Section 2

Introduction

1. Preliminaries

2. Introduction

2.1 PL design
2.2 Programming paradigms
2.3 History of programming languages
2.4 Syntax specification
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2. Introduction

2.1. PL design

1. Preliminaries

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Requirements from a PL

Universal every problem must have a solution (Exception: domain-specific languages, e.g., pure SQL has no recursion)
- Express recursive functions; it is sufficient to require
  - Conditionals
  - Loops

Natural application domain specific
Try writing a compiler in Cobol or a GUI in Fortran

Implementable
- Neither mathematical notation
- Nor natural language

Efficient open to debate
- More programming crimes were committed in the name of performance than for any other reason.
Desiderata for a PL I

Expressiveness
- Turing-completeness
- But also a practical kind of expressiveness: how easy is it to program simple concepts?

Efficiency
- Recursion in functional languages is expressive but sometimes inefficient
- Is there an efficient way to implement the language (in machine code)?

Simplicity
- as few basic concepts as possible
- Sometimes a trade-off with convenience (C has “for”, who needs “while” and “do-while”?)

Uniformity and consistency of concepts
- **for** in **Pascal** allows a single statement
- **repeat...until** allows any number of statements?
- Why?
Desiderata for a PL II

Software Engineering

- **Abstraction** – hide details
- **Modularity** – constrain dependences

Language Mechanism

- **Information hiding and encapsulation**
  Language should allow to factor out recurring patterns

Clarity to humans

The `=` vs. `==` in C is a bit confusing

Safety

Possibility to detect errors at compile time

AWK, Rexx and Snobol type conversions are error prone
Guiding principles in language design

Example: The C design rules:

- Division between preprocessor, compiler and linker.
- No hidden costs
- Programmer’s accountability and responsibility
“Less is more”

Two program fragments to find the $n^{th}$ Fibonacci number in **Algol-68**

```
x, y := 1;
to n do (if x < y then x else y) := x + y;
x := max(x, y);
```

```
x, y := 1;
to n do begin x, y := y, x; x := x + y end;
```
A legendary **FORTRAN** bug

Computing

\[ \sum_{i=1}^{314} \sin(i) \]

with **FORTRAN**:

```fortran
S = 0
DO 1000 I=1,314
S = S + SIN(I)
1000 CONTINUE
```

But if you accidentally replace "," by "." the code is very different

```fortran
S = 0
DO1000I = 1.314
S = S + SIN(I)
1000 CONTINUE
```

variable \( S \) becomes simply \( \sin(1) \).
The Mariner 1 aborted launch

Smoke and fire launch of the Mariner 1, less than five minutes prior to its abortion by a security officer due to a combination of a hardware problem and software bug; July 22nd 1962, 09:26:16 UTC
The bug leading to the abortion

Background:
- The “cold war” between the US and USSR
- The “space race” between the US and USSR
- America’s first planetary mission
- A very expensive project
- Designed in only 45 days
- Politicians wanted explanation
- The public wanted explanation

Outcome:
- **Official explanation:** “omission of a hyphen in coded computer instructions in the data-editing program”
- **Urban legend:** the famous FORTRAN bug
Poor design of the **FORTRAN PL**

- Bad lexical definition - spaces are immaterial
- No declaration of variables
- Implicit typing
- Poor control structure specification
- Lack of diagnostics
Concepts in the PL World

<table>
<thead>
<tr>
<th>Question to ask</th>
<th>Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>How it handles values?</td>
<td>values, types and expressions</td>
</tr>
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<td>How it checks types?</td>
<td>type systems</td>
</tr>
<tr>
<td>Its entities for storing values?</td>
<td>storage</td>
</tr>
<tr>
<td>Its means for storing values?</td>
<td>commands</td>
</tr>
<tr>
<td>How it alters control?</td>
<td>sequencers</td>
</tr>
<tr>
<td>How it attaches names to values?</td>
<td>binding</td>
</tr>
<tr>
<td>How it allows generalization?</td>
<td>functions</td>
</tr>
</tbody>
</table>

Paradigms...
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2.2. Programming paradigms

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SQL: what’s the difference?

A query,…

```
SELECT firstName, lastName, age
FROM user
WHERE firstName = "David"
ORDER BY age
```

and a similar query…

```
SELECT firstName, lastName, age
FROM user
WHERE age > 18 AND age < 65
ORDER BY age
```

- Think about implementing these queries in C++.  
- Would the code look just the same in both cases?
What is a paradigm?

- par·a·digm (Merriam-Webster Collegiate Dictionary)
  - “a philosophical and theoretical framework of a scientific school or discipline within which theories, laws, and generalizations and the experiments performed in support of them are formulated”
  - Model, pattern

- Thomas Kuhn (1922–1996)
  - A set of “universally” recognized scientific achievements that for

- The Sapir-Whorf hypothesis: The language spoken influences the way reality is perceived.

- In PLs: a family of languages with similar basic constructs and “mental model” of execution
Main paradigms

- **Imperative programming:** Fortran, Cobol, Algol, PL/I, C, Pascal, Ada, C++, Icon, Modula-2, Modula-3, Oberon, Basic.
- **Concurrent programming:** Ada, Occam, X10
- **Object-oriented programming:** Smalltalk, Self, C++, Objective-C, Object-Pascal, Beta, CLOS, Eiffel
- **Functional programming:** Lisp, Scheme, Miranda, ML.
- **Logic programming:** Prolog, Prolog-dialects, Turbo-Prolog, Icon.
2.2. Programming paradigms

- Imperative
- Procedural
- Declarative
- Functional
- Logic
- Object-Oriented

- (Not comprehensive)
- (Not to scale)
The imperative paradigm

- **Fortran, Algol, C, Pascal, Ada, ...**
- The program has a state reflected by storage and location
- It comprises commands (assignments, sequencers, etc.) that update the state of the program
  - They can be grouped into procedures and functions
- There are also expressions and other functional features
- Most familiar, but a large variety of possibilities must be mastered and understood
- Models real-world processes, hence still dominant
- Lends itself to efficient processing (optimizing compilers etc.)
- Will see Pascal in recitations and home assignment
The functional paradigm

- **Lisp, Scheme, ML, Haskell, ...**
- Everything is a function that takes arguments and returns results
- Moreover, the functions are just another kind of value that can be computed (created), passed as a parameter, etc.
- Don’t really need assignment operation or sequencers - can do everything as returning a result value of computing a function
  - E.g., use recursive activation of functions instead of iteration
- Elegant, extensible, few basic concepts
- Used for list manipulation, artificial intelligence, ...
- Requires a truly different perception using an imperative programming style in ML is even worse than a word-for-word translation among natural languages
- Will see ML, mainly in the recitations
Aren’t all languages pretty much the same?

- The move from C to C++ isn’t insurmountable.
- Moving from C++ to JAVA is trivial.
- And if you know JAVA, you pretty much know C#, too.
- Even if the syntax isn’t C-style used (e.g., EIFFEL), it can’t be that difficult, right?

Why make such a fuss about it?
The logic/declarative programming paradigm

- **PROLOG**, constraint languages, database query languages
- Predicates as the basis of execution
- Facts and rules are listed naturally
- A “computation” is *implicit* - it shows what follows from the given facts and rules
- Emphasizes what is needed, rather than how to compute it
- Used for “expert systems”
- Will see the basics of **PROLOG** later in the course
The object-oriented paradigm

- C++, Smalltalk, Eiffel, Java, C#
- The world has objects that contain both fields with values and operations (called methods) that manipulate the values
- Objects communicate by sending messages that ask the object to perform some method on its data
- Types of objects are declared using classes that can inherit the fields and methods of other classes
- Has become the primary paradigm because it seems to treat large systems better than other approaches
- Treated mainly in the follow-up course “Object-Oriented Programming” (236703)
- Will do a little bit of Java in the recitations
The main programming paradigms

<table>
<thead>
<tr>
<th>Imperative</th>
<th>Object Oriented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional</td>
<td>Logical</td>
</tr>
<tr>
<td>Aspect Oriented</td>
<td>Constraints</td>
</tr>
<tr>
<td>Parallel</td>
<td></td>
</tr>
</tbody>
</table>

However, there are many multiparadigm PLs.

<table>
<thead>
<tr>
<th>Mathematica</th>
<th>Oz</th>
</tr>
</thead>
<tbody>
<tr>
<td>F#</td>
<td>Visual-Basic.Net</td>
</tr>
<tr>
<td>C#</td>
<td>Scala</td>
</tr>
<tr>
<td>Object Pascal</td>
<td></td>
</tr>
</tbody>
</table>
2. Introduction

2.3. History of programming languages

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Language inception & evolution

Initial definition by a...

an Individual LISP (McCarthy), APL (Iverson), Pascal (Wirth), Rexx (Cowlishaw), C++ (Stroustrup), Java (Gosling)
a small team C (Kernighan and Ritchie), ML (Milner et al.), Prolog (Clocksin and Mellish), Icon (Griswold and Griswold)
a committee Fortran, Algol, PL/1, Ada

Some survived, many more perished for a variety of reasons

- usability
- compilation feasibility
- dependence on platform
- politics and sociology...

Most successful languages were taken over by a standards’ committees (ANSI, IEEE, ISO, …)
Language genealogy (till 1990)
Historical background

- Until early 1950s: no real PLs, but rather automatic programming, a mixture of assembly languages and other aids for machine code programming.
  - Mnemonic operation codes and symbolic addresses
  - Subroutine libraries where addresses of operands were changed manually
  - Interpretive systems for floating point and indexing
- Early 1950s: the Laning and Zierler System (MIT): a simple algebraic language, a library of useful functions.
- 1954: Definition of FORTRAN (FORmula TRANslator). Originally for numerical computing.
  - Symbolic expressions, subprograms with parameters, arrays, for loops, if statements, no blocks, weak control structures
- 1957: first working compiler
Early 1960s:

- **COBOL**: Data processing. Means for data description.
- **Algol 60**: Blocks, modern control structures
  - One of the most influential imperative languages
  - Gave rise to the Algol-like languages for two decades (*Pascal*, PL/1, 
  *C*, *Algol 68*, *Simula*, *Ada*)
- **LISP** (list processing language): symbolic expressions (rather than 
  numerical), computation by list manipulation, garbage collection; *the first functional language*
Mid 1960s

PL/1 an attempt to combine concepts from numerical computation languages (FORTRAN, ALGOL 60) and data processing languages (COBOL).

SIMULA object oriented, abstract data types
1970–1990

- Several OO languages: **Smalltalk, C++, Eiffel**
- Logic programming: **Prolog**
- Functional programming: **ML, Miranda, Haskell**
- **Ada**: Another attempt, more successful than PL/I, for a general purpose language, including concurrency.
- Domain specific:
  - **Snobol, Icon, AWK, Rexx, Perl**: String manipulation and scripting
  - **SQL**: Query language for relational databases
  - **Mathematica, Matlab**: Mathematical applications
  - **Python**: large scale script programming.
  - ...
1990–present

- Object oriented + WWW: JAVA, C#
- Scripting + [OO] + WWW: PERL, PYTHON, PHP, RUBY
- Client-side scripting: JAVASCRIPT
- Components and middleware between operating system and application levels
- Reuse and design patterns become useful and popular
- Multiple-language systems with standard interface - XML
- *Flexibility in choice of language and moving among languages*
Why **Pascal**?

- Extremely influential
- Easy to study: designed for beginners.
- Autarkic PL
- Nested functions
- Set type constructor
- Subrange types
- Nested functions and procedures
- Functions and procedures are not first class values
- Named labels, although naming is by integers
2. Introduction

2.4. Syntax specification
Linguistics of PLs: syntax & semantics

Two components of linguistics (as in natural linguistics):

Syntax  Which text files are correct programs? How expressions, commands, declarations, etc., are put together to form a program?

Semantics  What’s the meaning of correct programs? Behavior when executed on a computer?

Means for specification:

Syntax  Regular expressions, context-free grammars, BNF form, EBNF form, syntax diagrams (briefly touched here, subject of “Automata & formal Languages”)

Semantics  Tutorials, user guides, handbooks, Wikipedia entries, language legalese (briefly touched here), and formal semantics (outside our scope).

Common theme: recursively defined sets...
## 2. Introduction

### 2.4. Syntax specification

#### 2.4.1. Regular expressions
Recursively defined sets

Also known as \textit{inductively defined sets}

**Definition (Who is Jewish?)**

- \textit{Mother Sarah was Jewish.}
- \textit{Father Abraham was Jewish.}
- \textit{People who converted are Jewish.}
- \textit{People born to a Jewish mother are Jewish.}

Other natural examples:

- Who is a Muslim?
- Who can call himself a “\textit{Dr.}”?
- Who can call himself a “\textit{Rabbi}”?
The set of strings over an alphabet

- Regular expressions is a language for defining a subset of the strings over a given alphabet.
- But, what are "strings over a given alphabet"?
  - Let \( \Sigma \) be an alphabet
  - i.e., a set of letters (also called characters), e.g.,
    \[ \Sigma = \{ a, b, c, d, e, f \} \]
  - \( \Sigma \) can be used to write strings, e.g., \( abba, baa, daffacc, cafe, decaf, dafcaa \)
  - Let \( \varepsilon \) denote the empty string.
  - Let \( \Sigma^* \) be the set of all strings over \( \Sigma \),

\[
\Sigma^* = \{ \varepsilon, a, b, \ldots, f, \ldots \}
\]
Recursive definition of the set of non-empty strings

Given an alphabet $\Sigma$, the set $\Sigma^+$ is defined by

**All letters** All letters in $\Sigma$ are present in $\Sigma^+$

$$\ell \in \Sigma \Rightarrow \ell \in \Sigma^+ \quad (4.2)$$

**Concatenation** Set $\Sigma^+$ is closed under concatenation:

$$\alpha, \beta \in \Sigma^+ \Rightarrow \alpha\beta \in \Sigma^+ \quad (4.3)$$

where $\alpha\beta$ is the string obtained by concatenating $\alpha$ and $\beta$

**Minimality** there are no other members of $\Sigma^+$

$$\gamma \in \Sigma^+ \Rightarrow \gamma \in \Sigma \text{ or } \exists \alpha, \beta \in \Sigma^+ \bullet \gamma = \alpha\beta \quad (4.4)$$
Other recursive definitions of the set of strings

- There are many equivalent definitions of $\Sigma^+$
- All these definitions must be recursive
- A string $\alpha \in \Sigma^+$ can be constructed in several ways by the above definition
- There is an alternative definition of $\Sigma^+$ by which every $\alpha \in \Sigma^+$ has a single, unique construction.
Set of strings over an alphabet—defined recursively

**Definition (Set of strings over an alphabet)**

Given an alphabet $\Sigma$, the set $\Sigma^*$ is defined by

- $\varepsilon$, the empty string is in $\Sigma^*$, $\varepsilon \in \Sigma^*$
- if $\ell$ is a letter, $\ell \in \Sigma$, and $\alpha \in \Sigma^*$ is a string, then $\ell\alpha \in \Sigma^*$, where $\ell\alpha$ is the string obtained by prefixing letter $\ell$ to string $\alpha$
- there are no other members of $\Sigma^*$
# Examples of regular expressions

<table>
<thead>
<tr>
<th>RE</th>
<th>$S \subseteq \Sigma^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>{a}</td>
</tr>
<tr>
<td>b</td>
<td>{b}</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>{\varepsilon}</td>
</tr>
<tr>
<td>ab</td>
<td>{ab}</td>
</tr>
<tr>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>a*</td>
<td>{\varepsilon, a, aa, aaaa, ...}</td>
</tr>
<tr>
<td>(d</td>
<td>a)(a*)</td>
</tr>
<tr>
<td>(a</td>
<td>b</td>
</tr>
</tbody>
</table>
Regular expressions as a recursively defined set

Given an alphabet \( \Sigma \), the set \( \text{RE}(\Sigma) \) is defined by:

**All strings**

\[
\Sigma^* \subseteq \text{RE}(\Sigma) \quad (4.5)
\]

**Alternation**

\[
e_1, e_2 \in \text{RE}(\Sigma) \Rightarrow (e_1 | e_2) \in \text{RE}(\Sigma) \quad (4.6)
\]

**Concatenation**

\[
e_1, e_2 \in \text{RE}(\Sigma) \Rightarrow (e_1 e_2) \in \text{RE}(\Sigma) \quad (4.7)
\]

**Kleene closure**

\[
e \in \text{RE}(\Sigma) \Rightarrow (e^*) \in \text{RE}(\Sigma) \quad (4.8)
\]
Semantics can be recursively defined as well

The semantics of $e \in \mathbb{RE}(\Sigma^*)$ is a set $S(e)$, $S \subseteq \Sigma^*$

- **Strings**
  
  $$e \in \Sigma^* \Rightarrow S(e) = \{ e \}$$

- **Alternation:**
  
  $$e = (e_1 | e_2) \Rightarrow S(e) = S(e_1) \cup S(e_2)$$

- **Concatenation:**
  
  $$e = (e_1e_2) \Rightarrow S(e) = \{ \alpha\beta \mid \alpha \in S(e_1) \text{ and } \beta \in S(e_2) \}$$

- **Kleene closure:**
  
  $$e = (e')^* \Rightarrow S(e) = \bigcup_{i=0}^{\infty} S(e' \cdots e')$$
Syntactic sugaring & other variations in regular expression

- RE were adopted in various systems, including text editors, languages for text processing, shell scripts.
- Adoptions varying syntax for the same underlying concept
- Most adoptions offer syntactic sugaring

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Meaning</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>[a-z]</td>
<td>inclusive range</td>
<td>letters a through z</td>
</tr>
<tr>
<td>[^0-9]</td>
<td>exclusive range</td>
<td>all characters in the alphabet, except digits 0 through 9</td>
</tr>
<tr>
<td>a?</td>
<td>optional</td>
<td>{a, ε}</td>
</tr>
<tr>
<td>+</td>
<td>one or more</td>
<td>one or more spaces</td>
</tr>
<tr>
<td>UPPER = [A-Z]</td>
<td>naming</td>
<td>name a RE to be used in the definition of other REs</td>
</tr>
<tr>
<td>${UPPER}[a-z]</td>
<td>using name</td>
<td>upper case letter followed by a lower case letter</td>
</tr>
</tbody>
</table>

Note: recursive use of names is never allowed.
Three components of a recursive definition

1. **Atoms.** e.g., the empty string is in $\Sigma^*$

2. **Constructors.** how to make *compound* members out of the *atoms* and compound members constructed previously.

3. **Minimality.** usually implicit, but can be phrased as
   - The set has no members other than the atoms or the compound members constructed by the construction rules.
   - The set is the *intersection* of all sets which are consistent with the atoms and the construction rules specification.
   - The set is the smallest set that is consistent with the atoms and the construction rules specification.
Recursively defined sets in PLs

- **Arithmetical expressions.**
  - **Atoms** literals, references to named entities, ...
  - **Constructors** mathematical operators, user-defined functions, ...

- **Executable statements (commands) in C.**
  - **Atoms** assignment, `return`, ...
  - **Constructors** `if`, `for`, `{...}`, ...

- **Types in C.**
  - **Atoms** `int`, `char`, ...
  - **Constructors** aka *type constructors*
    - “points to”,
    - “array of”,
    - “record with fields”, *and*,
    - “function taking type τ and returning type σ”.
    - ...

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Fall 2017 (lecture)  
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Unit 2.4: p. 12/26
Example: types in JAVA

- JAVA’s types are recursively defined.
- Type constructors are e.g., `class`, array, and `enum`.
- Atomic types make the recursion base
- Atomic type are denoted in JAVA by reserved words:

<table>
<thead>
<tr>
<th>Kind</th>
<th>Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integral types</td>
<td><code>byte, short, int, long</code></td>
</tr>
<tr>
<td>Floating types</td>
<td><code>float, double</code></td>
</tr>
<tr>
<td>Other types</td>
<td><code>boolean, char</code></td>
</tr>
</tbody>
</table>
Compound vs. atomic members

Atomic member  indivisible, has no components which are members

Compound member  has smaller components which are members

Begin

\begin{align*}
    &a := b \ast c \\
    &; \\
    &\text{WriteLn}( \sin( (a + 3) \ast (a + c) ) )
\end{align*}

end
Decomposing a compound expression

\[
\sin((a + 3) \times (a + c))
\]

Some (but not all) of the compound expressions in the decomposition tree of the largest compound expression are marked as well.
Observations

- in an atomic command may contain a compound expression
- this does not make the command less atomic
- an expression never contains commands (at least not in Pascal)
- constructors are denoted by keywords as well
- these keywords can be thought of punctuation
- or as sort of “names” of the constructors
2. Introduction

2.4. Syntax specification

2.4.2. EBNF
Extended Backus-Naur form (EBNF)

\[ \text{if-stmt} = \text{if } \text{expression} \text{ then } \text{statement} \ [ \text{else } \text{statement} ] \]

- A meta-notation for describing the grammar of a language
  - Terminals = actual legal strings, written as is, or inside “” + ”
  - Nonterminals = concepts of the language, written <program> or program or \textit{program} in different variants
  - Rules = expanding a non-terminal to a series of nonterminals and Ts
- One nonterminal is designated as the start of any \textit{derivation}
- A sequence of terminals not derivable from start symbol by rules of the grammar is illegal
- | is choice among several possibilities
- [... ] enclose optional constructs
- A pair of “{” and “}” encloses zero or more repetitions
Example of an EBNF

**Terminals**
- v, n, +, -, ( ),

**Nonterminals**
- \(<a>\) \(<m>\) \(<F>\) \(<E>\) \(<T>\)

**Start Symbol**
- \(<E>\)

**Rules**
- \(<a>\) = + | -
- \(<m>\) = * | /
- \(<F>\) = v | n
- \(<F>\) = ( \(<E>\) )
- \(<E>\) = \(<T>\) \({\(<a>\) \(<T>\)}
- \(<T>\) = \(<F>\) \({\(<m>\) \(<F>\)}

More readable way for writing an EBNF

The common way for presenting an EBNF

- Employ meaningful names
- “Rules” is the only section; no
  - terminals list
  - non-terminals list
  - definition of a start symbol

Context free grammar for expressions

```
<expression> = <term> {<add-op> <term>}
<term> = <factor> {<mult-op> <factor>}
<factor> = <variable-name>
    | <number>
    | ( <expression> )
<add-op> = + | -
<mult-op> = * | /
```
Interpretation of the “expression” grammar

Context free grammar for expressions

<expression> = <term> {<add-op> <term>}
<term> = <factor> {<mult-op> <factor>}
<factor> = <variable-name>
    | <number>
    | (<expression> )
<add-op> = + | -
<mult-op> = * | /

- Terminals never occur at the left hand side of rules: +, −, *, and /.
- Non-terminals should always occur at the left hand side rules:
  - <expression>
  - <term>
  - <factor>

- Start symbol is <expression>
- Forget about <number> and <variable-name> for now.
Understanding the “expression” grammar

Context free grammar for expressions

- `<expression> = <term> {<add-op> <term>}`
- `<term> = <factor> {<mult-op> <factor>}`
- `<factor> = <variable-name>`
- `<number>`
- `<expression>`
- `<add-op> = + | -`
- `<mult-op> = * | /`

- Is $a + 2/b - c * 7$ a legal expression?
- Yes, because there is a sequence of rule applications, starting from `<expression>` that yields this string (these can be drawn as a “syntax tree”, also called “parse tree”)

- How about $a * (b + c)$?
Many variants for writing an EBNF

EBNFs are often written in a form intended to be readable, but only to the educated reader:

Context free grammar for expressions (another EBNF syntactical variant)

Expression ::= Term ((+' | '−') Term)*
Term ::= Factor (('∗' | '/' ) Factor )*
Factor ::= Variable-Name
     | Number
     | '(' Expression ')' 

- First rule defines the start symbol
- Terminals never occur in the left
- Use more RE-like syntax for right hand of rules
- Terminals show between quotes
Terminals can be regular expression as well

Don’t forget **Variable-name** and **Number**

- Can potentially be specified in EBNF
- Usually have no recursion in them
- Are usually written as regular-expression
- Are though of as *tokens* or *non-terminals*

**Context free grammar for expressions with regular expressions for tokens**

\[
\text{Expression} ::= \text{Term} (('+' | '-') \text{Term})* \\
\text{Term} ::= \text{Factor} (('*' | '/') \text{Factor})* \\
\text{Factor} ::= \text{Variable-Name} \\
| \text{Number} \\
| '(' \text{Expression} ')'
\]

**Variable-Name** := [a-zA-Z][a-zA-Z0-9]*

**Number** := [+|-]? [0-9]+
**BNF vs. EBNF**

only strings of (terminals/non-terminals) can be used on the left hand side; no regular expressions in the original Backus Naur Form

---

**Context free grammar for expressions (plain BNF)**

Expression = Terms  
Terms: Term  
Terms: Term Addition Terms;  
Term: Factors;  
Factors: Factor:  
Factors: Factor Multiplication Factor;  
Factor: Variable-Name;  
Factor: Number;  
Factor: '(' Expression ')';  
Addition: '+';  
Addition: '-';  
Multiplication: '*';  
Multiplication: '/';
Ambiguity in context free grammars

If there is a sequence of terminals with more than one derivation tree.

- Syntactical ambiguity often leads to ambiguous semantics, since there are several possible ways to interpret the input.
- Good PL design avoids ambiguity
- It is algorithmically impossible to determine whether a BNF gives rise to ambiguity
Expressive power of context free grammars

Some syntactical cannot be expressed even with EBNF. Examples

- Every variable used is previously declared
- The number of arguments in a procedure call equals the number of arguments in the declaration of the procedure

Much more on grammars and identifying legal programs you will learn in the courses *Automata and Formal Languages* and *Compilation*
2. Introduction

2.5. Tokens: the atoms of syntax

1. Preliminaries

2. Introduction
2.1 PL design
2.2 Programming paradigms

| 2.3 History of programming languages |
| 2.4 Syntax specification |
| 2.5 Tokens: the atoms of syntax |
| 2.5.1 Kinds of tokens |
| 2.5.2 Library identifiers |
| 2.5.3 Starting point |
Writing a “Hello, World!” program in C
Using Bash, Gnu/Linux, etc.

Programmed involves many technical activities:

**Actions**
- Authoring
- Compiling
- Linking
- Executing

**Concretely**

```c
rm −f hello.c a.out
cat << EOF > hello.c
#include <stdio.h>

int main(int argc, char *argv[], char **envp) {
    return printf("Hello, World!\n") <= 0;
}
EOF
cc hello.c
./a.out
```
Authoring “Hello, World!” with the **gvim** text editor

- The gtksourceview library makes these so similar...
- Still, the similarity of PLs makes gtksourceview possible!
2. Introduction

2.5. Tokens: the atoms of syntax

2.5.1. Kinds of tokens
Tokens are the terminals of a CFG

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Kind</th>
</tr>
</thead>
<tbody>
<tr>
<td>“(“, “)“</td>
<td>punctuation</td>
</tr>
<tr>
<td>“*“, “+“</td>
<td>operators</td>
</tr>
<tr>
<td>Variable-Name</td>
<td>identifier</td>
</tr>
<tr>
<td>Number</td>
<td>literal</td>
</tr>
</tbody>
</table>

Note that comments do not show up in the grammar.

Context free grammar for expressions (plain BNF)

Expression = Terms
Terms: Term
Terms: Term Addition Terms;
Term: Factors;
Factors: Factor:
Factors: Factor Multiplication Factor;
Factor: Variable-Name;
Factor: Number;
Factor: '(' Expression ')';
Addition: ‘+’;
Addition: ‘-’;
Multiplication: ‘*’;
Multiplication: ‘/’;
### What do tokens denote?

<table>
<thead>
<tr>
<th>Kind</th>
<th>Example</th>
<th>Denotes?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifier</td>
<td>main, i, printf, argv</td>
<td>a “nameable”</td>
</tr>
<tr>
<td>Literal</td>
<td>“132”, “Hello, World\n”</td>
<td>itself</td>
</tr>
<tr>
<td>Operator</td>
<td>“∗, “+, “*, “/”</td>
<td>a builtin function</td>
</tr>
<tr>
<td>Punctuation</td>
<td>“;,” “,” “(“, “)”</td>
<td>nothing (reading and parsing aide)</td>
</tr>
<tr>
<td>Reserved word</td>
<td>if, class, int</td>
<td>…</td>
</tr>
<tr>
<td>Reserved identifier</td>
<td>int, class, int</td>
<td>primitive type</td>
</tr>
<tr>
<td>Predefined identifier</td>
<td>Integer, &amp;primitive type</td>
<td></td>
</tr>
<tr>
<td>Comments</td>
<td>/* fubar */</td>
<td>Nothing!</td>
</tr>
</tbody>
</table>

Comments are not officially tokens, but they also belong to the atomic elements of the language.
Names aka identifiers

- Create an *entity* once, refer to it many times
- Essential for modular large-scale programming
- Largely a *nuisance*!
  - good names are scarce
  - difficult to make up, type, read, and understand
Nameables

**Definition (Nameable)**

A *nameable* is an entity kind, such as functions, modules, types, constants, variables, for which the programmer can provide a name.

**Nameable values in **Pascal**

```pascal
CONST
Pi = 3.14159265358979323846264
```

**Nameable types in **C**

```c
// Type named struct Date:
struct Date {
    int month, day, year;
};
```
Nameable values in C/C++/JAVA?

- Values are not in C, (the preprocessor is not part of the language)...
- not in C++, neither in JAVA,...
- but there are workarounds:

**C/C++:**

```c
// Only for integer constants
enum {
    BELL = '\b',
    TAB = '\t',
    NL = '\n',
    CR = '\r',
};
const double E = 2.718281824;
const int Merssene7 = 524287;
```

**JAVA:**

```java
final double E = 2.718281824;
final int Merssene7 = 524287;
```
Legal names

All PLs include a definition of “legal names”:

Definition (C identifiers)

A C identifier is a series of alphanumeric characters, the first being a letter of the alphabet or an underscore, and the remaining being any letter of the alphabet, any numeric digit, or the underscore.

- Regular expression

\[[_a-zA-Z] [/_a-zA-Z0-9]* \]  \hspace{1cm} (5.1)

- Most PLs follow the same pattern.
- But, there are always annoying exceptions:
  - TeX: digit and underscores are forbidden
  - Early Basic: a single letter, optionally followed by a digit
Variations

lower/UPPER case due to historical or ideological reasons.

Length limit typically 6–8 in ancient languages, ~32 or unlimited in modern languages

Special characters Can a name contain a dollar (yes, in JAVA), space (in Fortran), a quote (in JTL), or what have you?

Unicode Ain’t “α” an excellent variable name in certain contexts?
What’s Unicode?

• a system for encoding characters
• more than 110,000 characters
• covers ~100 scripts, representing most of the world’s writing systems
• Standard in Windows (NT/XP/Vista/2000/7), Linux, Mac OS X.
• Extends and replaces ASCII (7 bit standard, used primarily for American English)
Names and kind distinction

- Names can be used for *very different* entities.
- “Readability” (no one knows what “readability” really means”), concerns as well as parsing issues make PL impose rules such as:
  - **Prolog**: first character determines *grammatical role* (lowercase: function; uppercase/underscore: variable)
  - **Perl**: first character determines *structure*, e.g., “%” for hashtable.
  - **Fortran**: first character determines *type*, e.g., “i” must be an integer.
Names and naming conventions

Many PLs employ *naming conventions*,

- For distinguishing between categories, types “must” be capitalized.
- For making a single name out of multiple words:
  - **PascalCase** `FileOpen`, `WriteLn` (e.g., `PASCAL`)
  - **camelCase** `fileOpen`, `getClass` (e.g., `JAVA`)
  - **under_scoring** `file_open` (e.g., `C`)
  - **juxtaposition** `fileopen`, `\textbackslash`textbackslash` (e.g., `\LaTeX`)
- For denoting type, e.g., using the *Hungarian Notation*, denotes a variable `arru8NumberList` whose type is an `array` of `unsigned 8-bit integers`
Names & your new PL

- Try to understand the language peculiarities:
  - What “special characters” are allowed? Why?
  - Is there lower/upper case distinction? Why?
  - Is there a length limit? Why?
  - What is the language naming convention, if any?

- Remember, modern languages tend to:
  1. impose no length limit
  2. use Unicode
  3. distinguish between upper and lower case
  4. rely on conventions rather than syntax for distinguishing kinds.
Keywords

**Definition (Keywords/reserved words)**

A *keyword* (also called a *reserved word*) is a string of characters which makes a legal name, yet, it is reserved for special purposes and cannot be used by the programmer for any other purpose.

**Pascal Examples:**

- program
- begin
- end
- record
- of
Keywords & atomic types

- Each of the atomic types in JAVA is denoted by a keyword.
- Some C atomic types have names made of two, and even three keywords:
  - “unsigned short”
  - “unsigned long int”
- Some C atomic types have more than one name, e.g.,
  - “long”
  - “long int”
  - “signed long”
  - “signed long int”
- Atomic types in Pascal are denoted by predefined identifiers
Atomic types in **PASCAL** are predefined

a somewhat confusing fact of life

---

### Definition (Predefined identifier)

A *predefined identifier*

- identifier
- that is bounded to an entity (such as type, function, procedure or value)
- this binding is made by the PL, with no programmer intervention
- can be bounded to another entity later on.

---

Redefinition of predefined identifiers is legal, but might be confusing
Redefinition of predefined identifiers

**Confusing program**

```plaintext
Program misnomer;
TYPE
    Double = Real;
    Boolean = Integer;
VAR
    Integer: Boolean;
    Real: Double;
Begin
    Integer := 3;
    Real := Integer / Integer;
    WriteLn('i = ', Integer, ' r = ', real)
end.
```

Observe that my pretty printer got confused as well.
Reserved identifiers

**Definition (Reserved identifier)**

A reserved identifier *is a keyword used as an identifier.*

- The word `int` is a reserved identifier, it identifies the `integer` atomic type.
- The identifiers `Integer` and `WriteLn` in `Pascal` are not reserved. The programmer may redefine these.
- Not all reserved words are reserved identifiers:
  - `return` in `C` (an atomic command).
  - `begin`, `end`, `program` in `Pascal` (punctuation).
  - `struct` in `C` (a constructor for creating compound types from other types).
Routines whose name is a reserved identifier?

In most PLs, the names of “standard” routines (procedures and functions) are *not* reserved:

- They are either *imported* nor *builtin*
- A notable exception is AWK:
  - **print** A builtin function, for printing.
  - **exit** A builtin function, stopping execution.
  - **int** A builtin function, for conversion into an integral type.

Unlike **Pascal**, builtin names in AWK *are* reserved.
Summary: kinds of identifiers

- Identifiers:
  - Reserved identifier
  - Predefined identifier
  - Library identifier
  - Other

In addition, we have those reserved words which are not identifiers.

- Identifiers reserved for future use
- Denotation of atomic entities
- Punctuation (often used in constructors of entities)
- Other, e.g., marking Boolean attributes (register, auto, static in the C PL)
- there are so many PLs, we cannot hope to classify them all
The Go PL

Can you classify the identifiers and reserved words used here?

```go
// "Hello, World!" in Go
package main
import "fmt"
func main() { // main function
    fmt.Printf("Hello, World!\n")
}
```

- `package` reserved word, punctuation
- `import` reserved word, punctuation
- `func` reserved word, punctuation
- `main` identifier, other
- `fmt` identifier, library
- `Printf` identifier, library
2. Introduction

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2.5.2. Library identifiers
Why a library?

- The set of executable commands is always a recursively defined set.
- Derivation rules are language dependent, typically including blocks, iterations, conditionals, and routines.
- Atomic executables include:
  - Commands denoted by keywords, e.g., return, break and continue.
  - Other atomic commands such as assignment.
  - Invocation of routines.

Some routines are so

- low-level that they cannot be implemented within the language.
- essential that there is little point in having each programmer redo them.
- tiresome that most programmers could not be bothered implementing them.
Library identifiers

**Definition (Library)**

*A collection of pre-made routines (or modules) that are available to the programmer.*

- **standard library** replaceable (as in C)
- **builtin library** cannot be replaced (as in Pascal and AWK)

**Identification of entities in the library**

- **Reserved words** rare (e.g., AWK)
- **Predefined identifiers** as in Pascal.
- **Importing** as in Java and C.
## Replaceable- vs. builtin- library

<table>
<thead>
<tr>
<th>Replaceable</th>
<th>Builtin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Troublesome for programmer</td>
<td>Less work for the programmer</td>
</tr>
<tr>
<td>Small language specification</td>
<td>Bulky language specification</td>
</tr>
<tr>
<td>Flexible</td>
<td>Rigid</td>
</tr>
<tr>
<td>Modular language design</td>
<td>Tangled language design</td>
</tr>
<tr>
<td>Library can be very large</td>
<td>Library is typically small</td>
</tr>
<tr>
<td>Most modern PLs</td>
<td>PLs designed for beginners and for one-liner/scripting</td>
</tr>
</tbody>
</table>

**Dinosaurs**: Languages such as COBOL which included huge builtin library tend to collapse under their own weight
Import by preprocessing

Import at the source, textual level

```c
#include <stdio.h>

int main(int argc, char *argv[], char **envp) {
    return printf("Hello, World!\n") <= 0;
}
```

Preprocessor
Explicit (and implicit) import

Your program declares which library identifiers it uses:

- The keyword `import` seems to be used in so many PLs.
- Other languages may use other keywords, e.g., `uses`

Semantics is _greater_ than textual import.

**Properties of import**

- usually carried out for a bunch of identifiers (for now, we call such a bunch a module)
- there is an _implicit_ search path for the library
- may be used also for user-provided (non-library) modules
- may cause other modules to compile
Implicit import

Certain principal modules are automatically imported even if the programmer does not explicitly import these

e.g., `java.lang.*` in JAVA

Hello.java

```java
public class Hello {
    public static void main(final String[] args) {
        System.out.println("Hello, World!");
    }
}
```
Compilation unit

**Definition (Compilation unit)**

*compilation unit* is a portion of a computer program which is sufficiently complete to be compiled correctly.

- Usually a file
- Can be string, or a *buffer of the editor*
2. Introduction

2.5. Tokens: the atoms of syntax

2.5.3. Starting point
Order of execution

Yet, another thing to observe in any "Hello, World!" program:

- Normally sequential
- Can be changed by
  - Conditional commands
  - Iteration commands
  - Pluralization commands
  - Invoking routines
  - ...

But, in the presence of several compilation units, or even several routines in the same compilation unit, where do we start?
Autarkic approach

**au·tar·ky or au·tar·chy, pl. au·tar·kies or au·tar·chies**

1. A policy of national self-sufficiency and non-reliance on imports or economic aid.
2. A self-sufficient region or country.
Summary terminology

- identifiers, nameable entities (variables, values, functions, procedures, templates, namespaces, labels, modules),
- keywords, reserved identifiers, predefined identifiers
- literals, escaping, comments.
- separatist, terminist, and variations.