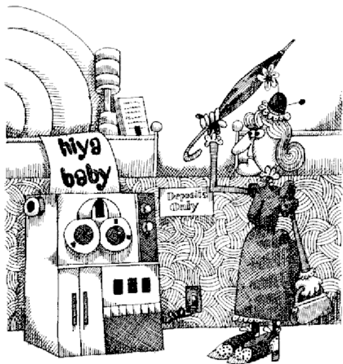
Computer Languages

Introduction & Regular Expressions

1. Introduction
   - Administrivia
   - Course contents
2. Regular Expressions
   - Definitions
   - Examples
   - Scanner generators

January 19th

Computer Languages



This is an elective course for the master programmes *Embedded Intelligent Systems* and *Computer Systems Engineering*.

Computer languages are

- The tools you use to build pieces of software!
  - you need to understand them properly
  - you need to learn new ones
- The solution to some problems
  - you need to know how to implement them

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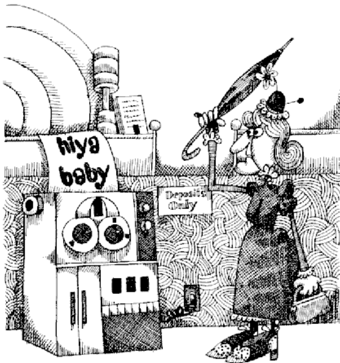

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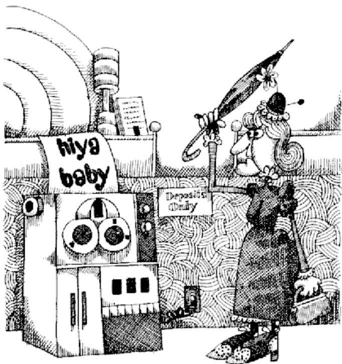

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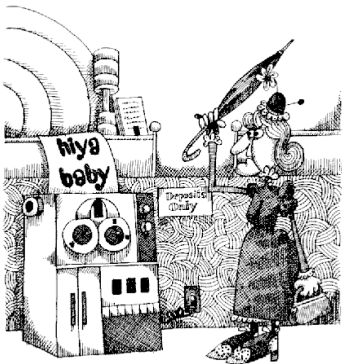

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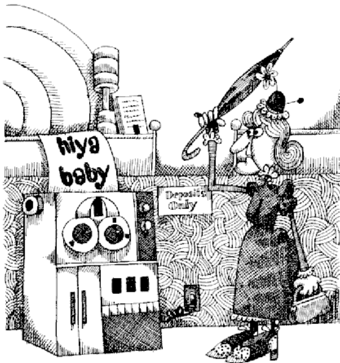

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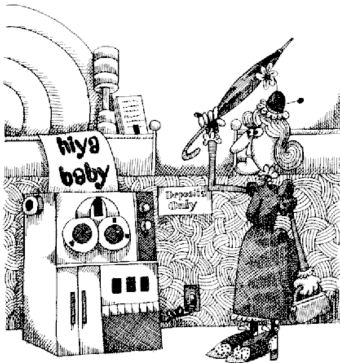

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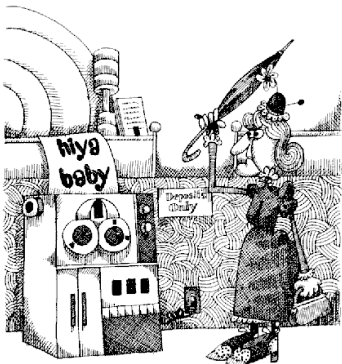

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Resources

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- Jerker Bengtsson
  www2.hh.se/staff/jebe
- Verónica Gaspes
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A good book, organized around building a compiler.

On Line

- Web page
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- Lecture notes, notice board, project instructions.
- Manuals for the tools we use.

A lot of material, helps even if you want to follow an advanced course. We look at the first part, upto chapter 12.

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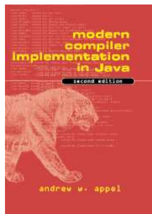

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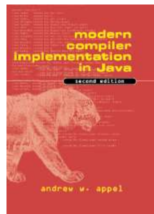

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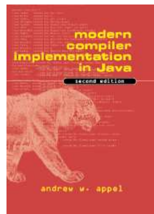

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A programming project where you implement a compiler for a subset of the Java programming language.

Small computer based exercises about formal languages

The instructions will be on the web, including deadlines.

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On formal languages about

- regular expressions and finite automata
- context free grammars and pushdown automata

Compiler techniques lectures

- abstract syntax
- types and type checking
- intermediate representations
- code generation and optimizations

Assignments

Short labs to confirm that you understand some theory and the tools we need.

Programming project

Organized as a series of laborations with strict deadlines.

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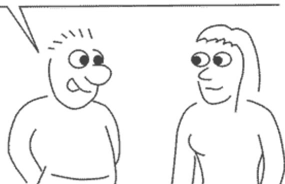

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- *xml* to describe the structure of documents and documents themselves.
- *xquery* to transform xml documents.
- *VHDL* to describe circuits.
- *VRML* to describe 3D scenes.
- *C, Java, Haskell* for programming.

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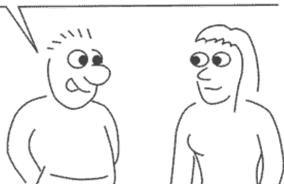

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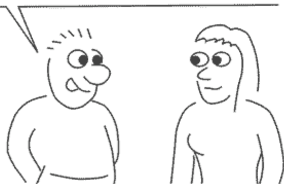

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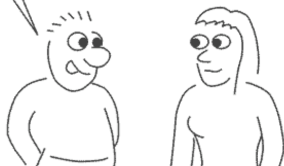

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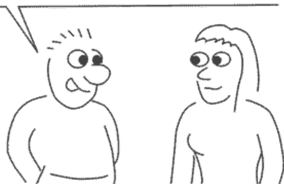

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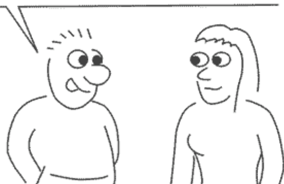

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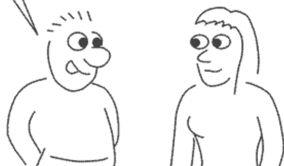

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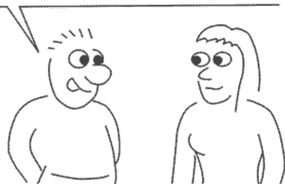

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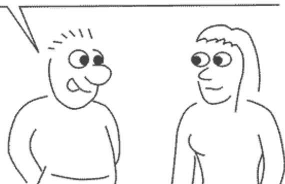

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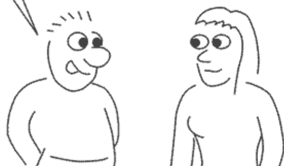

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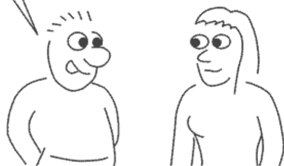

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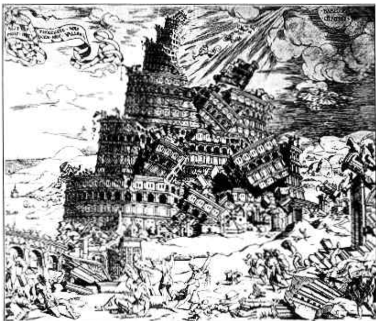

Different kinds of programs require different kinds of abstractions

- Symbolic manipulations functional languages like Haskell, ML, lisp, scheme or xquery.
- Concurrent languages with communication and synchronization mechanisms like Occam or MPD.
- Embedded languages with interface to hardware like C.
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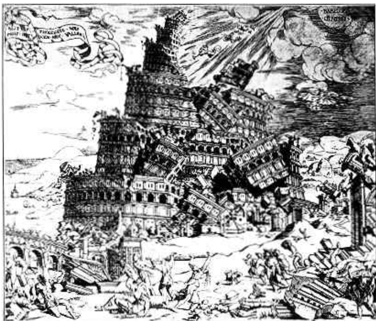

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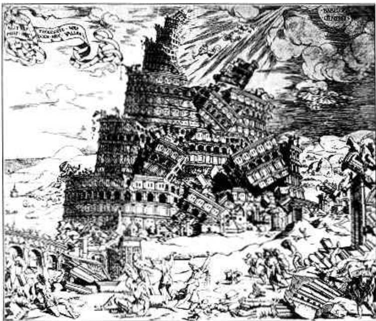

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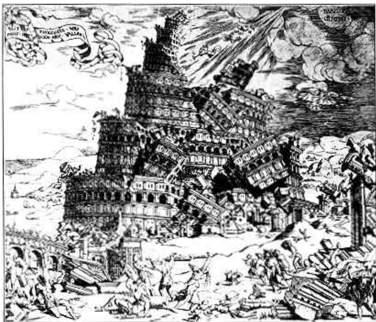

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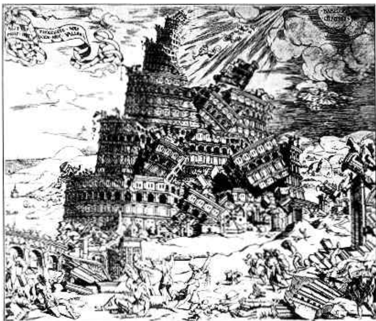

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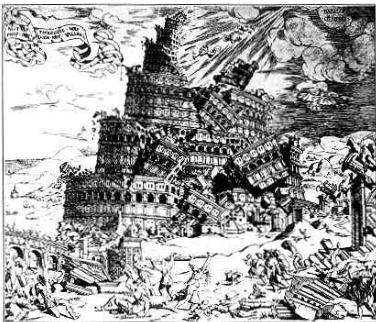

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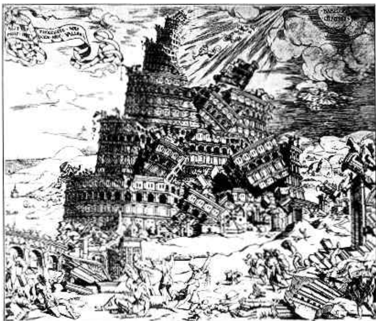

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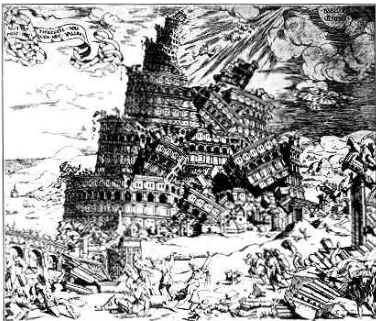

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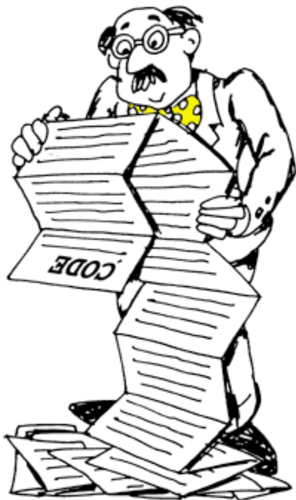

All these languages have a lot in common! They all have to be processed by a program in order to do what we express in them!

- They are formal languages,
- in most of them we can make definitions,
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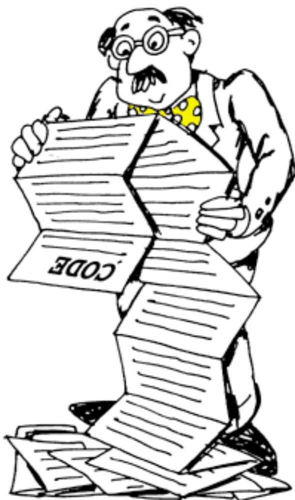

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Why a compiler?

In the course we study a compiler for an imperative programming language.

Language processors

There are two kinds of language processors

- Compilers
- Interpreters

that have much in common!

- They are complex programs!
- They use advanced algorithms and data structures
- They show an application of the theory of formal languages; we learn how to use tools that generate programs
- We learn programming techniques
- We learn to do semantic distinctions (for instance different parameter passing mechanisms)

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- They show an application of the theory of formal languages, we learn how to use tools that generate programs.
- We learn programming techniques.
- We learn to do semantic distinctions (for instance different parameter passing mechanisms!)

Why a compiler?

In the course we study a compiler for an imperative programming language.

Language processors

There are two kinds of language processors

- Compilers
- Interpreters

that have much in common!

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- A compiler is a large, complex program.
  - *The design and implementation of a compiler is a substantial exercise in software engineering.*
- A good compiler contains a microcosmos of computer science.
  - *Working inside a compiler provides practical experience in software engineering that is hard to obtain with smaller, less intrincate systems.*
- Most software is compiled. Compiler construction has given rise to tools for automatic programming that can be used for many purposes. In constructing a compiler you will get to use these tools (and hopefully you will find use for them in other areas!)

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Why a programming language?

We chose a programming language as running example of a computer language because you are familiar with it and because it illustrates a lot of concepts.

- definitions and scope
- variables and arguments
- types

Some side effects of the course.

Provides you with software tools to describe and implement computer languages

- lexer generators
- parser generators

Provides you with new programming techniques and datastructures useful in processing computer languages

- design patterns *component, visitor*
- front end/ back end, abstract machines
- abstract syntax
- environments

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Programming Project

- You will write a compiler for *minijava*, a small programming language presented in the course book.
- It is graded, it is the main contribution to the grade of the course!
- It is divided in parts. You will get instructions and deadlines for each part.
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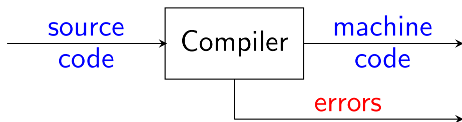

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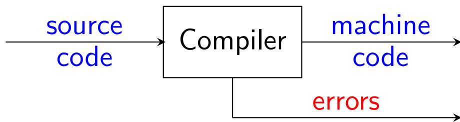

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- Has to generate correct machine code!
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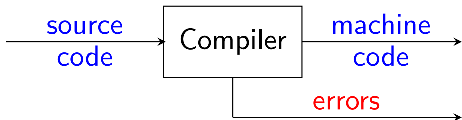

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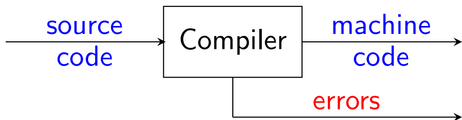

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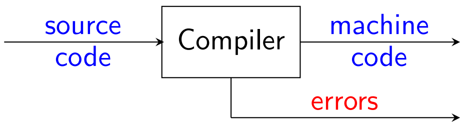

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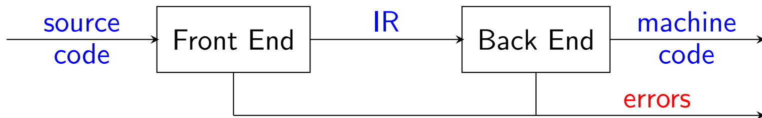

- Programs are analysed and translated to an intermediate representation IR, a form of abstract machine.
- IR is useful for many things:
  - detect some errors (indexing out of range)
  - reorganize the code (to gain efficiency)
  - to analyze the code (to assign registers)
- It also helps to think and understand the different tasks!

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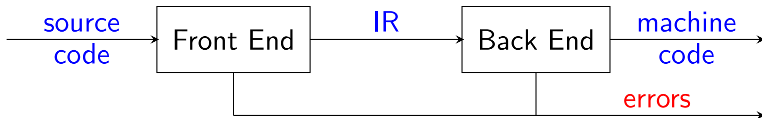

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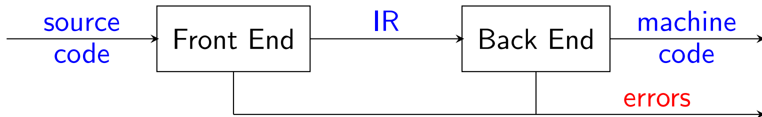

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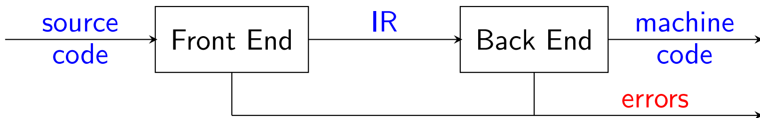

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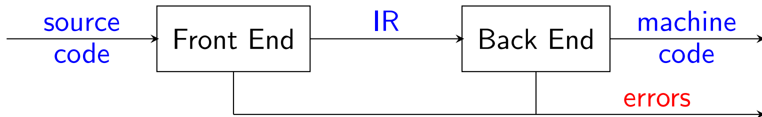

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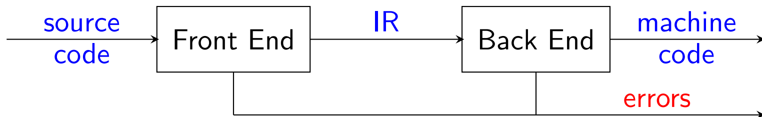

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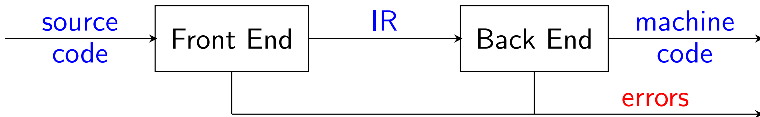

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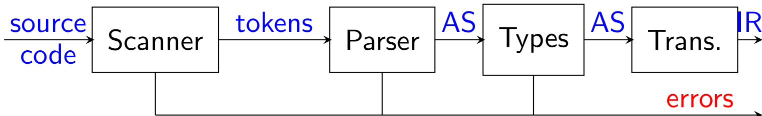

- The Scanner (lexical analyzer) transforms a sequence of characters (source code) into a sequence of tokens: a representation of the *lexemes* of the language.
- The Parser (syntactical analyzer) takes the sequence of tokens and generates a tree representation, the Abstract Syntax.
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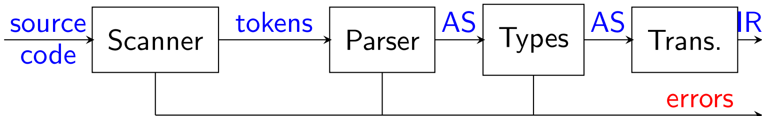

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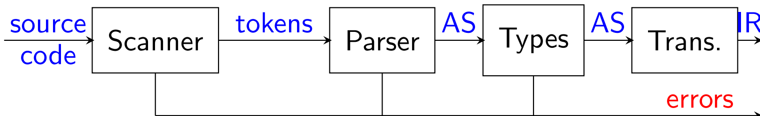

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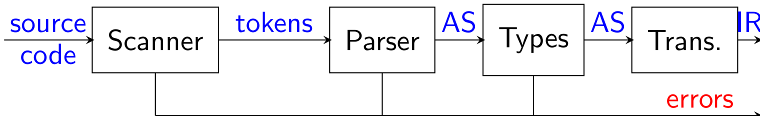

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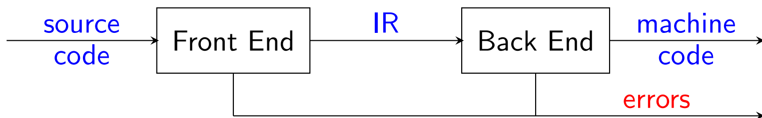

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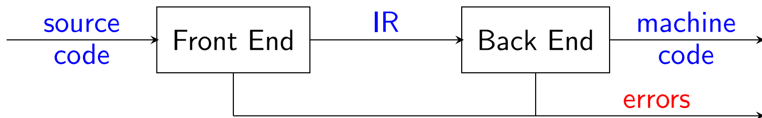

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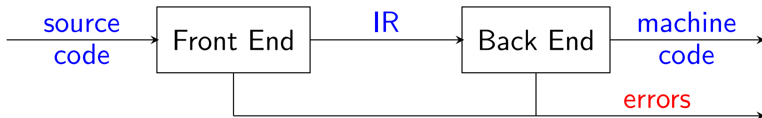

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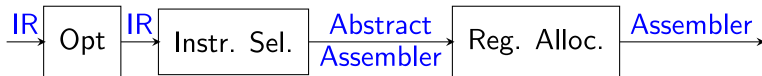

Describing a language

What are the phrases of the language? (Syntax)

What do phrases mean? (Semantics)

Example

In English some sentences have the form

`<noun phrase><verb phrase>`

where a `<noun phrase>` can be

`the <noun>`
`a <noun>`
`<name>`

Example

In Java the meaning of a statement like

`if <exp><stm1><stm2>`

is given by explaining what happens when it is executed:

When the value of <exp> is true <stm1> is executed, otherwise <stm2> is executed.

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Syntax

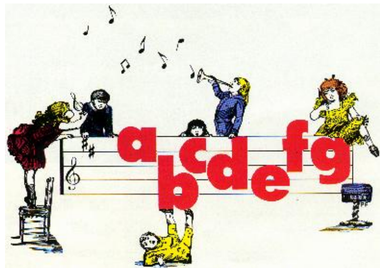
Alphabets

- Phrases are formed using words.
- Words are formed using characters.

Languages

In the context of our course we will deal with formal languages:

Sets of strings over some alphabet described by certain rules



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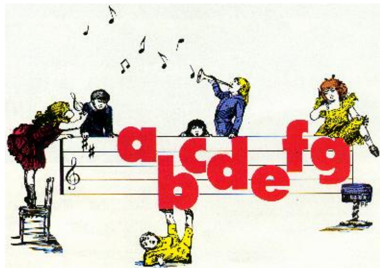

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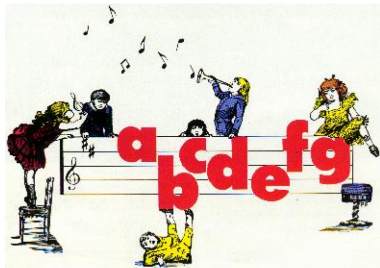
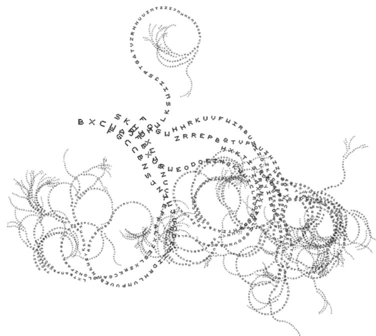


Syntax

- There are different kinds of rules to describe languages.
- According to what kind of rules we use the languages have certain structure and properties.
- Typically languages of words have a simpler structure than languages of phrases.
- Regular expressions are used to describe *words* of programming languages.
  - Easy to understand, usefull in many contexts, software tool support.



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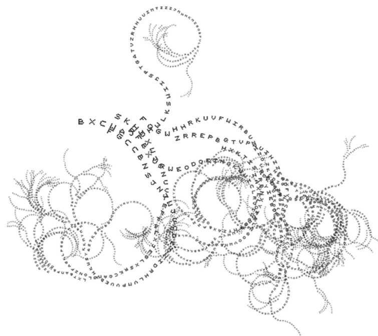

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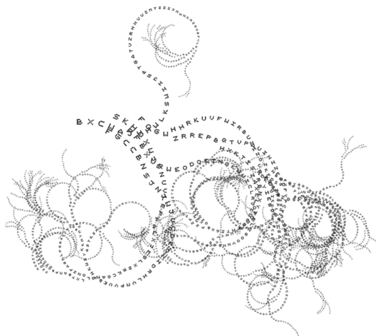

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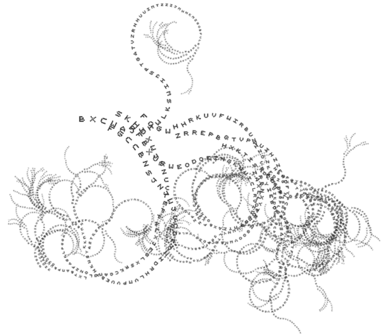

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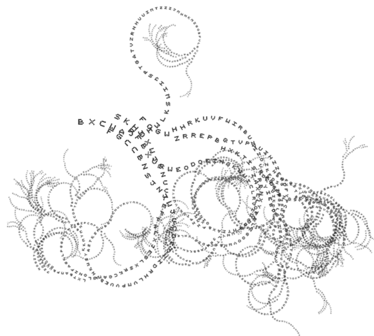

Notation

A regular expression r over an alphabet Σ describes a set of strings $L(r)$.

1. ϵ is a RE denoting the set with the empty string as only element.
2. if $a \in \Sigma$ then a is a RE denoting the set $\{a\}$
3. if r and s are RE denoting $L(r)$ and $L(s)$ respectively, then
   - (r) is a RE denoting $L(r)$
   - $r|s$ is a RE denoting $L(r) \cup L(s)$
   - rs is a RE denoting $\{xy \mid x \in L(r) \text{ and } y \in L(s)\}$
   - r^* is a RE denoting $L(r)^*$

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   rs is a RE denoting $\{xy | x \in L(r)\ and\ y \in L(s)\}$

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Notation

A regular expression r over an alphabet Σ describes a set of strings $L(r)$.

1. ϵ is a RE denoting the set with the empty string as only element.
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Recall set operations

We used two operations on sets when introducing regular expressions.

Union

$A \cup B = \{x | x \in A \text{ or } x \in B\}$

Example

$\{0, 2, 4, 6, 8, 10\} \cup$
$\{1, 3, 5, 7, 9, 10\} =$
$\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$

Kleene closure

$$A^* = \epsilon \cup A \cup \{xy | x, y \in A\} \cup \{xyz | x, y, z \in A\} \cup \ldots$$

Example

$\{a\}^* =$
$\{"", a, aa, aaa, aaaa, aaaaa, \ldots\}$

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Examples & Abbreviations

The set of strings that begin and end with an *a* and contain at least one *b*:

$$a(a|b)^*b(a|b)^*a$$

Example

aba

$aaba, abaa, abba$

$aabaa, abbaa, aabba, ababa \ldots$

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We omit many parenthesis by following precedence conventions:

- * has highest precedence
- then comes concatenation
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Examples & Abbreviations

The set of integer literals

$$0|(1|2|3|4|5|6|7|8|9)(0|1|2|3|4|5|6|7|8|9)^*$$

Example

0, 1, 2, 3, 4, 5, 6, 7, 8, 9
10, 11, 12, . . . , 20, 21, . . . , 99
100, 101, 102 . . .
. . .

- We use [] for either: [123456789]
- We use – for a range in an ordered part of the alphabet: [1 – 9]

$$0|[1-9][0-9]^*$$

Examples & Abbreviations

The set of integer literals

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Identifiers in a little programming language are words of any length formed using the characters of the latin alphabet.

$$[a-zA-Z][a-zA-Z]^*$$

Example

$a, b, c, \ldots, A, B, C, \ldots$
$aa, ab, ac, aZ, \ldots$
$the, myX, Int, \ldots$
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We use r^+ instead of rr^*

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Non regular languages

Not all sets of strings are regular!

Example

Given the alphabet $\Sigma = \{a, b\}$, the language $\{a^n b^n | n \geq 0\}$ is not regular.
It can be proved mathematicaly, but we will not do it

However, for any $m \geq 0$, the language $\{a^n b^n | 0 \leq n \leq m\}$ is regular.

Example

Given the alphabet $\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, +, *, (,)\}$, the set of wellformed arithmetical expressions is not regular.

We need recursion in order to allow for subexpressions and balanced partenthesis.

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Regular expressions on the web

There is a lot of material on the web, both in the form of lecture notes, slides and books. I will not link from the web page, but I will put some links on the slides that you can check.

A book on compilers

N. Wirth. *Compiler Construction*.
http://www.oberon.ethz.ch/WirthPubl/CBEAll.pdf

Lecture notes for a compiler course

L. Fegaras. *Design and Construction of Compilers* at Texas at Arlington.
http://lambda.uta.edu/cse5317/notes/

A similar course at Luleå

Where you can find slides.
http://www.sm.luth.se/csee/courses/smd/163/

Scanners

A *scanner* is a program that inspects a sequence of characters trying to identify words of a language. They can be used for many different purposes.

Example

In a compiler a scanner (or lexical analyzer) is used to begin with the analysis (understanding) of the source code:

- Read the sequence of characters and produce a sequence of tokens
  - Facilitates the analysis of the phrases of the program!
- Interrupt the compilation process in case of some lexicographic error, including reporting an error message.

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Generators

Scanners are tedious programs to write, with many cases to take care of, very error prone!

Some math that we will discuss in the second lecture has resulted in programs that generate scanners from a regular expression.

We will use , written in Java and generating a Java program.

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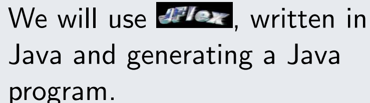

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We will use JFlex, written in Java and generating a Java program.

JFlex source

Regular expressions, directives, java code.

JFlex the source!

Scanner in Java, compile it!

Run the scanner on a file of text!

```
// code outside MyName
%%
%unicode
%int
%class MyName
%function next
%{
// code inside MyName
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%%
"veronica gaspes"
   {System.out.println(yytext());}
.|\n{}
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Directives and conventions

- `%line` allows you to use the variable `yyline` that is automaticaly incremented on every line change.
- `%column` allows you to use the variable `yycolumn` that is automaticaly incremented and reinitialized.
- `%implements InterfaceName` lets the generated java class implement the interface.

When scanning the input sequence of characters, there might be clashes between some of the regular expressions.

- Allways go for the longest sequence that matches an expression.
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