The View from 35,000 Feet

CS434 Compiler Construction
Spring 2005
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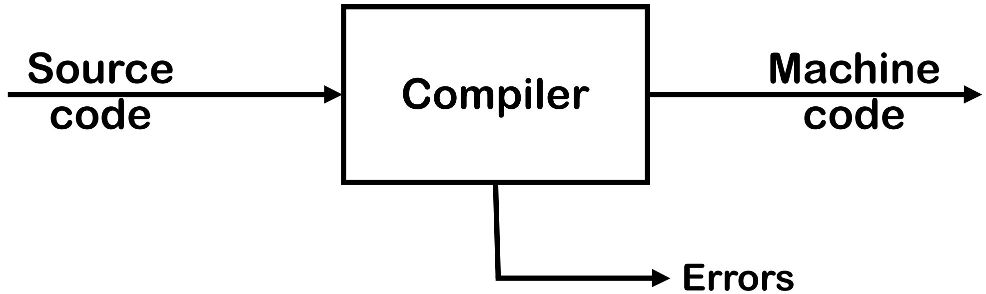
High-level View of a Compiler

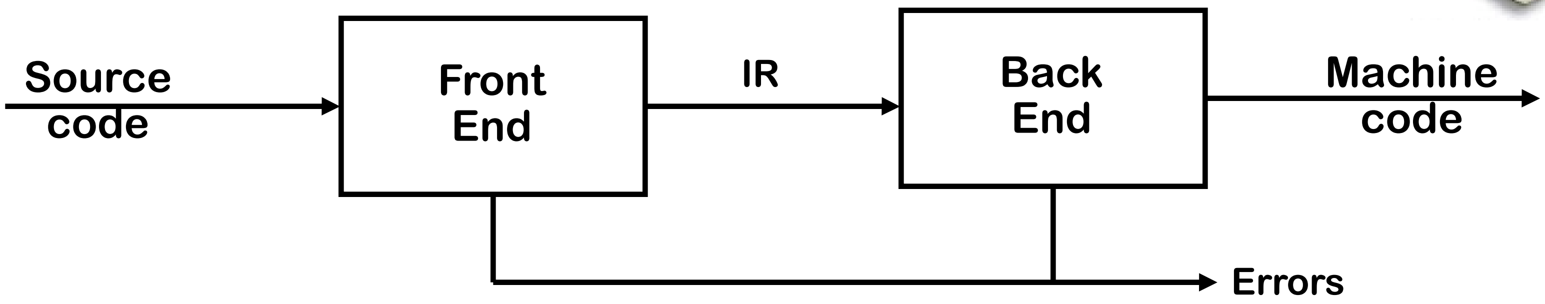


Implications

- Must recognize legal (and illegal) programs
- Must generate correct code
- Must manage storage of all variables (and code)
- Must agree with OS & linker on format for object code

Big step up from assembly language—use higher level notations

Traditional Two-pass Compiler

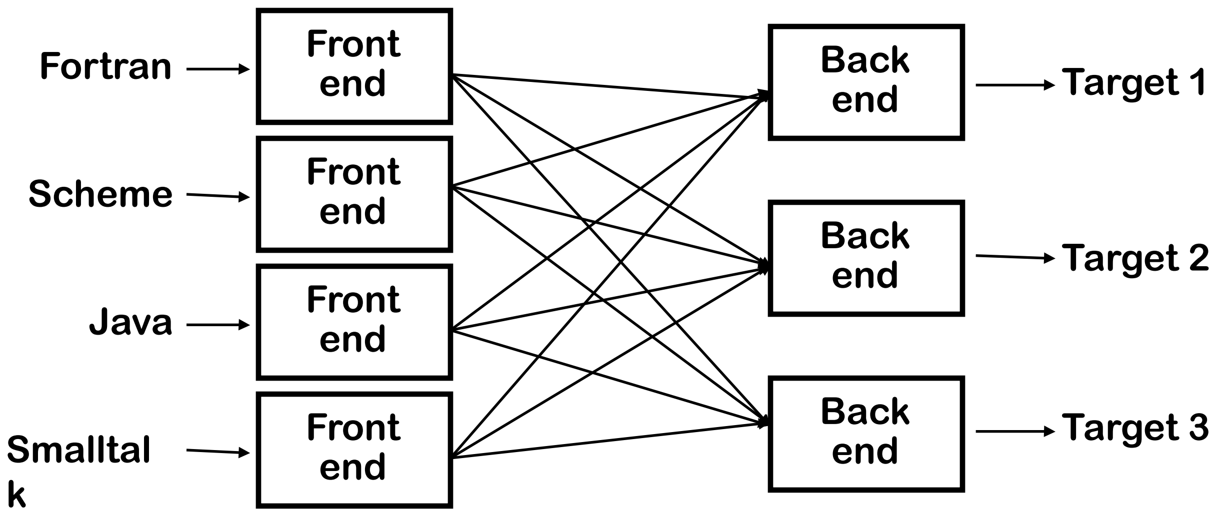


Implications

- Use an intermediate representation (IR)
- Front end maps legal source code into IR
- Back end maps IR into target machine code
- Admits multiple front ends & multiple passes (better code)

Typically, front end is O(n) or O(n log n), while back end is NPC

A Common Fallacy

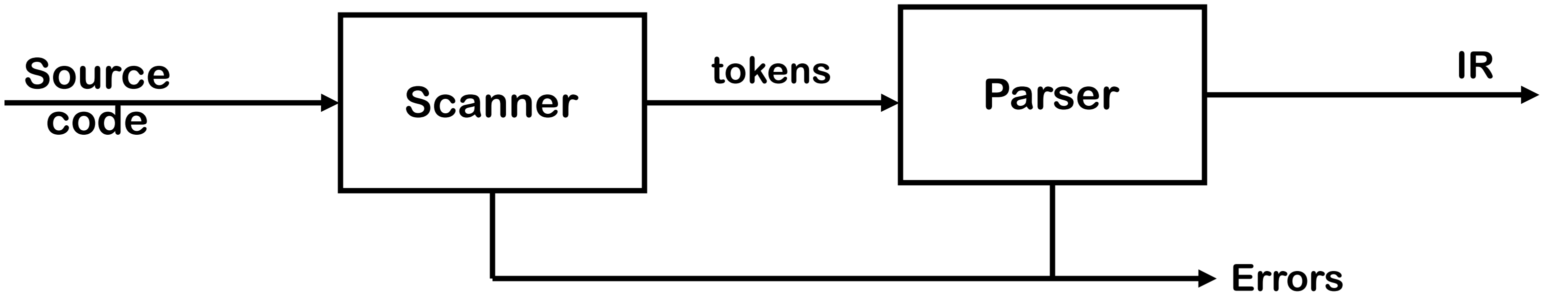


Can we build n x m compilers with n+m components?

- Must encode all language specific knowledge in each front end
- Must encode all features in a single IR
- Must encode all target specific knowledge in each back end

Limited success in systems with very low-level IRs

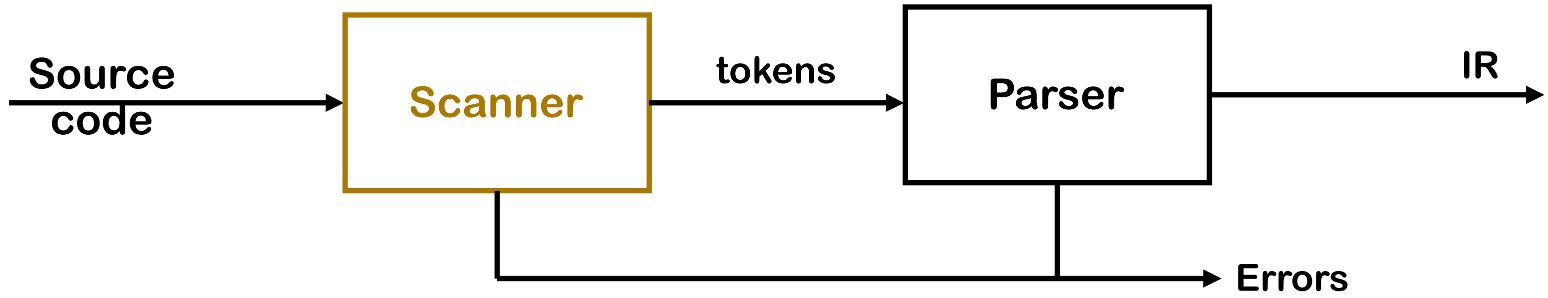
The Front End



Responsibilities

- Recognize legal (& illegal) programs
- Report errors in a useful way
- Produce IR & preliminary storage map
- Shape the code for the back end
- Much of front end construction can be automated

The Front End



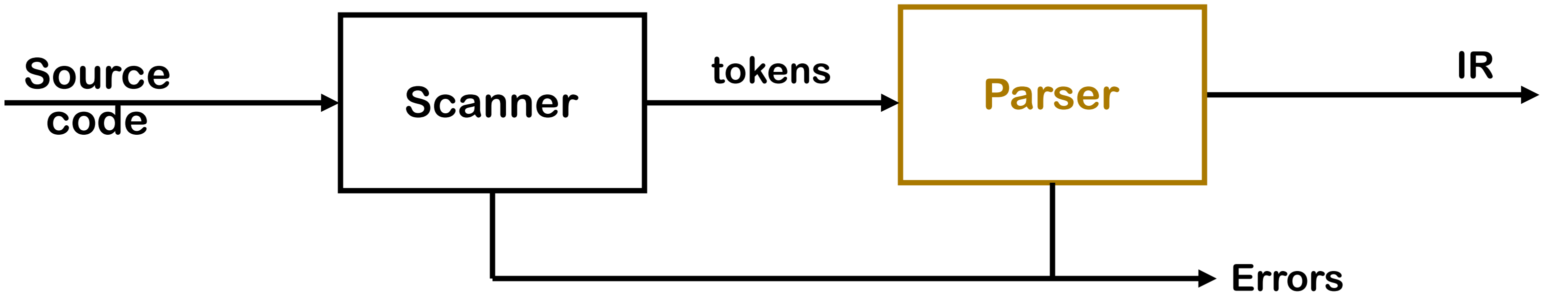
Scanner

- Maps character stream into words—the basic unit of syntax
- Produces pairs — a word & its part of speech

    x = x + y ; becomes <id,x> = <id,x> + <id,y> ;

    → word ≅ lexeme, part of speech ≅ token type
    → In casual speech, we call the pair a token
- Typical tokens include number, identifier, +, –, new, while, if
- Scanner eliminates white space (including comments)
- Speed is important

The Front End



Parser

- Recognizes context-free syntax & reports errors
- Guides context-sensitive ("semantic") analysis (type checking)
- Builds IR for source program

Hand-coded parsers are fairly easy to build for simple languages

C++ is not a simple language, Front-end $40K-$250K*

Most books advocate using automatic parser generators

* http://www.edg.com/faq.html

The Front End

Context-free syntax is specified with a grammar

SheepNoise → SheepNoise baa
| baa

This grammar defines the set of noises that a sheep makes under normal circumstances

It is written in a variant of Backus–Naur Form (BNF)

Formally, a grammar G = (S,N,T,P)

- S is the start symbol
- N is a set of non-terminal symbols
- T is a set of terminal symbols or words
- P is a set of productions or rewrite rules   ($P : N \rightarrow N \cup T$)

(Example due to Dr. Scott K. Warren)

The Front End

1. goal → expr
2. expr → expr op term
3. | term
4. term → <u>number</u>
5. | <u>id</u>
6. op → +
7. | -

S = goal

T = { <u>number</u>, <u>id</u>, +, - }

N = { goal, expr, term, op }

P = { 1, 2, 3, 4, 5, 6, 7}

Context-free syntax can be put to better use

- This grammar defines simple expressions with addition & subtraction over "number" and "id"
- This grammar, like many, falls in a class called "context-free grammars", abbreviated CFG

The Front End

Given a CFG, we can derive sentences by repeated substitution

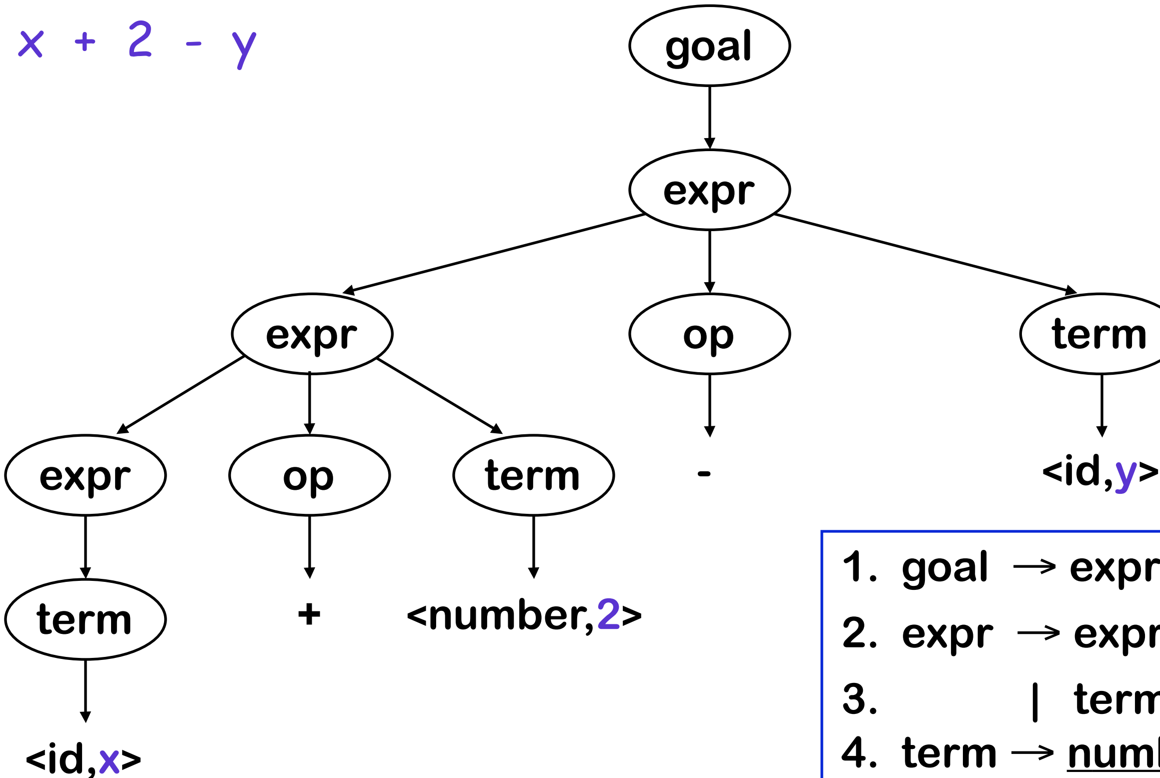
Production	Result
	goal
1	expr
2	expr op term
5	expr op y
7	expr - y
2	expr op term - y
4	expr op 2 - y
6	expr + 2 - y
3	term + 2 - y
5	x + 2 - y

To recognize a valid sentence in some CFG, we reverse this process and build up a parse

The Front End

A parse can be represented by a tree (parse tree or syntax tree)

x + 2 - y

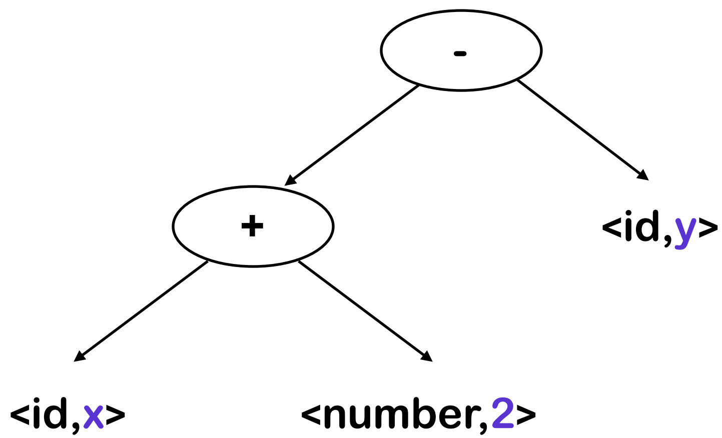


1. goal → expr
2. expr → expr op term
3. | term
4. term → <u>number</u>
5. | <u>id</u>
6. op → +
7. | -

This contains a lot of unneeded information.

The Front End

Compilers often use an abstract syntax tree

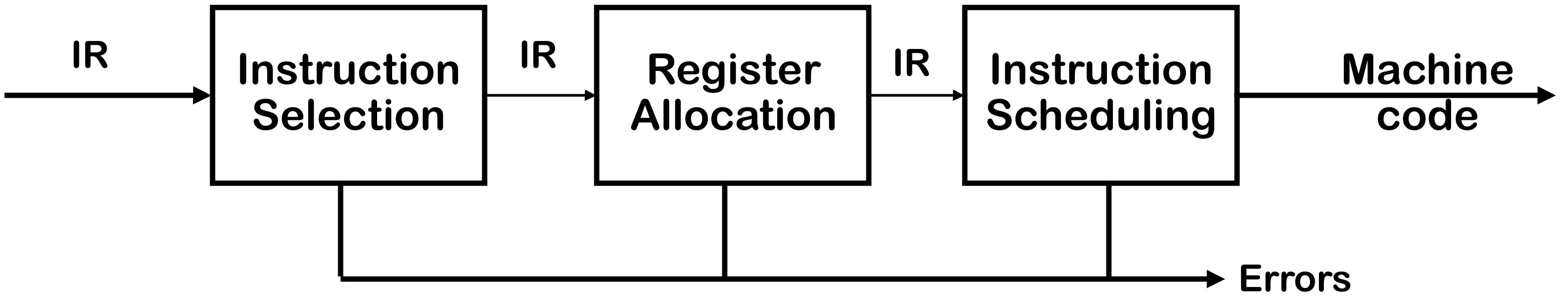


The AST summarizes grammatical structure, without including detail about the derivation

This is much more concise

ASTs are one kind of intermediate representation (IR)

The Back End

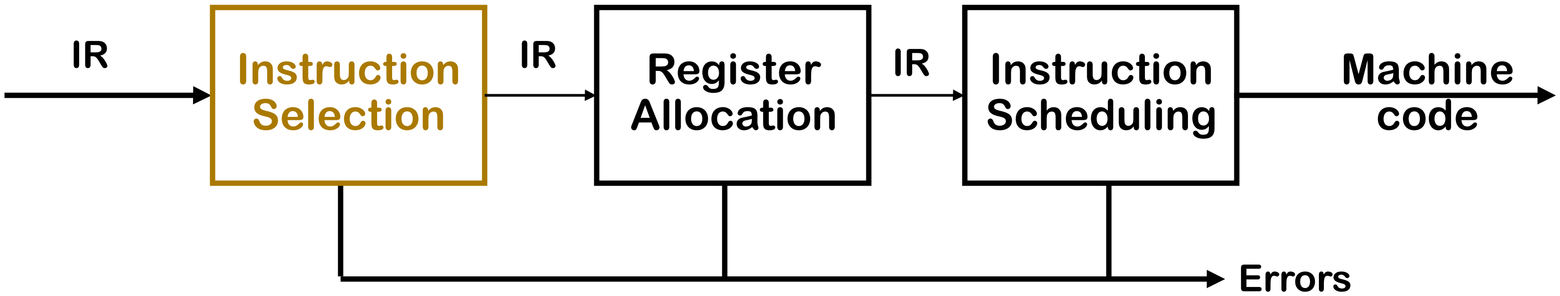


Responsibilities

- Translate IR into target machine code
- Choose instructions to implement each IR operation
- Decide which value to keep in registers
- Ensure conformance with system interfaces

Automation has been less successful in the back end

The Back End



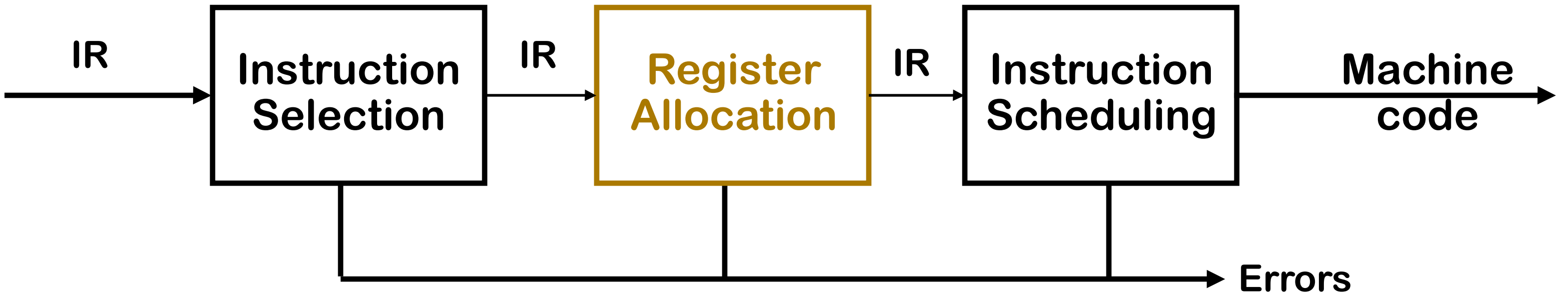
Instruction Selection

- Produce fast, compact code
- Take advantage of target features such as addressing modes
- Usually viewed as a pattern matching problem
  - → ad hoc methods, pattern matching, dynamic programming

This was the problem of the future in 1978

- → Spurred by transition from PDP-11 to VAX-11
- → Orthogonality of RISC simplified this problem

The Back End

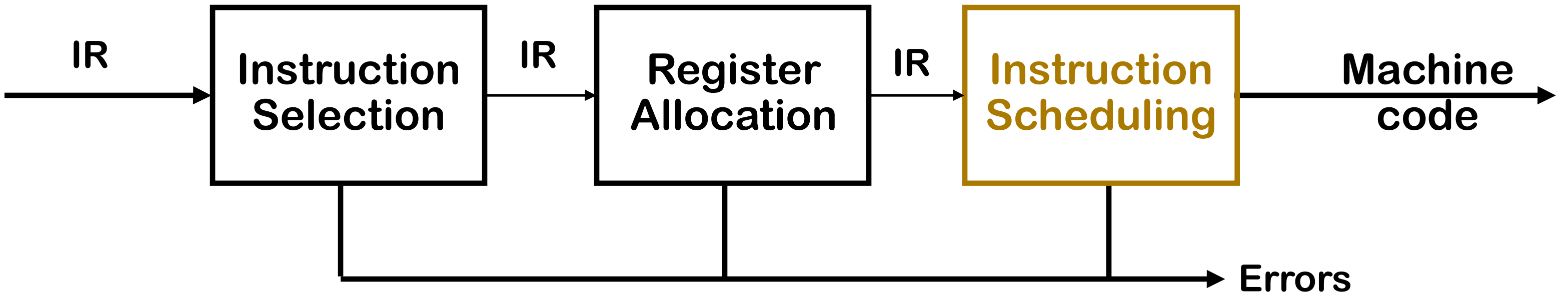


Register Allocation

- Have each value in a register when it is used
- Manage a limited set of resources
- Can change instruction choices & insert LOADs & STOREs
- Optimal allocation is NP-Complete (1 or k registers)

Compilers approximate solutions to NP-Complete problems

The Back End



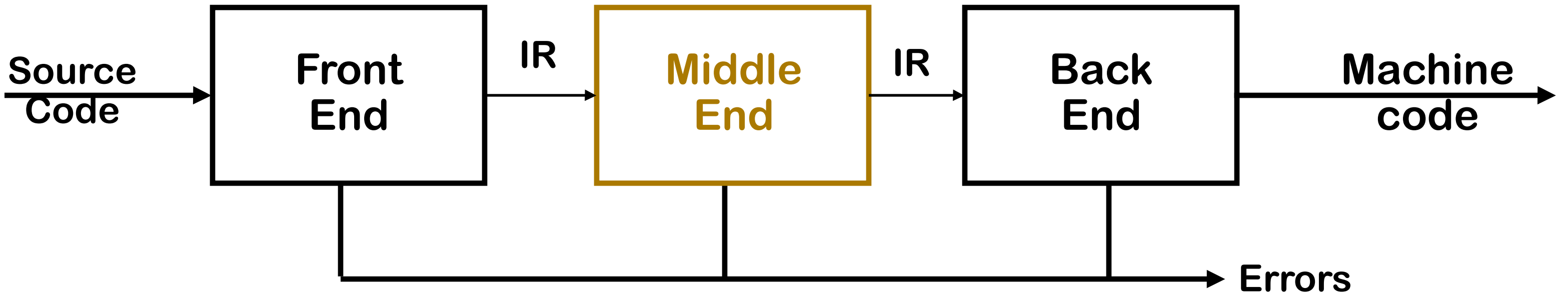
Instruction Scheduling

- Avoid hardware stalls and interlocks
- Use all functional units productively
- Can increase lifetime of variables (changing the allocation)

Optimal scheduling is NP-Complete in nearly all cases

Heuristic techniques are well developed

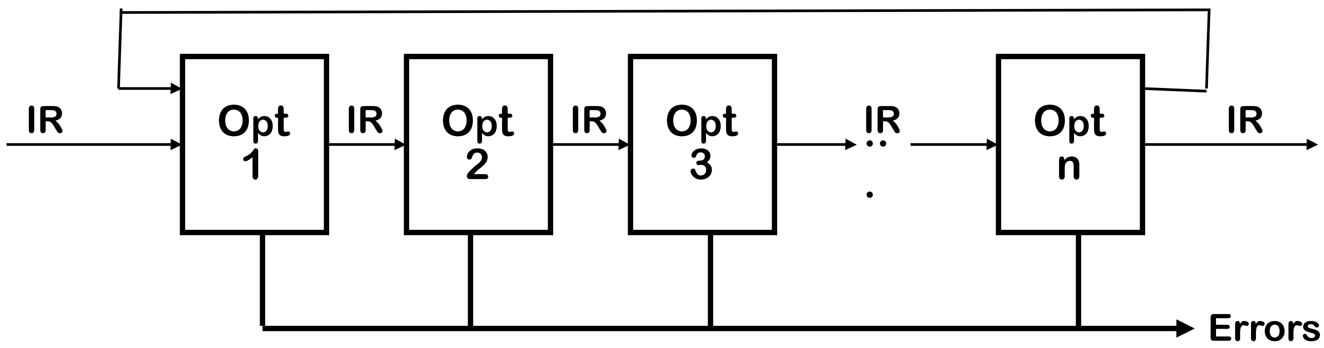
Traditional Three-pass Compiler



Code Improvement (or <u>Optimization</u>)

- Analyzes IR and rewrites (or <u>transforms</u>) IR
- Primary goal is to reduce running time of the compiled code
  - → May also improve space, power consumption, …
- Must preserve "meaning" of the code
  - → Measured by values of named variables

The Optimizer (or Middle End)



Modern optimizers are structured as a series of passes

Typical Transformations

- Discover & propagate some constant value
- Move a computation to a less frequently executed place
- Specialize some computation based on context
- Discover a redundant computation & remove it
- Remove useless or unreachable code
- Encode an idiom in some particularly efficient form

Example

- Optimization of Subscript Expressions in Fortran

A(I,J)

Address(A(I,J)) = address(A(0,0)) + J * (column size) + I

Does the user realize a multiplication is generated here?

```
DO I = 1, M
    A(I,J) = A(I,J) + C
ENDDO
```

Example

- Optimization of Subscript Expressions in Fortran

A(I,J)

Address(A(I,J)) = address(A(0,0)) + J * (column size) + I

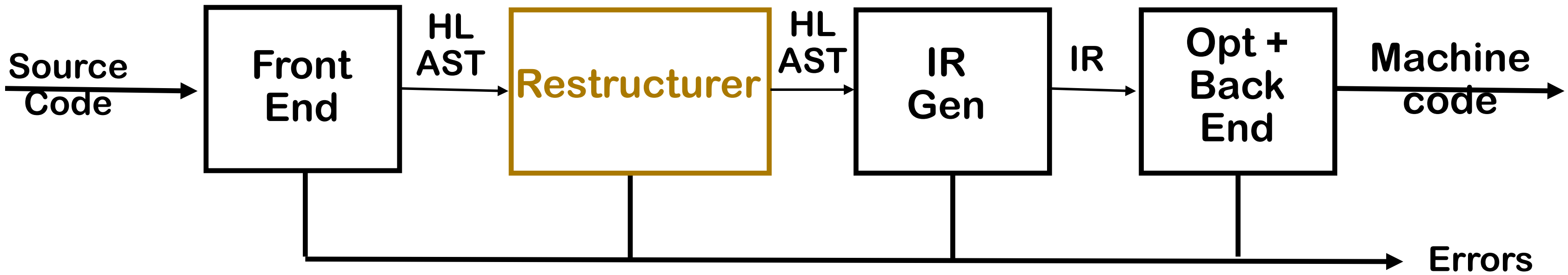
Does the user realize a multiplication is generated here?

```
DO I = 1, M
     A(I,J) = A(I,J) + C
ENDDO
```

→

```
compute addr(A(0,J)
DO I = 1, M
     add 1 to get addr(A(I,J)
     A(I,J) = A(I,J) + C
ENDDO
```

Modern Restructuring Compiler



Typical Restructuring Transformations:

- Blocking for memory hierarchy and register reuse
- Vectorization
- Parallelization
- All based on dependence
- Also full and partial inlining

Role of the Run-time System

- Memory management services
  - → Allocate
    - In the heap or in an activation record (stack frame)
  - → Deallocate
  - → Collect garbage
- Run-time type checking
- Error processing
- Interface to the operating system
  - → Input and output
- Support of parallelism
  - → Parallel thread initiation
  - → Communication and synchronization

Next Class

- Introduction to Parsing Techniques
  - Read 3.2–3.4.2.2 of "A Pattern Language for Language Implementation" at:
    - http://press.samedi-studios.com/drafts/jones2004pl4li.plopD5/jones2004pl4li.pdf