



Universiteit
Leiden
The Netherlands

Comparative visual analytics for multi-modal single-cell and spatial omics data

Basu, S.

Citation

Basu, S. (2026, September 15). *Comparative visual analytics for multi-modal single-cell and spatial omics data*. Retrieved from <https://hdl.handle.net/1887/4310004>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/4310004>

Note: To cite this publication please use the final published version (if applicable).

Comparative Visual Analytics for Multi-Modal Single-Cell and Spatial Omics Data

Soumyadeep Basu

Colophon

About the cover:

The front cover of this thesis features a human brain outline forming a border. Within this outline, a node-link diagram connects multiple nodes, each color-coded to correspond to a specific brain region. This visualization reflects the brain-related data examined in this work. Inside the brain outline, icons representing twenty-five mammalian species highlight the comparative focus of the thesis, which involves analyzing brain datasets across different species. Additional icons depicting charts and visual analytics tools, such as graphs and boards, emphasize the development and application of visual analytic methods throughout the research.

The back cover presents an abstract representation of a DNA strand, symbolizing the analysis of gene expression data across species.

Comparative Visual Analytics for Multi-Modal Single-Cell and Spatial Omics Data
Soumyadeep Basu

Thesis layout & cover designed by Soumyadeep Basu
with design suggestions from Thomas Kroes.

© 2026 Soumyadeep Basu, Leiden, the Netherlands

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the copyright owner.

Comparative Visual Analytics for Multi-Modal Single-Cell and Spatial Omics Data

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden,
op gezag van rector magnificus prof.dr. S. de Rijcke,
volgens besluit van het college voor promoties
te verdedigen op dinsdag 15 september 2026
klokke 10:00 uur

door

Soumyadeep Basu
geboren te Kolkata, West-Bengalen, India
in 1993

Promotor:	Prof. Dr. B. Lelieveldt
Co-promotor:	Dr. T. Höllt <i>Delft University of Technology, The Netherlands</i>
Leden promotiecommissie:	Prof. Dr. J. Batenburg <i>Leiden University, The Netherlands</i> Dr. O. Basak <i>University Medical Center Utrecht, The Netherlands</i> Dr. K. Buehler <i>Vienna Research Center for Visual Computing, Austria</i>
Secretaris:	Prof. Dr. O. Meijer

The research presented in this thesis was conducted in the Netherlands at the Division of Image Processing (LKEB), Department of Radiology at Leiden University Medical Center, and the Computer Graphics and Visualization (CGV) group within the Department of Intelligent Systems, Faculty of Electrical Engineering, Mathematics and Computer Science, at Delft University of Technology. It was financially supported by the NWO TTW project 3DOMICS (NWO project number 17126) and the NWO Gravitation project BRAINSCAPES: A Roadmap from Neurogenetics to Neurobiology (NWO project number 024.004.012).

“Arise, awake, and stop not till the goal is reached.”

SWAMI VIVEKANANDA

Dedicated to my parents

RUPASRI BASU AND SATYAJIT BASU

CONTENTS

1	General Introduction	1
1.1	Background	1
1.2	Visualization Challenges in Large-Scale Brain Cell Atlases	1
1.3	Web-Based, Desktop-Based, and Script-Based Computational Approaches	2
1.4	Towards Interactive Visual Analytics for Comparative Analysis	3
1.5	Thesis contributions and outline	4
2	Cytosplore Simian Viewer	7
2.1	Introduction	8
2.2	Biological Background	9
2.3	Related Work	10
2.4	Domain Abstraction	11
2.4.1	Data	12
2.4.2	Analysis Goals	14
2.4.3	Tasks	14
2.5	Cytosplore Simian Viewer	16
2.5.1	Heatmap View	17
2.5.2	Scatterplot View	19
2.5.3	Differential Gene Expression View	19
2.5.4	Gene Expression Comparison View	19
2.6	Use Cases	21
2.6.1	Analysis of Laminar Cell Distribution	21
2.6.2	Analysis of Gene Expression Patterns	23
2.7	Discussion and Conclusion	24
3	Cytosplore EvoViewer	27
3.1	Introduction	28
3.2	Biological Background	30
3.3	Related Work	32
3.3.1	Comparative Visualization	33
3.4	Domain Analysis	33
3.4.1	Design Process	33
3.4.2	Data	34
3.4.3	Domain Questions	35

3.4.4	Tasks	36
3.5	Cytosplore EvoViewer	36
3.5.1	Workflow	37
3.5.2	Cell Type Hierarchy	37
3.5.3	Cell Abundance and Gene Identification	38
3.5.4	Single Cell Embedding	41
3.5.5	Phylogenetic Tree	42
3.6	Validation	43
3.6.1	Case Study	43
3.6.2	Participants and Setup	46
3.6.3	User Study	47
3.7	Design Reflections	51
3.8	Conclusion	52
4	Cytosplore Gradient Surfer	53
4.1	Introduction	54
4.2	Results	55
4.2.1	Interactive probing of spatial directions reveals gene expression gradients	57
4.2.2	Cross-dataset projection is rotationally invariant and highly robust against protocol, cell subsampling, and feature subsampling	61
4.2.3	Cell-type-specific gradient decomposition reveals intra-type spatial variation	62
4.2.4	Cross-dataset projection and correlation analysis reveal conserved and divergent spatial gene expression gradients . . .	65
4.3	Discussion	67
4.4	Limitations and Future Work	69
5	Cytosplore Viewer	71
5.1	Introduction	72
5.2	Comparative brain atlas analysis	73
5.3	Impact through Cytosplore Viewer	74
5.3.1	Supporting Comparative Analysis with Visual Analytics . . .	74
5.3.2	Facilitating pairwise cross-species comparison	75
5.3.3	Scaling cross-species comparison to phylogenies	77
5.3.4	Exploring gene expression gradients across species	79
5.3.5	Investigating the coordination between regulatory landscapes and gene expression	81

5.4 Discussion	83
6 Discussion	85
Supplementary Information	91
S1: Supplementary for Cytosplore Gradient Surfer (Chapter 4)	91
S1.1: Technical validation	91
References	95
Summary	103
Samenvatting	105
List of publications	107
Acknowledgements	109
Curriculum Vitae	111

