Probabilistic Generative Modeling for Procedural Roundabout Generation for Developing Countries

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NEURAL INFORMATION PROCESSING SYSTEMS
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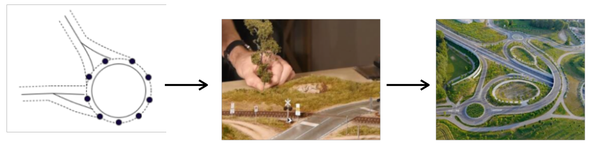
Introduction

- Synthetic road generation is important for **developing countries**



Computer simulation Laboratory testing Actual deployment

- **Diversity** important for area, location constraint, etc.
- Roundabouts difficult to generate despite popularity in many countries
- Procedural generation possible (Ikram et al. 2023), but does not produce diversity
- **GFlowNets** (Bengio et al. 2021) can sample x proportionally to a given **reward** R(x)
- Can we increase diversity in generated roundabouts using GFlowNets?

Background

$$Trajectory : (s_0 \rightarrow s_1 \rightarrow \ldots \rightarrow x), x \in \mathcal{X}$$

$$Forward-policy : P_F(s_{t+1} \mid s_t; \theta) \quad Backward-policy : uniform$$

$$\pi(x) = \sum_{\tau \in \mathcal{T} : x \in \tau} \prod_{t=0}^{|\tau-2|} P_F(s_{t+1} \mid s_t; \theta)$$

Total Flow

$$\sum_{x \in \mathcal{X}} R(x) = \sum_{s : s_0 \rightarrow s \in \tau \forall \tau \in \mathcal{T}} P_F(s \mid s_0; \theta)$$

Trajectory Balance Objective

$$\mathcal{L}(\tau; \theta) = \left(\log Z_\theta + \log \sum_{s_t \rightarrow s_{t+1} \in \tau} P_F(s_{t+1} \mid s_t; \theta) - \log R(x) - \log \sum_{s_t \rightarrow s_{t+1} \in \tau} P_B(s_t, s_{t+1}; \theta)\right)^2$$

Criteria For Roundabout Diversity

$$Diversity(\mathcal{D}) = \frac{\sum_{x_i \in \mathcal{D}} \sum_{x_j \in \mathcal{D} \setminus \{x_i\}} d(x_i, x_j)}{|\mathcal{D}|(|\mathcal{D}| - 1)}$$

d(·,·) : mean discrete **Fréchet distance** (Eiter and Mannila 1994)

Challenge

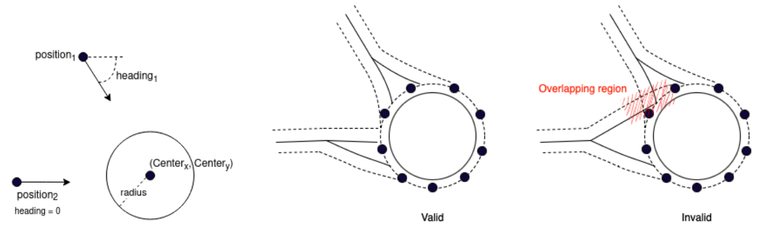
Problem Formulation

- GFlowNets good at discrete generation
- How to formulate the problem of roundabout generation in a way that **induces diversity**?

Time Complexity of Validating Roundabout

- GFlowNets require feedback after generation
- Validating roundabout takes time
- On a desktop, one roundabout takes 200ms to generate, meaning we can validate only 18000 configurations in an hour
- How to make it **faster**?

Problem Formulation & Proposed Solution



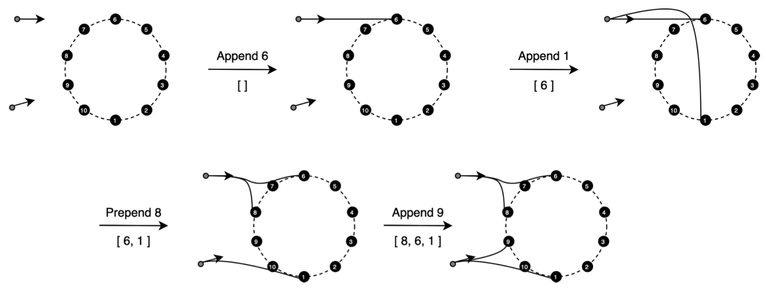
(a) Example problem (b) Solution

Task: road configurations => infer the circular structure from the incident roads

- **Input** : r road configurations P = {(position$_1$, heading$_1$, nleftlanes$_1$, nrightlanes$_1$), …, (position$_r$, heading$_r$, nleftlanes$_r$, nrightlanes$_r$)}
- **Output** : N-integer tuple where N is the total number of connection lanes and each integer denotes the slot where each connection lane is connected to in the circular segments (slots)

MDP Setup for Solution Generation

- Three type of actions : append, prepend, and terminate
- Starting from empty tuple, each action grows tuple by 1



Proxy Reward

- To reduce time complexity, estimate the validation using straight line intersection

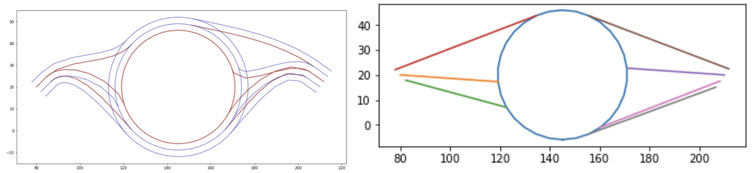
$$f(line_i, line_j) = [two\ lines\ intersect], f \rightarrow \{0,1\}$$

$$D(x) = \sum_{i<j}^{i,j \in N} \left(1 - f(line_i, line_j)\right) + \sum_{i}^{i \in N} (1 - f(line_i, circle))$$

$$D_{normalized}(x) = \frac{D(x)}{\frac{N(N-1)}{2} + N}$$

$$R_{proxy}(x) = base^{D_{normalized}(x)}$$

} Reward Calculation



Left: Geometry of a generated roundabout. Right: Geometry generated by the proxy reward function.

Selected Experiments & Results

Comparison with other methods

N	METHOD	$K = 50$ SCORE	$K = 50$ DIVERSITY	$K = 200$ SCORE	$K = 200$ DIVERSITY
4	BASELINE	6.6 ± 1.3	—	6.6 ± 1.3	—
	SAC	6.8 ± 0.6	0.4 ± 0.5	6.7 ± 0.8	0.5 ± 0.8
	OURS	6.6 ± 0.7	4.7 ± 1.7	6.6 ± 0.7	4.8 ± 1.5
6	BASELINE	17.4 ± 0.8	—	17.4 ± 0.8	—
	SAC	15.0 ± 1.1	2.4 ± 1.5	14.8 ± 1.2	2.9 ± 1.7
	OURS	15.6 ± 0.9	6.3 ± 0.6	15.6 ± 1.0	7.0 ± 0.5
8	BASELINE	30.3 ± 1.2	—	30.3 ± 1.2	—
	SAC	25.8 ± 2.1	3.4 ± 2.0	25.1 ± 2.3	3.4 ± 2.0
	OURS	28.1 ± 1.4	7.0 ± 0.48	27.8 ± 1.5	7.9 ± 0.4

- **Better diversity** than both Soft Actor Critic (SAC) and baseline
- Similar score to baseline despite producing **large number of diverse samples**

Conclusion

- GFlowNet samples proportionally to given reward
- Using MDP for roundabout generation, GFlowNet generates diverse solution for a given road configuration
- Proxy reward reduces the time needed to train GFlowNets significantly

References

Zarif Ikram, Golam Md Muktadir, and Jim Whitehead. Procedural generation of complex roundabouts for autonomous vehicle testing. In 2023 IEEE Intelligent Vehicles Symposium (IV), pages 1–6, 2023. doi: 10.1109/IV55152.2023.10186533

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