GENERATIVE ADVERSARIAL NETWORK BASED HEURISTICS FOR SAMPLING–BASED PATH PLANNING

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MIPT

Outline

PROBLEM STATEMENT

Given:

- $\mathcal{X} \in \mathbb{R}^n$ – the state space, $n \in \mathbb{N}^n$, $n \geqslant 2$
- $\mathcal{X}_{obs}$ – obstacle space, $\mathcal{X}_{free} = \mathcal{X} \setminus \mathcal{X}_{obs}$ – free space
- $x_{init} \in \mathcal{X}_{free}$ – the initial state, $x_{goal} \in \mathcal{X}_{free}$ – the goal state
- $\mathcal{X}_{goal} = \left\{ x \in \mathcal{X}_{obs} \middle| \left\| x - x_{goal} \right\| < r \right\}$ – the goal region
- $\mathbf{\Sigma}$ – the set of all feasible paths
- $c(\sigma)$ – the cost function, $\sigma \in \mathbf{\Sigma}$,

$$Cost(x_i, x_j) = \left\| x_i - x_j \right\|, \quad x_i, x_j \in \mathcal{X}_{free}$$

Find: feasible path $\sigma^* : [0, 1] \to \mathcal{X}_{free}$

$$\sigma^* = \underset{\sigma \in \mathbf{\Sigma}}{\arg\min}\, c(\sigma), \quad s.t.\ \sigma(0) = x_{init}, \sigma(1) \in \mathcal{X}_{goal}$$

APPROACH

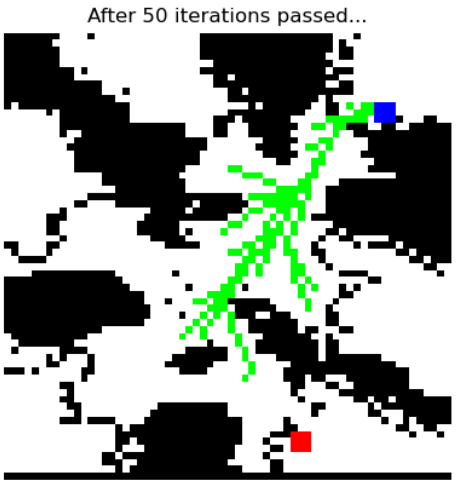
Background

- Sampling–based algorithms solve path planning problems through constructing space–filling trees to search a path σ.
- The tree is built incrementally with samples drawn randomly from the free space $\mathcal{X}_{free}$
- Drawbacks: the quality of initial solution, the convergence speed

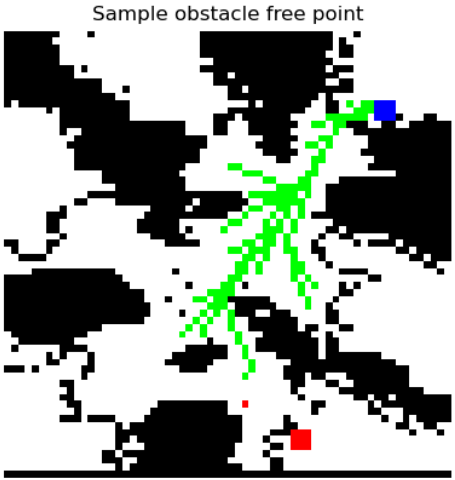
Idea

- Use generative adversarial network (GAN) to learn promising regions and construct heuristic non–uniform sampling distribution $\mathcal{X}_H \subset \mathcal{X}_{free}$ to reduce sampling space
- Use this heuristic in sampling–base algorithm (e.g., RRT*)

Step-by-step RRT*



Step-by-step RRT*



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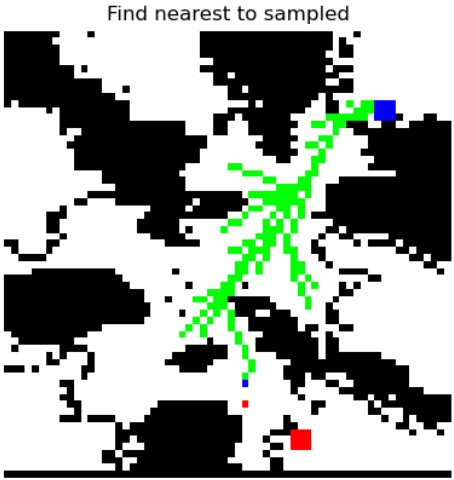
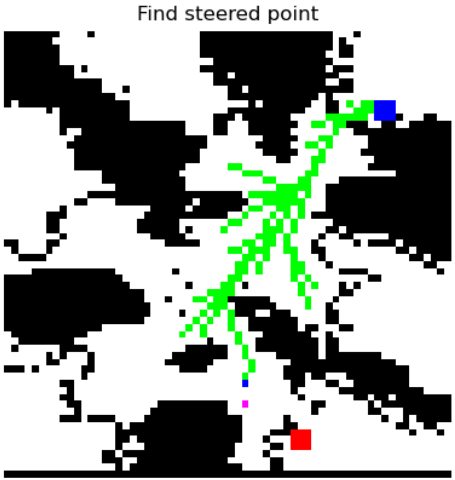
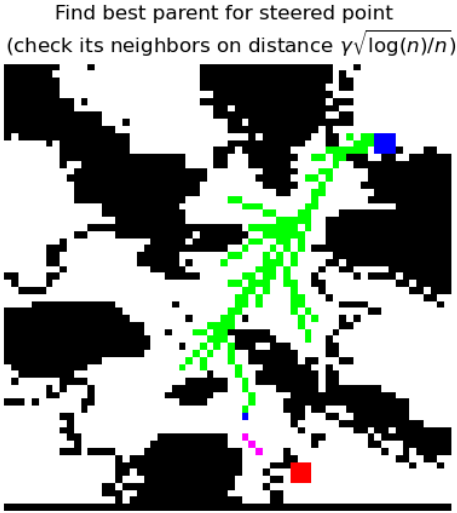


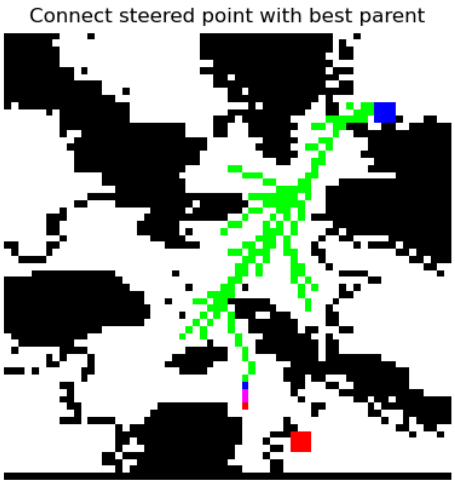
Step-by-step RRT*



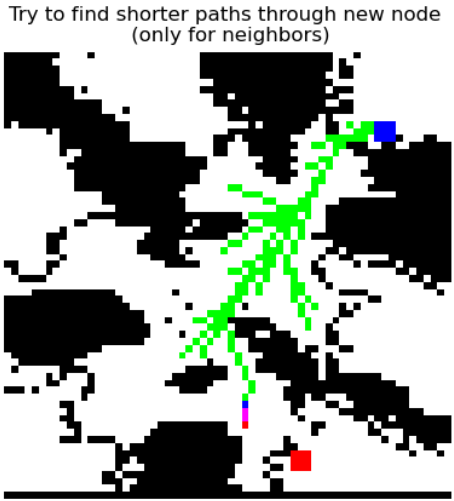
Step-by-step RRT*



Step-by-step RRT*

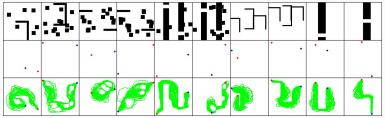


Step-by-step RRT*

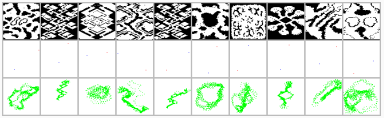


Data set

- **Generated dataset.** These maps were painted by hand. Their tasks (start and goal states) are generated randomly
- **MovingAI dataset.** These maps are resized to 64×64 maps from MovingAI to be fed into the GANs as test set (to check generalization ability).
- To obtain the 'ground truth' regions the RRT was launched 50 times on each task (for both data sets)



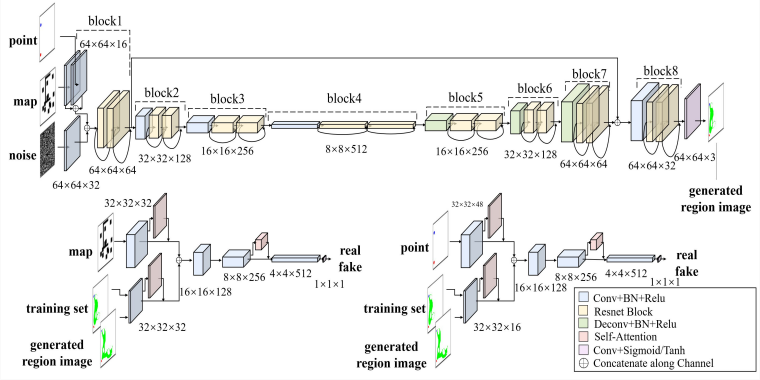
(a) Generated dataset



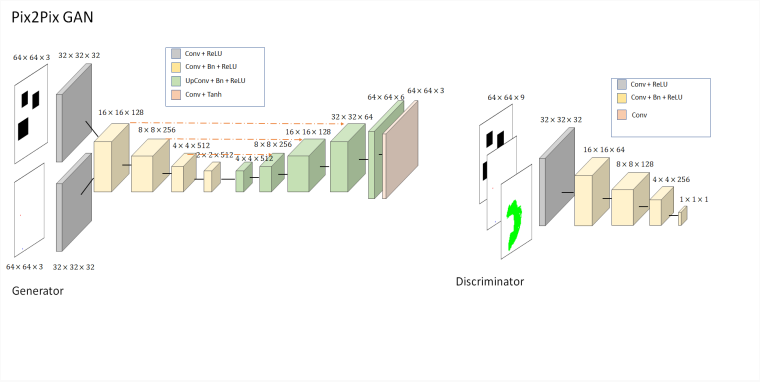
(b) MovingAI dataset

[0] *https://github.com/akanametov/pathgan*

GAN architecture: Original



GAN architecture: Pix2Pix



EVALUATION

As an image generation problem

- *Computer vision metrics* (DICE, IoU, FID and IS) between generated and ground truth regions of interest
- *The connectivity* (success rate, %) of the generated promising regions: if RRT algorithm is able to find feasible paths inside promising regions
- *Generalization ability* (success rate, %) – the connectivity of promising regions generated by trained model for completely different environments

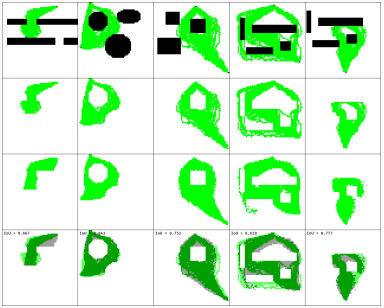
As a path planning problem

- RRT* vs. RRT* with GAN–generated heuristic were launched for 50 times on one randomly chosen task for each type of maps (both our maps and MovingAI)
- Metrics: time (# sec, # it), path cost and length (# nodes), #nodes in graph, #nodes sampled
- Metrics were collected for first and best[1] paths found and also checked after every 10 iterations

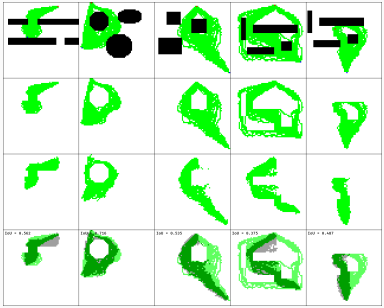
[1] by Euclidean distance

RESULTS

Results on generated dataset (test subset):



(c) Original GAN

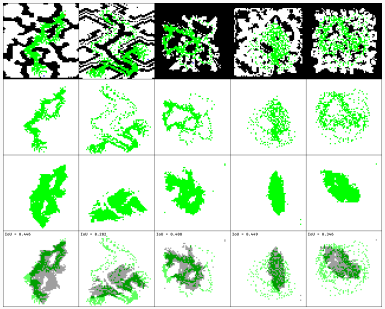


(d) Pix2Pix GAN

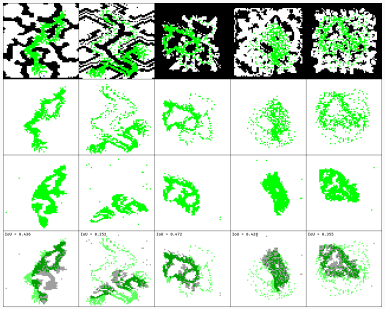
GAN	mIoU	mDICE	mFID	mIS	number of parameters
Original	**70.2%**	**82.0%**	**79.7**	**1.019**	21,231,827
Pix2Pix	58.1%	72.2%	91.2	1.017	**4,170,477**

[1] https://github.com/akanametov/pathgan

Results on MovingAI dataset (resized to 64×64):



(e) Original GAN



(f) Pix2Pix GAN

GAN	mIoU	mDICE	mFID	mIS	number of parameters
Original	**38.4%**	**53.8%**	**88.1**	**1.014**	21,231,827
Pix2Pix	30.8%	46.3%	100.1	1.012	**4,170,477**

[1] https://github.com/akanametov/pathgan

Connectivity and generalization ability

Success rate, % (found connected regions by total number of test maps).

GAN	Generated	MovingAI
Original	**65.8%**	54.5%
Pix2Pix	65.4%	**67.4%**

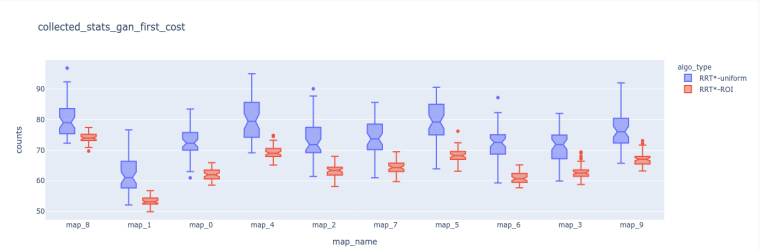
[1] *https://github.com/akanametov/pathgan*

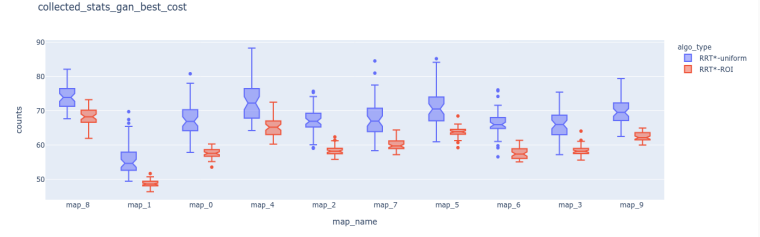
Path planning: RRT* vs. RRT* with GAN heuristic

In most cases RRT* with heuristic outperforms RRT* with uniform sampling:

1. It requires less time (#it, # sec) for both the first and the best path found (i.e., converges 1.5–2 times faster for first path and up to 4 times for best path)
2. It founds shorter paths by cost
3. It takes less nodes and samples (up to 3 times less for best path)
4. Metrics generated by RRT* with heuristic are more stable (i.e., have less variance)
5. On some maps RRT* works better than RRT* with heuristic, but only for first path found
6. The same observations are kept for unseen maps, but improvement is not so significant

Pathfindind: First vs best costs





Pathfindind: Cost and Number of nodes

CONTRIBUTION

Contribution

Timofey Zinenko
MovingAI maps adaptation, RRT for promising regions generation, connectivity evaluation

Azamat Kanametov
Initial data set generation, RRT for promising regions generation, GANs training and evaluation

Alina Kolesnikova
Embedding GAN–based heuristic into RRT*, path planning metrics evaluation

Thanks for attention!
Questions?