

# Scientific Computing

## Announcements

Wednesday, March 25

- \* Homework 4 due Friday!
- \* Monday, April 6: No lecture, work from home day

Office Hours:

Mon, 9:30-10:30

Fri, 2:00-3:00

Cudahy 307

At the start, the system has a high temperature and the prob. of accepting a worse move is high.

Over time, the system cools down (lower temp.) and the probability of accepting a worse move decreases.

Very high temp: basically a random walk, accepting all tweaks

Very low temp: basically hill climbing

## Process:

Pick an initial temperature  $T$

(How?)

$x =$  random solution

$best = x$  ← best ever seen

Repeat:

For a while: ← at a constant temp

(How long?)

(How long?)

$s =$  tweak( $x$ )

$\Delta =$  score( $s$ ) - score( $x$ )

if  $\Delta > 0$ :  $s$  is better than  $x$

$x = s$

if score( $x$ ) > score( $best$ ):

$best = x$

always move to improvements, save if best ever so far

else: ( $s$  is worse than  $x$ )

$r =$  random # in  $[0, 1]$  uniformly

if  $r < e^{\Delta/T}$ : prob. of accepting

$x = s$

$$T = 0.99 \cdot T$$

adjust the temperature according to the (How?)  
cooling schedule

# Code Review + Demos

\* #13, #12, no GUI

\* #5-8, TSP


50 cities	
SA Swap 2	9.82
SA RB	6.48
HC Swap 2	8.42
HC RB	6.45

300 cities	
SA Swap 2	32.82
SA RB	14.36
HC Swap 2	29.43
HC RB	14.25

HC = Hill Climbing  
SA = Steepest Ascent

RB = reverse a whole  
block of cities  
Swap 2 = swap just 2  
cities

There are tens of research papers about simulated annealing applications

 Journal of Heuristics, 5, 419–436 (1999)  
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## Best Practice Simulated Annealing for the Airline Crew Scheduling Problem

THOMAS EMDEN-WEINERT AND MARK PROKSCH  
*Institut für Informatik, Humboldt-Universität zu Berlin, December, 14th, 1998*  
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### *Abstract*

We report about a study of a simulated annealing algorithm for the airline crew pairing problem based on a run-cutting formulation. Computational results are reported for some real-world short- to medium-haul test problems with up to 4600 flights per month. Furthermore we find that run time can be saved and solution quality can be improved by using a problem specific initial solution, by relaxing constraints “as far as possible”, by combining simulated annealing with a problem specific local improvement heuristic and by multiple independent runs.

**Key Words:** airline crew scheduling, simulated annealing, pairing problem

### **1. Introduction**

The need to efficiently employ human and material resources increases with the competition on a world market. In recent years, the transportation industry including airline, railway, public transit, and parcel services has taken great effort to reduce the transportation costs. In the course, vehicle routing (Daduna and Paixao, 1995; Fisher, 1995; Gendreau, Laporte, and Potvin, 1997) and crew scheduling (Rushmeier, Hoffman, and Padberg, 1995; Desrosiers et al., 1995; Desaulniers et al., 1997; Andersson et al., 1997; Caprara et al., 1997; Wren and Rousseau, 1995) have become prominent application areas of mathematical programming

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## A hybrid constructive heuristic and simulated annealing for railway crew scheduling <sup>☆</sup>



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### ABSTRACT

Railway crew scheduling problem is the process of allocating train services to the crew duties based on the published train timetable while satisfying operational and contractual requirements. The problem is restricted by many constraints and it belongs to the class of NP-hard. In this paper, we develop a mathematical model for railway crew scheduling with the aim of minimising the number of crew duties by reducing idle transition times. Duties are generated by arranging scheduled trips over a set of duties and sequentially ordering the set of trips within each of duties. The optimisation model includes the time period of relief opportunities within which a train crew can be relieved at any relief point. Existing models and algorithms usually only consider relieving a crew at the beginning of the interval of relief opportunities which may be impractical. This model involves a large number of decision variables and constraints, and therefore a hybrid constructive heuristic with the simulated annealing search algorithm

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## Large Scale Adaptive 4D Trajectory Planning

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**Abstract**—Global air-traffic demand is continuously increasing. To handle such a tremendous traffic volume while maintaining at least the same level of safety, a more efficient strategic trajectory planning is necessary. Static 4D trajectory planning with constant 4D segments, where aircraft have to stay all along their flights, ensures a strong predictability of traffic and may reduce congestion in airspace. The main limitation of this approach is linked to the 4D constraint associated to aircraft. As a matter of fact, each aircraft has to comply to this 4D segment to maintain separation from other aircraft, but this induces a real time control of the engine in order to stay all the time in this 4D segment. This could result in extra fuel consumption and shorter engine life. In this work, we present an adaptive 4D strategic trajectory planning methodology which aims to minimize interaction between aircraft at the European-continent scale. The main purpose of this work is to associate to each aircraft a 4D bubble which is adapted to the current traffic situation. When aircraft are located in low density areas, the size of such bubbles can extend (with a maximum range of 20 minutes) and when aircraft enter high congestion areas, such

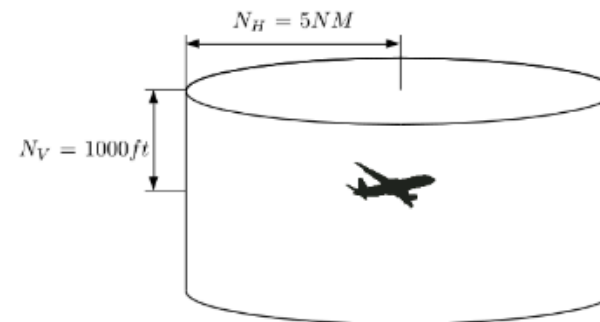


Figure 1: The cylindrical protection volume.

Eurocontrol which checks the availability of the airspace. If the request is compatible with the capacity limit, the flight plan will be accepted. Otherwise, the CFMU will suggest

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**IMPROVED SIMULATED ANNEALING FOR OPTIMIZATION OF VEHICLE ROUTING PROBLEM WITH TIME WINDOWS (VRPTW)**

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**Abstrak**

Vehicle routing problem with time windows (VRPTW) merupakan permasalahan optimasi kombinatorial yang banyak ditemui pada sistem distribusi permasalahan ini berkaitan dengan pengalokasian sejumlah kendaraan umum untuk melayani sejumlah konsumen, sejumlah konsumen mempunyai rentang waktu kesediaan yang berbeda dan harus dilayani dalam waktu tersebut. Paper ini memaparkan penggunaan metode simulated annealing yang diperkaya dengan beberapa fungsi khusus untuk menghasilkan solusi tetangga yang digunakan pada penelusuran dan pencarian solusi dari VRPTW. Serangkaian percobaan menunjukkan bahwa simulated annealing yang diperkaya dengan fungsi-fungsi khusus dapat menghasilkan solusi yang baik dalam waktu rata-rata 82.29 detik.

Kata kunci: *Vehicle Routing Problem with Time Windows (VRPTW)*, Permasalahan optimasi kombinatorial, *Simulated annealing*, solusi tetangga.

**Abstract**

*The Vehicle Routing Problem with Time Windows (VRPTW) is a combinatorial optimization problem that exists in various distribution systems. The problem deals with allocation of vehicles to service several customers, each customer has different available time, and the vehicles must visit the customers in their available time. This paper addresses the VRPTW by using an improved simulated annealing algorithm.*

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**Simulated  
Annealing for  
VLSI Design**

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**D.F. Wong  
H.W. Leong  
C.L. Liu**



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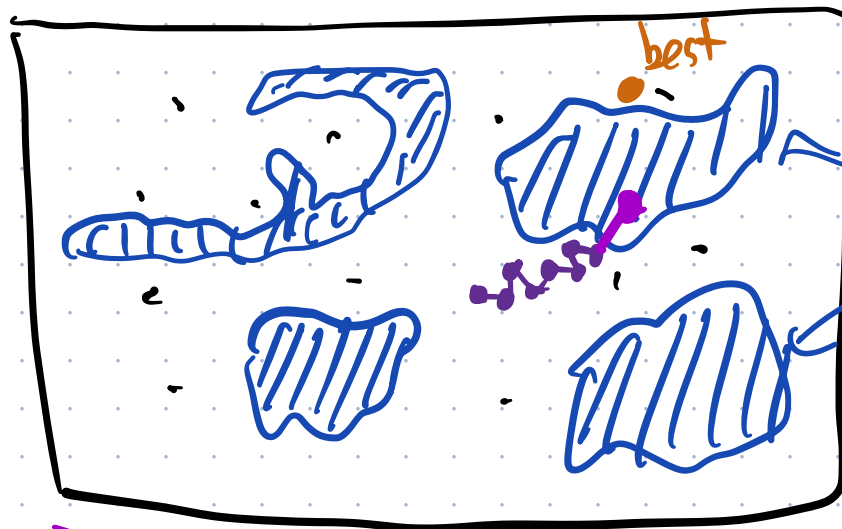
# \* Spring Demo

- staying within constraints by re-tweaking
- playing with parameters

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## Metaphorical Picture of the search space

how do we tweak to make sure we satisfy constraints?



constraints are violated

bound conditions