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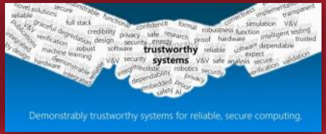
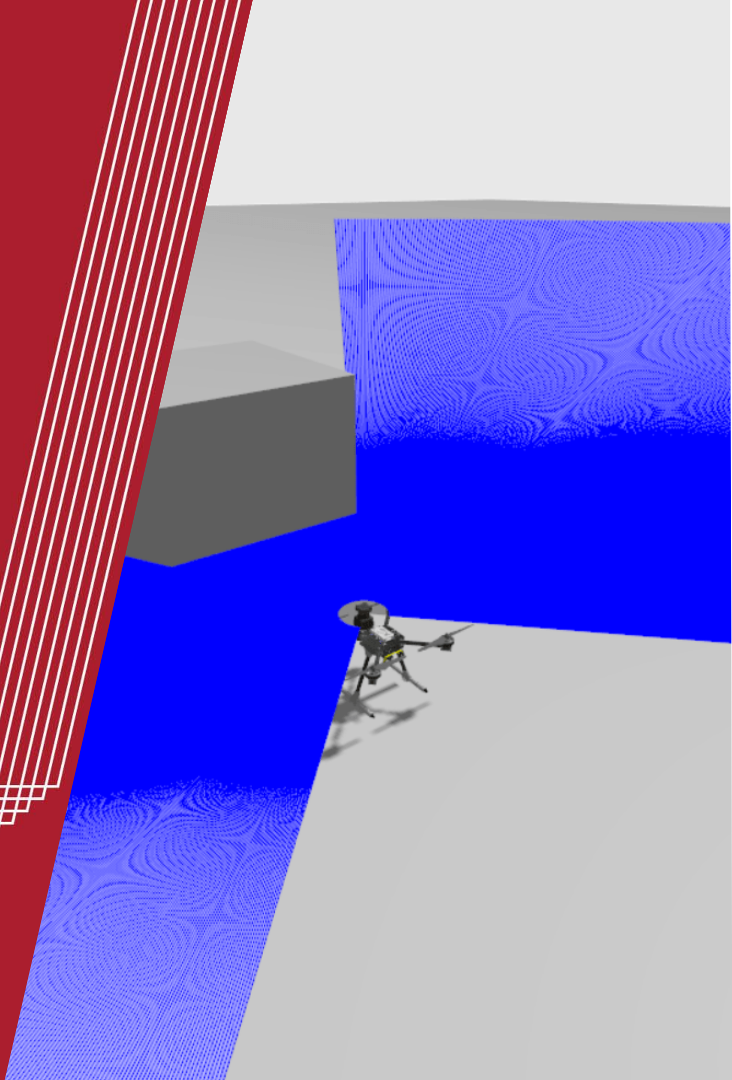


MODEL-BASED UAV TEST CASE GENERATION

DVClub, Bristol

Dr. Anas Shrinah & Dr. Chris Bennett

9th April 2025



Agenda

- SBFT / ICST 2025 UAV Testing Competition.
- Pseudo-Random UAV Test Generation Using Low-Fidelity Path Simulator.
- Genetic Algorithm-Based UAV Test Generation.

SBFT / ICST 2025 UAV Testing Competition

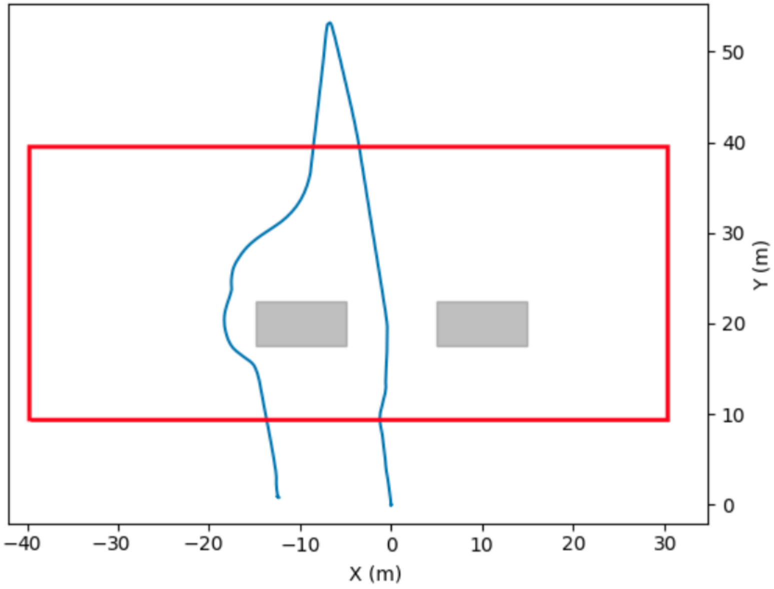
- The 18th International Workshop on Search-Based and Fuzz Testing (SBFT) and 18th IEEE International Conference on Software Testing, Verification and Validation (ICST).

- This is the second edition of this competition.

- Effective and diverse and test cases to identify underlying vulnerabilities in the system (Flying close to obstacles)

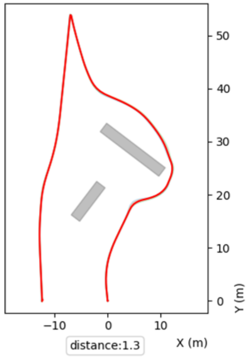
What is a test case

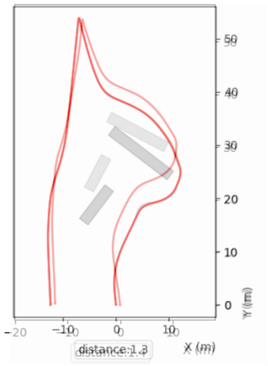
- A set of static obstacles (cuboids).
- Position, orientation and size.
- At most three obstacles, placed on the ground, taller than the flight height, must not overlap, contained within the specified arena, and keep the mission feasible.



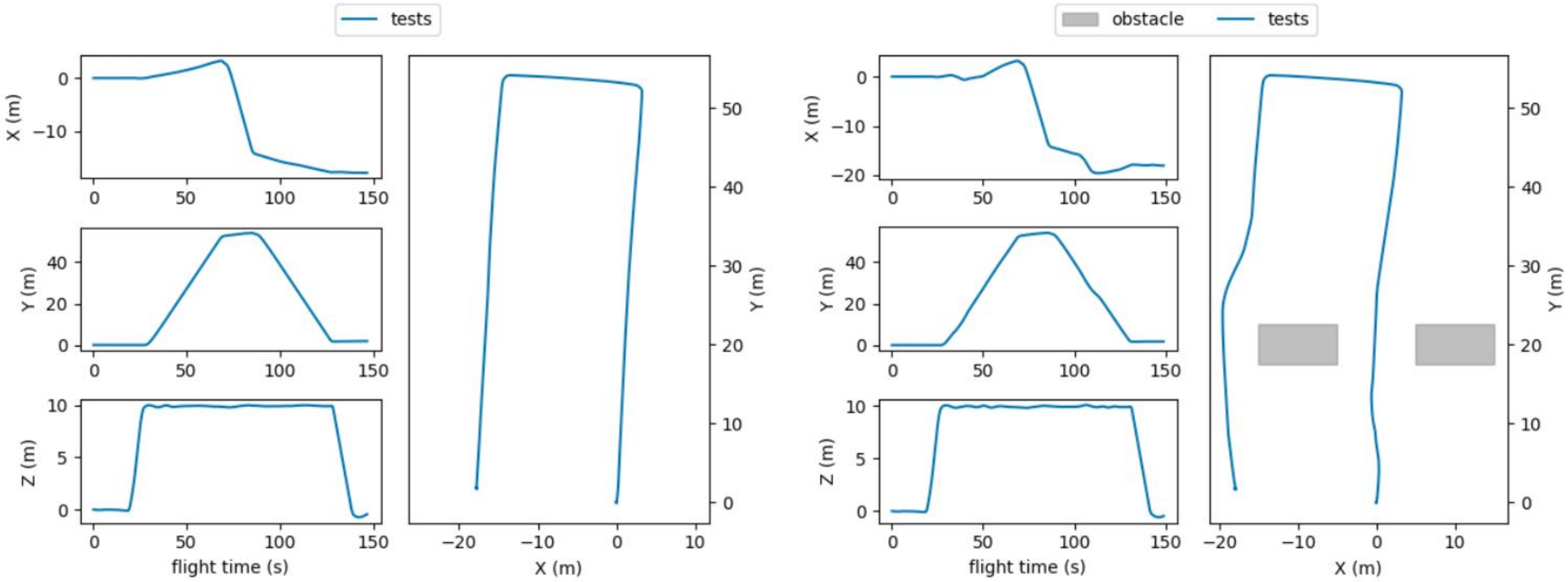
What is effective and diverse and test cases?

Effective	Diversity
$point(sim) = \begin{cases} 5, if\ minDist(sim) < 0.25m \\ 2, if\ 0.25m \le minDist(sim) < 1m \\ 1\ if\ 1m \le\ minDist(sim) < 1.5m \\ 0, if\ minDist(sim) > 1.5m \end{cases}$	$Similarity(t_i, t_j) = \frac{\lvert area(t_i) \cap area(t_j) \rvert}{\lvert area(t_i) \cup area(t_j) \rvert}$ $DiversityScore(TS) = 1 - \frac{1}{n} \sum_{t_i, t_j \in TS} Similarity(t_i, t_j)$





Case study – example



System Under Test

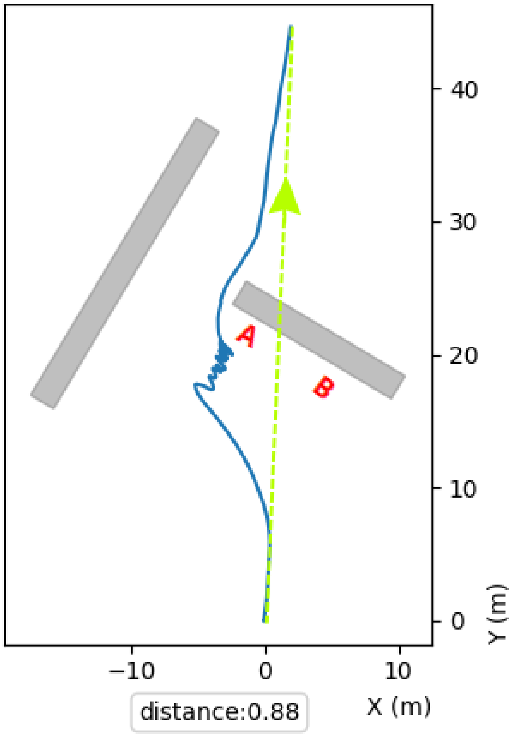
- **PX4-Autopilot** is open-source professional UAV autopilot system.
- **PX4-Avoidance** module is an open-source, vision-based autonomous obstacle avoidance system built on top of PX4-Autopilot.
- **PX4-Avoidance** uses a local planner based on the 3D Vector Field Histogram (3DVFH*) algorithm.

Simulation-Based Testing

- **Aerialist** is a test bench that automates UAV software testing and simulation.
- It employs high-fidelity simulation platforms such as Gazebo to perform flight testing.
- High-Fidelity Simulators (HFS) are computationally expensive (simulating a single UAV test case with Aerialist can take several minutes).

PSEUDO-RANDOM TEST GENERATOR

- Two obstacles are required to compel the UAV to follow an S-shaped path.
- The first obstacle must be placed in the path of the UAV to direct it away from the goal.
- The second obstacle is placed perpendicular to the first obstacle and close enough, but not too close to risk the planner failing to find a feasible solution.



First Obstacle Placement

- Fix the obstacle height to 20m.
- Set the width of the bases of the two obstacles to 2m.

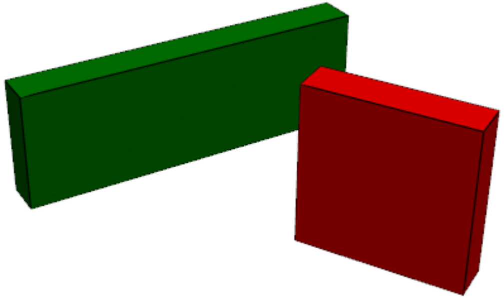
- Randomly selects the diagonal length, rotation angle, and y-coordinate from predefined ranges to ensure the base is fully contained within the designated area.
- The base length is then calculated using the diagonal and the width, and the x-coordinate is determined using the y-coordinate and the equation of the Segment of Interest.

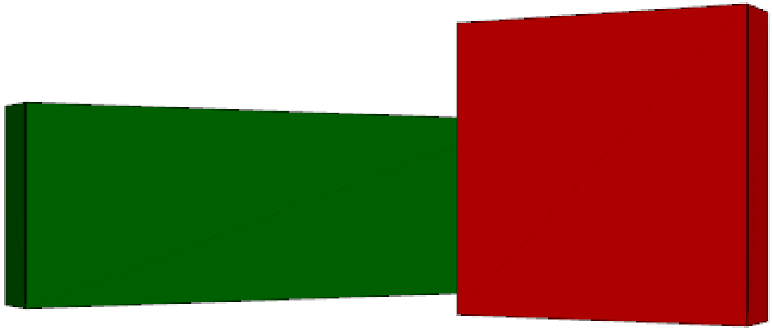
Second Obstacle Placement

- The x- and y-coordinates of the centre of the second obstacle's base are specified relative to the first obstacle and to the borders of the arena.

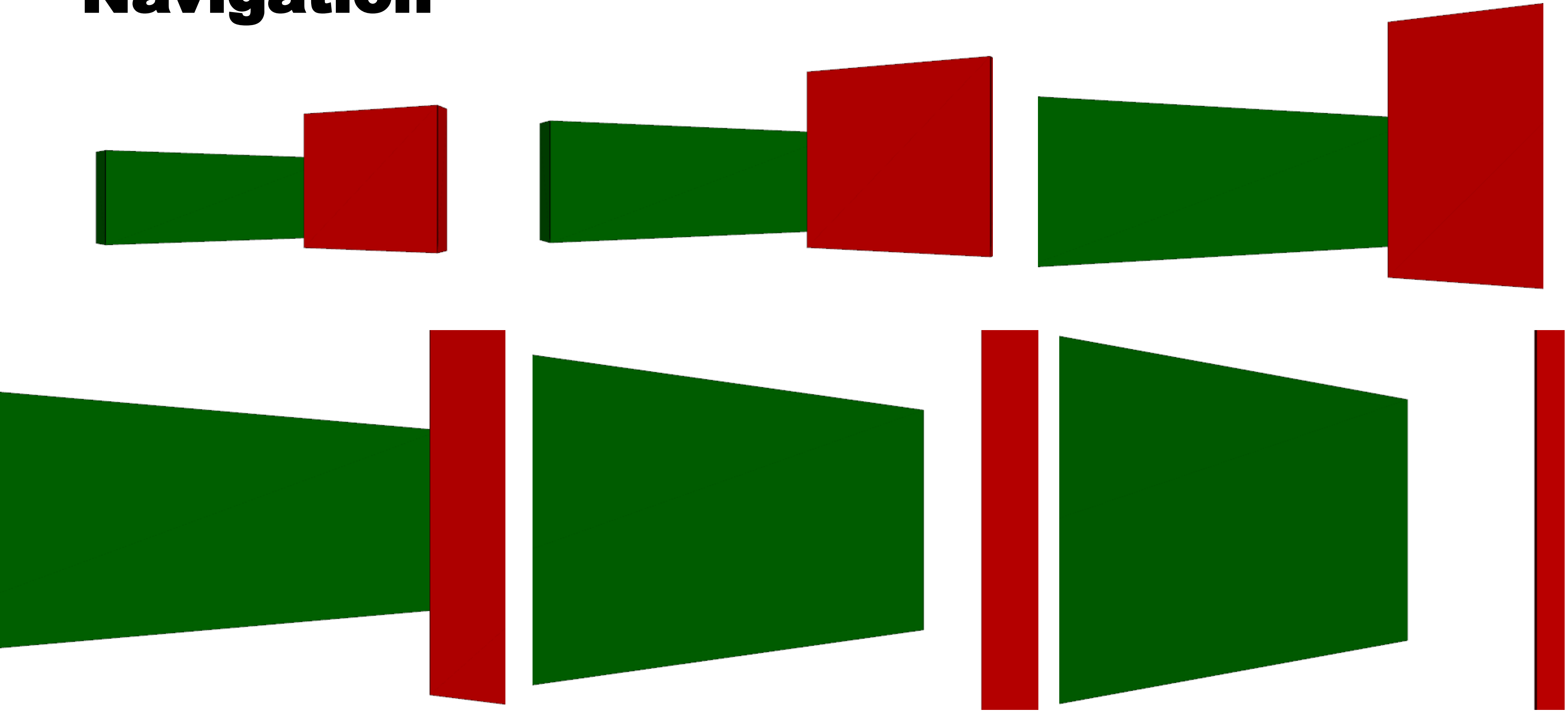
- The length of the second obstacle needs to be long enough to prevent the UAV from circling it from below; it is set to 1.75 of the first obstacle length.

LOW-FIDELITY PATH SIMULATOR – 3D Scene

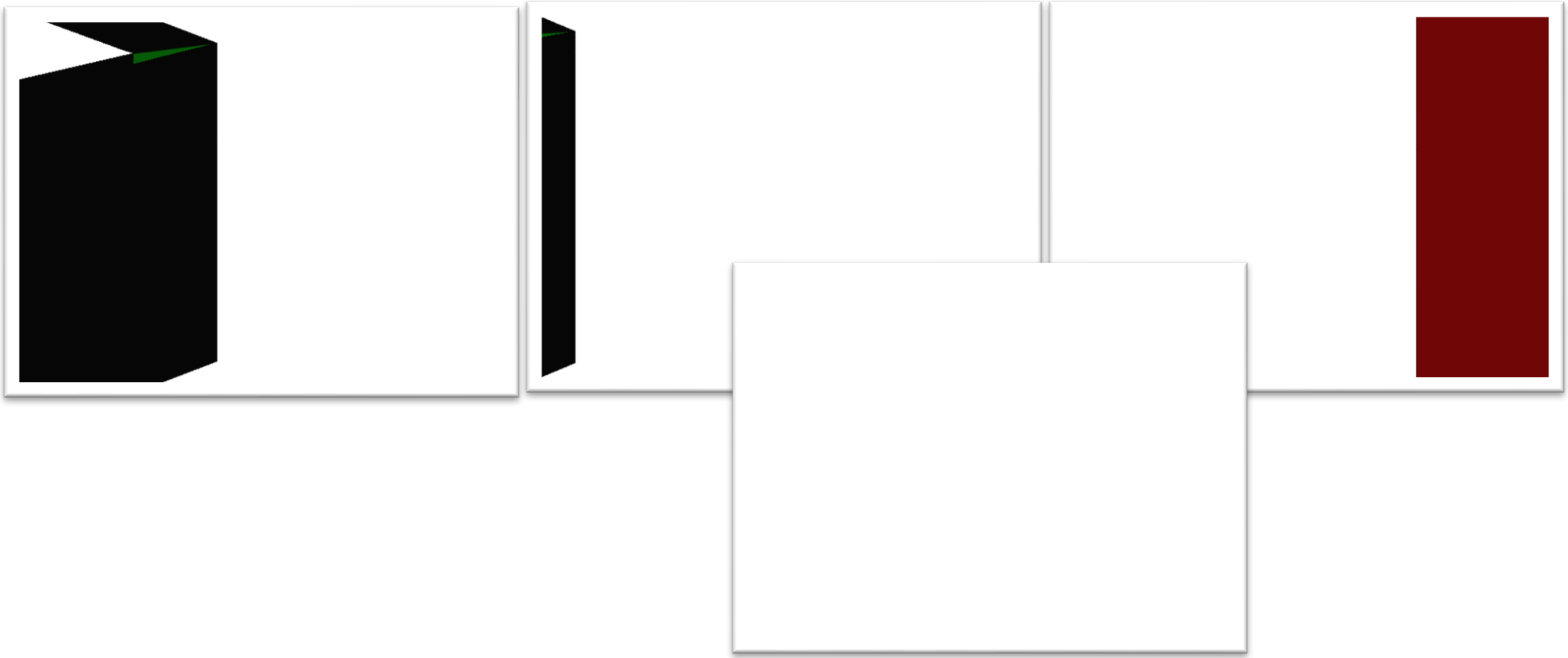




LOW-FIDELITY PATH SIMULATOR - Navigation

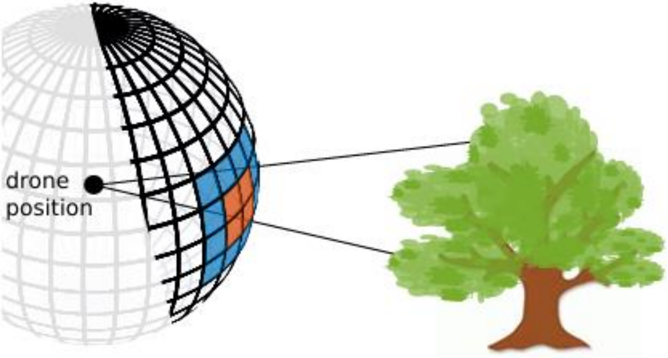


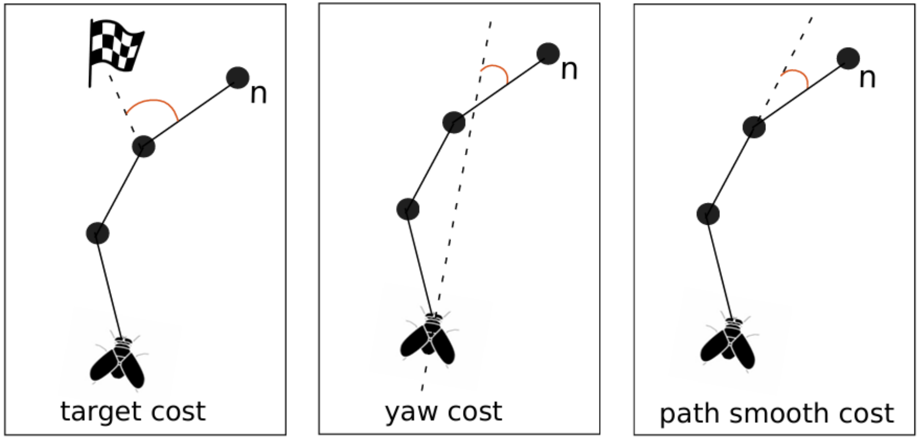
LOW-FIDELITY PATH SIMULATOR – Navigation 2



LOW-FIDELITY PATH SIMULATOR – Depth Images

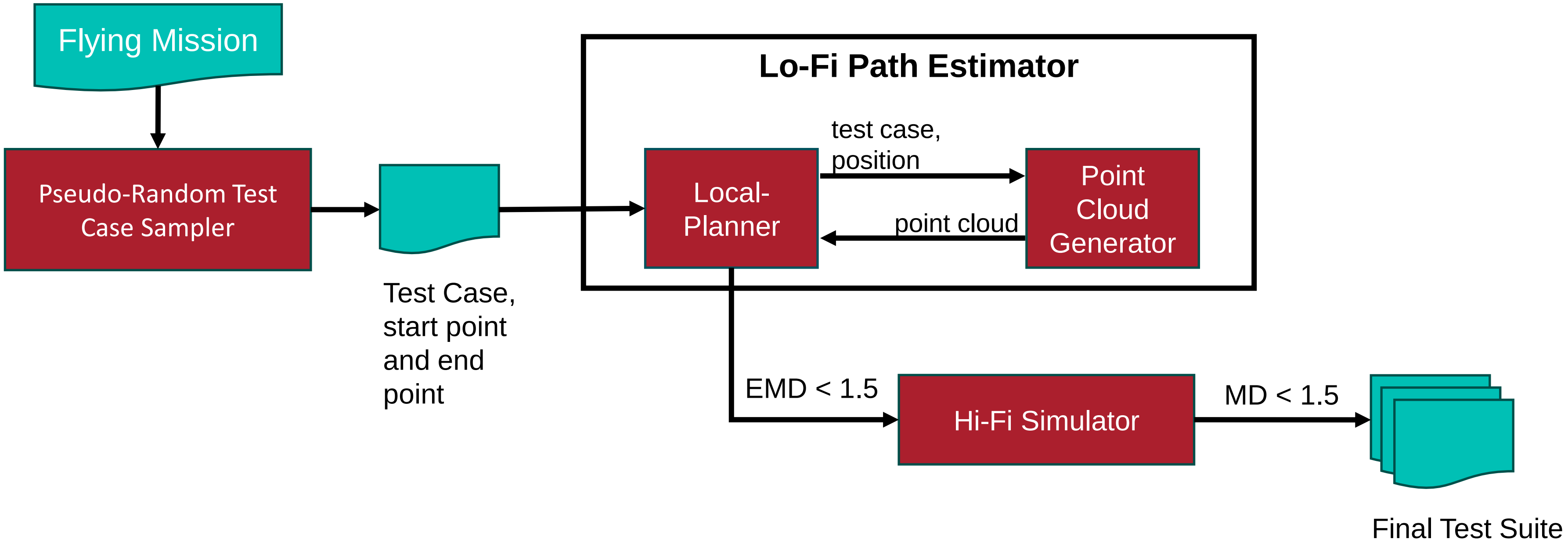
3DVFH* Algorithm (Baumann, 2018)



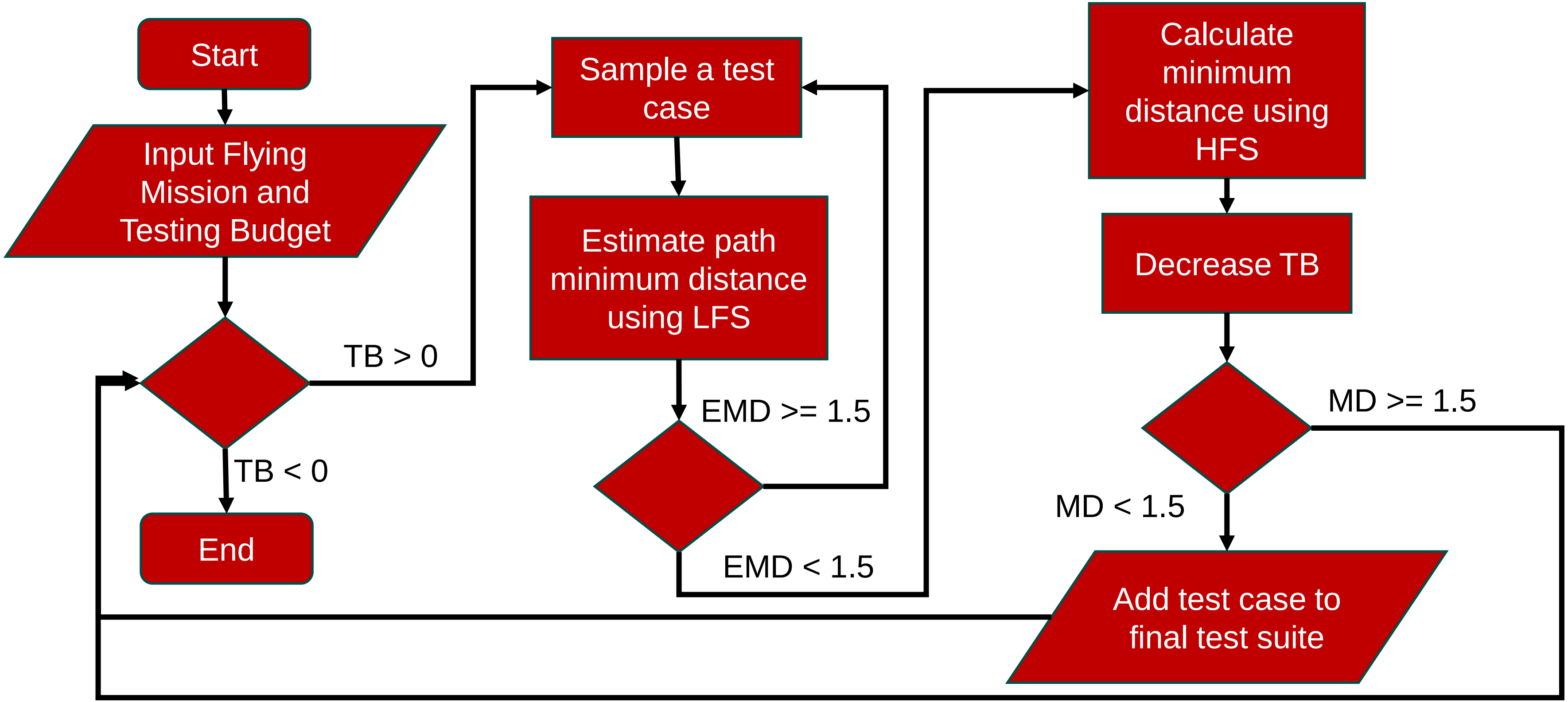


Tanja Baumann. Obstacle avoidance for drones using a 3DVFH* algorithm. Spring Term, 67:2018, 2018

Pseudo-Random UAV Test Generation Using Low-Fidelity Path Simulator – Block Diagram



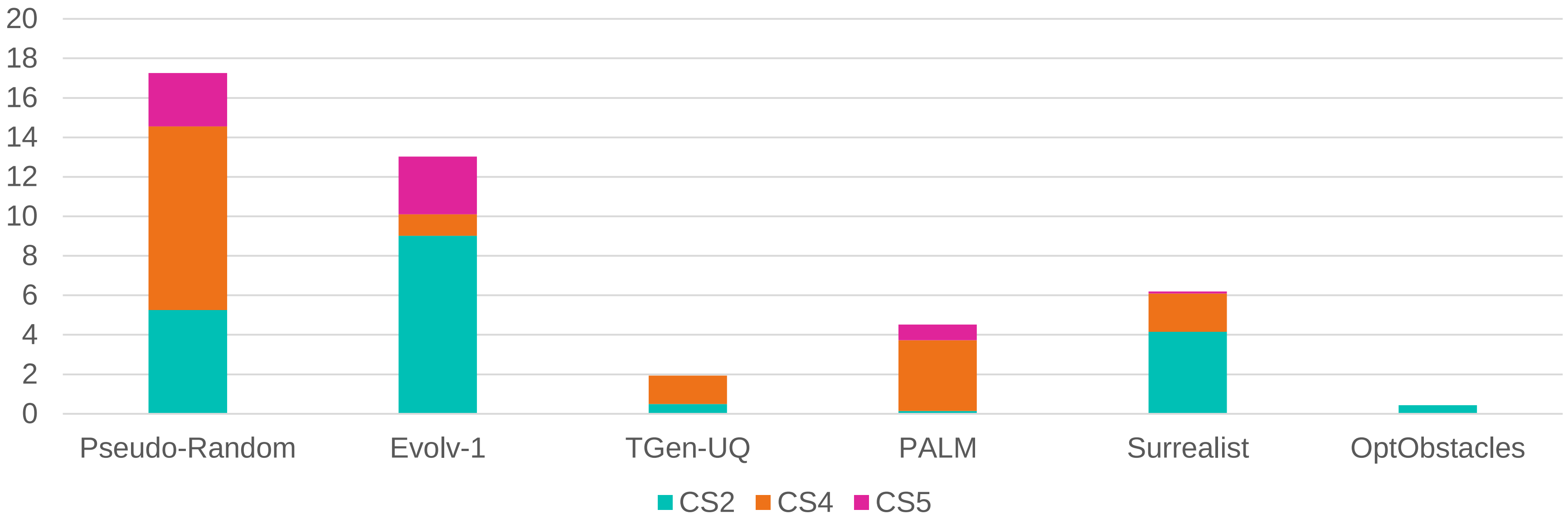
Pseudo-Random UAV Test Generation Using Low-Fidelity Path Simulator - Algorithm



SBFT and ICST 2025 Results

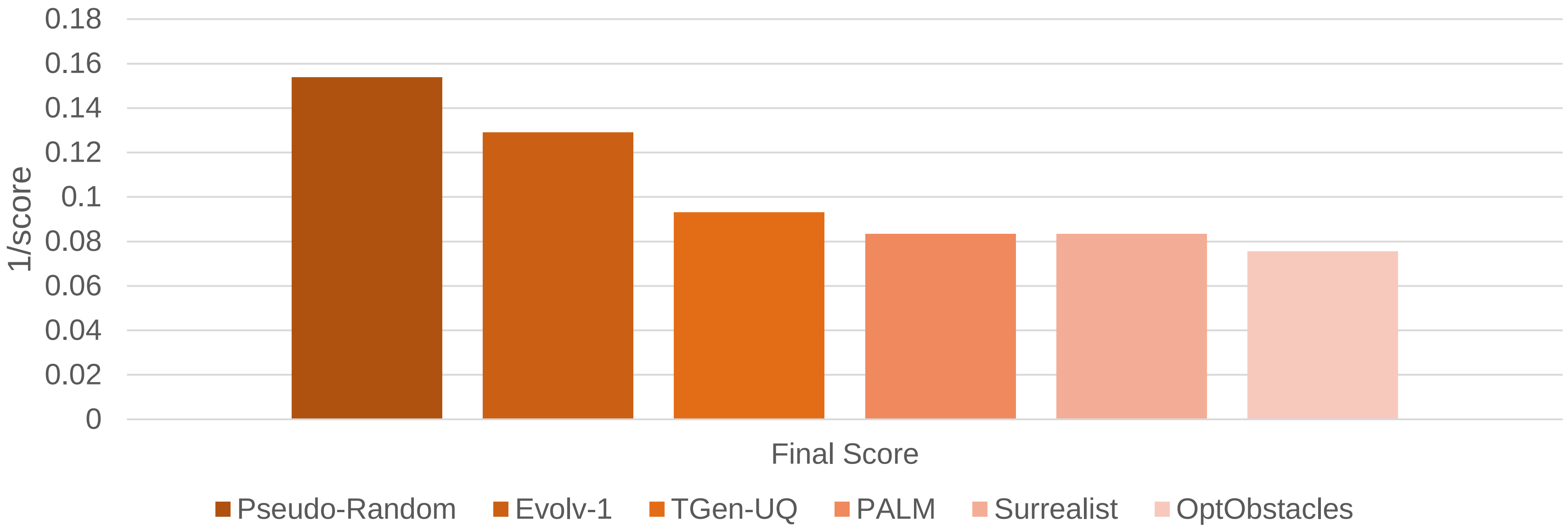
Tool	Venue	#Obst.	CS2			CS4			CS5			SUM		Final Rank
			#tests	failure	diversity	#tests	failure	diversity	#tests	failure	diversity	failure	diversity	
Pseudo-Random	SBFT	2	31 (7)	5.25 (2)	0.86 (4)	66 (12)	**9.30 (1)**	0.87 (3)	17 (5)	2.71 (2)	0.82 (4)	**17.26 (5)**	2.57 (11)	**6.50 (1)**
Evolv-1	ICST	2	57 (12)	**9.02 (1)**	0.88 (3)	22 (2)	1.08 (5)	0.82 (4)	37 (6)	**2.93 (1)**	0.85 (3)	13.04 (7)	2.57 (10)	7.75 (2)
TGen-UQ	ICST	2	5 (1)	0.50 (4)	**1.00 (1)**	6 (1)	1.44 (4)	**0.94 (1)**	6 (0)	0.00 (5)	0.89 (2)	1.95 (13)	**2.84 (4)**	10.75 (3)
PALM	ICST	2,3	58 (1)	0.14 (6)	0.57 (5)	82 (20)	3.58 (2)	0.42 (5)	76 (19)	0.80 (3)	0.46 (5)	4.52 (11)	1.47 (15)	12.00 (4)
Surrealist	Baseline	2	52 (11)	4.16 (3)	0.21 (6)	9 (3)	1.93 (3)	0.20 (6)	9 (1)	0.11 (4)	0.18 (6)	6.21 (10)	0.60 (18)	12.00 (4)
OptObstacles	SBFT	2,3	3 (1)	0.44 (5)	0.93 (2)	7 (0)	0.00 (6)	0.92 (2)	2 (0)	0.00 (5)	**0.89 (1)**	0.44 (16)	2.75 (5)	13.25 (6)

Failure Score



Diversity Score

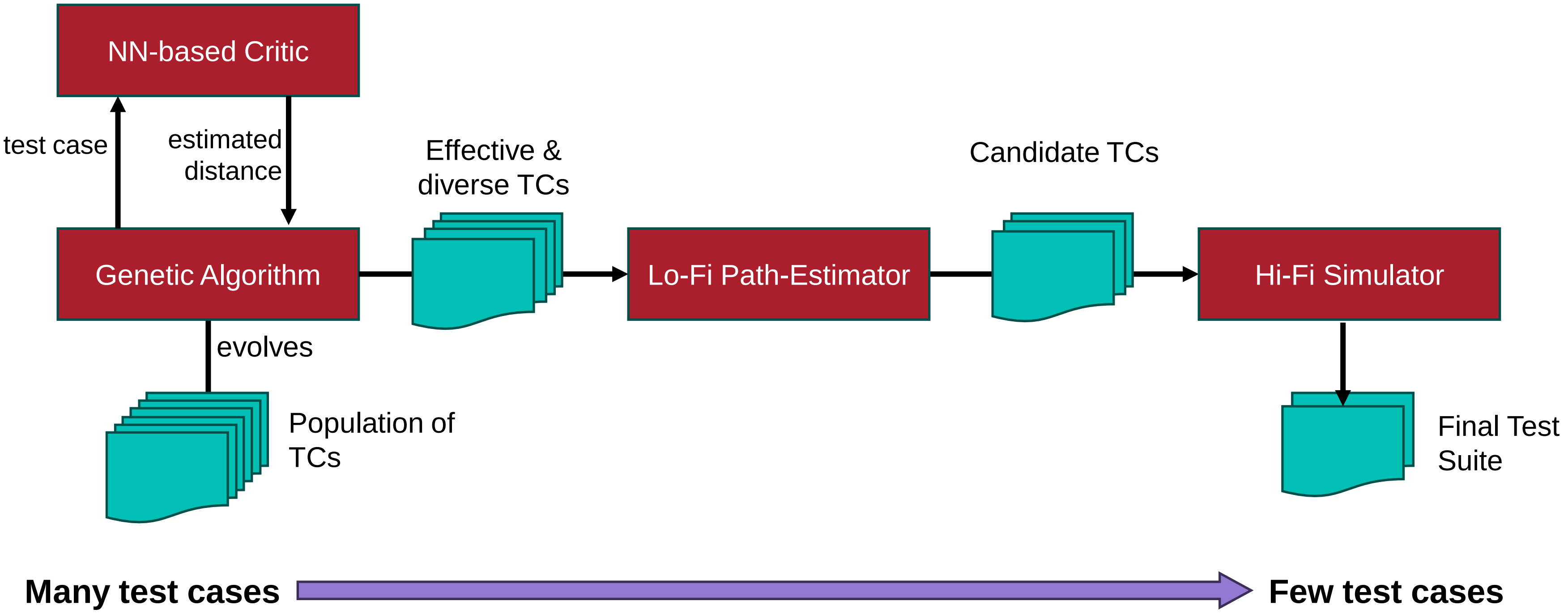
Final Score



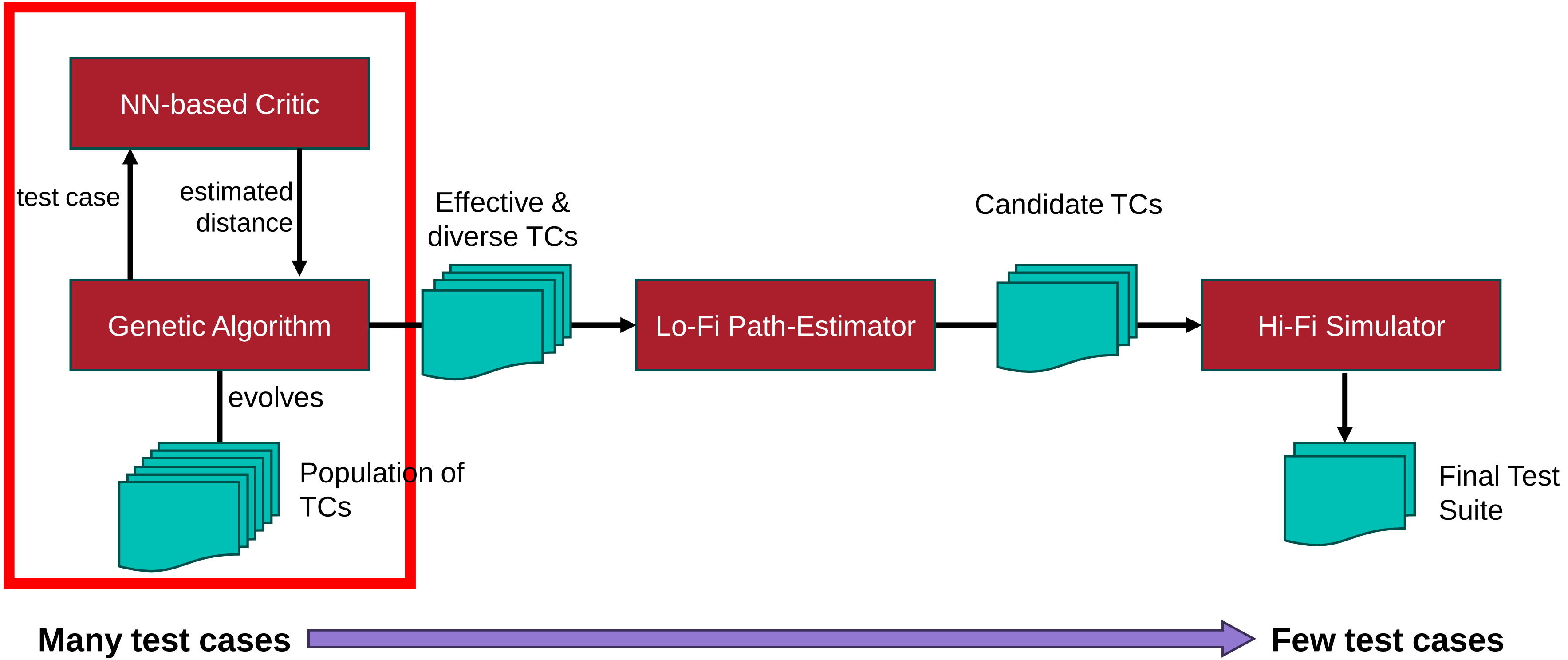
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1/score
Final Score
Pseudo-Random
Evolv-1
TGen-UQ
PALM
Surrealist
OptObstacles

Genetic Algorithm – Based UAV Test Case Generation

Building on the model-based approach

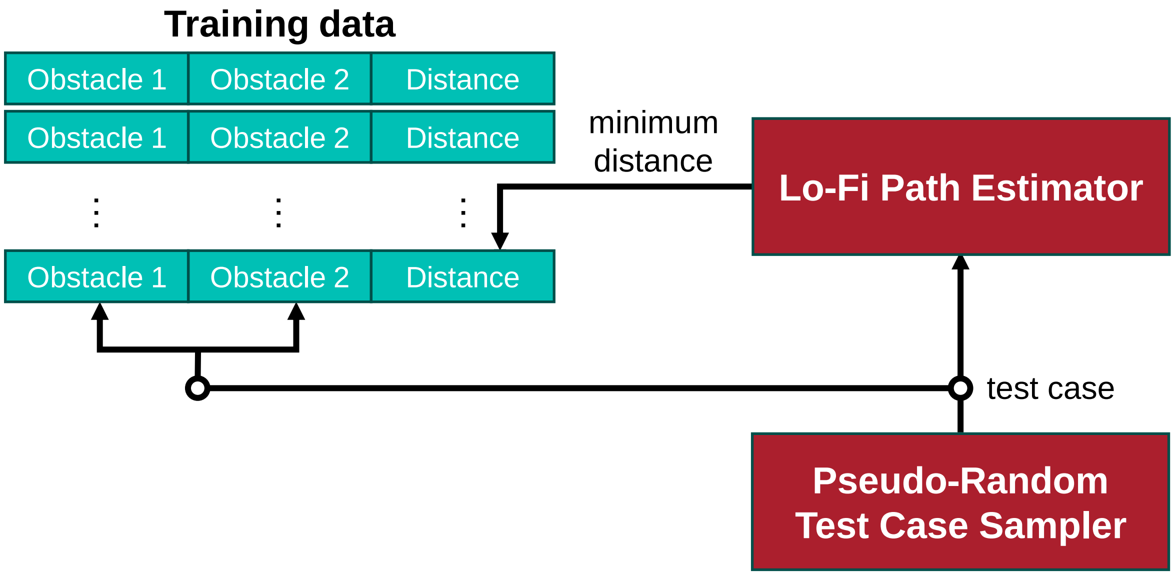


Building on the model-based approach



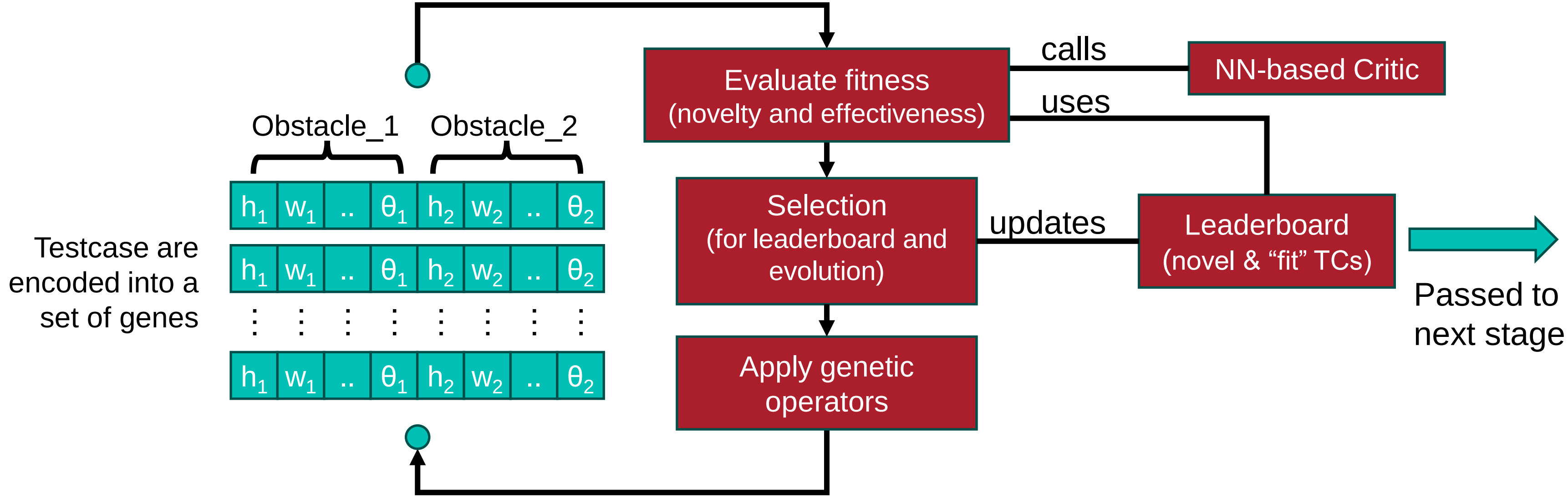
Training the NN Critic

- Lo-Fi Path Estimator **generates** labels for **training** the NN
- The NN Critic **approximates** the Lo-Fi Path Estimator



Running the Genetic Algorithm

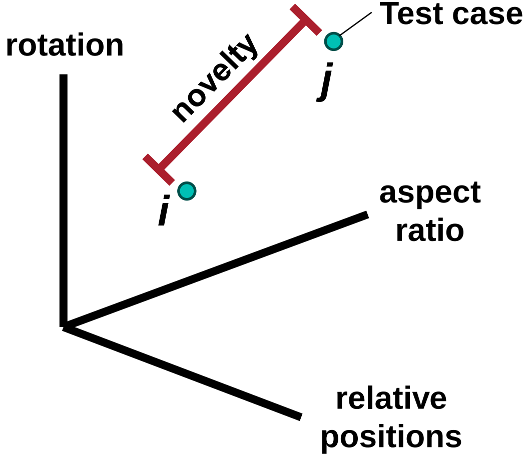
- Also used for finding bugs in FPGAs
- Tests cases (TCs) are initially randomised
- Novel component of fitness changes as leaderboard populated



Evaluating test case fitness

- GA uses simulations to evaluate the quality (fitness) of each test case
- **Cost of evaluating fitness** based on 1000 calculations:
  - Hi-Fi Simulator ~ 100 hours
  - Lo-Fi Estimator ~ 1.5 hours
  - NN-based Critic ~ 65 seconds
- **Fitness function components**
  - **Distance**: supplied by NN-based critic
  - **Novelty**: based on the Euclidean distance between features including obstacle aspect ratio and position

  ➡ Multi-objective optimisation



Summary

- SBFT / ICST 2025 hosted the second edition of the UAV Testing Competition.
- Tools are assessed based on the effectiveness and diversity of the produced test cases.
- Our winning test case generator samples valid and effective random test cases and evaluate them efficiently using our low-fidelity path simulator.
- Our Genetic Algorithm-Based UAV Test Generator produce diverse test cases and evaluate their fitness efficiently by using a NN-critic.