Surge Research Project

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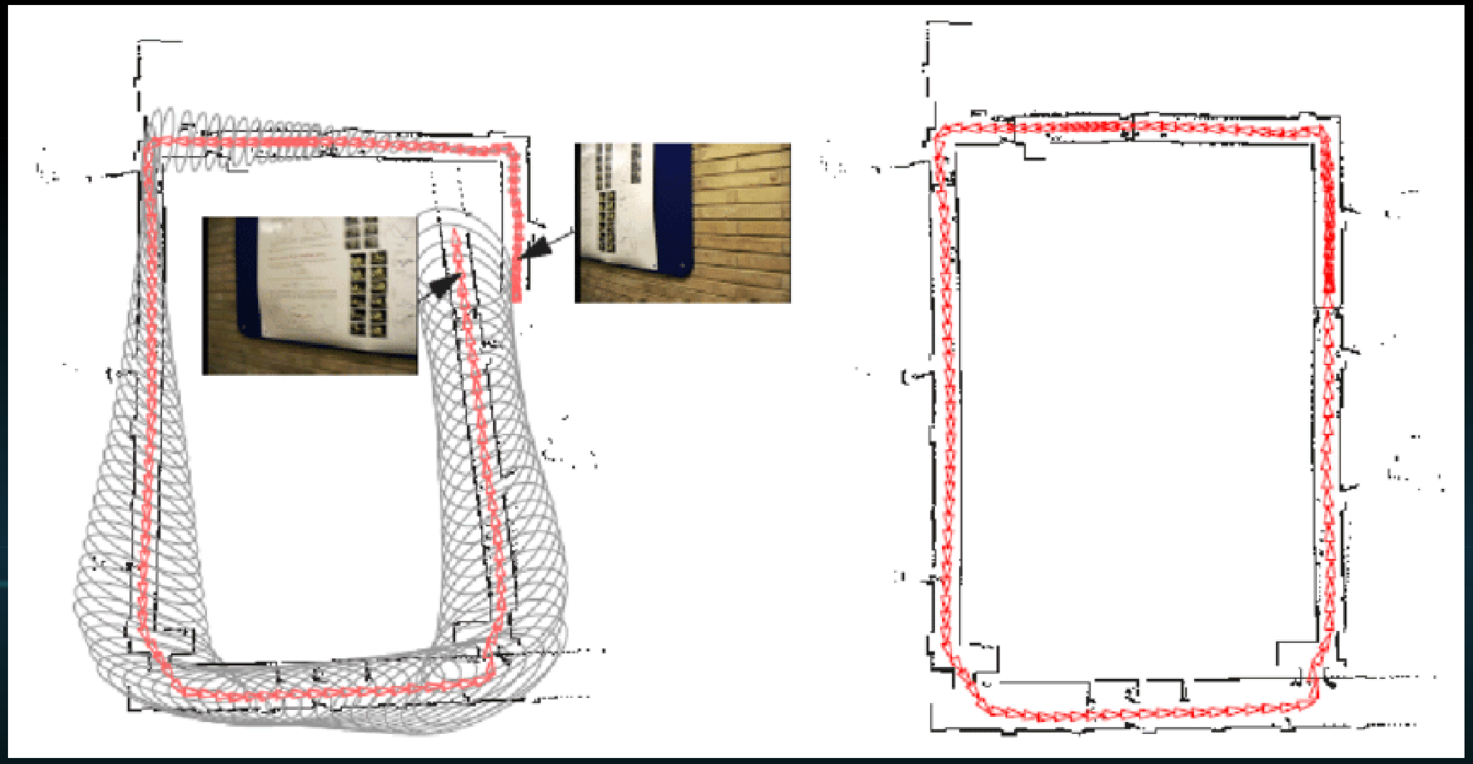
Loop Closure Detection

Loop closure detection is a critical component of Simultaneous Localization and Mapping (SLAM) systems. It ensures that the robot or agent can recognize when it has returned to a previously visited location, which helps correct accumulated drift in the estimated trajectory and map.



Why Loop Closure is Important

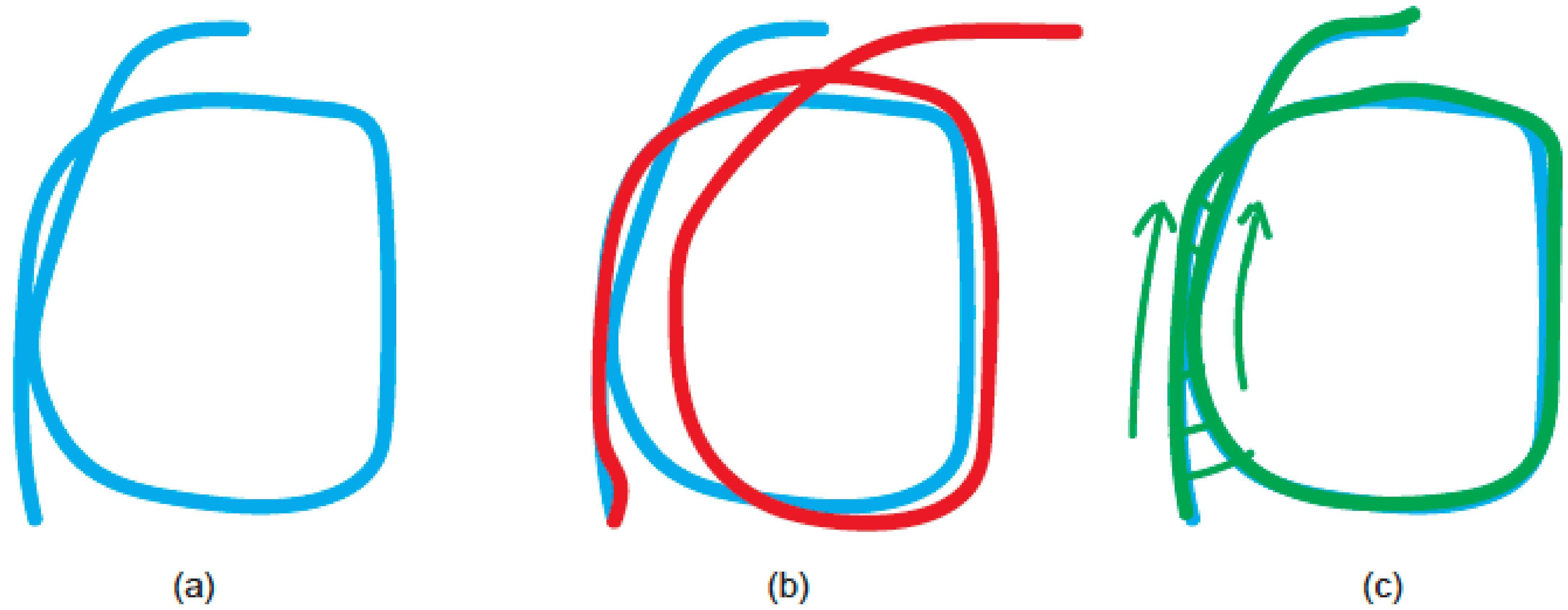


Figure 10-1: Accumulated drift. (a) Real trajectory. (b) Accumulated error if we only consider adjacent keyframes. (c) Add loop closure to reduce the accumulated drift.

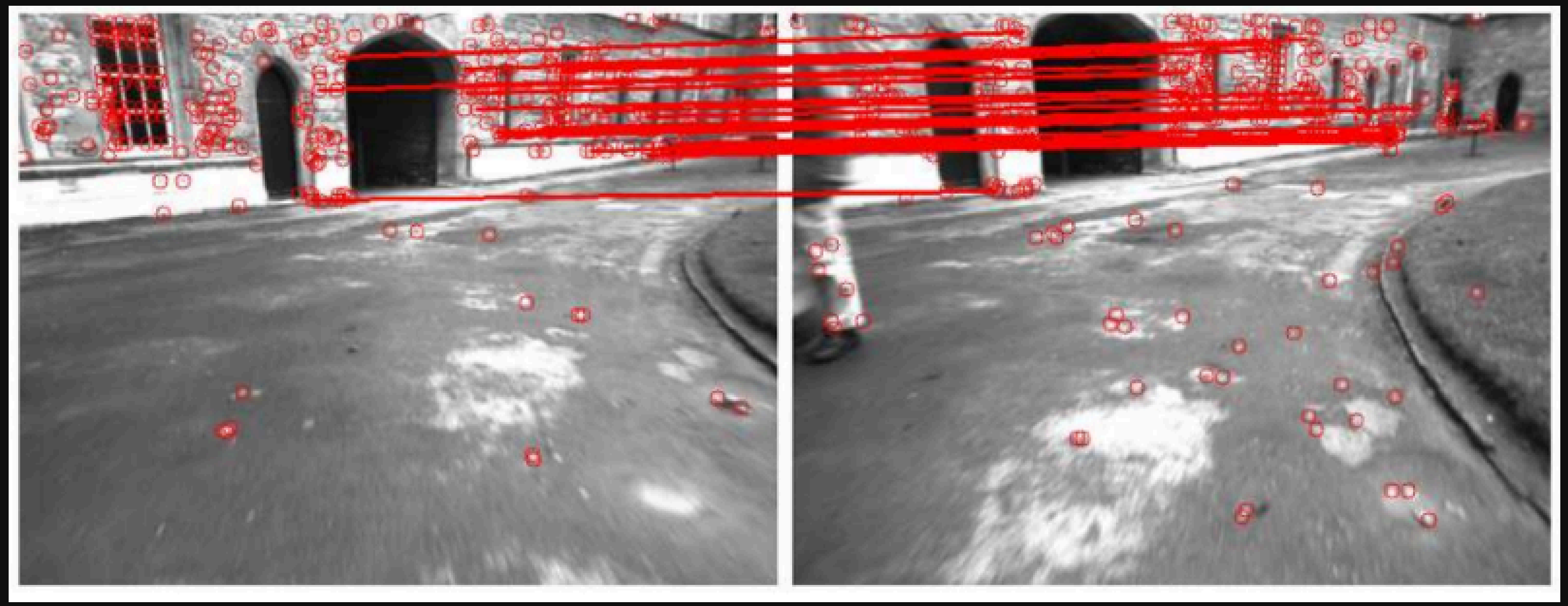
How Loop Closure Works

There are Several Loop Closure Detection Techniques:

- Vision Based/ Appearance Based Loop Closure Detection.
- LIDAR- Based Loop Closure Detection.
- Sensor- Fusion Based Methods.
- Hybrid Methods.

Vision Based Loop Closure Detection

Vision-based loop closure detection methods are some of the most widely used approaches in Visual SLAM (V-SLAM) systems. These methods rely on recognizing places by comparing images captured by the robot or device at different times.



Feature Detection & Matching

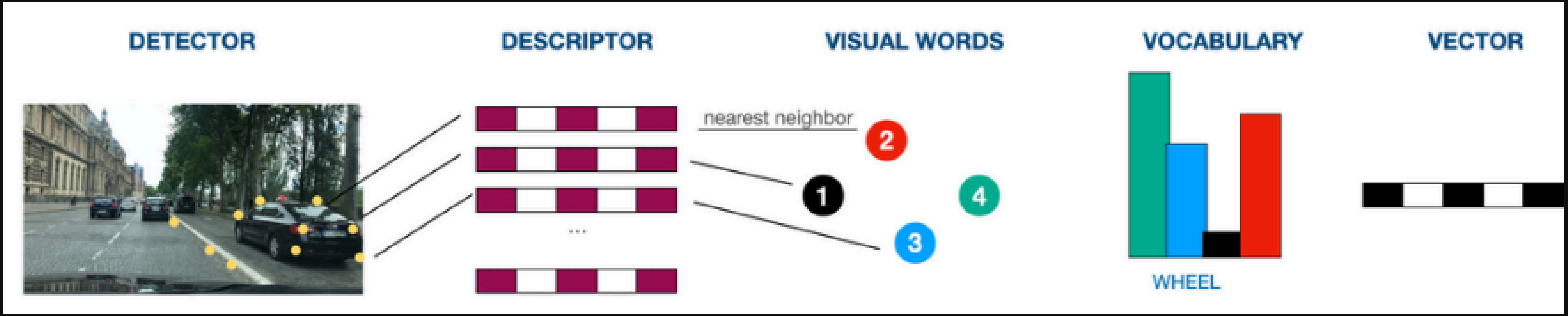
Vision Based Methods

Bag of Words (BOW) Methods.

- They Represents Image as histogram of Visual Words.
- Sensitive to Appearance Change (lighting, Viewpoint)
- Compare Current Image histogram with previous Keyframes.

Summary

The raw descriptors are assigned to the nearest visual word in the vocabulary, and a histogram of visual words is constructed for each image. This histogram represents the BoW vector for the image, which is a fixed-size representation of the image features. This BoW vector can then be used for efficient matching and loop closure detection.



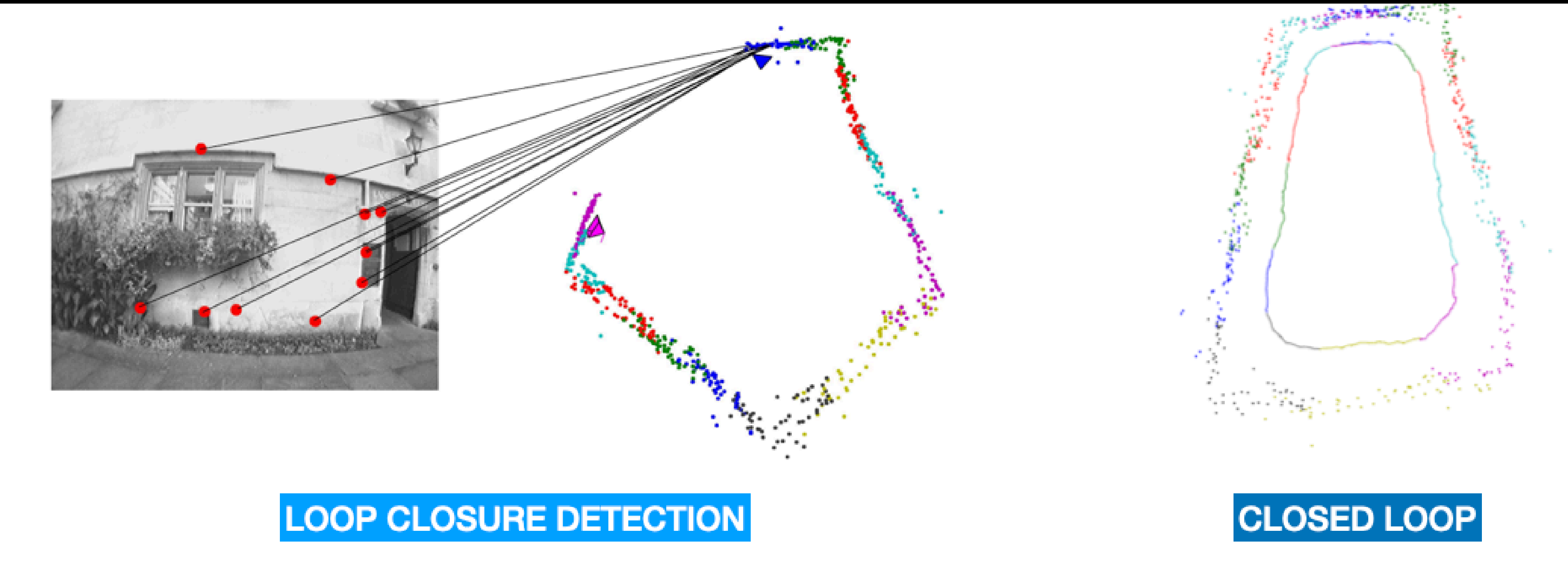
Converting features into visual words and vectors

And then we're matching the vectors together with the previous keyframes when we need to run place recognition.

Vision Based Methods

CNN(Convolutional Neural Networks) Method.

- Uses Deep Neural Networks to extract smart features.
- They give more accurate and robust results and are semantic aware.
- With Sufficient Data can outperform BOW in many Scenarios.



LIDAR Based Methods

Scan Context

- It converts 3D Lidar Scan into 2D Image like format.
- It works well where the Visual Features are limited.
- Improves the overall performance of robotic systems by allowing them to accurately localize and map their surroundings

Summary

Instead of using images or handcrafted descriptors like BoW or deep CNNs, Scan Context creates a compact 2D descriptor from 3D LiDAR scans that captures the spatial distribution of the environment.

It represents a point cloud in a cylindrical grid around the vehicle and encodes maximum height values in each grid cell.

LIDAR Based Methods

ICP(Iterative Closest Point)

- Tries to match Current 3D scans to past ones by minimizing the diff b/w point clouds.
- Easy to Implement and Understand.

- It gives precise alignment and estimate the precise transformation.
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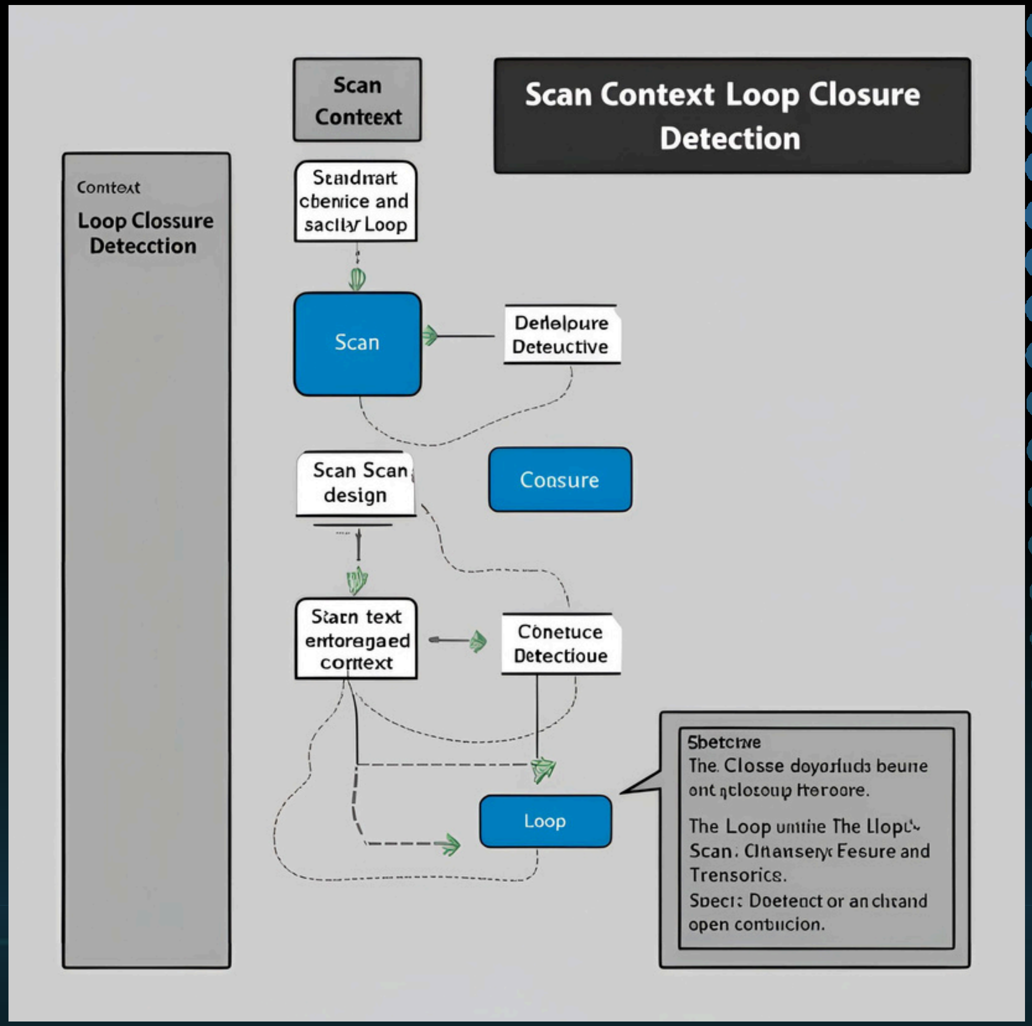
Scan Context

Code for Scan Context (LIDAR Based Method) Implementation.

- Scan Context cpp Code.

Source: This C++ code implements a Scan Context-based loop closure detection method for LiDAR-based SLAM systems. The method is based on the paper "Scan Context: Egocentric Spatial Descriptor for Place Recognition Within 3D Point Cloud Map" (Kim and Kim, IROS 2018).



Why Scan Context?

- Fast Global Descriptor Based Method
- Robustly Detect Loop Closure in Large Scale Environment
- Uses KD-Tree Search , Suitable for Real Time large-Scale loop closure Detection.
- Built-in Rotation invariance helps recognize places regardless of orientation differences.

Point Cloud

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[Make Scan Context]

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[Extract Ring Key + Sector Key]

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[KD-Tree Search on Ring Key]

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[Alignment via Sector Key Shift]

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[Descriptor Matching: Cosine Similarity]

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Loop Closure Detection ✓

How KD-Tree is used in Scan Context.

In Scan Context, a KD-tree is used as an efficient method to search for similar past scans (potential loop closure candidates) based on a rotation-invariant feature vector called the Ring Key.

Efficiently find previously seen scans that are similar to the current scan without comparing every past scan — this reduces computational cost from O(N) to O(log N) (where N is the number of stored scans).

Thank You