ADVANCING THE VISUALIZATION CAPABILITIES OF ALMA DATA CUBES THROUGH TOPOLOGICAL DATA ANALYSIS

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PART I: TDAV FOR ALMA DATA CUBES
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Vector Fields
stationary, time-varying combustion simulation
ocean eddy simulation
lifted jet flame simulation

Point Clouds
high-dim para space
nuclear engineering
cosmic phenomena
material science
high-energy physics

Large Complex Data

Networks
brain imaging fMRI
brain networks
biological networks
social networks

Multivariate Ensembles
windstorm, precipitation
hurricane forecasting
fire weather prediction
ANALYSIS AND VISUALIZATION OF ALMA DATA CUBES

ATACAMA LARGE MILLIMETER/SUBMILLIMETER ARRAY (ALMA)
ONE OF THE WORLD’S MOST POWERFUL TELESCOPES, LOCATED IN CHILE

COLLABORATE WITH NRAO SCIENTISTS: ANALYSIS AND VIS OF SPATIAL AND KINEMATIC STRUCTURES WITHIN ALMA DATA CUBES, E. G. BLACK HOLES

DEVELOP TECHNIQUES AND SOFTWARE TOOLS FOR DATA TRANSFORMATION, FEATURE EXTRACTION, FEATURE EXPLORATION AND FEATURE COMPARISON
"There simply are no tools capable of simultaneously visualizing, comparing, and analyzing the dozens to hundreds of data cubes for all of the detected spectral lines in a given source."

Credit: ALMA and Jeff Kern, NARO
PROCESSING PIPELINE
PROCESSING PIPELINE

Data Transformation to Scalar Field
**PROCESSING PIPELINE**

- Data Transformation to Scalar Field
- Feature Extraction Using Contour Trees
PROCESSING PIPELINE

Data Transformation to Scalar Field

Feature Extraction Using Contour Trees

Feature Exploration Visualization

Feature Comparison Visualization
RESEARCH QUESTIONS: DATA TRANSFORMATION

How are the spectral lines represented in a 3D data cube meaningfully converted to scalar functions for contour tree-based analysis?
RESEARCH QUESTIONS: FEATURE EXTRACTION

Once a contour tree is generated, there are many methods for selecting the important features of the tree. Therefore, how do we extract meaningful features of the data via contour tree simplification to suit the needs of astronomers?
RESEARCH QUESTIONS: FEATURE EXPLORATION

What is a MEANINGFUL visualization of contour trees to enable feature exploration of a single data cube by the astronomers?
Can contour tree representations be used for meaningful feature comparisons among multiple data cubes to characterize secular changes with observed properties (for example, transition energy, molecular species and chemical families), or derived properties such as temperature and density?
INTERDISCIPLINARY RESEARCH IS HARD

What we say to dogs
Okay, Ginger! I've had it!
You stay out of the garbage!
Understand, Ginger? Stay out of the garbage, or else!

What they hear
Blah, blah GINGER, blah, blah, blah, blah, blah, blah, blah...

Me
You
ONE CASE STUDY:
BLACK HOLE WITHIN THE GHOST OF MIRACH GALAXY

• Stellar and gas kinematics (movement of stars/gas w/o needing to understand how they acquired their motion)
• Contours: light distribution of the galaxy, or the luminosity in the gas emission lines.

IMAGE COURTESY: ANIL SETH
Mo’ Data Mo’ Problem
Mo’ Data Mo’ Problem
Mo’ Data Mo’ Problem
Mo’ DATA Mo’ PROBLEM
TOPOLOGICAL DATA ANALYSIS AND VISUALIZATION (TDAV)

study of approaches to EXTRACT structure from NOISY or COMPLEX data and REPRESENT that data in an actionable form
PERSISTENT HOMOLOGY

a method for computing topological FEATURES of a space at DIFFERENT spatial RESOLUTIONS
How Does This Relate to Radio Astronomy?

TDAV represents a diverse toolbox capable of addressing analysis needs in many contexts.

Our development study addresses these needs specifically via the Contour Tree.
TOPOLOGICAL SKELETON: CONTOUR TREE
CONTOUR TREES
CONTOUR TREES
CONTOUR TREES
CONTOUR TREES
Contour Trees
CONTOUR TREES
CONTOUR TREES
CONTOUR TREES
A CLOSER LOOK AT THE CONTOUR TREE

Scalar Value of Event
A CLOSER LOOK AT THE CONTOUR TREE

Birth of the Feature

Scalar Value of Event
A CLOSER LOOK AT THE CONTOUR TREE

Death of the Feature

Birth of the Feature

Scalar Value of Event
A CLOSER LOOK AT THE CONTOUR TREE

Persistence of the Feature

Scalar Value of Event
FEATURE REMOVAL
FEATURE REMOVAL
FEATURE REMOVAL
Scalar field simplification
SCALAR FIELD SIMPLIFICATION
SCALAR FIELD SIMPLIFICATION
SCALAR FIELD SIMPLIFICATION
SCALAR FIELD SIMPLIFICATION
RESULTS

Simple Spinning Disk
from Anil Seth
Phys. & Astro.
University of Utah
VARYING
PERSISTENT
SIMPLIFICATION
Stepping through slices
MOMENT 0 ANALYSIS

original

simplified

Range: 13-26

Range: 13-26
Volume Rendered
• Video
• https://youtu.be/TUJ9j82mYn8
SUMMARY

Early results convincing

Open questions remain
  Scalar field simplification choice
  Scalability of software
  Related visualization needs
  Additional uses of the contour trees
  Scientific impact of simplification
  Other TDAV data structures
SOFTWARE

Software will be publicly released before the end of the year
We invite interested users to contact us for early access
More Research Questions
A Bit More Technical Details
ALTERNATIVE SIMPLIFICATIONS
ALTERNATIVE SIMPLIFICATIONS
ALTERNATIVE SIMPLIFICATIONS
ALTERNATIVE SIMPLIFICATIONS
Outstanding issue: multiple slices

- How to co-simplify?
- Multiple 2D vs 3D contour trees?
Outstanding issue: Local vs. global contour tree

• Precomputation?
• Data storage and query?
• Efficient computation on parallel machine(s)?
PART II: DATA HAS SHAPE
AND WHAT TDAV CAN DO
FOR YOUR DATA
VOIDS, WALLS, FILAMENTS, CLUSTERS, AND THEIR CONFIGURATION WITHIN THE COSMIC WEB
Morse-Smale Complex
TDA+ASTRONEMY POTENTIALS

Filaments Structure T. Sousbie, DISPERSE
TDA+ASTRONEMY POTENTIALS

FILAMENTS STRUCTURE T. SOUSBIE, 2010,
QUESTIONS?

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Outstanding issue: Boundary Conditions
Outstanding issues: Boundary Conditions
Outstanding issues: Boundary Conditions

• Are boundaries true critical points?