



Leveraging Diffusion Models for Urban Change Detection and Classification from Historical Maps

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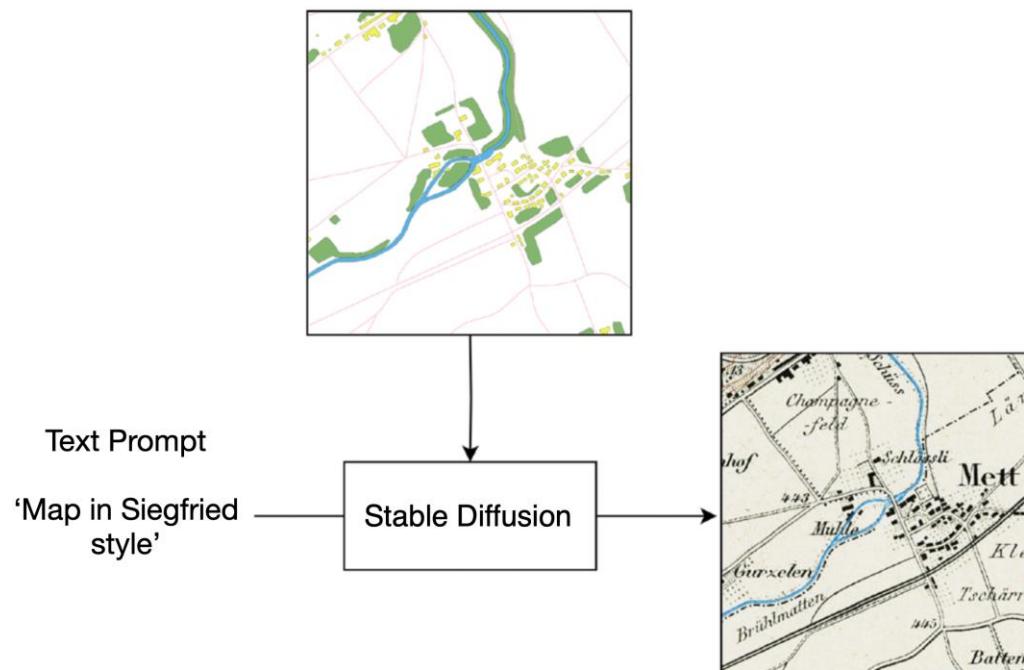
Introduction

Urbanization

- Urban areas are changing through **growth, shrinkage, densification, or restructuring** [1].
- Understanding these changes is crucial for creating **sustainable and livable cities**

Stable diffusion

- ControlNet allows control over **semantic layout and spatial composition** to generates images from prompts (e.g., text, edge maps). -> Claudio Affolter's work [2]
- Potential applications in **historical map analysis** -> Change simulation in a specific map style



Motivation

Why

- Remote sensing imagery: change detection -> uncover urban change patterns
- Historical map: investigate long-term urban change patterns over decades or even centuries, but **lack ground truth** change mask for change detection

Solution

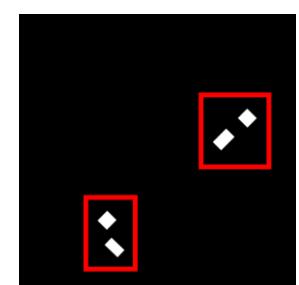
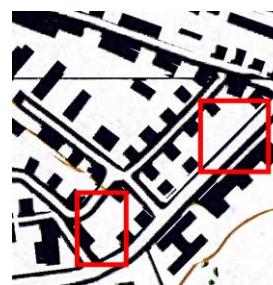
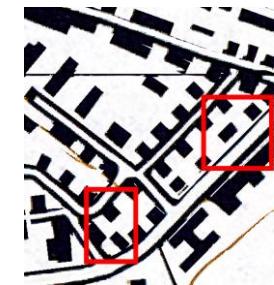
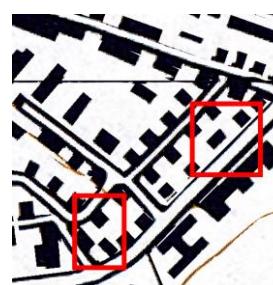
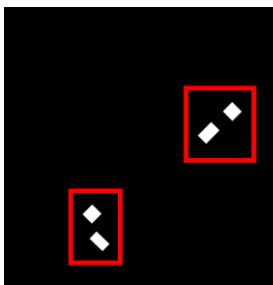
- **Simulate various urban change scenarios** through manipulating vectors and save the change mask
- **Leverage diffusion models to generate pre- and post-change historical maps** given the vector input
- **Train the change detection model** and utilize the trained model to infer the changes in real-world datasets

Goals

Conceptualize and categorize urban change types and manipulate vectors for different urban change scenarios

Generate pre- and post-change map tiles given the vector input using trained ControlNet

Train change detection model and evaluate on real datasets



Train ChangeFormer and MambaCD

Methods

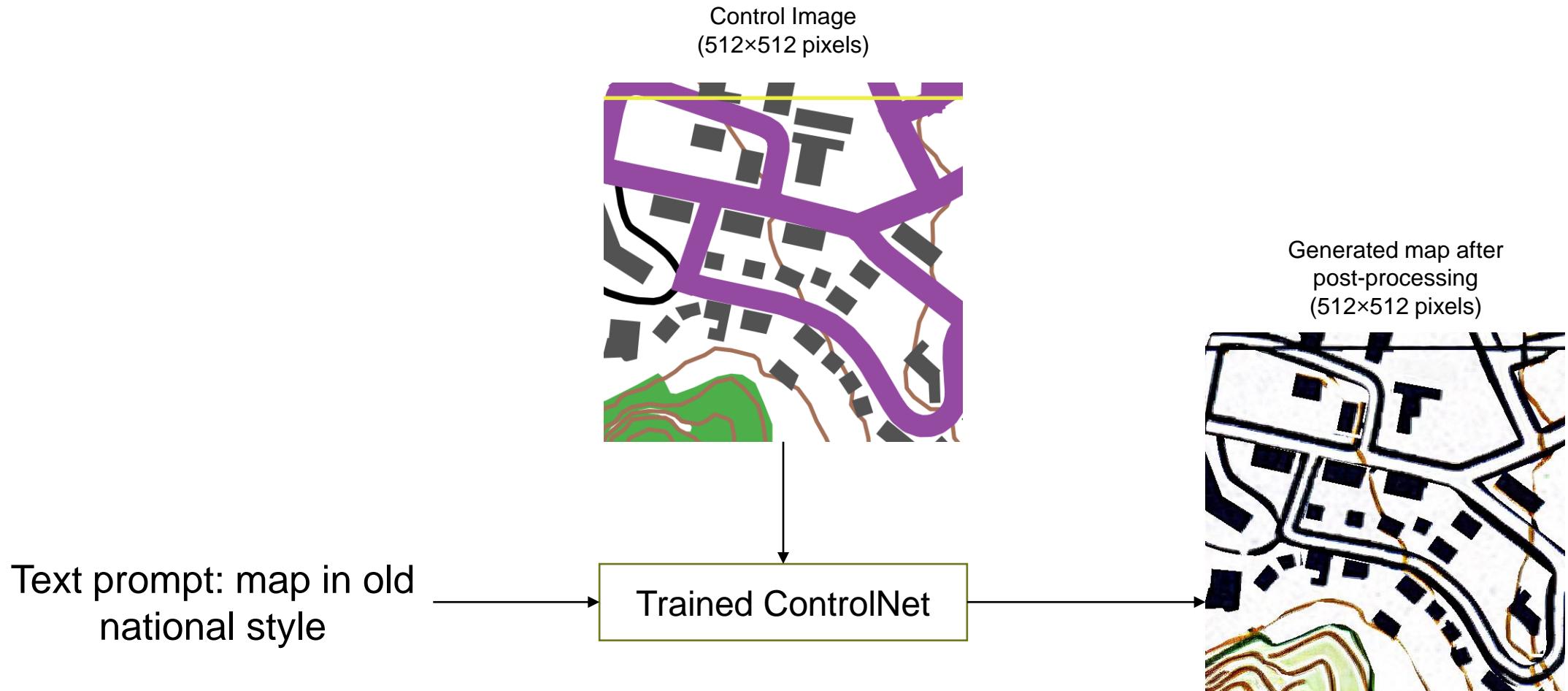
Urban change type definition and manipulation

Feature Class	Change	Sub-change	Implementation
Building	Addition		Copy and move buildings
	Deletion		Delete buildings
	Morphology		Make buildings overlap
Road, railway	Expansion	Addition	Extend from existing nodes
		Longer	Extend from existing nodes
		Wider	Not implemented
	Shrinkage	Deletion	Remove line segments
		Shorter	Remove line segments
		Narrower	Not implemented
River, lake	Expansion	Addition	Copy and move river, lake
		Larger	Create outward buffer
	Shrinkage	Deletion	Delete river, lake
		Smaller	Create inward buffer
Stream	Expansion	Addition	Copy and move stream
		Longer	Add nodes
	Shrinkage	Deletion	Delete stream
		Shorter	Delete nodes
Forest	Expansion		Create outward buffer
	Shrinkage		Create inward buffer

Mainly used libraries:
geopandas
shapely
networkx (for road expansion)

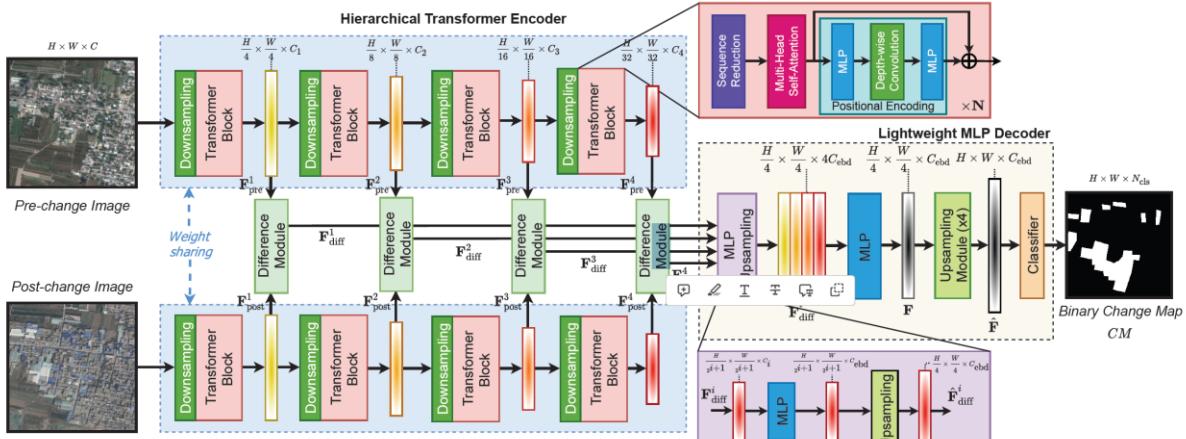
Methods

Map tile generation (Claudio Affolter's specialized Old National model)

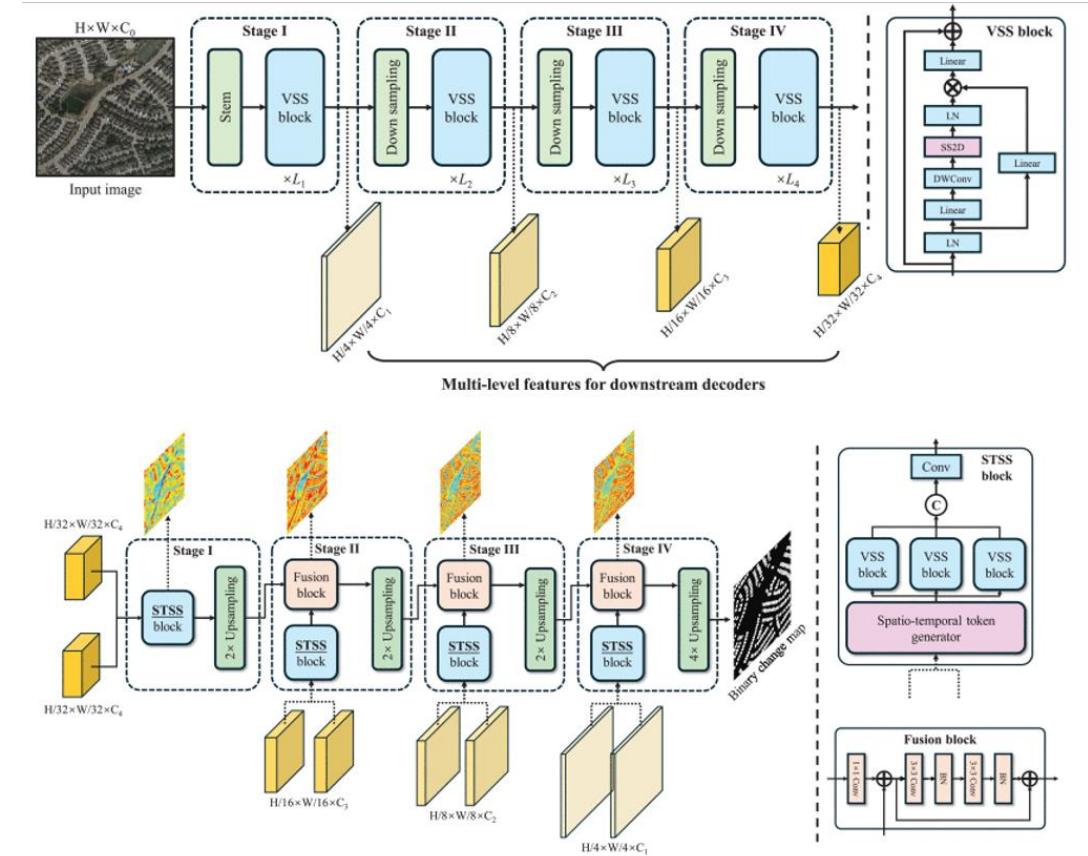


Methods

Change detection



ChangeFormer architecture (Transformer based)[3]

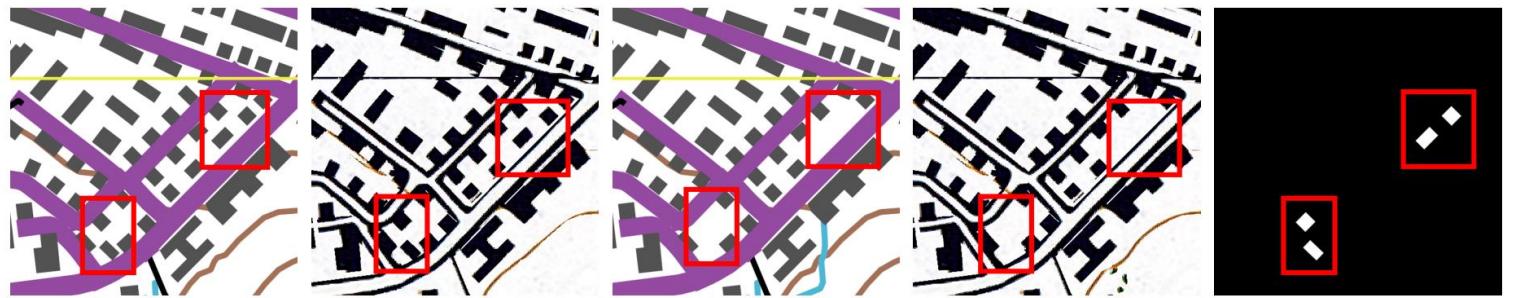


ChangeMamba architecture (state space models (SSMs) based)[4]

Results

Vector manipulation and map tile generation

Building deletion



(1) Building

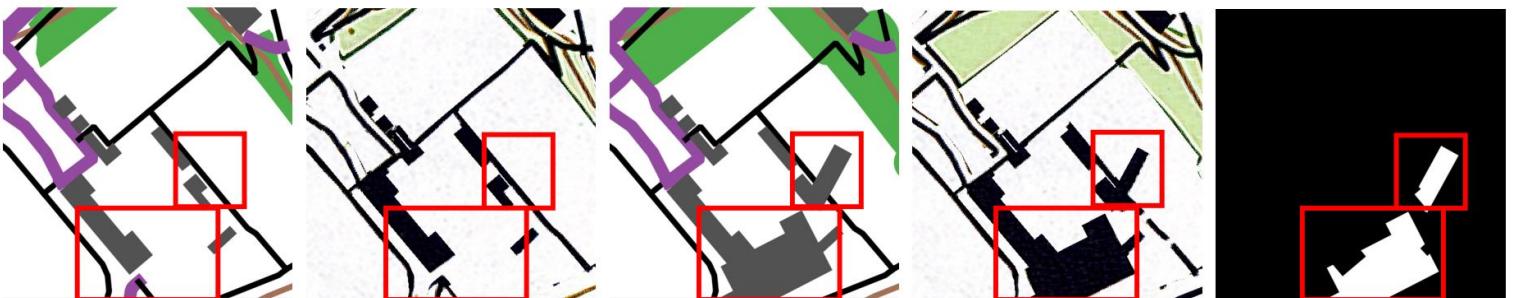
(2) Road, railway

(3) River, lake

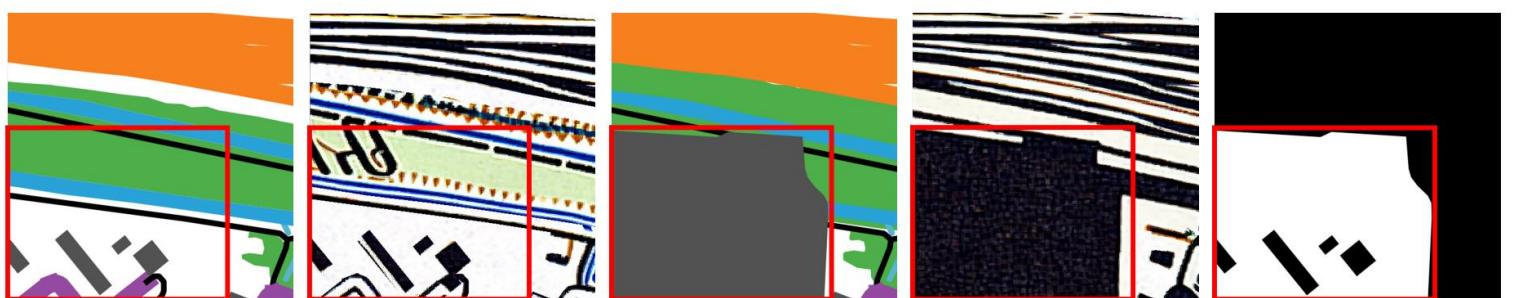
(4) Stream

(5) Forest

Building addition



Building
morphology change



(a) Before vector

(b) Before map

(c) After vector

(d) After map

(e) Change mask

Results

Vector manipulation and map tile generation

(1) Building

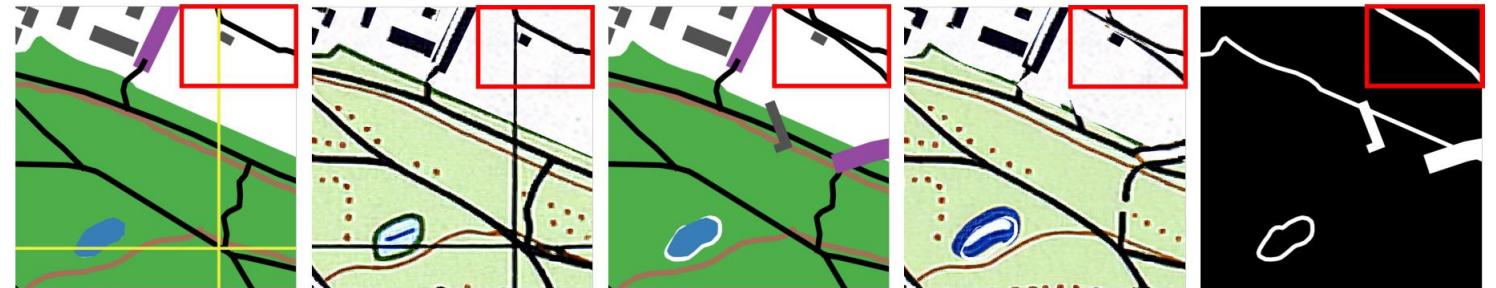
(2) Road, railway

(3) River, lake

(4) Stream

(5) Forest

Road addition



Road deletion



(a) Before vector (b) Before map (c) After vector (d) After map (e) Change mask

Results

Vector manipulation and map tile generation

(1) Building

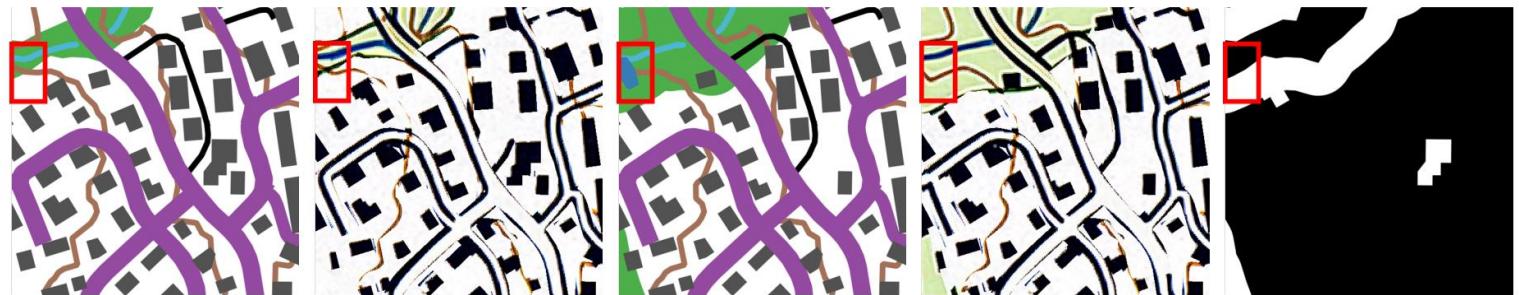
(2) Road, railway

(3) River, lake

(4) Stream

(5) Forest

Lake addition



Lake shrinkage
through building
coverage



(a) Before vector (b) Before map (c) After vector (d) After map (e) Change mask

Results

Vector manipulation and map tile generation

(1) Building

(2) Road, railway

(3) River, lake

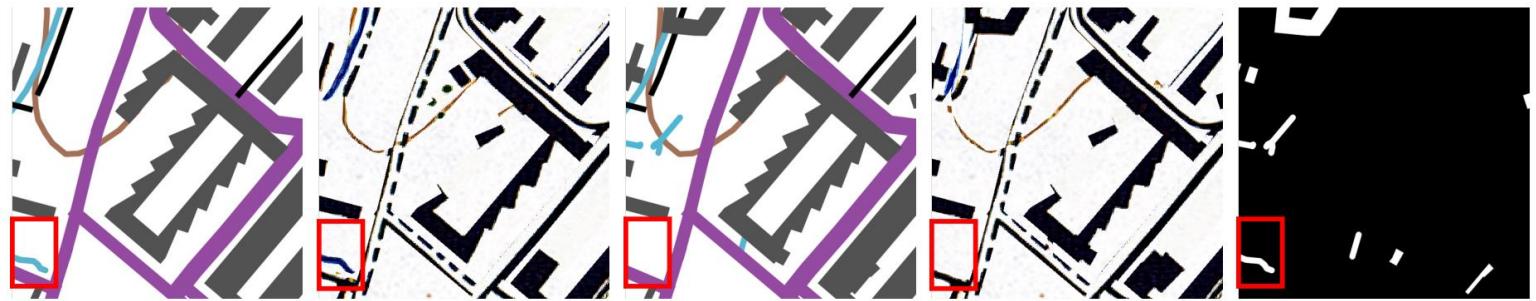
(4) Stream

(5) Forest

Stream addition



Stream deletion



(a) Before vector (b) Before map (c) After vector (d) After map (e) Change mask

Results

Vector manipulation and map tile generation

(1) Building

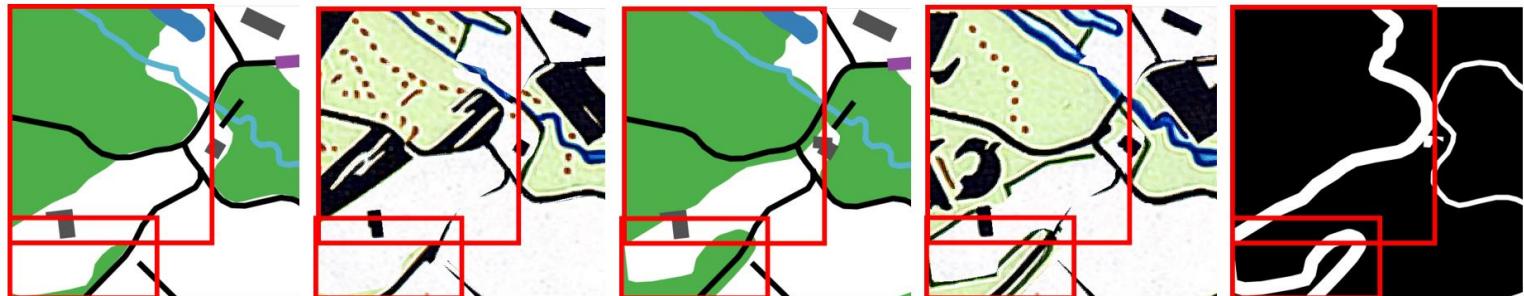
(2) Road, railway

(3) River, lake

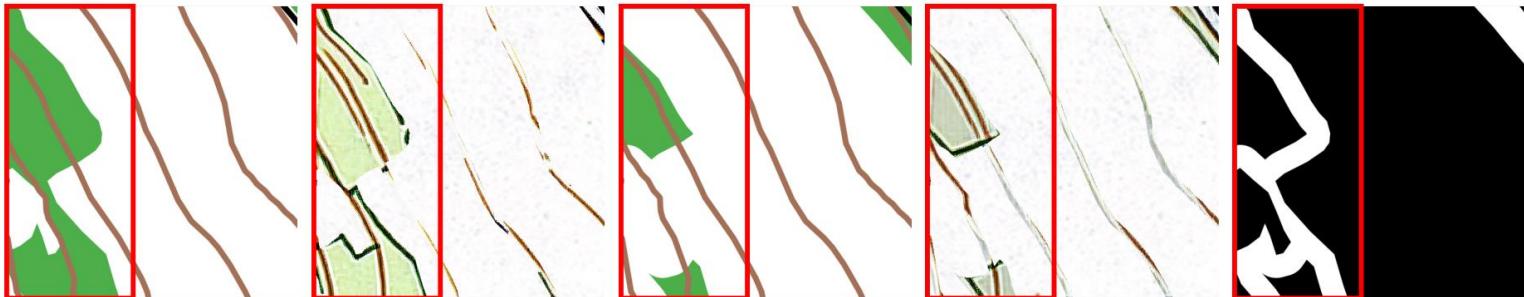
(4) Stream

(5) Forest

Forest expansion



Forest shrinkage



(a) Before vector

(b) Before map

(c) After vector

(d) After map

(e) Change mask

Results

Change detection (evaluation on real-world datasets) – building change detection (ChangeFormer and ChangeMamba)

Building addition detection



Building deletion detection



Building morphology change
detection



(a) 1954 map

(b) 1987 map

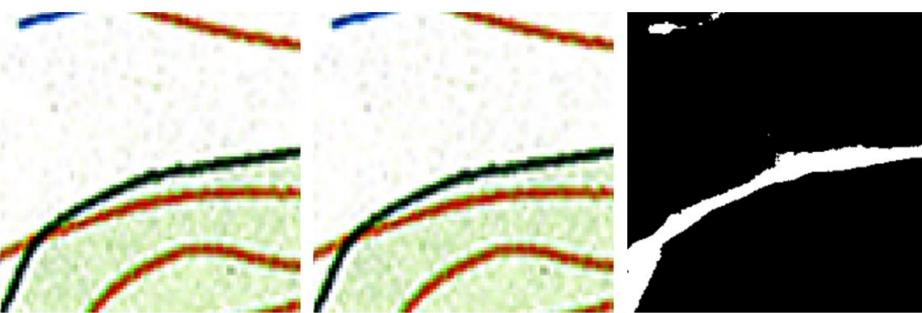
(c) ChangeForm

(d) MambaBCD

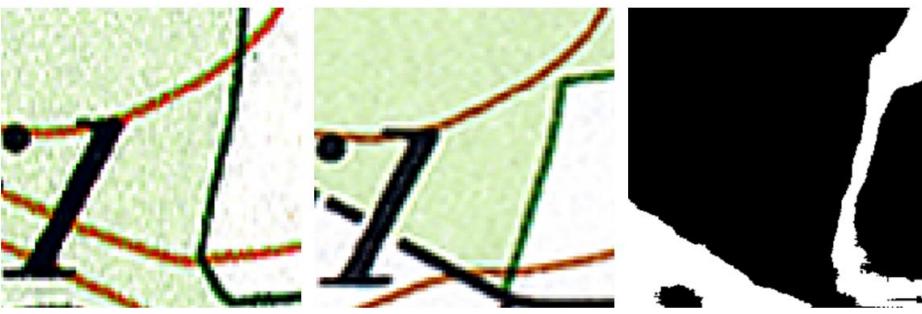
(e) GT

Results

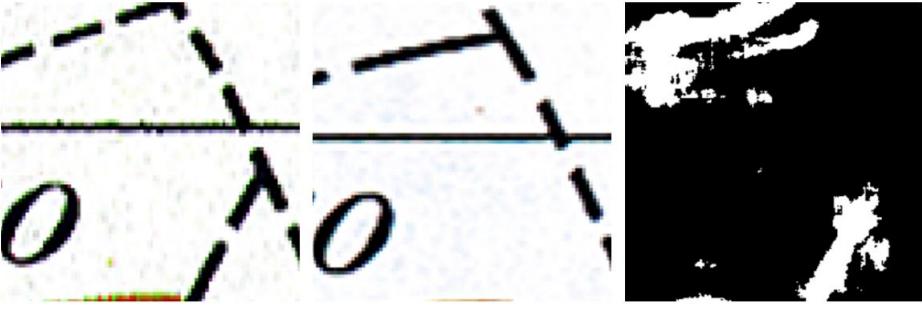
Change detection – Overall change detection (ChangeFormer)



Forest shrinkage detection



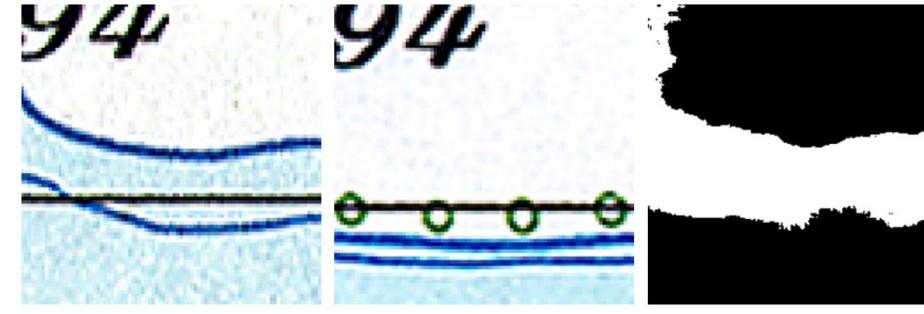
Forest expansion detection



(a) 1954 map (b) 1987 map (c) Change map
Road expansion detection



Road wider detection (not implemented)



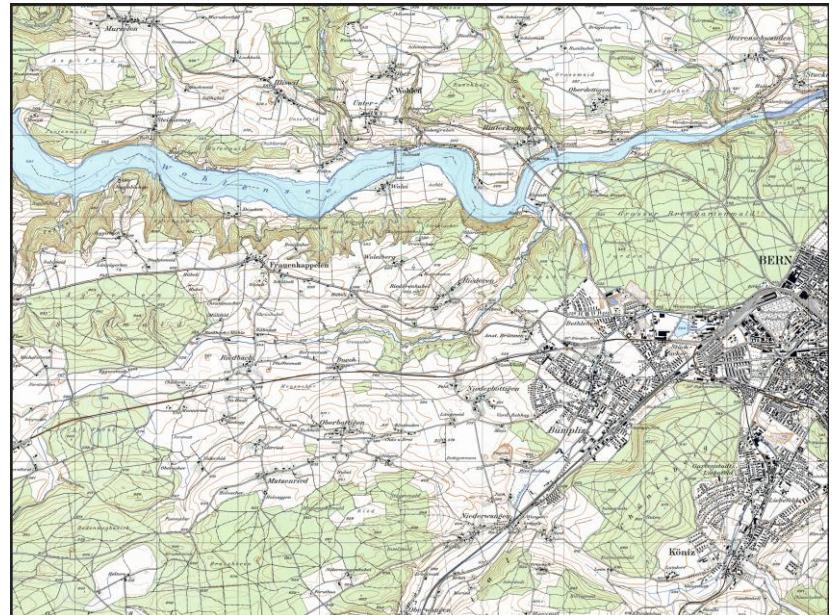
River expansion detection



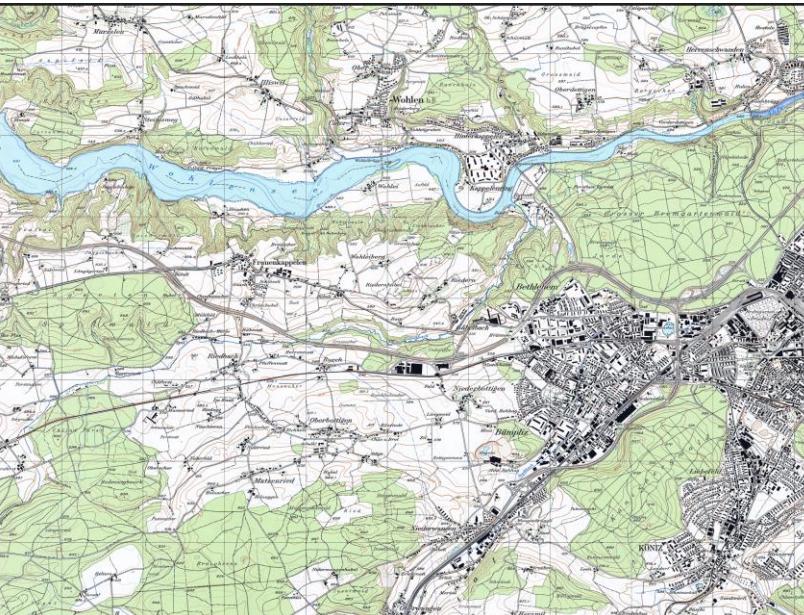
(a) 1954 map (b) 1987 map (c) Change map
Other feature detection

Results

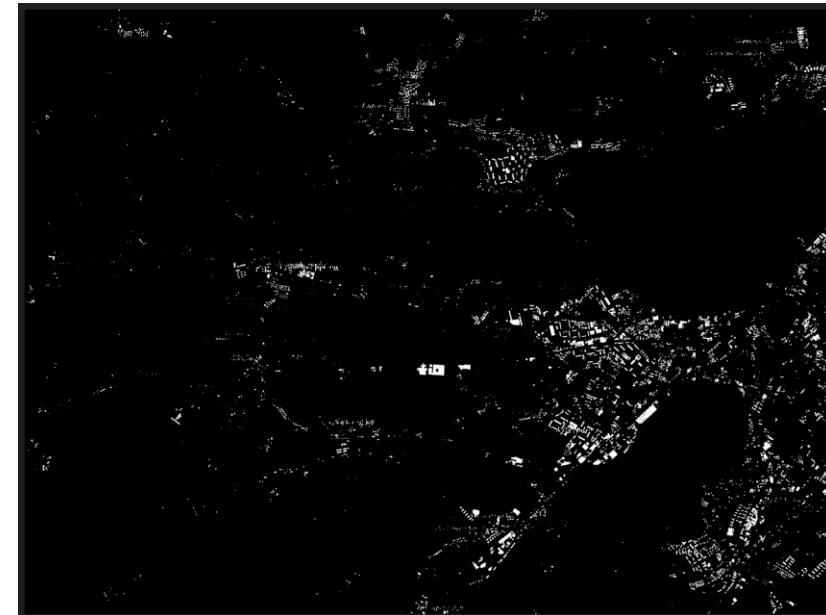
Change detection – Urban change pattern recognition (according to building change detection result)



1954 map



1987 map



Building change detection result
(ChangeFormer)

- Bern undergoes significant urbanization during this period, characterized by a rapid increase in buildings. New buildings spread outward from already developed areas.

Conclusion and Outlook

Conclusion

- Urban change in historical map can be simulated through various geospatial object change scenarios.
- The specialized ControlNet for generating Old National-style map tiles can produce maps with textures and structures similar to those in real-world datasets. However, discrepancies exist (e.g., road classes are not represented correctly and trees are not generated.)
- Synthetic map can be used for change detection (but only accurate for certain features, such as buildings)

Outlook

- Establish conflict detection rules to generate more realistic synthetic maps.
- Define broader urban change types for a more comprehensive classification.
- Perform semantic change detection on urban changes.

Reference

- [1] Reba M, Seto K C. A systematic review and assessment of algorithms to detect, characterize, and monitor urban land change[J]. *Remote sensing of environment*, 2020, 242: 111739.
- [2] Affolter, C. (2024). From vector features to stylized maps – exploration of stable diffusion applied to maps [Master's thesis]. ETH Zurich.
- [3] Bandara, W. G. C., & Patel, V. M. (2022, July). A transformer-based siamese network for change detection. In *IGARSS 2022-2022 IEEE International Geoscience and Remote Sensing Symposium* (pp. 207-210). IEEE.
- [4] Chen, H., Song, J., Han, C., Xia, J., & Yokoya, N. (2024). Changemamba: Remote sensing change detection with spatio-temporal state space model. *IEEE Transactions on Geoscience and Remote Sensing*.

Thanks