When Geospatial Big Data Meets High Performance Computing in 3D GIS

Tianyang Chen & Wenwu Tang
Center for Applied Geographic Information Science
Department of Geography and Earth Sciences
University of North Carolina at Charlotte

4-5-2019

The 2019 Annual Meeting of the American Association of Geographers

Acknowledgement

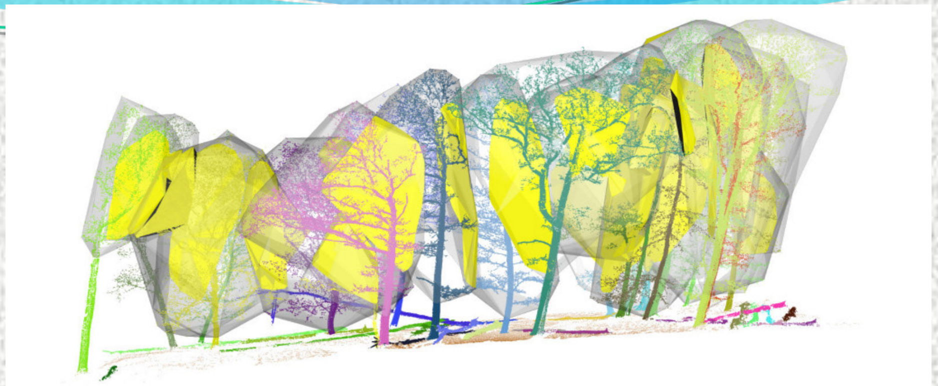
- North Carolina Department of Transportation (NCDOT)
- Steering and Implementation Committee from NCDOT:
  - Matthew Lauffer, John W. Kirby, Tom Langan, Gary Thompson, Paul Jordan, Mark Swartz, Mark Ward, Derek Bradner, Brian Radakovic, Kevin Fischer
- This study is supported by the NCDOT project entitled "DeepHyd: A Deep Learning-based Artificial Intelligence Approach for the Automated Classification of Hydraulic Structures from LiDAR and Sonar Data"
  - PIs: Drs. Wenwu Tang, Shenen Chen, John Diemer, Craig Allan from the University of North Carolina at Charlotte

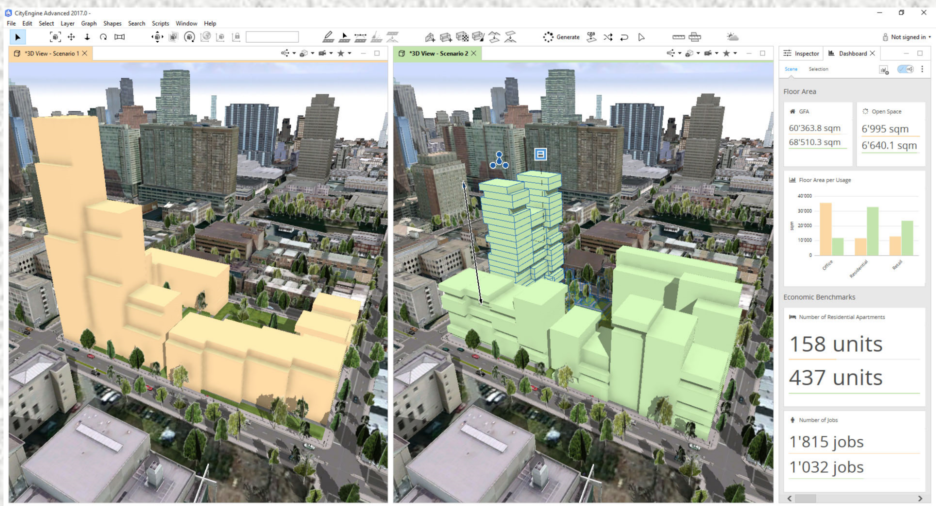
Objective

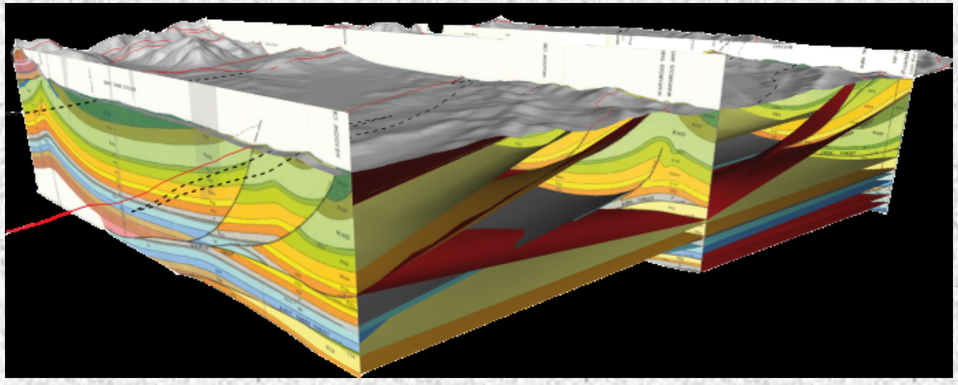
- The objective of this study is to present a cyberinfrastructure-enabled high performance computing solution to resolve the big data challenge facing geospatial data analytics in 3D GIS.
- We focus on using a state-of-the-art photogrammetry technique, structure from motion (SfM), for the 3D modeling of hydraulic structures (e.g., bridges).

Background

- 3D GIS instead of conventional 2D GIS
  - Applications of 3D GIS
    - Hydraulic structure (e.g., bridges)
    - Forest (e.g., tree attribute estimation)
    - Urban planning (e.g., building)
    - Geology (e.g., geological layers)







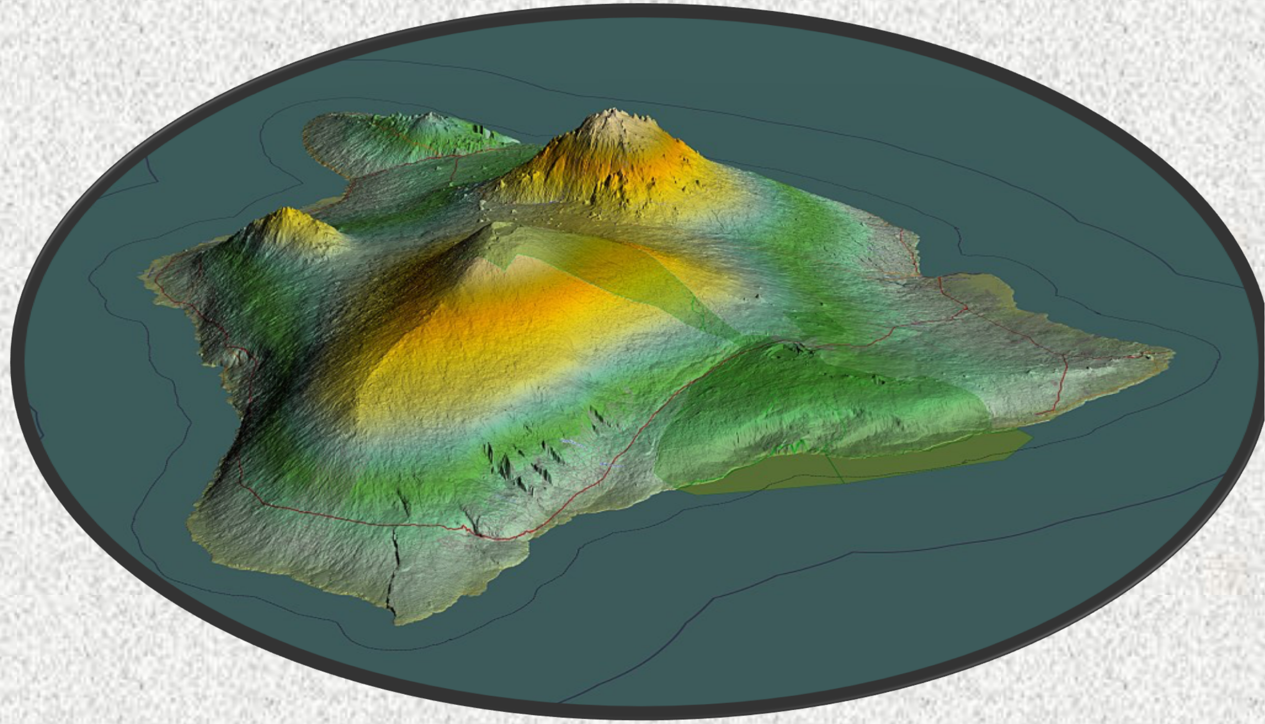
http://www.3dforest.eu/

https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwjJha7X5LfhAhVphOAKHeo2ARgQjRx6BAgBEAU&url=https%3A%2F%2Fwww.esri.com%2Farcgis-blog%2Fproducts%2F3d-gis%2F3d-gis%2Fcityengine-2017-highlight-reel%2F&psig=AOvVaw1R_WIU0StNb79K9PAIEKuW&ust=1554513627998513

https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwiKuf2J5bfhAhXIJt8KHcKoA3IQjRx6BAgBEAU&url=https%3A%2F%2Fwww.mve.com%2Fsoftware%2Fmove&psig=AOvVaw1WGpzvpqDYpEWbWZBHwSCN&ust=1554513728559137

Background

- 3D GIS
  - 3D geospatial data collection and processing
    - LiDAR, sonar, camera
    - Collected from satellite, airplane, drone, vehicles, etc.
  - 3D geospatial analysis and modeling
  - 3D geo-visualization



https://upload.wikimedia.org/wikipedia/commons/d/d6/Hawaii-Big-Island-TF.jpg

Structure from Motion: a Revolutionary Photogrammetry Technique

- Structure from Motion (Westoby et al., 2012) is a technique to <u>reconstruct 3D scene with images and ground control</u>
- Differences between traditional photogrammetry and SfM
  - Traditional photogrammetry relies on 3D location and pose of camera, ground control, and images.
  - Structure from Motion solves the camera pose by matching features extracted from overlapping images leveraging **feature detection techniques.**

Feature Detection

- Common Feature Detection Techniques:
  - Scale Invariant Feature Transform (Sift) (Lowe, 2004)
  - Speed Up Robust Feature (Surf) (Herbert, 2008)
  - Oriented FAST, Rotated BRIEF (Orb) (Calonder, 2010)

Method	Intensity (light)	Rotation (angle)	Scaling (distance)	Fish eye (distortion)	Noise	Time cost
SIFT	3	3	1	3	2	5
SURF	2	2	2	1	1	2
ORB	1	1	3	2	3	1

*Performance (level 1-3) of feature extraction techniques in different scenarios and time cost (source from Karami, 2017)

Problem Statements

- Big Data-driven Computing Challenges:
  - To solve the pose of camera, SfM relies on feature extraction technique. However, it is a time consuming especially adopting best performance technique SIFT for tons of images
  - The later step of SfM, dense reconstruction, also faces issues of data-intensive computing when massive images are involved.

Solution?

- Cyberinfrastructure-enabled High Performance and Parallel Computing!

https://i0.wp.com/hanusoftware.com/wp-content/uploads/event_218867862.png?w=360&ssl=1

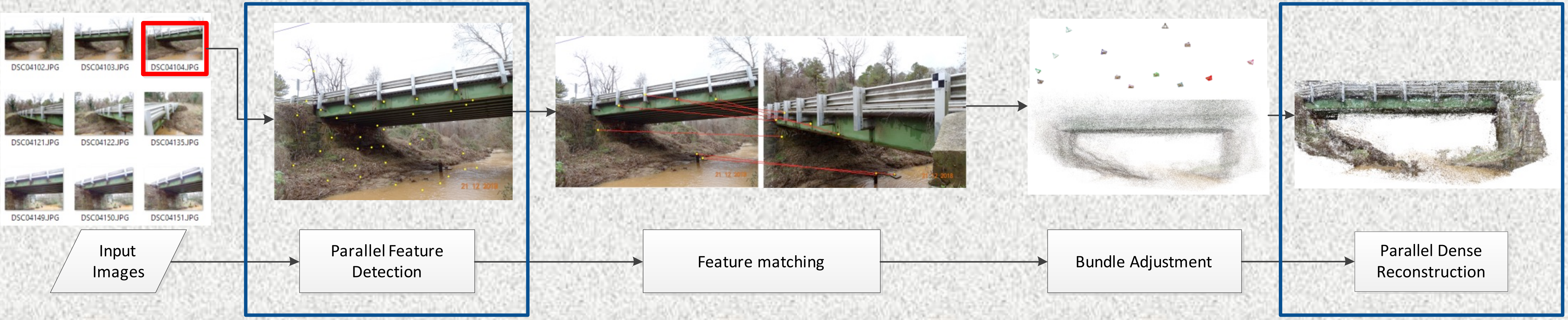
Study Area and Data

- Bridges in Mount Holly, Gaston County, NC
- RGB images collected from GPS camera
  - GPS Camera: Sony DSC-HX400V
  - 208 images with resolution 5,184*3,888

https://www.google.com/maps

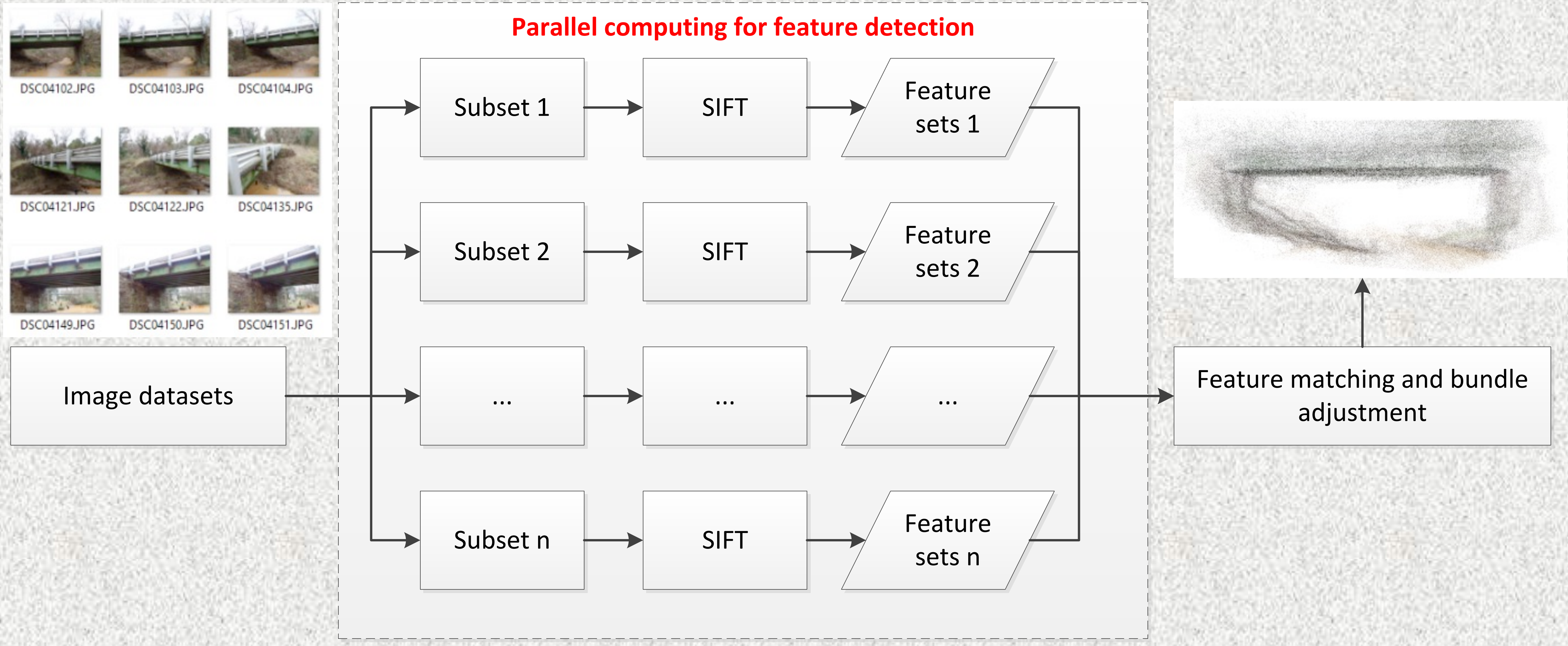
Methods

- Parallel algorithms of structure from motion technique
  - Parallel feature detection
  - Parallel dense reconstruction



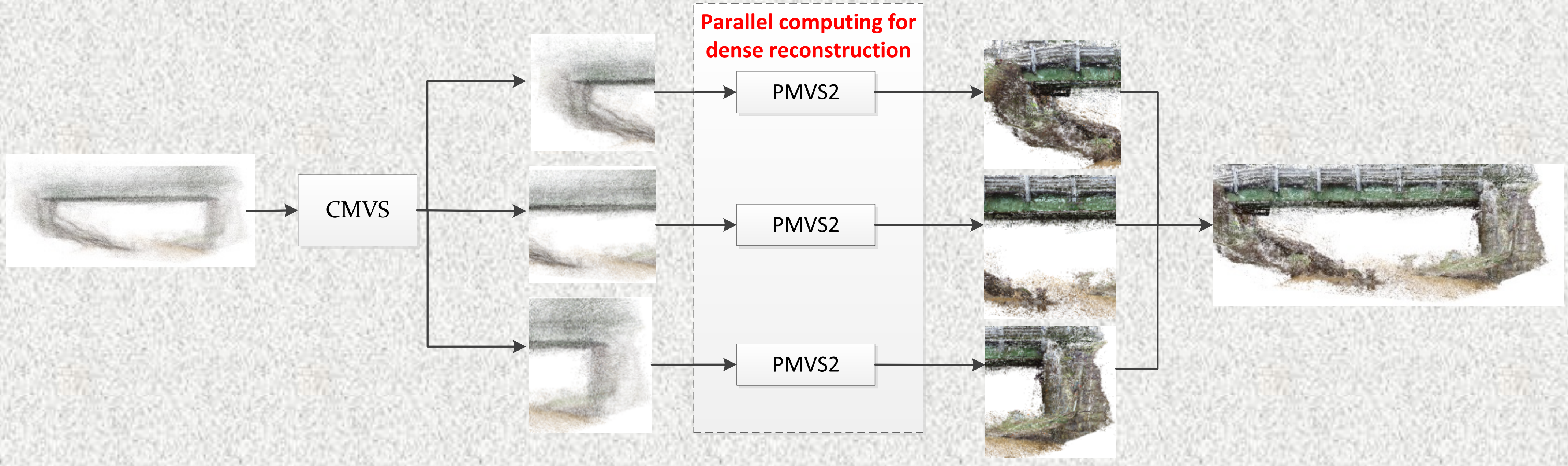
Parallel Feature Detection

- The computing of subsets can be parallelized over multiple CPUs
  - Share-nothing parallelism



Parallel Dense Reconstruction

- Clustering View for multi-view Stereo (CMVS) (Furukawa & Ponce, 2007; Furukawa et al., 2010)
- Patch-based Multi-view Stereo (PMVS2) (Furukawa and Ponce, 2007)
- CMVS decomposes overlapping images to subsets and PMVS2 reconstructs 3D data independently for each of them



Implementation

- Testing Data: To avoid endless time when to test time cost of each test involving different #CPUs, we use a testing dataset with 29 images (resolution 1,024*768).
- OpenSfM, an open-source Structure from Motion software package
  - https://github.com/mapillary/OpenSfM

High Performance Computing Resources

- Linux Cluster
  - **Copperhead**: **Linux**-based HPC Cluster
    - 96 compute nodes
    - 2,060 computing cores (CPUs)
    - Total Memory: 18,004 GB
    - Located at University Research Computing at the University of North Carolina at Charlotte (https://urc.uncc.edu/)

Intel® Xeon® Processor E5 v3 10cores 3.1GHz

https://i0.wp.com/hanusoftware.com/wp-content/uploads/event_218867862.png?w=360&ssl=1

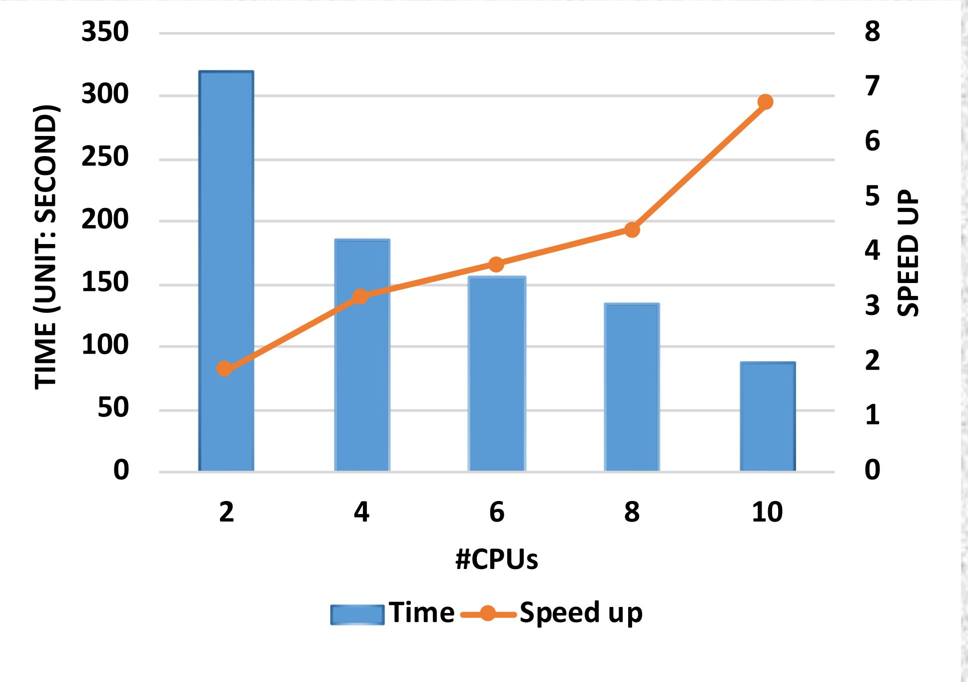
3D Reconstruction Results for bridges

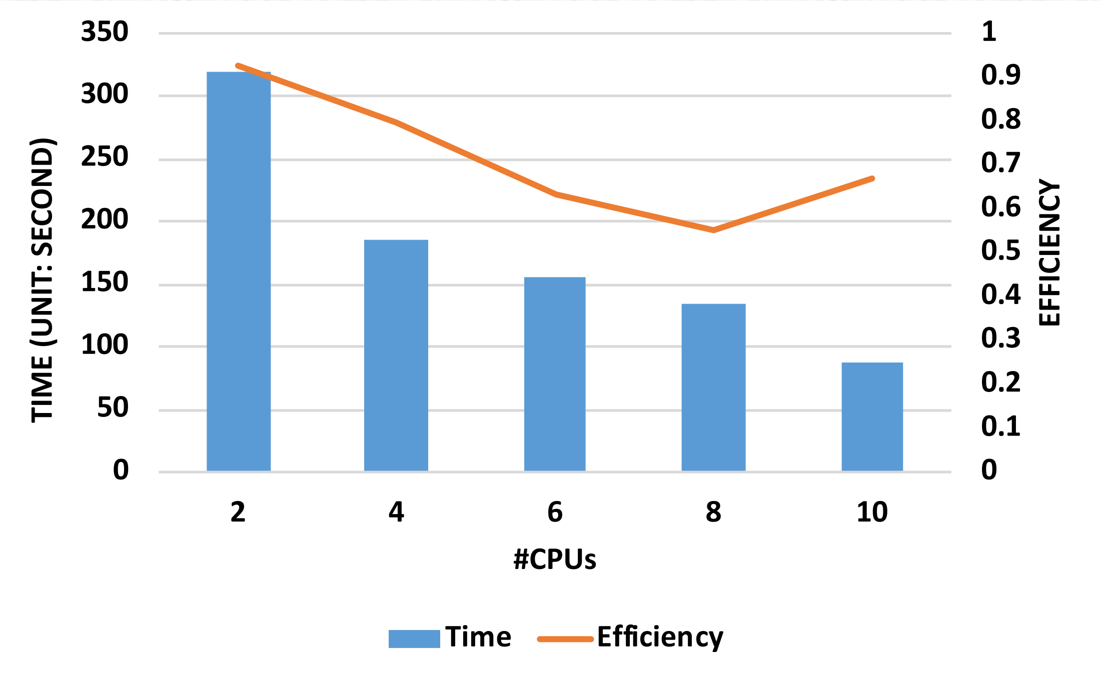
2D image of the study site

3D point cloud scene of the study site

Results

- Sequential computing time: 591 seconds
- Parallel computing time using different #CPUs





Discussion

- Paralleling feature detection and dense reconstruction speeds up 7 times with 10 cores than the sequential computing time. This result support the feasibility of using HPC technique to accelerate Structure from Motion.
- Leveraging HPC, geospatial big data can then be well used for highly accurate modeling in 3D structures such as bridges.

Conclusion and Future work

- Using parallel computing is a powerful approach to accelerate Structure from Motion as a cutting-edge photogrammetry technique. In this study, we use this technique to speed up two important steps in SfM: feature detection and dense reconstruction.
- However, feature matching and bundle adjustment also face data-intensive computing problem, especially with large-volume datasets.
- Further work should address the computing issues in the mentioned two steps so that SfM can be accelerated in facing increasing number of images for highly accurate 3D scene reconstruction.

Reference

- M. Calonder, V. Lepetit, C. Strecha, and P. Fua. “BRIEF: Binary robust independent elementary features,” In European Conference on Computer Vision, 2010.
- David G Lowe, “Distinctive Image Features from Scale-Invariant Keypoints,” International Journal of Computer Vision, vol.50, No. 2, 2004, pp.91-110
- Herbert Bay, Tinne Tuytelaars and Luc Van Gool, "Speeded-up robust features (SURF)," Computer vision and image understanding, vol.110, No.3, 2008, pp. 346-359.
- Karami, E., Prasad, S., & Shehata, M. (2017). Image matching using SIFT, SURF, BRIEF and ORB: performance comparison for distorted images. *arXiv preprint arXiv:1710.02726*.
- Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). ‘Structure-from-Motion’photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, *179*, 300-314.

Thanks for listening!