Capacity-Driven Automatic Design of Dynamic Aircraft Arrival Routes

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TEAMWORK with automation

LFV

Overview

- ✓ **ODESTA project**: optimal design for TMA
- ✓ **LiU-LFV** joint project funded by Vinnova (Sweden)
- ✓ **Recap:** optimal Stars (static), sectors, simultaneous design-- *Strategic planning*
- ✓ **New:** time-separated demand-weighter ***arrival routes (dynamic)***-- *Pre-tactical planning*
  - problem description
  - constraints and objectives
  - experimental study: Arlanda Airport
- ✓ **Future:** moving objects avoidance, robust against weather uncertainties

ODESTA project : TMA optimization

- ✓ **Recap:**
- ✓ Automated optimal STARs (static)
- ✓ Grid-based approach
- ✓ MIP formulation (solved using GUROBI, CPLEX)
- ✓ Experimental Study: Arlanda Airport

Recap: optimal STARs - Problem description

Given

- ✓ location and direction of the airport runway
- ✓ locations of the entry points to the TMA

Output

Optimal arrival tree that merges traffic from the entries to the runway

Constraints

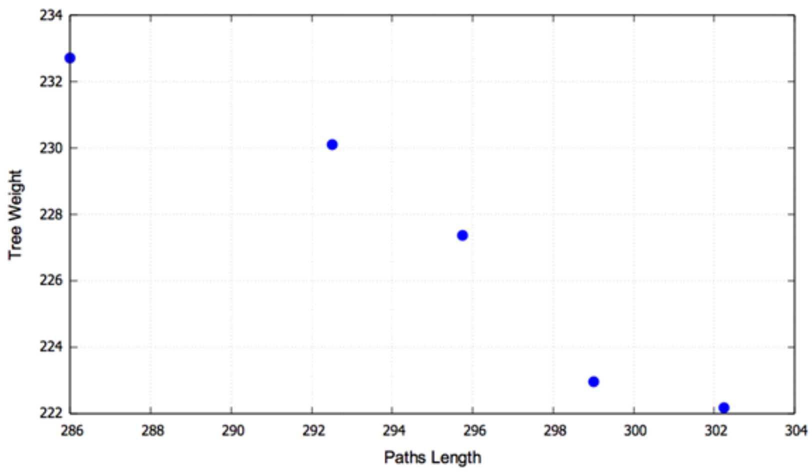
- ✓ No more than two routes merge at a point
- ✓ Merge point separation
- ✓ No sharp turns
- ✓ Obstacle avoidance (static)
- ✓ STAR/SID separation

Objectives

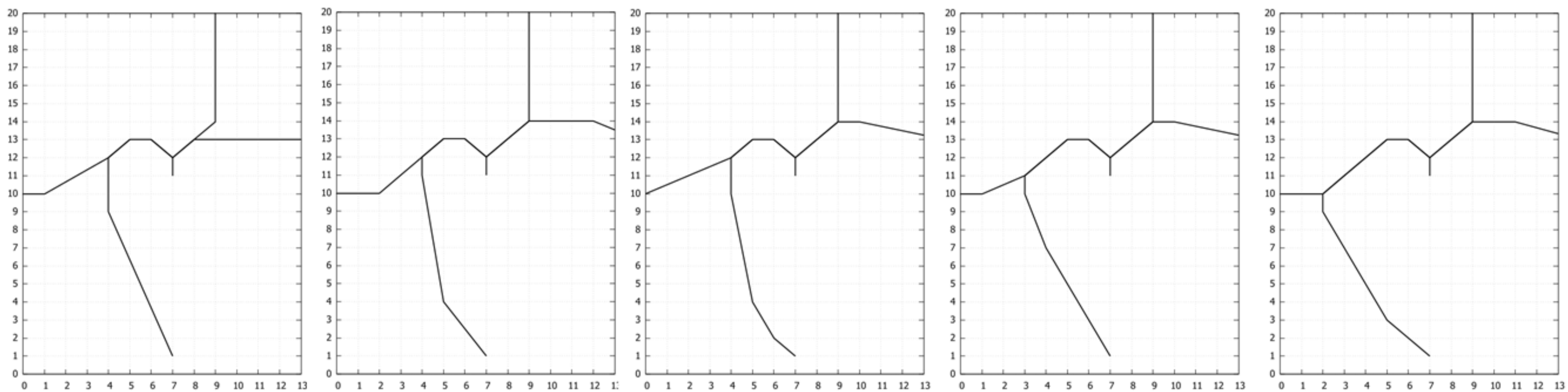
- ✓ Minimize total tree weight
- ✓ Minimize the sum of the total paths

RECAP: Arlanda Airport TMA (19R): solutions

Pareto frontier:



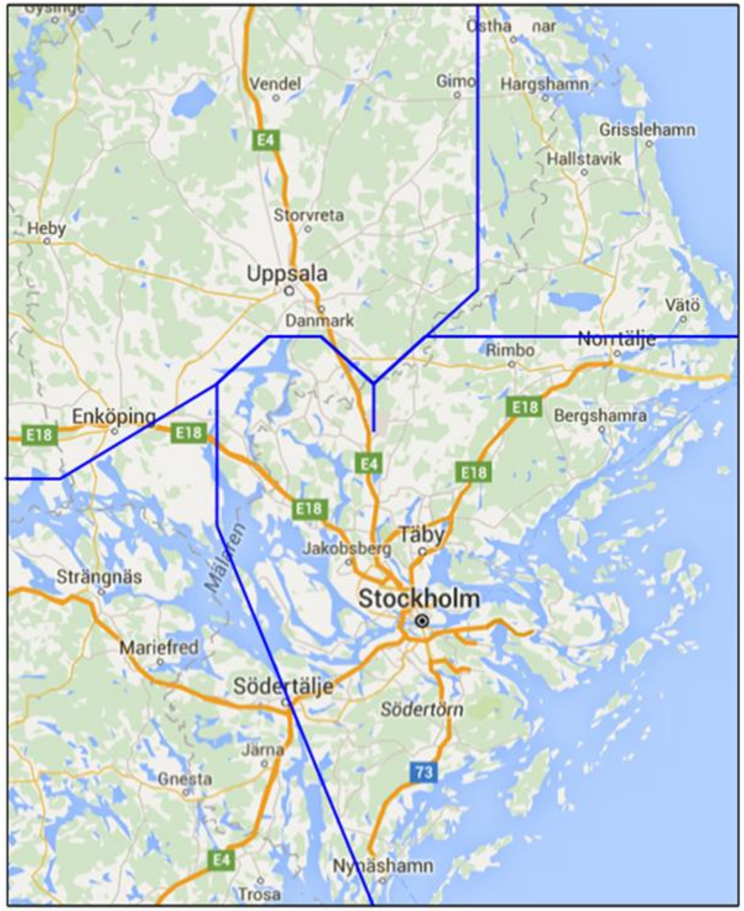
Pareto optimal solutions:

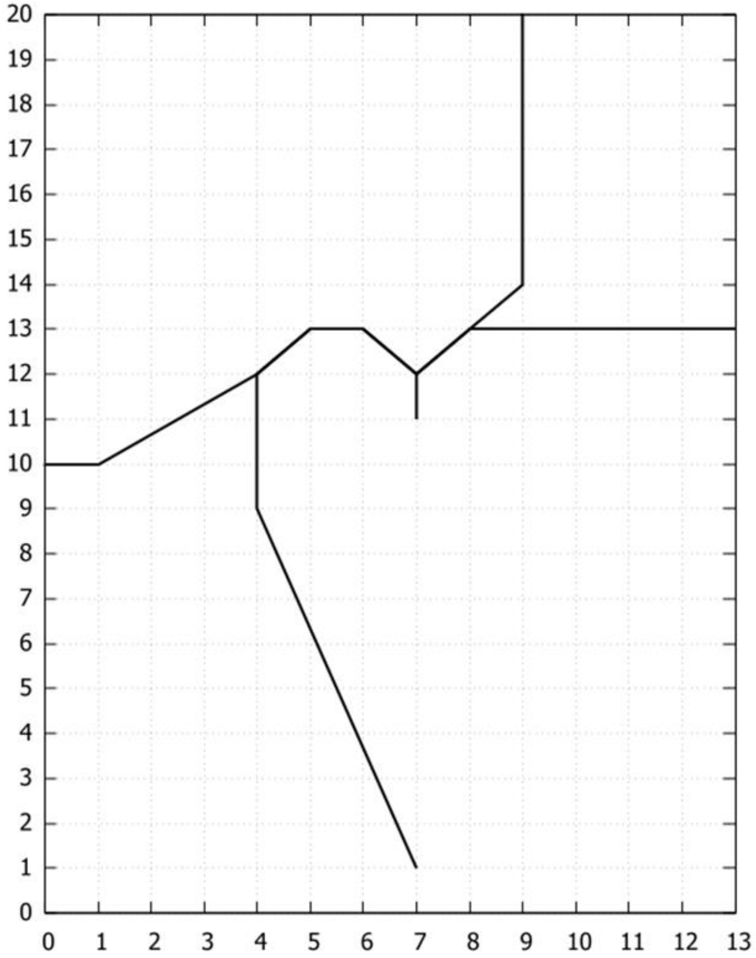


Re: Grid-based IP formulation

- ✓ Square grid in the TMA
- ✓ Snap locations of the entry points and the runway onto the grid
- ✓ Side of the grid: L (for safe separation)
- ✓ Every grid node connected to its 8 neighbors

RE: Arlanda Airport TMA (19R)





NEW: optimal time-separated demand-weighted -- Problem description

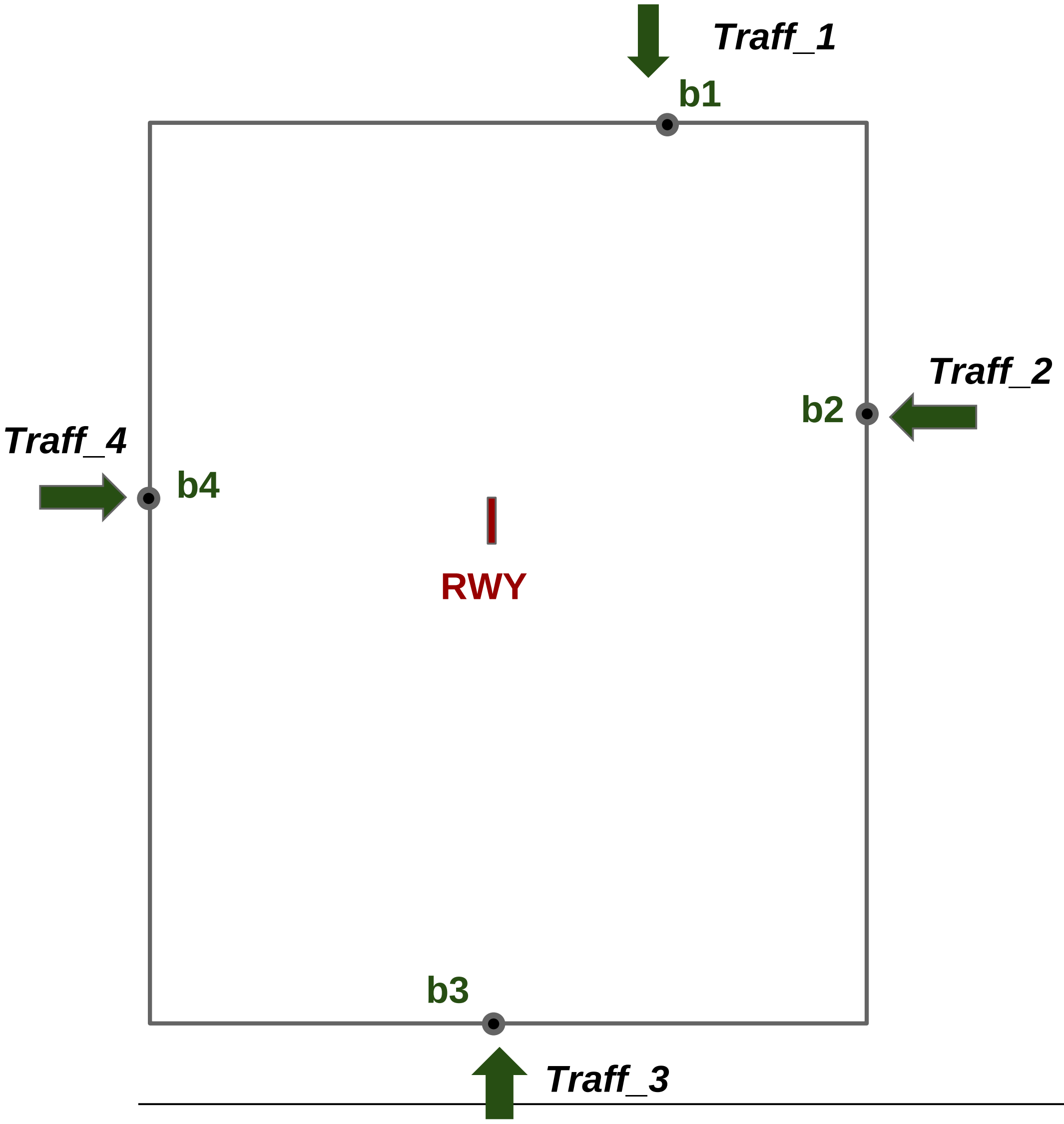
Given

- ✓ location and direction of the airport runway
- ✓ locations of the entry points to the TMA
- ✓ *times aircraft arrivals at the entry points for a fixed time period*

Output

Optimal arrival tree that merges traffic from the entries to the runway and *ensures safe aircraft separation for the given time period*

New: Dynamic Demand-driven Arrival Routes



Input +:
Aircraft arrivals for a given period

Output:
arrival tree = a set of optimal demand-weighted aircraft trajectories

optimized w.r.t. the **traffic demand during the given period**

Data: EUROCONTROL DDR

Constraints

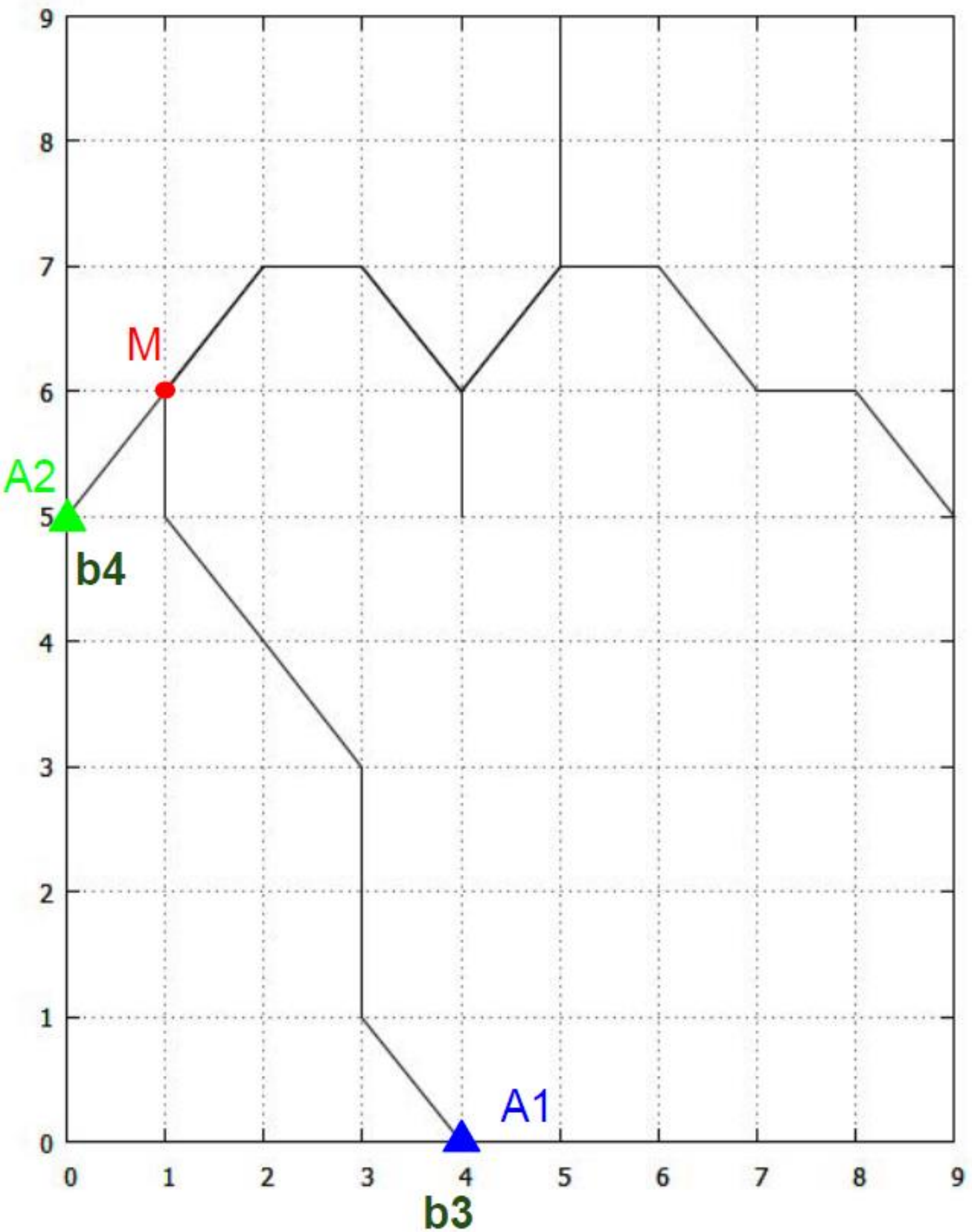
OLD:

- ✓ No more than two routes merge at a point
- ✓ Merge point separation
- ✓ No sharp turns
- ✓ Obstacle avoidance (static)
- ✓ STAR/SID separation

NEW (DASC'18):

- ✓ Temporal separation of all aircraft along the routes

Idea: temporal aircraft separation

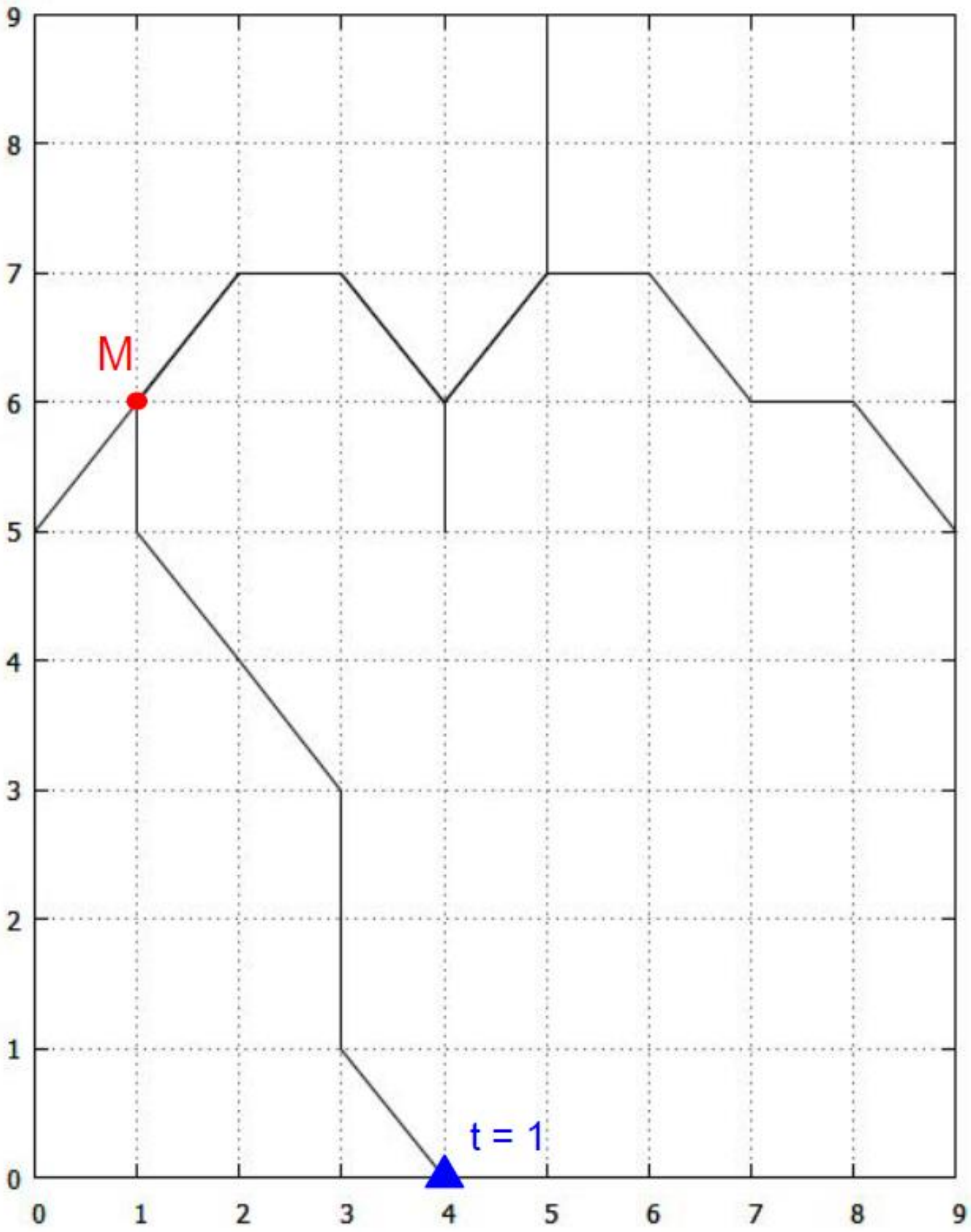


A1 - airplane 1 starts from b3

A2 - airplane 2 starts from b4

M - merge point

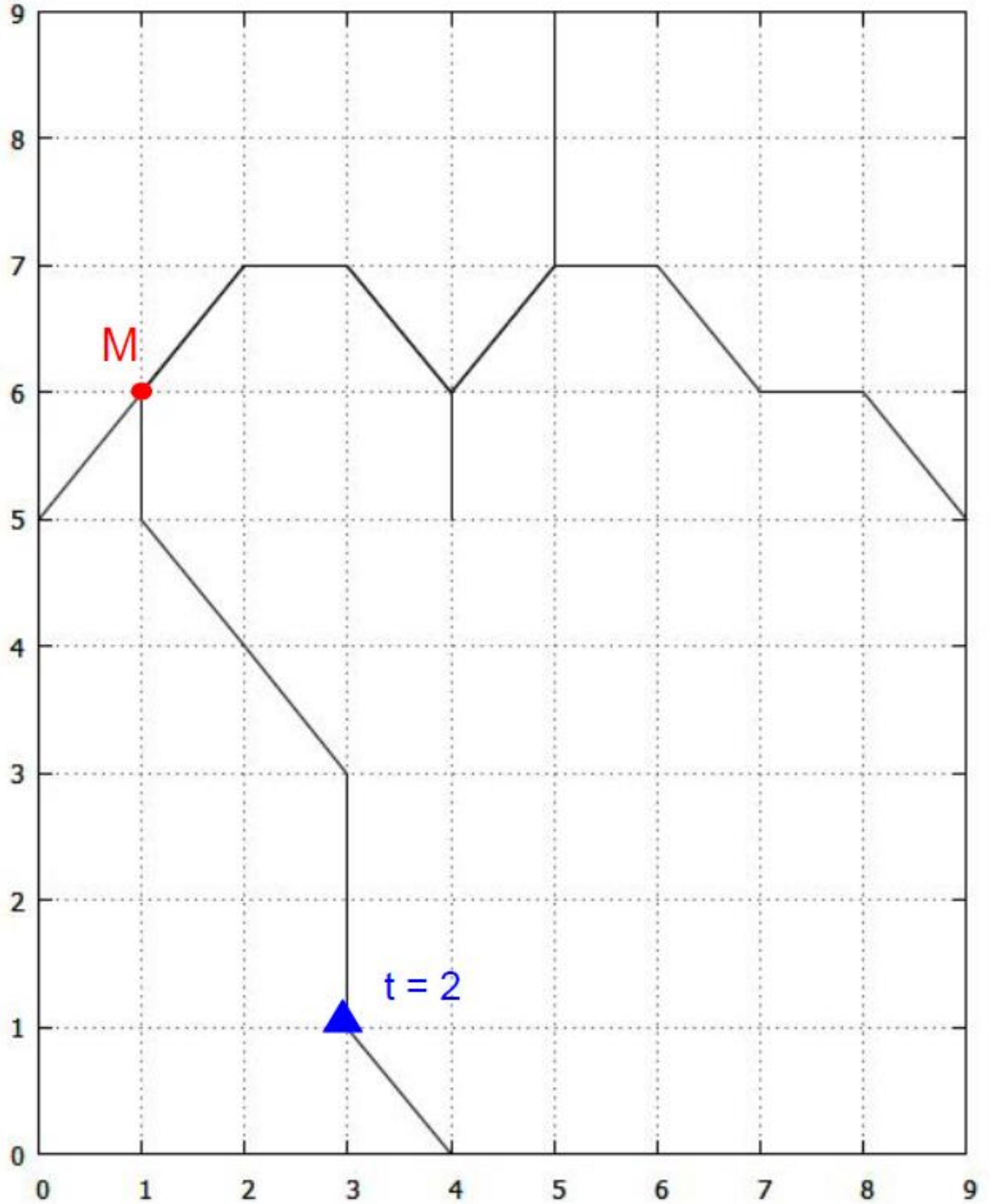
t = 1



If

A1 starts at t = 1

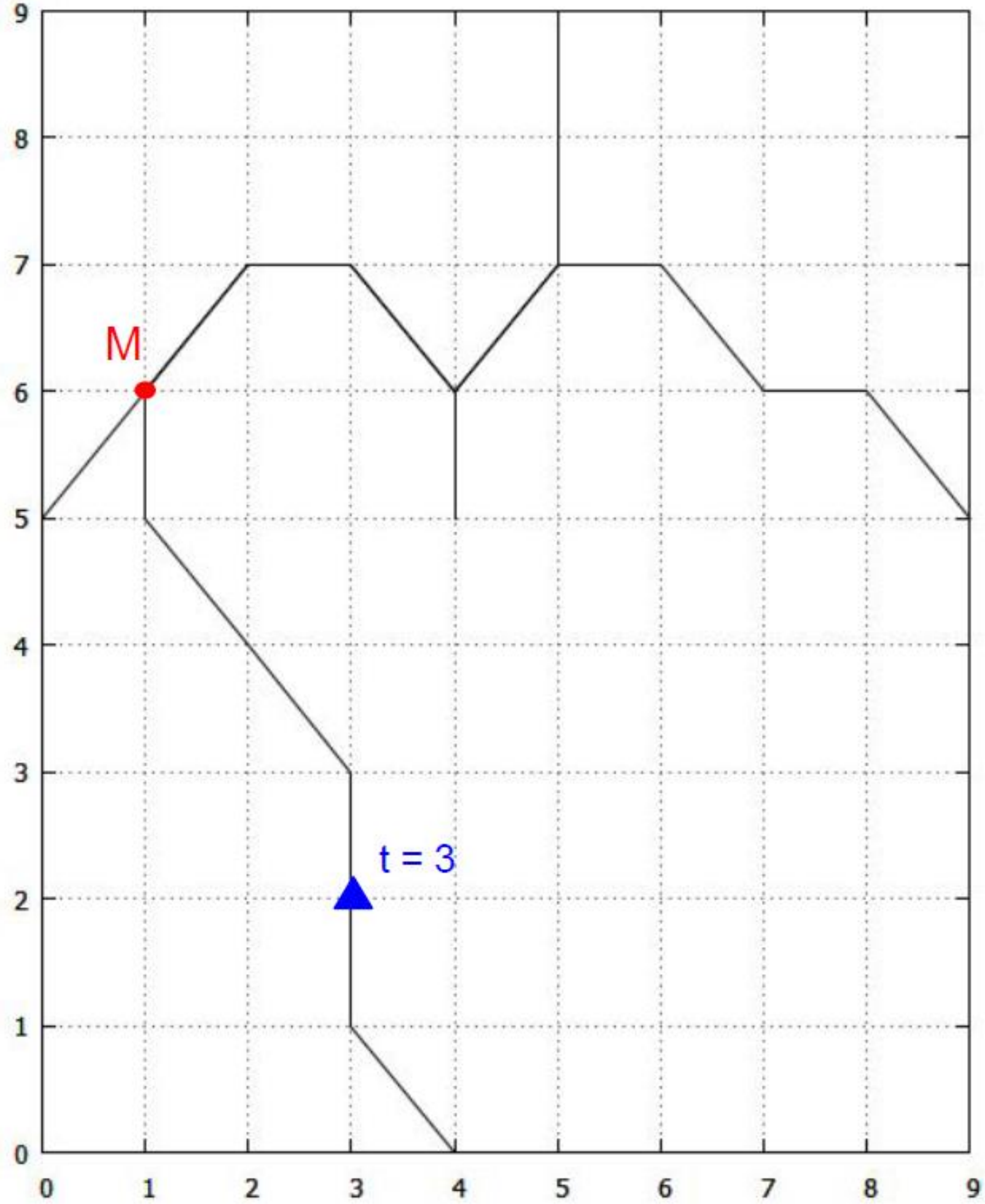
t = 2



If

A1 starts at t = 1

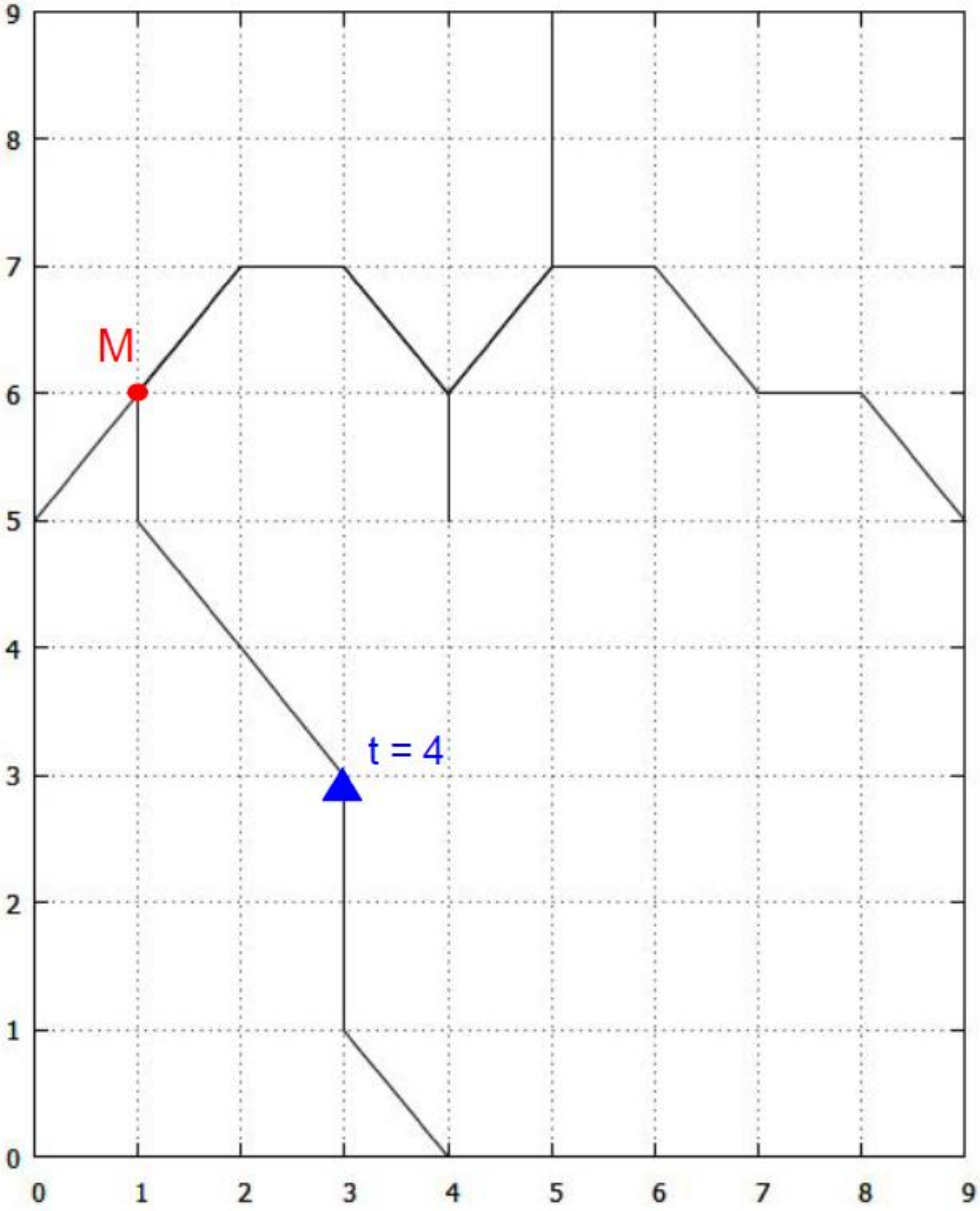
t = 3



If

A1 starts at t = 1

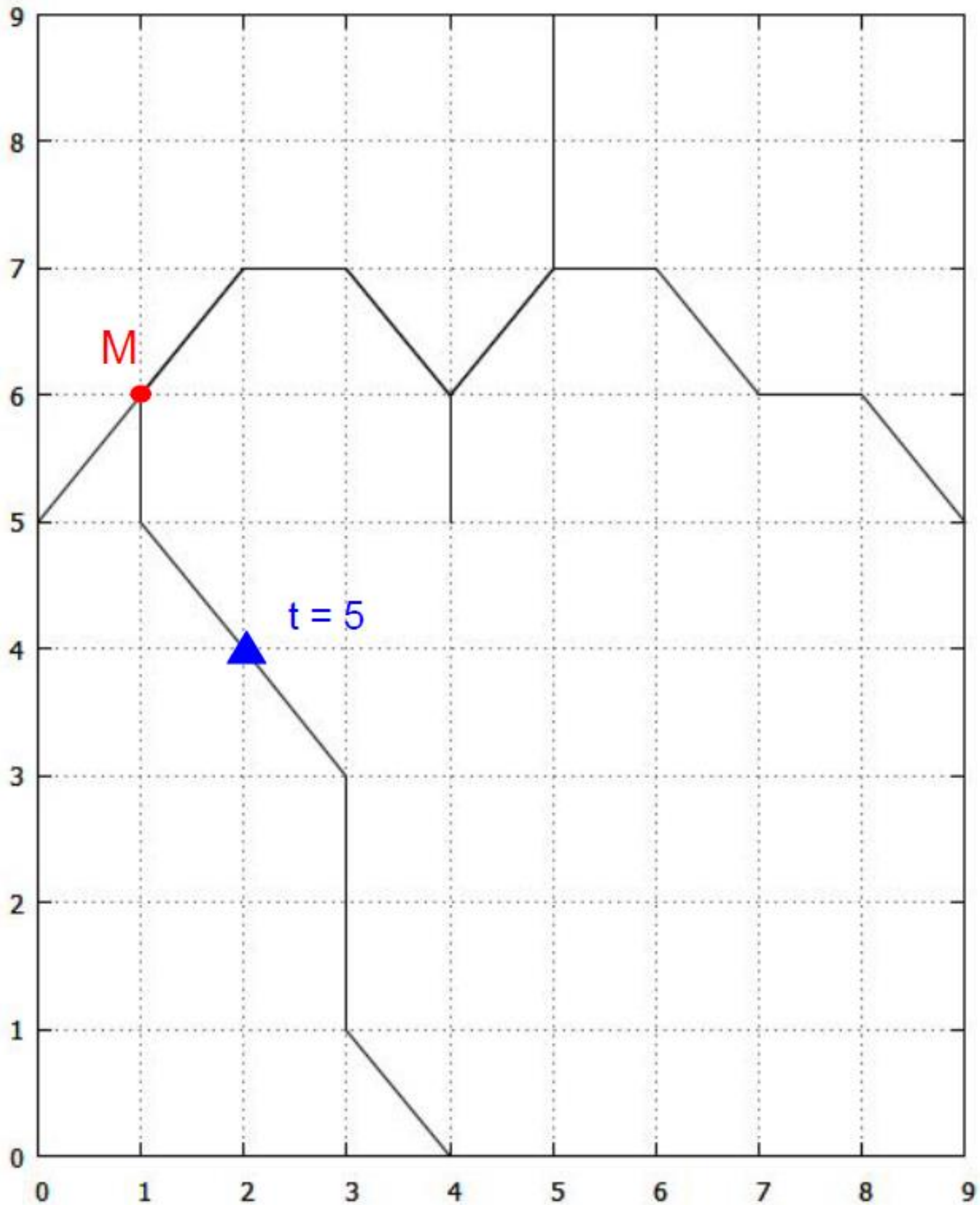
t = 4



If

A1 starts at t = 1

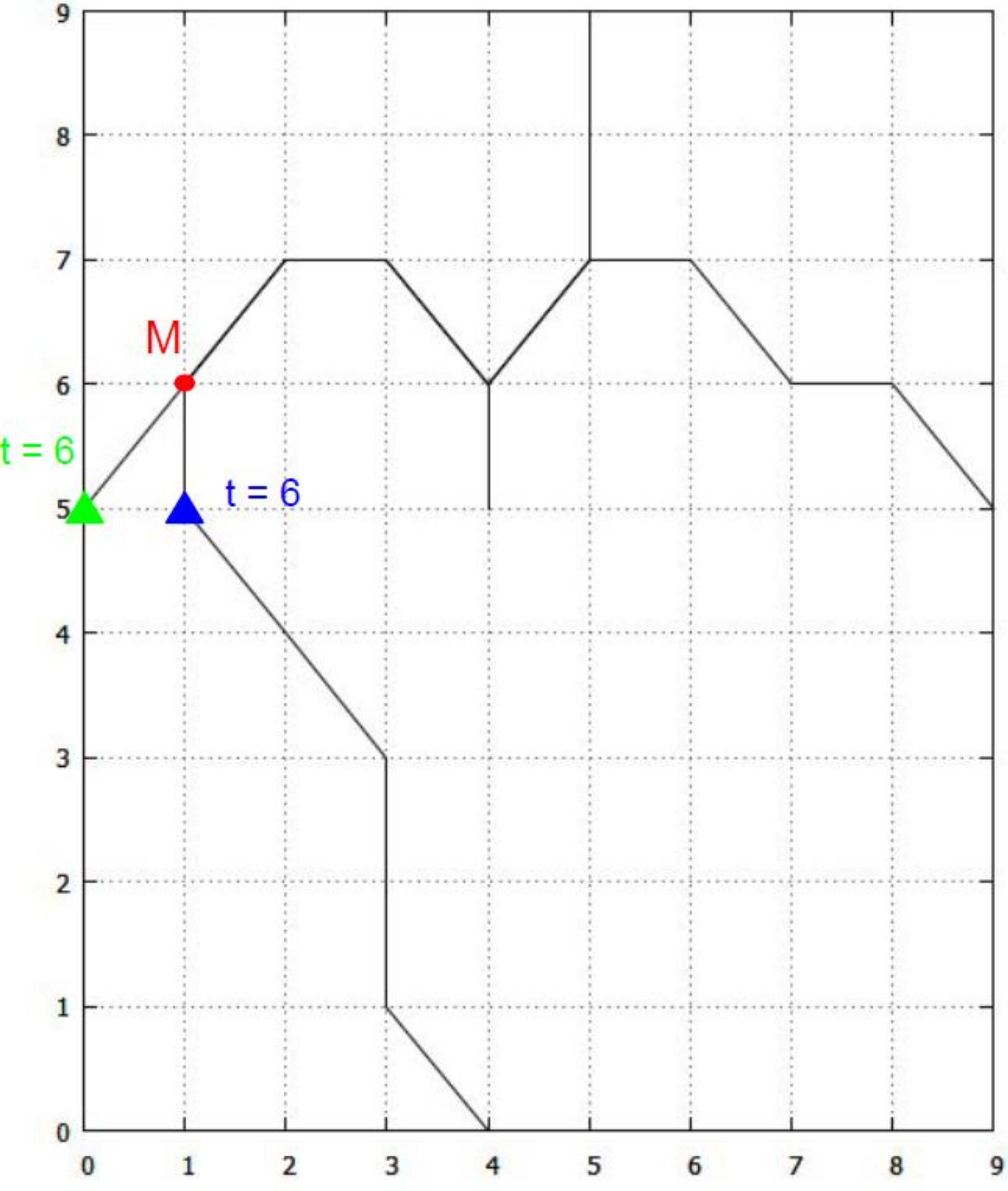
t = 5



If

A1 starts at t = 1

t = 6

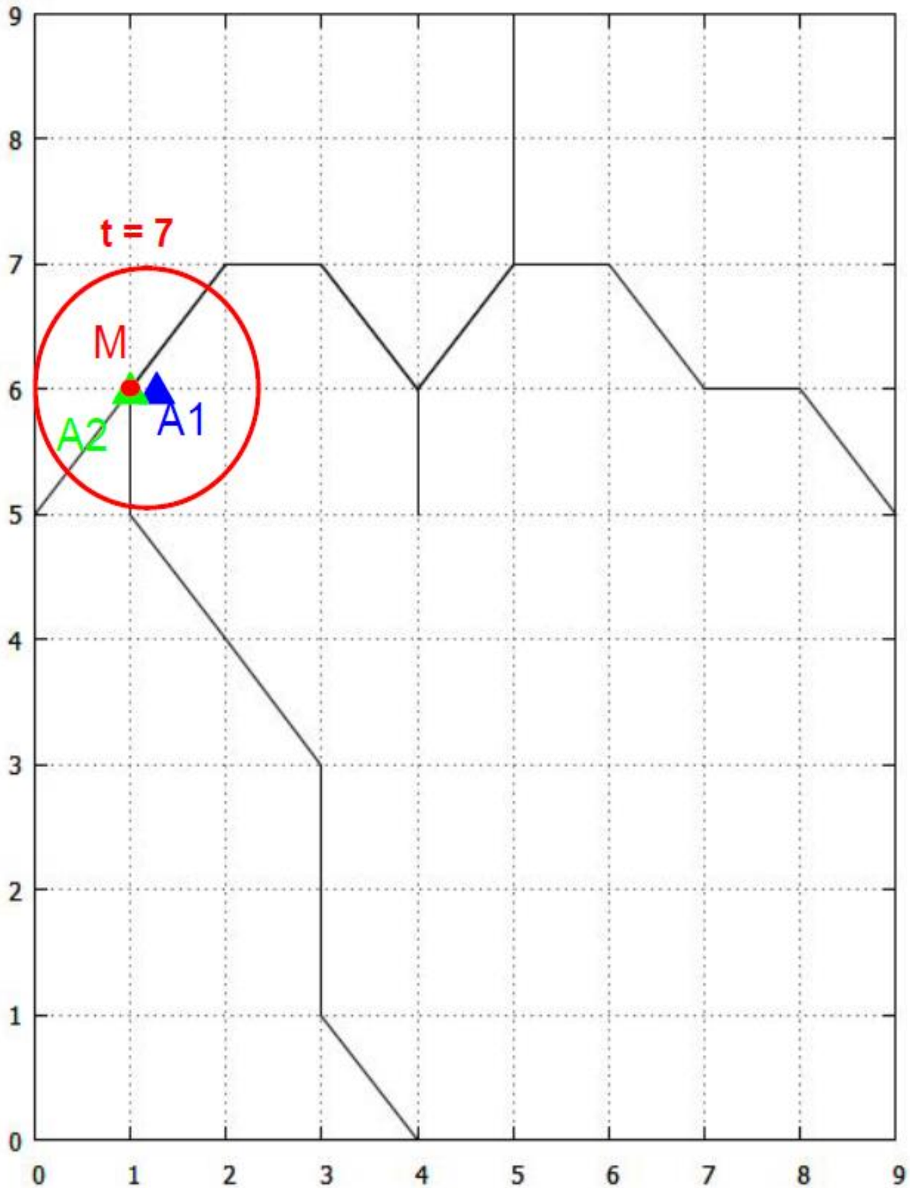


If

A1 starts at t = 1

A2 starts at t = 6

t = 7



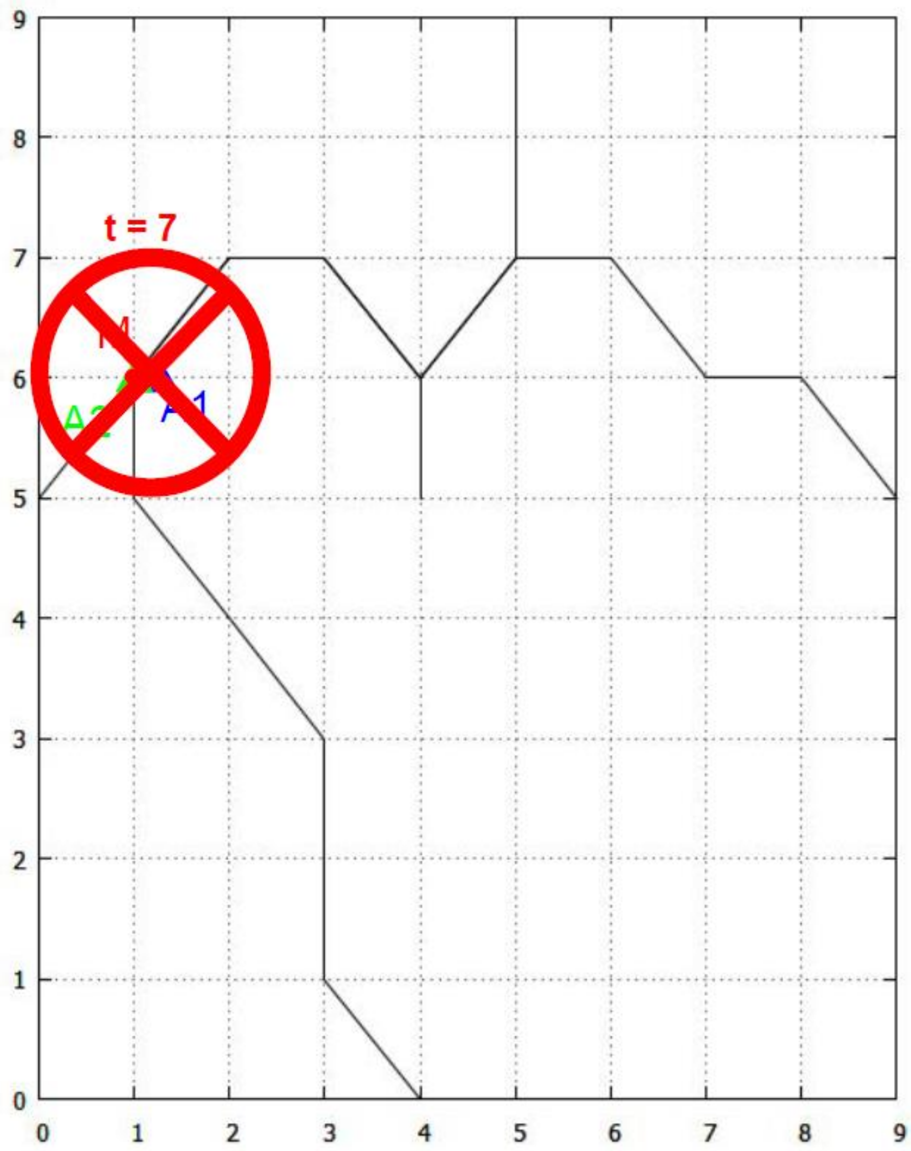
If

A1 starts at t = 1

A2 starts at t = 6

then

At t = 7 they meet at the merge point **M**



If

A1 starts at t = 1

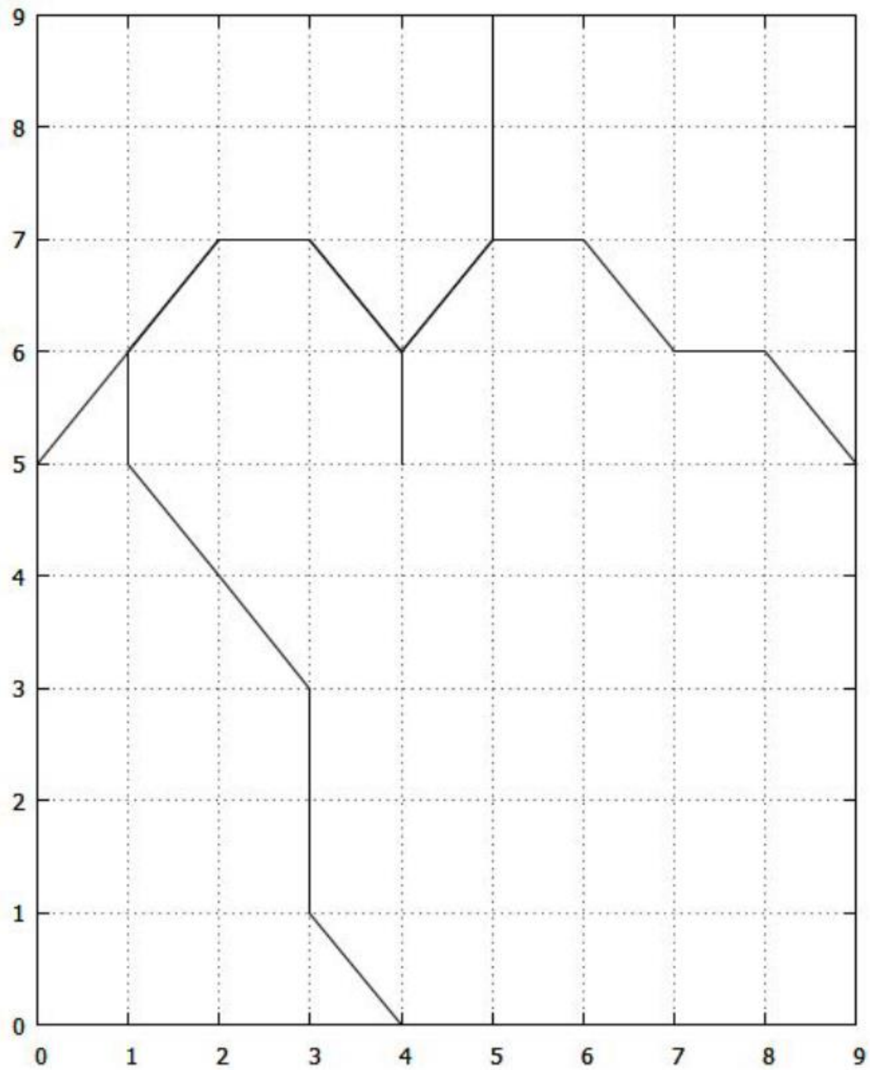
A2 starts at t = 6

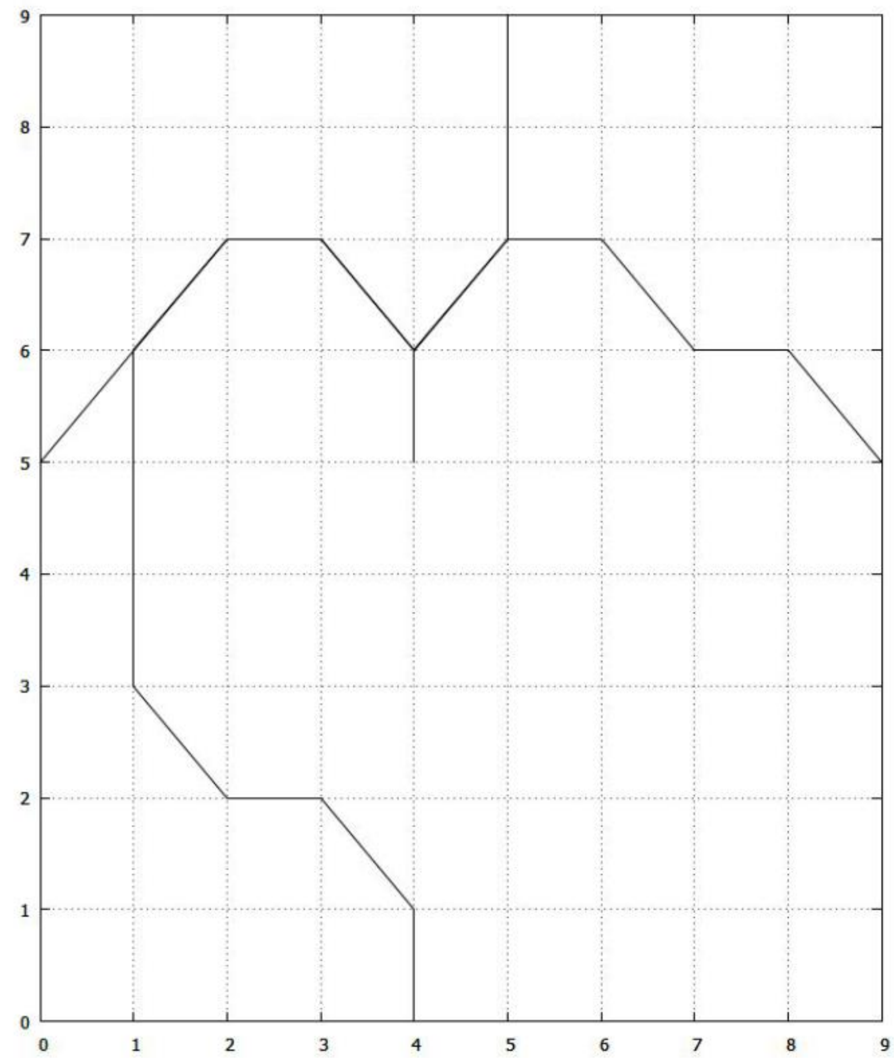
then

At t = 7 they meet at the merge point **M**

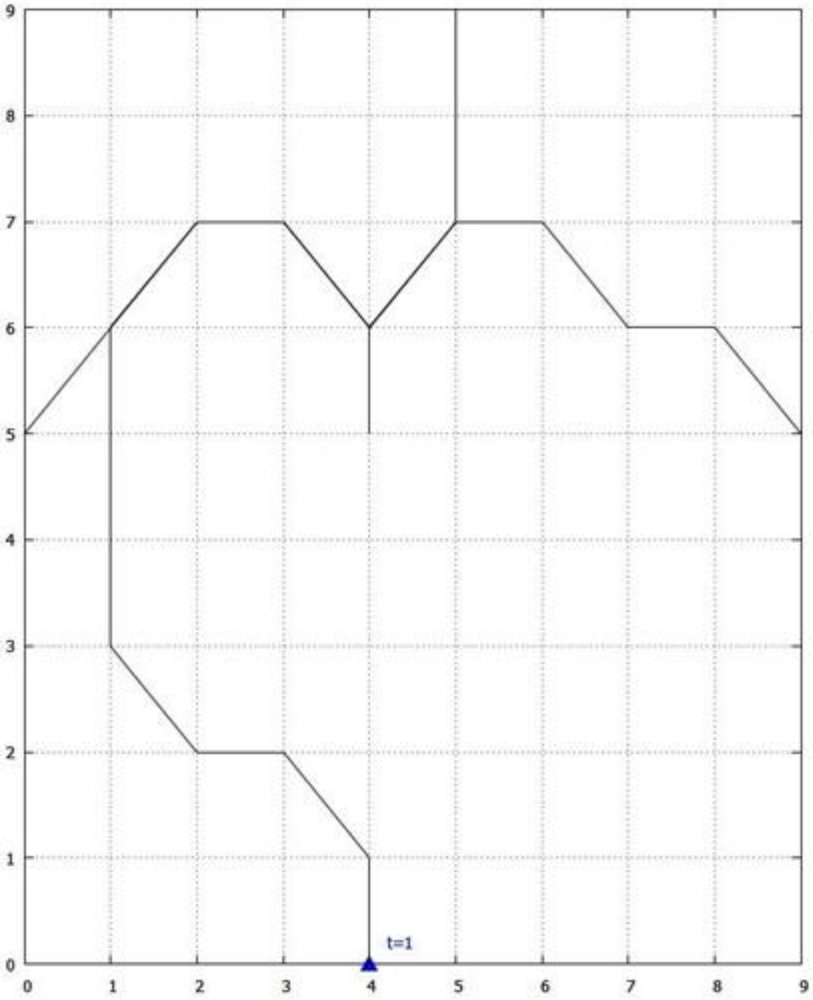
=> COLLISION

Tree adjustment





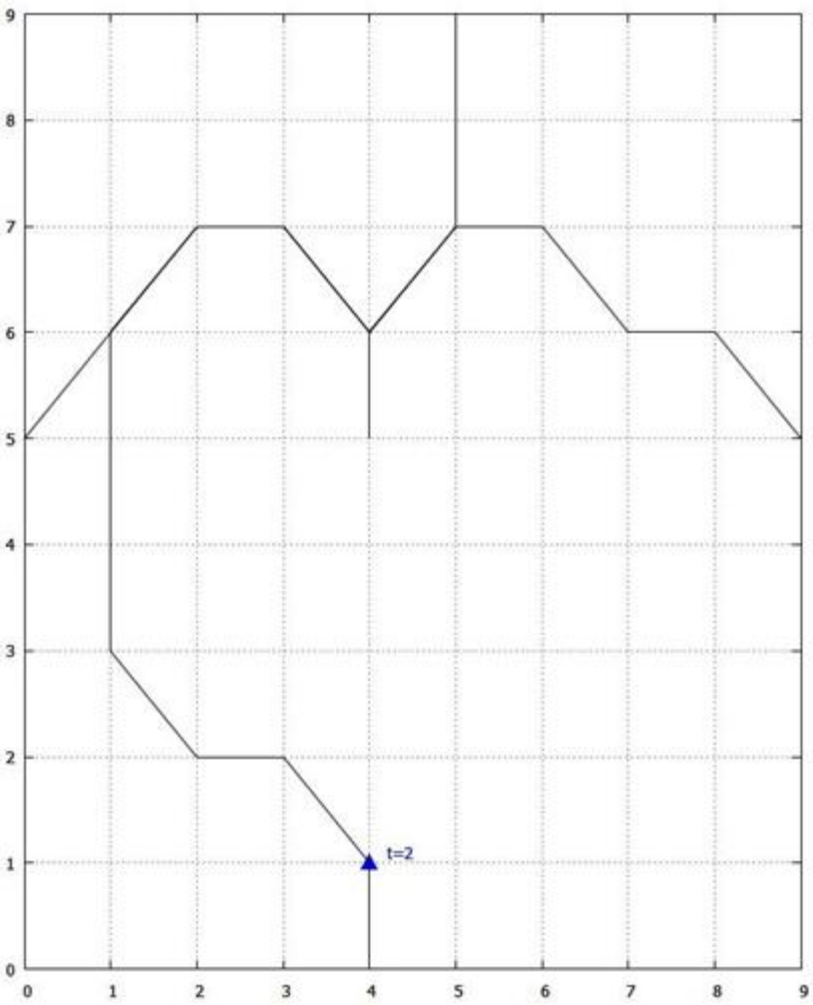
t = 1



If

A1 starts at t = 1

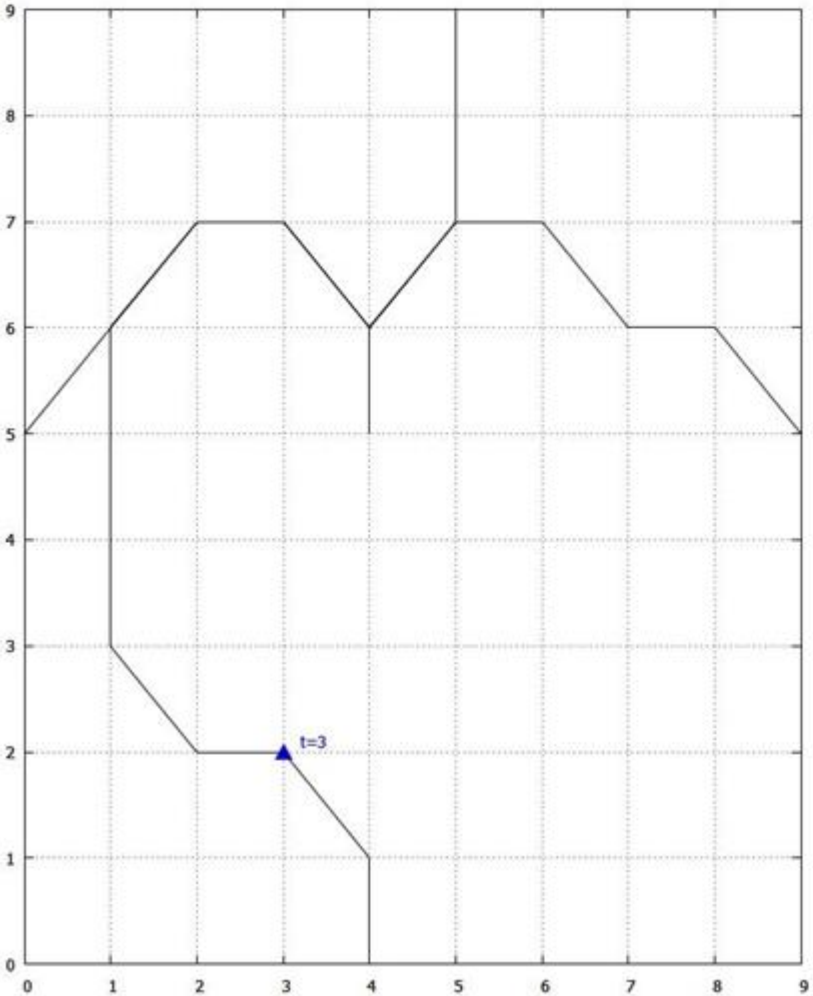
t = 2



If

A1 starts at t = 1

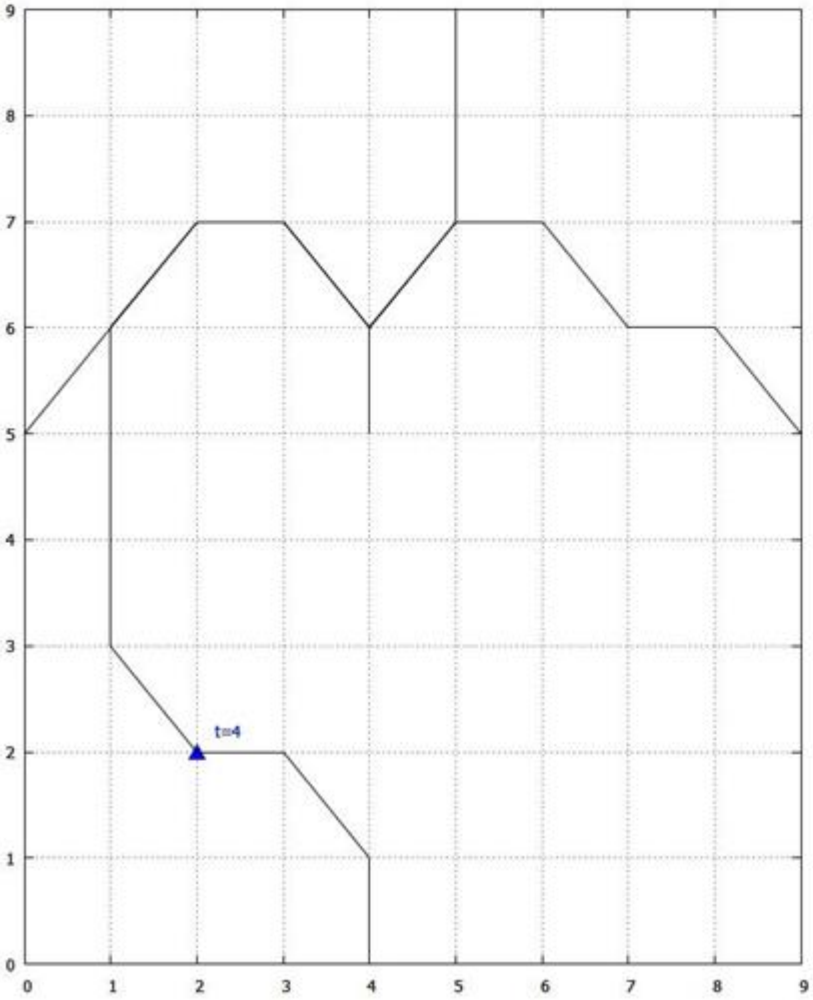
t = 3



If

A1 starts at t = 1

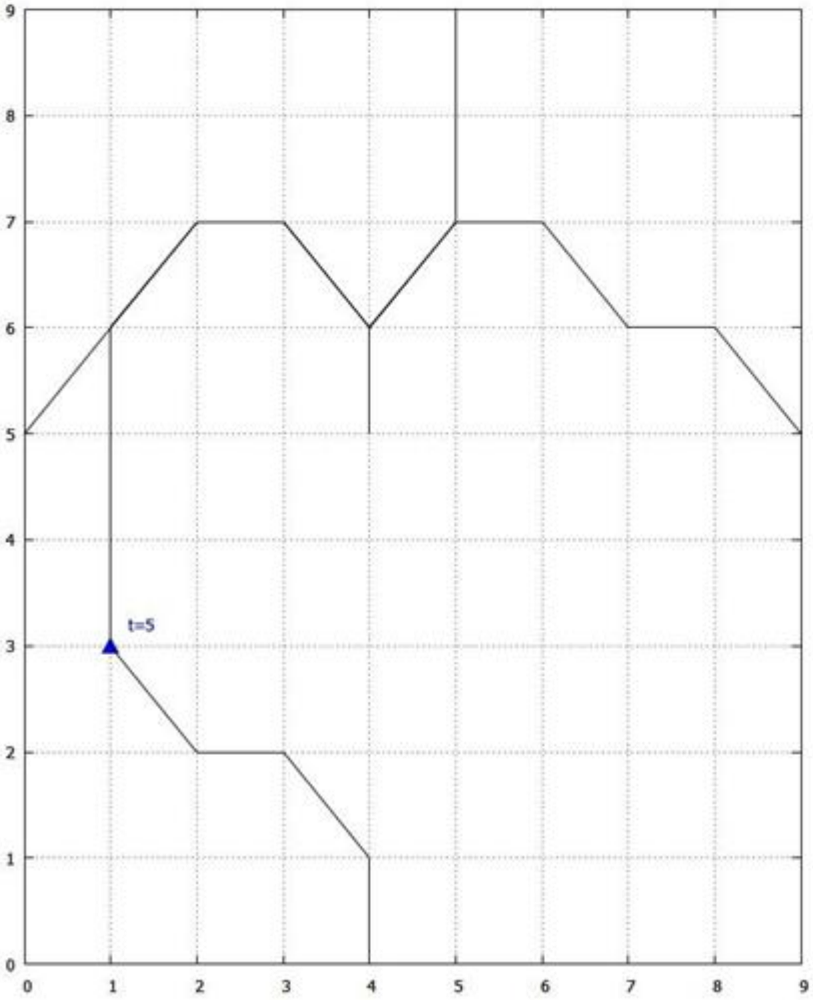
t = 4



If

A1 starts at t = 1

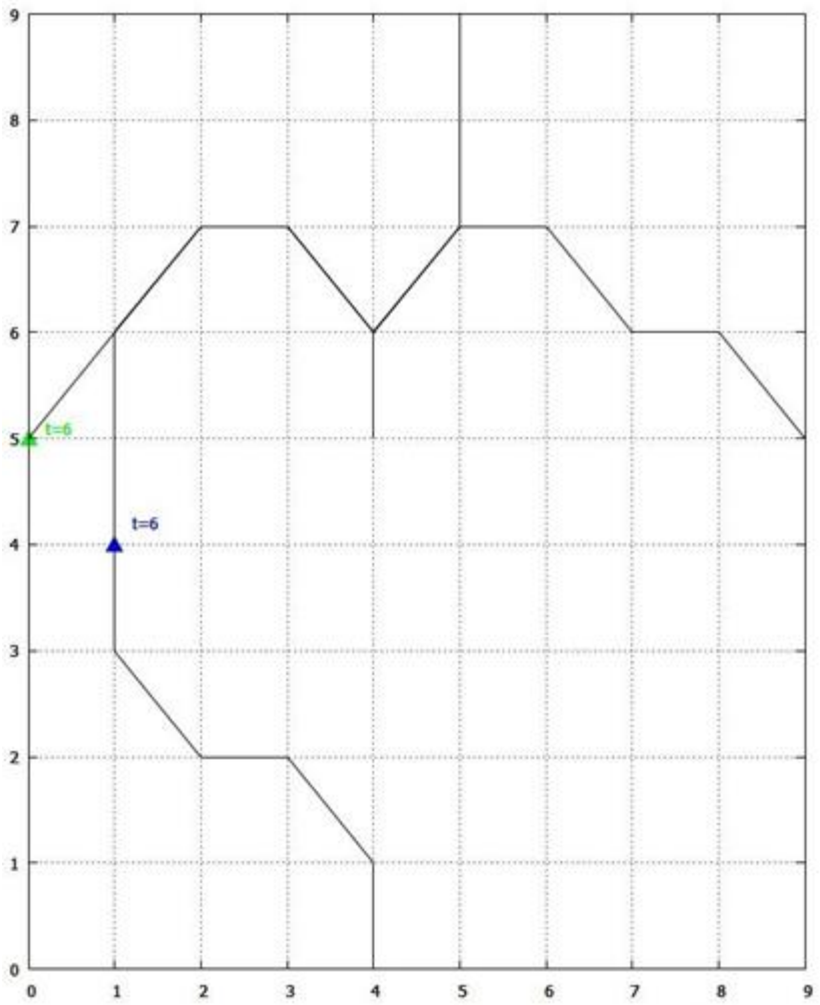
t = 5



If

A1 starts at t = 1

t = 6

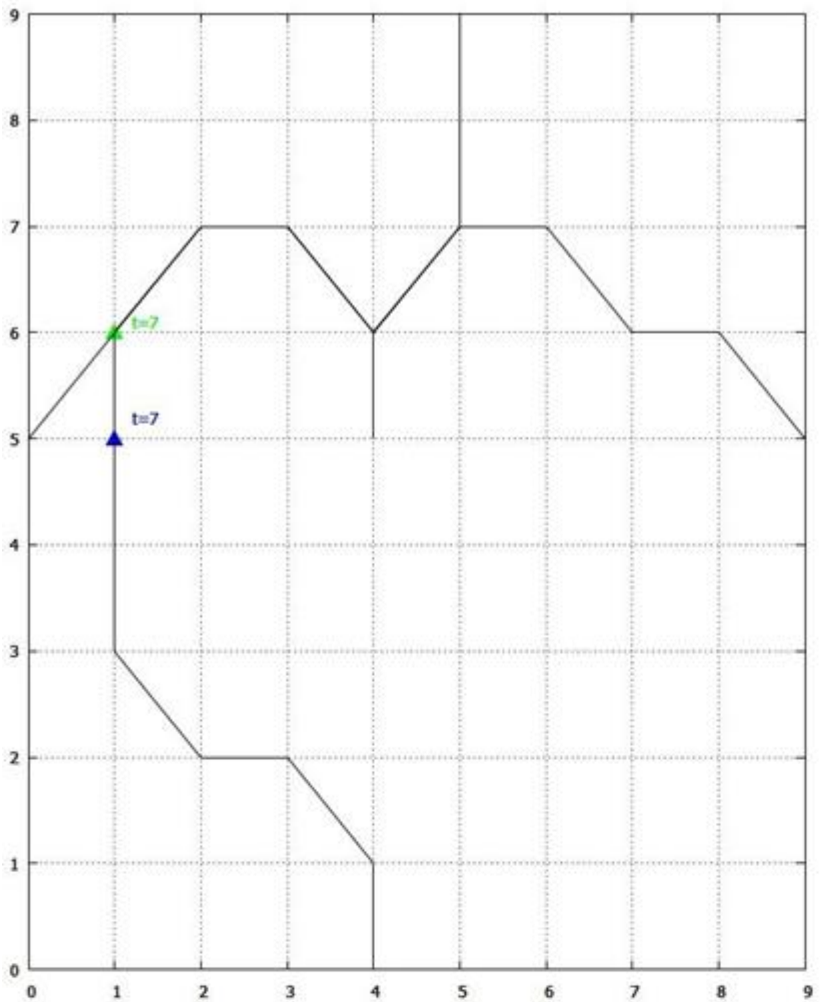


If

A1 starts at t = 1

A2 starts at t = 6

t = 7

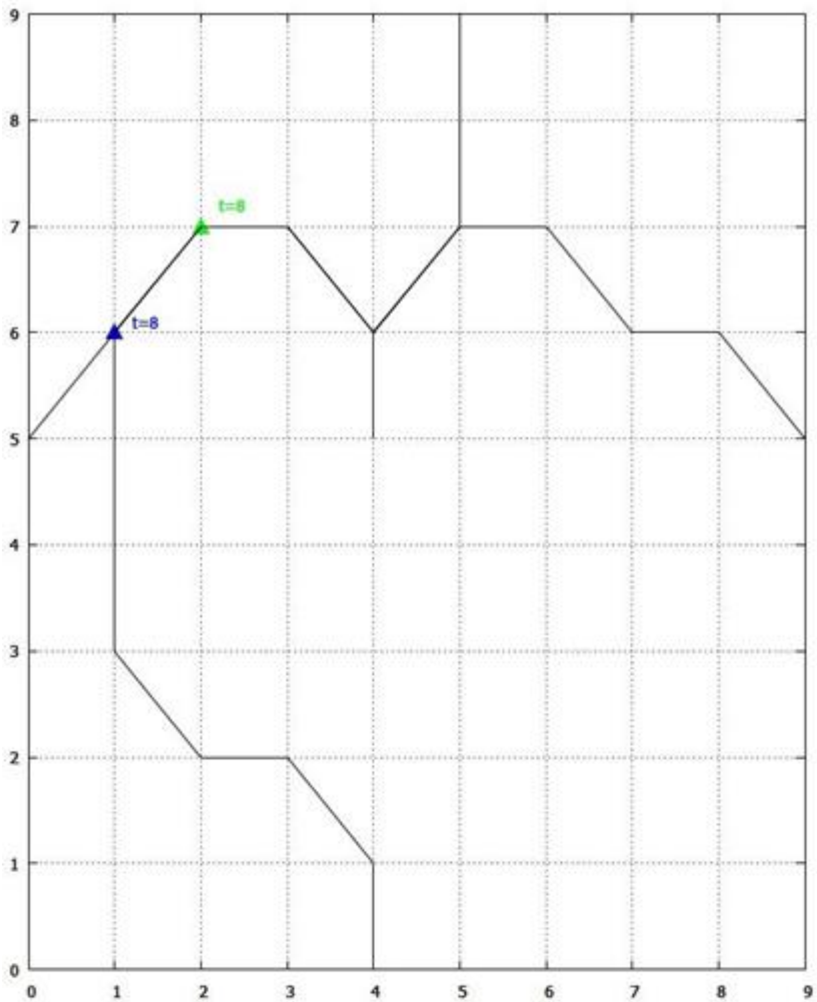


If

A1 starts at t = 1

A2 starts at t = 6

t = 8



If

A1 starts at t = 1

A2 starts at t = 6

then

At t = 7 they do not meet at the merge point **M**

COLLISION AVOIDANCE AUTOMATED

Objective

Minimize the sum of trajectory lengths flown by all aircraft

= Minimize the demand-weighted distances

for the given time period!

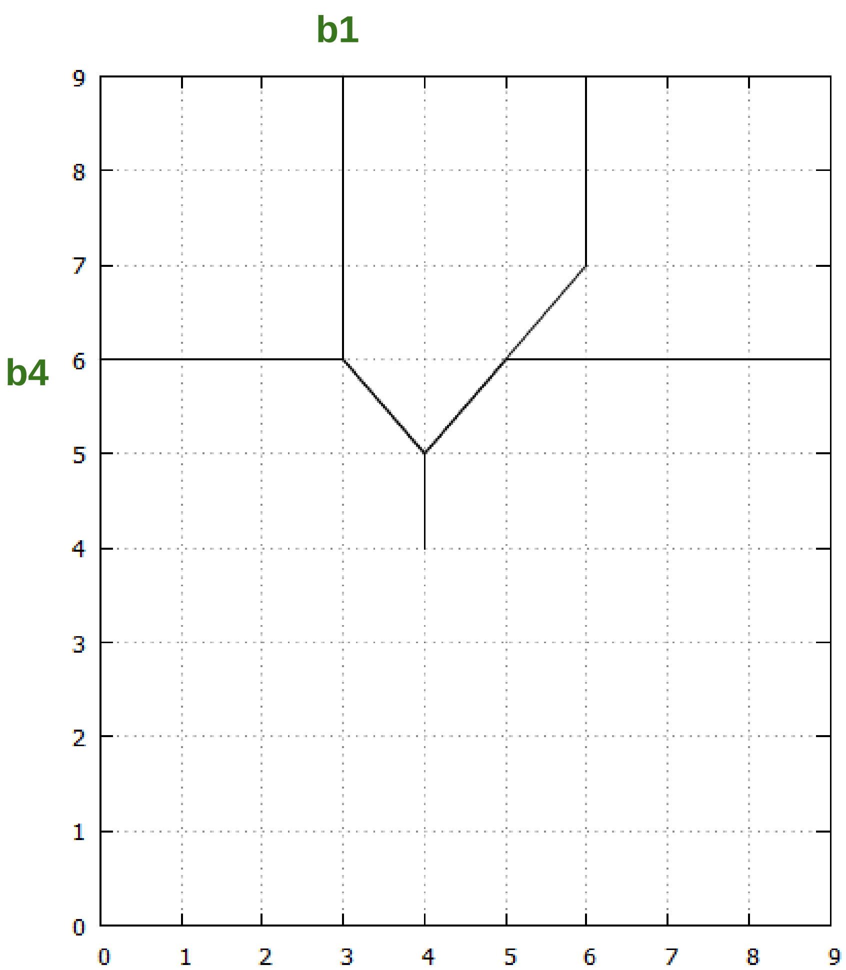
Automatic Time Separation

- ✓ Discrete time (t= 1, 2, 3,.. n)
- ✓ Simplified aircraft speed profile (currently one cell = 1 time unit)
- ✓ Required time separation of S=1 step in a grid cell

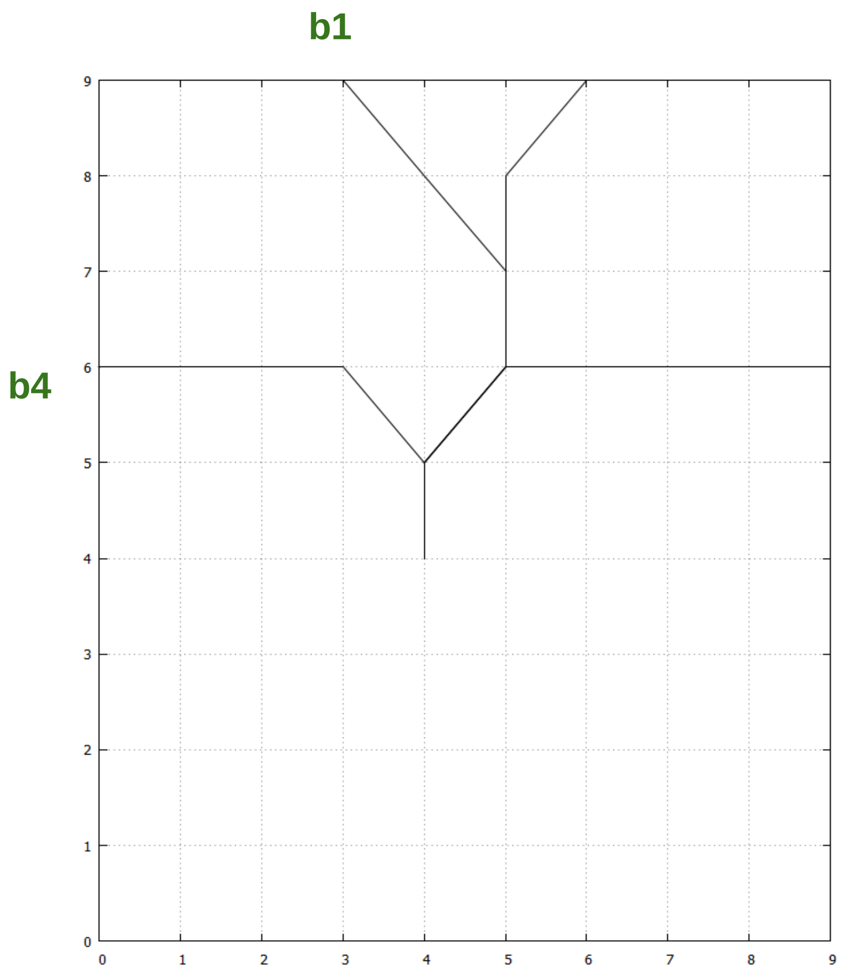
Problem formulation and solution

- ✓ Formulated as MIP (Mixed Integer Program)
- ✓ Based on flow MIP formulation for Steiner trees
- ✓ NP-hard to in general
- ✓ Solved using Gurobi solver
- ✓ Run on a server with two 10-core Intel E52650v3 2.3 GHz CPUs, 64 Gb and 1.7 TB temporary disc space

Experimental Evaluation: *synthetic data*
Proof of concept: Time separation example

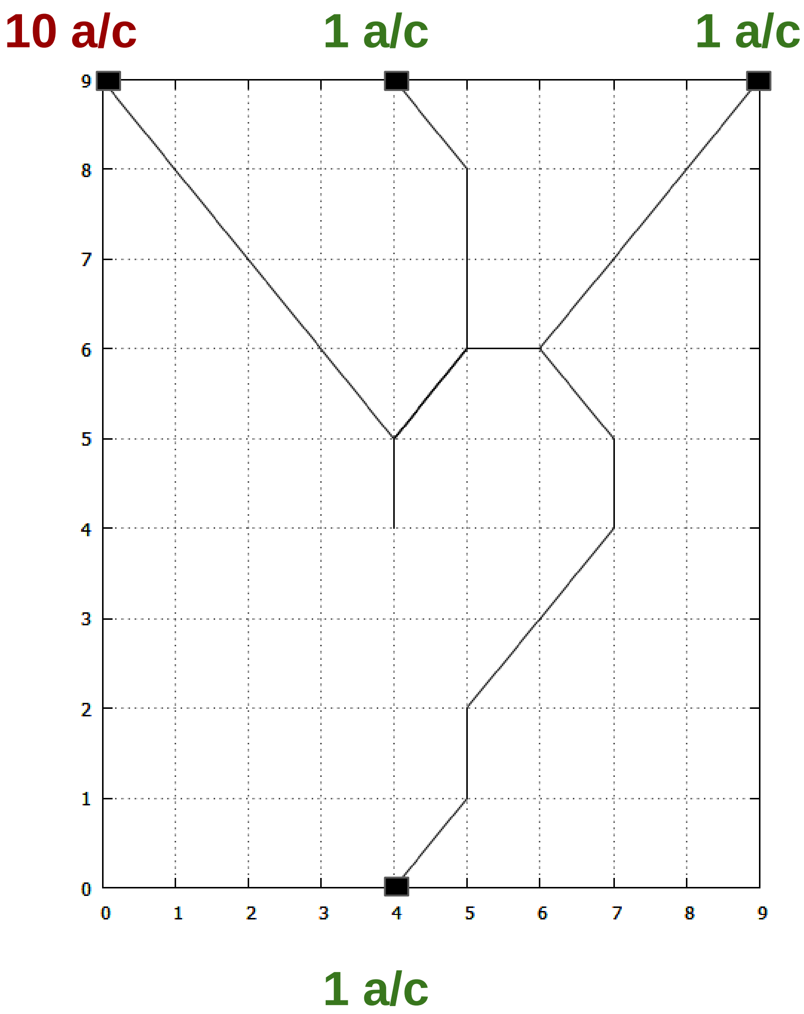


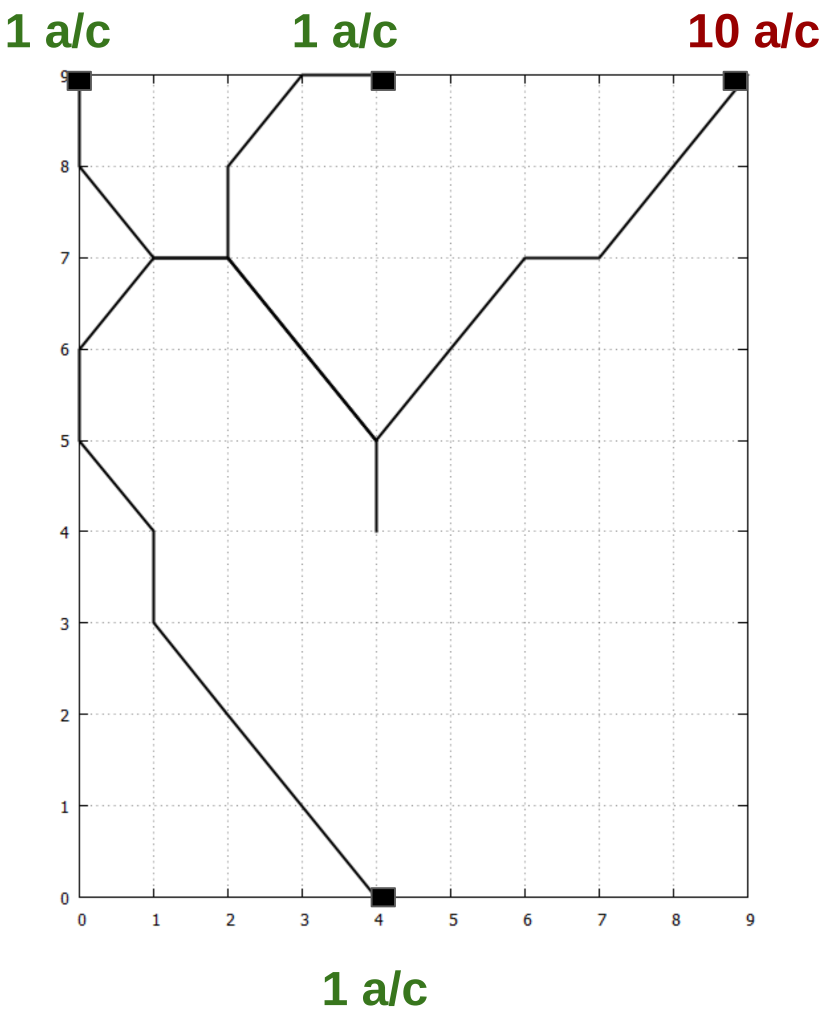
b4: t = 1, 3, 6, 9
b1: t = 2, 5, 8, 11



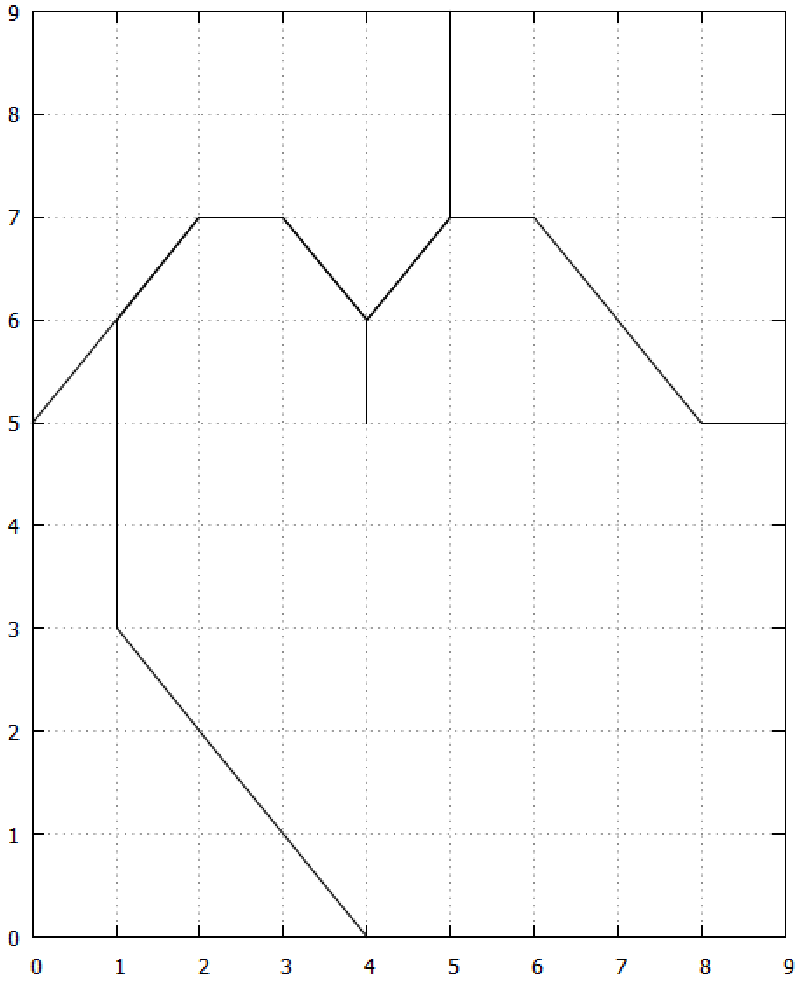
b4: t = 1, 3, 6, 9
b1: t = 1, 3, 6, 9

Experimental Evaluation: *synthetic data*
Proof of concept: Demand-Weighted solution

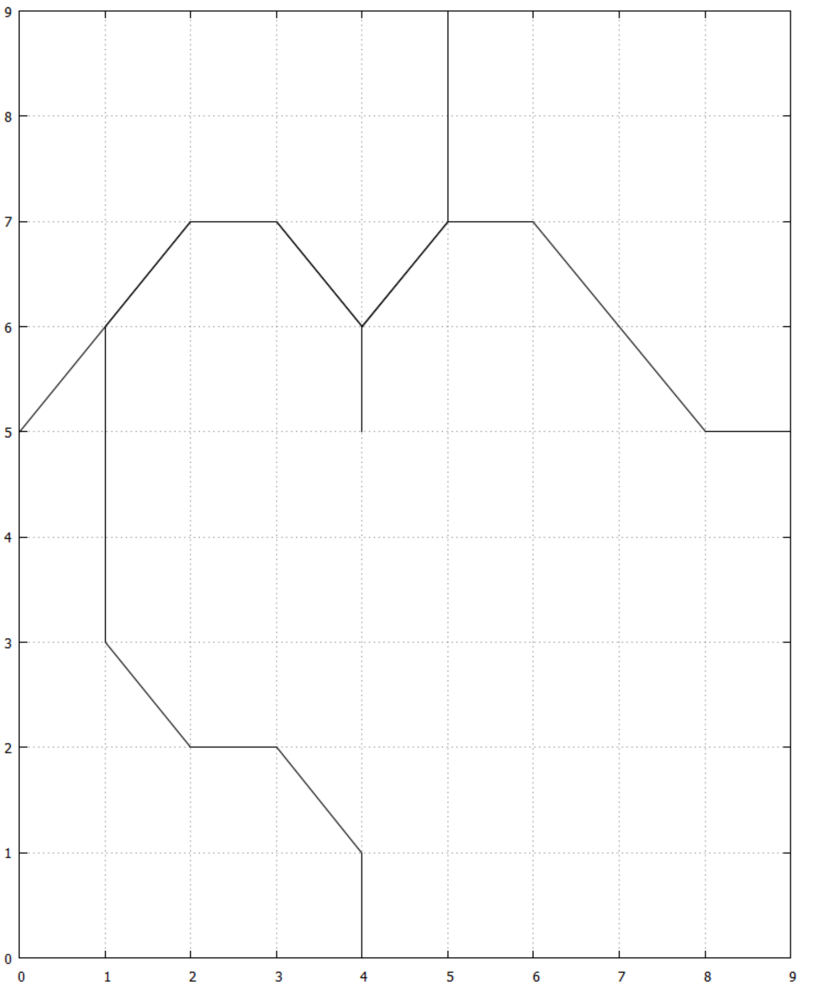




Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

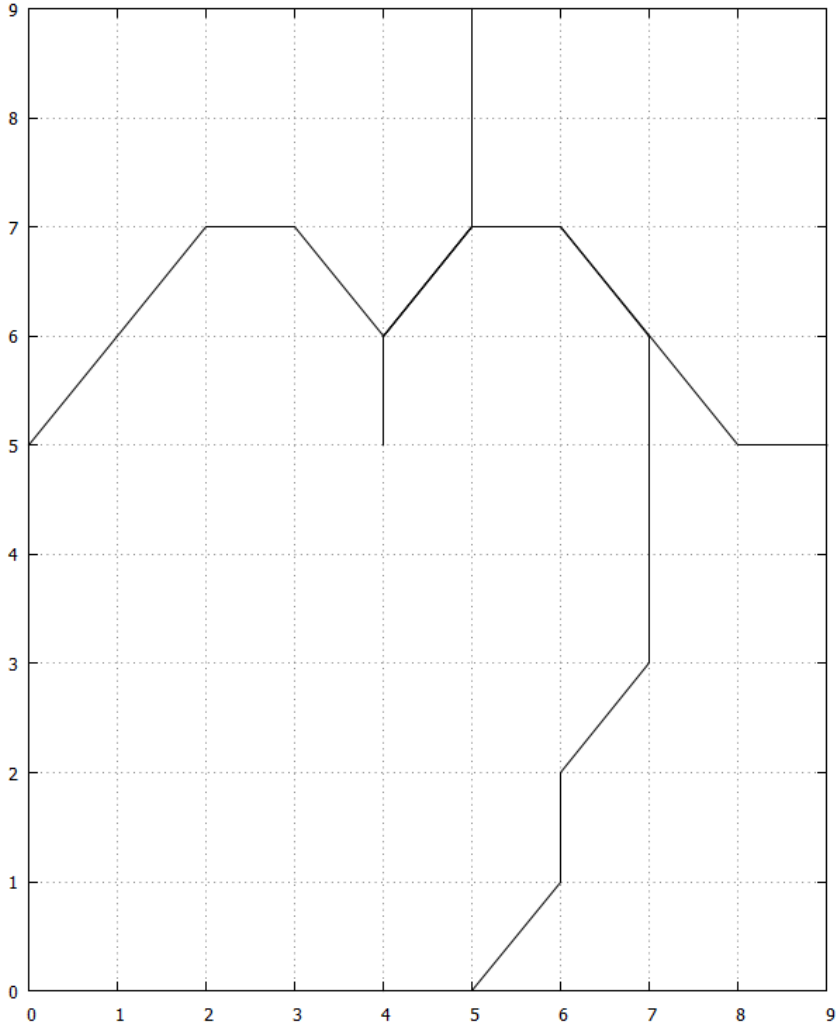


6-7 am

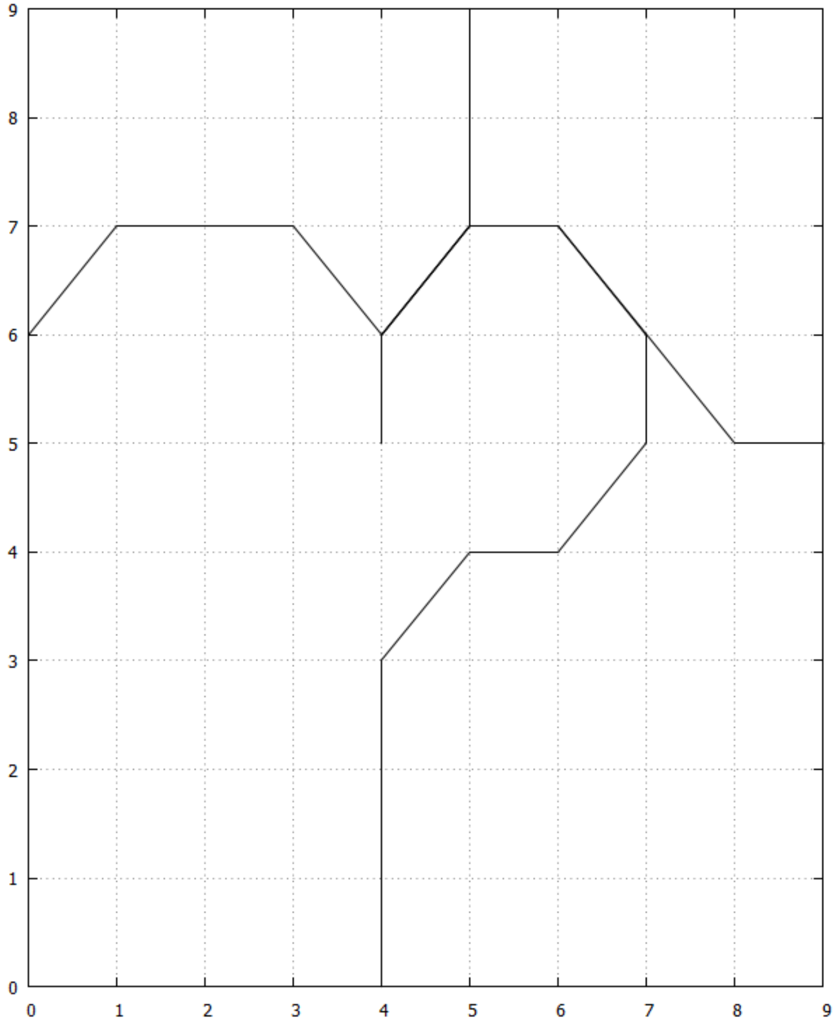


7-8 am

Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

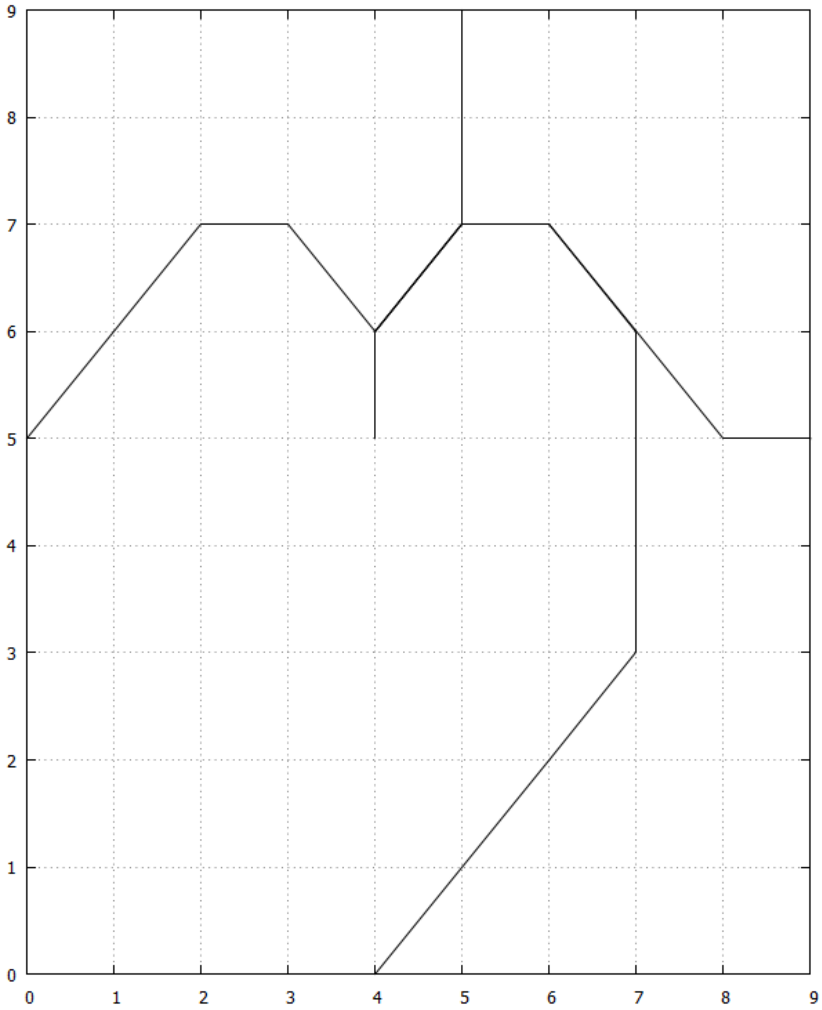


8-9 am

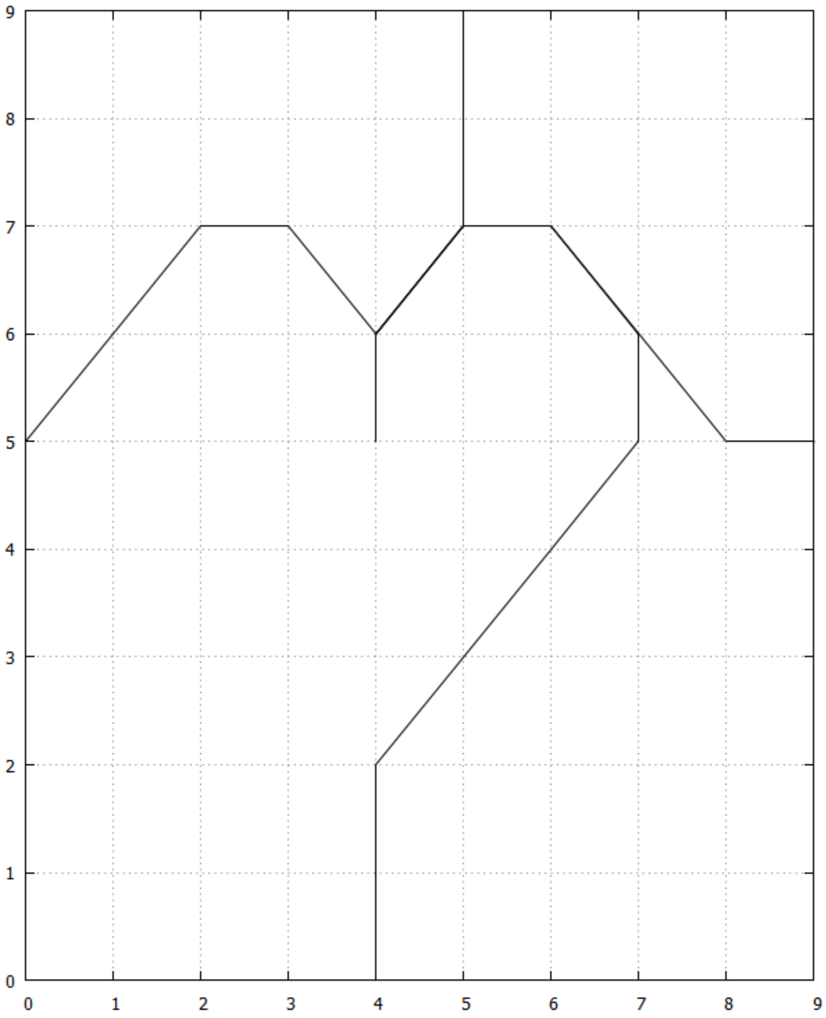


12-1 pm

Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017

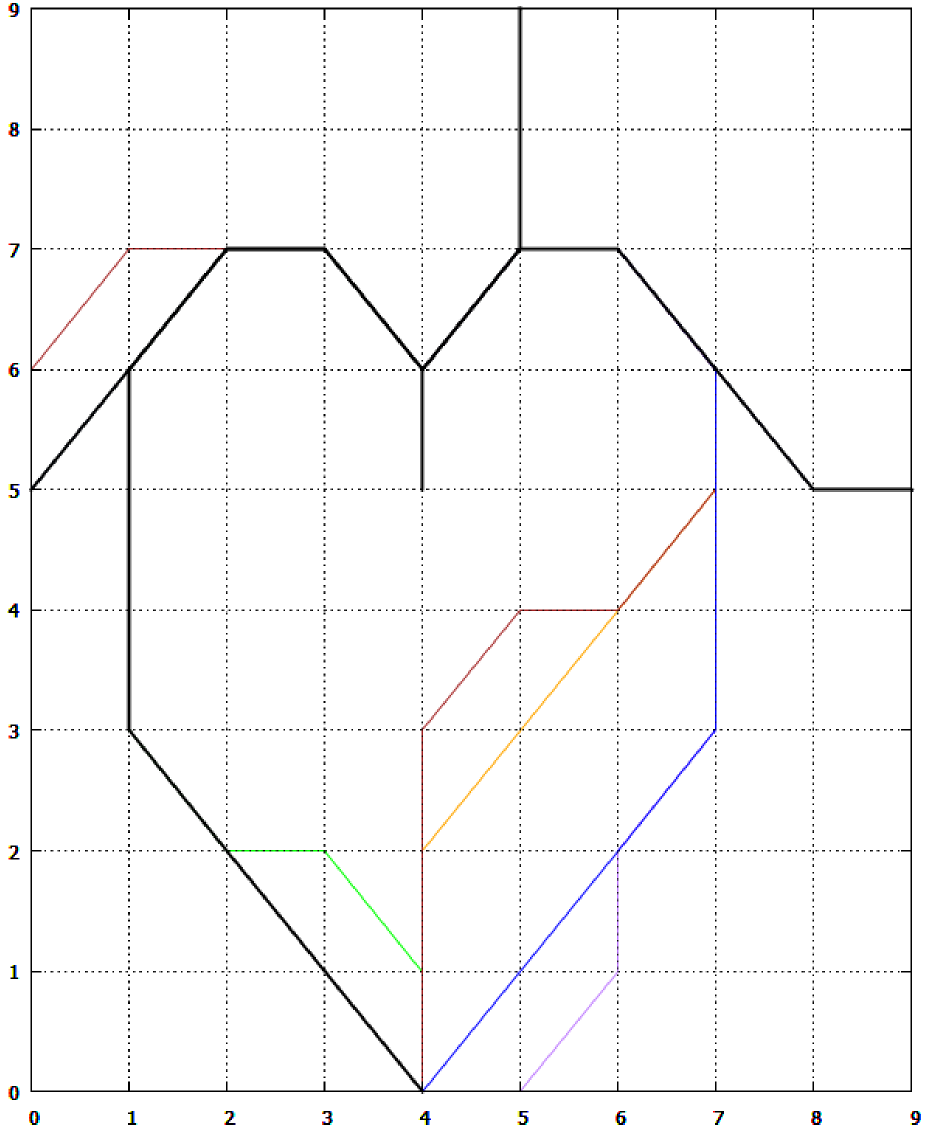


3-4 pm

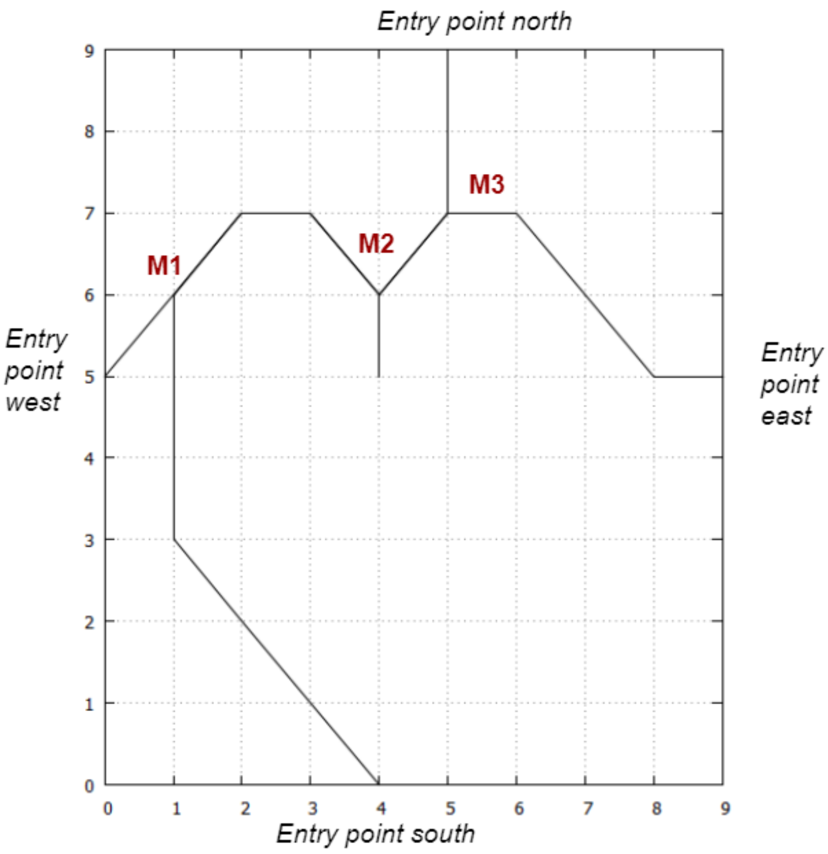


4-5 pm

Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017



Experimental Evaluation: real data
Arlanda Airport Arrivals: Oct 4, 2017



6-7 am

EXAMPLE TIME SCHEDULE FOR 10 AIRCRAFT ARRIVED BETWEEN 6 and 7 am on October 4, 2017

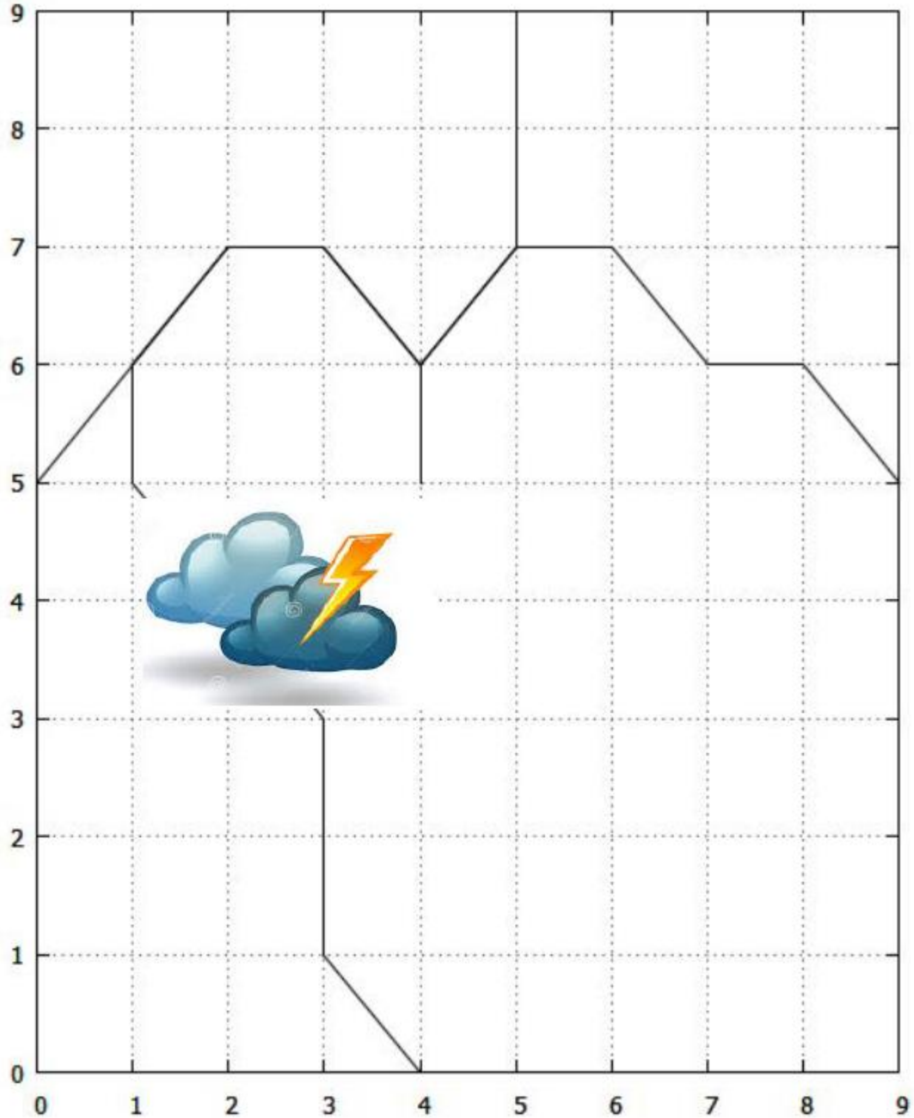
Arrivals		Simulated time				
Aircraft	**Entry point**	**Entry time**	**M1**	**M2**	**M3**	**RWY**
a1	south	1	7	10	x	11
a2	south	9	15	18	x	19
a3	south	10	16	19	x	20
a4	north	1	x	4	3	5
a5	north	11	x	14	13	15
a6	east	27	x	30	29	31
a7	east	1	x	6	5	7
a8	west	18	19	22	x	23
a9	west	23	24	27	x	28
a10	north	30	x	33	32	34

Conclusions

- ✓ Dynamic mathematical framework for airspace optimization
- ✓ Automated space and time separation (optimal)
- ✓ Demand-driven
- ✓ Improved predictability
- ✓ Enable TMA capacity evaluation
- ✓ High flexibility

Future Work

- ✓ Realistic aircraft slow down procedures
- ✓ Uncertainties due to variations in arrival times
- ✓ Dynamic obstacle avoidance
- ✓ Uncertainties due to changing weather



9
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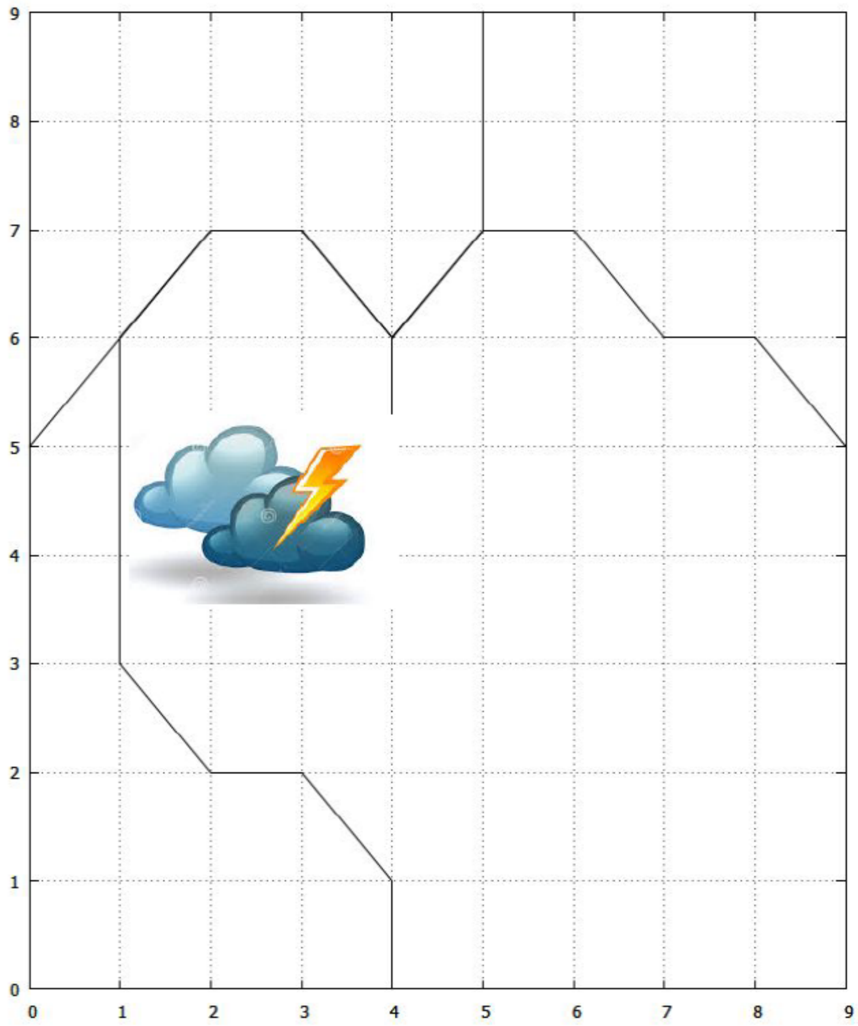
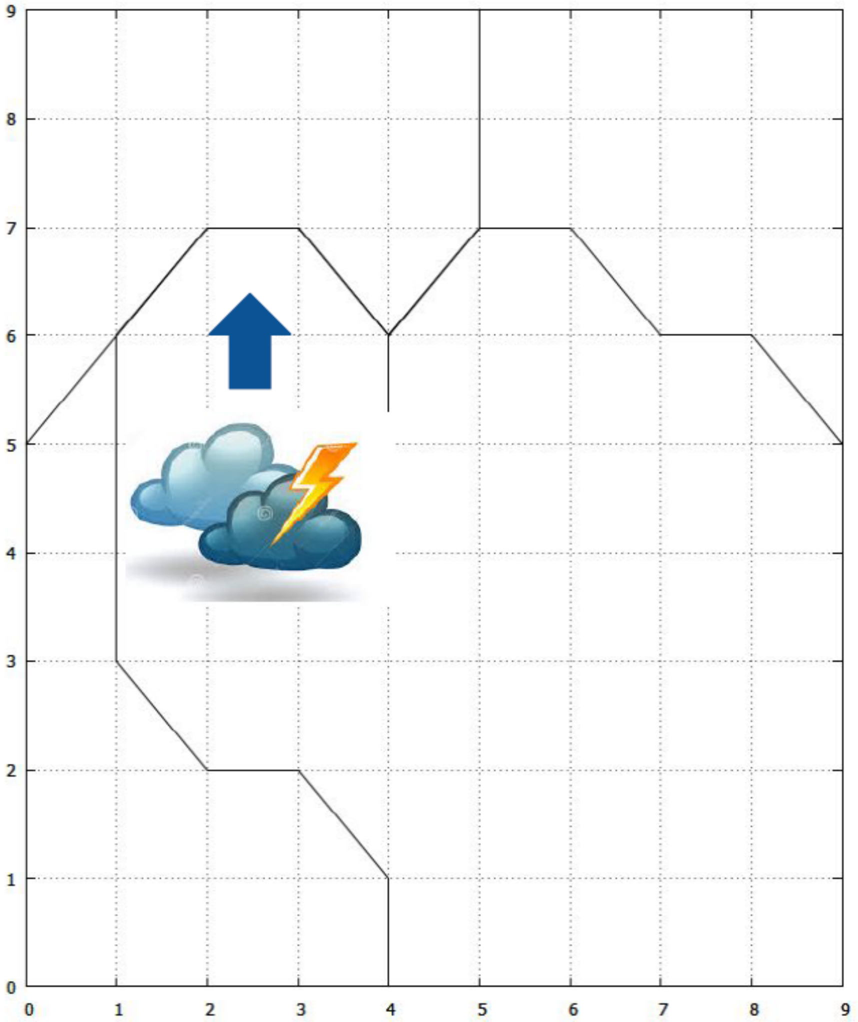
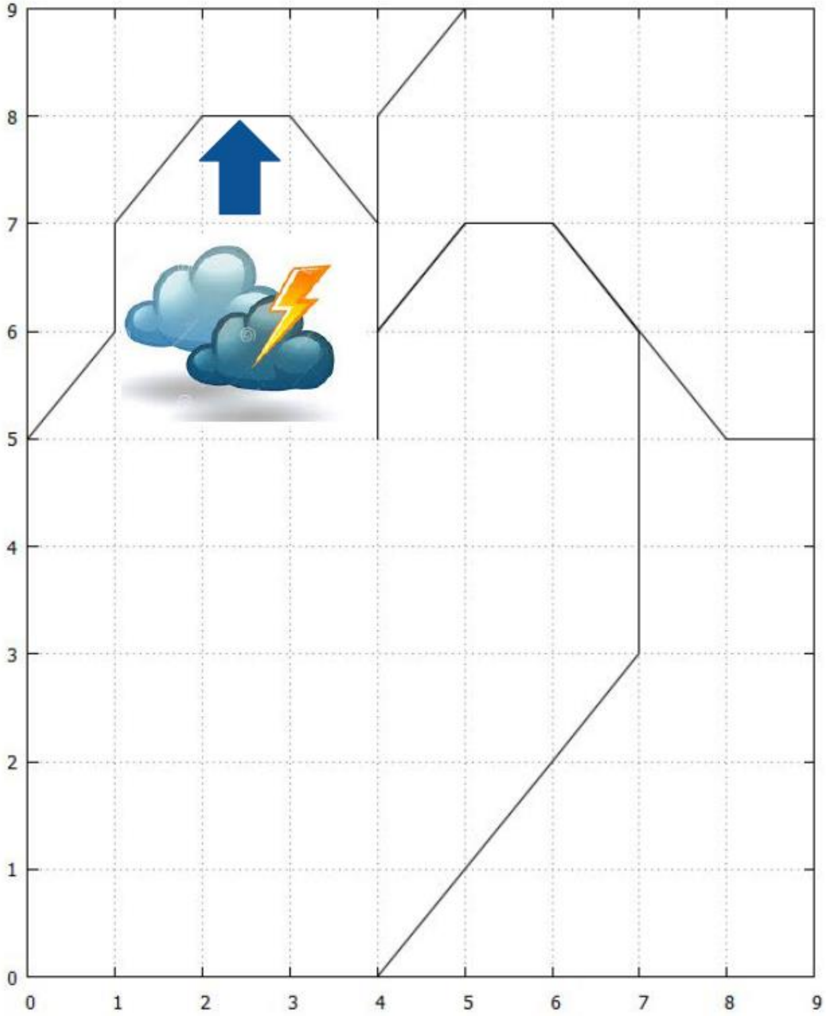


BAD WEATHER AVOIDANCE AUTOMATED



BAD WEATHER AVOIDANCE AUTOMATED



BAD WEATHER AVOIDANCE AUTOMATED

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Thank you!

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Thank you!

Questions?