

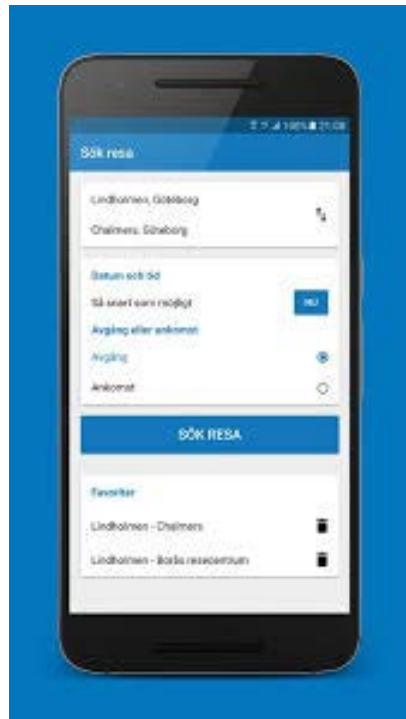
Algorithms

Birgit Grohe

2019-05-06



Used an Algorithm Today?



Reseplaneraren - Västtrafik

Startsida Att resa Trafikläget Priser & Kort Om Västtrafik Aktuellt Kontakta oss Mina sidor

Att resa / Reseplaneraren

Heltrafik
Kompletteringstrafik
Ledsagarservice
Linjenäts- & hållplatskartor
Mobila tjänster
Närtrafik
Ormlottzoner
Pendelparkering
Resor med barnvagn
Resor med Swebus Express
Resor med tåg
Resor vidare
Vegetarant
Reseplaneraren
Avstånd från hållplats
Resor med genvägar
Resor på din sida
Resor som passerar?

Att resa

Reseplaneraren

Sökt resa: Korsvägen, GÖTEBORG (Hållplats) - Opalatorget, GÖTEBORG (Hållplats) (torsdag 16 oktober 2008)

Ny sökning | Ändra sökning

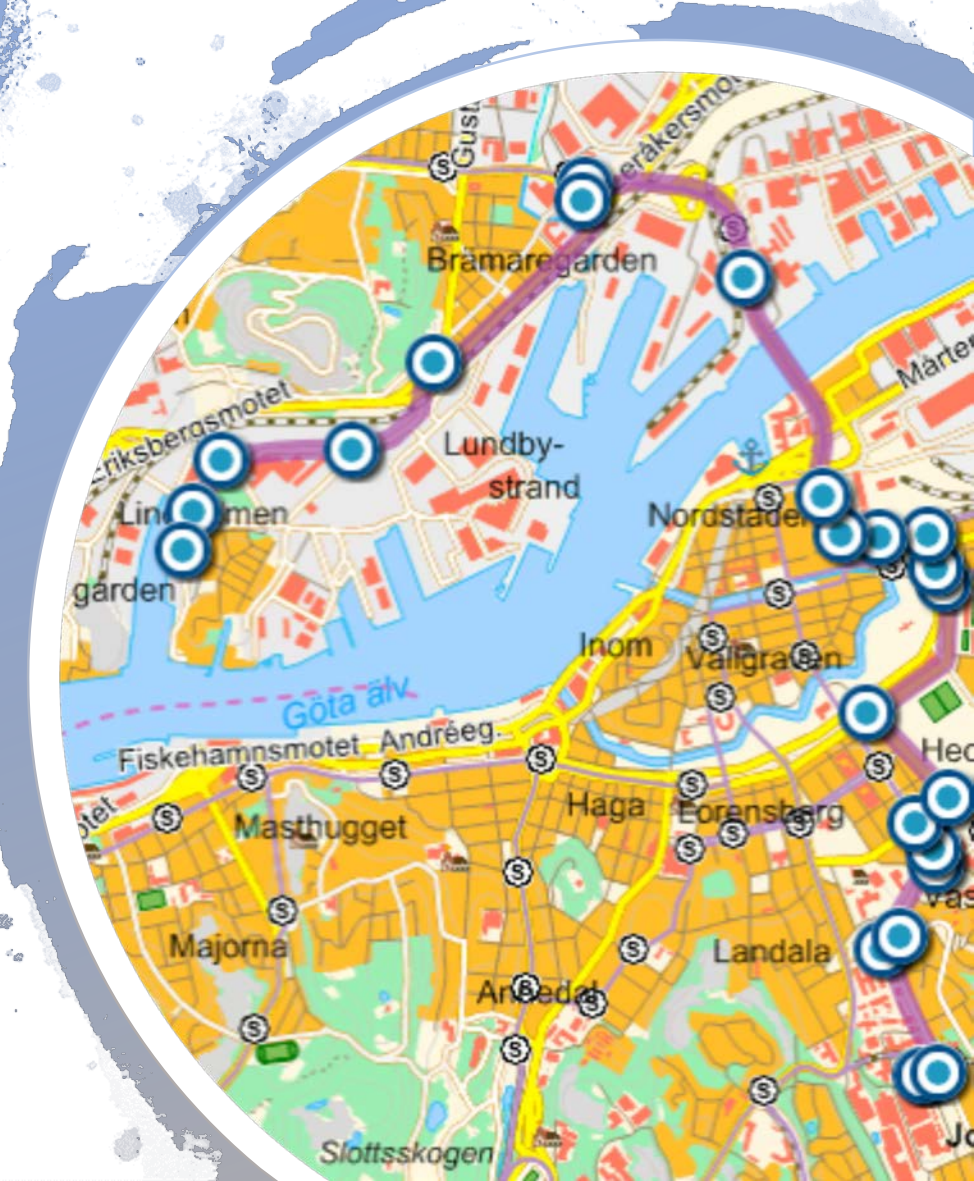
Avgång	Ankomst	Resetid	Byten	Trafikslag
<input type="checkbox"/> 17:50	18:19	00:29	1	Spårvagn 8, Spårvagn 7
<input checked="" type="checkbox"/> 17:59	18:28	00:29	1	Spårvagn 8, Spårvagn 7
<input type="checkbox"/> 18:08	18:38	00:30	1	Spårvagn 8, Spårvagn 7
<input type="checkbox"/> 18:25	18:49	00:24	0	Spårvagn 8
<input type="checkbox"/> 18:31	19:02	00:31	1	Spårvagn 6, Spårvagn 7
<input type="checkbox"/> 18:35	19:07	00:32	1	Spårvagn 8, Spårvagn 1

[Returresa](#) [Tillbaka resor](#) [Barnresor](#)

Detaljerad resväg | [Resväg som text](#) | [Mellanliggande hållplatser](#) | [Skicka till e-post](#) | [Skriv ut resor](#)

Detaljerad resväg:
Korsvägen - Opalatorget (torsdag 16 oktober 2008)

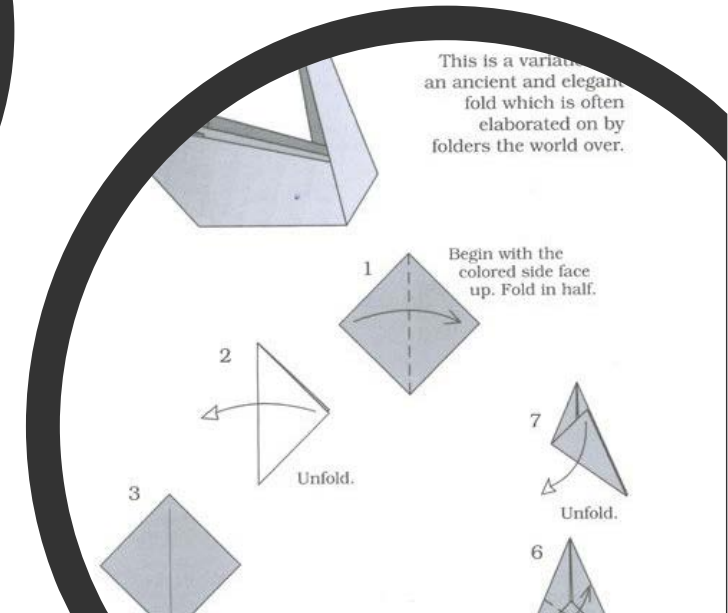
Linje	Från/Till	Tid	Information
Spårvagn 8	Korsvägen Läge F Frökunda Torp Läge B	Avg: 17:59 Ank: 18:19	Mot: Frökunda Torp
Spårvagn 7	Frökunda Torp Läge B Opalatorget Läge B	Avg: 18:24 Ank: 18:28	Mot: Opalatorget



Used an Algorithm Today?

Used an algorithm today?

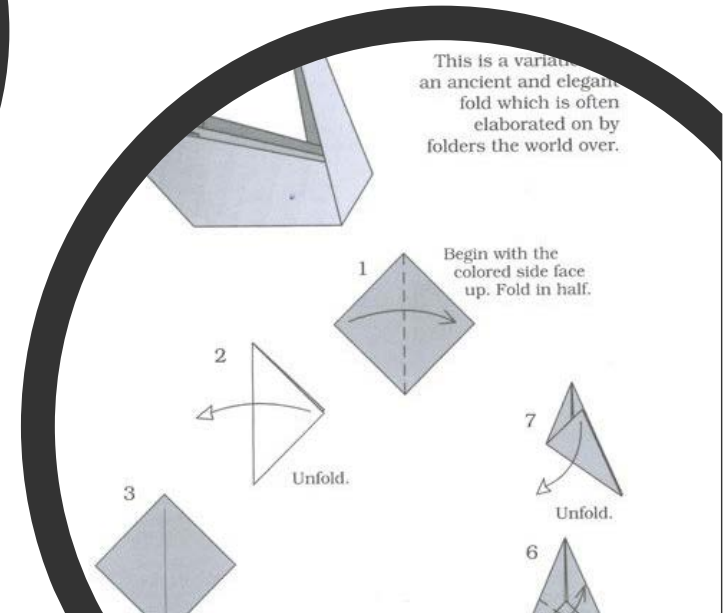
- Bake a cake
- Google translate
- Internet banking
- Google search
- Origami Swan



Used an algorithm today?



FTFTALILL-AVAV
--FTAL-LLAAV--



What is an Algorithm?

A set of steps that defines how a task is performed.

An algorithm is an ordered set of unambiguous, executable steps that defines a terminating process.

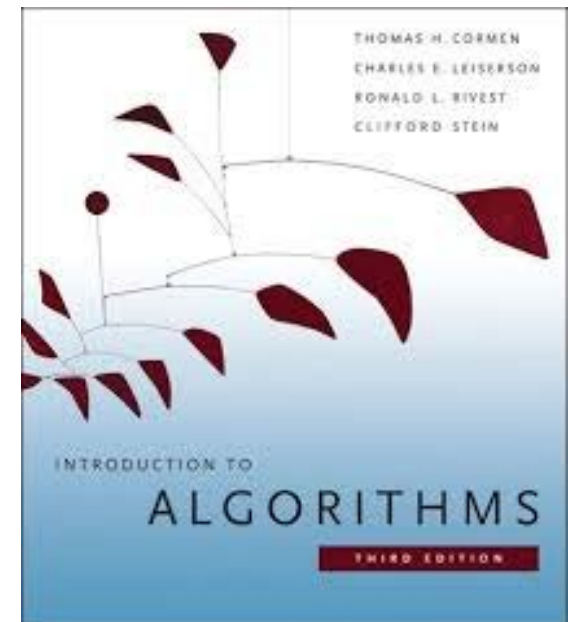
Brookshear

What is an Algorithm?

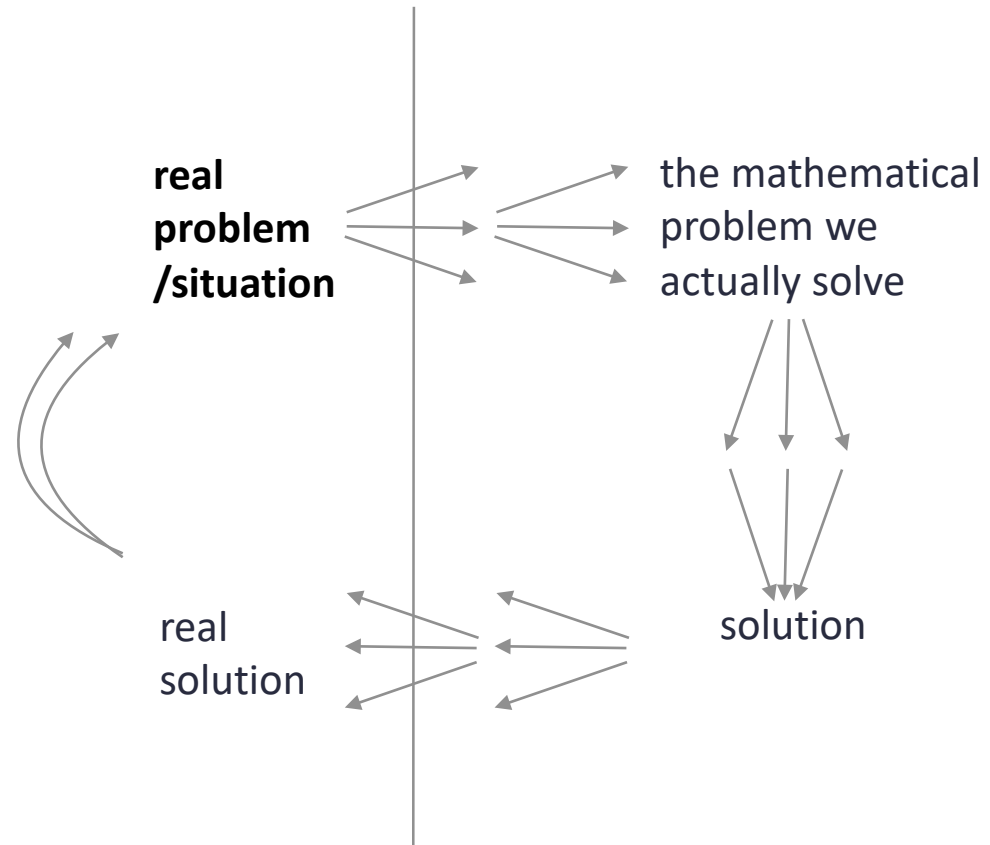
An Algorithm is a well-defined computational procedure that takes some value, or a set of values, as input and produces some value, or set of values as output.

An algorithm is thus a sequence of computational steps that transform input into output.

- More formal definition uses Turing machines



Algorithms in relation to modelling and problem solving



An iterative and creative design process!

First Known Algorithm?



- Greatest common divisor (GCD) algorithm by Euclid ca 300 B.C.

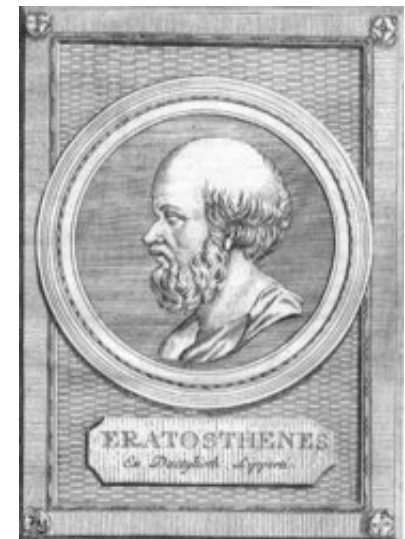
Euclid's Elements

- Prime numbers: Sieve of Eratosthenes, ca 200 B.C.

Animations:

[https://en.wikipedia.org/wiki/Algorithm_\(GCD\)](https://en.wikipedia.org/wiki/Algorithm_(GCD))

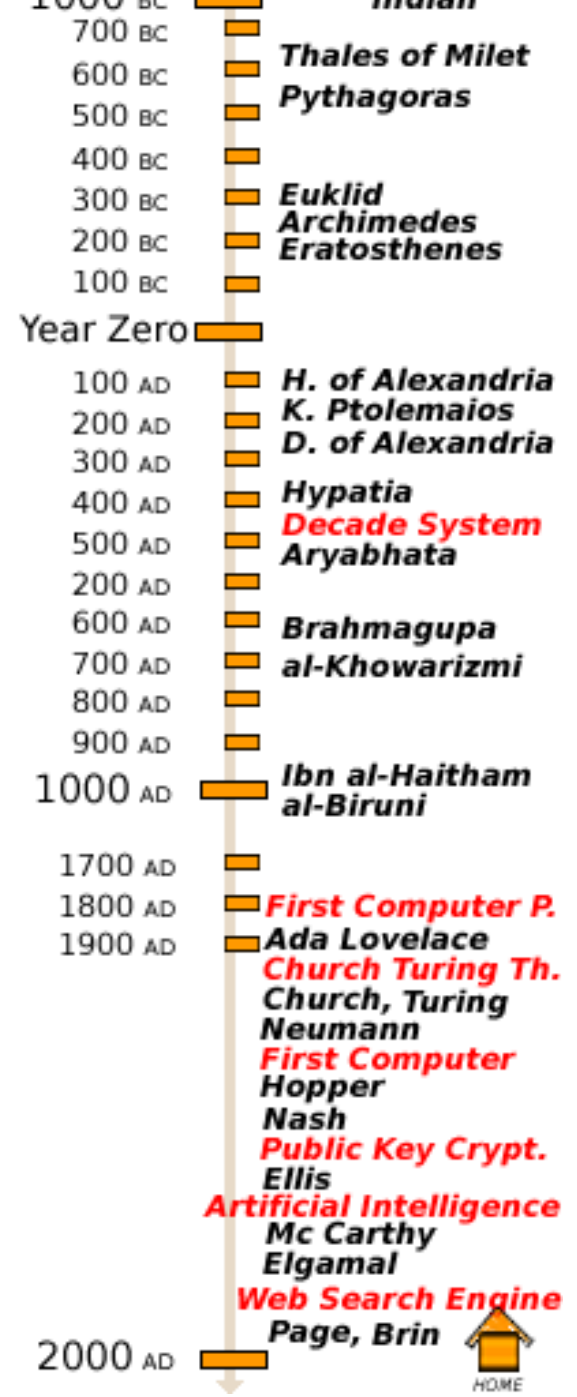
https://en.wikipedia.org/wiki/Sieve_of_Eratosthenes



Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

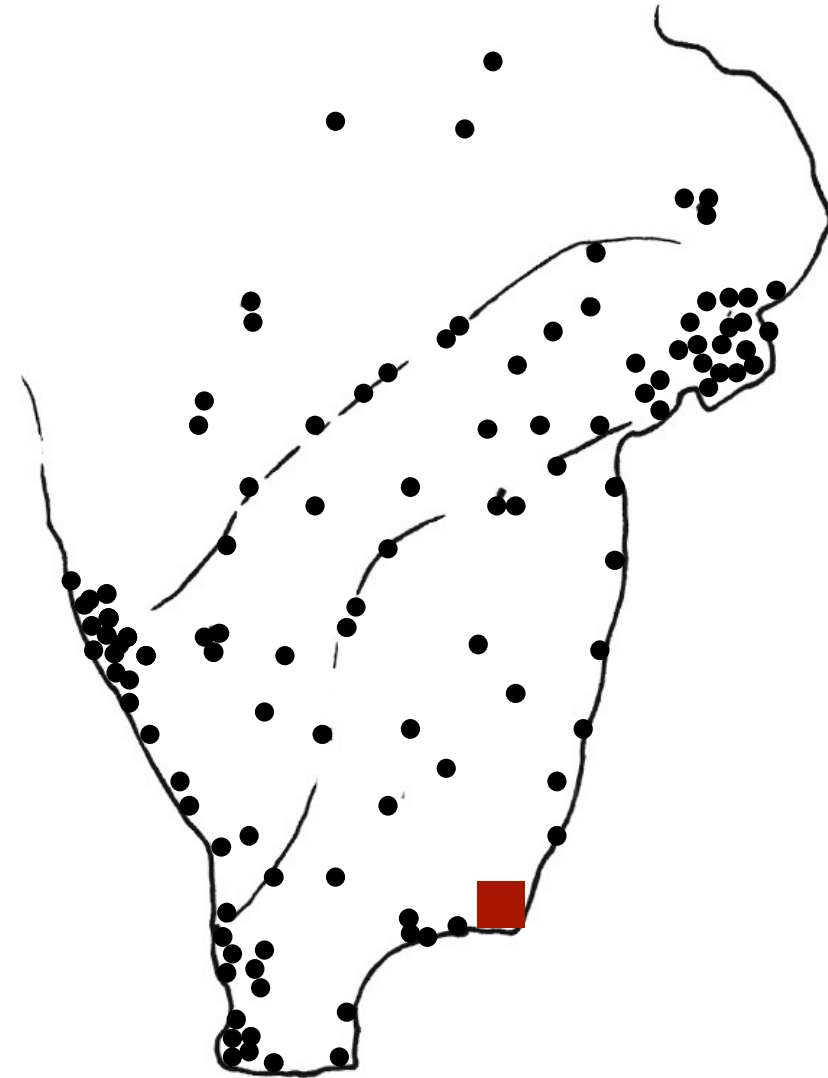
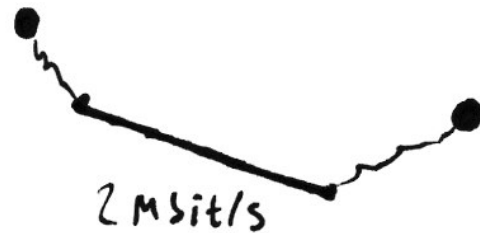
Some History



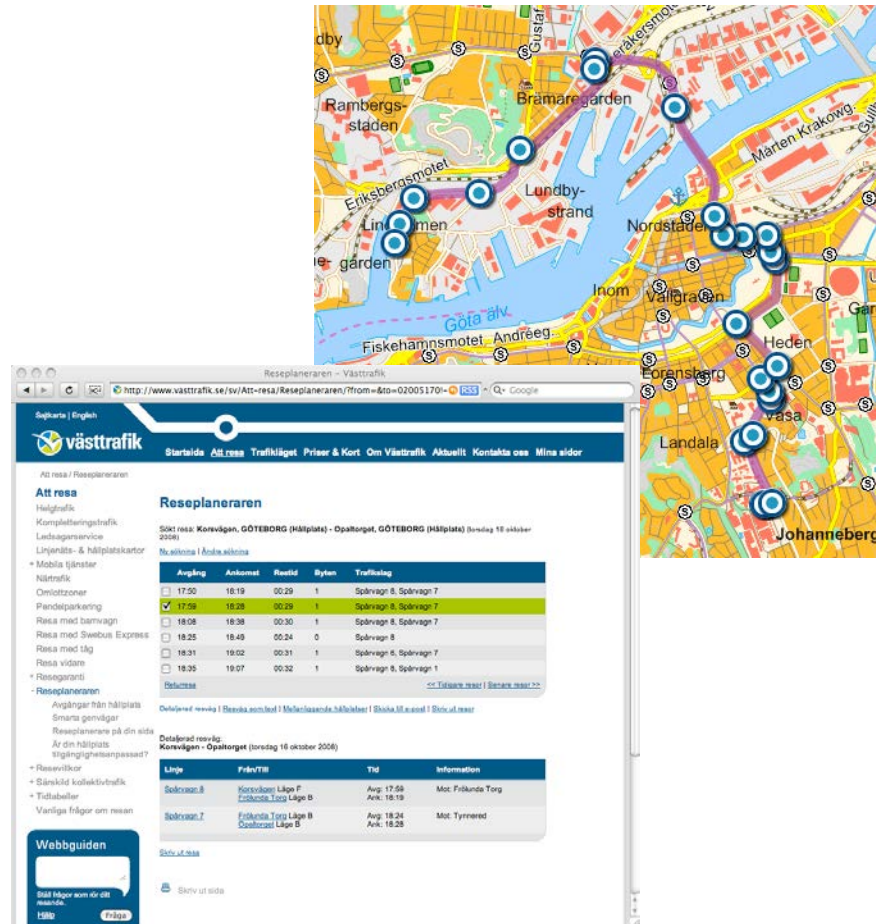
Telephone operator problem (real applied problem)

A Swedish mobile phone operator needs to connect all base station to its main switch.

How can we best rent communication lines from the national fixed network?



The Shortest Path Problem



The image displays a map of Göteborg, Sweden, with a highlighted purple path connecting several stations: Korevägen, Göteborg (Hälsiplats), Opalstorg, Göteborg (Hälsiplats), and Johanneberg. Below the map is a screenshot of the Västtrafik website's 'Reseplaneraren' interface, showing search results for a journey on October 16, 2008.

Reseplaneraren
SÖK resa: Korevägen, GÖTEBORG (Hälsiplats) - Opalstorg, GÖTEBORG (Hälsiplats) (torsdag 16 oktober 2008)
Sökresultat i Rödskalken

Ångång	Ankomst	Rasttid	Byten	Trafikslag
<input type="checkbox"/> 17:50	18:19	00:29	1	Spårvagn 8, Spårvagn 7
<input checked="" type="checkbox"/> 17:58	18:28	00:29	1	Spårvagn 8, Spårvagn 7
<input type="checkbox"/> 18:08	18:38	00:30	1	Spårvagn 8, Spårvagn 7
<input type="checkbox"/> 18:25	18:49	00:24	0	Spårvagn 8
<input type="checkbox"/> 18:31	19:02	00:31	1	Spårvagn 8, Spårvagn 7
<input type="checkbox"/> 18:35	19:07	00:32	1	Spårvagn 8, Spårvagn 1

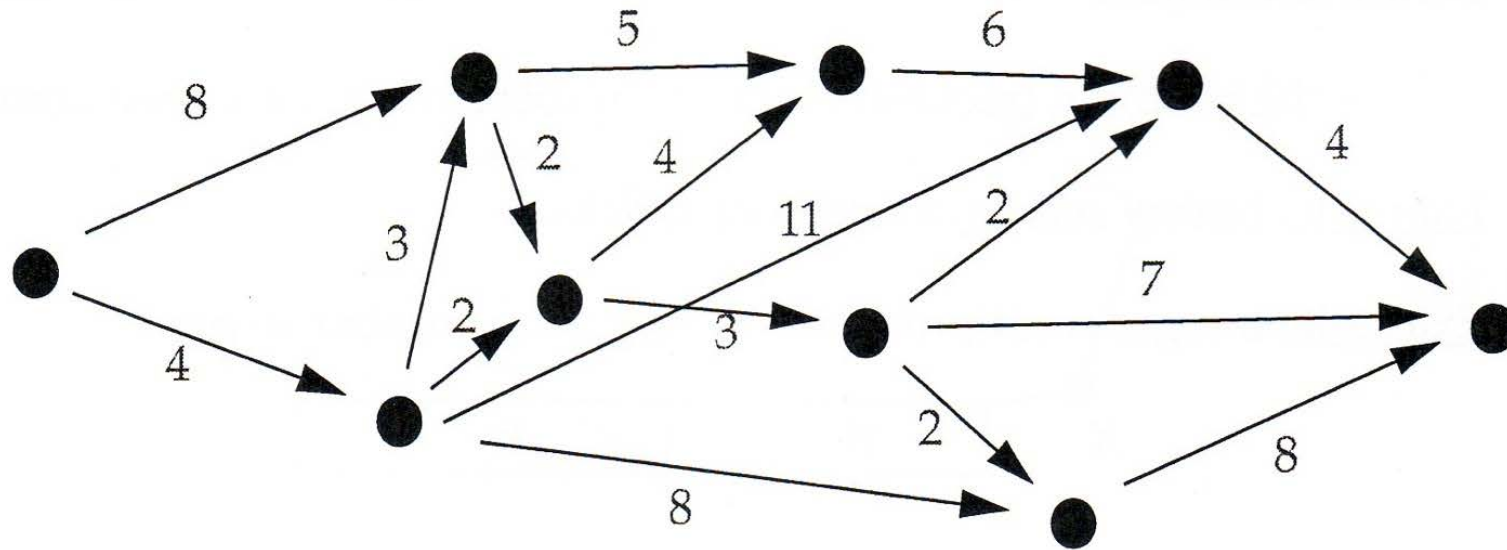
Detaljrad reorlag:
Korevägen - Opalstorg (torsdag 16 oktober 2008)

Läge	Frid/Tid	Tid	Information
Spårvagn 8	Korevägen Läge F Opalstorg Läge B	Ång 17:58 Ank 18:19	Mot: Frikskida Tong
Spårvagn 7	Frikskida Tong Läge B Opalstorg Läge B	Ång 18:24 Ank 18:28	Mot: Tyrnered

Revis ut data
Skriv ut sida

How solve?

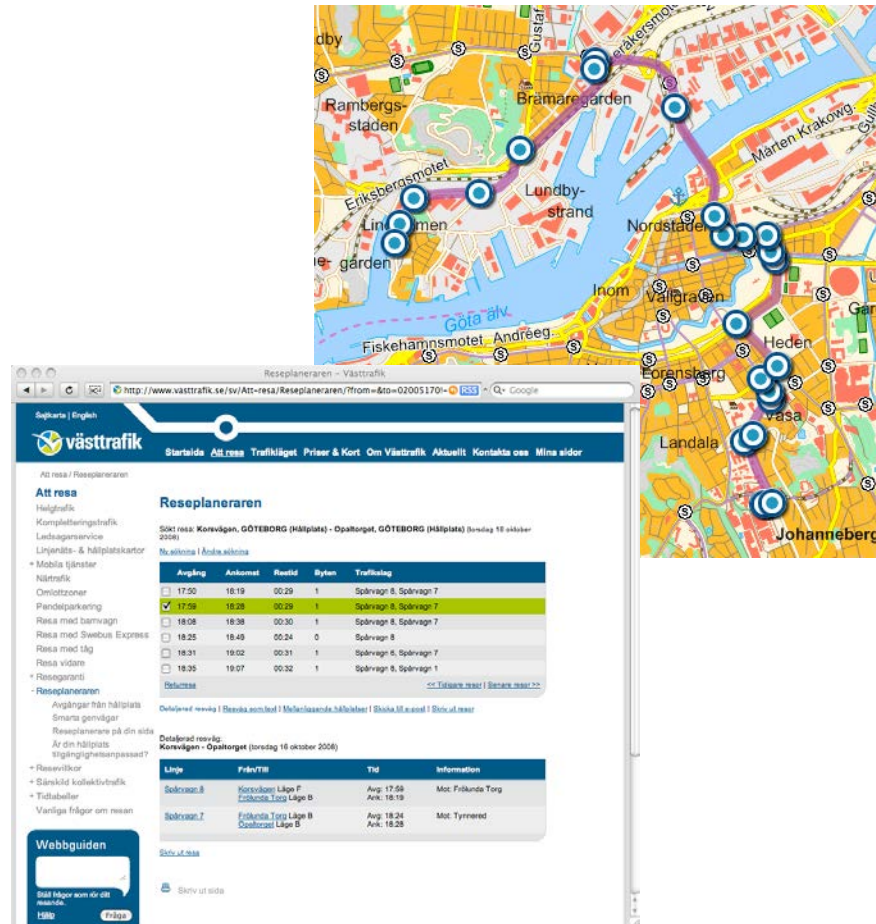
Solving the directed shortest path problem with dynamic programming



Traverse nodes from left to right and mark with distance from origin. Dijkstra's algorithm 1956 .

Circumvents the combinatorial explosion!
(not possible for all kinds of problems)

The Shortest Path Problem

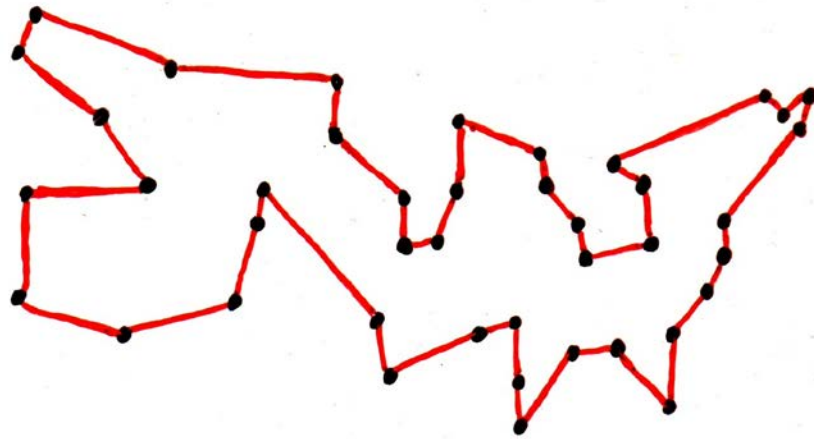


polynomial growth



n	$c n^2$
10	0,001 s
20	0,004 s
30	0,009 s
40	0,016 s
50	0,025 s
60	0,036 s

The Travelling Salesperson Problem



no known polynomial algorithm!

exponential growth



n	$c 2^n$
10	0,001 s
20	1 s
30	18 min
40	13 days
50	36 years
60	36600 years

TSP

Sweden Tour

24,978 Cities

0 50 100 Kilometers
0 50 100 Miles

Lambert Conformal Conic Projection, SP 47N/E24



Data	Plan	Rule	APC	Report	Options	Help	15:25							
Window	01/11	02/11	03/11	04/11	05/11	06/11	07/11	08/11	09/11	10/11	11/11	12/11	13/11	14/11
	01/11			02/11			03/11			04/11				
1 12 0/0/0/0/1/2	FRA	3 3	3	LIN	LIN	36 325 3251 5-0 5-0	FRA							
1 1 0/0/0/0/1/2	MUC	43 43 40 40 0-0 00	MUC											
1 12345 0/0/0/0/1/2	FRA	40 40 40 40 - 0-0	HAM	HAM	40 40 41 41	HAM		HAM	0 3725 5-5	ATH		ATH	372 380 0-5 5-0	IST
1 123456 0/0/0/0/1/2	FRA	2 4 4 4 4	DUS	DUS	4 4 4 4	DUS		DUS	4 4 4 4	DUS		DUS	4 4 4 4	DUS
1 123456 0/0/0/0/1/2	FRA	0 HAJ 40 40	HAJ	HAJ	40 40 41 41	HAJ		HAJ	40 40 41 41	HAJ		HAJ	40 40 41 41	HAJ
1 12 0/0/0/0/1/2	FRA	31 31 3210 0005	SVO	SVO	3213 481 470 0-0 0-0	FRA								
1 12356 0/0/0/0/1/2	FRA	3210 3211 0005 05-20	GVA	GVA	45 4	BRU		BRU	4 36 3	NAP				
1 12 0/0/0/0/1/2	MUC	40 40 3 0-0 00	BUD	BUD	30 30 3 05	MUC								
1 12345 0/0/0/0/1/2	FRA	3 34 3818 1515	IST	IST	380 373 5-0 0-5	ATH		ATH	3723 3846 5050 5-5	IST		IST	380 373 5-0 0-5	ATH
1 12 0/0/0/0/1/2	FRA	4 4 4	GVA	GVA	45 0065 0830-1530	FRA								
1 12 0/0/0/0/1/2	FRA	4 4 4	CDG	CDG	4 0075 0830-1530	FRA								
1 123 0/0/0/0/1/2	FRA	3 35 4	BRU	BRU	4 3 3 4			BRU	4 4815 4901 10-45 45-10	FRA				
1 123456 0/0/0/0/1/2	FRA	3846 3847 0 5-5 5055	HAM	HAM	40 40	HAM		HAM	40 40	HAM		HAM	40 40	HAM
1 1 0/0/0/0/1/2	FRA	4 46 005 0-0	FRA											
1 123 0/0/0/0/1/2	FRA	3736 5-0	ATH	ATH	3723 3 5050	LIN		LIN	36 325 3251 5-0 5-0	FRA				
1 1 0/0/0/0/1/2	FRA	4815 4901 10-45 45-10	FRA											
1 123 0/0/0/0/1/2	FRA	3 3 0	HAJ	HAJ	0 28 28 4 55 55	GVA		GVA	45 4 4	FRA				
1 1234 0/0/0/0/1/2	FRA	2 3230 3221 10-20 20-40	DUS	DUS	4 4 4 4	DUS		DUS	3230 10-20	SVO		SVO	3213 481 470 0-0 0-0	FRA
1 123456 0/0/0/0/1/2	FRA	481 470 3 0-0 0-0	STR	STR	40 40 00	STR		STR	40 40 00	STR		STR	40 40	STR
1 123456 0/0/0/0/1/2	FRA	33 3 8	DUS	DUS	4 4	DUS		DUS	4 4	DUS		DUS	4 4	DUS
1 1 0/0/0/0/1/2	FRA	480 475 3 3 0-5 5-0	FRA											
1 1 0/0/0/0/1/2	FRA	325 3251 5-0 5-0	FRA											
1 1 0/0/0/0/1/2	FRA	341 341 4 45 0-5 5-0	FRA											
1 1 0/0/0/0/1/2	FRA	47 471 43 43 5-5 5-0	FRA											
1 123 0/0/0/0/1/2	MUC	35 05	NAP	NAP	3 35 4	GVA		GVA	45 3 3	MUC				

Window	01/11	02/11	03/11	04/11	05/11	06/11	07/11	08/11	09/11	10/11	11/11	12/11	13/11	14/11
	01/11	02/11	03/11	04/11	05/11	06/11	07/11	08/11	09/11	10/11	11/11	12/11	13/11	14/11

Assign value: 0/0/0/0/1/2. Crew filter: On
 SVO - FRA LH 3211 -1 J 123.56. A320 LH3306 0 F000 C144 M000 1/0/1/0/0//1/2
 Gmt : 1605 - 1920 G00R 1 Date(G00P): 931101 SSIX 320 area : EU LH LH
 Local : 1905 - 2020 Crew comp: booked:0/0/0/0//1/2

931101 - 931114 : READY
 A320Nov01No cab14 scrat MTW
 352 rows. Dated CRs 931101 - 931104
 0 931101 - 931114

The resulting optimization problem

$$\begin{aligned} \text{minimize} \quad & 2x_1 + 2x_2 + 2x_3 + 2x_4 + x_5 + x_6 + x_7 + x_8 + 2x_9 + 2x_{10} \\ & + 2x_{11} + 2x_{12} + 2x_{13} + 2x_{14} + 2x_{15} + 2x_{16} + 2x_{17} \end{aligned}$$

subject to

$$x_1 + x_2 + x_3 + x_4 + x_9 + x_{10} = 1$$

$$x_1 + x_2 + x_3 + x_4 + x_9 + x_{10} = 1$$

$$x_2 + x_5 + x_6 + x_8 + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} = 1$$

$$x_2 + x_3 + x_5 + x_8 + x_{11} + x_{13} + 2x_{14} + 2x_{15} + x_{16} + x_{17} = 1$$

$$x_3 + x_4 + x_7 + x_8 + x_{10} + x_{13} + x_{14} + 2x_{15} + x_{16} + 2x_{17} = 1$$

$$x_4 + x_6 + x_7 + x_8 + x_{10} + x_{12} + x_{13} + x_{15} + x_{17} = 1$$

$$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17} \in \{0, 1\}$$

PAROS



Prereq: Math &
data structure

Courses and Programs

Core:

- *Algorithms* TIN093/DIT602
- Algorithms, advanced TDA251/DITDIT281

Related:

- Algorithms for Machine learning and inference TDA231/DIT380
- Applied Machine learning DAT340/DIT866
- Discrete optimization TDA206/DIT370
- *Mathematical modelling and problem solving*, Applied mathematical thinking

CS bachelor
and master
(GU)

"CS-all" (MPALG)
master (CTH)

Data
science and
AI master
(CTH)

Applied data
science master
(GU)

More Courses

- *Introduction to data science and AI* DAT405 (new)
- Techniques for large scale data DAT345/DIT871
- Design of AI systems (new)
- Computational methods for bioinformatics TDA507/DIT741
- Natural language processing with machine learning (new)
- Bachelor thesis and master's thesis projects
- Project course and seminar course

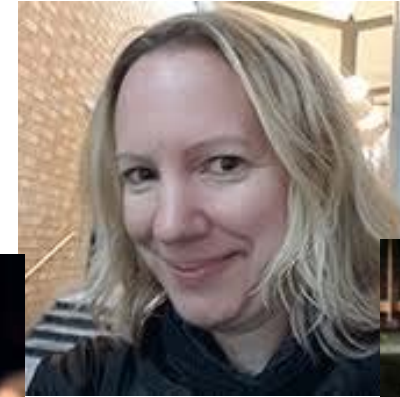
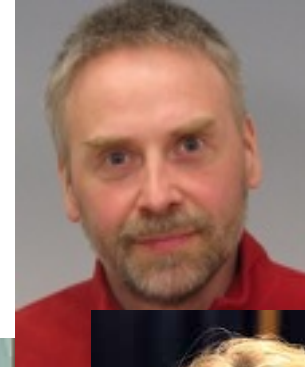
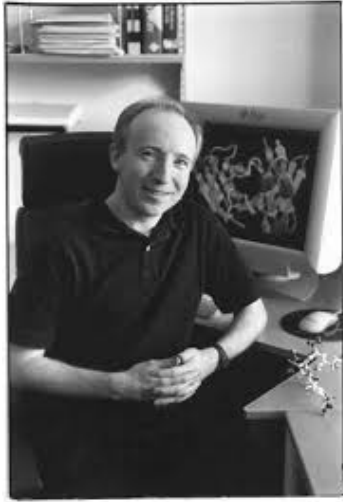
Research Areas within the Division DSAI

Machine learning, Artificial intelligence, Bioinformatics, ***Algorithms***, Graph theory, Randomized algorithms, Combinatorial optimization, Natural Language processing, Reinforcement learning, Unsupervised learning, Neural networks, Self-driving cars, Applications of machine learning in health, ***Mathematical modelling*** ...

Talks earlier in
this seminar
series

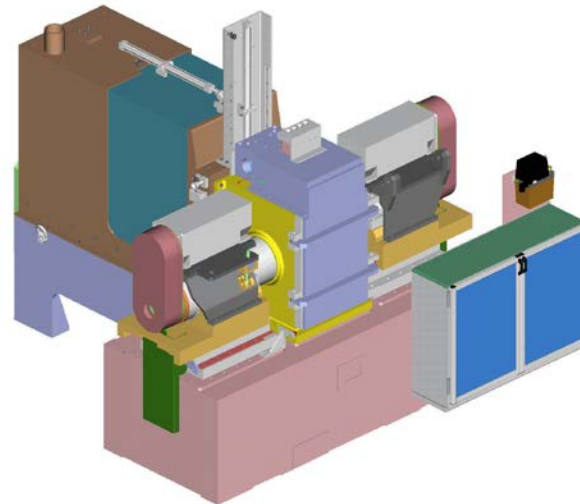
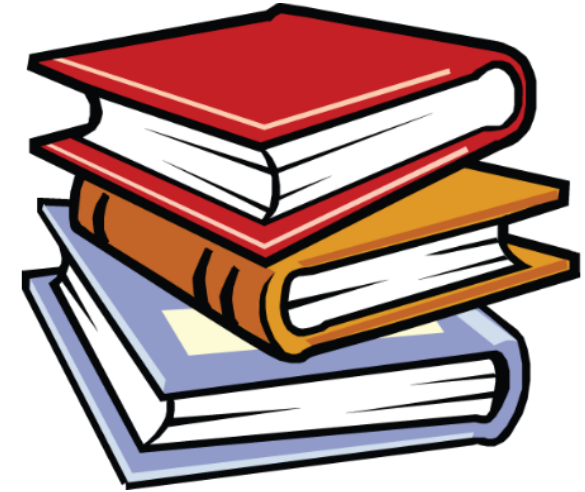
<https://www.chalmers.se/en/departments/cse/organisation/ds/Pages/default.aspx>

Division Data science and AI



Graham Kemp, Alexander Schliep, Dag Wedelin, Birgit Grohe, *Ashkan Panahi*,
Christos Dimitrakakis, Devdatt Dubhashi, Richard Johansson, Claes Strannegård, *Fredrik Johansson*
Morteza Chehregani, Peter Damaschke (+Phd students and postdocs)

Algorithms Courses – What's in it?



Course Content – Algorithms Toolbox

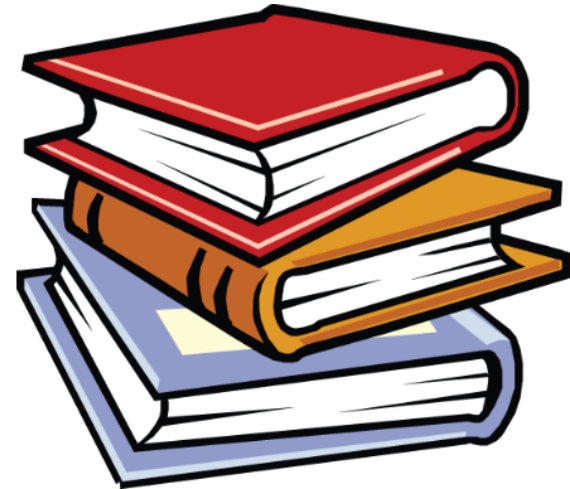
Algorithm design principles

- Greedy
- Divide and Conquer
- Dynamic Programming
- Complete Search
- Heuristics
- ...



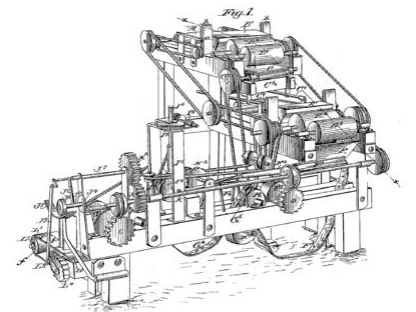
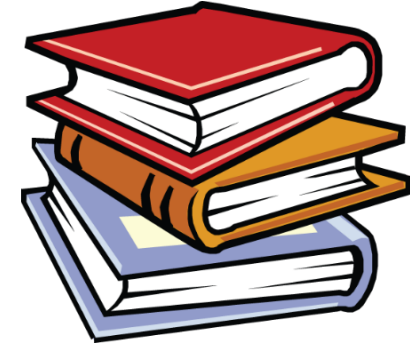
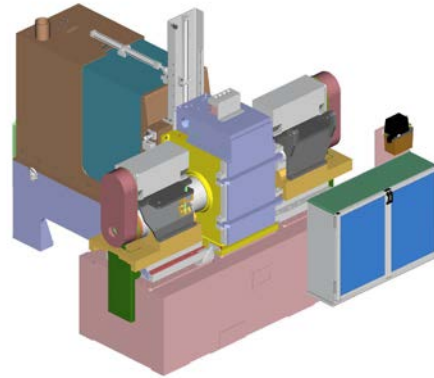
Course Content: Standard Problems

- Searching
- Sorting
- Finding shortest path (SP)
- Finding longest path
- Max flow problem
- Travelling salesperson problem (TSP)
- Graph Coloring
- Satisfiability problem (SAT)
- ...



Course Content: Standard Algorithms

- Binary Search
- Insertion Sort, Quicksort ...
- Breadth first search ...
- Dijkstras Algorithm
- Floyd Warshall Algorithm
- Ford Fulkerson Algorithm
- ...
- ...
- Randomized Algorithm for Scheduling Multi-Resource Jobs in the Cloud?





Good Algorithms?

”[...] We want *good* algorithms in some loosely defined aesthetic sense. One criterion is the length of the time to perform the algorithm [...] Other criteria are adaptability of the algorithm to computers, its simplicity and elegance etc ”

Knuth 1973:3