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Development of a Query Language for Full-Text Search in Relational Databases

by

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Index of Abbreviations

APT   Automatically Programmed Tools

DDL   Data Definition Language

DSL   Domain-Specific Language

EBNF Extended Backus-Naur Form

GPL   General-Purpose Language

HTML Hypertext Markup Language

MS   Microsoft

PDF   Portable Document Format

SQL   Structured Query Language

XML   Extensible Markup Language

Index of Symbols

p	precision
r	recall
n	number of relevant retrieved documents
d	total number of retrieved documents
v	total number of relevant documents
F_β	weighted harmonic mean
β	nonnegative weight

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1 Abstract

Abstract

2 Theory

2.1 Full-Text Search

Commercial database management has long focused on structured data and the industry requirements have matched those of structured storage applications quite well. The problem is that only a small part of the data stored is completely structured, while most of it is completely unstructured or only semi-structured, in the form of documents, emails, web pages, etc. (cf. HAMILTON, NAYAK 2001, p. 7) Full-text search describes a search technique in which all words of a document or a full-text database are matched with search criteria, whereby not only exact matches but also word reflections and the like can be searched. A full-text database, as opposed to a regular bibliographic database, contains not only metadata but also the complete textual content of books and similar documents. (cf. TENOPIR, RO 1990, pp. 2-3)

With large amounts of data, matching every word of all entries is time-consuming and non-performant. To improve this process, a full-text search is divided into an indexing and query phase. In the indexing phase, all words found to be irrelevant, e.g. 'and' or 'the', are ignored by matching them against stoplists, words are normalized, e.g. the capitalization of words, and are merged into an index. (cf. COLES, COTTER 2009, p. 11) In the query phase, full-text query predicates are used to execute search queries. These allow not only a search for exact matches but also generational forms. Generational forms can be, for example, words that stem from the same word or alternative search terms using a language-specific thesaurus. A query processor then calculates the most efficient query plan which delivers the required results. The previously created index is searched for documents and text passages that match the search, and the results are returned in a ranked order. (cf. COLES, COTTER 2009, pp. 11-12)

To determine a rank for a search result the quality has to be measured. Two key metrics are used when measuring the quality of search results: precision p and recall r. Precision is defined as the relation of relevant search results to irrelevant search results. If, for example, many results are desired about the Jupiter moon Europa, the search term 'Europa' has low precision, since results for the continent 'Europe', as well as for the mythological figure and the moon are displayed. The search term 'Europa Moon' will again have higher precision. Algebraically, precision can be represented as in Formula 1, where n represents the number of relevant retrieved documents and d represents the total number of retrieved documents.

Formula 1: Precision

$$p = \frac{n}{d} \tag{1}$$

Source: COLES, COTTER 2009, p. 14

The recall is defined as the relation between relevant search results and relevant documents that were not displayed. For example, if five documents in a database deal with the moon Europa and only two are displayed in a search recall is low. Formula 2 shows the mathematical definition, where v represents the total number of relevant documents.

Formula 2: Recall

$$r = \frac{n}{v} \tag{2}$$

Source: COLES, COTTER 2009, p. 14

Although it is nearly impossible to maximize both recall and precision it is still relevant to keep both values as high as possible. Formula 3 offers the possibility to prefer one of the two metrics precision and recall when calculating the quality of a search result. The nonnegative weight β weights both metrics equally for a value of 1.0. A value less than 1.0 prefers recall, while a value above 1.0 prefers precision.

Formula 3: Weigthed harmonic mean

$$F_\beta = \frac{\left(1 + \beta^2\right) \cdot (p \cdot r)}{\beta^2 \cdot p + r} \tag{3}$$

Source: COLES, COTTER 2009, p. 15

This means F_β represents the desired search quality and should be as high as possible, deciding whether to focus on recall or precision or both. (cf. COLES, COTTER 2009, pp. 13-15)

2.1.1 MS SQL Server Search Architecture

Structured Query Language (SQL) Server uses the same access method and infrastructure for full-text search as other Microsoft (MS) products and the Index Service for file

systems. This decision enables standardized semantics for full-text search of data in re-lational databases, web-hosted data, and data stored in the file system and mail systems. On SQL servers, not only simple strings can be indexed, but also data structures, such as Hypertext Markup Language (HTML) and Extensible Markup Language (XML), and even complex documents, such as Portable Document Format (PDF), Word, PowerPoint, Excel and other custom document formats. (cf. HAMILTON, NAYAK 2001, p. 7)

The architecture can be divided into five modules, which interact with each other to per-form a full-text search. (See Figure 1)

The **content reader** scans indexed data stored in SQL Server tables to assemble data and its associated metadata packets. These packets are then injected into the main search en-gine, which triggers the search engine filter daemon to consume the data.

Depending on the content, the **filter daemon** calls different filters, which parse the con-tent and output so-called chunks of the processed text. A chunk is a related section with relevant information about this section like the language-id of the text. These chunks are output separately for any properties, which can be elements like the title, an author or other content-specific elements.

Figure 1: Architecture of MS SQL Server Full-Text Search

Source: HAMILTON, NAYAK 2001, p. 8

Word breakers split the chunks into keywords and additionally provide alternative keywords and the corresponding position in the text. Word breakers can recognize human languages and on SQL Server several word breakers for different languages are installed by default. The generated keywords and metadata are passed on to the MS Search process, which processes the data with an indexer.

The **indexer** generates an inverted keyword list with a batch containing all keywords of one or more items. These indexes are compressed to use memory efficiently, this may lead to high costs for updates of these indexes. Therefore a stack of indexes is maintained. New documents first create their small indexes, which are regularly merged into a larger index, which in turn is merged into the base index. This stack can be deeper than three, but the concept remains and allows a strongly compressed index without driving the update costs too high. If a keyword is searched, all indexes are accessed, so the depth should still be kept reasonable.

A **query processor** manages the insertion and merge operations and collects statistics on distribution and frequency for ranking purposes and query execution. (cf. HAMILTON, NAYAK 2001, pp. 8-9)

2.1.2 MS SQL Server Full-Text Query Features

Full-text indexes can be created on SQL Servers with the Data Definition Language (DDL) statement `CREATE INDEX` and can make use of other SQL Server utilities; these include backup and restore and attachment of databases. There are three options to create and manage indexes on SQL Servers. **Full Crawl** always rebuilds the whole full-text index by scanning the entire table. **Incremental Crawl** logs the timestamp of the last re-index and retains changes by storing them in a column. **Change Tracking** enables a near real-time validity between the full-text index and the table by tracking changes to the indexed data using the SQL Server Query Processor. (cf. HAMILTON, NAYAK 2001, p. 9)

Full-text search is represented in SQL with three possible constructs: (cf. HAMILTON, NAYAK 2001, p. 9)

1. Contains Predicate: A contains predicate is true if one of the specified columns contains terms that satisfy the specified search condition. E.g. `Contains(author , ('Ag* or "Marc Miller"'))` will match entries where the column author contains words like 'Ag', 'Agatha', or 'Marc Miller'.

2. Freetext Predicate: Freetext predicates are true if one of the specified columns contains terms that stem from the terms in the specified search condition. E.g. `Freetext(content, 'fishing')` will match entries where content contains words like 'fishing', 'fish', or 'fisher'.

3. ContainsTable and FreetextTable: ContainsTable and FreetextTable are functions that match entries similar to their corresponding function, but additionally return multiple matches including a ranking for each entry and the entire corpus.

The search conditions of these constructs can be of various types to find the intended results: (cf. HAMILTON, NAYAK 2001, p. 9)

1. Keyword, phrase, prefix: E.g. 'fishing', 'Marc Miller', 'Ag*'

2. Inflections and Thesaurus: E.g. `Contains(*, 'FORMSOF(INFLECTIONAL, fishing)AND FORMSOF(THESAURUS, boat)')` will find all entries containing words that stem from 'fishing' and all words sharing the meaning with 'boat' (Thesaurus support).

3. Weighted terms: Keywords and phrases can be assigned a relative weight to impact the rank of entries. E.g. `ContainsTable(*, 'ISABOUT(generator weight (.7), full-text weight (.3))')` will rank entries higher in the result corpus which mention 'generator' over 'full-text'.

4. Proximity: E.g. `Contains(*, 'corn NEAR salad')` contains the proximity term 'NEAR' to match entries where 'corn' appears close to 'salad'.

5. Composition: E.g. `Contains(*, 'full-text AND NOT database')` uses two search query components that are composed using a term like 'AND', 'OR', or 'AND NOT'.

2.2 Domain-Specific Languages

Commonly known programming languages, such as C or Java, are also called a General-Purpose Language (GPL). GPLs are designed to handle any problem with relatively equal levels of efficiency and expressiveness. However, many applications do not require a multifunctional GPL and can describe a problem more naturally using a Domain-Specific Language (DSL). DSLs are languages that have been developed specifically for a particular application or domain, to be able to develop faster and more effectively. (cf. HUDAK 1997, p. 1) By tailoring notations and constructs to the domain in question, DSLs offer significant gains in expressiveness and usability compared to GPLs for the domain in question, with corresponding productivity gains and lower maintenance costs. (cf. MERNIK et al. 2005, p. 317) DSLs are by no means a product of modern software development but have existed since the beginning of programming. One of the first DSLs ever designed

was Automatically Programmed Tools (APT), which was used for the development of numerically controlled machine tools in 1957. (cf. Ross 1978, pp. 283-284)

DSLs can be found everywhere in the world of IT, for example, this thesis was written with the help of LaTeX to design layout and formatting. Table 1 lists some well-known DSLs and their application/domain to give examples of what is classified as a DSL.

Table 1: Popular DSLs

DSL	Applicaiton
Lex and Yacc	program lexing and parsing
PERL	text/file manipulation/scripting
VDL	hardware description
TeX, LaTeX, troff	document layout
HTML, SGML	document markup
SQL, LDL, QUEL	databases
pic, postscript	2D graphics
Open GL	high-level 3D graphics
Tcl, Tk	GUI scripting
Mathematica, Maple	symbolic computation
AutoLisp/AutoCAD	computer aided design
Csh	OS scripting (Unix)
IDL	component technology (COM/CORBA)
Emacs Lisp	text editing
Prolog	logic
Visual Basic	scripting and more
Excel Macro Language	spreadsheets and many things never intended

Source: Hudak 1997, p. 3

Programs written in a DSL are considered to be more concise, quicker to write, easier to maintain and easier to reason about and most importantly they can be written by non-programmers. In particular, experts in the domain for which the DSL was developed can use DSLs to program applications without having to acquire programming skills. An expert of a domain already knows the semantics of the domain, all that is needed to start development is the corresponding notation that expresses these semantics. (cf. Hudak 1997, pp. 2-4)

2.3 Building a language

For a compiler or an interpreter to be able to interpret a DSL, the language must be accurately and precisely defined. Accurately means that the language must be defined consistently down to the smallest detail. Precisely means in this case that all aspects of the

language must be laid out. If parts of the language are inconsistent or too vague, authors of compilers are forced to interpret these aspects themselves. This inevitably leads to different authors having different approaches to the same problem. If a DSL is to be created that meets the criteria described above, two components are needed. The first component is a set of rules, also called syntax. The second component is a formal definition of the meaning, also called semantics. (cf. FARRELL 1995, p. 2)

2.3.1 Syntax

The first step when defining syntax is defining an alphabet. This alphabet consists of tokens, which do not necessarily have to be letters. Several tokens, formulated according to a set of rules, make up a sentence or string. The alphabet of the English language is, in the context of syntax, not a list of the permissible characters, which is predominantly called the alphabet or 'ABC', but the permissible tokens. E.g. in the sentence 'the donkey screams' the tokens 'the', 'donkey' and 'screams' are part of the alphabet of the English language. The token 'gHArFk' consists of permissible characters but is not part of the valid alphabet. However, the use of permissible tokens alone does not make a sentence correct. The sentence 'on sleep blue' consists of tokens that are part of the English alphabet, but it is still not a valid sentence. The correct application of the rule set is still missing, in this example a missing object. Only the correct use of the alphabet AND the set of rules make a sentence syntactically correct. (cf. FARRELL 1995, p. 2)

If the alphabet and the set of rules are notated in a normal form, they can be called grammar. Relevant to this thesis is the Extended Backus-Naur Form (EBNF), which will be described in section 2.3.2.

2.3.2 Extended Backus-Naur Form

EBNF, as the name suggests, is based on the Backus-Naur Form, which was proposed by a group of thirteen international representatives in 1960, to serve as a basic reference and guide for building compilers. Backus-Naur Form is a notation for describing computational processes and rules as arithmetic expressions, variables, and functions. (cf. BACKUS et al. 1960, p. 300)

The syntax can be described as a set of metalinguistic formulae best described with an example. The grammar describing a number can be written in Backus-Naur Form as:

$\langle number \rangle ::= \langle positive \rangle | \text{-} \langle positive \rangle | 0$
$\langle positive \rangle ::= \langle digit\ not\ zero \rangle \langle optional \rangle$

⟨*optional*⟩ ::= ⟨*digit*⟩⟨*optional*⟩|
⟨*digit*⟩ ::= ⟨*digit not zero*⟩|0
⟨*digit not zero*⟩ ::= 1|2|3|4|5|6|7|8|9

Characters contained in angel brackets '<>' represent a metalinguistic variable. The character '::=' describes a definition of this variable. The character '|' represents the metalinguistic connective 'or'. Other characters in this example have no special meaning but only represent themselves. So the first line of the grammar means that the variable <number> can be defined or replaced as <positive> or -<positive> or as 0. Since the variable <positive> is mentioned in the definition, there must be a definition for this variable in the grammar, otherwise, the grammar would be incomplete. In the third line, we see a metalinguistic connective without content on its right side. This means that the variable <optional> can also be empty and thus without value. Furthermore, in this line, a variable calls itself recursively, which is allowed. (cf. BACKUS et al. 1960, pp. 301-303)
So following this grammar, numbers such as 42 or -3141592 are valid.
In 1977 Wirth proposed a new variant of the Backus-Naur Form to further improve language definition notation. The main goals of this new notation were to (cf. WIRTH 1977, p. 822)

- distinguish clearly between metaterminal and nonterminal symbols
- not exclude metaterminals as possible symbols of the language
- enable iteration without using recursion

This proposal was the basis for the ISO/IEC 14977:1996(E) which now defines the standard for EBNF. The major changes that EBNF brought can be summarized as: (cf. ISO/IEC 14977:1996(E) 1996, p. VI)

- Terminal symbols must be quoted so any symbol can be a terminal symbol of the language
- Added square brackets to indicate optional symbols and avoid the use of a <empty> symbol
- Added curly brackets to indicate repetition
- Every rule must have a final character
- Normal Brackets group items together, similar to their arithmetic use

The number example from above can be rewritten in EBNF as:

⟨*number*⟩ ::= (['-']⟨*digit not zero*⟩{⟨*digit*⟩})|'0';
⟨*digit*⟩ ::= ⟨*digit not zero*⟩|'0';
⟨*digit not zero*⟩ ::= '1'|'2'|'3'|'4'|'5'|'6'|'7'|'8'|'9';

This version of the grammar produces the same set of numbers but is more concise and arguably more readable for humans.

3 Implementation

When using the full-text search, large parts of the SQL statements needed to describe the search are the same, since the search criteria are defined as either WHERE conditions or JOIN criteria. If you want to define a full-text search, you usually use a combination of the given functions. In MSSQL this would be for example CONTAINS or FORMSOF. Therefore I want to develop a query language where you only have to specify this combination of functions and a few parameters to generate the corresponding SQL.

3.1 Language definition

The first step to define a language is to define its purpose. In this case, there should be functions that represent full-text functions. Furthermore, one must be able to pass parameters to these functions and one should be able to combine both parameters and functions with logical operators and, or and not. To announce a function, this query language uses an '@', e.g. '@contains'. From programming languages of the C-family one recognizes the use of parentheses '()' to define parameters. To avoid later confusion with parentheses used for logical grouping, this language uses the colon ':' to enclose parameters. For now, a parameter is defined as a simple word or phrase, which is delimited with quotes '"'. These few rules already allow the definition of a query, such as **@contains**:apple: where 'contains' is the name of a function. This first set of rules can be written in EBNF as:

⟨*search*⟩ ::= '@'⟨*function*⟩':'⟨*parameter*⟩':';
⟨*function*⟩ ::= 'contains';
⟨*parameter*⟩ ::= ⟨*word*⟩|' " '{[' ']⟨*word*⟩}' " ';
⟨*word*⟩ ::= {'a'-'z'|'A'-'Z'};

Note that the function variable only includes 'contains'. In future definitions, it should accept the different functions that are going to be defined.
A feature that is also needed is the logical combination and negation of multiple search terms. For example, it should be possible to search for 'apple' or 'tree' and not 'worm'. For and the language accepts the characters '&' and '+', for or it accepts '|' and for negation it accepts '!' and '-'. To cover all possible logical operations, groups are also needed to allow precedence between the different operators. For this parentheses are used. Using groups it is now possible to build a logic like 'apple' AND NOT('tree' OR 'worm'), where the whole statement inside the parentheses is processed negated, and prioritized instead of being processed from left to right.

3.2 Lexer

The first part of a code generator is the lexer. A lexer gets a file or in this case a string as input and divides this input into a series of tokens. So the input `@contains:apple:` becomes the tokens: '@', 'contains', ':', 'apple' and ':'. These tokens are not interpreted yet but are only being recognized as separate characters. To achieve this in code the crate logos is used, to avoid writing redundant code. To understand the code written in lexer.rs what follows is a short explanation of how this crate is used in the context of this prototype. To define tokens, Logos can be added to the derive statement of an enumeration and a matching rule can be defined using a literal string or a regular expression. For example, in line 73 of code listing 1, a literal string is used to recognize the colon token, and line 33 uses a regular expression to recognize decimals between 0 and 1. It also calls an arbitrary function to_float (see line 17) to define that in this case the data should be put into the datatype f64. Logos also requires an error type (see line 78), which is also used to skip whitespaces. (cf. HIRSZ 2022, n.p.)

Code Listing 1: Token defintions

```rust
1  use logos::{Lexer, Logos};

16 // helper function to format floats
17 fn to_float(lex: &mut Lexer<Token>) -> Option<f64> {
18     Some(lex.slice().parse().ok()?)
19 }

26 // List of all tokens that are accepted by the language
27 #[derive(Debug, Clone, Logos, PartialEq)]
28 pub enum Token {

32     // Regex: any float between 0 and 1
33     #[regex(r"0+(\.[0-9]+)?|1", to_float)]
34     ZeroToOne(f64),

72     // Colon to surround functions parameters
73     #[token(":")]
74     Colon,
75     // End of File
76     EoF,
77     // Error and skip whitespaces
78     #[error]
79     #[regex(r"[\s\t\n\f]+", logos::skip)]
80     Error,
81 }
```

Source: lexer.rs

These tokens are then compiled in a list and passed over to the parser as the work of the lexer is done.

3.3 Parser

In the parser, a large part of the heavy lifting is done, because here the list of tokens is interpreted and checked for their 'admissibility' in the language. The parser of this custom query language stores a copy of the token list still to be parsed and additionally the current token and the next one in the list. The current token is often used to make comparisons between it and the token that would be expected, while the peek token is often used to see

whether the end of the token list has already been reached. When initializing the parser both the current and the peek token are set to `Token::EoF` which represents the edge case end of file.

Code Listing 2: Parser struct

```
49  // Parser saves current and next tokens as attribute
50  struct Parser<'p> {
51      tokens: Iter<'p, Token>,
52      current: Token,
53      peek: Token,
54  }
55
56  impl<'p> Parser<'p> {
57      // Initial parser creation
58      fn new(tokens: Iter<'p, Token>) -> Self {
59          Self {
60              tokens,
61              current: Token::EoF,
62              peek: Token::EoF,
63          }
64      }
```

Source: parser.rs

In the parsing process, two different levels are distinguished: expressions and statements. Statements are the various functions that can be used in the language, such as 'near', which in lines 25 to 28 of code listing 3 is defined with several expressions as 'parameters' and another expression as a 'proximity' variable. Expressions are the several values that can appear in a search query, for example, words, phrases, or numbers (lines 37 and 38). The special cases of operators are also represented by both statements and expressions. These will be discussed in more detail later.

Code Listing 3: Statements and expressions

```rust
#[derive(Debug, Clone, PartialEq)]
pub enum Statement {
    Group {
        expression: Expression,
    },
    Infix {
        statement: Box<Statement>,
        operator: Operator,
        second_statement: Box<Statement>,
    },
    Contains {
        expression: Expression,
    },
    Starts {
        expression: Expression,
    },
    Inflection {
        expression: Expression,
    },
    Thesaurus {
        expression: Expression,
    },
    Near {
        parameter: Vec<Expression>,
        proximity: Expression,
    },
    Weighted {
        parameter: Vec<(Expression, Expression)>,
    },
    EoF,
}

#[derive(Debug, Clone, PartialEq)]
pub enum Expression {
    WordOrPhrase(String),
    Number(u64),
    ZeroToOne(f64),
    Infix(Box<Expression>, Operator, Box<Expression>),
    Prefix(Operator, Box<Expression>),
}
```

Source: ast.rs

4 Summary

Summary

Appendix

Appendix 1: main.rs

```rust
use actix_web::{web, App, HttpResponse, HttpServer, Responder};
use regex::Regex;
use serde::{Deserialize, Serialize};
use std::fs::{read_to_string, File};
use std::io::{Error, ErrorKind, Write};
use std::process::Command;
use tera::{Context, Tera};

mod code_gen;

// Path Variables
const PATH_SQL: &str = "files\\fulltext.sql";
const PATH_RESULTS: &str = "files\\results.txt";

// Main function to start website on localhost:8080
// Run using 'cargo watch -x run'
#[actix_web::main]
async fn main() -> std::io::Result<()> {
    HttpServer::new(|| {
        let tera = Tera::new("templates/**/*").unwrap();
        App::new()
            .data(tera)
            .route("/", web::get().to(search))
            .route("/", web::post().to(result))
    })
    .bind("127.0.0.1:8080")?
    .run()
    .await
}

// Code generator to translate an input to SQL
// Input: search string and path to write result to
// Output: SQL statement written to a file
fn run_code_gen(search: String, path: &str) -> std::io::Result
    <()> {
```

```rust
35      // Transform string to list of tokens
36      let tokens = code_gen::lexer::lex(search.as_str());
37      // Parse tokens to an abstract syntax tree (ast)
38      let ast = code_gen::parser::parse(tokens);
39      match ast {
40          // If parser returns no error, start code generation
41          Ok(ast) => {
42              let generator = code_gen::generator::generate(ast);
43              // If generator returns no error, write SQL
                    statement to file, otherwise throw an error
44              match generator {
45                  Ok(generator) => write!(File::create(path)?, "
                        {}", generator),
46                  Err(gen_err) => Err(Error::new(ErrorKind::
                        InvalidData, format!("{:?}", gen_err))),
47              }
48          }
49          // If parser returns error, throw an error aswell
50          Err(parse_err) => Err(Error::new(
51              ErrorKind::InvalidInput,
52              format!("{:?}", parse_err),
53          )),
54      }
55  }
56
57  // Runs a command to execute an sql statement to a local MSSQL
        Server
58  // Input: paths to the input file and where to write the result
59  // Output: txt file interpretation of the MSSQL Server result
60  fn execute_sql(sql_path: &str, results_path: &str) {
61      Command::new("cmd")
62          .args(&[
63              "/C",
64              "sqlcmd",
65              "-S",
66              "DESKTOP-JKNEH40\\SQLEXPRESS", //Local server name
67              "-i",
68              sql_path,
69              "-o",
70              results_path,
```

```rust
            ])
            .output()
            .expect("failed to execute operation");
}

// Reads the txt file result and extracts the actual results
// Input: path to the txt file
// Output: vec of titles and their search rank
fn read_results(path: &str) -> Option<Vec<(String, u64)>> {
    let contents = read_to_string(path).unwrap();
    let mut contents_vec: Vec<&str> = contents.split("\n").
        collect();
    // In case of error message, break
    if contents_vec.len() < 6 {
        return None;
    }
    // Remove metadata rows
    // First 3-4 rows and last three rows
    while !contents_vec[0].starts_with("---") {
        contents_vec.remove(0);
    }
    contents_vec.remove(0);
    contents_vec.remove(contents_vec.len() - 1);
    contents_vec.remove(contents_vec.len() - 1);
    contents_vec.remove(contents_vec.len() - 1);
    // Go through each row and extract the titles and their
        ranks
    let mut results: Vec<(String, u64)> = Vec::new();
    for row in contents_vec {
        // Remove unnecessary whitespaces
        let row = row.replace("\r", "");
        let re = Regex::new(r"\s+").unwrap();
        let row = re.replace_all(&row, " ").to_string();
        // Extract last 'word' as rank and save the rest as the
            title
        let mut words: Vec<&str> = row.split(" ").collect();
        let rank = words[words.len() - 1].parse::<u64>().unwrap
            ();
        words.remove(words.len() - 1);
        let title = words.join(" ");
```

```rust
            results.push((title, rank));
        }
        Some(results)
}


// Search and Result structs to (de)serialize rust and website
    datatypes
#[derive(Deserialize)]
struct Search {
    search: String,
}
#[derive(Serialize)]
struct Result {
    title: String,
    rank: u64,
    link: String,
}


// Define functional parts of the search page
async fn search(tera: web::Data<Tera>) -> impl Responder {
    let mut data = Context::new();
    data.insert("title", "Search field");
    let rendered = tera.render("search.html", &data).unwrap();
    HttpResponse::Ok().body(rendered)
}


// Define functional parts of the result page
async fn result(tera: web::Data<Tera>, data: web::Form<Search>)
    -> impl Responder {
    let mut page_data = Context::new();
    let mut results: Vec<Result> = Vec::new();
    // Run code generator with the string from the search field
    match run_code_gen(data.search.clone(), PATH_SQL) {
        // If code generator returns no error execute SQL and
            read the results
        Ok(_) => {
            execute_sql(PATH_SQL, PATH_RESULTS);
            let results_vec = read_results(PATH_RESULTS);
```

```rust
                // Fit search results into Result struct to
                    properly display on the page, otherwise diplay
                    error
                match results_vec {
                    Some(results_vec) => {
                        for result in results_vec {
                            results.push(Result {
                                title: result.0.clone(),
                                rank: result.1,
                                // link to the Wikipedia article is
                                    also provided, whitespaces need
                                    to be replaced
                                link: result.0.replace(" ", "_"),
                            })
                        }
                        page_data.insert("title", "Results");
                        page_data.insert("search", &data.search);
                    }
                    None => {
                        page_data.insert("title", "Error");
                        page_data.insert(
                            "search",
                            &format!("{} results cannot be read", &
                                data.search),
                        );
                    }
                }
            // If code generator returns error, display error
                instead of search results
            Err(error) => {
                page_data.insert("title", "Error");
                page_data.insert(
                    "search",
                    &format!("{} threw an error: {}", &data.search,
                        &error.to_string()),
                );
            }
        }
    page_data.insert("results", &results);
```

```
176     let rendered = tera.render("result.html", &page_data).
            unwrap();
177     HttpResponse::Ok().body(rendered)
178 }
```

Appendix 2:   lexer.rs

```
1  use logos::{Lexer, Logos};
2
3  // Main function to start lexing process
4  // Input: string
5  // Output: vec of tokens
6  pub fn lex(input: &str) -> Vec<Token> {
7      Token::lexer(input).collect()
8  }
9
10 // helper function to format strings
11 fn to_string(lex: &mut Lexer<Token>) -> Option<String> {
12     let string = lex.slice().to_string();
13     Some(string)
14 }
15
16 // helper function to format floats
17 fn to_float(lex: &mut Lexer<Token>) -> Option<f64> {
18     Some(lex.slice().parse().ok()?)
19 }
20
21 // helper function to format unsigned integer
22 fn to_u64(lex: &mut Lexer<Token>) -> Option<u64> {
23     Some(lex.slice().parse().ok()?)
24 }
25
26 // List of all tokens that are accepted by the language
27 #[derive(Debug, Clone, Logos, PartialEq)]
28 pub enum Token {
29     // Regex: phrase starting and ending with " and escaped
           character \" or just a word allowing a list of special
           characters
30     #[regex(r##""(?:[^"\\]|\\.)*"|[a-zA-Zß?üÜöÖäÄ;\._<>´'#§$
           %/\\=€]+"##, to_string)]
```

```rust
    WordOrPhrase(String),
    // Regex: any float between 0 and 1
    #[regex(r"0+(\.[0-9]+)?|1", to_float)]
    ZeroToOne(f64),
    // Regex: any postive integer
    #[regex(r"[0-9]+", to_u64)]
    Number(u64),
    // ! and - for NOT
    #[token("!")]
    Bang,
    #[token("-")]
    Minus,
    // & and + for AND
    #[token("&")]
    And,
    #[token("+")]
    Plus,
    // | for OR
    #[token("|")]
    Or,
    // Parentheses for grouping
    #[token("(")]
    LeftParen,
    #[token(")")]
    RightParen,
    // Comma for parameter separation
    #[token(",")]
    Comma,
    // Functions
    #[token("@contains")]
    Contains,
    #[token("@startswith")]
    Starts,
    #[token("@inflection")]
    Inflection,
    #[token("@thesaurus")]
    Thesaurus,
    #[token("@near")]
    Near,
    #[token("@weighted")]
```

```
71      Weighted,
72      // Colon to surround functions parameters
73      #[token(":")]
74      Colon,
75      // End of File
76      EoF,
77      // Error and skip whitespaces
78      #[error]
79      #[regex(r"[\s\t\n\f]+", logos::skip)]
80      Error,
81  }
82
83  // Enable tokens to be casted as strings
84  impl Into<String> for Token {
85      fn into(self) -> String {
86          match self {
87              Token::WordOrPhrase(s) => s,
88              _ => unreachable!(),
89          }
90      }
91  }
```

Appendix 3:   parser.rs

```
1  use std::slice::Iter;
2  use thiserror::Error;
3
4  use crate::code_gen::ast::*;
5  use crate::code_gen::lexer::Token;
6
7  // Main function to start parsing process
8  // Input: vec of tokens
9  // Ouput: abstract syntax tree (vec of statements)
10 pub fn parse(tokens: Vec<Token>) -> Result<Vec<Statement>,
       ParseError> {
11     let mut parser = Parser::new(tokens.iter());
12     // read twice to overwrite intial EoF tokens
13     parser.read();
14     parser.read();
```

```
15      let mut ast: Vec<Statement> = Vec::new();
16      while let Some(statement) = parser.next()? {
17          ast.push(statement);
18      }
19      Ok(ast)
20 }
21
22 // Precedence to enable priorities between expressions
23 // Example: this OR that AND some (AND should have a higher
       priority)
24 #[derive(Debug, Clone, PartialEq, PartialOrd)]
25 enum Precedence {
26      Lowest,
27      Statement,
28      Or,
29      And,
30      Not,
31      Prefix,
32      Group,
33 }
34
35 // Match tokens to precedences
36 impl Precedence {
37      fn token(token: Token) -> Self {
38          match token {
39              Token::Bang | Token::Minus => Self::Not,
40              Token::Plus | Token::And | Token::WordOrPhrase(..)
                  => Self::And,
41              Token::Or => Self::Or,
42              Token::LeftParen => Self::Group,
43              Token::Contains | Token::Starts | Token::Inflection
                  => Self::Statement,
44              _ => Self::Lowest,
45          }
46      }
47 }
48
49 // Parser saves current and next tokens as attribute
50 struct Parser<'p> {
51      tokens: Iter<'p, Token>,
```

```rust
52      current: Token,
53      peek: Token,
54  }
55
56  impl<'p> Parser<'p> {
57      // Initial parser creation
58      fn new(tokens: Iter<'p, Token>) -> Self {
59          Self {
60              tokens,
61              current: Token::EoF,
62              peek: Token::EoF,
63          }
64      }
65
66      // Parse next statement if possible
67      // Output: statement or error
68      fn next(&mut self) -> Result<Option<Statement>, ParseError>
            {
69          if self.current == Token::EoF {
70              return Ok(None);
71          }
72          Ok(Some(self.parse_statement(Precedence::Lowest)?))
73      }
74
75      // Set current and peek one step further in the vec of
            tokens
76      fn read(&mut self) {
77          self.current = self.peek.clone();
78          self.peek = if let Some(token) = self.tokens.next() {
79              token.clone()
80          } else {
81              Token::EoF
82          };
83      }
84
85      // See what the current token is
86      // Output: boolean
87      fn current_is(&self, token: Token) -> bool {
88          std::mem::discriminant(&self.current) == std::mem::
                discriminant(&token)
```

```rust
89        }

91      // Current token should match the one given
92      // Input: token
93      // Output: token or error
94      fn expect_token(&mut self, token: Token) -> Result<Token,
            ParseError> {
95          if self.current_is(token) {
96              Ok(self.current.clone())
97          } else {
98              Err(ParseError::UnexpectedToken(self.current.clone
                    ()))
99          }
100     }

102     // Current token should match the one given and read to
            next token
103     // Input: token
104     // Output: token or error
105     fn expect_token_and_read(&mut self, token: Token) -> Result
            <Token, ParseError> {
106         let result = self.expect_token(token)?;
107         self.read();
108         Ok(result)
109     }

111     // Parse statement, can only be a function or combination
            of functions
112     // Input: precedence
113     // Output: statement or error
114     fn parse_statement(&mut self, precedence: Precedence) ->
            Result<Statement, ParseError> {
115         let mut statement = match self.current.clone() {
116             Token::Contains => Statement::Contains {
117                 expression: self.parse_contains()?,
118             },
119             Token::Starts => Statement::Starts {
120                 expression: self.parse_starts()?,
121             },
122             Token::Inflection => Statement::Inflection {
```

```
123                    expression: self.parse_inflection()?,
124                },
125            Token::Thesaurus => Statement::Thesaurus {
126                    expression: self.parse_thesaurus()?,
127                },
128            Token::Near => {
129                    let (parameter, proximity) = self.parse_near()
                        ?;
130                    Statement::Near {
131                        parameter,
132                        proximity,
133                    }
134                }
135            Token::Weighted => Statement::Weighted {
136                    parameter: self.parse_weighted()?,
137                },
138                _ => return Err(ParseError::UnexpectedToken(self.
                    current.clone())),
139        };
140        // After a function could be an infix operator
141        while !self.current_is(Token::EoF) && precedence <
                Precedence::token(self.current.clone()) {
142            if let Some(in_statement) = self.
                    parse_infix_statement(statement.clone())? {
143                statement = in_statement
144            } else {
145                break;
146            }
147        }
148        Ok(statement)
149    }
150
151    // Parse expression, could be a search term, number,
            operator or combination of epxressions
152    fn parse_expression(&mut self, precedence: Precedence) ->
            Result<Expression, ParseError> {
153        let mut expr = match self.current.clone() {
154            Token::WordOrPhrase(s) => {
155                self.expect_token_and_read(Token::WordOrPhrase(
                    "".to_string()))?;
```

```
156              Expression::WordOrPhrase(s.to_string())
157          }
158      Token::Number(u) => {
159          self.expect_token_and_read(Token::Number(0))?;
160          Expression::Number(u)
161      }
162      Token::ZeroToOne(f) => {
163          self.expect_token_and_read(Token::ZeroToOne
                  (0.0))?;
164          Expression::ZeroToOne(f)
165      }
166      t @ Token::Minus | t @ Token::Bang => {
167          self.expect_token_and_read(t.clone())?;
168          Expression::Prefix(
169              Operator::token(t),
170              Box::new(self.parse_expression(Precedence::
                      Prefix)?),
171          )
172      }
173      // Start a group which gets higher precedence
174      Token::LeftParen => {
175          let group_expression = match self.parse_group()
                  ? {
176              Statement::Group { expression } =>
                      expression,
177              _ => return Err(ParseError::Unreachable),
178          };
179          group_expression
180      }
181      _ => return Err(ParseError::UnexpectedToken(self.
              current.clone())),
182  };
183  // Afer an expression could be an infix operator or
        directly a new expression (here called postfix
        operator)
184  while !self.current_is(Token::EoF) && precedence <
        Precedence::token(self.current.clone()) {
185      if let Some(expression) = self.
            parse_postfix_expression(expr.clone())? {
186          expr = expression;
```

```
187            } else if let Some(expression) = self.
                   parse_infix_expression(expr.clone())? {
188                expr = expression
189            } else {
190                break;
191            }
192        }
193        Ok(expr)
194    }
195
196    // Postfix operator is called when two expressions are read
           , automatically inserting an AND inbetween
197    // Second Expression could have an NOT operator before the
           actual expression
198    fn parse_postfix_expression(
199        &mut self,
200        expr: Expression,
201    ) -> Result<Option<Expression>, ParseError> {
202        Ok(match self.current {
203            Token::Minus | Token::Bang | Token::WordOrPhrase
                   (..) => {
204                let sec_expr = self.parse_expression(Precedence
                       ::And)?;
205                Some(Expression::Infix(
206                    Box::new(expr),
207                    Operator::And,
208                    Box::new(sec_expr),
209                ))
210            }
211            _ => None,
212        })
213    }
214
215    // Infix operators AND and OR expect an expression on
           either side
216    fn parse_infix_expression(
217        &mut self,
218        expr: Expression,
219    ) -> Result<Option<Expression>, ParseError> {
220        Ok(match self.current {
```

```rust
            Token::Plus | Token::And | Token::Or => {
                let token = self.current.clone();
                self.read();
                let sec_expr = self.parse_expression(Precedence
                    ::token(token.clone()))?;
                Some(Expression::Infix(
                    Box::new(expr),
                    Operator::token(token),
                    Box::new(sec_expr),
                ))
            }
            _ => None,
        })
    }

    // Infix operators AND and OR expect a statement on either
        side
    fn parse_infix_statement(
        &mut self,
        statement: Statement,
    ) -> Result<Option<Statement>, ParseError> {
        Ok(match self.current {
            Token::Plus | Token::And | Token::Or => {
                let token = self.current.clone();
                self.read();
                let second_statement = self.parse_statement(
                    Precedence::token(token.clone()))?;
                Some(Statement::Infix {
                    statement: Box::new(statement),
                    operator: Operator::token(token),
                    second_statement: Box::new(second_statement
                        ),
                })
            }
            _ => None,
        })
    }

    // Functions all have a similar strucure needing colons to
        surround their parameters
```

```
256
257     // Contains function only expects one word or phrase or
            combination of expressions
258     fn parse_contains(&mut self) -> Result<Expression,
            ParseError> {
259         self.expect_token_and_read(Token::Contains)?;
260         self.expect_token_and_read(Token::Colon)?;
261         let expression: Expression = self.parse_expression(
                Precedence::Statement)?;
262         self.expect_token_and_read(Token::Colon)?;
263         Ok(expression)
264     }
265
266     // Startswith function only expects one one word or phrase
            or combination of expressions
267     fn parse_starts(&mut self) -> Result<Expression, ParseError
            > {
268         self.expect_token_and_read(Token::Starts)?;
269         self.expect_token_and_read(Token::Colon)?;
270         let expression: Expression = self.parse_expression(
                Precedence::Statement)?;
271         self.expect_token_and_read(Token::Colon)?;
272         Ok(expression)
273     }
274
275     // Inflection function only expects one one word or phrase
            or combination of expressions
276     fn parse_inflection(&mut self) -> Result<Expression,
            ParseError> {
277         self.expect_token_and_read(Token::Inflection)?;
278         self.expect_token_and_read(Token::Colon)?;
279         let expression: Expression = self.parse_expression(
                Precedence::Statement)?;
280         self.expect_token_and_read(Token::Colon)?;
281         Ok(expression)
282     }
283
284     // Thesaurus function only expects one one word or phrase
            or combination of expressions
```

```
285    fn parse_thesaurus(&mut self) -> Result<Expression,
          ParseError> {
286        self.expect_token_and_read(Token::Thesaurus)?;
287        self.expect_token_and_read(Token::Colon)?;
288        let expression: Expression = self.parse_expression(
              Precedence::Statement)?;
289        self.expect_token_and_read(Token::Colon)?;
290        Ok(expression)
291    }
292
293    // Near function expects multiple comma-seperated words or
          phrases with an optional number as the last parameter
294    fn parse_near(&mut self) -> Result<(Vec<Expression>,
          Expression), ParseError> {
295        self.expect_token_and_read(Token::Near)?;
296        self.expect_token_and_read(Token::Colon)?;
297        let mut parameter: Vec<Expression> = Vec::new();
298        // Proximity has a default value of 5 if no number is
              given
299        let mut proximity = Expression::Number(5);
300        while !self.current_is(Token::Colon) {
301            if self.current_is(Token::Comma) {
302                self.expect_token_and_read(Token::Comma)?;
303            }
304            match self.parse_expression(Precedence::Lowest)? {
305                Expression::WordOrPhrase(s) => parameter.push(
                      Expression::WordOrPhrase(s)),
306                Expression::Number(u) => {
307                    if self.current_is(Token::Colon) {
308                        proximity = Expression::Number(u)
309                    } else {
310                        return Err(ParseError::UnexpectedToken(
                              self.current.clone()));
311                    }
312                }
313                _ => return Err(ParseError::UnexpectedToken(
                      self.current.clone())),
314            }
315        }
316        self.expect_token_and_read(Token::Colon)?;
```

```rust
        Ok((parameter, proximity))
    }

    // Weighted function expects pairs of words or phrases and
        a weight between 0 and 1
    // All weights must add up to exactly 1
    fn parse_weighted(&mut self) -> Result<Vec<(Expression,
        Expression)>, ParseError> {
        self.expect_token_and_read(Token::Weighted)?;
        self.expect_token_and_read(Token::Colon)?;
        let mut parameter: Vec<(Expression, Expression)> = Vec
            ::new();
        let mut sum_weights: f64 = 0.0;
        while !self.current_is(Token::Colon) {
            if self.current_is(Token::Comma) {
                self.expect_token_and_read(Token::Comma)?;
            }
            let expression = match self.parse_expression(
                Precedence::Lowest)? {
                Expression::WordOrPhrase(s) => Expression::
                    WordOrPhrase(s),
                _ => return Err(ParseError::UnexpectedToken(
                    self.current.clone())),
            };
            self.expect_token_and_read(Token::Comma)?;
            let weight = match self.parse_expression(Precedence
                ::Lowest)? {
                Expression::ZeroToOne(f) => {
                    sum_weights += f;
                    Expression::ZeroToOne(f)
                }
                _ => return Err(ParseError::UnexpectedToken(
                    self.current.clone())),
            };
            parameter.push((expression, weight));
        }
        if sum_weights != 1.0 {
            return Err(ParseError::WeightError(sum_weights));
        }
        self.expect_token_and_read(Token::Colon)?;
```

```
349          Ok(parameter)
350      }
351
352      // Groups must encapsulate an expression with parentheses
                and have higher precedence then other operators
353      fn parse_group(&mut self) -> Result<Statement, ParseError>
            {
354          self.expect_token_and_read(Token::LeftParen)?;
355          let expression = self.parse_expression(Precedence::
                Statement)?;
356          self.expect_token_and_read(Token::RightParen)?;
357          Ok(Statement::Group { expression })
358      }
359  }
360
361  // Types of errors covered by the parser
362  #[derive(Debug, Error)]
363  pub enum ParseError {
364      #[error("Unexpected token {0:?}.")]
365      UnexpectedToken(Token),
366      #[error("Entered unreachable code.")]
367      Unreachable,
368      #[error("Weights do not add up to 1.0. Sum of all weights:
                {0}")]
369      WeightError(f64),
370  }
```

Appendix 4:   ast.rs

```
1  use crate::code_gen::lexer::Token;
2
3  #[derive(Debug, Clone, PartialEq)]
4  pub enum Statement {
5      Group {
6          expression: Expression,
7      },
8      Infix {
9          statement: Box<Statement>,
10         operator: Operator,
```

```rust
        second_statement: Box<Statement>,
    },
    Contains {
        expression: Expression,
    },
    Starts {
        expression: Expression,
    },
    Inflection {
        expression: Expression,
    },
    Thesaurus {
        expression: Expression,
    },
    Near {
        parameter: Vec<Expression>,
        proximity: Expression,
    },
    Weighted {
        parameter: Vec<(Expression, Expression)>,
    },
    EoF,
}

#[derive(Debug, Clone, PartialEq)]
pub enum Expression {
    WordOrPhrase(String),
    Number(u64),
    ZeroToOne(f64),
    Infix(Box<Expression>, Operator, Box<Expression>),
    Prefix(Operator, Box<Expression>),
}

#[derive(Debug, Clone, PartialEq)]
pub enum Operator {
    And,
    Or,
    Not,
}
```

```rust
impl Operator {
    pub fn token(token: Token) -> Self {
        match token {
            Token::And | Token::Plus => Self::And,
            Token::Or => Self::Or,
            Token::Minus | Token::Bang => Self::Not,
            _ => unreachable!("{:?}", token),
        }
    }
}
```

Appendix 5:   generator.rs

```rust
use std::slice::Iter;
use thiserror::Error;

use crate::code_gen::ast::{Expression, Operator, Statement};

// Database constants
const DB_NAME: &str = "Wikipedia";
const TBL_NAME: &str = "[dbo].[Real_Article]";
const RETURN_ATTRIBUTE: &str = "Title";
const TOP_ROWS: u64 = 5;

// Main function to start the generation process
// Input: vec of statements (ast)
// Output: string (sql statement)
pub fn generate(ast: Vec<Statement>) -> Result<String,
    GenerateError> {
    let mut generator = Generator::new(ast.iter());
    // write twice to overwrite initial EoF tokens
    generator.write();
    generator.write();
    let mut sql_parts: Vec<String> = Vec::new();
    sql_parts.push(format!(
        "USE {}; SELECT TOP {} * FROM(SELECT FT_TBL.{}, KEY_TBL
            .RANK FROM {} AS FT_TBL INNER JOIN CONTAINSTABLE({},
            *, '",
        DB_NAME, TOP_ROWS, RETURN_ATTRIBUTE, TBL_NAME, TBL_NAME
```

```rust
        ));
        // generate all functions as JOIN constraints
        while let Some(sql_part) = generator.next()? {
            sql_parts.push(sql_part);
        }
        sql_parts.push("') AS KEY_TBL ON FT_TBL.[ID] = KEY_TBL.[KEY
            ] WHERE KEY_TBL.RANK > 5) AS FS_RESULT ORDER BY
            FS_RESULT.RANK DESC;".to_owned());
        Ok(sql_parts.join(" "))
}

// Generator struct with current and next token as attributes
struct Generator<'p> {
    statements: Iter<'p, Statement>,
    current: Statement,
    peek: Statement,
}

impl<'p> Generator<'p> {
    // Initial generator creation
    fn new(statements: Iter<'p, Statement>) -> Self {
        Self {
            statements,
            current: Statement::EoF,
            peek: Statement::EoF,
        }
    }

    // Generate next statement if possible
    fn next(&mut self) -> Result<Option<String>, GenerateError>
        {
        if self.current == Statement::EoF {
            return Ok(None);
        }
        Ok(Some(self.generate_statement(self.current.clone())?)
            )
    }

    // Set current and peek one step further in the ast
    fn write(&mut self) {
```

```
60          self.current = self.peek.clone();
61          self.peek = if let Some(statement) = self.statements.
               next() {
62              statement.clone()
63          } else {
64              Statement::EoF
65          };
66      }
67
68      // Generate statement, always a function or combination of
           functions
69      // Input: statement to generate
70      // Output: string
71      fn generate_statement(&mut self, statement: Statement) ->
           Result<String, GenerateError> {
72          let sql: String = match statement {
73              Statement::Infix {
74                  statement,
75                  operator,
76                  second_statement,
77              } => {
78                  let sql_parts = [
79                      self.generate_statement(*statement)?,
80                      self.generate_operator(operator)?,
81                      self.generate_statement(*second_statement)
                           ?,
82                  ];
83                  sql_parts.join(" ")
84              }
85              // Contains generates it's search condition without
                   mutation
86              Statement::Contains { expression } => {
87                  format!("{}", self.generate_expression(
                       expression)?)
88              }
89              // Startswith adds a * to end of a word or before
                   the last " in a phrase
90              Statement::Starts { expression } => {
91                  let mut word_or_phrase = self.
                       generate_expression(expression)?;
```

```
92              if word_or_phrase.starts_with('"') &&
                    word_or_phrase.ends_with('"') {
93                  word_or_phrase.insert(word_or_phrase.len()
                        - 1, '*');
94              } else {
95                  word_or_phrase.push('*');
96              }
97              format!("{}", word_or_phrase)
98          }
99          // Inflection calls the inflection function from
                MSSQL
100         Statement::Inflection { expression } => {
101             let mut word_or_phrase = self.
                    generate_expression(expression)?;
102             if word_or_phrase.starts_with('"') &&
                    word_or_phrase.ends_with('"') {
103                 word_or_phrase.remove(0);
104                 word_or_phrase.remove(word_or_phrase.len()
                        - 1);
105             }
106             format!("FORMSOF(INFLECTIONAL,\"{}\")",
                    word_or_phrase)
107         }
108         // Thesaurus calls the thesaurus function from
                MSSQL
109         Statement::Thesaurus { expression } => {
110             let mut word_or_phrase = self.
                    generate_expression(expression)?;
111             if word_or_phrase.starts_with('"') &&
                    word_or_phrase.ends_with('"') {
112                 word_or_phrase.remove(0);
113                 word_or_phrase.remove(word_or_phrase.len()
                        - 1);
114             }
115             format!("FORMSOF(THESAURUS,\"{}\")",
                    word_or_phrase)
116         }
117         // Near generates a parameter list of all search
                criteria and proximity in the end
118         Statement::Near {
```

```rust
                    parameter,
                    proximity,
                } => {
                    let mut sql_parts: Vec<String> = Vec::new();
                    sql_parts.push(format!("NEAR(("));
                    for expression in parameter {
                        let string = self.generate_expression(
                            expression)?;
                        sql_parts.push(format!("{}", string));
                        sql_parts.push(String::from(", "));
                    }
                    sql_parts.remove(sql_parts.len() - 1);
                    sql_parts.push(format!("), {})", self.
                        generate_expression(proximity)?));
                    sql_parts.join("")
                }
                // Weighted generates tuples of search criteria and
                    their respective weight
                Statement::Weighted { parameter } => {
                    let mut sql_parts: Vec<String> = Vec::new();
                    sql_parts.push(format!("ISABOUT("));
                    for (word_or_phrase_expr, weight_expr) in
                        parameter {
                        let word_or_phrase = self.
                            generate_expression(word_or_phrase_expr)
                            ?;
                        let weight = self.generate_expression(
                            weight_expr)?;
                        sql_parts.push(format!("{} WEIGHT({})",
                            word_or_phrase, weight));
                        sql_parts.push(String::from(", "));
                    }
                    sql_parts.remove(sql_parts.len() - 1);
                    sql_parts.push(String::from(")"));
                    sql_parts.join("")
                }
                _ => return Err(GenerateError::UnexpectedStatement(
                    self.current.clone())),
            };
        self.write();
```

```rust
150        Ok(sql)
151    }
152
153    // Generate expression, any search criteria or number or
           combination of those
154    // Input: expression to generate
155    // Output: string
156    fn generate_expression(&mut self, expression: Expression)
          -> Result<String, GenerateError> {
157     let sql: String = match expression {
158         Expression::WordOrPhrase(s) => s,
159         Expression::Number(u) => u.to_string(),
160         Expression::ZeroToOne(f) => f.to_string(),
161         // Infix operator enclose their expressions with
               parentheses to ensure precedence
162         Expression::Infix(expr1, operator, expr2) => {
163             let mut sql_parts = [
164                 String::from("("),
165                 self.generate_expression(*expr1)?,
166                 String::from(")"),
167                 self.generate_operator(operator)?,
168                 String::from("("),
169                 self.generate_expression(*expr2.clone())?,
170                 String::from(")"),
171             ];
172             // If the second expression is a not operator
                   it must write NOT before the parentheses
173             match *expr2 {
174                 Expression::Prefix(Operator::Not, ..) =>
                        sql_parts[4] = String::from("NOT ("),
175                 _ => (),
176             }
177             sql_parts.join(" ")
178         }
179         Expression::Prefix(operator, expr) => {
180             let sql_parts = [
181                 self.generate_operator(operator)?,
182                 self.generate_expression(*expr)?,
183             ];
184             sql_parts.join(" ")
```

```rust
185              }
186          };
187          Ok(sql)
188      }
189
190      // Generate operator
191      // Input: operator to generate
192      // Output: string
193      fn generate_operator(&mut self, operator: Operator) ->
             Result<String, GenerateError> {
194          let op = match operator {
195              Operator::And => "AND",
196              Operator::Or => "OR",
197              // has to be set infront of parentheses, see
                 generate_expression for infix
198              Operator::Not => "",
199          };
200          Ok(op.to_owned())
201      }
202  }
203
204  // Types of error covered by the generator
205  #[derive(Debug, Error)]
206  pub enum GenerateError {
207      #[error("Unexpected statement {0:?}.")]
208      UnexpectedStatement(Statement),
209  }
```

Appendix 6:   mod.rs

```rust
1  mod ast;
2  pub mod generator;
3  pub mod lexer;
4  pub mod parser;
```

Appendix 7:   base.html

```html
1  <!DOCTYPE html>
2  <html lang="en">
```

```
3    <head>
4        <meta charset="utf-8">
5        <title>{{title}}</title>
6    </head>
7    <body>
8        {% block content %}
9        {% endblock %}
10    </body>
11 </html>
```

Appendix 8: search.html

```
1 {% extends "base.html" %}
2
3 {% block content %}
4 <form action="" method="POST">
5     <div>
6         <label for="search">Search:</label>
7         <input type="text" name="search">
8     </div>
9     <input type="submit" value="Submit">
10 </form>
11 {% endblock %}
```

Appendix 9: result.html

```
1 {% extends "base.html" %}
2
3 {% block content %}
4 <div>
5     <p>{{ search }}</p>
6 </div>
7 {% for result in results %}
8 <div>
9     <a href="https://en.wikipedia.org/wiki/{{ result.link }}">
        {{ result.title }}</a>
10    <small>{{ result.rank }}</small>
11 </div>
12 {% endfor %}
```

```
13 {% endblock %}
```

Appendix 10:   convert_wiki_to_csv.py

```python
1  from lxml import etree
2  from glob import glob
3  import bz2
4  import codecs
5  import csv
6  import time
7  import os
8
9  PATH_WIKI_XML = "/Users/light/Documents/Wikipedia/"
10 FILENAME_ARTICLES = "articles.csv"
11
12
13 def hms_string(sec_elapsed):
14     h = int(sec_elapsed / (60 * 60))
15     m = int((sec_elapsed % (60 * 60)) / 60)
16     s = sec_elapsed % 60
17     return "{}:{:>02}:{:>05.2f}".format(h, m, s)
18
19
20 def get_parser(filename):
21     ns_token = "{http://www.mediawiki.org/xml/export-0.10/}ns"
22     title_token = "{http://www.mediawiki.org/xml/export-0.10/}
           title"
23     revision_token = "{http://www.mediawiki.org/xml/export
           -0.10/}revision"
24     text_token = "{http://www.mediawiki.org/xml/export-0.10/}
           text"
25
26     with bz2.BZ2File(filename, "rb") as bz2_file:
27         for event, element in etree.iterparse(bz2_file, events
               =("end",)):
28             if element.tag.endswith("page"):
29                 namespace_tag = element.find(ns_token)
30
31                 if namespace_tag.text == "0":
```

```python
32                        title_tag = element.find(title_token)
33                        text_tag = element.find(revision_token).
                              find(text_token)
34                        yield title_tag.text, text_tag.text

35
36                    element.clear()

37

38
39  def pluck_wikipedia_titles_text(
40      out_file, pattern="enwiki-*-pages-articles-multistream*.xml
            -*.bz2"
41  ):
42      totalCount = 0
43      longestTitle = 0
44      longestText = 0
45      with codecs.open(out_file, "a+b", "utf8") as out_file:
46          writer = csv.writer(out_file)
47          for bz2_filename in sorted(
48              glob(pattern),
49              key=lambda a: int(a.split("articles-multistream")
                  [1].split(".")[0]),
50          ):
51              print(bz2_filename)
52              parser = get_parser(bz2_filename)
53              for title, text in parser:
54                  if not (text.startswith("#REDIRECT") or text.
                        startswith("#redirect")):
55                      totalCount += 1
56                      writer.writerow([title, text])
57                      longestTitle = (
58                          len(title) if len(title) > longestTitle
                                  else longestTitle
59                      )
60                      longestText = len(text) if len(text) >
                          longestText else longestText
61                      if totalCount > 1 and (totalCount % 100000)
                              == 0:
62                          print("{:,}".format(totalCount))
63                      if totalCount >= 1000:
64                          break
```

```
65    print(
66        f"Total Count: {totalCount}\nLongest Title: {
              longestTitle}\nLongest Text: {longestText}"
67    )
68
69
70 pathArticles = os.path.join(PATH_WIKI_XML, FILENAME_ARTICLES)
71
72 start_time = time.time()
73
74 pluck_wikipedia_titles_text(pathArticles)
75
76 time_took = time.time() - start_time
77 print(f"Total runtime: {hms_string(time_took)}")
```

Appendix 11:   create_article.sql

```
1  USE Wikipedia;
2  DROP TABLE Real_Article;
3  CREATE TABLE [dbo].[Real_Article](
4      [Title] [varchar](255) NULL,
5      [Text] [varchar](max) NULL
6  );
7  INSERT INTO Real_Article(Title, Text)
8  VALUES ('Example', 'Fulltext');
9  SELECT *
10 FROM Real_Article;
11 DELETE FROM Real_Article
12 WHERE Title = 'Example';
```

Appendix 12:   bulk_insert.sql

```
1  USE Wikipedia;
2  BULK
3  INSERT Real_Article
4  FROM 'C:\Users\light\Documents\Wikipedia\enwiki-20220901-pages-
       articles-multistream-no-redirect.csv' WITH (
5          FIRSTROW = 1,
6          FIELDQUOTE = '\'
```

```
 7        , FIELDTERMINATOR = ',
 8              '
 9        , ROWTERMINATOR = ' \ n ',
10            TABLOCK);
```

Appendix 13: alter_id.sql

```
1 USE Wikipedia;
2 ALTER TABLE [dbo].[Real_Article]
3 ADD ID INT IDENTITY(1, 1) PRIMARY KEY
```

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