Statistics from Tracer Particles in Turbulent Flows using R

J. Pratt

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Introduction

Outline

About me:

- computational physics
- astrophysics: simulations of turbulent flows within stars
- fusion energy: simulations of highly unstable flows in fusion machines
- **plasmas:** fluids that are so hot that the electrons and ions separate, shaped by electromagnetic effects.

Outline

- Why R?
- Convex hulls
- The physical problem of particle dispersion in a flow
### Why R?

- Thorough web documentation and tutorials (e.g. [http://www.r-bloggers.com/](http://www.r-bloggers.com/))
- High quality, highly-customizable vector graphics.
- Huge number of user-created packages.
- Free and cross-platform software, installed on all large parallel computer systems. Run with scripts, in parallel. This makes R a practical choice for post-processing of data from large simulations.

#### Table: Benchmark Times Relative to C

<table>
<thead>
<tr>
<th>Function</th>
<th>Fortran</th>
<th>Julia</th>
<th>Python</th>
<th>R</th>
<th>Matlab</th>
<th>Octave</th>
<th>Mathematica</th>
<th>JavaScript</th>
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<tbody>
<tr>
<td></td>
<td>gcc 4.8.1</td>
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<td>3.0.2</td>
<td>R2012a</td>
<td>3.6.4</td>
<td>8.0</td>
<td>V8</td>
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<td>13.95</td>
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<td>7109.85</td>
<td>29.54</td>
<td>2.43</td>
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<td>1.14</td>
<td>31.98</td>
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<td>1132.04</td>
<td>35.74</td>
<td>3.51</td>
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<td>mandel</td>
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<td>14.19</td>
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<td>6.07</td>
<td>3.49</td>
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<td>15.42</td>
<td>1.29</td>
<td>237.41</td>
<td>1.32</td>
<td>0.84</td>
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<td>3.28</td>
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<tr>
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<td>3.41</td>
<td>3.98</td>
<td>1.10</td>
<td>3.41</td>
<td>1.16</td>
<td>14.60</td>
</tr>
</tbody>
</table>

**Figure:** Benchmark times relative to C (smaller is better, C performance = 1.0).
The convex hull of a set of points

Fig. 5.1 Left illustration of Jarvis’ convex hull algorithm. Right the generalization to constructing shapes obtained by shortening the line to a line segment

R package geometry: Mesh generation and surface tesselation (http://cran.r-project.org/web/packages/geometry/index.html/)
Alpha Convex Hulls

Fig. 5.2 A set of points sampling the letter ‘R’, with its $\alpha$-hull on the left and its $\alpha$-shape on the right.

R package alphahull: Generalization of the convex hull of a sample of points in the plane (http://cran.r-project.org/web/packages/alphahull/index.html/)
How is this useful?

- shape/volume/surface area of molecules (folded or unfolded)
- spreading of forest fires
- shape of animal habitats
- dispersion of particles in a fluid (smoke in the air)


Fig. 3. Protein–DNA complex interface obtained from the alpha shape model. (A) The alpha shape model of the protein–DNA complex with the secondary structure inside. (B) The alpha shape model of the protein shown with the secondary structure of the DNA chain. The interface surface of the complex is shown in red.
Flow conditions in stellar interiors

- The sun and the earth both have magnetic fields. How do these magnetic fields form? Why do they not decay away?
- In plasmas the fluid motions stretch, twist, fold the fluid and produce electromagnetic fields.

- Stars are heated from the inside, and cooled from the outside: convection must be considered.
- Complex chaotic flows can only be understood statistically.
Flow conditions in stellar interiors

High velocity flows = fully developed turbulence.

Lagrangian tracer particles: particles that have no volume or mass, and do not interact. They mark bits of fluid, so we can trace where it moves.

Thermal fluctuations in a simulation of turbulent magnetoconvection.
Convex hulls of tracer particles

Concepts of stretching/shrinking (area and volume growth), orientation, and asymmetry are comparable between different types of flows.
Dispersive hot-spots at high spatial resolution

randomly forced

Driven by convection

Volume of convex hulls in a horizontal slab. Volume is normalized to the minimum convex hull volume in the system.

Lattice/trellis graphics package
http://lattice.r-forge.r-project.org/

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Thanks!