CS3300 - Compiler Design

Introduction

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IIT Madras

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Contact (Anytime) :
Instructor: Krishna, Email: nvk@cse.iitm.ac.in, Office: BSB 352.
TA: A Raghesh:raghesh@cse, Office: PACE Lab.

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  - A programming language is an artificial language designed to communicate instructions to a machine, particularly a computer.
  - For a computer to execute programs written in these languages, these programs need to be translated to a form in which it can be executed by the computer.

Images of the day

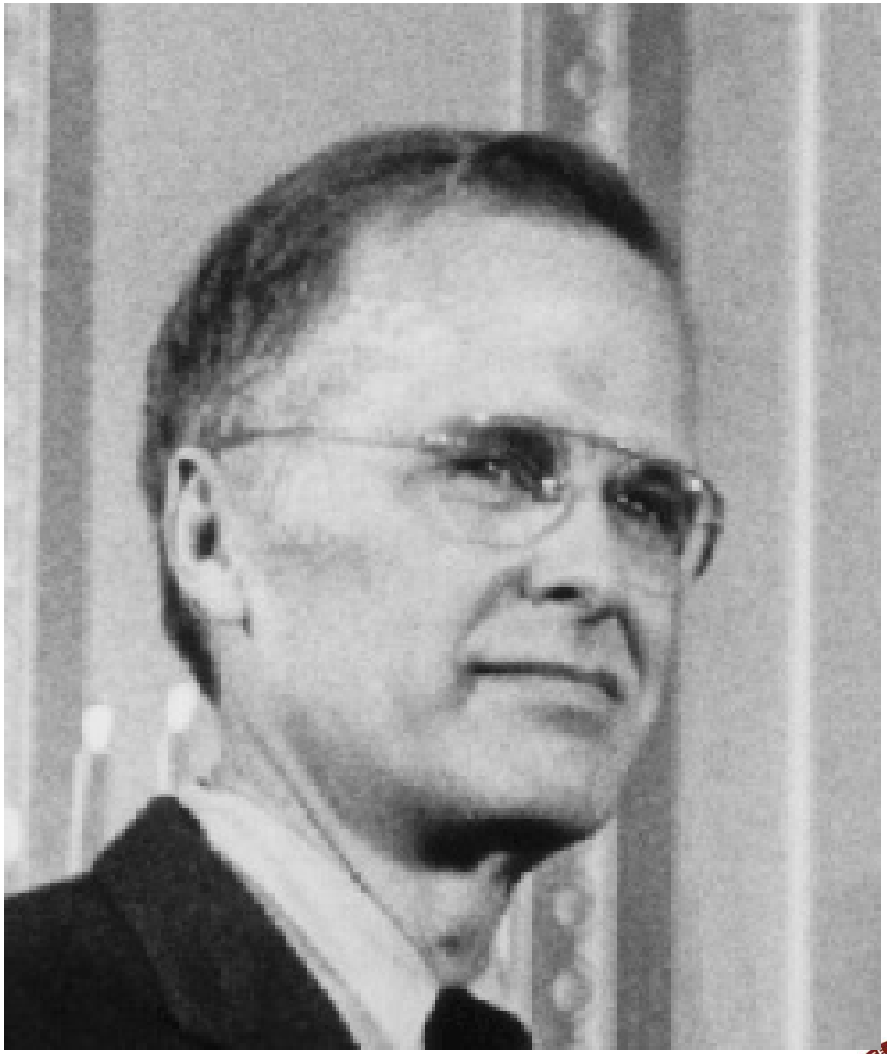

Figure: Grace Hopper and John Backus

Compilers – A “Sangam”

Compiler construction is a microcosm of computer science

- **Artificial Intelligence** greedy algorithms, learning algorithms, ...
- **Algo** graph algorithms, union-find, dynamic programming, ...
- **theory** DFAs for scanning, parser generators, lattice theory, ...
- **systems** allocation, locality, layout, synchronization, ...
- **architecture** pipeline management, hierarchy management, instruction set use, ...
- **optimizations** Operational research, load balancing, scheduling, ...

Inside a compiler, all these and many more come together. Has probably the healthiest mix of theory and practise.

Mutual expectations

For the class to be a mutually learning experience:

- What will be required from the students?
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- What are the students expectations?

Course outline

A rough outline (we may not strictly stick to this).

- Overview of Compilers
- Regular Expressions and Context Free Grammars (glance)
- Lexical Analysis and Parsing
- Type checking
- Intermediate Code Generation
- Register Allocation
- Code Generation
- Overview of advanced topics.

Your friends: Languages and Tools

Start exploring

- C and Java - familiarity a must - Use eclipse to save you valuable coding and debugging cycles.
- Flex, Bison, JavaCC, JTB – tools you will learn to use.
- Make / Ant / Scripts – recommended toolkit.
- Find the course webpage: http://www.cse.iitm.ac.in/ krishna/cs3300/
- Find the lab webpage: http://www.cse.iitm.ac.in/ krishna/cs3300/cs3310.html

Get set. Ready steady go!

Acknowledgement

These slides borrow liberal portions of text verbatim from Antony L. Hosking @ Purdue, Jens Palsberg @ UCLA, and the Dragon book.

A common confusion: Compilers and Interpreters

- What is a compiler?
  - a program that translates an executable program in one language into an executable program in another language
  - we expect the program produced by the compiler to be better, in some way, than the original.
- What is an interpreter?
  - a program that reads an executable program and produces the results of running that program
  - usually, this involves executing the source program in some fashion

  This course deals mainly with compilers
  Many of the same issues arise in interpreter
- A common (mis?) statement – XYZ is an interpreted (or compiled) languaged.

Compilers – A closed area?

"Optimization for scalar machines was solved years ago"

Machines have changed drastically in the last 20 years

Changes in architecture $\Rightarrow$ changes in compilers

- new features pose new problems
- changing costs lead to different concerns
- old solutions need re-engineering

Changes in compilers should prompt changes in architecture

- New languages and features

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9. Cross language calls
10. Consistent, predictable optimization

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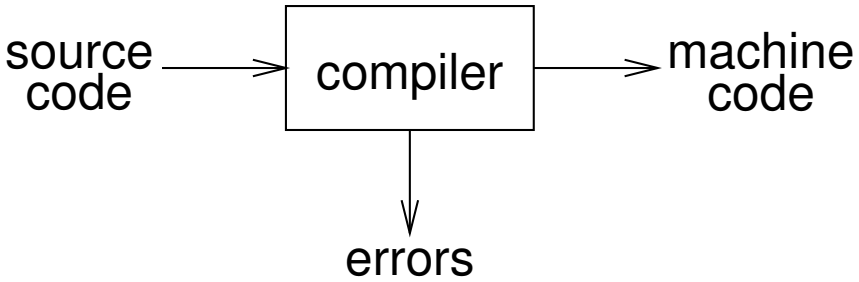
Abstract view

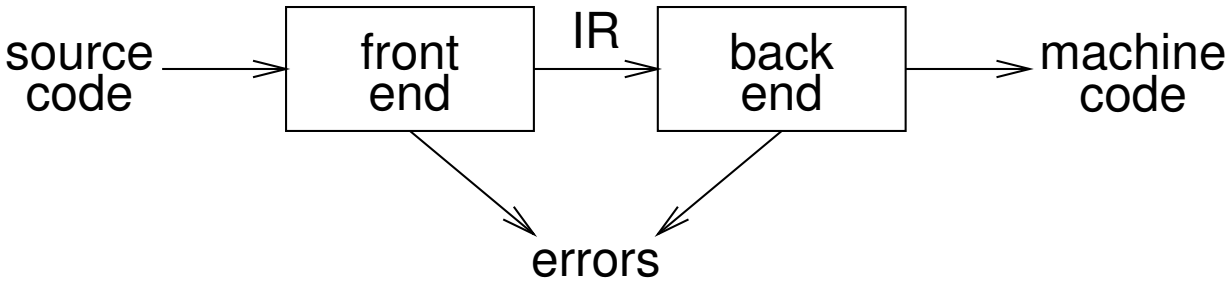


Implications:

- recognize legal (and illegal) programs
- generate correct code
- manage storage of all variables and code
- agreement on format for object (or assembly) code

Big step up from assembler — higher level notations

Traditional two pass compiler



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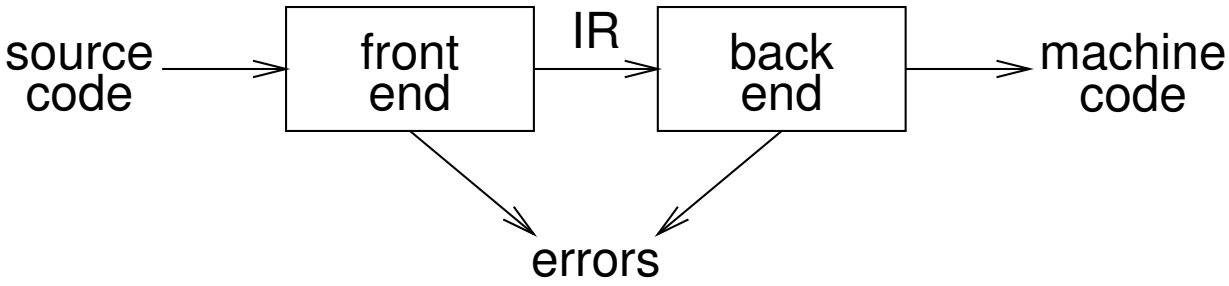

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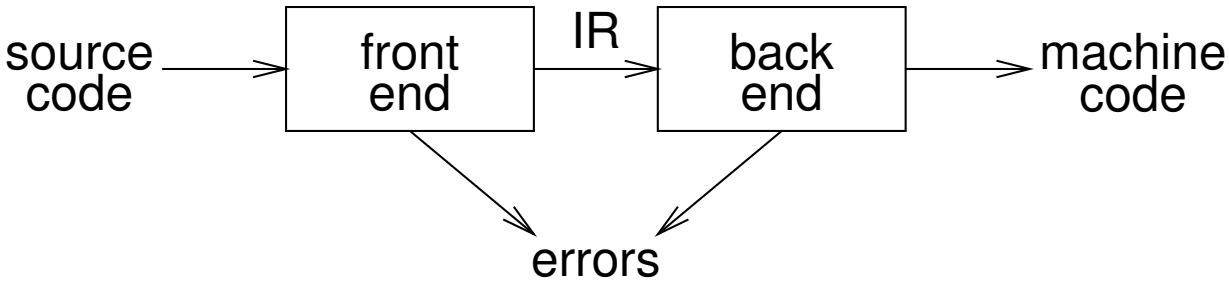

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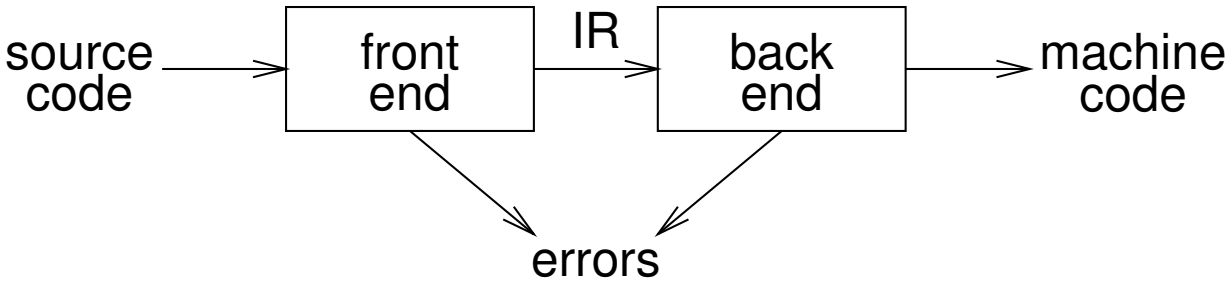

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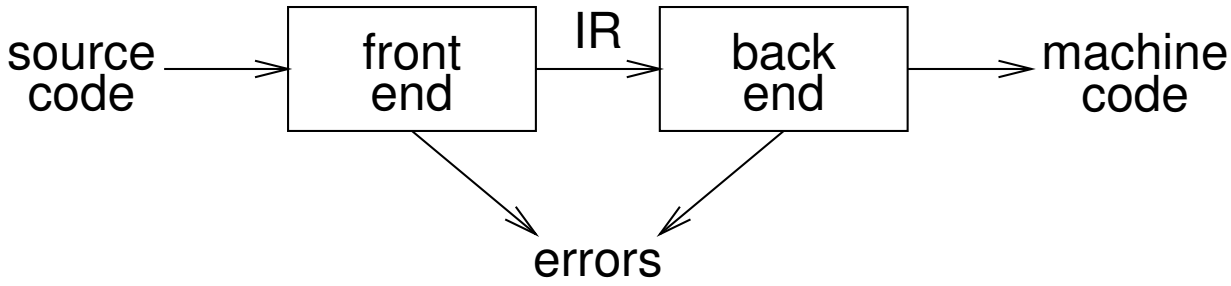

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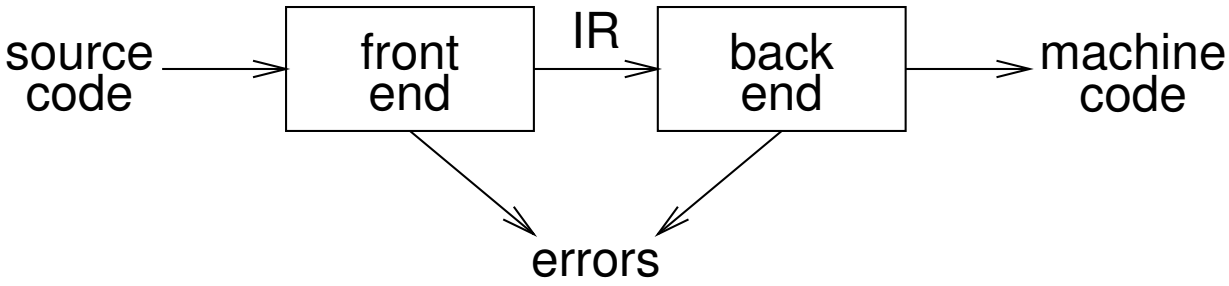

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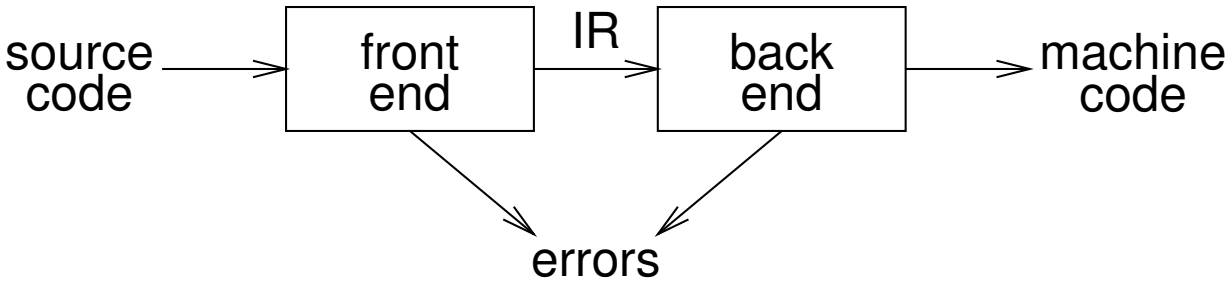

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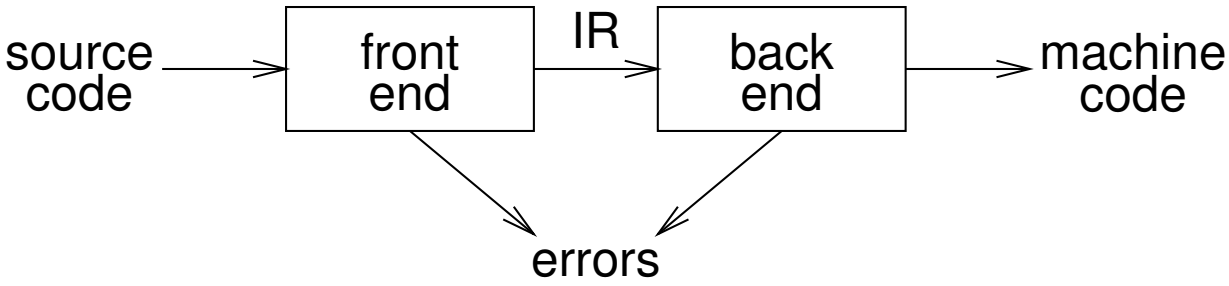

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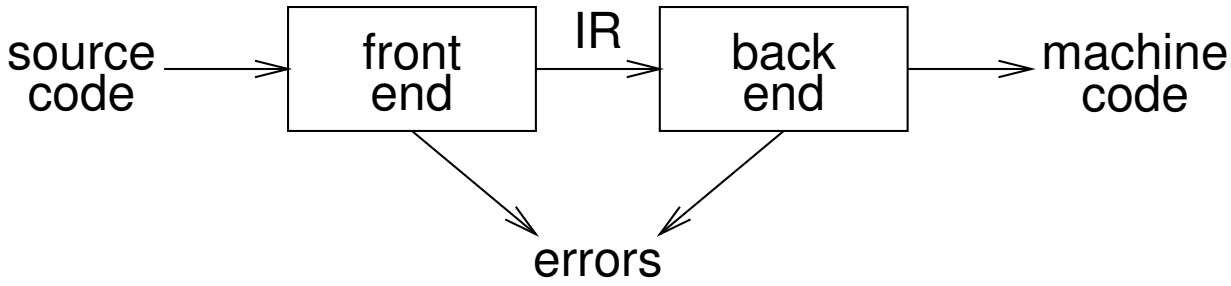

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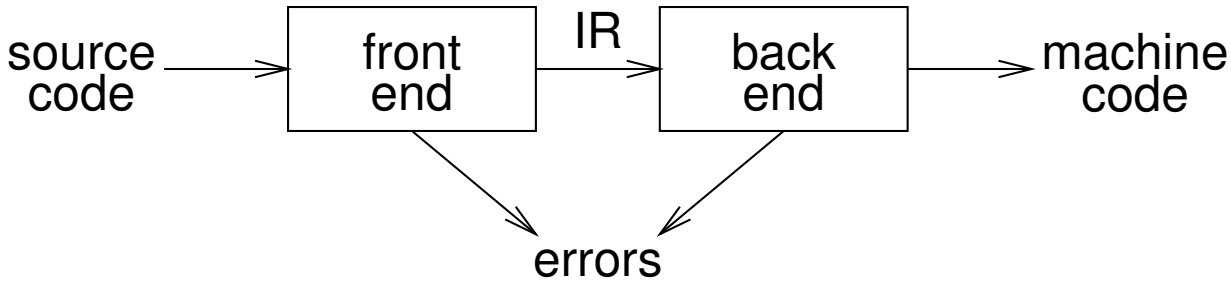

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Our focus: Mainly front end and little bit of back end.

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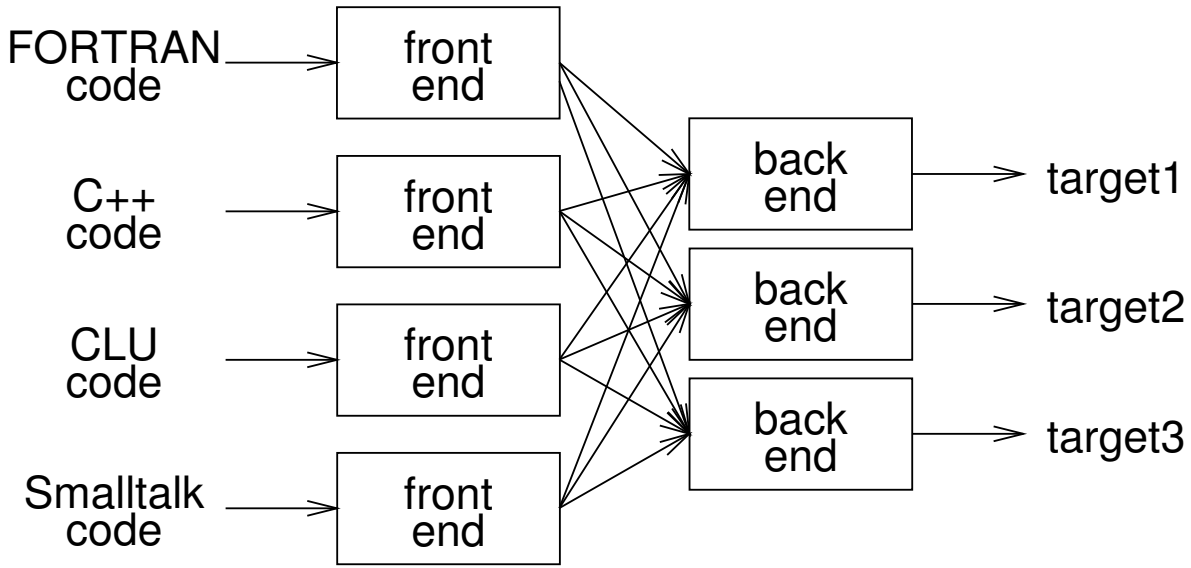

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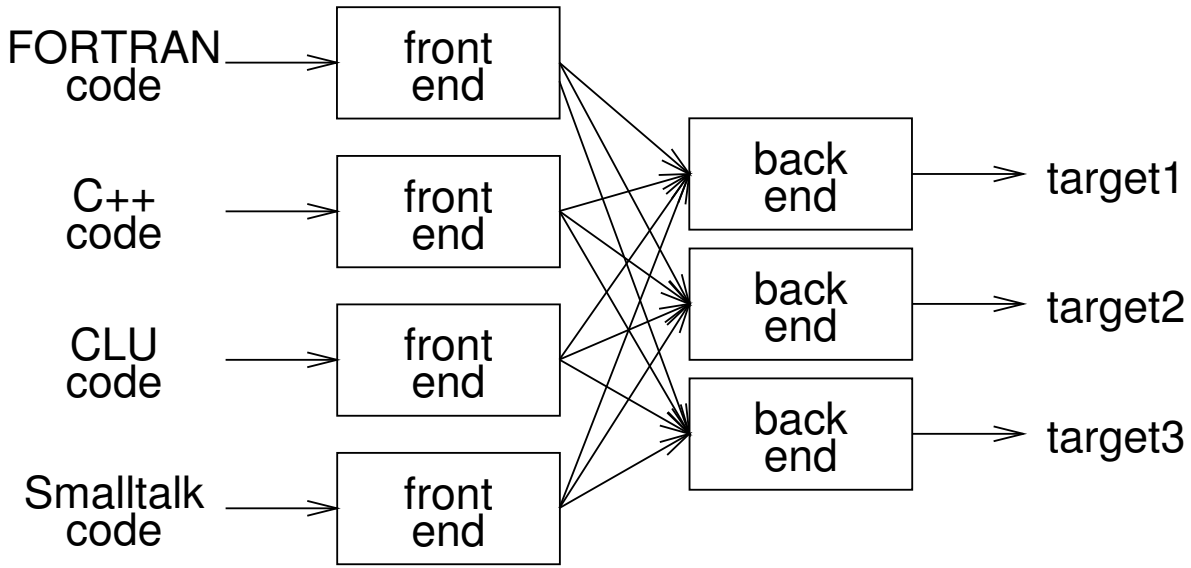
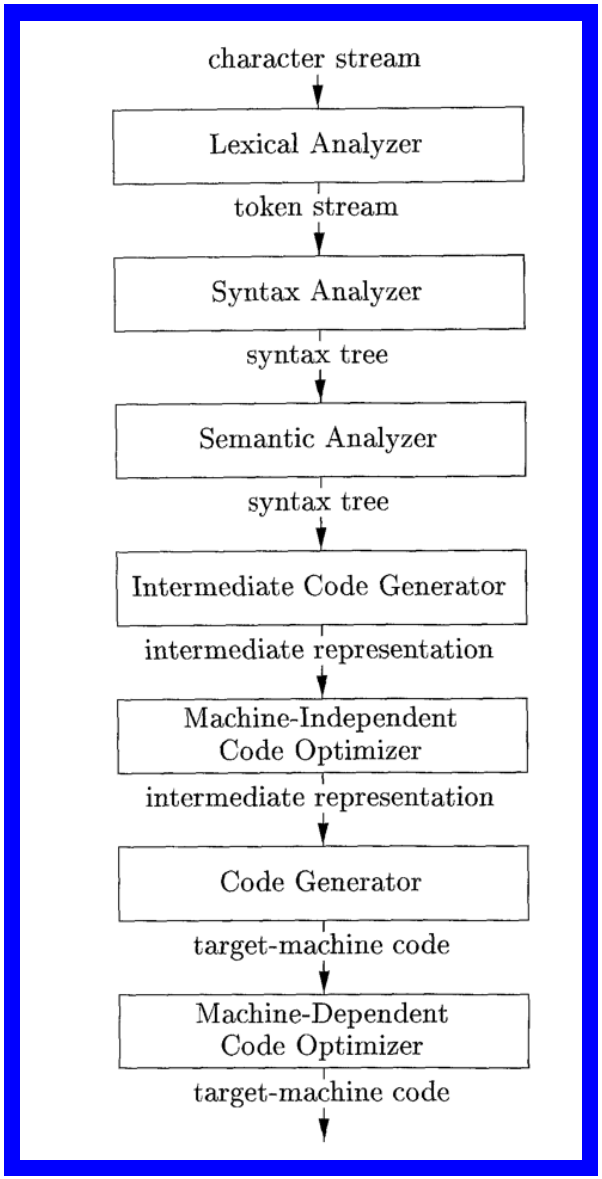


Can we build $n \times m$ compilers with $n + m$ components?

- must encode all the knowledge in each front end
- must represent all the features in one IR
- must handle all the features in each back end

Limited success with low-level IRs

Phases inside the compiler



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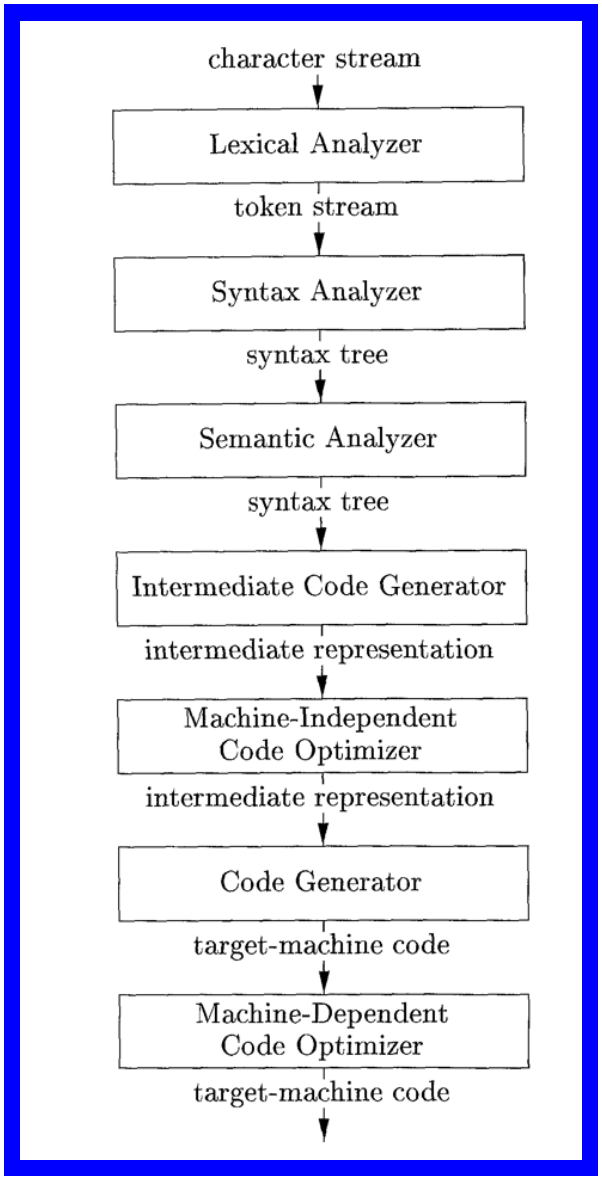

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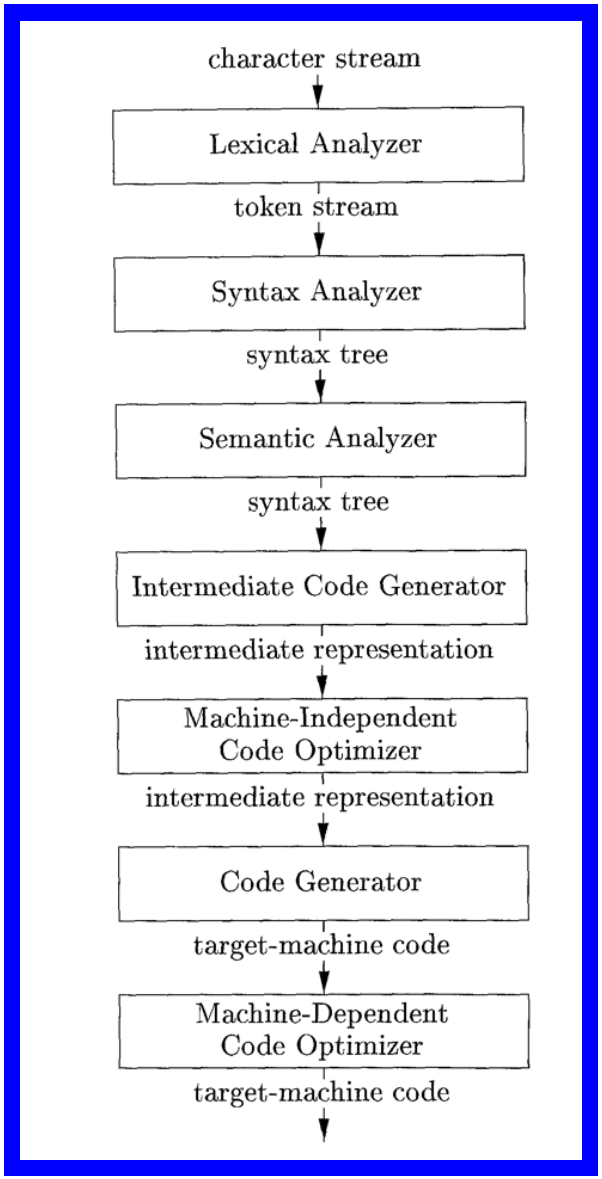

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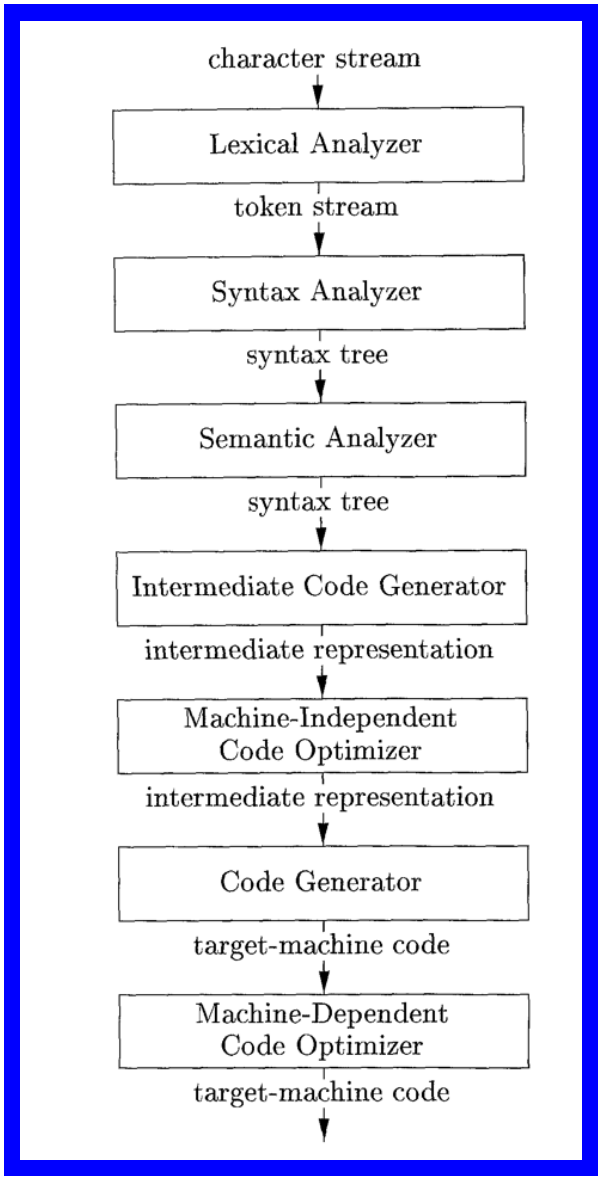

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Our target

- five out of seven phases.
- glance over optimizations – attend the graduate course if interested.

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`rate`	⟨id, rate⟩
`*`	⟨op, *⟩
`60`	⟨num, 60⟩

Specifying patterns

Q: How to specify patterns for the scanner?

Examples:

- white space

$$\begin{array}{lcl} \langle ws \rangle & ::= & \langle ws \rangle \text{ ' '} \\ & | & \langle ws \rangle \text{ '\textbackslash t'} \\ & | & \text{' '} \\ & | & \text{'\textbackslash t'} \end{array}$$

- keywords and operators
  specified as literal patterns: `do`, `end`

Specifying patterns

A scanner must recognize the units of syntax

- identifiers
  alphabetic followed by k alphanumerics (_, $, &, . . .)
- numbers
  - integers: 0 or digit from 1-9 followed by digits from 0-9
  - decimals: integer |'.'| digits from 0-9
  - reals: (integer or decimal) |'E'| (+ or -) digits from 0-9
  - complex: |'('| real |','| real |')'—

We need a powerful notation to specify these patterns

Regular Expressions

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Regular expressions (over an alphabet Σ):

1. ε is a RE denoting the set $\{\varepsilon\}$
2. if $a \in \Sigma$, then a is a RE denoting $\{a\}$
3. if r and s are REs, denoting $L(r)$ and $L(s)$, then:
   - (r) is a RE denoting $L(r)$
   - $(r) \mid (s)$ is a RE denoting $L(r) \bigcup L(s)$
   - $(r)(s)$ is a RE denoting $L(r)L(s)$
   - $(r)^*$ is a RE denoting $L(r)^*$

Examples of Regular Expressions

- identifier
  letter $\rightarrow (a \mid b \mid c \mid \ldots \mid z \mid A \mid B \mid C \mid \ldots \mid Z)$
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Most tokens can be described with REs
We can use REs to build scanners automatically

Generic examples of REs

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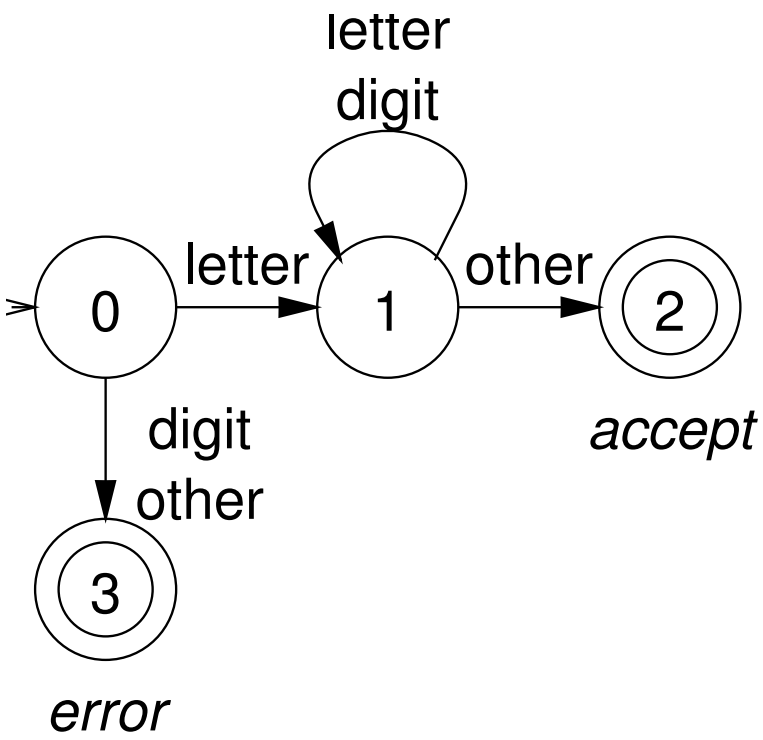
- $a|a*b$ denotes $\{a, b, ab, aab, aaab, aaaab, \ldots\}$

Recognizers

From a regular expression we can construct a

deterministic finite automaton (DFA)

Recognizer for identifier:



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```
case 2: // accept state
      tokenType=id;
      done = true;
      break;
   case 3: // error
      tokenType=error;
      done=true;
      break;
  } // end switch
} // end while
return tokenType;
```

Tables for the recognizer

Two tables control the recognizer

`charClass:`

	$a-z$	$A-Z$	$0-9$	other
value	letter	letter	digit	other
class	0	1	2	3

`nextState:`

letter	1	1	—	—
digit	3	1	—	—
other	3	2	—	—

To change languages, we can just change tables

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Language features that can cause problems:

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finite closures

some languages limit identifier lengths

adds states to count length

FORTRAN 66 $\rightarrow$ 6 characters

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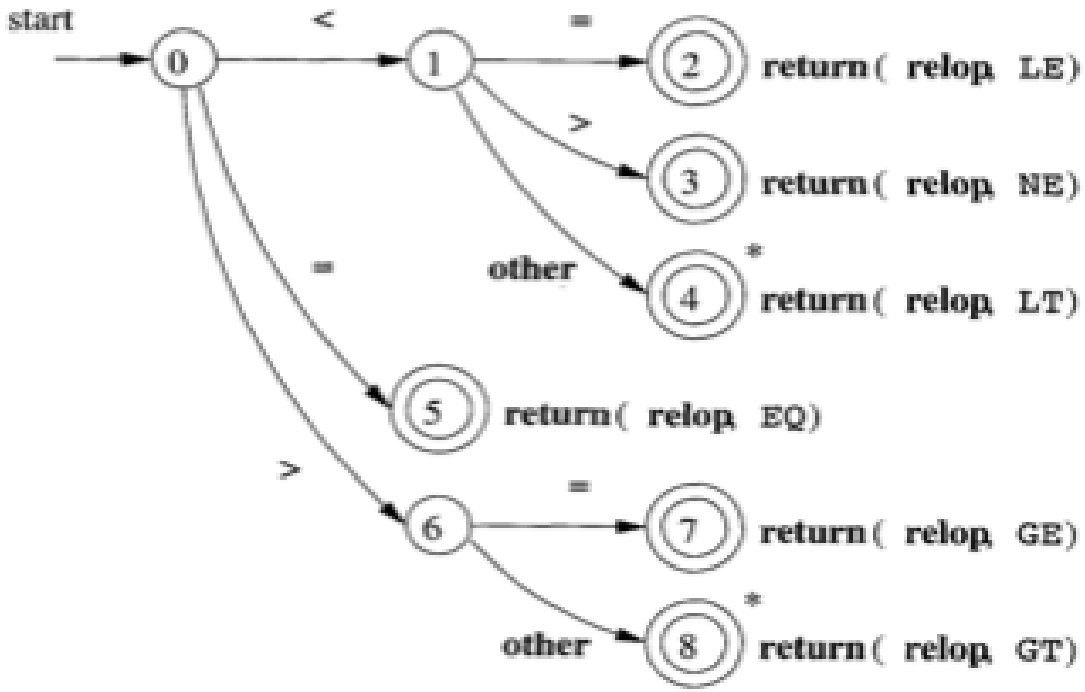

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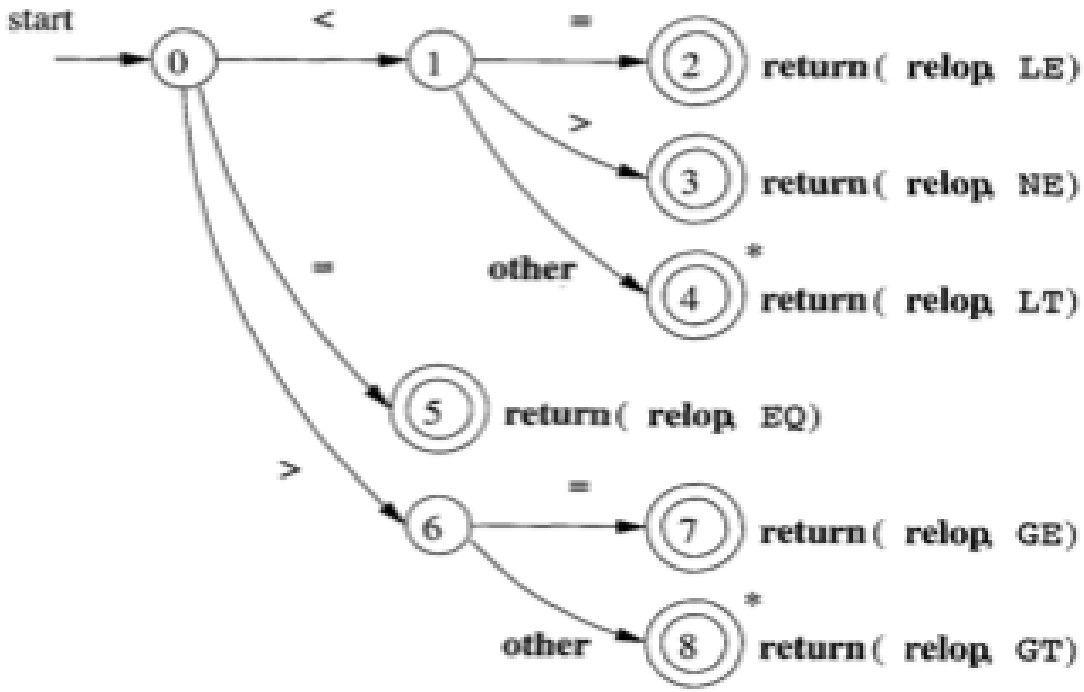

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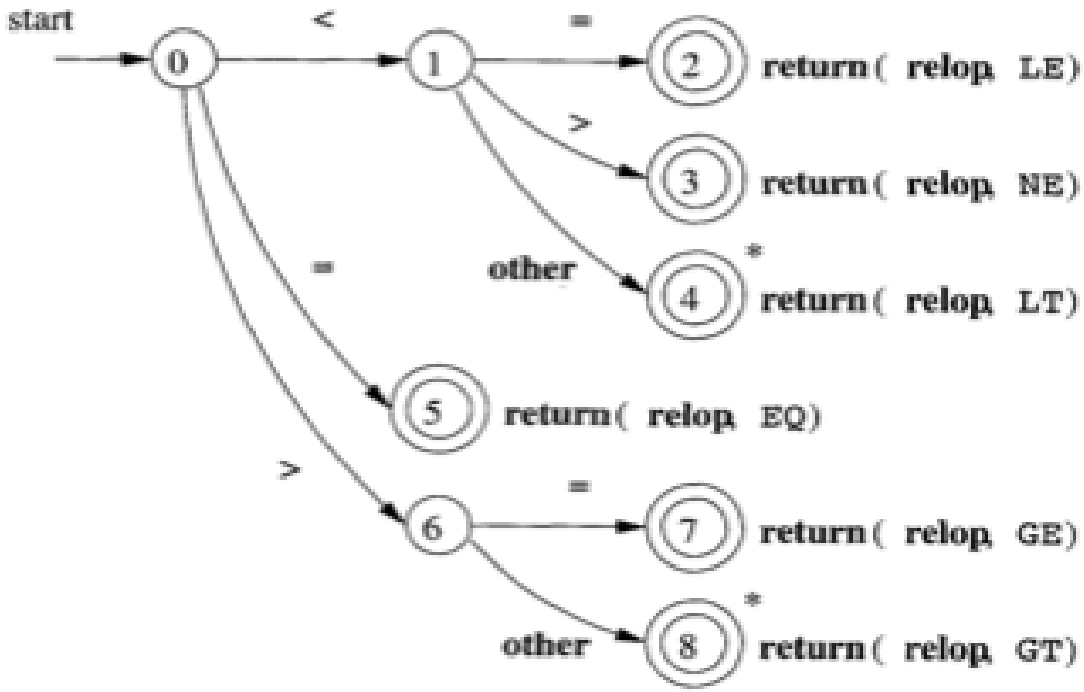

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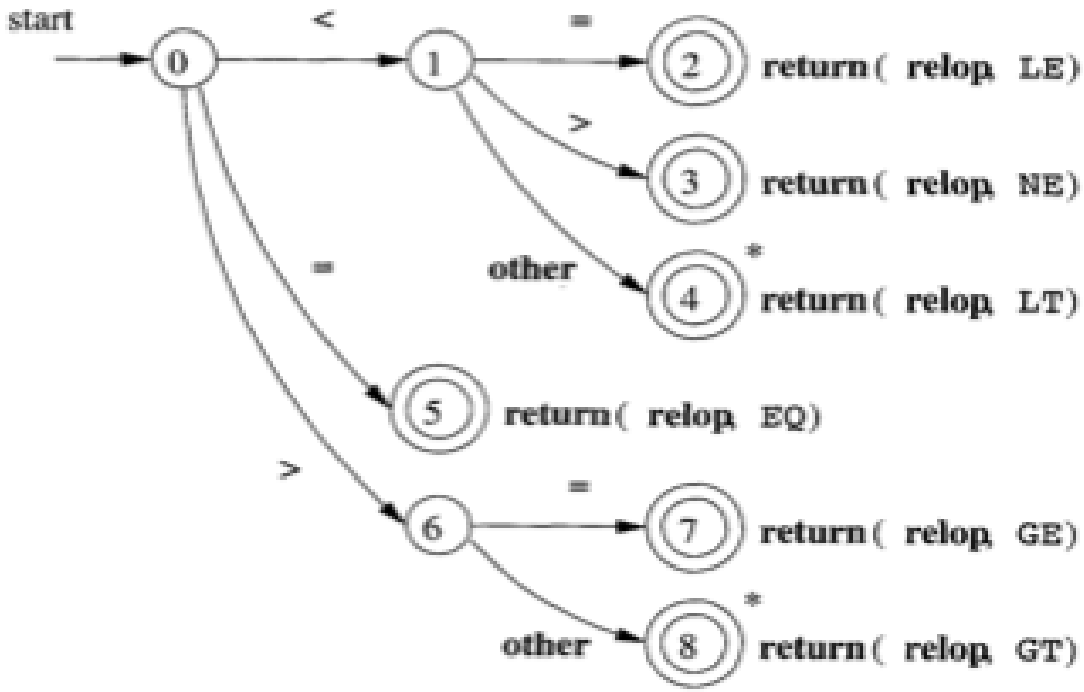

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  - Let it be identified as both reserved word and identifier. Higher priority to reserved words.

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- Many other one character related fixes (examples?)

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- provides macro definitions for each token
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