Spatial omics in the AI era: Technologies, algorithmic ecosystems, biological applications, and large model perspectives

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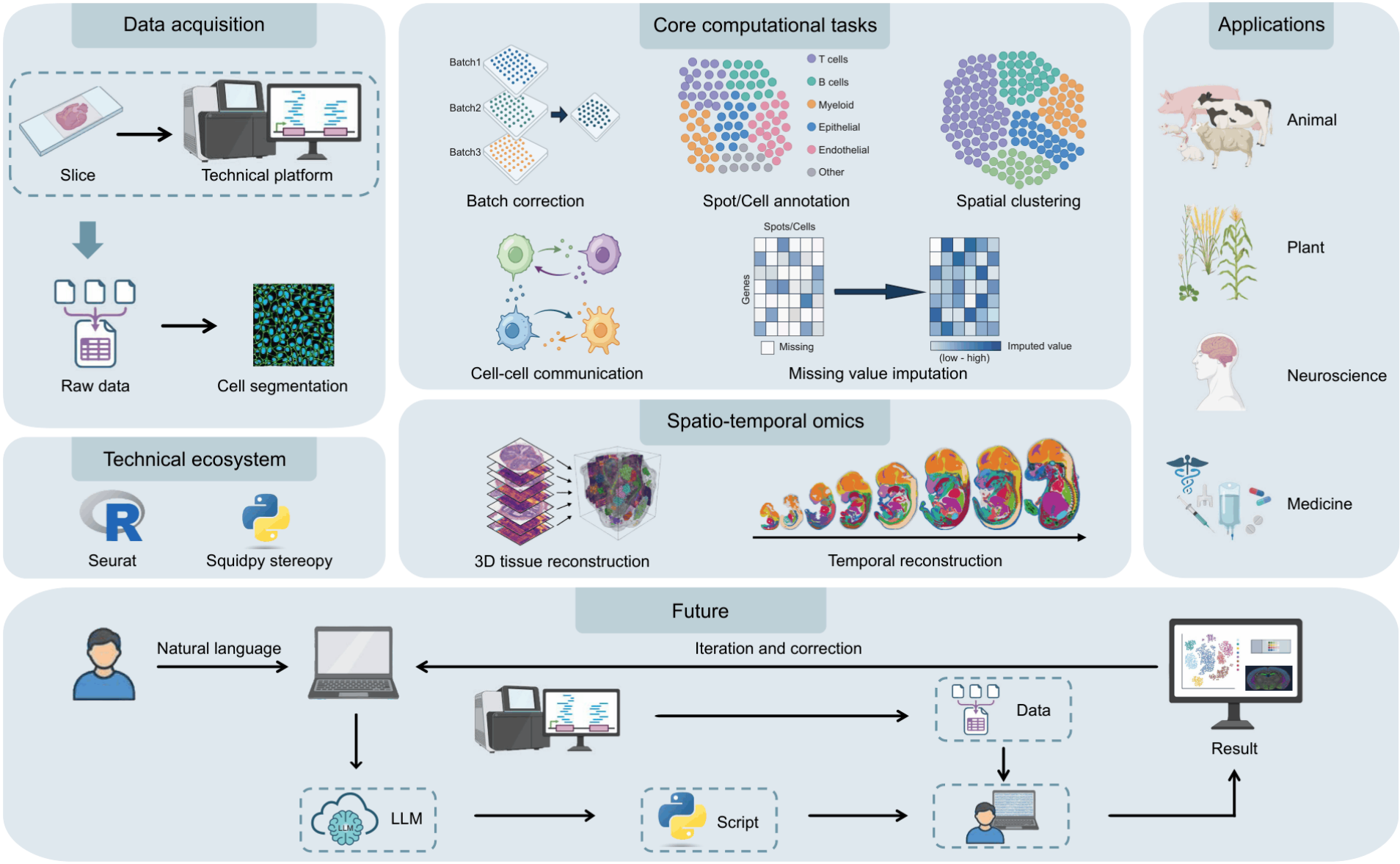
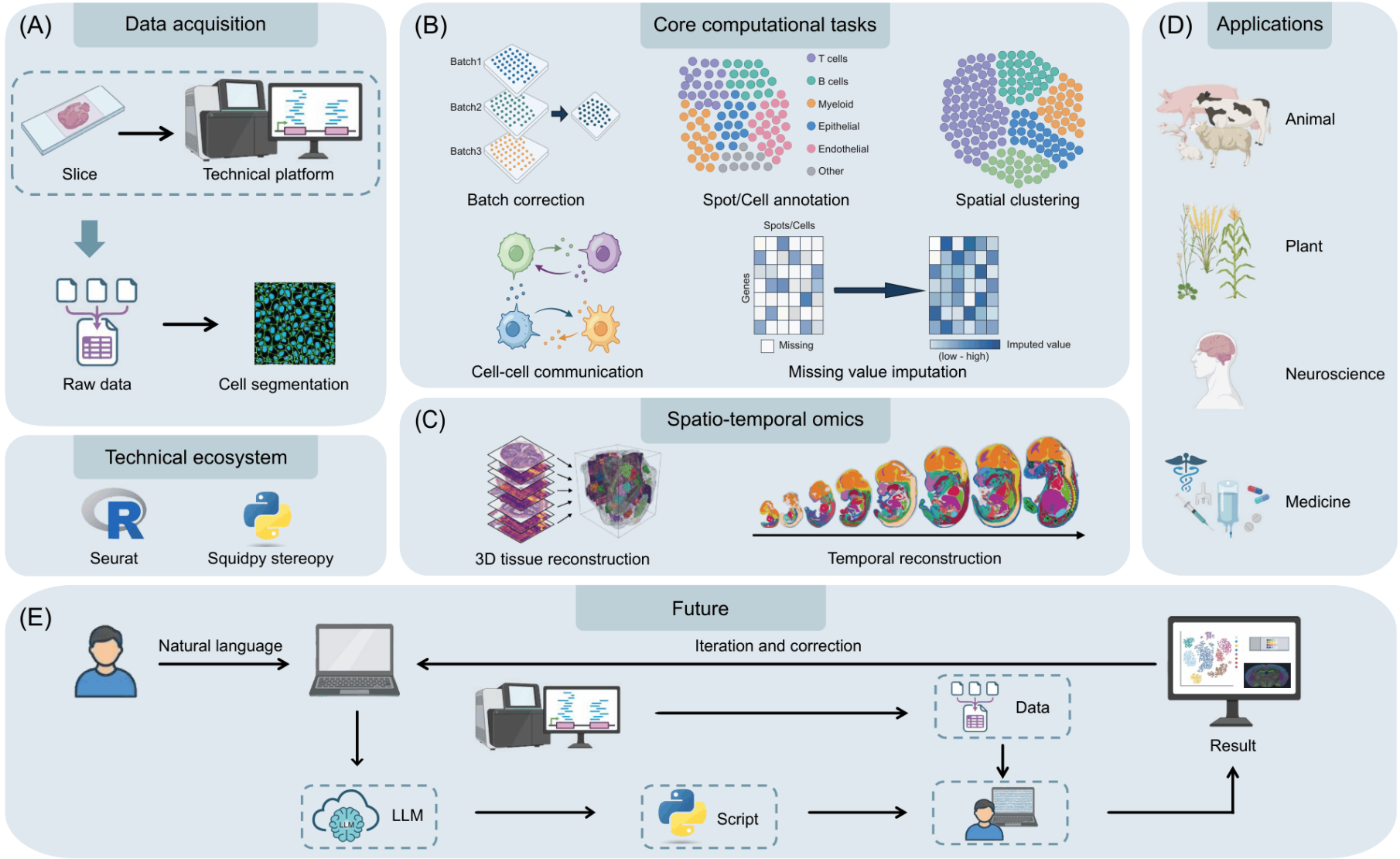
Introduction



Highlights

- Systematically reviews recent spatial omics and their core computational tasks.
- Critically assesses algorithm scenarios, bottlenecks, and recommended strategies.
- Comprehensively outlines spatial omics applications in biomedicine, neuroscience, and plant/animal sciences.
- Outlines future trends in 3D reconstruction, virtual cells, temporal modeling, and large language models.

Content Overview



This review will follow the data workflow logic of spatial omics research, providing a step-by-step overview of the entire process from data generation to data analysis and scientific discovery.

Computational System and Analytical Workflow of Spatial Omics

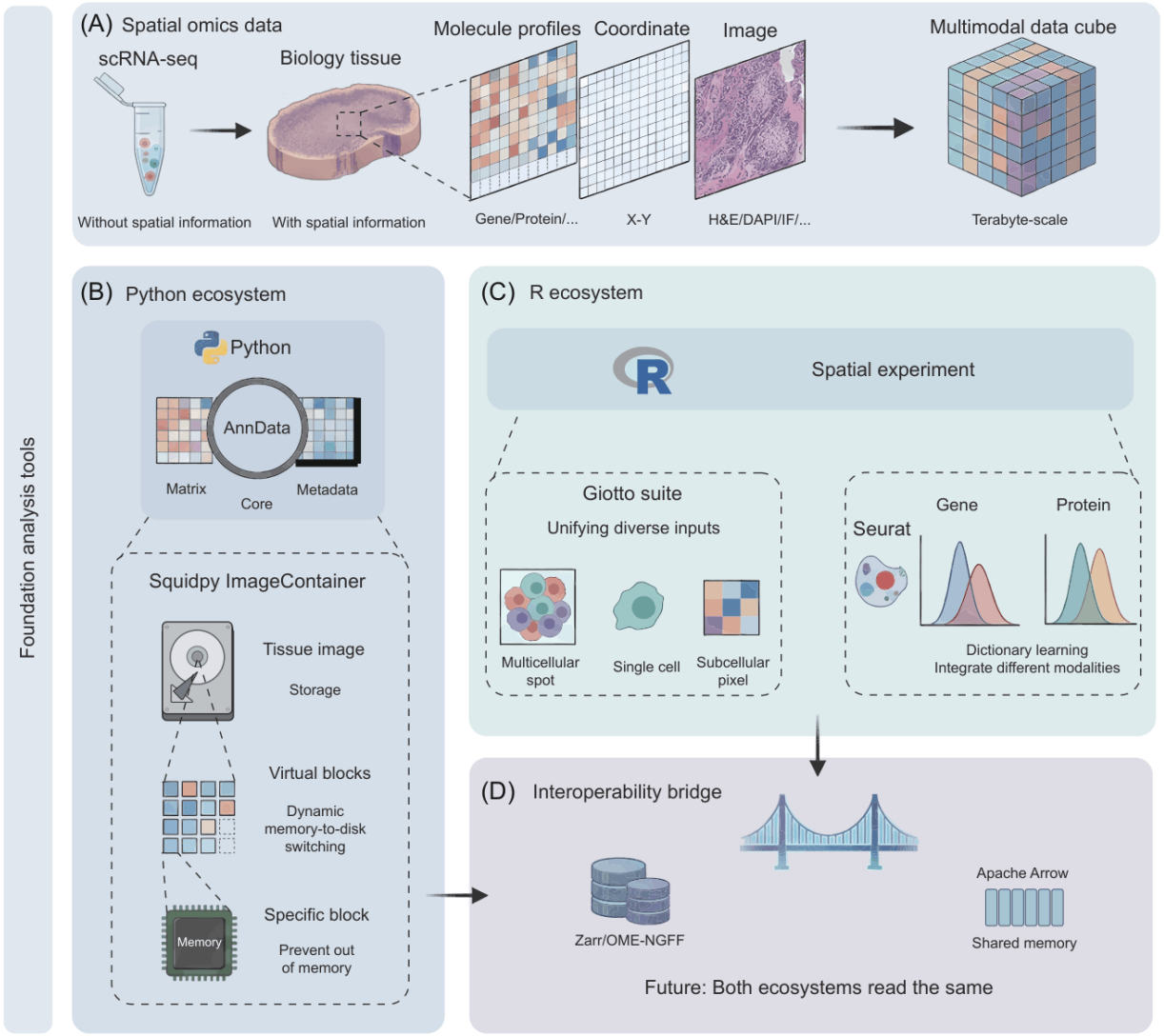


Figure 2: Computational Frameworks and Analysis Workflows for Spatial Omics

Spatial omics has developed distinct computational frameworks in Python and R, centered around AnnData and SpatialExperiment, respectively. These mainstream tools can perform tasks such as data integration, image loading, and multimodal analysis. Both ecosystems leverage common formats such as Zarr, OME-NGFF, and Apache Arrow to enable cross-language data exchange and compatibility.

Key computational tasks in spatial omics

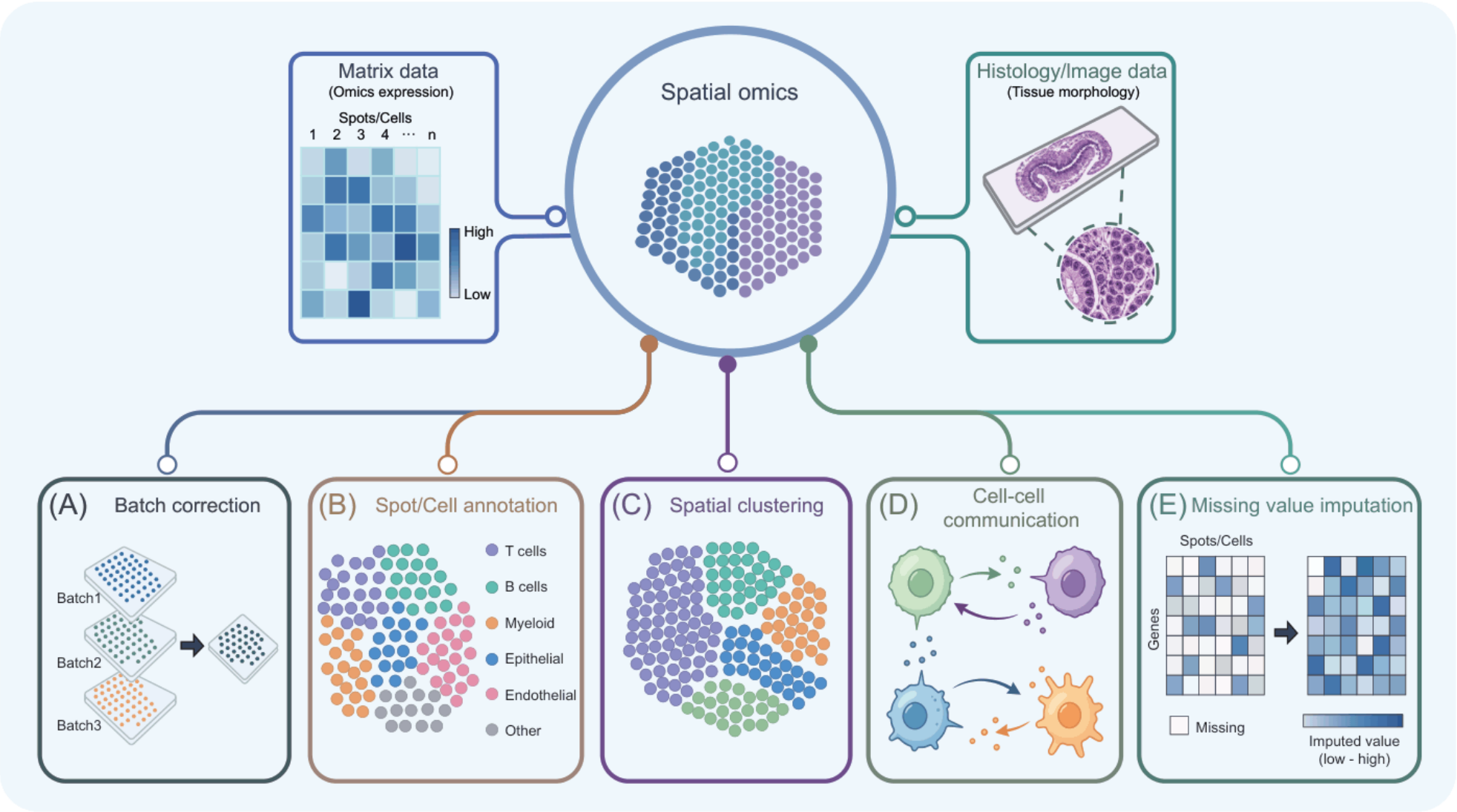


Figure 3: The five core computational tasks in the field of spatial omics

3D spatial omics reconstruction and virtual cell modeling

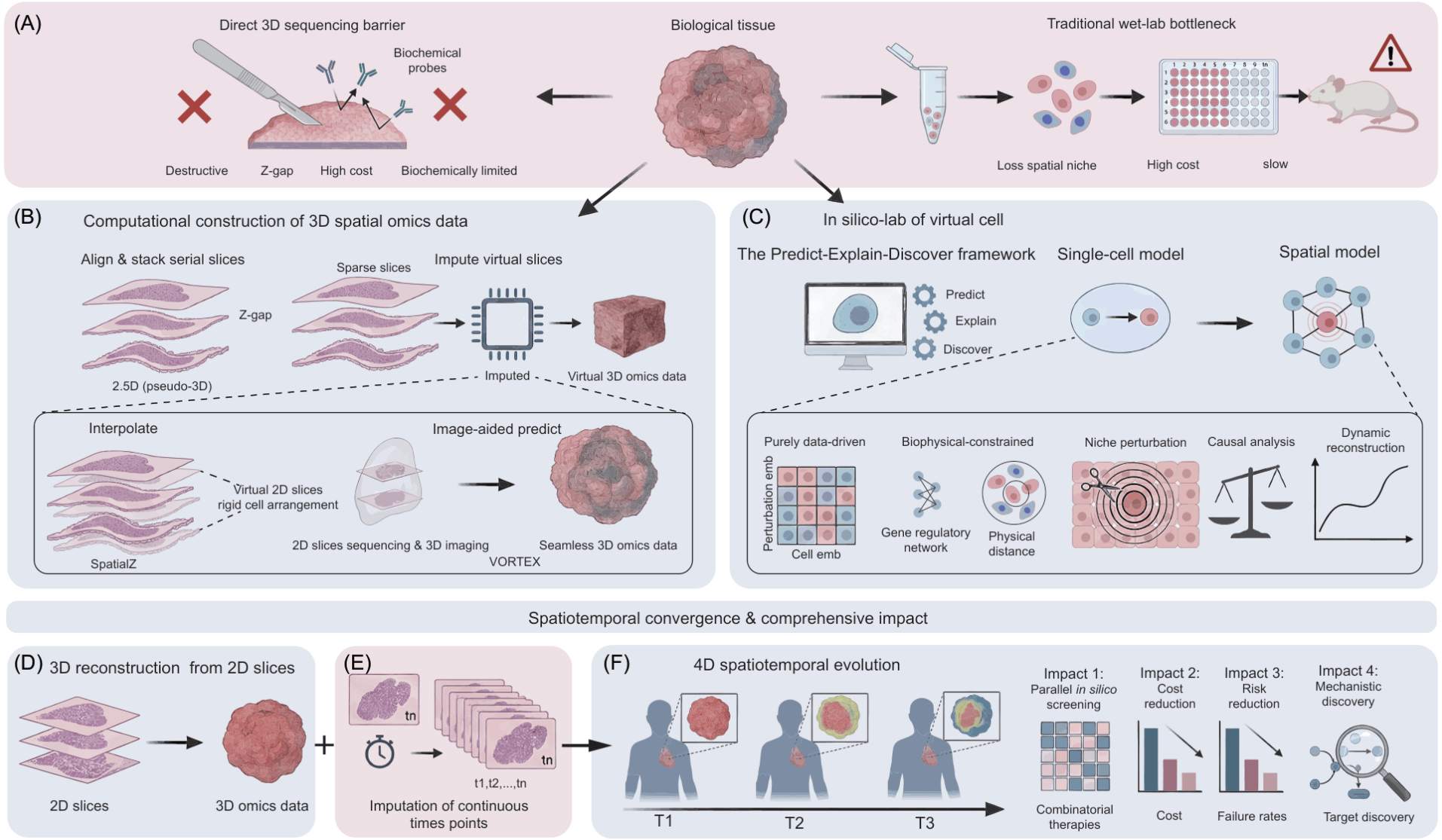


Figure 4: 3D spatial omics reconstruction and virtual cell modeling.

Temporal modelling of spatial omics

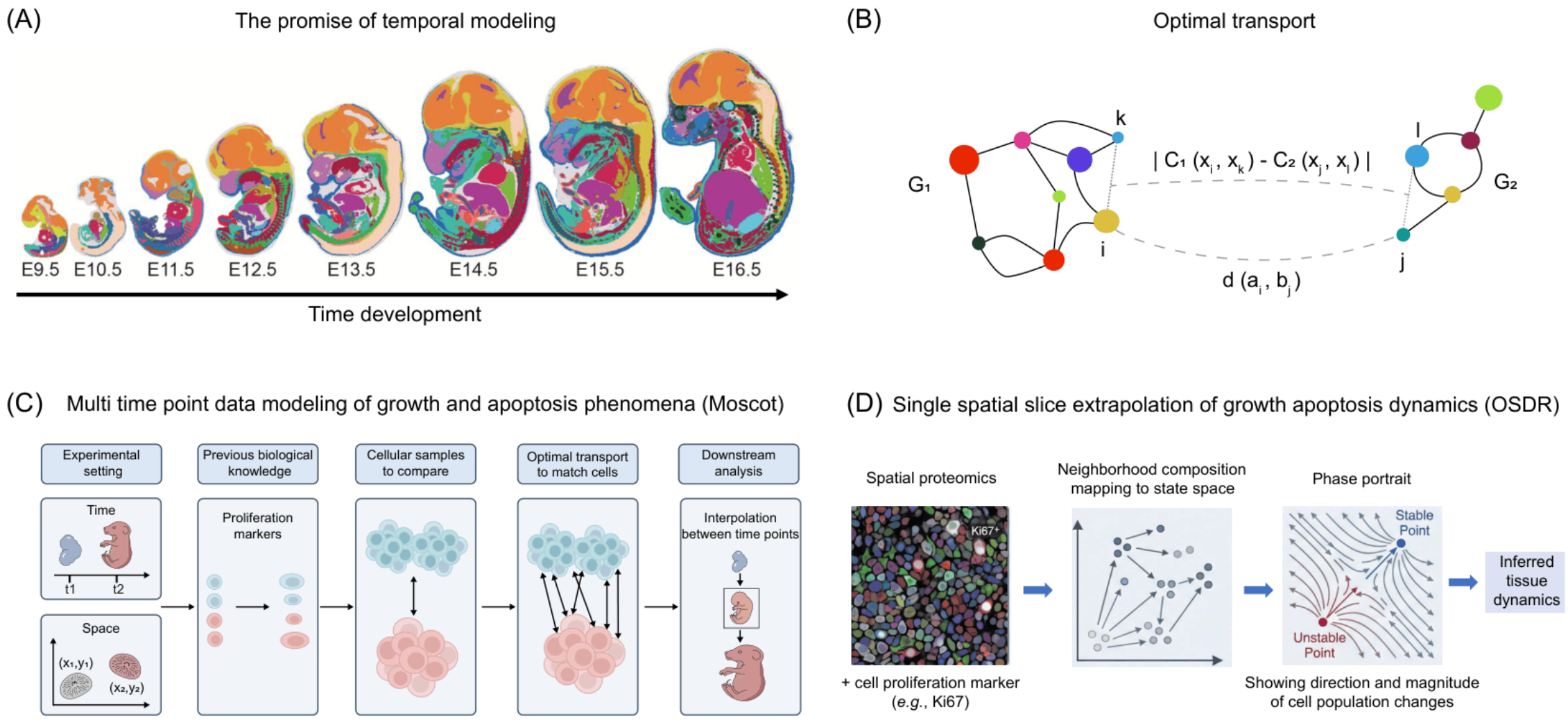


Figure 5: Prospects for temporal modeling in spatial omics and a selection of software tools.

Applications of spatial omics in medical research

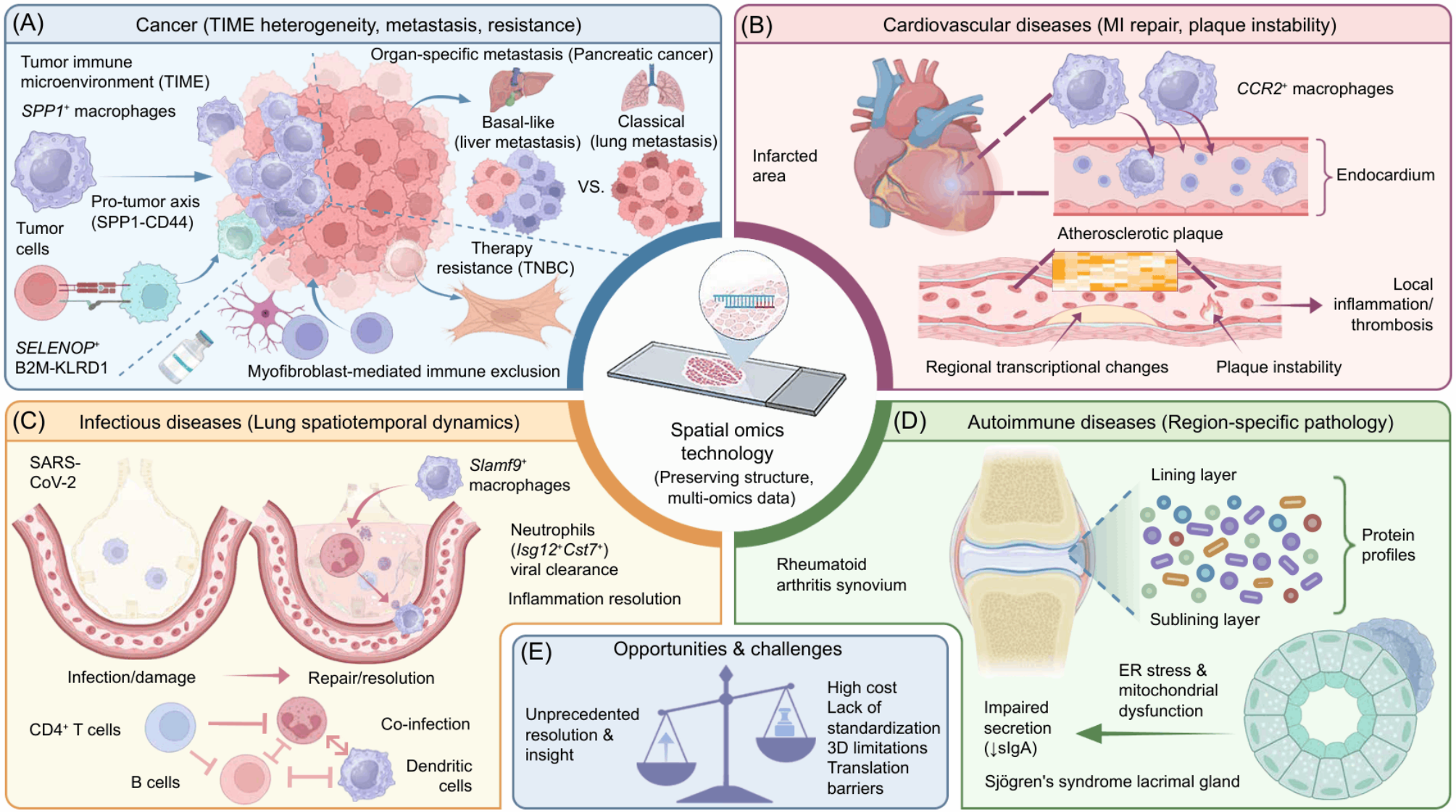


Figure 6: Applications of spatial omics in medical research

Applications of spatial omics in neuroscience research

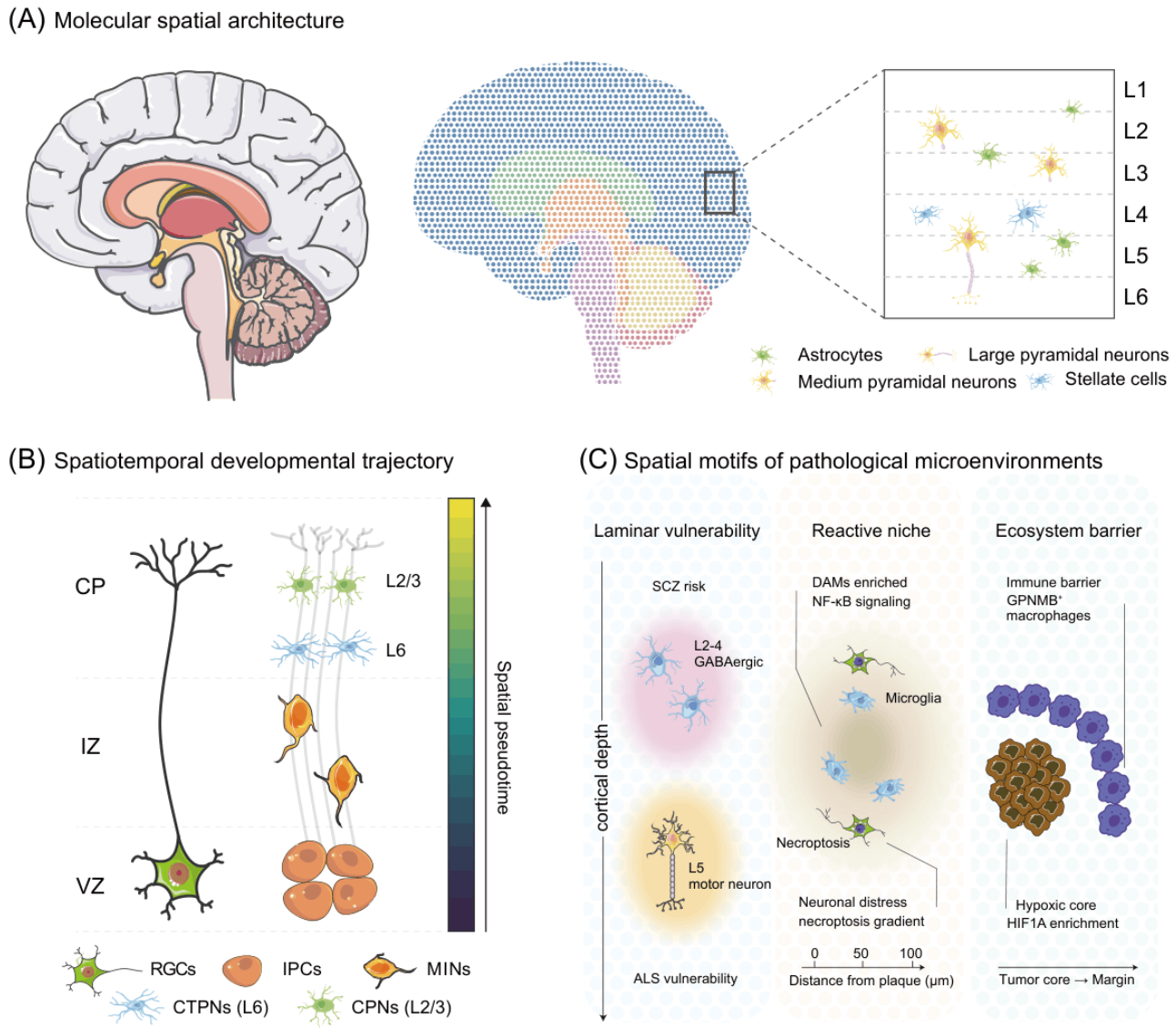


Figure 7: Overview and summary of spatial omics applications in neuroscience

Applications of spatial omics in the fields of animal and plant science

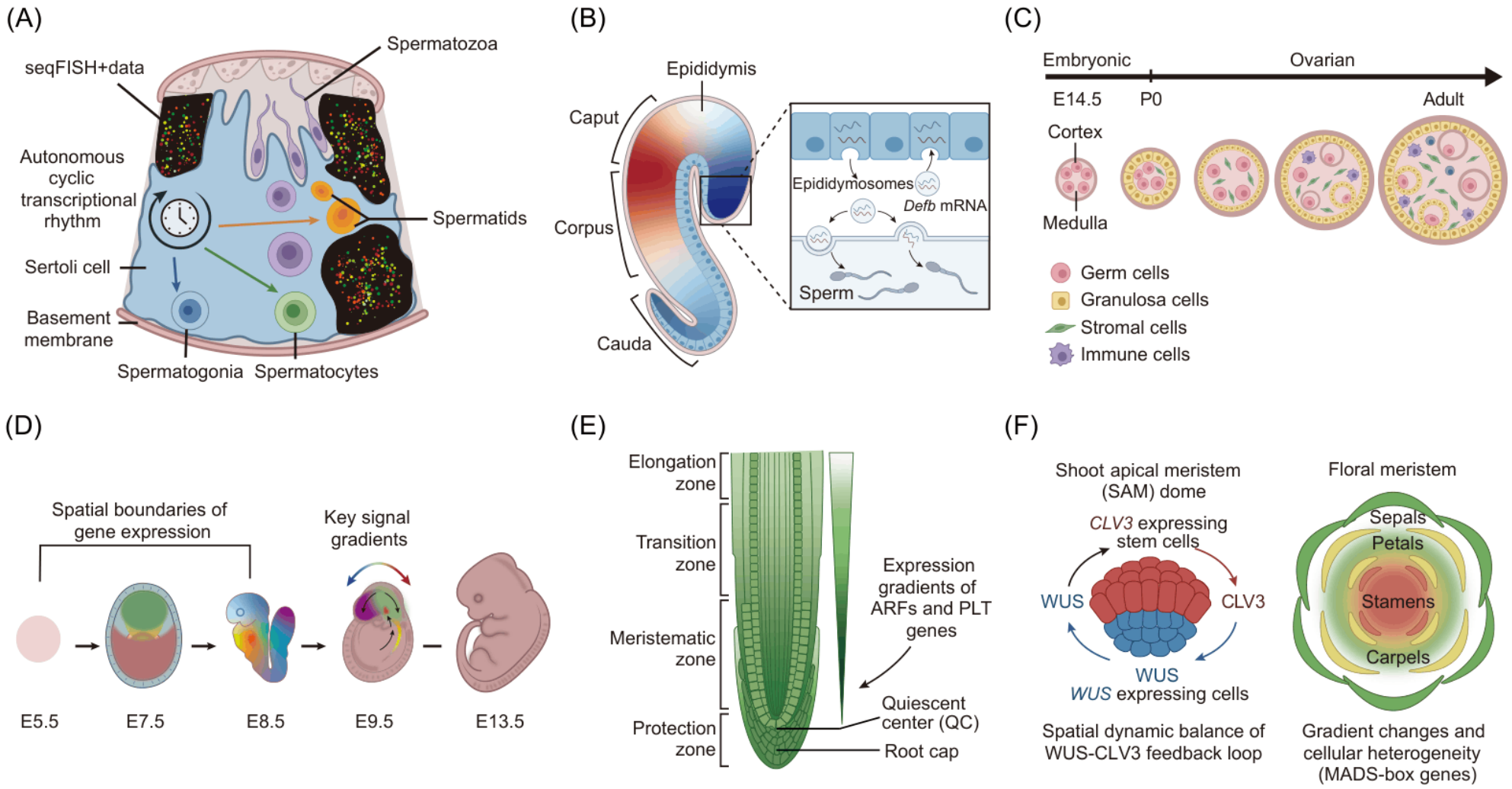


Figure 8. Examples of spatial omics applications in the fields of animal and plant science

Spatial omics in the field of large-scale models

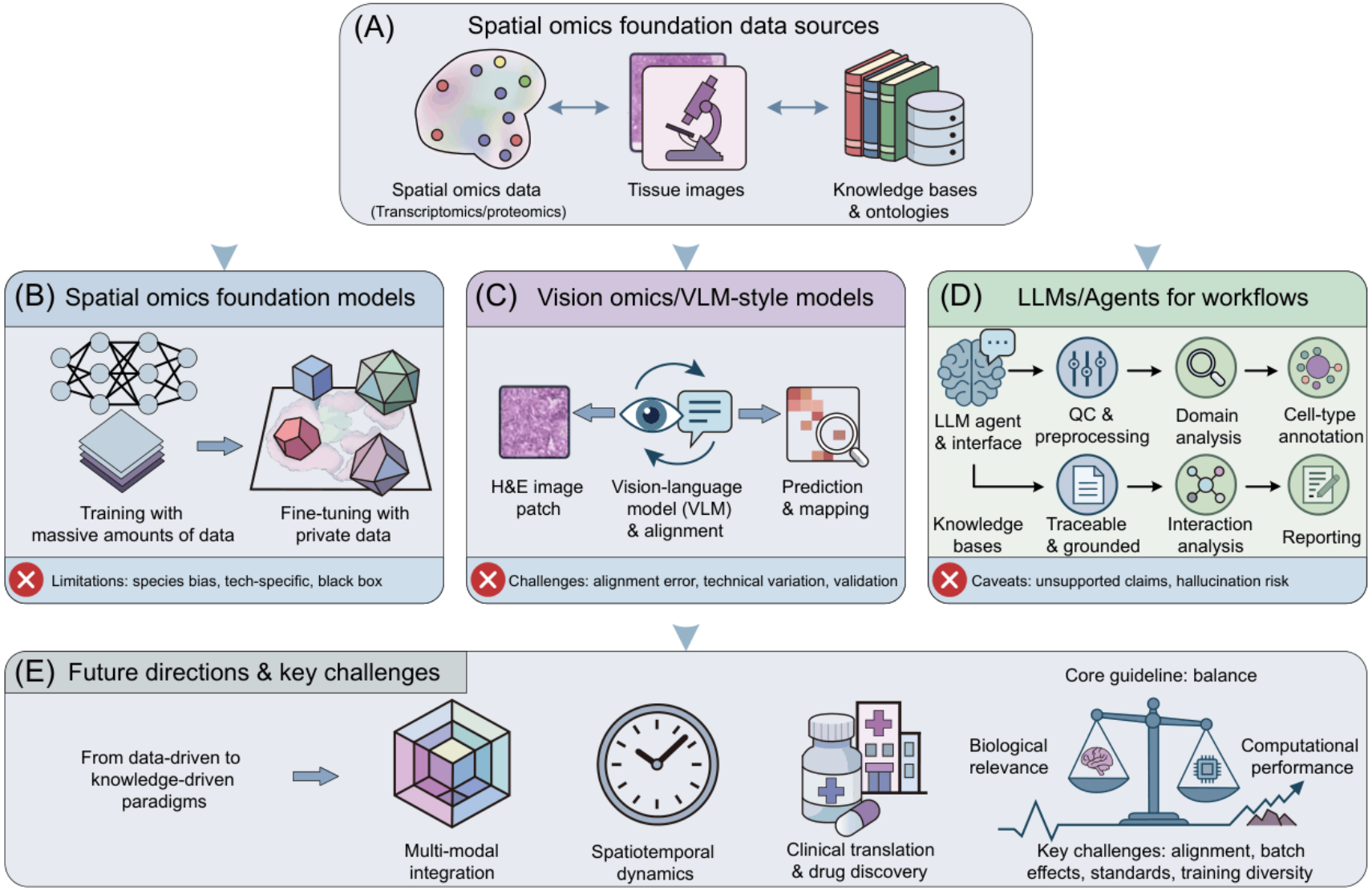


Figure 9. Introduction to and challenges of spatial omics in the field of large-scale models

Summary

- We systematically summarize the entire workflow of spatial omics to help beginners quickly establish a macroscopic understanding.
- Different from most existing reviews on spatial omics, this work introduces cutting-edge fields including 3D reconstruction, virtual cell and temporal modelling, and presents relevant software tools.
- Based on benchmark tests and algorithm principles, we recommend tools for various computational tasks to assist users in selecting appropriate methods.
- From the perspective of biological applications, we illustrate representative cases of spatial omics in medicine, neuroscience, zoology and botany.
- Against the current boom of artificial intelligence, we also systematically review large models for spatial omics.

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