete problem.
- Target, machine-specific properties may be used to optimise the code.
- Finally, machine code and associated information required by the Operating System are generated.

Phases with example

$x = a + b * c;$ /*statement*/

⇓

Lexical analyser $\quad l(l+d)^*$

⇓

$id = id + id * id;$

⇓

Syntax analyser ⇐

$S \rightarrow id = E;$
$E \rightarrow E + T / T$
$T \rightarrow T * F / F$
$F \rightarrow id$

⇓

(parse tree)

⇒ **Semantic analyser**

⇓

(Parse tree Semantic...)

⇓

ICG

⇓

$t_1 = b * c;$
$t_2 = a + t_1;$
$x = t_2;$

⇓

ICO

⇓

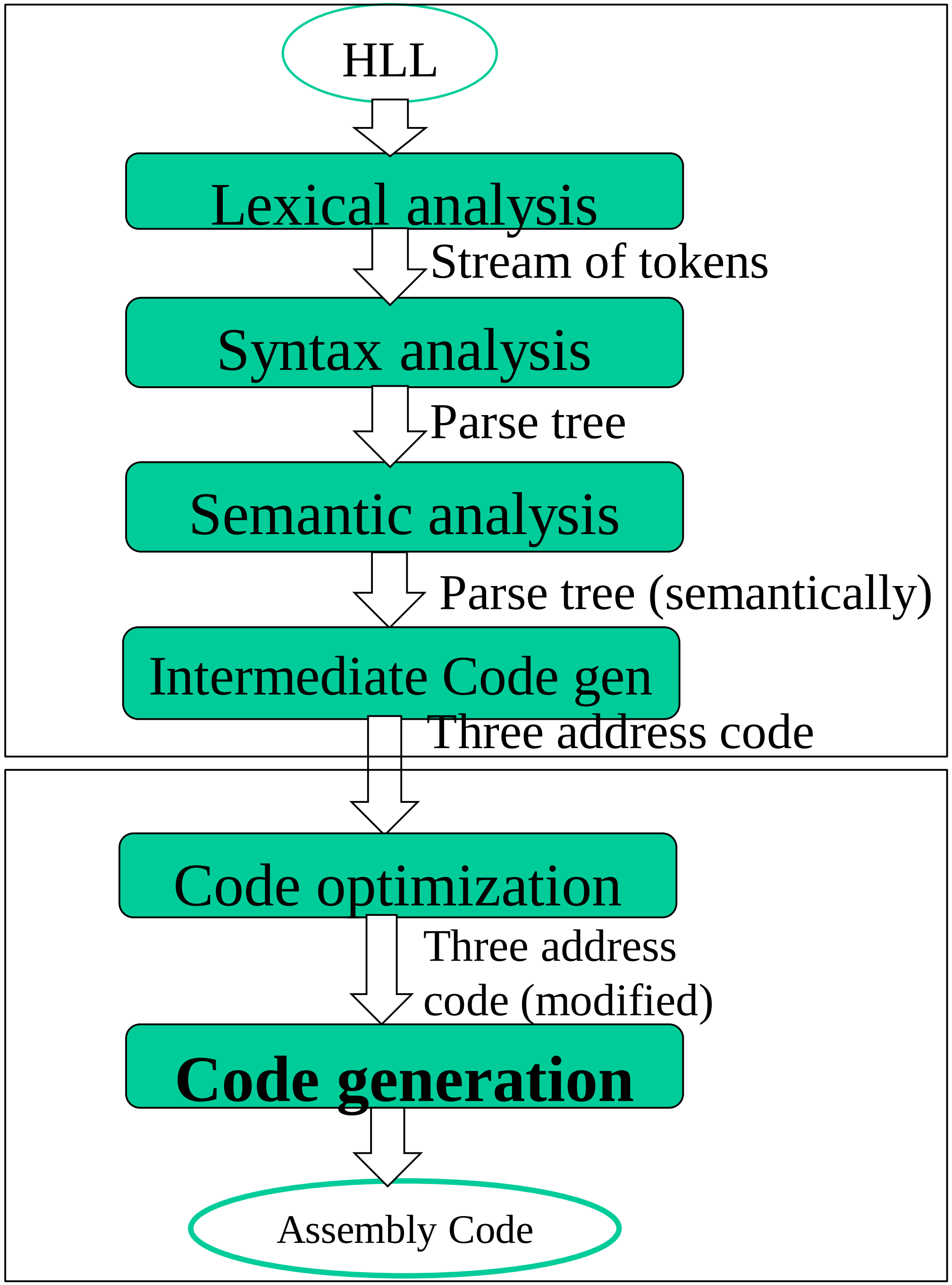
$t_1 = b * c;$
$t_2 = a + t_1;$

⇓

TCG

⇓

mul	R_1, R_2	$a \rightarrow R_0$
add	R_0, R_2	$b \rightarrow R_1$
mov	R_2, x	$c \rightarrow R_2$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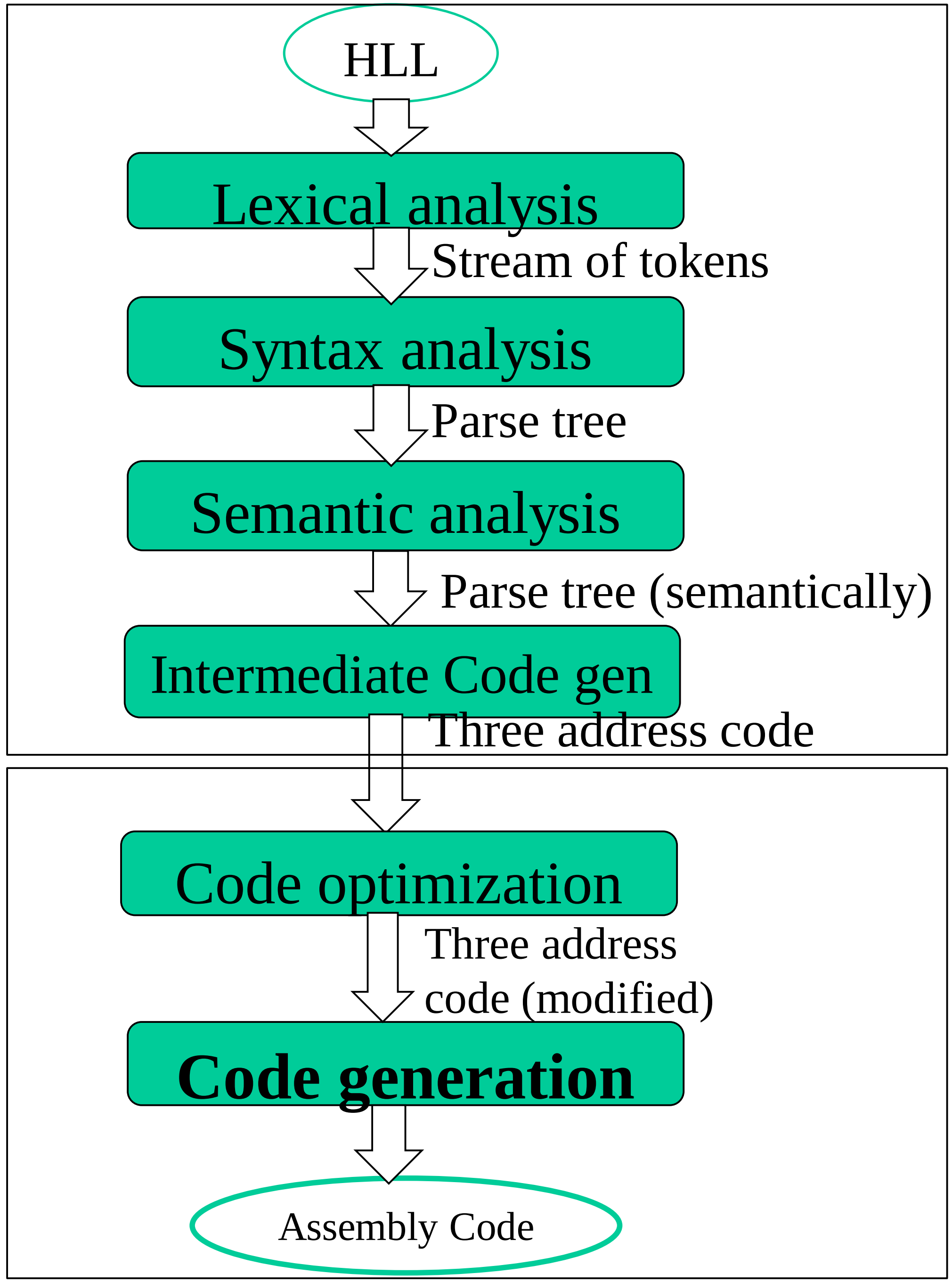
Front-end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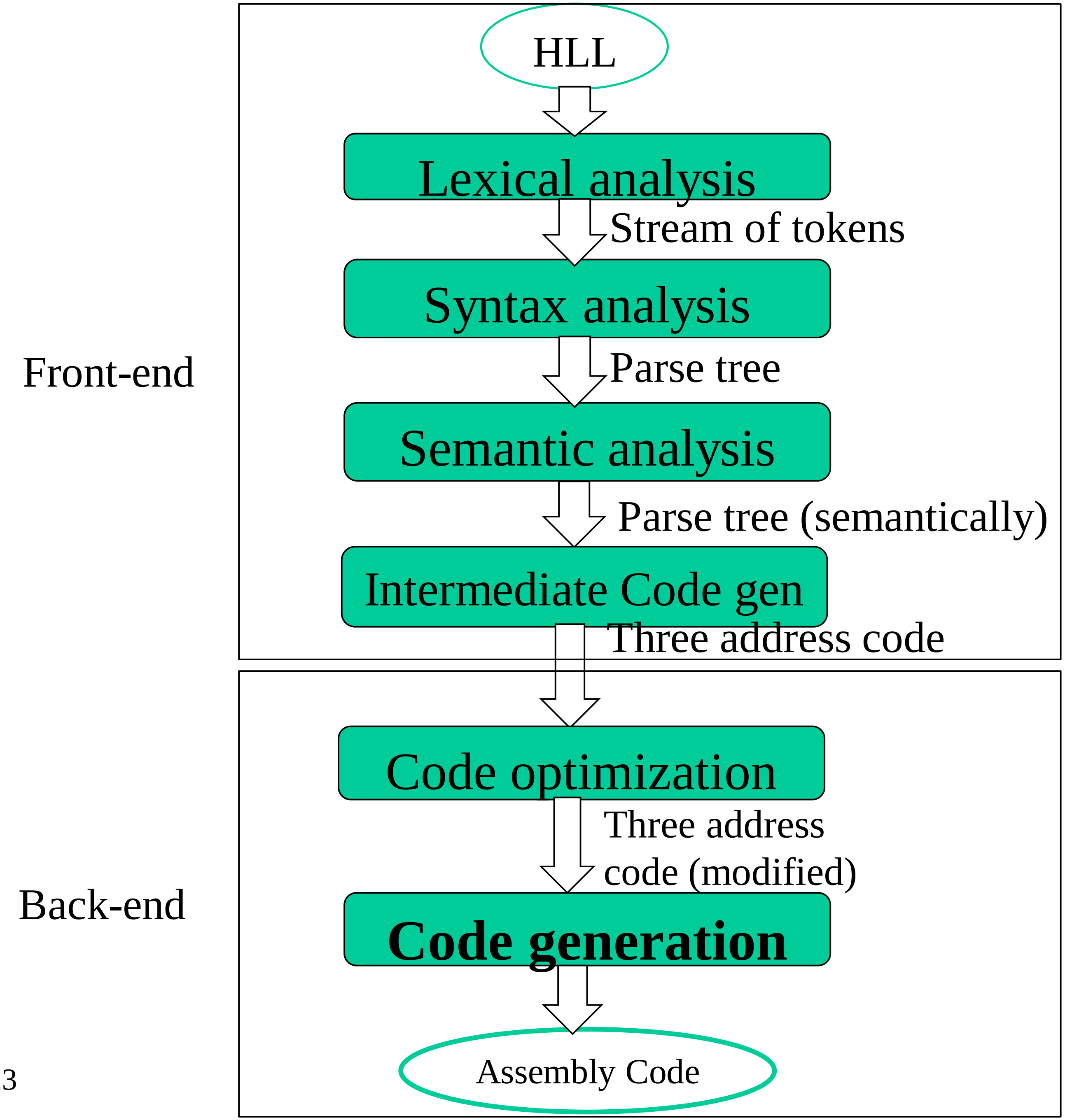
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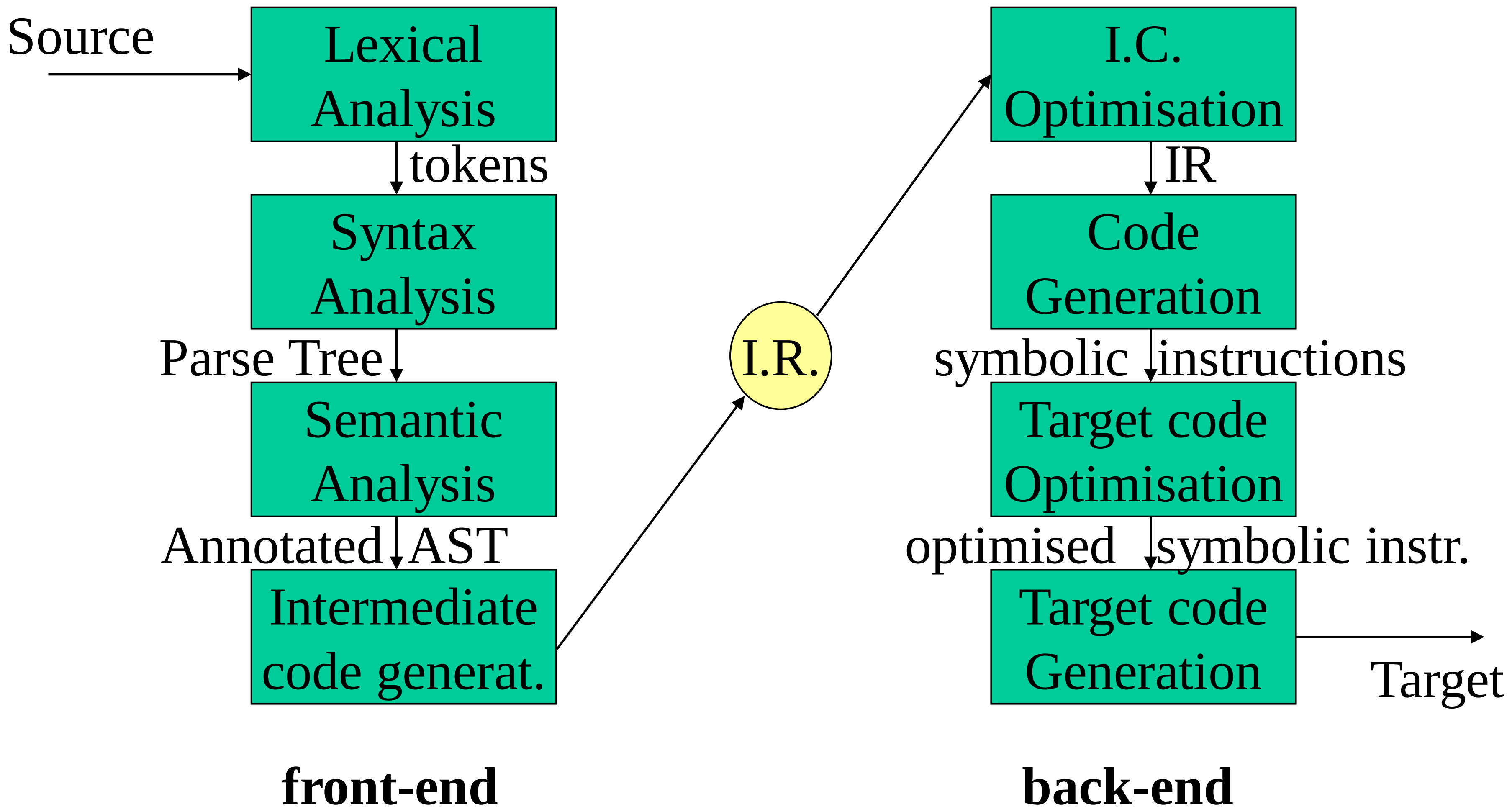
General Structure of a compiler

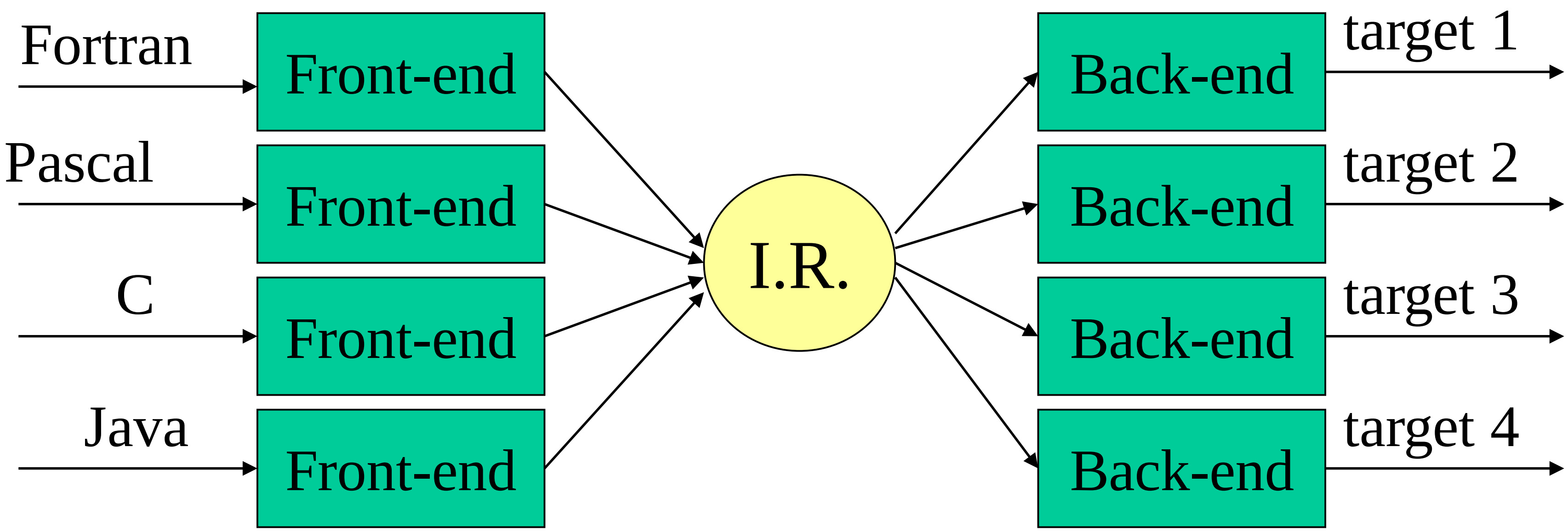


Conceptual Structure:two major phases

- **Front-end** performs the **analysis** of the source language:
  - Recognises legal and illegal programs and reports errors.
  - “understands” the input program and collects its semantics in an IR.
  - Produces IR and shapes the code for the back-end.
  - Much can be automated.

- **Back-end** does the target language **synthesis**:
  - Chooses instructions to implement each IR operation.
  - Translates IR into target code.
  - Needs to conform with system interfaces.
  - Automation has been less successful.

m×n compilers with m+n components!



- All language specific knowledge must be encoded in the front-end
- All target specific knowledge must be encoded in the back-end

But: in practice, this strict separation is not free of charge.

Qualities of a Good Compiler

What qualities would you want in a compiler?

- generates correct code (first and foremost!)
- generates fast code
- conforms to the specifications of the input language
- copes with essentially arbitrary input size, variables, etc.
- compilation time (linearly)proportional to size of source
- good diagnostics
- consistent optimisations
- works well with the debugger

Principles of Compilation

The compiler must:

- *preserve the meaning of the program being compiled*.
- *"improve" the source code in some way*.

Other issues (depending on the setting):

- Speed (of compiled code)
- Space (size of compiled code)
- Feedback (information provided to the user)
- Debugging (transformations obscure the relationship source code vs target)
- Compilation time efficiency (fast or slow compiler?)

Historical Notes:

The Move to Higher-Level Programming Languages

- Machine Languages (1st generation)
- Assembly Languages (2nd generation) – early 1950s
- High-Level Languages (3rd generation) – later 1950s
- 4th generation higher level languages (SQL, Postscript)
- 5th generation languages (logic based, eg, Prolog)
- Other classifications:
  - Imperative (how); declarative (what)
  - Object-oriented languages
  - Scripting languages

Finally...

Parts of a compiler can be generated automatically using generators based on formalisms. E.g.:

- Scanner generators: flex
- Parser generators: bison