Visualization and Visual Analysis of Multi-faceted Scientific Data: A Survey

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Multi-faceted Scientific Data

- **Spatiotemporal data**
- **Multi-variate/multi-field data**
  (multiple data attributes, e.g., temperature or pressure)
- **Multi-modal data**
  (CT, MRI, large-scale measurements, simulations, etc.)
- **Multi-run/ensemble simulations** (repeated with varied parameter settings)
- **Multi-model scenarios** (e.g., coupled climate model)
Multi-faceted Scientific Data

Coupled climate models

SPACE

NET SOLAR (SHORT-WAVE) RADIATION

ATMOSPHERE

CLOUDS

PRECIPITATION

ABSORPTION

REFLECTION

EMISSION

BIOGEOCHEMICAL CYCLES

VOLCANIC GASES AND PARTICLES

RUNOFF

LAKES AND RIVERS

LAND SURFACE PROCESSES

HUMAN ACTIVITIES

OCEAN

SEA-ICE

CURRENTS

ICE-OCEAN INTERACTIONS

LAND

AIR-ICE INTERACTIONS

AIR-OCEAN INTERACTIONS

WIND

Net terrestrial (long-wave) radiation

Net solar (short-wave) radiation

multi-variate data (f2)

multi-modal data (f3)

multi-run data (f4)

multi-model data (f5)

traditional setting

Böttinger, ClimaVis08

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Visualization and Analysis of Multi-faceted Scientific Data
Categorization

- Literature review of 200+ papers on scientific data
- How are vis., interaction, and comput. analysis combined?

**how** to represent the data

**interaction** concepts
(linking & brushing, zooming, view reconfiguration, etc.)

**what** are main characteristics / features

visual mapping --- interactive visual analysis --- comput. analysis

- visual data fusion
- relation & comparison
- navigation

- focus+context & overview+detail

- data abstraction & aggregation

- interactive feature spec.

[compare to Keim et al. 2009; Bertine & Lalanne 2009]
Fusion within a single visualization

- common frame of reference
- layering techniques (e.g., glyphs, color, transparency)
- multi-volume rendering (coregistration, segmentation)

Helix glyphs [Tominski et al. 05]

Layering [Kirby et al. 99]

Multi-volume rendering [Beyer et al. 07]
Fusion of multiple simulation runs

- spaghetti plots [Diggle et al. 02]
- summary statistics (box plots and glyphs)

EnsembleVis [Potter et al. 09]

Glyph-based overview [Kehrer et al. 11]
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**Visual Data Fusion**

- Fusion of multiple simulation runs
- EnsembleVis [Potter et al. 09]
- Glyph-based overview [Kehrer et al. 11]

**Visual Mapping**
- Visual mapping
- Relation & comparison

**Interactive Visual Analysis**
- Interactive visual analysis
- Focus+context & overview+detail

**Computational Analysis**
- Computational analysis
- Data abstraction & aggregation

**Multi-run**
- Isocontours
- Multi-run

**EnsembleVis** [Potter et al. 09]

**Glyph-based overview** [Kehrer et al. 11]
**Taxonomy** [Gleicher et al. 2011]

- side-by-side comparison
- overlay in same coordinate system
- explicit encoding of differences / correlations

- Interactive search, zooming, and panning
- Ranking/quality metrics [Bertini et al. 2011]
  - clustering, correlations, outliers, image quality, etc.
- Automated viewpoint selection
  - information-theoretic measures

Visual mapping

relation & comparison

visual data fusion

Multi-variate

Navigation

Focused Volume Data

Segmented

Volume Data

Interactive visual analysis

focus+context & overview+detail

Comput. analysis

data abstraction & aggregation

Visual data fusion

Visual mapping

Interactive visual analysis

Comput. analysis

Data abstraction & aggregation

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Parameter space navigation (multi-run data)

[Diagram showing parameter space navigation with input and output points, variations, and focal points.]

[Reference: Berger et al. 11]
- Overview+detail representation of multi-run data

Brushing statistical moments [Kehrer et al. 10]
- Brushing in multiple linked views
- Tight integration with supervised machine learning

Multi-variate visual human+machine learning [Fuchs et al. 09]
Fluid-structure interactions (multi-model data)

- heat exchange between fluid ⇔ structure
- feature specification/transfer across data parts [Kehrer et al. 11]
Algorithmically extract values & patterns

- dimensionality reduction (PCA, SOM, MDS)
- aggregation, summary statistics
- clustering, outliers, etc.

clustering of multi-run simulations [Bruckner & Möller 10]

[Andrienko & Andrienko 11]
## Categorization of approaches

<table>
<thead>
<tr>
<th>visual mapping</th>
<th>interactive visual analysis</th>
<th>computational analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>maps [13], [14], [92]; Helix glyphs [93]; flow maps [105]; function graphs [70], [71], [72]; Time Histograms [94], [110], [111]; chrono volumes [98]; illustrative techniques [99]; texture-based flow vis. [100]</td>
<td>2-tone coloring [20]; Helix glyphs [93]; juxtaposed views [19], [110]; difference views [107]</td>
<td>brushing [21], [70], [71], [95], [113]; transfer functions [110], [111]</td>
</tr>
<tr>
<td>multi-dimensional attribute views [22], [50], [67]; color &amp; texture [119]; layering [115], [124], [126]; 2-level volume rendering [127], [128]; glyphs [120], [121], [122], [123], [124], [125]</td>
<td>correlation fields [133]; operators [134]; multiple linked views [9], [26], [29], [73], [74], [76]</td>
<td>illustrative vis. [115], [116]; outlier-preserving methods [69]; smooth brushing [80]</td>
</tr>
<tr>
<td>multi-modal resampling [138]; data model [142]; illumination model [143]; multi-volume rendering [128], [139], [143], [144], [145], [146]</td>
<td>difference views [107]; multi-image view [153]; nested surfaces [31], [154], [156]; features [44], [155]</td>
<td>viewpoint selection [49]</td>
</tr>
<tr>
<td>multi-run glyphs &amp; box plots [37], [43], [162], [163], [164]; shape descriptors [164]; families of surfaces [41]; spaghetti plots [35], [42], [165]</td>
<td>aggregated &amp; multi-run data [36], [37], [41], [174]; HyperMoVal [51], [52]</td>
<td>aggregated &amp; multi-run data [36], [37], [41]; parameter space nav. [51], [52]</td>
</tr>
<tr>
<td>multi-modal feature fusion across multiple data parts [37]</td>
<td>feature relation across data parts [37]</td>
<td>x</td>
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Open Issues

- **How to deal with data heterogeneity?**
  - most approaches only address one or two data facet
  - coordinated multiple views with linking & brushing
  - investigation of features across views, data facets, levels of abstraction, and data sets
  - fusion of heterogeneous data at feature/semantic level

- **Combination of vis., interaction, and comput. analysis**
  - analytical methods can control steps in visualization pipeline (e.g., visualization mapping or quality metrics)
  - interactive feature specification + machine learning
Conclusions

- Scientific data are becoming multi-faceted.

- Categorization based on common visualization, interaction, and comput. analysis methods.

- Promising data facets, e.g., multi-run & multi-model data.
Thank you for your attention!

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