Exploring Switzerland's rural-urban continuum through unsupervised learning

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Swiss Geocomputing Centre

Marj Tonini[1], Jingyan Yu[2], and Alex Hagen-Zanker[3]

[1]University of Lausanne, Institute of Earth Surface Dynamics, Faculty of Geosciences and the Environment, Lausanne, Switzerland (marj.tonini@unil.ch)
[2]Newcastle University, Newcastle upon Tyne, United Kingdom (Jingyan.Yu@newcastle.ac.uk)
[3]School of Sustainability, Civil and Environmental Engineering, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom (a.hagen-zanker@surrey.ac.uk)

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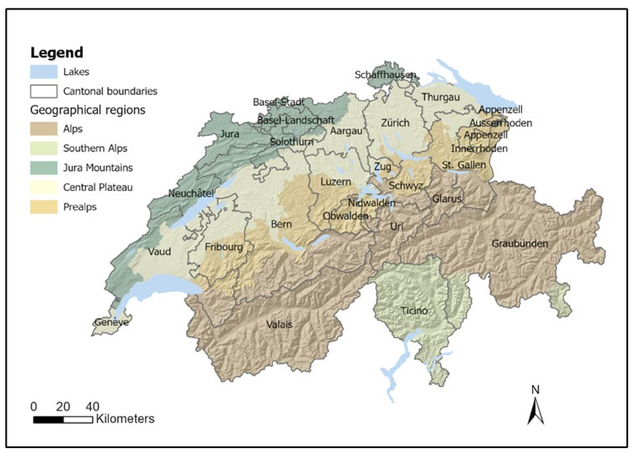
Introduction

- Urban expansion in Switzerland has blurred the boundaries between rural and urban areas, giving rise to complex peri-urban zones.
- To understand these evolving patterns, we need flexible territorial typologies that go beyond the traditional urban-rural divide.
- Conventional methods rely on fixed thresholds, which often fail to capture regional and temporal variations.
- Machine learning, a key component of GeoAI, provides a powerful alternative by uncovering patterns within complex, multi-dimensional, data-driven relationships.



***Swiss geographical regions**, by Federal Office for the Environment*

Main Objectives

- This study applies an unsupervised learning neural network to classify territorial typologies at the municipal level across Switzerland.
- By integrating physical, demographic, and socioeconomic data, we aim to identify and map rural-urban dynamics, detect patterns of urban expansion, and assess impacts on sensitive alpine regions.

Physical space	Demographic	Socio-economic
Settlement areas	Natural growth	Employment rate
Forest areas	Population density	New buildings
Agricultural areas	International migration	New houses
Unproductive areas	Internal migration	Individual houses
Traffic areas	Foreigners	New enterprise
	Young population	Net income
	Senior population	

Input Census Data

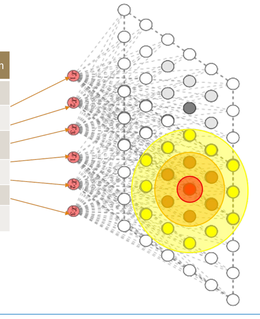
- Eighteen variables selected from census 2020 at the municipality level.
- These variables gives a well-rounded representation of three key categories:
  - Physical space: settlement, forest, agricultural, unproductive, and traffic areas.
  - Demographic profile: natural growth, population density, international and internal migration, foreigners, young and senior population.
  - Socio-economic characteristics: employment rate, new buildings, new houses, individual houses, new enterprise, and net income.

Data source: Federal Statistical Office - Statistical Atlas of Switzerland. https://www.bfs.admin.ch/bfs/en/home/statistiken/regionalstatistik/atlanten/statistischer-atlas-schweiz.html. Accessed 12 Dec 2024

Self Organizing Maps (SOM)

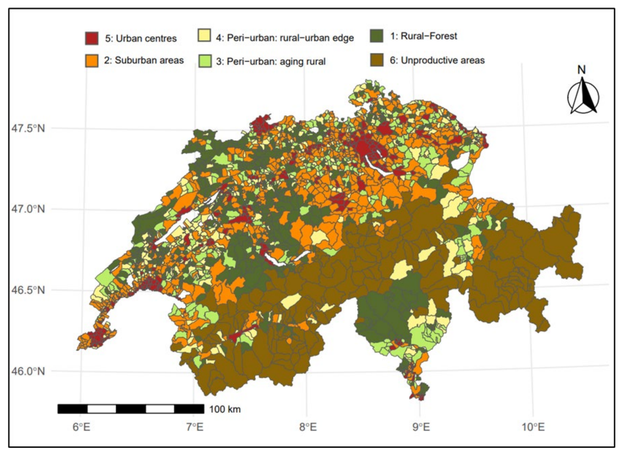
- SOM is an unsupervised machine learning technique that helps identify patterns and classify spatial units based on a set of multiple variables.
- SOM operates in a data-driven manner. Similar spatial units are grouped based on inherent patterns in the dataset.
- SOM units can be aggregated into a lower number of main clusters; hierarchical clustering was used to form this final partition.

Items	Variable 1	Variable 2	...	Variable m
$X_{1,1}$	$X_{1,2}$	$X_{1,2}$	...	$X_{1,m}$
$X_{2,1}$	$X_{2,2}$	$X_{2,2}$	...	$X_{2,m}$
$X_{3,1}$	$X_{3,2}$	$X_{3,2}$	...	$X_{3,m}$
$X_{4,1}$	$X_{4,2}$	$X_{4,2}$	...	$X_{4,m}$
...	...	...	...	...
$X_{n,1}$	$X_{n,2}$	$X_{n,2}$	...	$X_{n,m}$



Results: territorial typologies

- At the end of the data-driven clustering process, municipalities that share similar geodemographic, socio-economic, and land use characteristics were grouped into the same main cluster representing the territorial typologies in Switzerland, derived from the 2020 census data.
- Six distinct clusters were identified, revealing nuanced rural-urban configurations.
- The machine learning approach proved effective for analyzing urbanization and sustainability challenges, especially in ecologically vulnerable Alpine areas.

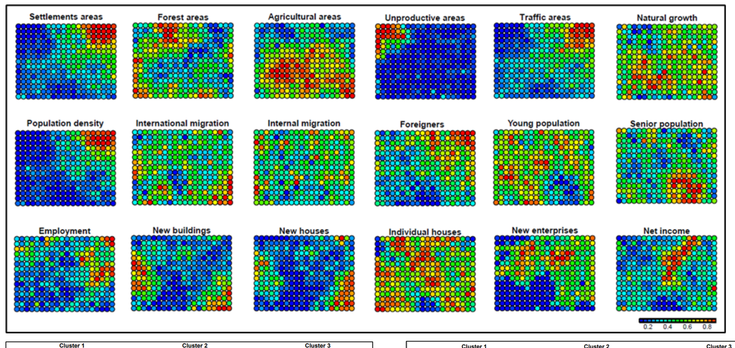


***Spatial organization of territorial typologies** at the municipality level across the rural-urban continuum in Switzerland*

Territorial typologies	Cluster #	Number of municipalities	Total covered area (Km2)
Urban centres	Cluster 5	271 (12.2%)	2,090 (5.2%)
Suburban areas	Cluster 2	625 (28.1%)	8,956 (22.3%)
Peri-urban: aging rural	Cluster 3	288 (13.0%)	4,027 (10.0%)
Peri-urban: rural-urban edge	Cluster 4	293 (13.2%)	3,733 (9.3%)
Rural-Forest	Cluster 1	579 (26.1%)	7,786 (19.4%)
Unproductive	Cluster 6	166 (7.4%)	13,605 (33.8%)

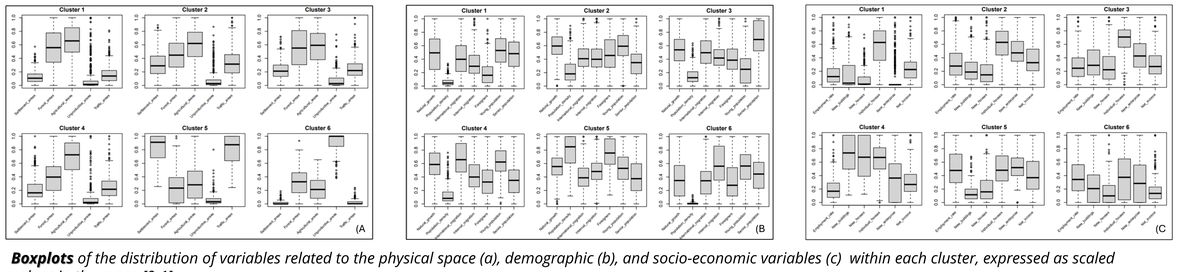
Key insights

- Complex rural-urban interface, ranging from the Central Plateau around main urban centres (Geneva, Lausanne, Zurich, Lucerne, Fribourg) into the rural areas in the Northen, Eastern and Central Alpine regions.
- Key trends include agricultural land loss, urban sprawl, and aging populations in peri-urban/rural areas.



Graphical outputs, such as heatmaps and boxplots, represents an effective visual tools to aid in results interpretation, uncover variables distributions and relationships, and enhance the analytical process.

***Heatmaps** illustrating the relative distribution of each input variable across the output grid.*



***Boxplots** of the distribution of variables related to the physical space (a), demographic (b), and socio-economic variables (c) within each cluster, expressed as scaled values in the range [0-1].*

- Tonini M, Yu J, Hagen-Zanker - *An Unsupervised Learning Approach to the Rural-Urban Continuum*. Journal of Geovisualization and Spatial Analysis. Accepted (April 2025)
- Kohonen T (2000) Self-organizing maps, 3rd ed. Springer, Berlin