INDICATE

INdex to Define Inherent Clustering And TEndencies

A. Buckner[1] and the StarFormMapper Collaboration

1 School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, United Kingdom

What is it?

A new novel automated statistical clustering tool (Buckner et al., in prep.).

Traditional clustering algorithms find cluster centroids and members in datasets- but this is insufficient for studies of e.g. mass segregation and substructure in young star clusters/forming regions. INDICATE enables the user to quantitatively trace how "clustered" individual objects are in distribution and how this changes as the system evolves.

Why do YOU want to use it?

INDICATE has been developed as a tool for the community to quantitatively trace:

- **Mass Segregation**
- **Stellar Substructure**
- **Dynamical Evolution of a Cluster System**
- **Spatial Evolution of Individual Stars in Cluster Mergers**

As stars' Clustering Indices are derived through direct comparisons to generated uniform distributions, direct comparisons of the Index values derived for individual stars in the cluster system, as well as between multiple cluster systems, is possible.

Thus INDICATE grants the ability to trace how the degree of clustering varies for individual stars, whole cluster systems, and globally, with e.g. stellar/cluster mass, age, position etc.

How does it work?

Calculates a 'clustering' index for every vector in a discrete distribution.

The Index:

- quantitatively describes the degree (or lack) of spatial clustering in the local neighbourhood of the vector
- derived by comparing the number density of the vector's local neighbourhood with a generated evenly spaced uniform distribution (i.e. definitively non-clustered) with the same overall number density of the distribution
- as such, is independent of shape (circular, filamentary etc.), size and spatial compactness of distributions sub/structure
- can be derived for 2D, 3D and/or 6D discrete distributions
- is calibrated against random distributions

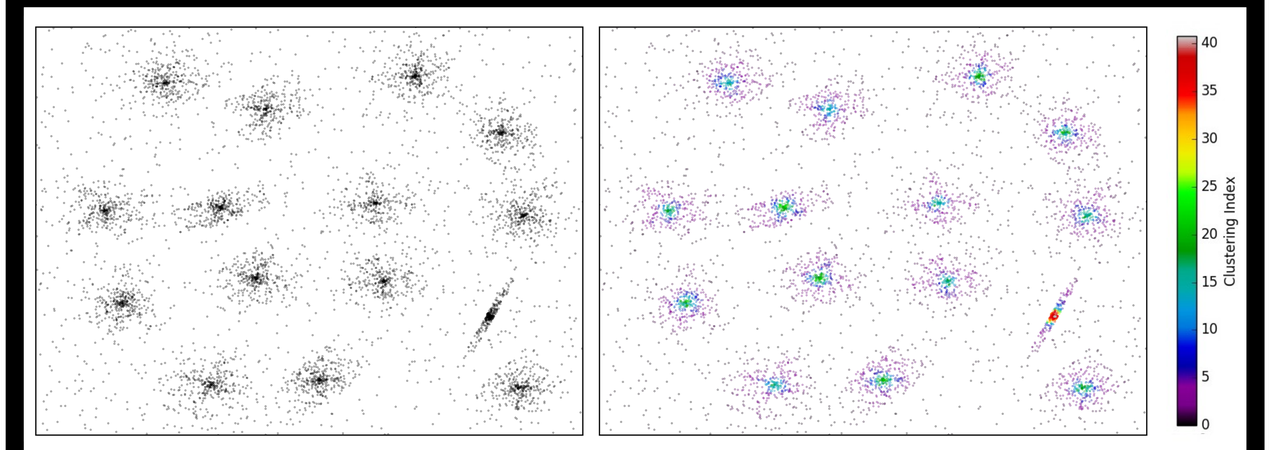


Figure 1. Demonstration of applying INDICATE to a discrete 2D dataset. ***(Left:)*** Synthetic 2D dataset of 6000 vectors and 15 Gaussian clusters with different degrees of cluster overlapping (augmented from original form by Fränti & Virmajoki, 2006) ***(Right:)*** after applying INDICATE. The higher the Clustering Index, the more (absolutely) spatially clustered the vector is.

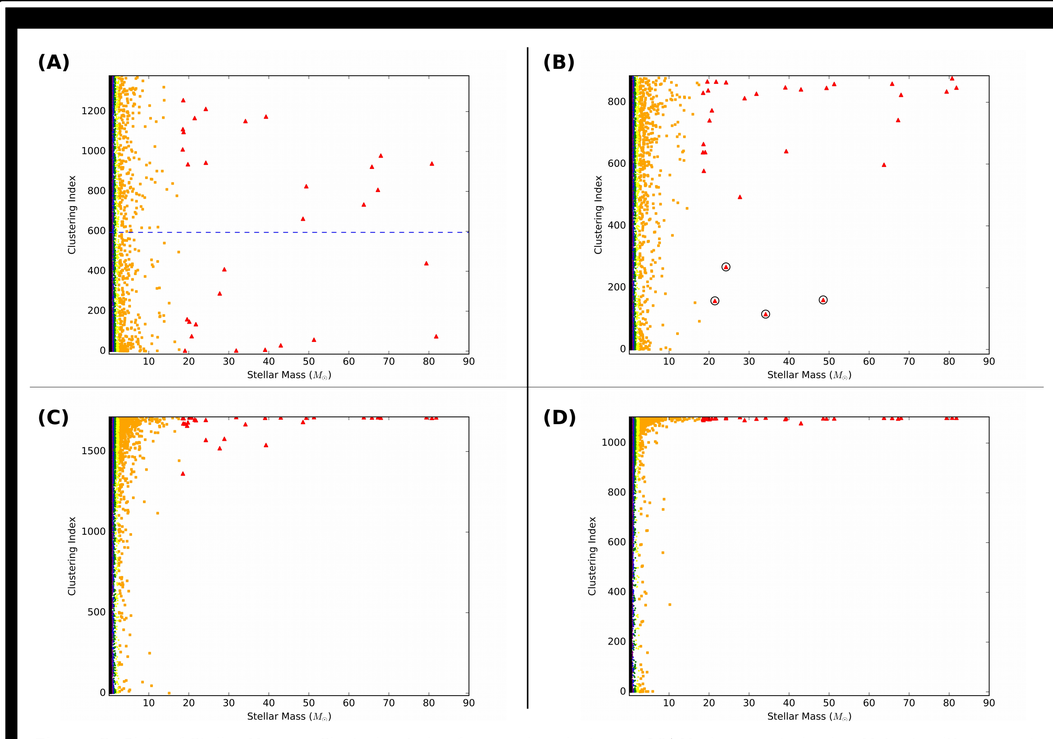


Figure 2: Plots of Stellar Mass vs Clustering Index for massive clusters (~10^4 M_{sun}) generated using McLuster (Kuepper et al., 2011) with a ZAMS stellar population of 20,000 members between 0.08-100 M_{sun}; no binaries; half-mass radius of 1pc; and ***(A)*** S=0.0 ***(B)*** S=0.25 ***(C)*** S=0.50 and ***(D)*** S=0.99 degree of mass segregation respectively. As a visual aid stars are tentatively colour coded by spectral type based on mass ranges given for MS stars by Pecaut & Mamajek (2013) [O-red, B-orange, A-yellow, F-green, G-blue, K-purple, M-black] and the blue dashed line on (A) marks the median Clustering Index of the cluster.

Example: Mass Segregation

Mass segregation can be defined as a difference in distribution of stars as a function of stellar mass, such that the more massive stars are more spatially concentrated than their lower mass counterparts.

Thus INDICATE (which quantifies the spatial concentration of objects) allows the variation in the spatial distribution of stars as a function of mass to be easily seen. Advantageously, it is independent (and does not require prior knowledge) of cluster centres, radii or density profiles. An example is shown in **Figure 2**: cluster ***(A)*** has no mass segregation so the Index values of the most massive stars are randomly distributed about the median value of the cluster. Comparatively, clusters ***(B)*** ***(C)*** & ***(D)*** show a trend of increasing higher Clustering Index values for the individual massive stars with greater degrees of mass segregation.

However, the true power of INDICATE for mass segregation applications is the ability to quantitatively describe and compare the spatial clustering of individual stars of similar masses. For example in ***(B)*** there are 4 O-type stars [circled] which have a Index value that is statistically significantly lower than the other stars in the cluster with similar masses. Therefore INDICATE has identified/quantified which massive stars are not spatially clustered (respectively) – information which can then be used as a focal point for further studies into e.g. the effects of local environment formation conditions on the dynamical history's of cluster members and cluster spatial structure.

The StarFormMapper Project

INDICATE was developed for, and this research was conducted on behalf of, the StarFormMapper (SFM) project. The key aim of the project is to combine data from two of ESA's major space missions, Gaia and Herschel, together with ground based facilities and simulations to constrain the mechanisms that underlie massive star and star cluster formation.

SFM has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687528. It is a joint collaboration between the University of Leeds, University of Cardiff, Université Grenoble Alps and Quasar Science Resources, S.L.

Scan me to discover the SFM Website!

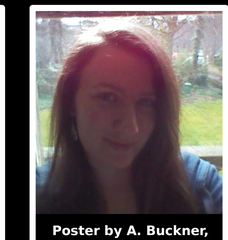
References

A.Buckner et al., "*The Spatial Evolution of Young Massive Clusters I. – A New Tool to Quantify Substructure & Mass Segregation*", A&A, in prep.

Fränti & Virmajoki, (2006), Pattern Recognition, 39 (5), 761-765.

Kuepper et al., (2011), MNRAS, 417, 2300.

Pecaut & Mamajek (2013) , ApJS, 208, 9.



Poster by A. Buckner, Postdoc @ Uni. of Leeds