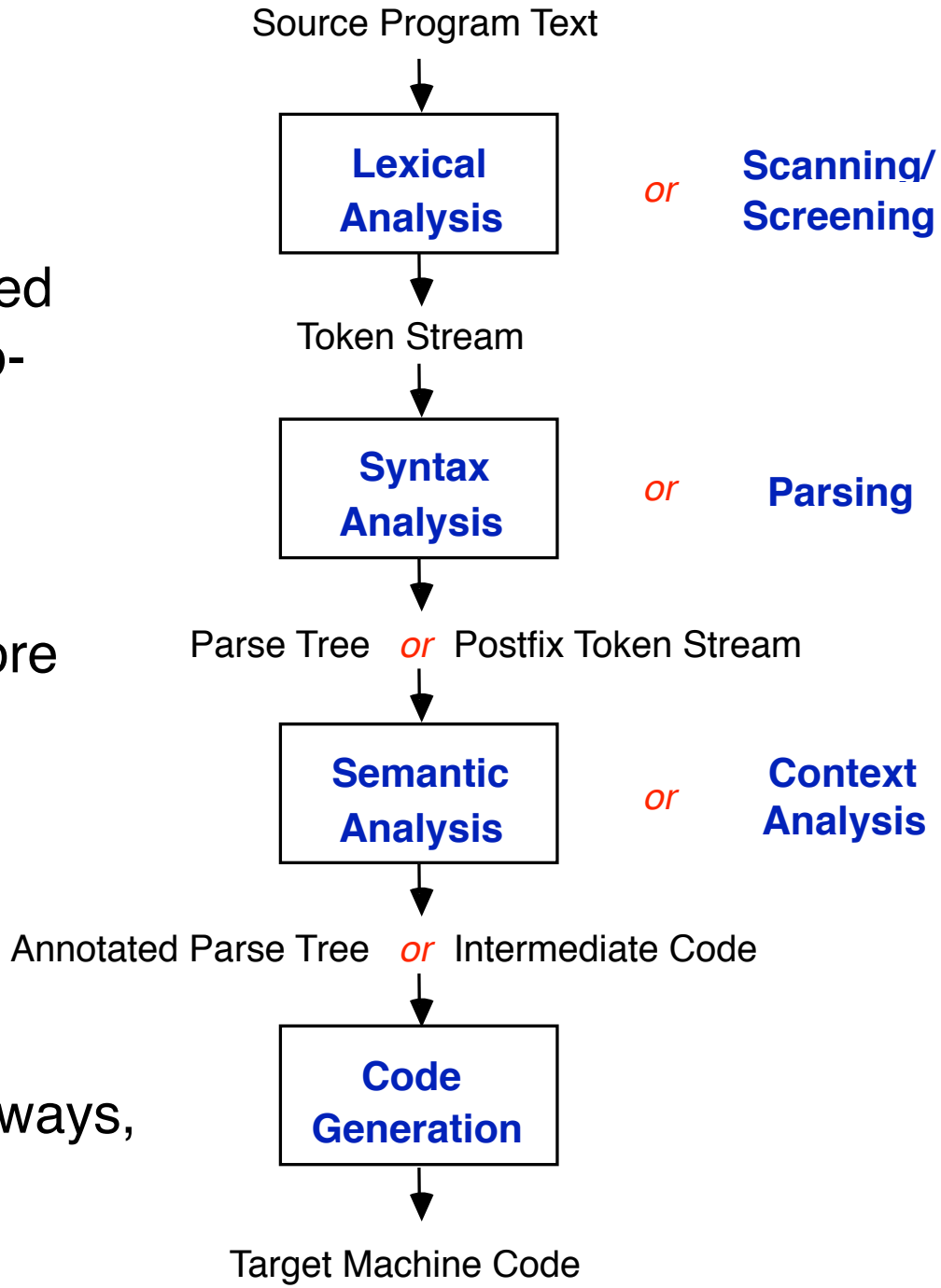
Compiler Structure

Phases of Compilation

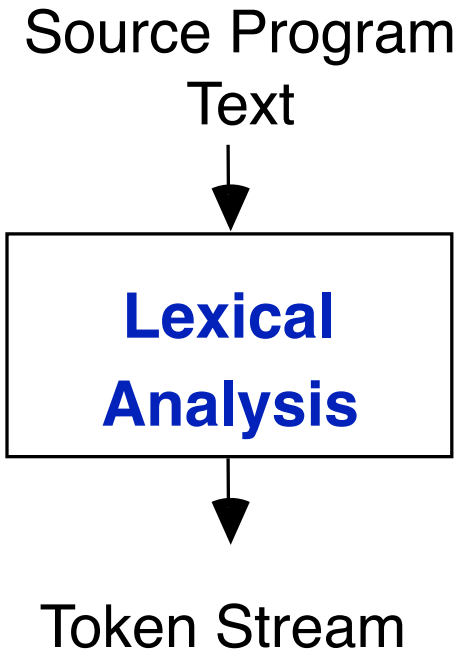
- Compilation process is partitioned into a series of four distinct sub-problems called phases, each with a separate well-defined translation task
- This structure is the result of more than 40 years of experience in compiler engineering
- Can be run in sequence, in which case they are called passes
- Or can be integrated in various ways, such as"parallel" execution as co-routines



Phase 1: Lexical Analysis

Lexical Analysis

- Lexical analysis, or scanning/screening, partitions source text into the "words" or tokens of the input language

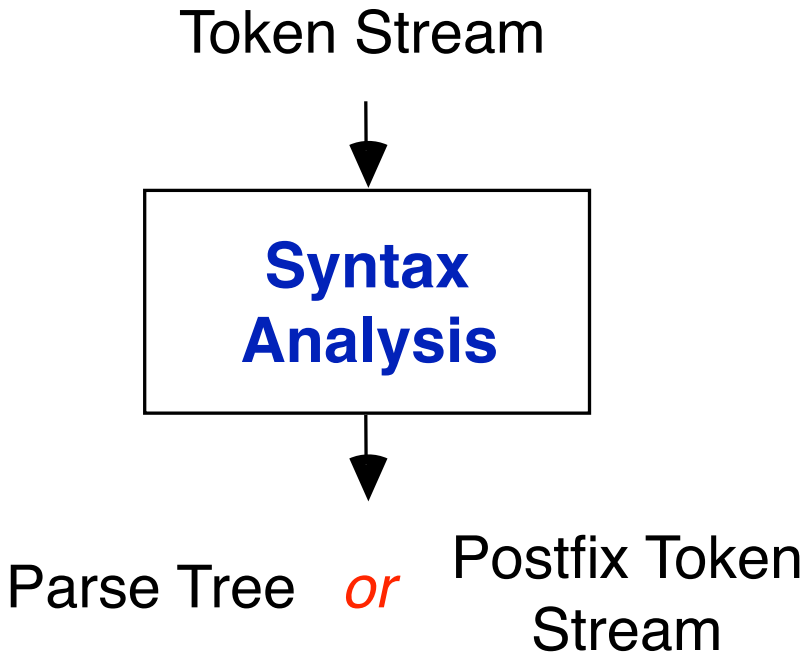


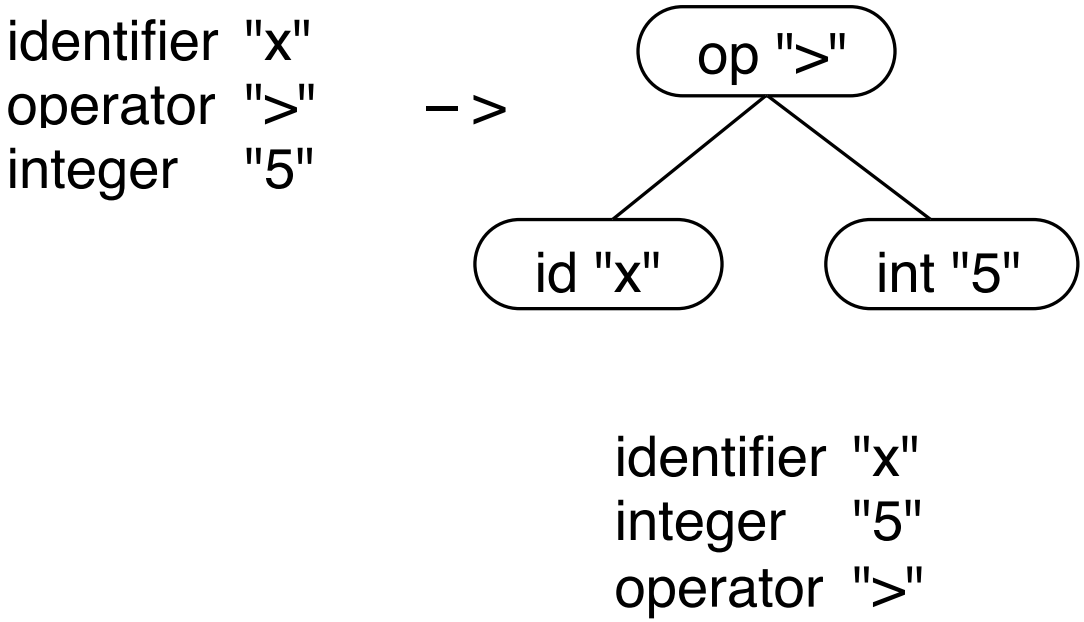

```
if x>5 then   —>   keyword  "if"
                   identifier  "x"
                   operator  ">"
                   integer   "5"
                   keyword  "then"
```

Phase 2: Syntax Analysis

Syntax Analysis

- Syntax analysis, or parsing, groups tokens together into the grammatical structures of the language, often represented as a parse tree or (equivalently) a postfix token stream

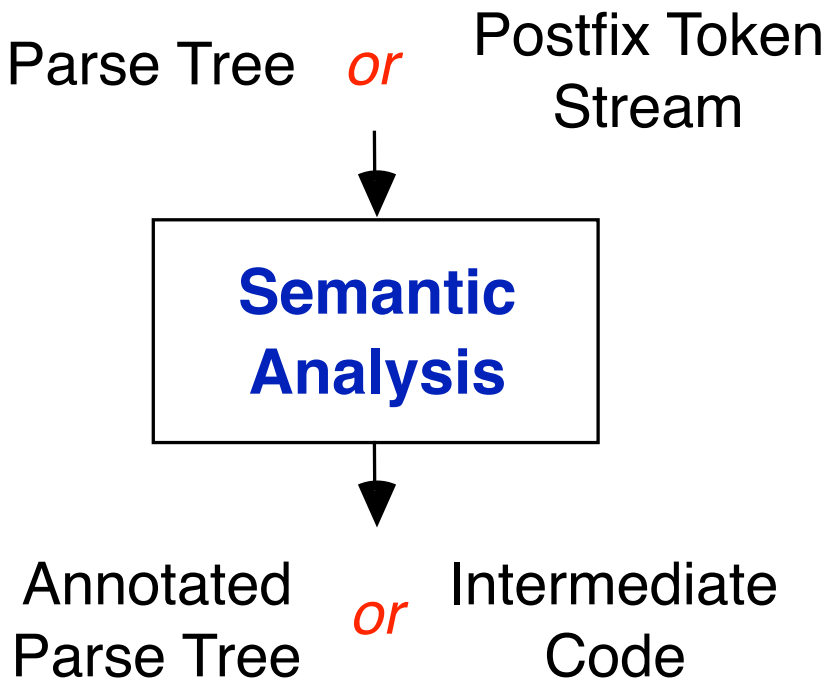


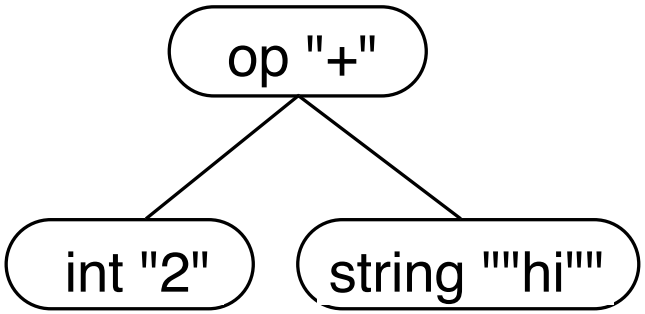


Phase 3: Semantic Analysis

Semantic Analysis

- Semantic analysis, or context analysis, analyzes and verifies the meaning of the structures, and checks for semantic legality



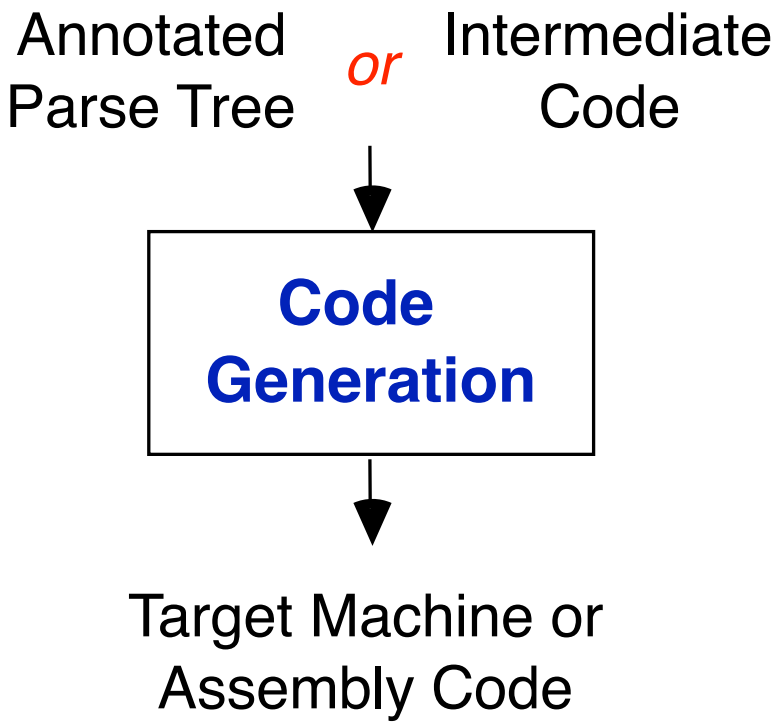


–> ERROR

Phase 4: Code Generation

Code Generation

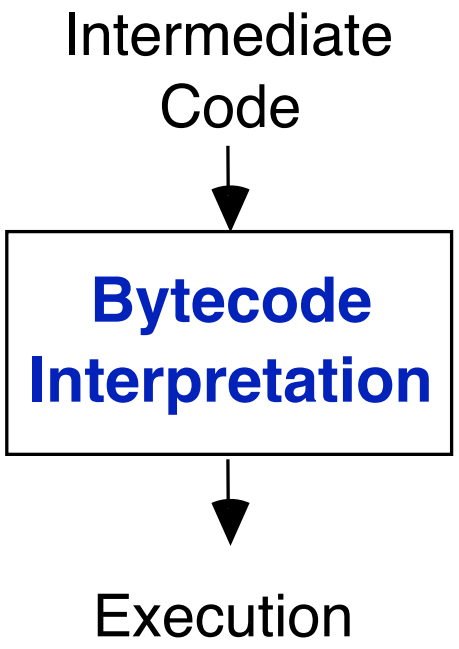
- Generates target machine code for analyzed structures
- May include optimization of structures, operations and code



Alternate Phase 4: Interpretation

Bytecode Interpretation

- Simulates the virtual machine of the intermediate code in software
- Executes the intermediate code directly



Compiler Architectures

Merging Phases

- Some compilers merge or integrate one or more phases together (although they are still designed separately) to gain efficiency
- If all phases are merged, we have a one pass compiler
- One pass compilers can be very fast, but they can also be much more complex and difficult to maintain

Refining Phases

- In order to reduce complexity and increase maintainability and reliability, very high quality production compilers (e.g. IBM's) often to the opposite - they actually split phases into even more independent sub-tasks
- For example, the IBM PL/I compiler actually has about 40 separate phases, each a separate pass

Tables

Why is it called a "Compiler" ?

- Language processing involves compiling tables of information about the program, to be used to analyze scopes, look up references and determine meaning - hence the term "compiler"
- Such tables may be shared between phases of compilation, using databases or disk files
- Or in other compilers each phase builds it own tables
- Either way, a big part of compiler engineering is the design of the table structures to support efficient analysis

PT Pascal

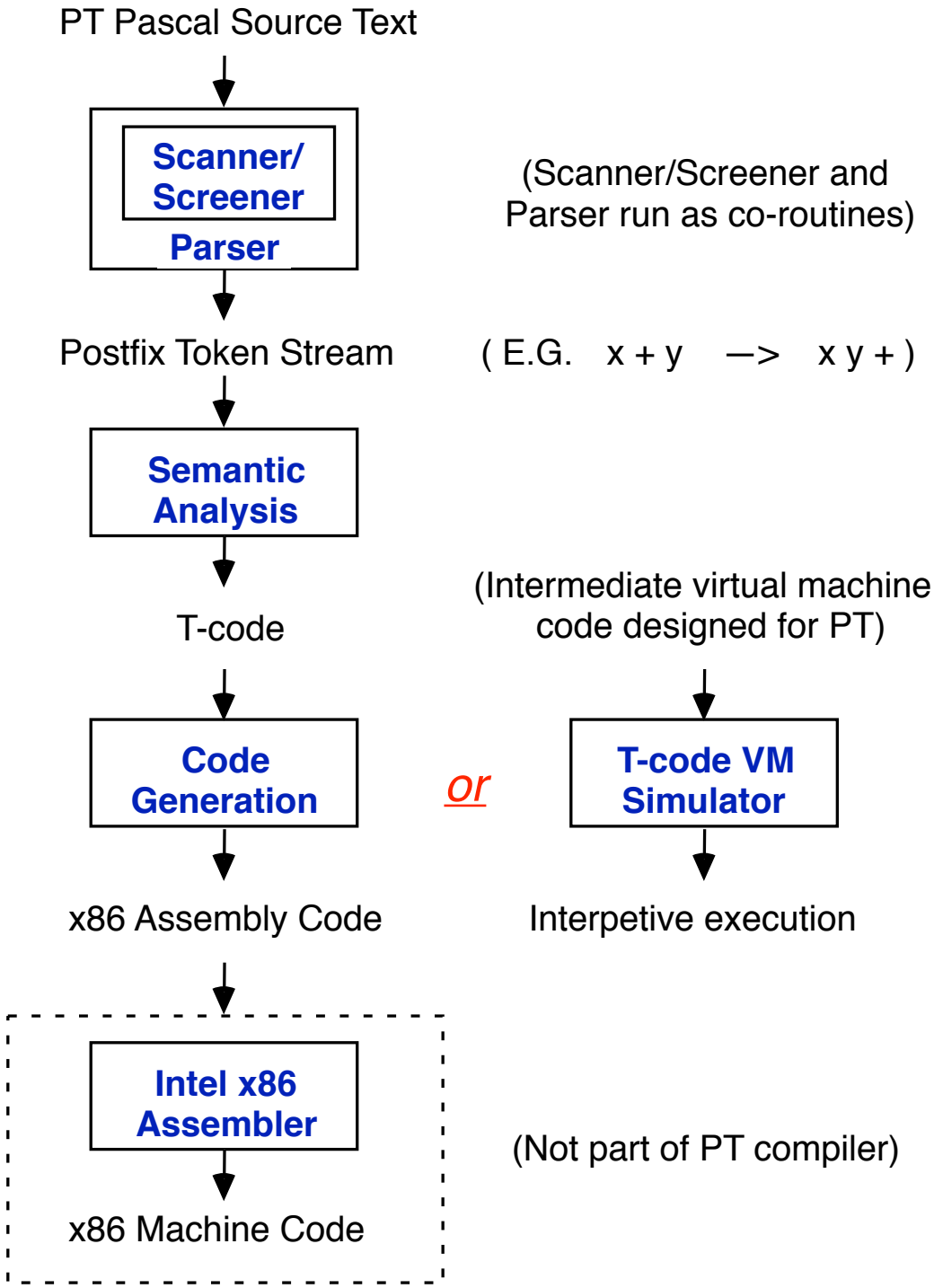
The PT Pascal Compiler

- Originally designed and implemented by J. Alan Rosselet (U. of Toronto) about 1980, as a proof of concept for the S/SL compiler technology (then a new research result)
- Specifically designed for teaching and learning about compilers
- Designed to be easily portable (Pascal was at that time the standard portable language, as C is now) - it takes an expert about three days to port PT to a new machine (mostly spent understanding the new machine's assembly language)
- Designed to be real - generates good quality code for target machines, can compile and run itself, the S/SL Processor, and other quite large real programs
- Self-compiling - implemented entirely in PT Pascal itself, using S/SL

PT Compiler Structure

Four Phase, Three Pass

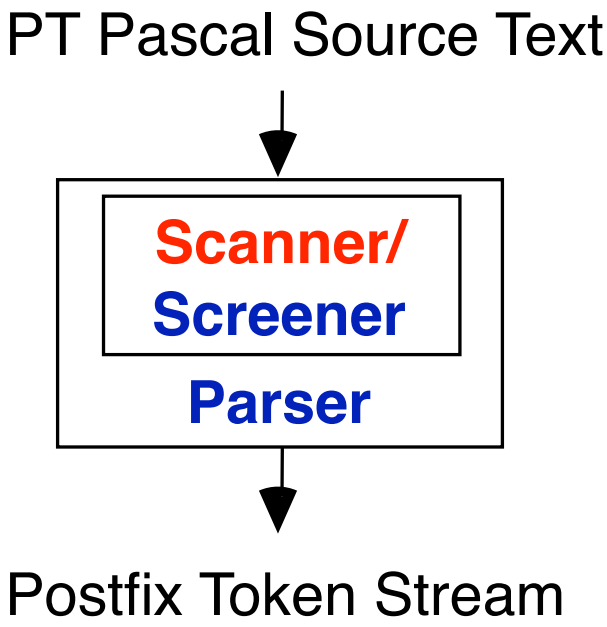
- Scanner / Screener run as co-routine with Parser in Parser pass
- Parse tree represented as postfix stream of tokens
- Special PT "abstract" (virtual) machine code ("T-code")



PT Phase Overview: Scanner

Scanner

- Breaks up input text into PT language tokens, ignores blanks, newlines etc.



Input to Scanner

```
a :=b+ 11;
```

Output from Scanner

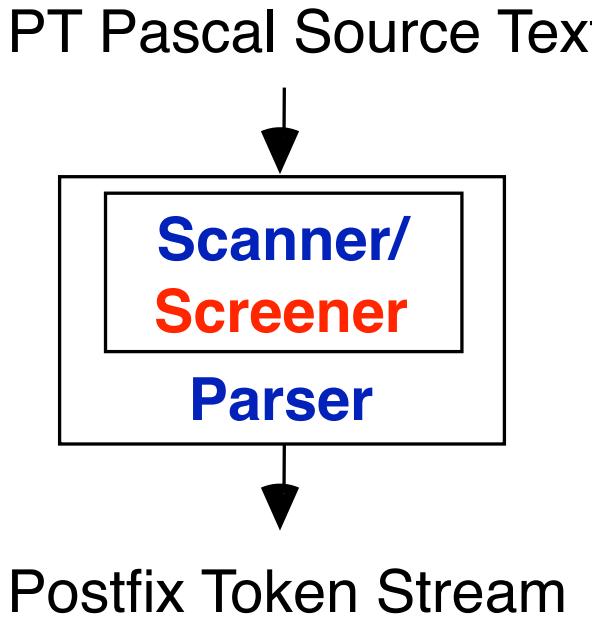
pIdentifier "a"
pColonEquals
pIdentifier "b"
pPlus
pInteger "11"
pSemicolon

(The "p" prefix on token names indicates that they are to be Parser input stream tokens)

PT Phase Overview: Screener

Screener

- A filter between the Scanner and the Parser
- Recognizes keywords, evaluates literals, builds identifier table



Input to Scanner

```
const x=22;
```

Output from Scanner
(before screening)

```
pIdentifier  "const"
pIdentifier  "x"
pEquals
pInteger     "22"
pSemicolon
```

Output from Scanner/
Screener to Parser
(after screening)

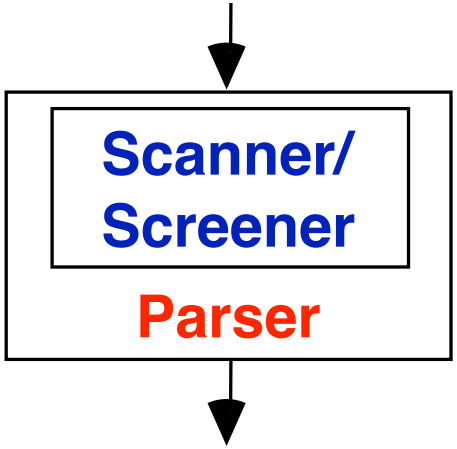
```
pConst
pIdentifier  273
pEquals
pInteger     22
pSemicolon
```

PT Phase Overview: Parser

Parser

- Context-free syntax checking (syntax error detection)
- Converts expressions to expression trees in postfix form, recognizes statement structure, disambiguates operators

PT Pascal Source Text



Postfix Token Stream

Input to Scanner/Screener

```
a := b + 11;
```

Input to Parser from Scanner/Screener

```
pIdentifier     632
pColonEquals
pIdentifier     243
pPlus
pInteger        11
pSemicolon
```

Output from Parser

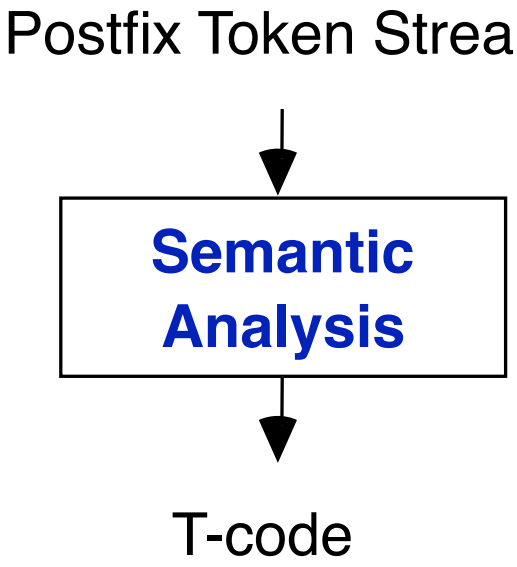
(The "s" prefix to token names indicates that they are Semantic pass input stream tokens)

```
sAssignmentStmt
sIdentifier     632
sIdentifier     243
sInteger        11
sAdd
sExpnEnd
```

PT Phase Overview: Semantic Analyzer

Semantic Phase

- Checks semantic constraints (e.g., type checking)
- Constructs symbol table, analyzes scopes, resolves references
- Generates T-code representation of program



PT Phase Overview: Semantic Analyzer

Input to Semantic Analyzer from Parser

```
sAssignmentStatement
sIdentifier     632
sIdentifier     243
sInteger        11
sAdd
sExpnEnd
```

Output from Semantic Analyzer

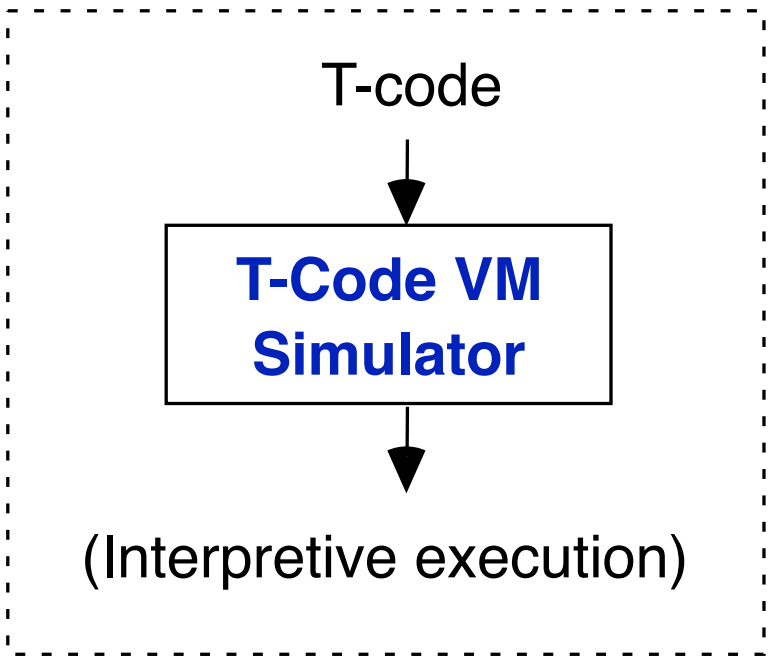
(PT virtual machine bytecode - T-code)

```
tAssignBegin
tLiteralAddress     120
tLiteralAddress     150
tFetchInteger
tLiteralInteger     11
tAddInteger
tAssignInteger
```

The PT Interpreter

T-code Virtual Machine Simulator

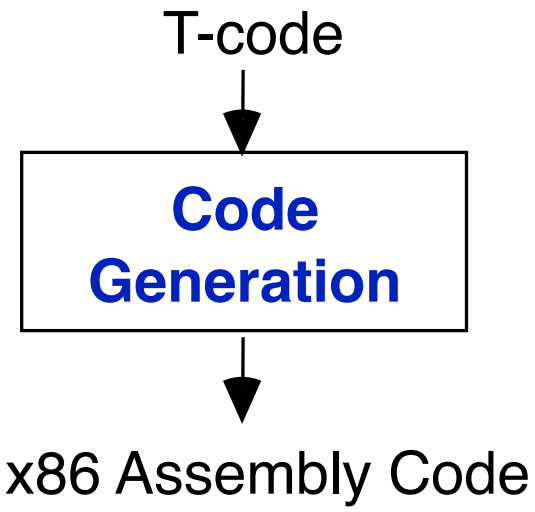
- The T-code output by the Semantic Analyzer can be executed directly by a PT VM Simulator, to make a PT Interpreter



PT Phase Overview: Code Generator

Code Generator

- Translates the T-code form of the program into machine code for the target computer
- Our target computer is the Intel x86, and the code generator outputs Linux x86 assembly code



PT Phase Overview: Code Generator

Input from
Semantic Analyzer

```
tAssignBegin
tLiteralAddress    120
tLiteralAddress    150
tFetchInteger
tLiteralInteger    11
tAdd
tAssignInteger
```

Output from
Code Generator

(x86 assembly code)

```
movl    u+150, %eax
addl    $11, %eax
movl    %eax, u+120
```

Summary

Compiler Structure

- Compilers split into four phases:
  Lexical, Syntactic, Semantic, Code generation
- Phases may be implemented as separate passes,
  or integrated for performance
- PT Compiler implements four phases in three passes,
  using token streams between passes
- Uses PT virtual machine T-code as intermediate code

References

- Text, chapter 2

Next Time

- The Syntax/Semantic Language (S/SL) - a domain-specific
  language (DSL) for specifying compiler phases