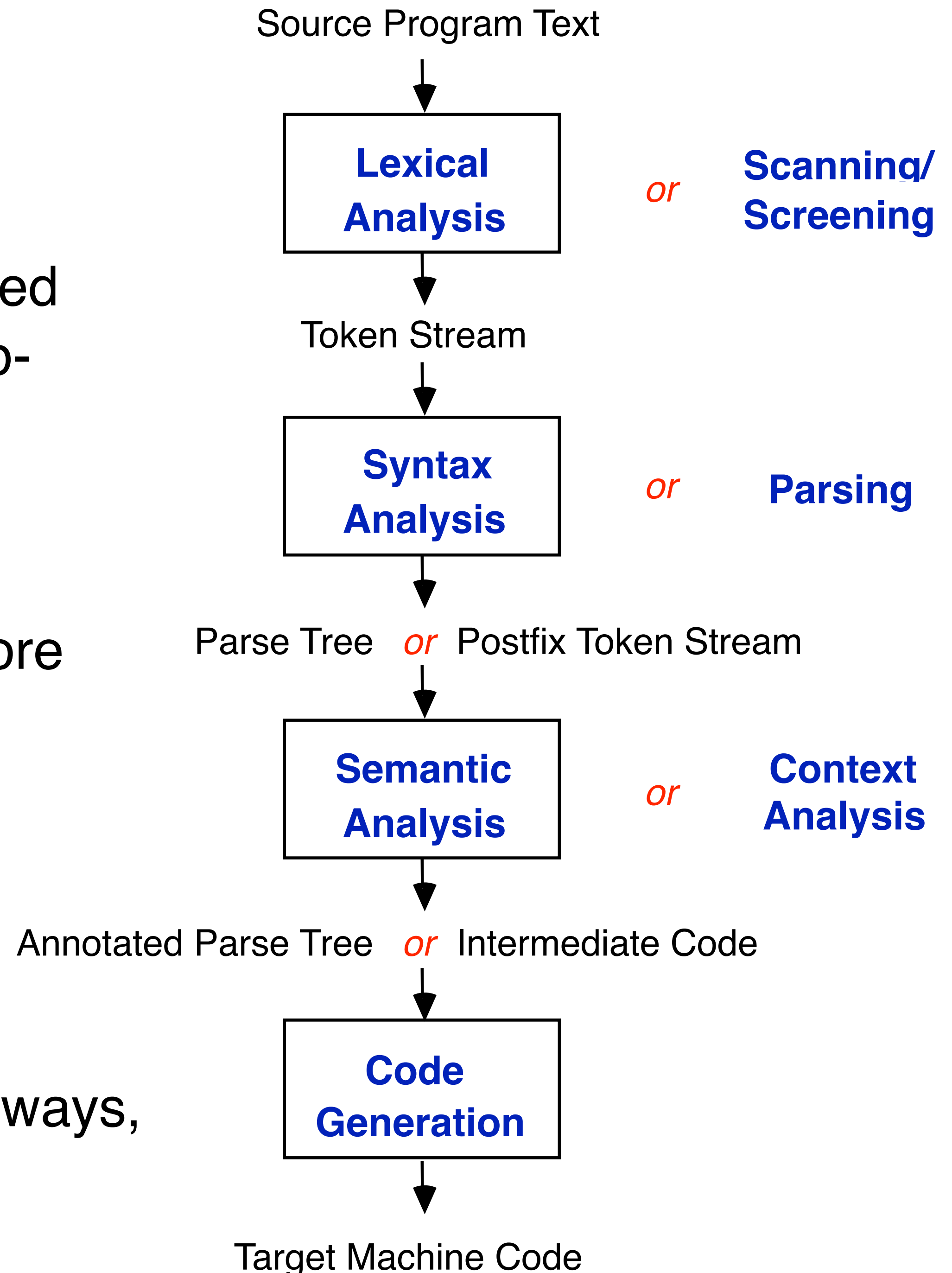
Compiler Structure

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

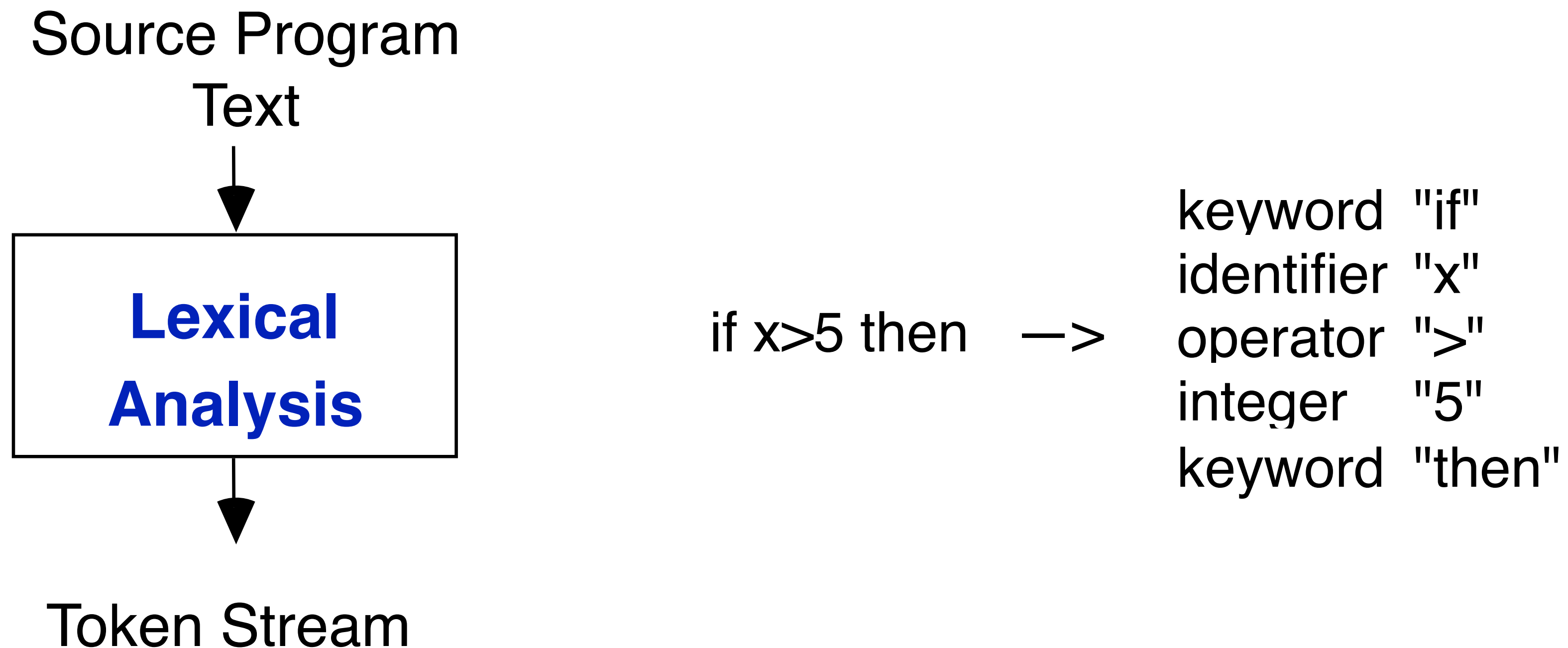


© 2020 J.R. Cordy

Phase 1: Lexical Analysis

Lexical Analysis

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

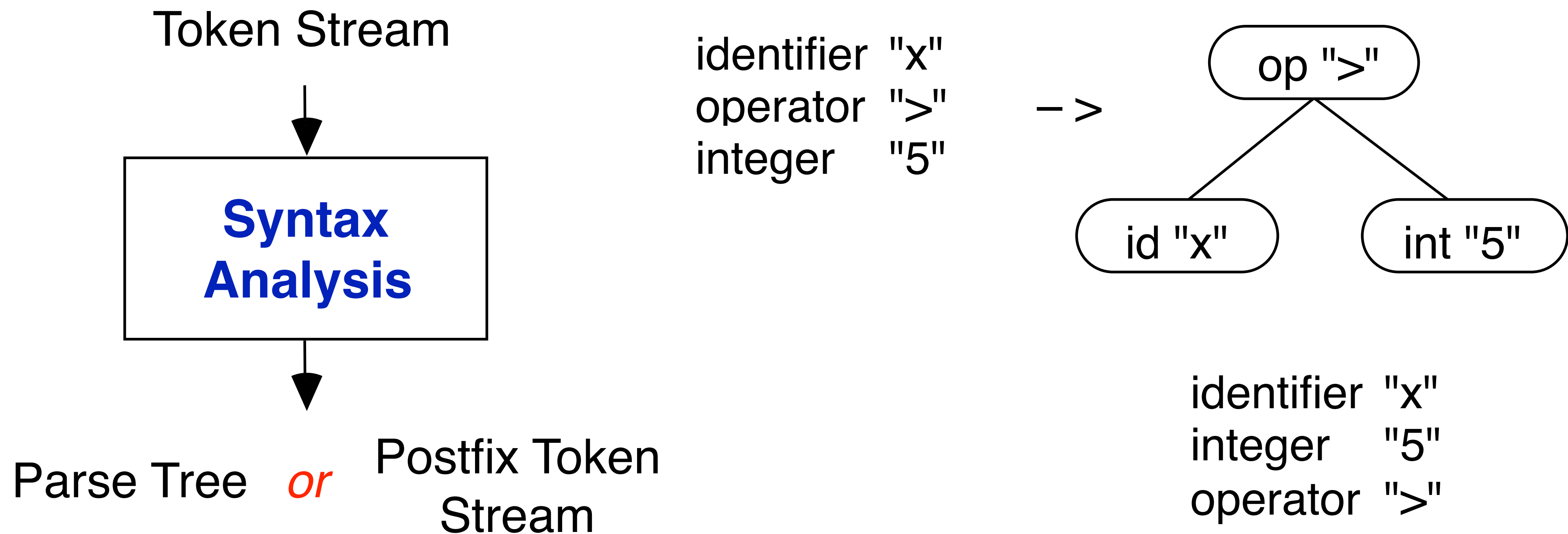


© 2020 J.R. Cordy

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

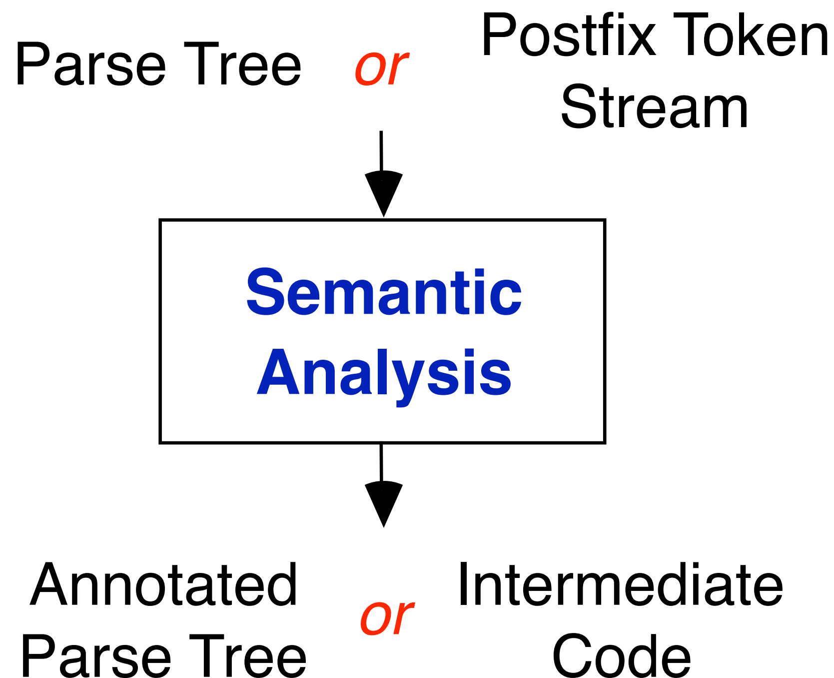


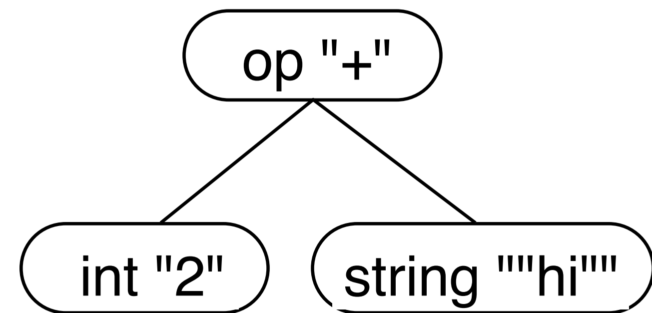
© 2020 J.R. Cordy

Phase 3: Semantic Analysis

Semantic Analysis

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





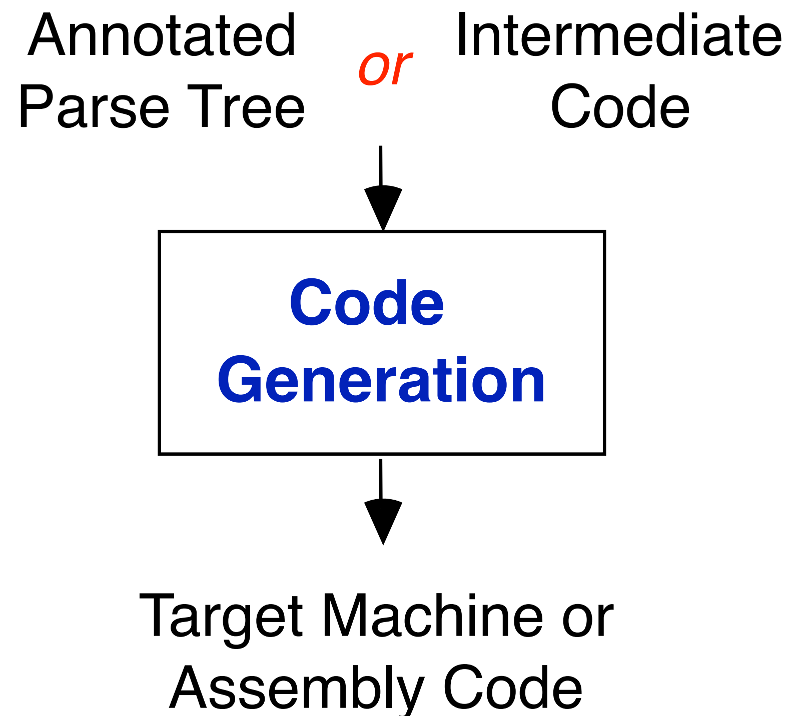
-> ERROR

© 2020 J.R. Cordy

Phase 4: Code Generation

Code Generation

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

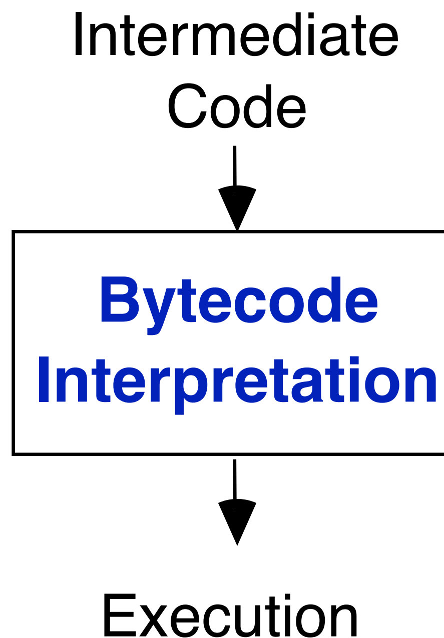


© 2020 J.R. Cordy

Alternate Phase 4: Interpretation

Bytecode Interpretation

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



© 2020 J.R. Cordy

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

© 2020 J.R. Cordy

PT Pascal

The PT Pascal Compiler

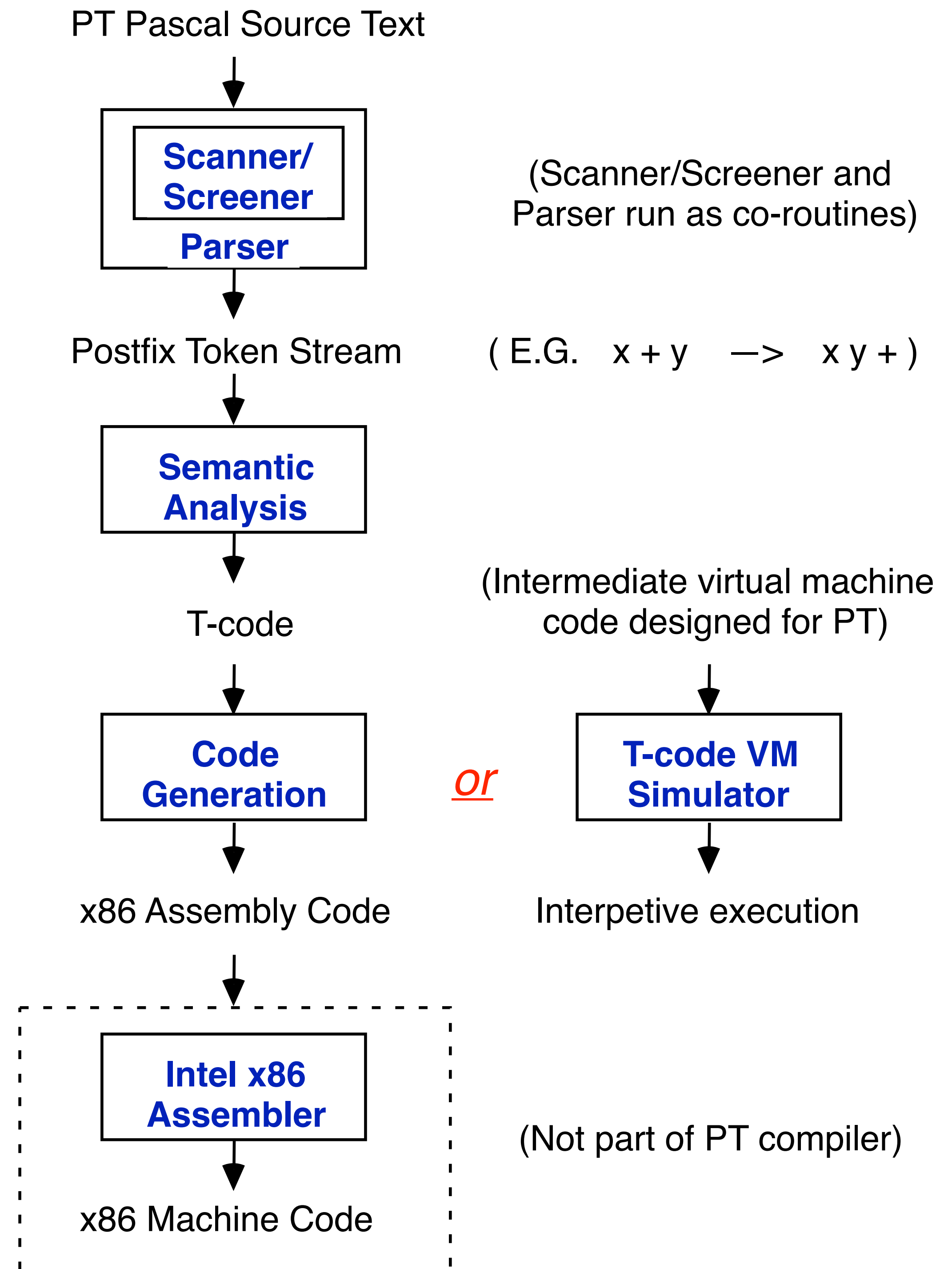
- Originally designed and implemented by J. Alan Rosselet (U. of Toronto) about 1980, as a proof of concept for the S/SL compiler technology (then a new research result)
- Specifically designed for teaching and learning about compilers
- Designed to be easily portable (Pascal was at that time the standard 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

© 2020 J.R. Cordy

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")



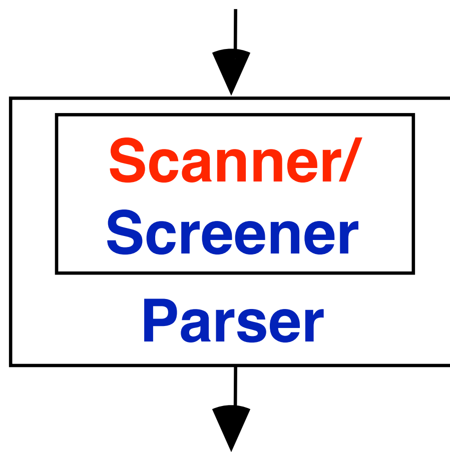
© 2020 J.R. Cordy

PT Phase Overview: Scanner

Scanner

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

PT Pascal Source Text



Postfix Token Stream

Input to Scanner

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

Output from Scanner

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

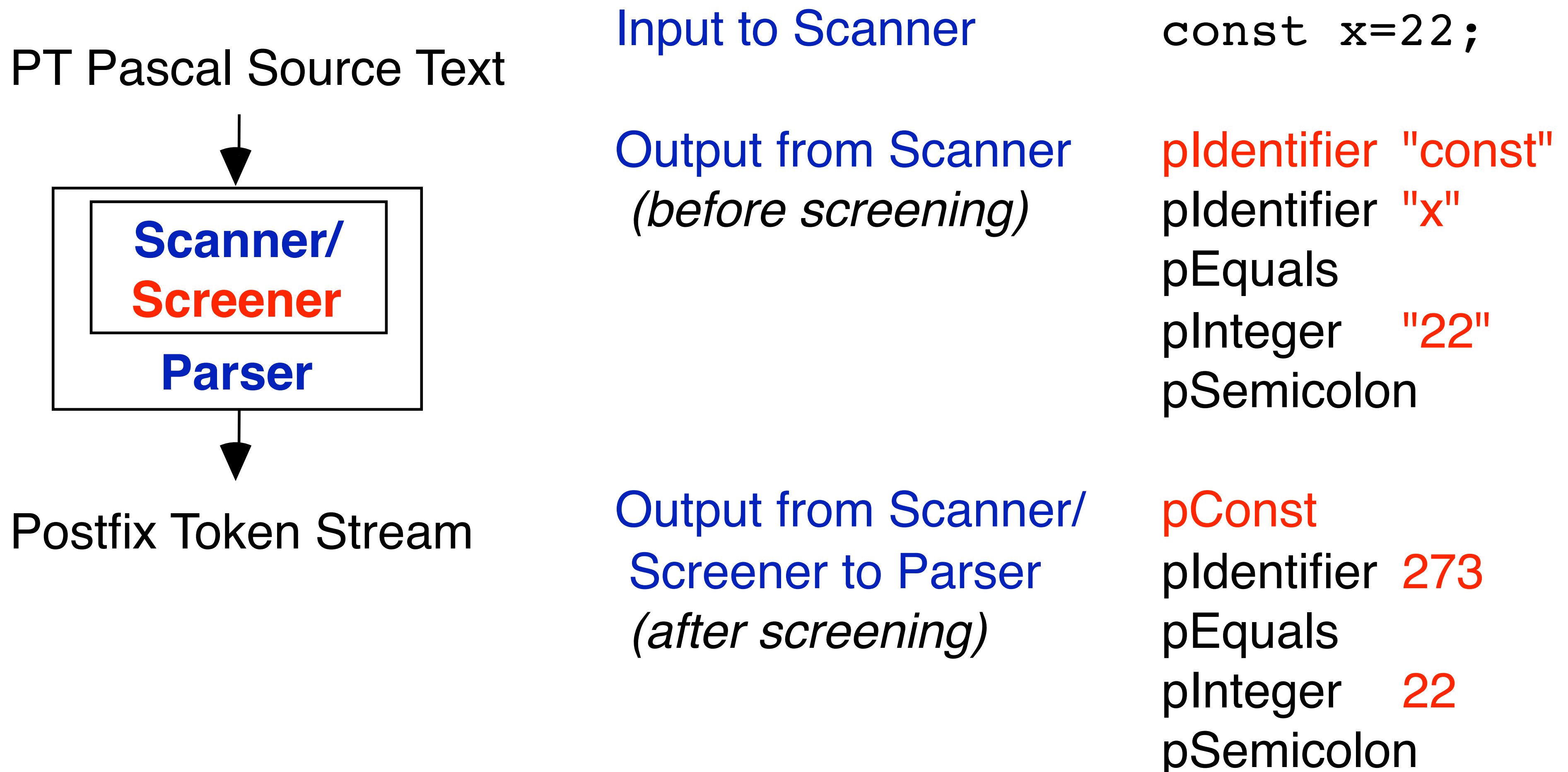
(The "p" prefix on token names indicates that they are to be Parser input stream tokens)

© 2020 J.R. Cordy

PT Phase Overview: Screener

Screener

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

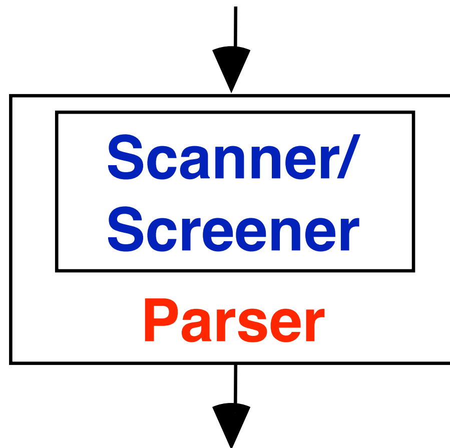


© 2020 J.R. Cordy

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

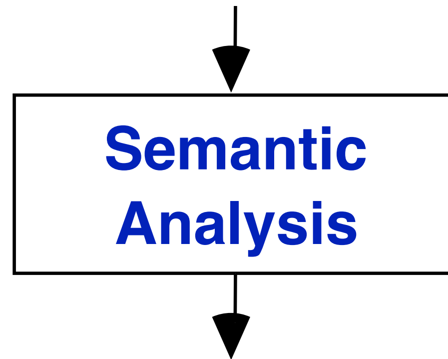


Input to Scanner/Screener	`a := b + 11;`
Input to Parser from Scanner/Screener	pIdentifier 632 pColonEquals pIdentifier 243 pPlus pInteger 11 pSemicolon
Output from Parser *(The "s" prefix to token names indicates that they are Semantic pass input stream tokens)*	sAssignmentStmt sIdentifier 632 sIdentifier 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



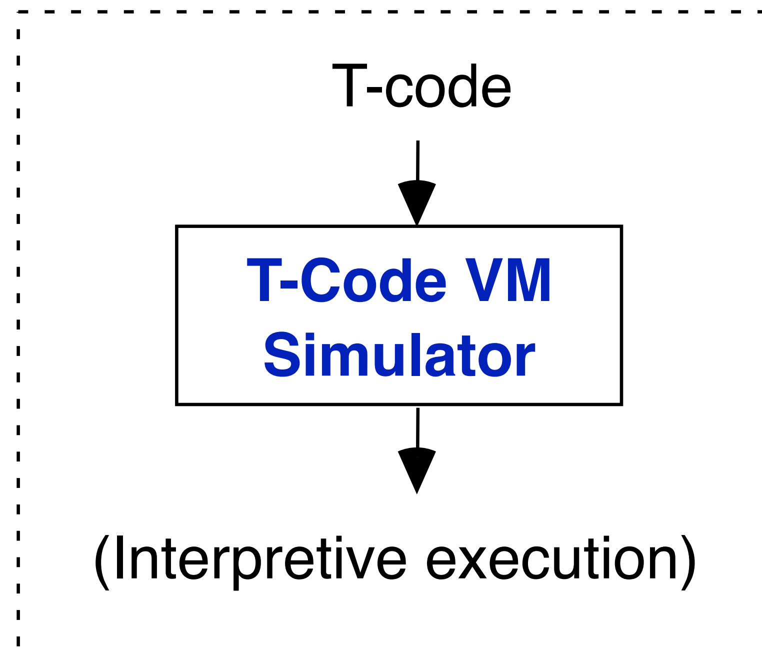
PT Phase Overview: Semantic Analyzer

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

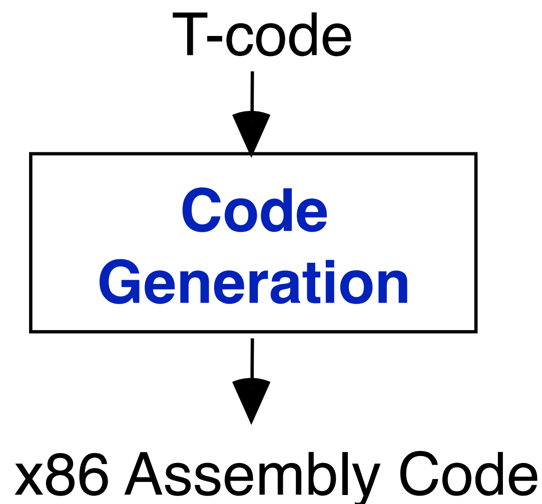
- The T-code output by the Semantic Analyzer can be executed directly by a PT VM Simulator, to make a PT Interpreter



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



© 2020 J.R. Cordy

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
```


© 2020 J.R. Cordy

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

© 2020 J.R. Cordy