1. Grammatiken – Grundbegriffe

a)

| VT(G) = { "DATA", ",", "/", "*", id, num, str, "+", "-", "(", ")", "=", expr } | = 13

| VN(G) = { DataDecl, DataDeclRest, DataNameList, DataValueList, DataName, DataNameList, DataDoList, DataValue, DataDoListRest } | = 9

b)

shortest:

- DATA id / num /
- DATA id / str /
- DATA id / id /

c)

Direkt rekursiv:

- DataDeclRest: links
- DataNameList: rechts
- DataValueList: links
- DataDoList: zentral
- DataDoListRest: links

Indirekt rekursiv:

- DataDoList => DataDoListRest: zentral
- DataDoListRest => DataDoList: zentral

d)

DataStat -> "Data" DataDecl DataDeclRest .

DataDeclRest -> ε | DataDeclRest DataDecl | DataDeclRest "," DataDecl .

DataDecl -> DataNameList "/" DataValueList "/" .

DataNameList -> DataName | DataName "," DataNameList .

DataName -> id | DataDoList .

DataValueList -> DataValue | DataValueList "," DataValue .

DataValue -> OptSign num | str | id

- | num "*" id
- | num "*" OptSign num

- | num "*" str
- | id "*" id
- | id "*" OptSign num
- | id "*" str
- .

OptSign -> ε | "+" | "+" .

DataDoList -> "(" DataDoList DataDoListRest ")"

- | "(" id "(" IdList ")" DataDoListRest ")"
- . IdList -> id | IdList "," id .

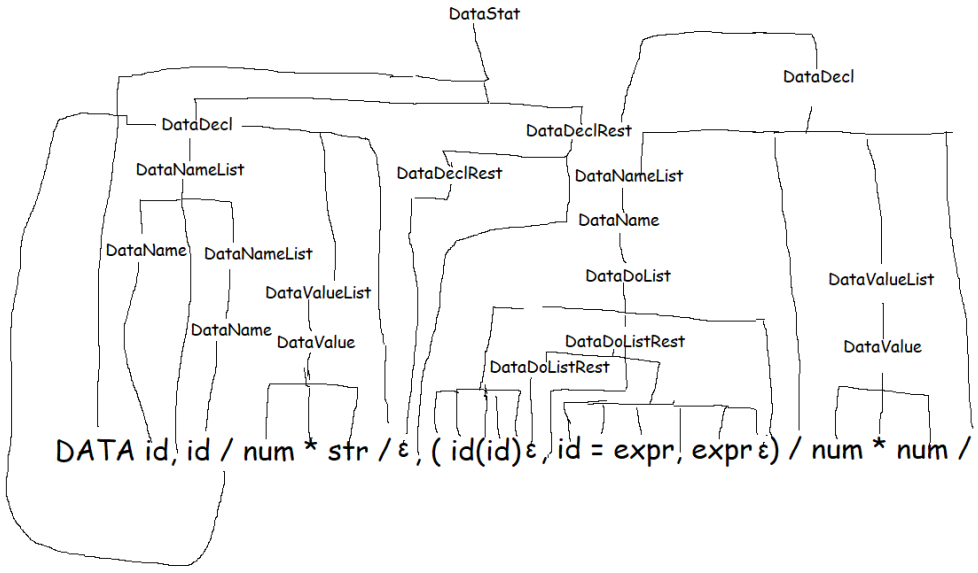
DataDoListRest -> ε

- | DataDoListRest "," DataDoList
- | DataDoListRest "," id "(" ExprList ")"
- | DataDoListRest "," id "=" expr "," expr
- | DataDoListRest "," id "=" expr "," expr, expr
- .

ExprList -> expr | ExprList "," expr .

EBNF ist lesbarer, da man mit weniger Alternativen durch Verwendung von "[" und "]" benötigt kann und keine Rekursion mit NTs für das mehrfache Vorkommen von [Terminal-]Symbolen verwenden muss.

e)



Die Grammatik ist zwar mehrdeuting aber ich konnte keinen zweiten Syntax-Baum für diesen Satz finden.

2. Konstruktion einer Grammatik

Regelsystem

S -> OptSign LeadingDigit MiddleDigits UnevenNaturalDigit | OptSign UnevenNaturalDigit . // man könnte auch OptSign weglassen und dafür 4 weitere Optionen im NT "S" hinzufügen

OptSign -> ε | + | - .

MiddleDigits -> ε | 0 MiddleDigits | LeadingDigit MiddleDigits .

UnevenNaturalDigit -> 1 | 3 | 5 | 7 | 9 .

LeadingDigit -> UnevenNaturalDigit | 2 | 4 | 6 | 8 .

EBNF

S = [+ | -] [(1|2|3|4|5|6|7|8|9) { (0|1|2|3|4|5|6|7|8|9) }] (1|3|5|7|9) .

3. Oo-Implementierung von Grammatiken

No changes made to existing code. I used C++20.

a)

main.cpp

```
Grammar* newEpsilonFreeGrammarOf(Grammar* g) {
    // step 1
    VNt deletable = g->deletableNTs();

    // step 2

    // use symbolpool to get instances by name
    // (symbols from initial creation are still stored in SymbolPoolData)
    SymbolPool sp{};
    GrammarBuilder gb{g->root}; // reuse old root for now

    // for each rule
    // c++20 structureed binding
    for (const auto& [nt, sequenceSet] : g->rules)
    {
        // iterate over old sequence set
        for (const Sequence* seq : sequenceSet)
        {
            // begone epsilon
            if (seq->isEpsilon()) continue;

            // add copy
            gb.addRule(nt, new Sequence(*seq));

            // evaluate which indices of current sequence are deletable NTs
            std::vector<int> indicesForCombination{};
            for (int i = 0; i < seq->size(); i++) {
                Symbol* currSy = seq->at(i);
                if (currSy->isNT() &&
                    deletable.contains(dynamic_cast<NTSymbol*>(currSy))) {
                    indicesForCombination.push_back(i);
                }
            }

            // add the current sequence with every possible combination
            // of not including NTs in indicesForCombination
             // 2^n(-1) iterations
            for (int i = 0; i < 1 << indicesForCombination.size(); ++i) {
                Sequence* copy = new Sequence(*seq);
                for (int j = indicesForCombination.size() - 1; j >= 0; --j) {
                    // generate all possible combinations
                    // of indices in indicesForCombination
                    if (((1 << j) & i) > 0) {
                        copy->removeSymbolAt(indicesForCombination[j]);
                    }
```

```
                }
                // don't add empty alternatives
                // also duplicates are ignored
                if (!copy->isEpsilon()) gb.addRule(nt, copy);
            }
        }
    }

    // step 3
    if (deletable.contains(g->root)) {
        // add S' (or rather name of original root node + ')
        NTSymbol* newRoot = sp.ntSymbol(g->root->name + "'");
        gb.addRule(newRoot, { new Sequence({g->root}), new Sequence() /* eps */});
        gb.setNewRoot(newRoot);
    }

    return gb.buildGrammar();
}
```

Testcode:

```
#elif TESTCASE == 4

        gb2 = new GrammarBuilder(string("G1.txt"));
        g2 = gb2->buildGrammar();
        Grammar* epsilonFree = newEpsilonFreeGrammarOf(g2);
        // or for short: g2 = GrammarBuilder(string("G.txt")).buildGrammar();

        cout << "grammar from text file:" << endl << *g2 << endl;
        cout << "newEpsilonFreeGrammarOf(g2):" << endl << *epsilonFree << endl;


#elif TESTCASE == 5
```

Result:

```
START Main

symbol pool: 0 terminals and 0 nonterminals
  terminals    = {  }
  nonterminals = {  }

TESTCASE 4

grammar from text file:

G(S):
S -> A B C
A -> eps | B B
B -> C C | a
C -> A A | b
---
VNt = { A, B, C, S }, deletable: { A, B, C, S }
VT  = { a, b }

newEpsilonFreeGrammarOf(g2):

G(S'):
S' -> eps | S
S -> A | A B | A B C | A C | B | B C | C
A -> B | B B
B -> C | C C | a
C -> A | A A | b
---
VNt = { A, B, C, S, S' }, deletable: { S' }
VT  = { a, b }


symbol pool: 2 terminals and 5 nonterminals
  terminals    = { a, b }
  nonterminals = { C, S, A, B, S' }

elapsed time: 0.009

END Main
```

b) and also c)

main.cpp

```
void languageOfRecursive(
    Language * language,
    const RulesMap & rules,
    const SequenceSet& sequences,
    // copy ctor of Sequence copies the collection, making use of call stack
    Sequence currSentence,
    int maxLen
) {
    if (currSentence.length() >= maxLen) return;

    for (const Sequence* rule : sequences) {
        // look at each symbol of current rule (alternative)
        for (Symbol* sy : *rule) {
            if (sy->isNT()) {
                // go to coresponding NTSymbol in the RulesMap
                NTSymbol* ntSy = dynamic_cast<NTSymbol*>(sy); // cannot be null
                languageOfRecursive(language, rules, rules[ntSy], currSentence, maxLen);
            }
            else {
                // add TSymbol to current sentence
                currSentence.append(sy);
            }
        }
        if (currSentence.length() <= maxLen) {
            // copy is necessary here because otherwise
            // we would get the TSymbols of the next alternative
            // in the previously added sentence (which we don't want)
            language->addSentence(new Sequence(currSentence));
        }
    }
}

Language* languageOf(const Grammar* g, int maxLen) {
    Language* language = new Language(maxLen);
    Sequence s{};
    languageOfRecursive(language, g->rules, g->rules[g->root], s, maxLen);
    return language;
}
```

Language.h

```
// Language.h:                                                SWE, 2022
// ----------------
// Lengwidsch
//================================

#ifndef Language_h
#define Language_h

#include <vector>
#include <set>
#include <iostream>

class Sequence;

class Language {

    friend std::ostream& operator <<(std::ostream& os, const Language& language);

    private:
        std::set<Sequence*> sentences{};
        int maxLength;

    public:
        Language(int maxLength);

        Sequence& at(int i) const;
        void addSentence(Sequence* s);
        bool hasSentence(Sequence* s) const;

};

#endif

// end of GrammarBuilder.h
//=========================================================================
```

Language.cpp

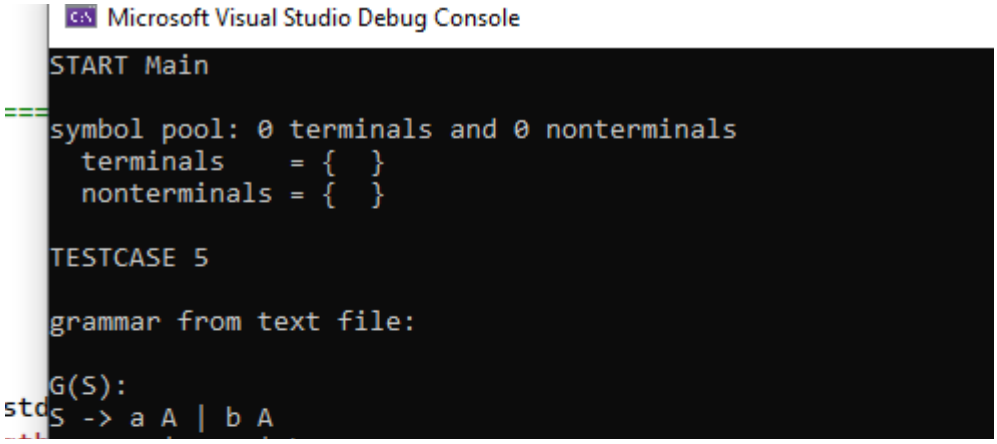
```cpp
// Language.h:                                                SWE, 2022
// ----------------
// Lengwidsch
//================================

#include <exception>

#include "Language.h"
#include "SymbolStuff.h"
#include "SequenceStuff.h"

std::ostream& operator <<(std::ostream& os, const Language& language) {
    os << "L(G(S)): maxLength=" << language.maxLength << " {\n";
    for (const Sequence* sentence : language.sentences) {
        os << *sentence << "\n";
    }
    os << "}";
    return os;
}


Sequence& Language::at(int idx) const {
    if (idx >= sentences.size() || idx < 0)
        throw std::invalid_argument("invalid index");
    auto it = sentences.cbegin();
    std::advance(it, idx);
    return **it;
}

Language::Language(int maxLength)
    : maxLength{maxLength} {

}

void Language::addSentence(Sequence* s) {
    sentences.insert(s);
}

bool Language::hasSentence(Sequence* s) const {

    for (const Symbol* sy : *s) {
        if (sy->isNT())
            throw std::runtime_error("NT found in sentence");
    }

    for (const Sequence* curr : sentences) {
        // Sequence already has equality comparison (op ==) implemented
        if (*curr == *s) {
            return true;
        }
    }
    return false;
}
```

```
// end of GrammarBuilder.h
//========================================================================
```

Testcode:

```
#elif TESTCASE == 5

        gb2 = new GrammarBuilder(string("G23.txt"));
        g2 = gb2->buildGrammar();
        Grammar* epsilonFree = newEpsilonFreeGrammarOf(g2);

        Language* languageG2 = languageOf(epsilonFree, 6);
        Sequence& s1 = languageG2->at(1);
        Sequence madeUpSequence{
            sp->symbolFor("a"),
            sp->symbolFor("a"),
            sp->symbolFor("a"),
            sp->symbolFor("b")
        };
        Sequence madeUpSequenceNotContained{
            sp->symbolFor("a"),
            sp->symbolFor("b"),
            sp->symbolFor("b"),
            sp->symbolFor("b")
        };

        cout << "grammar from text file:" << endl << *g2 << endl;
        cout << "newEpsilonFreeGrammarOf(g2):" << endl << *epsilonFree << endl;
        cout << "language(g2):" << endl << *languageG2 << endl;
        cout << "s1: " << s1 << endl;
        cout << "languageG2.hasSentence(s1): " << boolalpha
            << languageG2->hasSentence(&s1) << endl;
        cout << "madeUpSequence: " << madeUpSequence << endl;
        cout << "languageG2.hasSentence(madeUpSequence): " << boolalpha
            << languageG2->hasSentence(&madeUpSequence) << endl;
        cout << "madeUpSequence: " << madeUpSequenceNotContained << endl;
        cout << "languageG2.hasSentence(madeUpSequenceNotContained): " << boolalpha
            << languageG2->hasSentence(&madeUpSequenceNotContained) << endl;

#else // none of the TESTCASEs above
```

Result:



```
A -> a | a S | b A A
B -> a B B | b | b S
---
VNt = { A, B, S }, deletable: {  }
VT  = { a, b }


newEpsilonFreeGrammarOf(g2):

G(S):
S -> a A | b A
A -> a | a S | b A A
B -> a B B | b | b S
---
VNt = { A, B, S }, deletable: {  }
VT  = { a, b }


language(g2):
L(G(S)): maxLength=6 {
a b a a a
a b a a a b
a b a a a a
a b a a
a a a b a a
a a a b a a
a a a b a
a a a
a
a b a
a a a b
a a a a b
a a a b a
a a a a b a
a a a a
a a
a a a a a
a a a a a a
a b a a b a
a b a a b a
a b a a b
a b
}
s1: a b a a a b
languageG2.hasSentence(s1): true
madeUpSequence: a a a b
languageG2.hasSentence(madeUpSequence): true
madeUpSequence: a b b b
languageG2.hasSentence(madeUpSequenceNotContained): false

symbol pool: 2 terminals and 3 nonterminals
  terminals    = { a, b }
  nonterminals = { S, A, B }

elapsed time: 0.009

END Main
```