A Map Algebra Approach to Analyzing Spatiotemporal Data

Xingong Li[1], David Tarboton[2], Mike Hodgson[3], Shaowen Wang[4] and Eric Shook[5]

[1]Department of Geography & Atmospheric Science, University of Kansas

[2]Department of Civil and Environmental Engineering, Utah State University

[3]Department of Geography, University of South Carolina

[4]Department of Geography and Geographic Information Science, University of Illinois at Urbana-Champaign

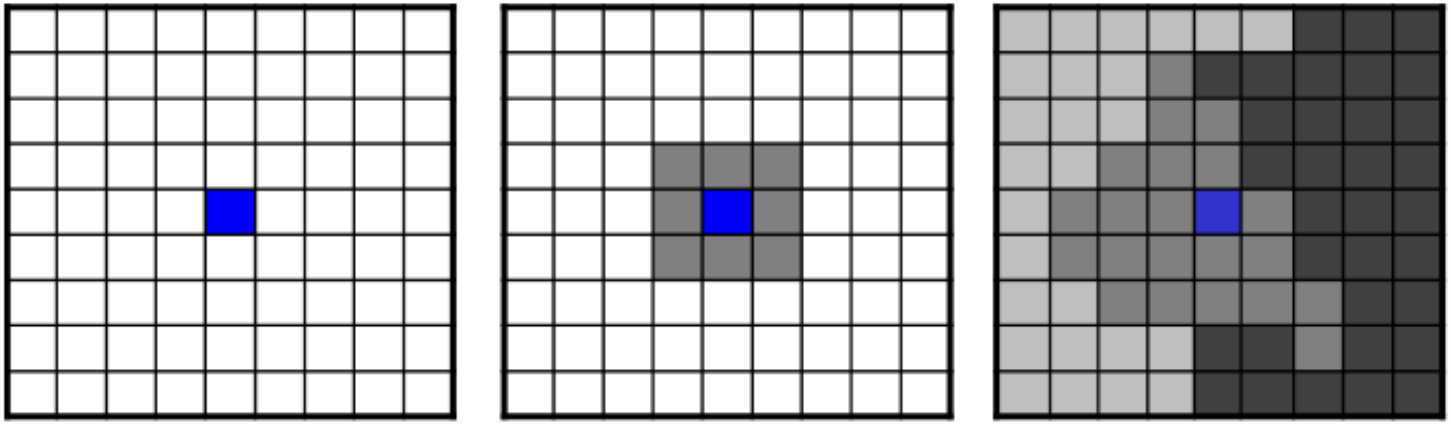
[5]Department of Geography, Environment, and Society, University of Minnesota

Outline

- Map algebra and its extensions
- Nature of map algebra
- Extension to time series rasters

The Original Raster Map Algebra

- Tomlin (1990, 2012) organizes raster analysis operations as ***local***, ***focal***, and ***zonal*** according to the *spatial scope* of those operations



Major Extensions to MA

- 2D (pixels/cells) → 3D (voxels/cubes)
  - Scott (1999) and Neteler (2004)
- Scalar raster → vector raster
  - Li and Hodgson (2004) and Wang and Pullar (2005)
- Feature-based
  - French and Li (2010)
- Flow network (raster & vector)
  - Tarboton and Baker (2008)
  - She & Li (2016)
- Time series of rasters
  - Mennis et al. (2005) and Mennis (2010)

The Nature of Map Algebra

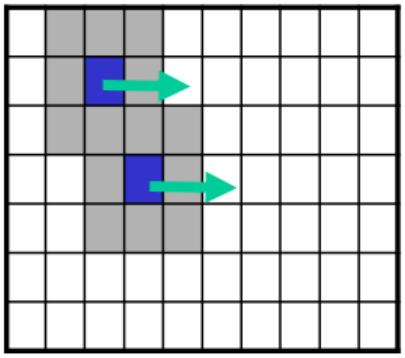
- Simple but powerful approach
  - Primarily way of analyzing raster data
  - Implemented in commercial /open source GIS software and cloud-based geospatial analysis platform
- What's the nature of map algebra?
  - What kind of computational instrument does MA provide?

Neighborhoods and Zones

- “A neighborhood is a set of locations at specified cartographic distances and/or directions from a given location” (Tomlin, 2012)
- “A zone is the set of data pertaining to a specific geographic conditions. The cartographic form of a zone can be large or small and in one piece or in a number of disconnected fragments.” (Tomlin, 2012)

Zones Are Stored Neighborhoods

- A zone is a neighborhood where all the cells in the zone share exactly the same neighborhood
- The zone raster is a map of neighborhoods
- Zones don’t overlap in space



1	1	1	1	1
1	3	3	3	1
1	1	2	2	2
1	1	2	3	2
1	3	3	3	2

The Nature of Map Algebra

- Perform an operation within a cell's neighborhood on a raster
- *Iteration*
  - Perform the operation at each cell (spatilization)
  - Iterate through the cells on a raster
- *Neighborhood*
  - Define the cells related to a cell
  - Represent a certain relationship between a cell and its neighborhood cells
- *Operation*
  - Data manipulations performed on neighborhood cells

Neighborhood

- Neighborhood(cell, otherArgs)
  - cell—currently processed cell
  - otherArgs—additional parameters used to define neighborhood
  - Returns a set of cells called the neighborhood of the cell
- Represents a certain relationship between a cell and its neighborhood cell(s)
  - Link location based relationships
- Examples
  - AdjacentNeighborhood(cell, kernel)
  - DistanceDirectionNeighborhood(cell, distance, direction)
  - NearestNeighbor(cell, featuresRaster)
  - Watershed(cell, flowDirectionRaster)
  - Viewshed(cell, visibleDistance, offset, …)

Data Manipulation Operation

- Operation(cell, valueRasters, otherArgs)
  - cell—currently processing cell
  - valueRasters--A set of rasters from which values are retrieved
  - otherArgs--Additional parameters used in data manipulation
- Major steps
  - Get the neighborhood cells from Neighborhood() function
  - Retrieve values from valueRasters at neighborhoodCells and/or cell
  - Perform data manipulation
    - location (neighborhoodCells and/or cell)
    - values (at neighborhoodCells and/or cell) retrieved from valueRasters
  - Return a value or a set of values

Link Data by Location

- Link data (raster values) at neighborhood cells and/or cell
  - v = f(cell, rasters)
  - Cell and rasters may have different size
- Link data at the cell and at its neighborhood cells
  - Link data through the link in location
  - Link in location defined Neighborhood

Cartographic Modeling "Operations"

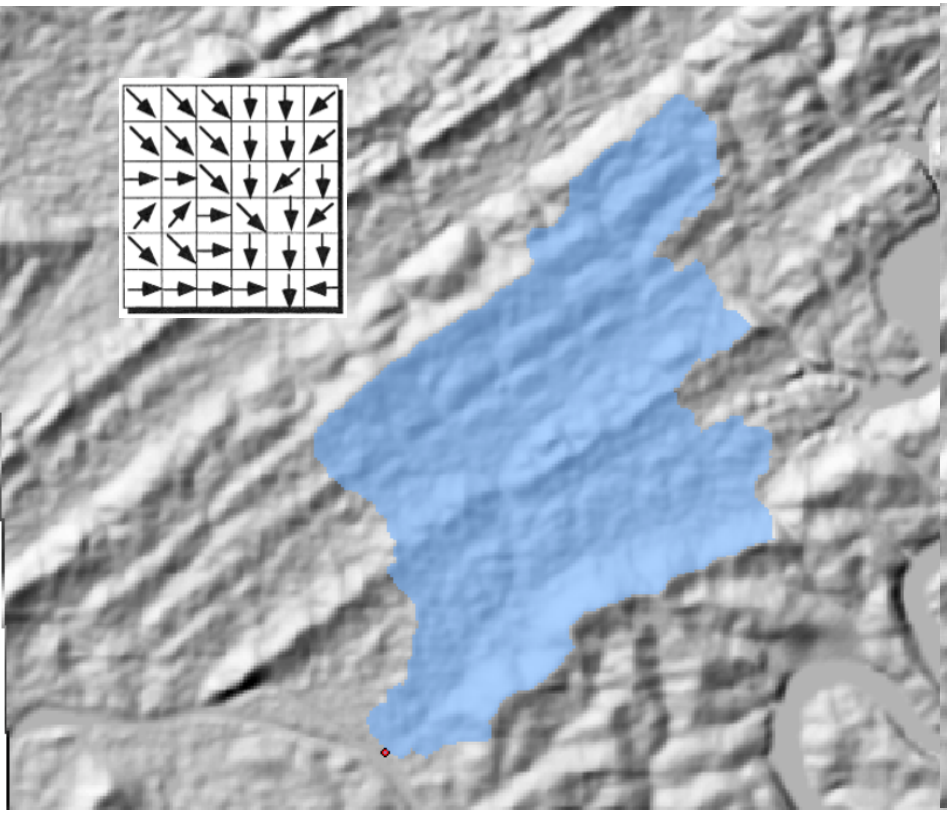
- "Local operations"—use the cell value at the same location
  - Neighborhood(cell)
    - Returns the cell
- "Zonal operations"—use the cell values within the same zone
  - Neighborhood(cell, zoneRaster)
    - Get the value of the cell on zoneRaster
    - Returns the cells with the same value on zoneRaster as neighborhood cells
  - Neighborhood is defined and stored in zoneRaster
- "Focal operations"—use the cell values bear a certain distance and/or direction
  - Neighborhood(cell, distance, direction)
    - Returns the cells bearing certain distance and direction from the cell as neighborhood cells

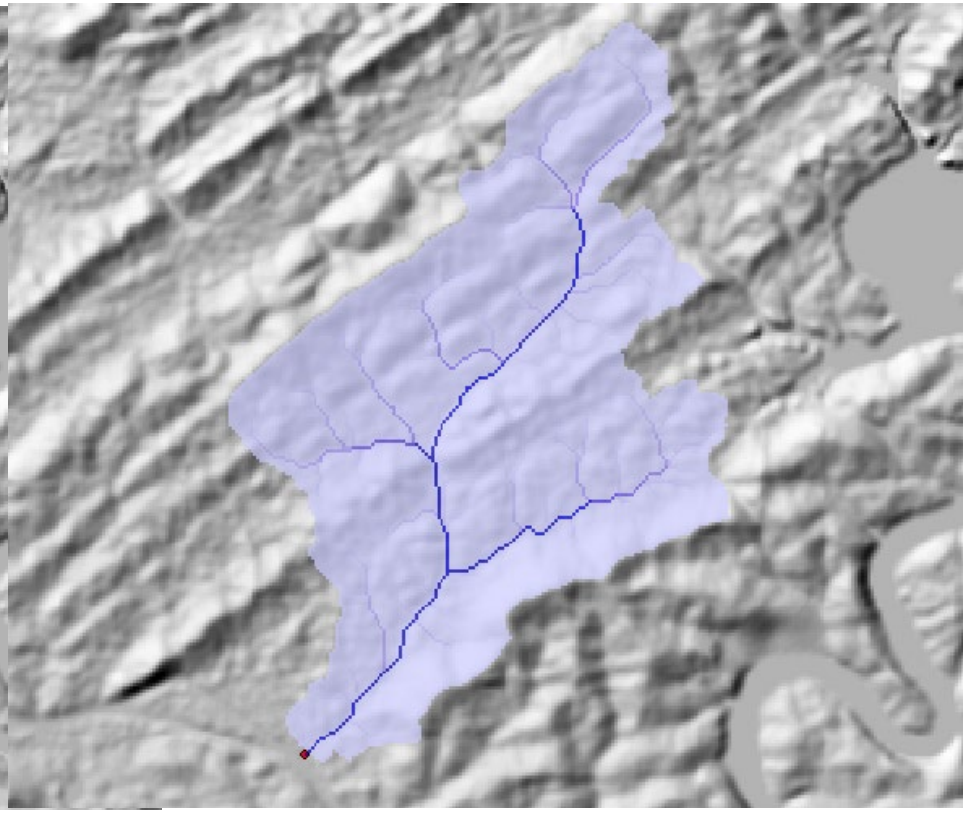
The Nature of Map Algebra

- What does MA offer?
  - A form of convolution?
  - Iteration
  - Neighborhoods
- Reveal emergent spatial patterns/forms by convolution
  - Spatial consequences/effects from local relationships represented by neighborhoods
- Geographical convolution
  - Neighborhood defined in geographical space
  - Convolution on multiple attributes (local neighborhood)
  - Convolution on irregular neighborhoods (watershed) and different neighborhood at different cells
- A computational instrument helps see what we cannot see
  - Explore local relationships and emergent forms

Drainage Networks As an Emergent Form

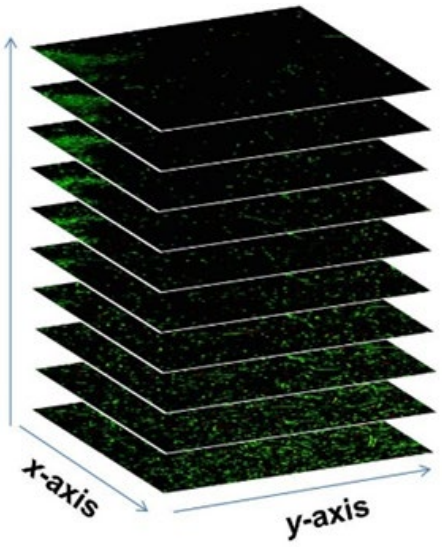
- Watershed() as the neighborhood
- valueRaster = 1
- Sum the values within a cell's watershed neighborhood





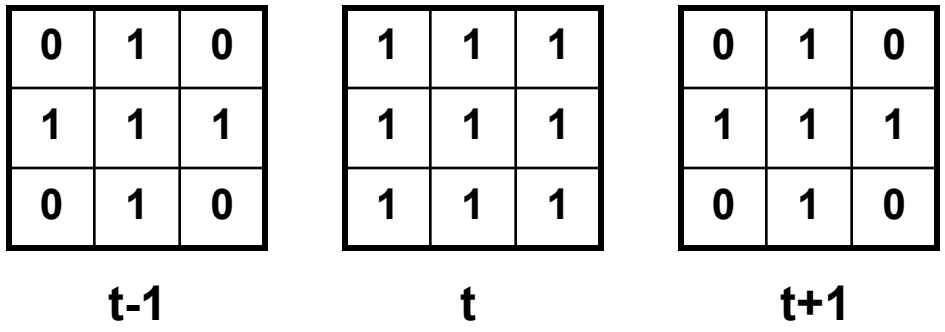
Map Algebra for Time Series of Rasters

- Perform an operation within a cell's neighborhood on a time series of rasters
- *Iteration in space and time*
  - Perform the operation at each cell and time
  - Iterate through the cells in space and time
- *Neighborhood in space and time*
  - Define the cells related to a cell in space and time
  - Represent a certain relationship between a cell and its neighborhood cells in space and time
- *Operation*
  - Data manipulations performed on neighborhood cells



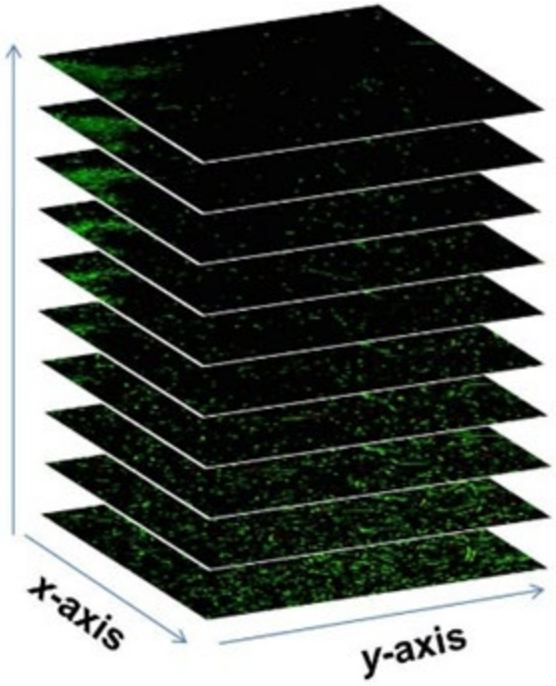
Spatiotemporal Neighborhoods

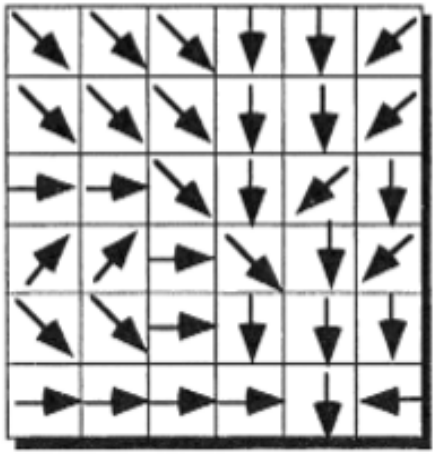
- Neighborhood(tsCell, otherArgs)
  - tsCell—currently processed cell in time and space
  - otherArgs—additional parameters used to define neighborhood
  - Returns a set of cells
- Represents a certain relationship between a tsCell and its neighborhood tsCell(s)
  - Link location and time based relationships
- Examples
  - AdjacentNeighborhood(tsCell, tsKernel)

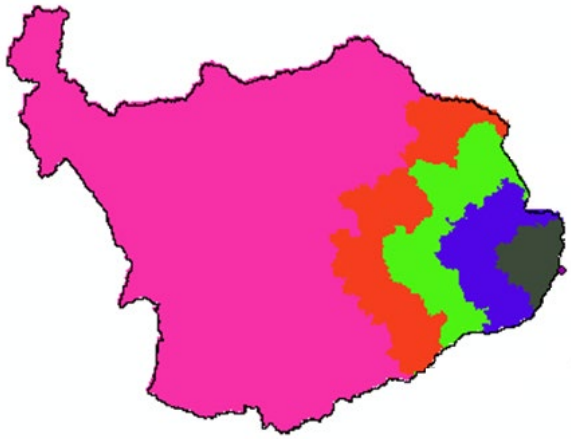


Watershed as Neighborhood

- Watershed(cell, flowDirectionRaster, flowSpeed)
- It takes time for the water in a cell's watershed to reach the cell
- Inflow at each cell's the time of concentration







Spatiotemporal Neighborhoods

- Define neighborhood based the interactions between spatial and temporal component neighborhoods
  - Local spatiotemporal neighborhoods (1)
  - Zonal spatiotemporal neighborhoods (2, 3, 4)
  - Focal spatiotemporal neighborhoods (5, 6, 7, 8, 9)

		Time		
		local	**zonal**	**focal**
Space	**local**	1	2	5
	zonal	3	4	6
	focal	7	8	9

Data Manipulation Operation

- Operation(tsCell, tsRasters, otherArgs)
  - tsCell—currently processing cell in time and space
  - tsRasters--A set of time series rasters from which values are retrieved
  - otherArgs--Additional parameters used in data manipulation
- Major steps
  - Get the neighborhood tsCells from Neighborhood() function
  - Retrieve values from tsRasters at neighborhood tsCells and/or tsCell
  - Perform data manipulation
    - Location of neighborhood tsCells and/or tsCell)
    - Time of neighborhood tsCells and/or tsCell)
    - Values at neighborhood tsCells and/or tsCell retrieved from tsRasters
  - Return a value or a set of values

Link Data by Location and Time

- Link data (tsRaster values) at neighborhood tsCells and/or tsCell
  - v = f(tsCell, tsRasters)
  - tsCell and tsRasters may have different spatial and temporal resolutions
- Link data at the tsCell and at its neighborhood tsCells
  - Link data through the link in location and time
  - Link in location and time is defined by Neighborhood
- Time
  - Local vs absolute
  - Circular (days, years)
  - Relationship between time and attribute

Conclusions

- Zones are special neighborhoods
- Map algebra as a computational instrument for geographical convolution
- Extension to analyze time series of rasters
- Future work
  - Vector data model and spatiotemporal vector data
  - Implementation

Questions?

- lixi@ku.edu