DATA STRUCTURES AND ALGORITHMS FOR COMPUTATIONAL LINGUISTICS III

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https://dsacl3-2018.github.io

DSA-CL III course overview

What is DSA-CL III?

- Intermediate-level survey course.
- Programming and problem solving, with applications.
  - Algorithm: method for solving a problem.
  - Data structure: method to store information.
- Second part focused on Computational Linguistics

Prerequisites:

- Data Structures and Algorithms for CL I
- Data Structures and Algorithms for CL II

Lecturers:

- Çağrı Çöltekin
- Claus Zinn

Tutors:

- Marko Lozajic
- Michael Watkins

Slots:

- Mon 12:15 & 18:00 (R 0.02)
- Wed 14:15 — 18:00 (lab)

Course Materials: https://dsacl3-2018.github.io

Coursework and grading

Reading material for most lectures

Weekly programming assignments

Four graded assignments. 60%

- Due on Tuesdays at 11pm via electronic submission (Github Classroom)
- Collaboration/lateness policies: see web.

Written exam. 40%

- Midterm practice exam 0%
- Final exam 40%

Honesty Statement

Honesty statement:

- Feel free to cooperate on assignments that are not graded.
- Assignments that are graded must be your own work. Do **not**:
  - Copy a program (in whole or in part).
  - Give your solution to a classmate (in whole or in part).
  - Get so much help that you cannot honestly call it your own work.
  - Receive or use outside help.
- Sign your work with the honesty statement (provided on the website).
- Above all: You are here for yourself, practice makes perfection.

Organisational issues

Presence:

- A presence sheet is circulated **purely** for statistics.
- Experience: those who do not attend lectures or do not make the assignments usually fail the course.
- Do not expect us to answer your questions if you were not at the lectures.

Office hours:

- Office hour: **Monday, 14:00-15:00**, please make an **appointment**!
- Please ask questions about the material presented in the lectures during the lectures — Everyone benefits
- We will discuss each assignment that is not graded during the next lab.

Registration:

- Do the first assignment, A0.

Assignment Process

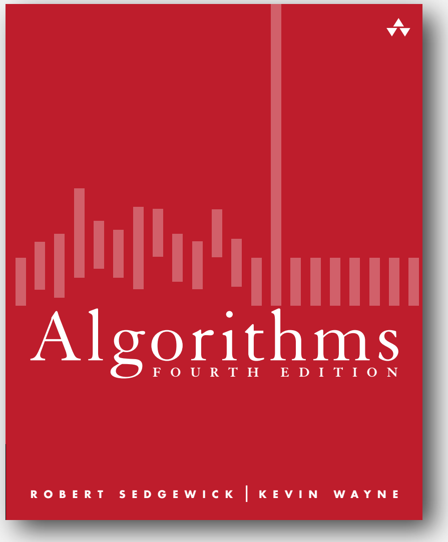
Walk-Through

GIT Classroom

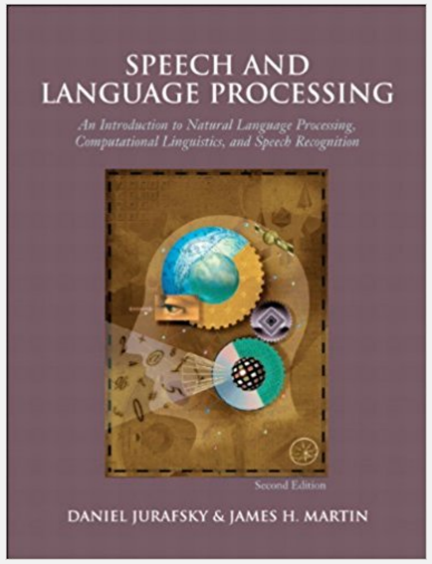
Resources (textbook)

Required reading.

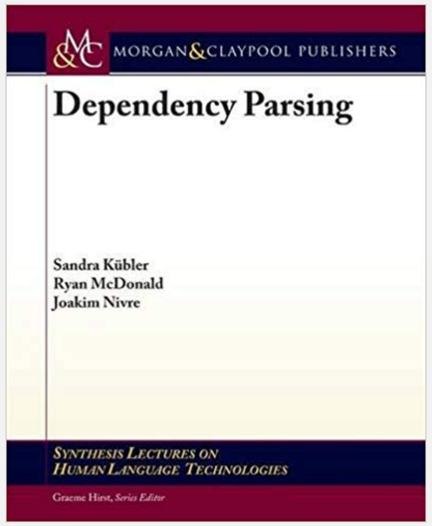
- Algorithms 4th edition by R. Sedgewick and K. Wayne, Addison-Wesley Professional, 2011, ISBN 0-321-57351-X.
  - Readable from university network thru Safari books:
  - see proquest.tech.safaribooksonline.de/9780132762571



- Speech and Language Processing, Jurafsky & Martin, 2nd Edition, Prentice Hall
  - Draft chapters of 3rd. edition available
  - see web.stanford.edu/~jurafsky/slp3/



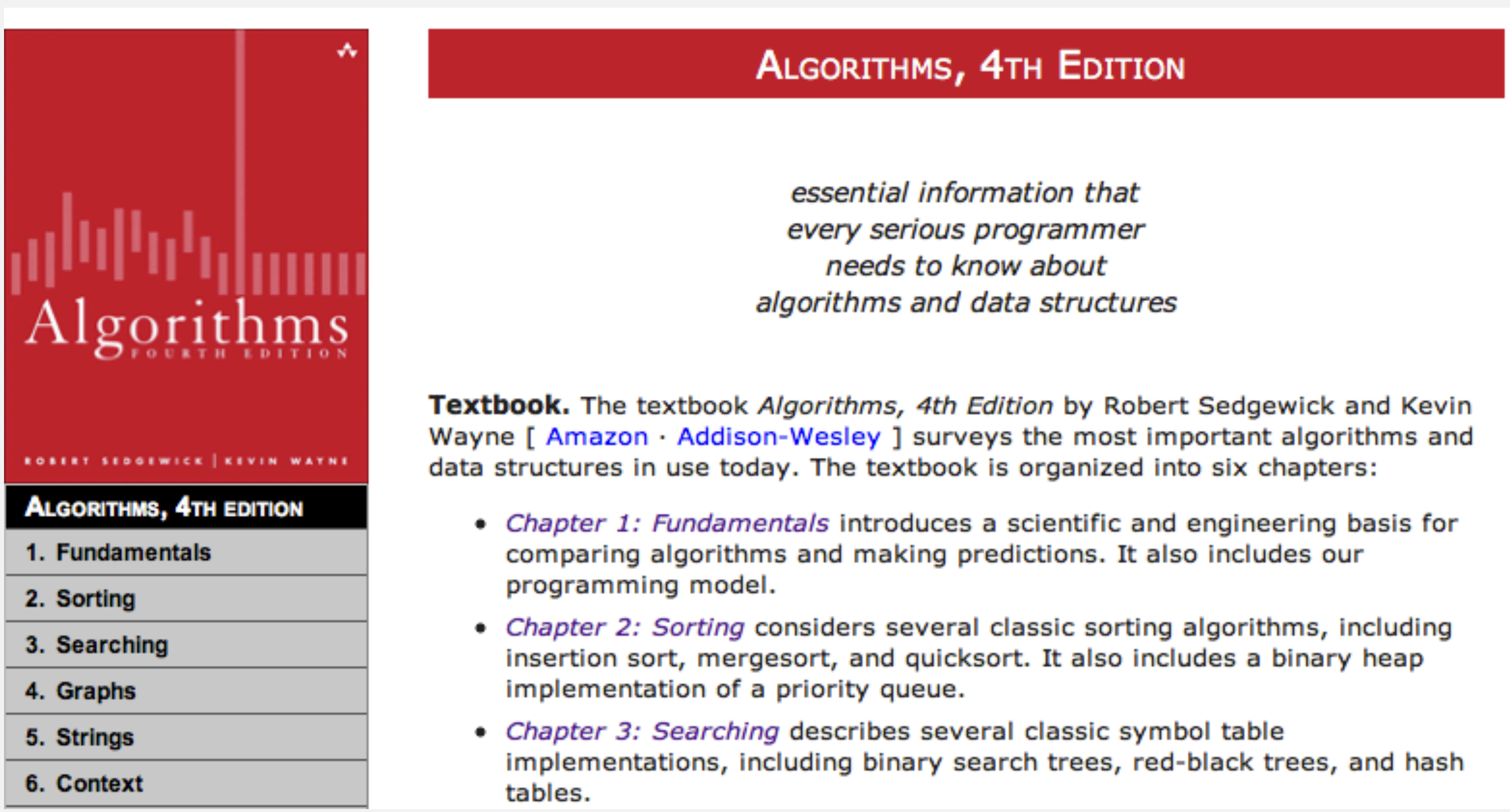
- Dependency Parsing, Kübler, McDonald & Nivre, Morgan & Claypool



Resources (web)

Book site for first part of class

- Brief summary of content.
- Download code from book.
- APIs and Javadoc.



http://algs4.cs.princeton.edu

Why study algorithms?

Their impact is broad and far-reaching.

Internet. Web search, packet routing, distributed file sharing, ...

Biology. Human genome project, protein folding, …

Computers. Circuit layout, file system, compilers, …

Computer graphics. Movies, video games, virtual reality, …

Security. Cell phones, e-commerce, voting machines, …

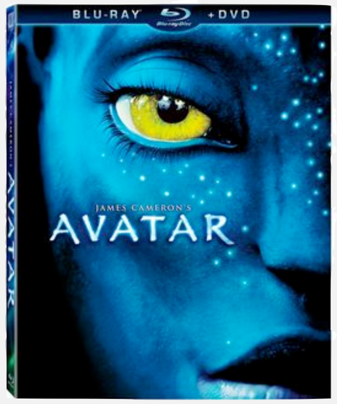
Multimedia. MP3, JPG, DivX, HDTV, face recognition, …

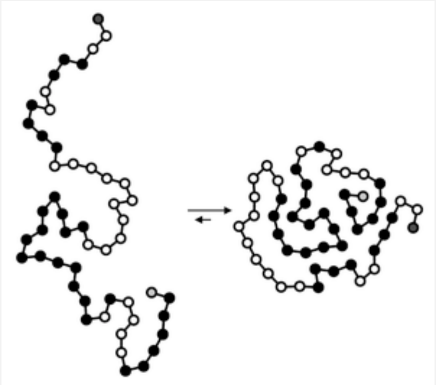
Social networks. Recommendations, news feeds, advertisements, …

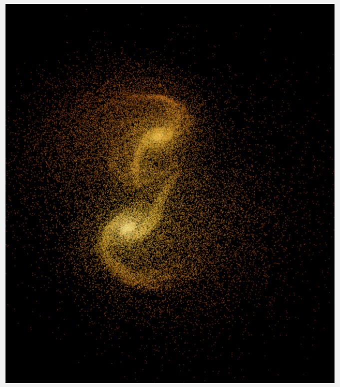
Physics. N-body simulation, particle collision simulation, …

⋮

Google YAHOO! bing







Why study algorithms?

Their impact is broad and far-reaching.

Mysterious algorithm was 4% of trading activity last week

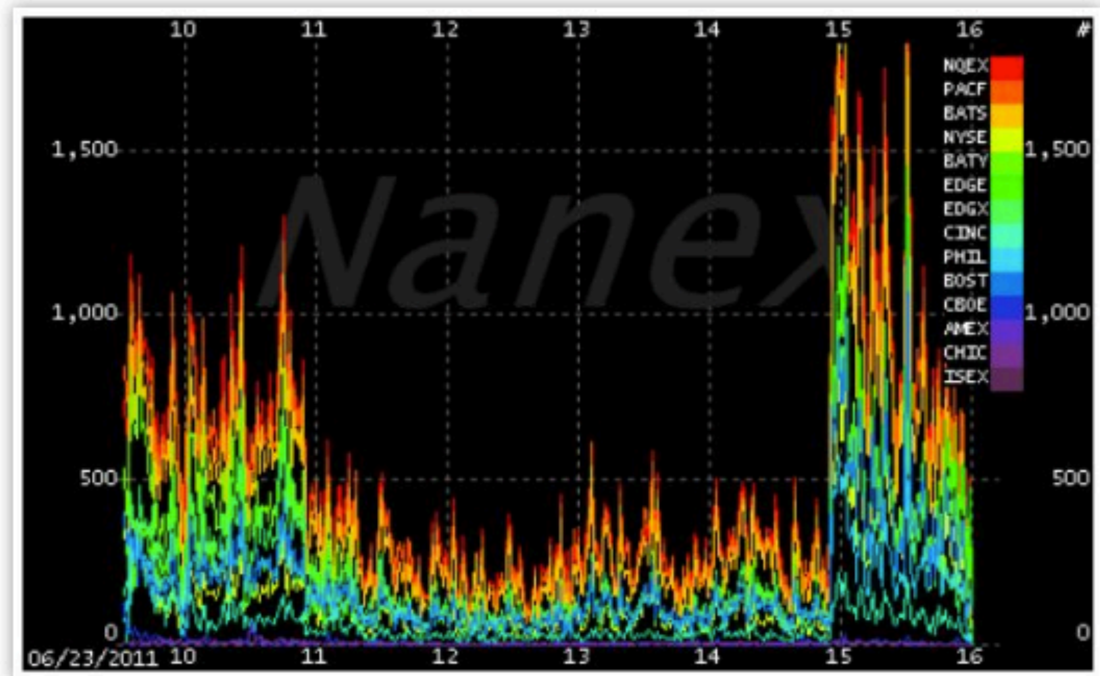
October 11, 2012

A single mysterious computer program that placed orders — and then subsequently canceled them — made up 4 percent of all quote traffic in the U.S. stock market last week, according to the top tracker of high-frequency trading activity.

The motive of the algorithm is still unclear, *CNBC* reports.

The program placed orders in 25-millisecond bursts involving about 500 stocks, according to Nanex, a market data firm. The algorithm never executed a single trade, and it abruptly ended at about 10:30 a.m. ET Friday.

[+]



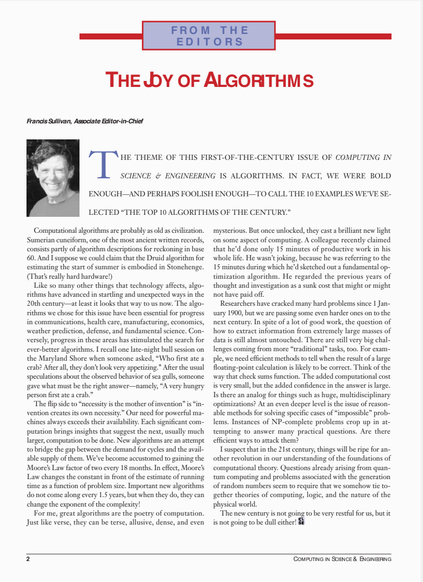
Generic high frequency rrading chart (credit: Nanex)

"My guess is that the algo was testing the market, as high-frequency frequently does," says Jon Najarian, co-founder of TradeMonster.com. "As soon as they add bandwidth, the HFT crowd sees how quickly they can top out to create latency." (*Read More*: Unclear What Caused Kraft Spike: Nanex Founder.)

Why study algorithms?

For intellectual stimulation.

> " *For me, great algorithms are the poetry of computation. Just like verse, they can be terse, allusive, dense, and even mysterious. But once unlocked, they cast a brilliant new light on some aspect of computing.* " — *Francis Sullivan*


FROM THE EDITORS

THE JOY OF ALGORITHMS

Francis Sullivan, Associate Editor-in-Chief

THE THEME OF THIS FIRST-OF-THE-CENTURY ISSUE OF *COMPUTING IN SCIENCE & ENGINEERING* IS ALGORITHMS. IN FACT, WE WERE BOLD ENOUGH—AND PERHAPS FOOLISH ENOUGH—TO CALL THE 10 EXAMPLES WE'VE SELECTED "THE TOP 10 ALGORITHMS OF THE CENTURY."

Computational algorithms are probably as old as civilization. Sumerian cuneiform, one of the most ancient written records, consists partly of algorithm descriptions for reckoning in base 60. And I suppose we could claim that the Druid algorithm for estimating the start of summer is embodied in Stonehenge. (That's really hard hardware!)

Like so many other things that technology affects, algorithms have advanced in startling and unexpected ways in the 20th century—at least it looks that way to us now. The algorithms we chose for this issue have been essential for progress in communications, health care, manufacturing, economics, weather prediction, defense, and fundamental science. Conversely, progress in these areas has stimulated the search for ever-better algorithms. I recall one late-night bull session on the Maryland Shore when someone asked, "Who first ate a crab? After all, they don't look very appetizing." After the usual speculations about the observed behavior of sea gulls, someone gave what must be the right answer—namely, "A very hungry person first ate a crab."

The flip side to "necessity is the mother of invention" is "invention creates its own necessity." Our need for powerful machines always exceeds their availability. Each significant computation brings insights that suggest the next, usually much larger, computation to be done. New algorithms are an attempt to bridge the gap between the demand for cycles and the available supply of them. We've become accustomed to gaining the Moore's Law factor of two every 18 months. In effect, Moore's Law changes the constant in front of the estimate of running time as a function of problem size. Important new algorithms do not come along every 1.5 years, but when they do, they can change the exponent of the complexity!

For me, great algorithms are the poetry of computation. Just like verse, they can be terse, allusive, dense, and even mysterious. But once unlocked, they cast a brilliant new light on some aspect of computing. A colleague recently claimed that he'd done only 15 minutes of productive work in his whole life. He wasn't joking, because he was referring to the 15 minutes during which he'd sketched out a fundamental optimization algorithm. He regarded the previous years of thought and investigation as a sunk cost that might or might not have paid off.

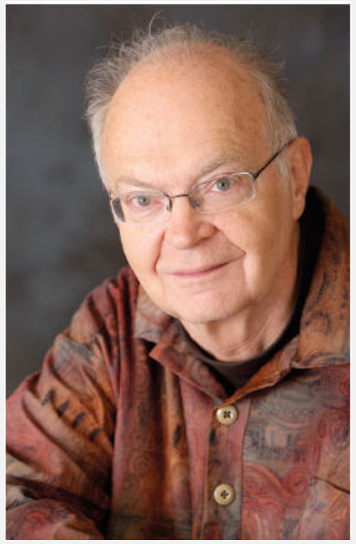
Researchers have cracked many hard problems since 1 January 1900, but we are passing some even harder ones on to the next century. In spite of a lot of good work, the question of how to extract information from extremely large masses of data is still almost untouched. There are still very big challenges coming from more "traditional" tasks, too. For example, we need efficient methods to tell when the result of a large floating-point calculation is likely to be correct. Think of the way that check sums function. The added computational cost is very small, but the added confidence in the answer is large. Is there an analog for things such as huge, multidisciplinary optimizations? At an even deeper level is the issue of reasonable methods for solving specific cases of "impossible" problems. Instances of NP-complete problems crop up in attempting to answer many practical questions. Are there efficient ways to attack them?

I suspect that in the 21st century, things will be ripe for another revolution in our understanding of the foundations of computational theory. Questions already arising from quantum computing and problems associated with the generation of random numbers seem to require that we somehow tie together theories of computing, logic, and the nature of the physical world.

The new century is not going to be very restful for us, but it is not going to be dull either!

2 COMPUTING IN SCIENCE & ENGINEERING

> " *An algorithm must be seen to be believed.* " — *Donald Knuth*

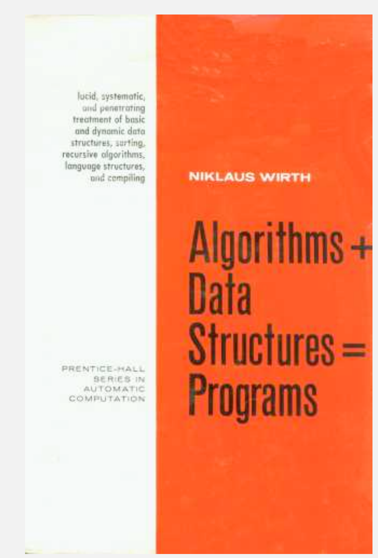


Why study algorithms?

To become a proficient programmer.

> *" I will, in fact, claim that the difference between a bad programmer and a good one is whether he considers his code or his data structures more important. Bad programmers worry about the code. Good programmers worry about data structures and their relationships. "*
>
> *— Linus Torvalds (creator of Linux)*

> *" Algorithms + Data Structures = Programs. "* *— Niklaus Wirth*

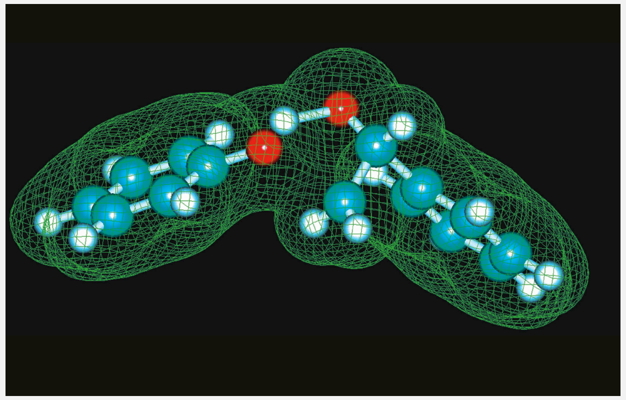


Why study algorithms?

They may unlock the secrets of life and of the universe.

> *" Computer models mirroring real life have become crucial for most advances made in chemistry today.... Today the computer is just as important a tool for chemists as the test tube. "*
>
> — *Royal Swedish Academy of Sciences (Nobel Prize in Chemistry 2013)*

Martin Karplus, Michael Levitt, and Arieh Warshel

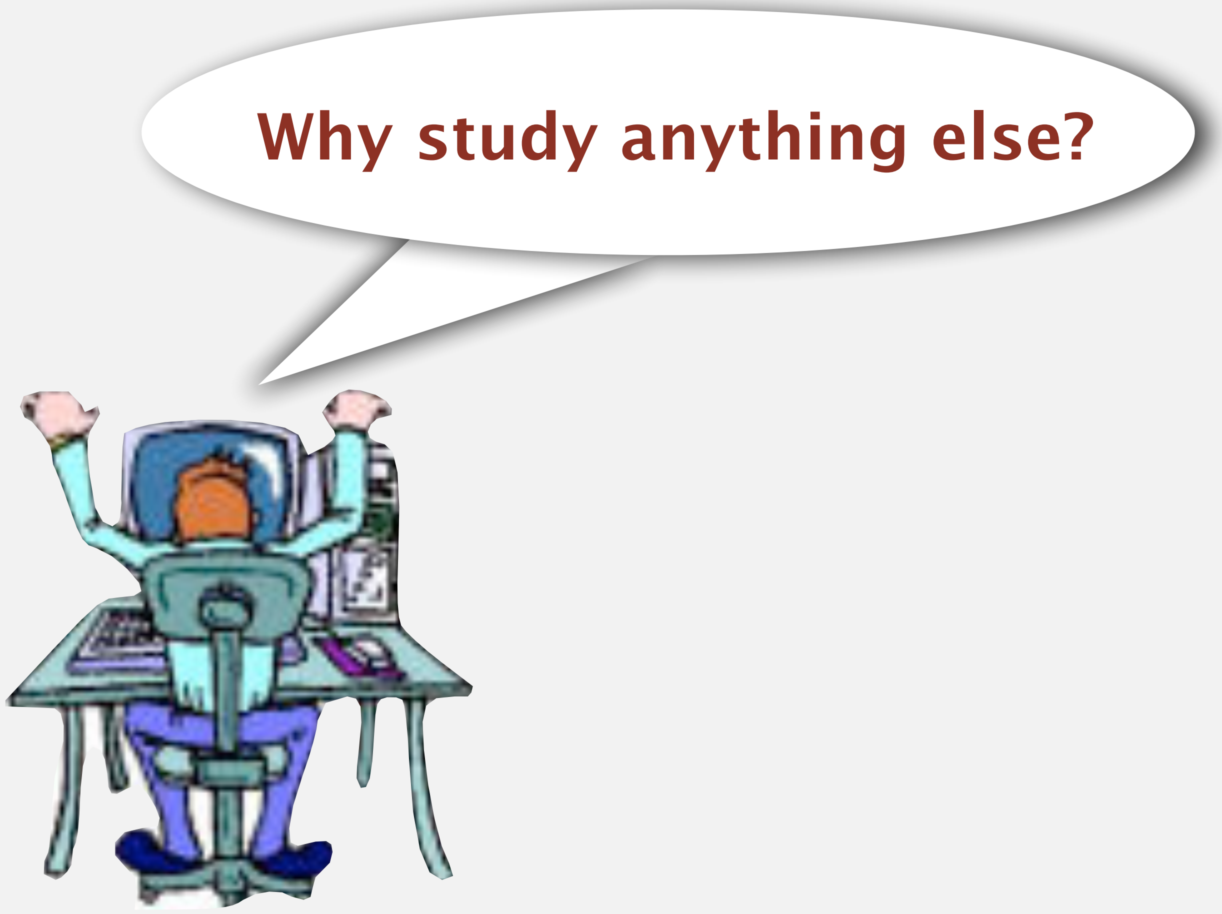


Why study algorithms?

For fun and profit.

Why study algorithms?

- Their impact is broad and far-reaching.
- Old roots, new opportunities.
- For intellectual stimulation.
- To become a proficient programmer.
- They may unlock the secrets of life and of the universe.
- To solve problems that could not otherwise be addressed.
- Everybody else is doing it.
- For fun and profit.



What's ahead

Week	Monday (lectures)	Wednesday (lab)
01	Oct 22 A: *Introduction* B: *Complexity theory*	Oct 24 lab: *Language Guessing*
02	Oct 29 A: *Elemenary sorts* B: *Quicksort*	Nov 1 *No class*
03	Nov 05 A: *Undirected graphs* B: *Undirected graphs*	Nov 07 lab: *Sorting*
04	Nov 12 A: *Directed graphs* B: *Directed graphs*	Nov 14 lab: *Undirected graphs*
05	Nov 19 A: *Distance measures* B: *Binary heaps & heapsort*	Nov 21 lab: *Directed graphs*
06	Nov 26 A: *Binary heaps & heapsort* B: *Exam practice*	Nov 28 lab: *Burkhard-Keller trees*
07	Dec 03 A: *Formal languages and automata* B: *Formal languages and automata*	Dec 05 lab: *TBA*
08	Dec 10 A: *Regular grammars and finite state automata* B: *Regular grammars and finite state automata*	Dec 12 lab: *TBA*

What's Ahead

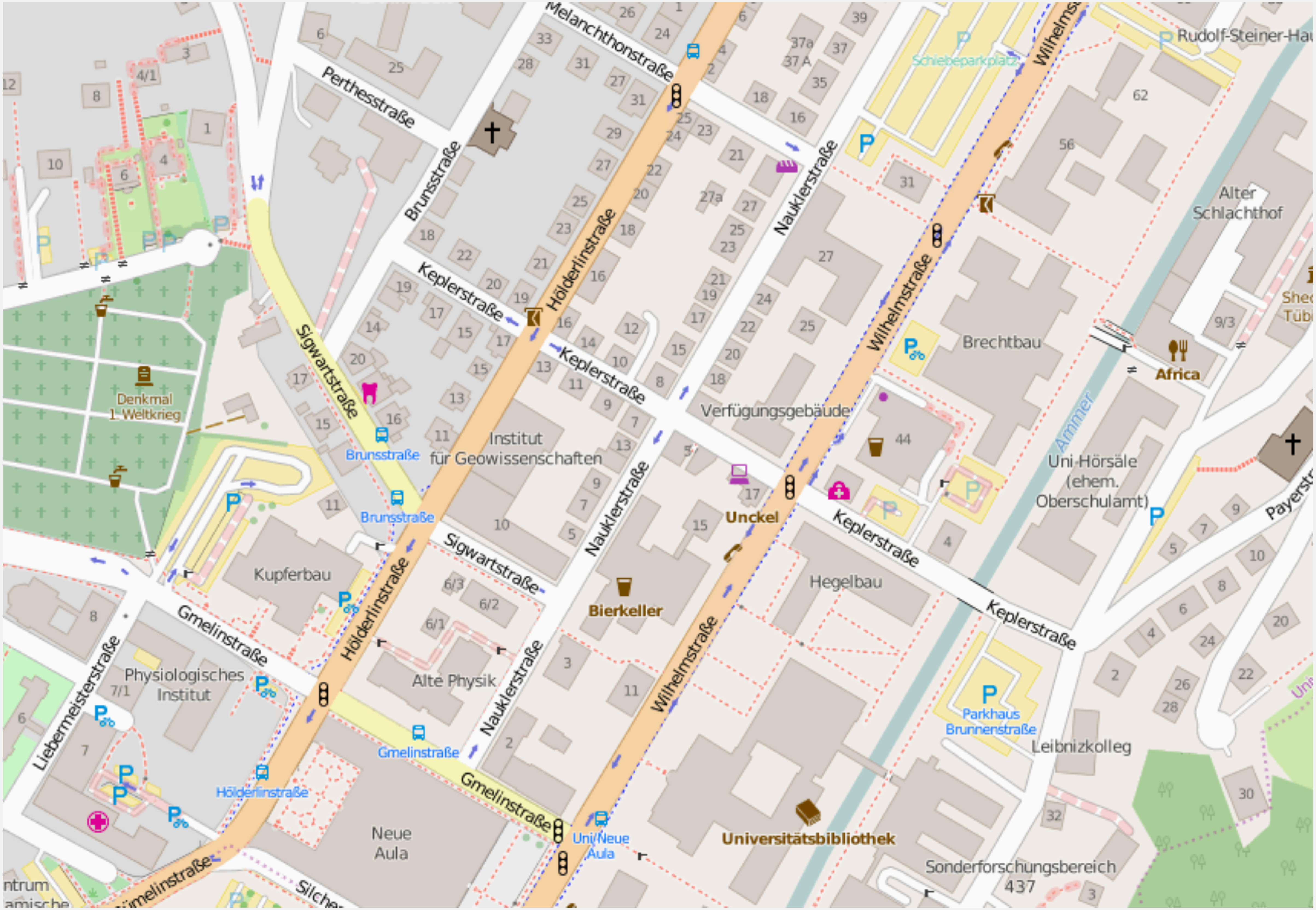
09	Dec 17 A: *Finite-state transducers* B: *Finite-state transducers and computational morphology*	Dec 19 lab: *TBA*
Sem. break	*No class*	*No class*
10	Jan 7 A: *Context-free languages and constituency parsing* B: *Context-free languages and constituency parsing*	Jan 9 lab: *TBA*
11	Jan 14 A: *Dependency grammars and treebanks* B: *Dependency grammars and treebanks*	Jan 16 lab: *TBA*
12	Jan 21 A: *Dependency parsing* B: *Dependency parsing*	Jan 23 lab: *TBA*
13	Jan 28 A: *A gentle introduction to classification* B: *Transition-based dependency parsing*	Jan 30 lab: *TBA*
14	Feb 04 A: *Exam review / practice* B: *Exam review / practice*	Feb 06 lab: *TBA*
15	Feb 11 A: *Exam* B:	Feb 13 lab: *TBA*

Sorting

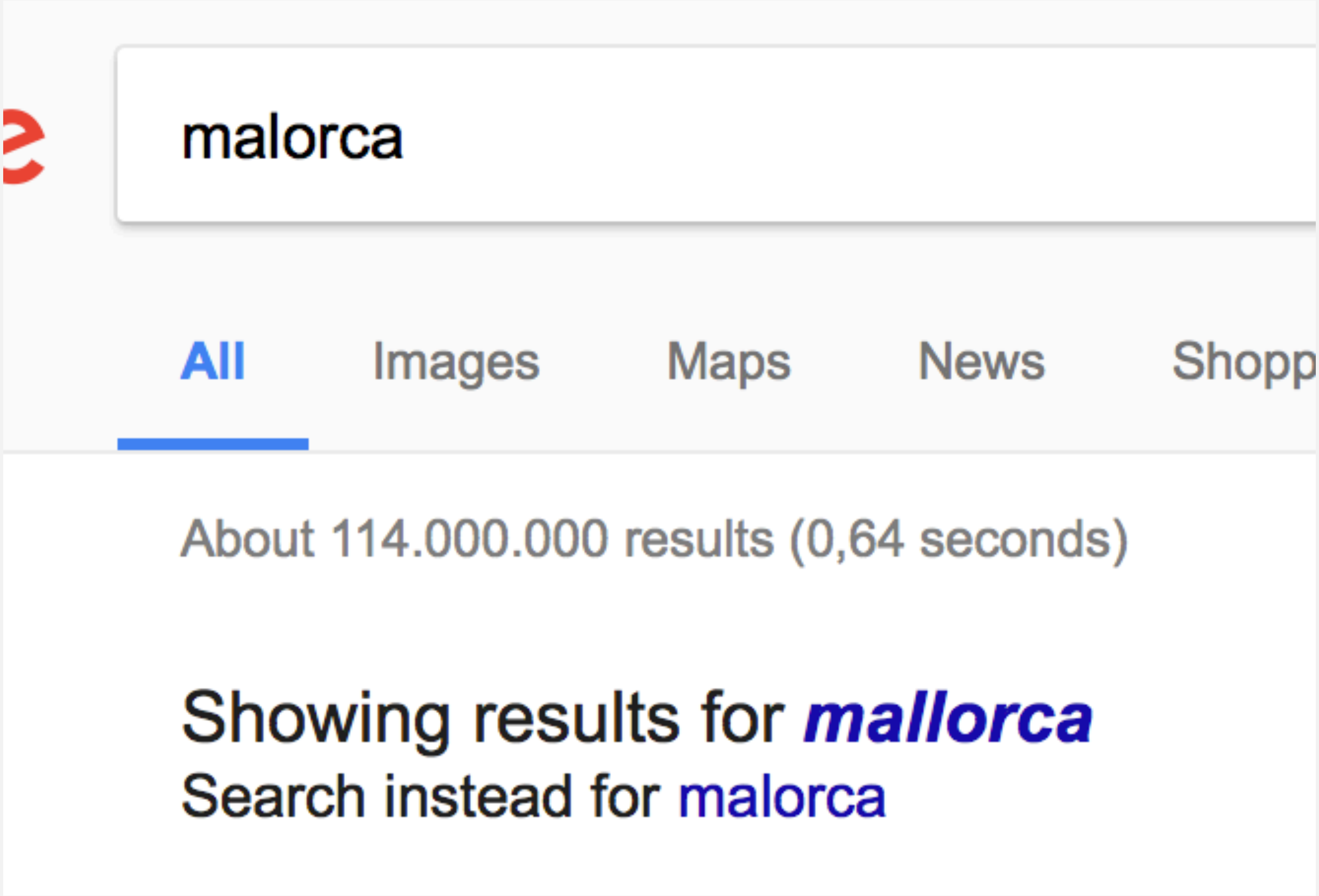
Bundesarchiv, Bild 183-22350-0001
Foto: Junge, Peter Heinz | 20. November 1953

Undirected Graphs

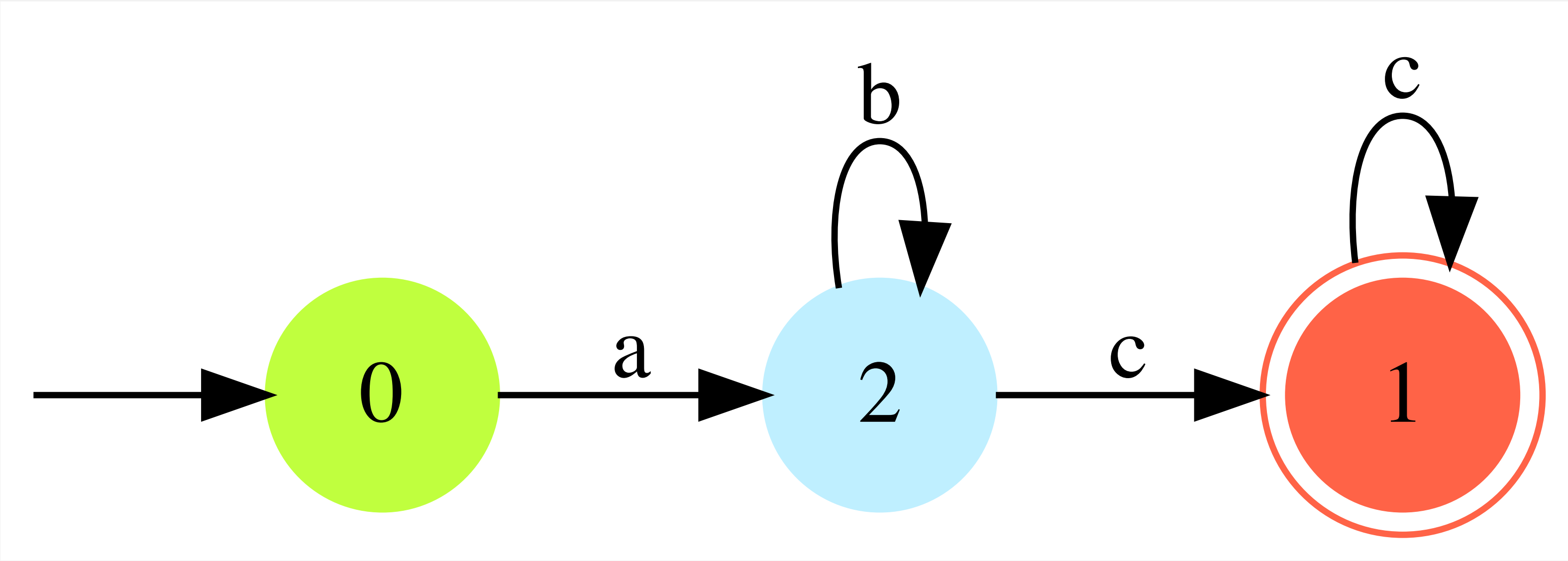
Directed Graphs

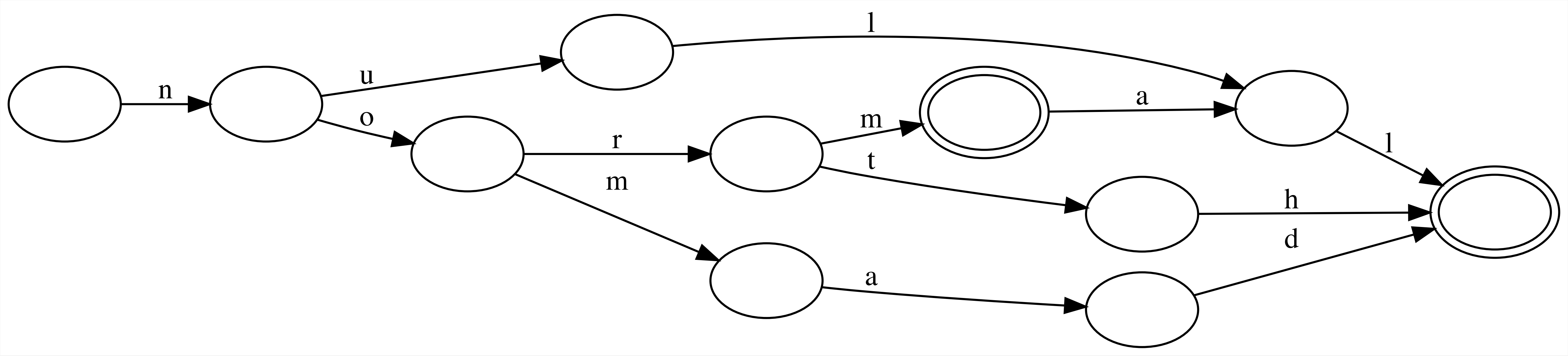


String Distance

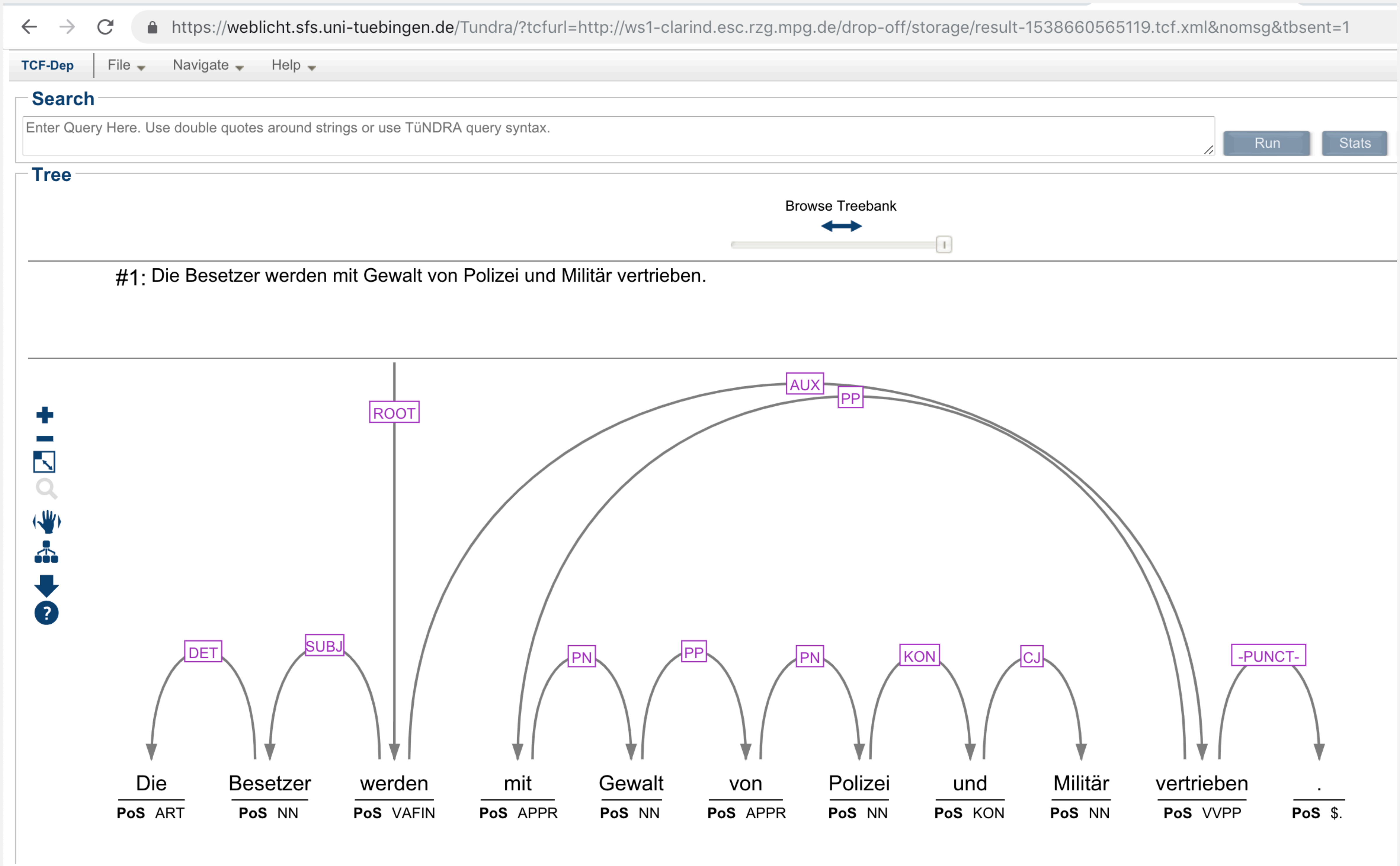


Finite State Automata





Parsing



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TCF-Dep
File
Navigate
Help
Search
Enter Query Here. Use double quotes around strings or use TüNDRA query syntax.
Run
Stats
Tree
Browse Treebank
#1: Die Besetzer werden mit Gewalt von Polizei und Militär vertrieben.
ROOT
AUX
PP
DET
SUBJ
PN
PP
PN
KON
CJ
-PUNCT-
Die
PoS ART
Besetzer
PoS NN
werden
PoS VAFIN
mit
PoS APPR
Gewalt
PoS NN
von
PoS APPR
Polizei
PoS NN
und
PoS KON
Militär
PoS NN
vertrieben
PoS VVPP
.
PoS $.

Language Guessing

Language Guessing

Applications:

- Spamassassin uses the guessed language as a feature in spam identification.
- Web browsers language identification to offer you to translate a page when it is not in your native language.
- Google Translate uses language identification to determine the source language of a text to be translated.
- The CLARIN Language Resource Switchboard uses language identification (together with the identification of the resource’s media type) to determine tools that can process the resource.

Language I

De **lambdacalculus**, soms ook als **λ-calculus** geschreven, is een formeel systeem dat in de wiskunde en theoretische informatica wordt gebruikt om het definiëren en uitvoeren van berekenbare functies te onderzoeken. Hij werd in 1936 door Alonzo Church en Stephen Kleene geïntroduceerd als onderdeel van hun onderzoek naar de grondbeginselen van de wiskunde, maar wordt tegenwoordig vooral gebruikt bij het onderzoeken van berekenbaarheid. De lambdacalculus kan worden gezien als een soort minimale programmeertaal die in staat is elk algoritme te beschrijven. De lambdacalculus is Turing-volledig en vormt de basis van het paradigma voor functionele programmeertalen.

De rest van dit artikel gaat over de oorspronkelijke, ongetypeerde lambdacalculus. De meeste toepassingen gebruiken varianten daarvan met een type-aanduiding.

Language II

Ля́мбда-исчисле́ние (*λ-исчисление*) — формальная система, разработанная американским математиком Алонзо Чёрчем, для формализации и анализа понятия вычислимости.

λ-исчисление может рассматриваться как семейство прототипных языков программирования. Их основная особенность состоит в том, что они являются языками *высших порядков*. Тем самым обеспечивается систематический подход к исследованию операторов, *аргументами* которых могут быть другие операторы, а значением также может быть оператор. Языки в этом семействе являются функциональными, поскольку они основаны на представлении о функции или операторе, включая функциональную аппликацию и функциональную абстракцию. λ-исчисление реализовано Джоном Маккарти в языке Лисп. Вначале реализация идеи λ-исчисления была весьма громоздкой. Но по мере развития Лисп-технологии (прошедшей этап аппаратной реализации в виде Лисп-машины) идеи получили ясную и четкую реализацию.

Language III

A **lambda-kalkulus** (vagy λ-kalkulus) egy formális rendszer, amit eredetileg matematikai függvények tulajdonságainak (definiálhatóság, rekurzió, egyenlőség) vizsgálatára vezettek be. Az elmélet kidolgozói Alonzo Church és Stephen Cole Kleene voltak az 1930-as években. Church, 1936-ban, a λ-kalkulus segítségével bizonyította, hogy nem létezik algoritmus a híres Entscheidungsproblem (döntési probléma) megoldására. A λ-kalkulus (akárcsak a Turing-gép) lehetővé teszi, hogy pontosan (formálisan) definiáljuk, mit is értünk kiszámítható függvény alatt.

A λ-kalkulust nyugodtan nevezhetjük a legegyszerűbb általános célú programozási nyelvnek. Csak egyfajta értéket ismer: a függvényt (absztrakciót), és csak egyfajta művelet van benne: a függvény alkalmazás (változó-behelyettesítés). Ezen látszólagos egyszerűsége ellenére minden algoritmus, ami Turing-gépen megvalósítható, az megvalósítható tisztán a λ-kalkulusban is. Ez az azonosság a λ-kalkulus és a Turing-gép kifejező ereje (expressive power) között adja egyébként a Church–Turing-tézis alapját.

Míg korábban a λ-kalkulus elsősorban a kiszámíthatóságelmélet (Theory of Computation) miatt volt érdekes, napjainkban ez már kevésbé hangsúlyos, és sokkal inkább a funkcionális programozási nyelvek elméleti és gyakorlati megalapozásában játszott jelentős, mondhatni központi szerepe került előtérbe.

Language IV

λ演算（英语：lambda calculus，λ-calculus）是一套用于研究函数定义、函数应用和递归的形式系统。它由阿隆佐·邱奇和他的学生斯蒂芬·科尔·克莱尼在20世纪30年代引入。邱奇运用λ演算在1936年给出判定性问题（Entscheidungsproblem）的一个否定的答案。这种演算可以用来清晰地定义什么是一个可计算函数。关于两个lambda演算表达式是否等价的命题无法通过一个“通用的算法”来解决，这是不可判定性能够证明的头一个问题，甚至还在停机问题之先。Lambda演算对函数式编程语言有巨大的影响，比如Lisp语言、ML语言和Haskell语言。

Lambda演算可以被称为最小的通用程序设计语言。它包括一条变换规则（变量替换）和一条函数定义方式，Lambda演算之通用在于，任何一个可计算函数都能用这种形式来表达和求值。因而，它是等价于图灵机的。尽管如此，Lambda演算强调的是变换规则的运用，而非实现它们的具体机器。可以认为这是一种更接近软件而非硬件的方式。

本文讨论的是邱奇的“无类型lambda演算”，此后，已经研究出来了一些有类型lambda演算。

Language V

関数を表現する式に文字ラムダ (λ) を使うという慣習からその名がある。アロンゾ・チャーチとスティーヴン・コール・クリーネによって1930年代に考案された。1936年にチャーチはラムダ計算を用いて一階述語論理の決定可能性問題を（否定的に）解いた。ラムダ計算は「計算可能な関数」とはなにかを定義するために用いられることもある。計算の意味論や型理論など、計算機科学のいろいろなところで使われており、特にLISP、ML、Haskellといった関数型プログラミング言語の理論的基盤として、その誕生に大きな役割を果たした。

ラムダ計算は1つの変換規則（変数置換）と1つの関数定義規則のみを持つ、最小の（ユニバーサルな）プログラミング言語であるということもできる。ここでいう「ユニバーサルな」とは、全ての計算可能な関数が表現でき正しく評価されるという意味である。これは、ラムダ計算がチューリングマシンと等価な数理モデルであることを意味している。チューリングマシンがハードウェア的なモデル化であるのに対し、ラムダ計算はよりソフトウェア的なアプローチをとっている。

この記事ではチャーチが提唱した元来のいわゆる「型無しラムダ計算」について述べている。その後これを元にして「型付きラムダ計算」という体系も提唱されている。

Any Ideas

Language Guessing

- Any ideas
- (Brainstorming)

Method

- We can make a computer guess the language:
  - Using simple **n-gram** statistics
  - Using a small amount of training data
  - With high accuracy
- Here we will discuss the method of Cavnar and Trenkle, 1994

- We can usually identify a language using only a very short fragment. E.g.:
  - German: *plötzlichen Ausbruch des Vulkans Ontake in Japan*
  - English: *cross-country navigational exercise and made a banking*
  - Spanish: *provenientes del idioma japonés que describen una*

- Some examples of n-grams that frequently occur these languages:
  - German: *ung, chen, der, die, ö*
  - English: *th, y_, ed_, wh*
  - Spanish: *la, que, ió, los_*

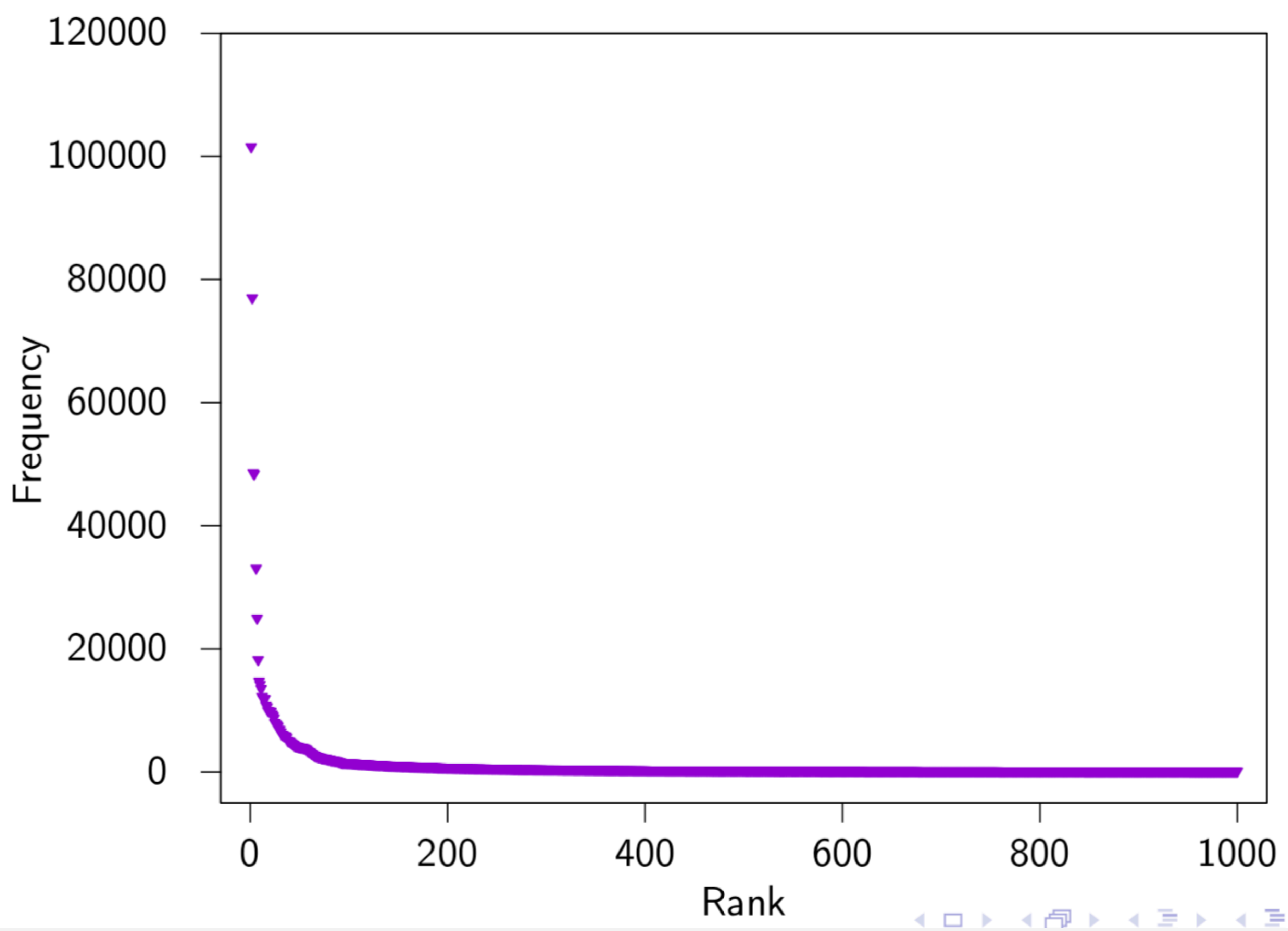
How much information is needed

- If we were to build a model of a couple of languages, how much information do we need per language to classify most texts correctly?
- To find an answer to this question, we look at Zipf's law:

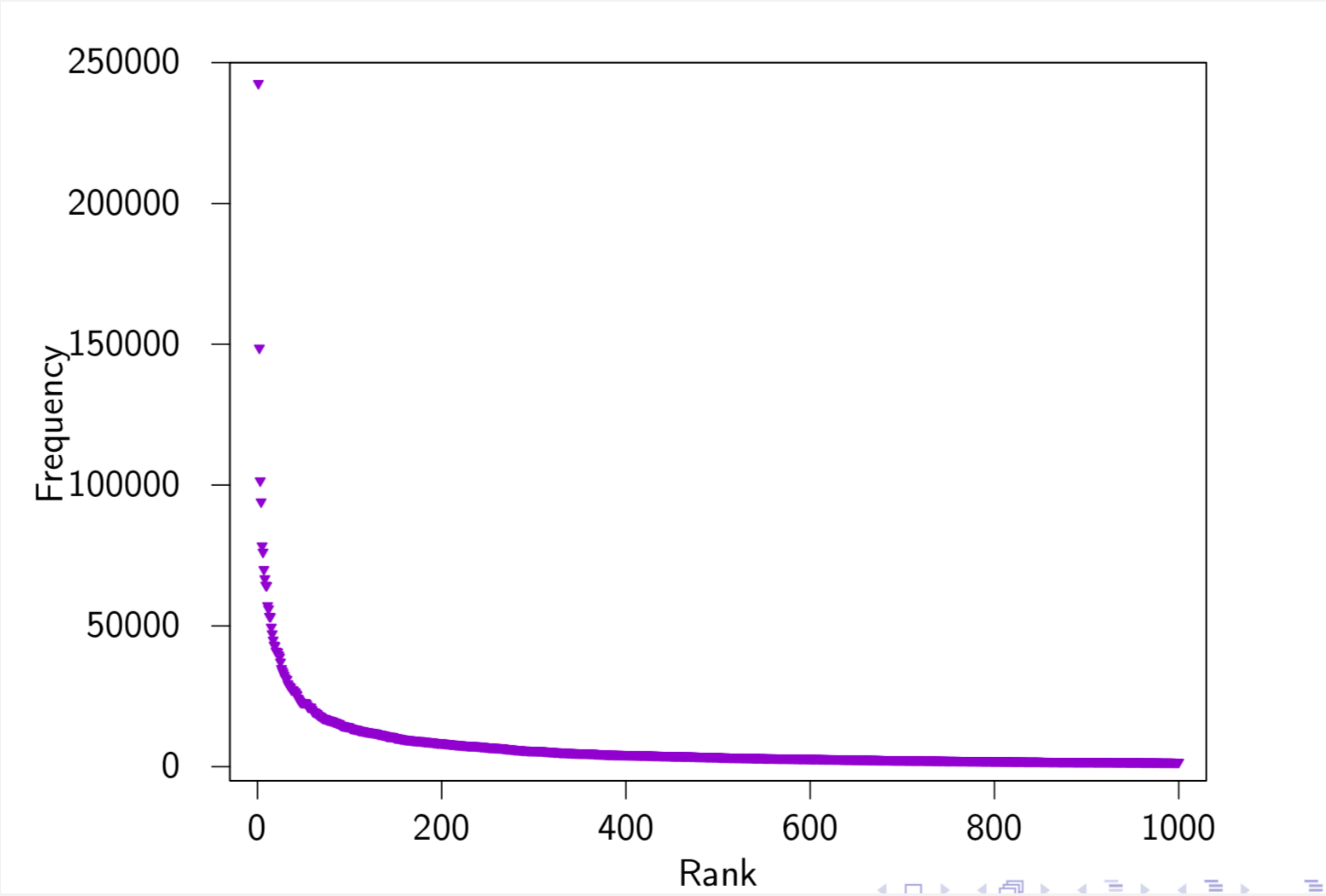
  - *The frequency of a word is inversely proportional to its frequency-based rank*

- That is,
  - the most frequent word will occur approximately twice as many times as the second most frequent word,
  - thrice as many times as the third most frequent word *etc*.

Distributions of tokens in TüBa-D/Z



Distributions of character trigrams in TüBa-D/Z



Lessons Learned

- A small number of n-grams pop up ’all over the place’;
- consequently, only a small number of n-grams are effective indicators;
- documents from a language should have similar n-gram frequency distributions.

- Cavnar and Trenkle create a profile of a language using a small amount of text in the following manner:
  - Count each 1..5-gram in the text
  - Sort the n-grams by frequency (most frequent first)
  - Retain the 300 most frequent n-grams

- Note: Cavnar and Trenkle discard all characters that are not letters or quotes.

Example: bananas

bi-grams: _T, TE, EX, XT, T_

tri-grams: _TE, TEX, EXT, XT_, T_ _

quad-grams: _TEX, TEXT, EXT_, XT_ _, T_ _ _

In general, a string of length k, padded with blanks, will have k+1 bi-grams, k+1tri-grams, k+1 quad-grams, and so on.

n-gram	freq	n-gram	freq
a	3	ba	1
an	2	ban	1
ana	2	bana	1
n	2	banan	1
na	2	nan	1
anan	1	nana	1
anana	1	nanas	1
anas	1	nas	1
as	1	s	1
b	1		

Example: bananas

n-gram	rank	n-gram	rank
a	1	ba	11
an	2	ban	12
ana	3	bana	13
n	4	banan	14
na	5	nan	15
anan	6	nana	16
anana	7	nanas	17
anas	8	nas	18
as	9	s	19
b	10		

Language identification

- Generate a profile for each language, based on a longer text. When classifying the language of a document:
  - Create a profile of the document.
  - Compare the profile of the document with the profile of each language.
  - Choose the language with the most similar profile.
- How do we compare two profiles?

Given the document profile p and language profile q, the distance function is defined as:

$$d(p, q) = \sum_{\text{ngram} \in p} |\mathit{rank}(\text{ngram}, p) - \mathit{rank}(\text{ngram}, q)|$$

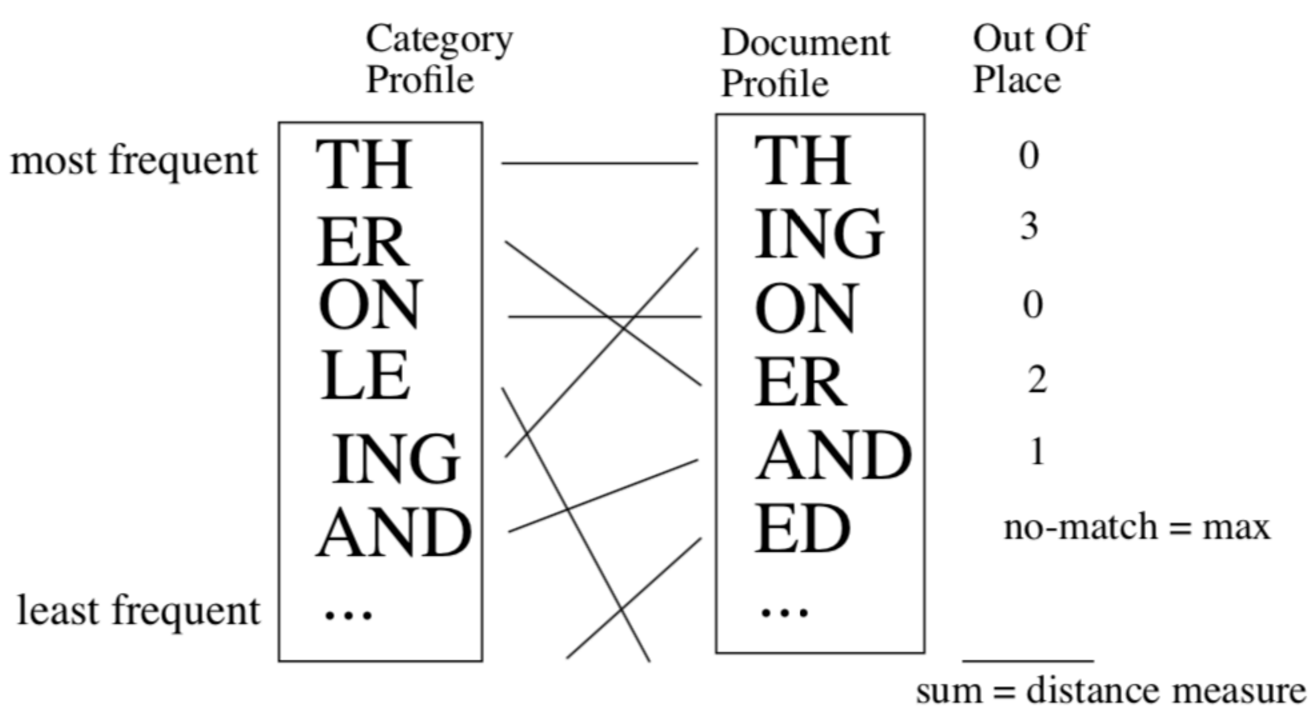
The *rank* function gives the rank of an n-gram in the profile, or the size of the profile if it does not have the n-gram.

Example & Algorithm

p	q	$\lvert\Delta\rvert$
th	th	0
ing	er	3
on	on	0
er	le	2
and	ing	1
ed	and	max
...	...	...

$L \leftarrow \{\langle \text{language}, \text{profile} \rangle\}$
$p \leftarrow$ document profile
$guess \leftarrow \epsilon$
$guess\_dist \leftarrow \infty$
for all $(l, q) \in L$ **do**
    dist $\leftarrow d(p, q)$
    if dist $<$ guess_dist **then**
        guess_dist $\leftarrow$ dist
        guess $\leftarrow$ l
    end if
end for

FIGURE 3. Calculating The Out-Of-Place Measure Between Two Profiles



Method Evaluation

Article Length	≤ 300	≤ 300	≤ 300	≤ 300	> 300	> 300	> 300	> 300
Profile Length	**100**	**200**	**300**	**400**	**100**	**200**	**300**	**400**
Newsgroup								
australia	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
brazil	70.0	80.0	90.0	90.0	91.3	91.3	95.6	95.7
britain	96.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
canada	100.0	100.0	100.0	100.0	100.0	*99.6	100.0	100.0
celtic	100.0	100.0	100.0	100.0	99.7	100.0	100.0	100.0
france	90.0	95.0	100.0	*95.0	99.6	99.6	*99.2	99.6
germany	100.0	100.0	100.0	100.0	98.9	100.0	100.0	100.0
italy	88.2	100.0	100.0	100.0	91.6	99.3	99.6	100.0
latinamerica	91.3	95.7	*91.3	95.7	97.5	100.0	*99.5	*99.0
mexico	90.6	100.0	100.0	100.0	94.8	99.1	100.0	*99.5
netherlands	92.3	96.2	96.2	96.2	96.2	99.0	100.0	100.0
poland	93.3	93.3	100.0	100.0	100.0	100.0	100.0	100.0
portugual	100.0	100.0	100.0	100.0	86.8	97.6	100.0	100.0
span	81.5	96.3	100.0	100.0	90.7	98.9	98.9	99.45
Overall	**92.9**	**97.6**	**98.6**	**98.3**	**97.2**	**99.5**	**99.8**	**99.8**

Note: Asterisks indicate combinations of test variables that did worse than similar combinations using shorter profiles.

Complications

The classification problem can be made more complicated by:

- Adding more languages
- Adding languages that are very similar
- Adding dialects
- Identification of very short fragments
- Documents with multiple languages

- Apache OpenNLP includes char n-gram based statistical detector and comes with a model that can distinguish 103 languages
- Apache Tika contains a language detector for 18 languages

- There are newer methods that use more sophisticated statistical modeling and/or machine learning to identify languages.

Maven

Maven

Apache Maven is a tool for building and managing Java projects.

Advantages of Maven are:

- Declarative: you do not have to specify the steps to build a project.
- Dependency management: you specify the dependencies of your project and Maven will automatically download them and make them available in the classpath.
- IDE agnostic: all major IDEs (including IntelliJ, NetBeans, and Eclipse) have plugins for Maven, meaning that you can open a Maven project in any IDE.
- Plugins: the functionality of Maven can easily be extended using plugins.

Maven Project Layout

- **pom.xml** Maven project description
- **src/main** Main project sources
  - **java** Main Java sources
  - **resources** Resources
- **src/test** Test sources
  - **java** Java sources for tests
  - **resources** Resources for tests

Dependencies:

- Many Java libraries are in the Maven Central Repository
  - search.maven.org
- Usually, you will find a fragment on the website of a project.

```
<dependency>
  <groupId>com.google.guava</groupId>
  <artifactId>guava</artifactId>
  <version>18.0</version>
</dependency>
```

Basic Maven Commands

- # Clean up a project (remove compiled Java code)
  - **mvn clean**

- # Compile a project
  - **mvn compile**

- # Run unit tests
  - **mvn test**