FreneticV at the SBST 2022 Tool Competition

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ABSTRACT

FreneticV is a search-based testing tool based on an evolutionary approach that generates roads where an automated driving agent possibly fails the lane-keeping task. It uses a curvature-based road representation and, compared to its predecessor Frenetic, considers the validity of the generated roads. In particular, it tries to avoid generating roads with overly sharp turns, detects self-intersecting roads, and can rotate and relocate roads to fit them in a given map.

CCS CONCEPTS

• **Computer systems organization → Embedded and cyber-physical systems**; • **Software and its engineering → Search-based software engineering**.

KEYWORDS

search-based testing, autonomous driving, Frenet frame, FreneticV

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1 INTRODUCTION

Frenetic [2] is a search-based approach to generate roads for simulation-based testing of autonomous driving systems. Namely, Frenetic aims at generating roads in which the ego vehicle drives off the lane, so possibly exhibiting failures of the lane-keeping component. Frenetic participated in the first competition on CPS testing at SBST'21 [4]. It has been later also used in an empirical study [1] to assess the influence of the road representation in search-based testing of autonomous driving systems.

In the CPS competition at SBST'21 [4], Frenetic obtained very good results in terms of diversity of the generated roads, but it also produced a relatively large number of invalid tests (i.e., too sharp, or self-intersecting roads). Therefore, for the second edition of the competition at SBST'22 [3], we extended Frenetic with FreneticV [1] (i.e., Frenetic + Validation), that employs particular strategies to avoid generating invalid roads.

In Sect. 2, we introduce the generation algorithm employed by FreneticV, focusing in particular on the new features introduced to achieve valid roads. Then, in Sect. 3, we provide a critical discussion about the performance of FreneticV at the SBST'22 competition, and outline possible future improvements.

2 FRENETICV

FreneticV is built upon Frenetic. Please refer to [2] for a complete description of Frenetic; we here provide a short description, and focus on the additional features introduced by FreneticV.

Given a list of *curvature values* and *segment lengths*, FreneticV builds a road as explained in [2]. Alg. 1 shows how it searches for curvature values describing roads that possibly lead to failures.

FreneticV aims at producing roads that are short, but yet useful from a testing perspective. Compared to Frenetic, the segment length between each road point has been reduced from 10 to 5 meters, whereas the number of points for a randomly generated road has been always calculated based on the size of the map and the segment length (lines 1-2), meaning that FreneticV has more variables to control the shape of the road.

First, it generates an initial population of random roads for a given period of time *rndBdgt* set to 1h (lines 3-6); the length of these roads is defined as the number of points *numPoints* ±5.

Then, for the remaining generation time (line 7), the algorithm keeps on searching for new roads as follows. It first selects the best candidate for mutation based on the *minimum out-of-bounds distance* (MOOBD), i.e., the distance between the center of mass of the car and the center lane. A candidate is suitable for mutation if its MOOBD is lower than a threshold *thMOOBD* (line 8), which was fixed at −0.5 for the competition, meaning that the center of mass of the car crossed the lane at some point. If no suitable candidate is available, new roads are generated randomly (lines 24-26). If a candidate *parent* exists (line 9), different mutations are applied to it (lines 15-22), depending on whether it is a failing (line 12) or passing test (line 14). Refer to [2] for details on the operators.[2]

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[1] FreneticV code is available at https://github.com/ERATOMMSD/freneticV-sbst22
[2] Note that we did not apply operator mut_{f1} from Frenetic [2] as not effective; moreover, differently from [2], in mut_{p6}, the curvature values are modified of 1-5%.

Algorithm 1 `FreneticV`

```
Require: mapSize, totalTime, rndBdgt, crossFreq, crossNum, thMOOBD
 1: segmentLength ← 5
 2: numPoints ← max(20, min(mapSize/segmentLength, 50))
 3: while elapsedTime < rndBdgt do
 4:     road ← genRndRoad(numPoints + rnd(−5, 5), segmentLength)
 5:     if ¬validate(road) then
 6:         discard(road)
 7: while elapsedTime < totalTime do
 8:     if |candidatesDeviatingFromMOOBDth(thMOOBD)| > 0 then
 9:         parent ← bestNotVisitedCandidate(thMOOBD)
10:         parent.visited ← true
11:         if parent.failed then
12:             mutations ← [mut_f2, mut_f3]
13:         else
14:             mutations ← [mut_p1, mut_p2, mut_p3, mut_p4, mut_p5, mut_p6]
15:         for mutation ∈ mutations do
16:             road ← mutation(parent)
17:             if ¬validate(road) then
18:                 discard(road)
19:             else
20:                 road.visited ← parent.failed
21:                 if road.failed then
22:                     break
23:     else
24:         road ← genRndRoad(numPoints + rnd(−5, 5), segmentLength)
25:         if ¬validate(road) then
26:             discard(road)
27:     if recent_count > crossFreq then
28:         while |children| < crossNum do
29:             parent_1, parent_2 ← bestCandidates(thMOOBD)
30:             crossover ← rndChoice([cross_1, cross_2])
31:             road ← crossover(parent_1, parent_2)
32:             if ¬validate(road) then
33:                 discard(road)
34:             else
35:                 children.append(road)
```

After generating a number of mutants (line 27), the crossover is applied between the tests having lowest MOOBD (lines 27-35). Two types of crossover are applied; refer to [2] for their description.

2.1 Road validation

`FreneticV` uses some mechanisms to generate roads that fit into given maps, while avoiding overly sharp turns and self-intersections. In Alg. 1, when a road is generated, function `validate` applies these mechanisms, and, if the road is still not valid, it is discarded.

2.1.1 Avoiding overly sharp turns and self-intersections. For a planar curve, the magnitude of the curvature and the radius of the curve are reciprocals. Both `Frenetic` and `FreneticV` use curvature-based road representations. This allows exploiting the reciprocal relationship to identify a global upper bound for the curvature values so that the radius of the generated road does not go below the threshold, and thus the turns are not overly sharp.

`FreneticV` also implements a method to check if a generated road is self-intersecting, which accounts for the road width, because a road with a positive width may be self-intersecting even if the curve corresponding to its center-line is not. In particular, it considers left and right edges of the road and checks if those edges are intersecting with themselves or with each other. Roads that are detected to be self-intersecting are discarded.

2.1.2 Road rotation and relocation to ensure validity. When transforming curvature values into Cartesian coordinates, a road generated by `FreneticV` can cross the boundaries of a given map, even if the initial point of the road is inside the map. `FreneticV` rotates and relocates road points so as to fit the entire road in the map.

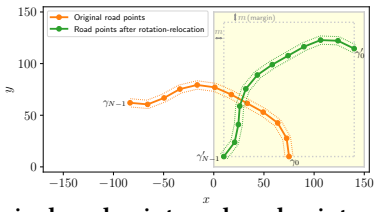

Figure 1: Original road points and road points after rotation and relocation operations to ensure validity on a square map.

Specifically, it iterates over a set of orientation values, and for each orientation ϑ, it rotates the road points $\gamma_0, \ldots, \gamma_{N-1}$ around the center of the road's bounding box by ϑ degrees. Furthermore, in each iteration, it also calculates the convex hull of the rotated road points and relocate the entire rotated road so that the minimum x and y coordinates of the exterior points of the convex hull both equal m, a small margin value that we use to avoid road edges being too close to map boundaries. If the rotated-and-relocated road points γ'_i are all contained in the map with margin m, then it stops iteration, and uses $\gamma'_0, \ldots, \gamma'_{N-1}$ as a valid road test (see Fig. 1).

3 RESULTS AND DISCUSSION

The *effectiveness* score of `FreneticV` provided in SBST'22 competition report [3] indicates the usefulness of the newly developed validity-checking mechanisms. However, as there is a trade-off between checking road validity and generating more roads, `FreneticV` obtained a relatively lower *efficiency* score. The *diversity* score of `FreneticV` is among the top. To further increase diversity, we believe that directional coverage of the roads can be improved. Specifically, the method discussed in Sect. 2.1.2 can be modified to generate new valid roads with extra rotations (e.g., 90, 180, and 270 degrees for square maps). This would increase directional coverage and it would be particularly useful for testing driving agents whose correctness could be affected by the direction of driving.

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