A shared understanding between humans and autonomous cyber collectives

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Situational Awareness

- May have smart sensors, System-of-Systems(SoS).
  - May be distributed SoS over large areas.
  - May have thousands of smart entities (Battlespace).
  - May produce large volumes of data.
- Need to share information with humans.
  - Big Data problem = need to semantically integrate the voluminous data.
  - Aggregate data needs to be summarized to relevant details, in an actionable (i.e. short) timeframe.
- Need to create: sparse yet relevant data stream for shared “world model”.

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Problems in Achieving Data Rendering

- Many methods are computationally intensive.
- Want to render Big Data to sparse data without losing relevant information.
  - Nature example: Stigmergy = collective behaviors.
  - How to do this in our synthetic autonomy?
- Leverage off topology for distributed systems.
  - Map topological relationships, each sensor's "perspective" can overlap to derive permutation of shared information = renders to sparse info.

To What and Where Do We Look?

- Big Data starts out as a “high dimensional” problem.
  - All or most information is there, but too complex or time-consuming to decipher.
  - One solution = reduce dimensionality from higher to lower, preserving relevant information.
- Look at methods to reduce dimensionality from theoretical mathematics, physics, to stigmergy and multivariate analysis.
  - Most methods use a variety of tools from topology.

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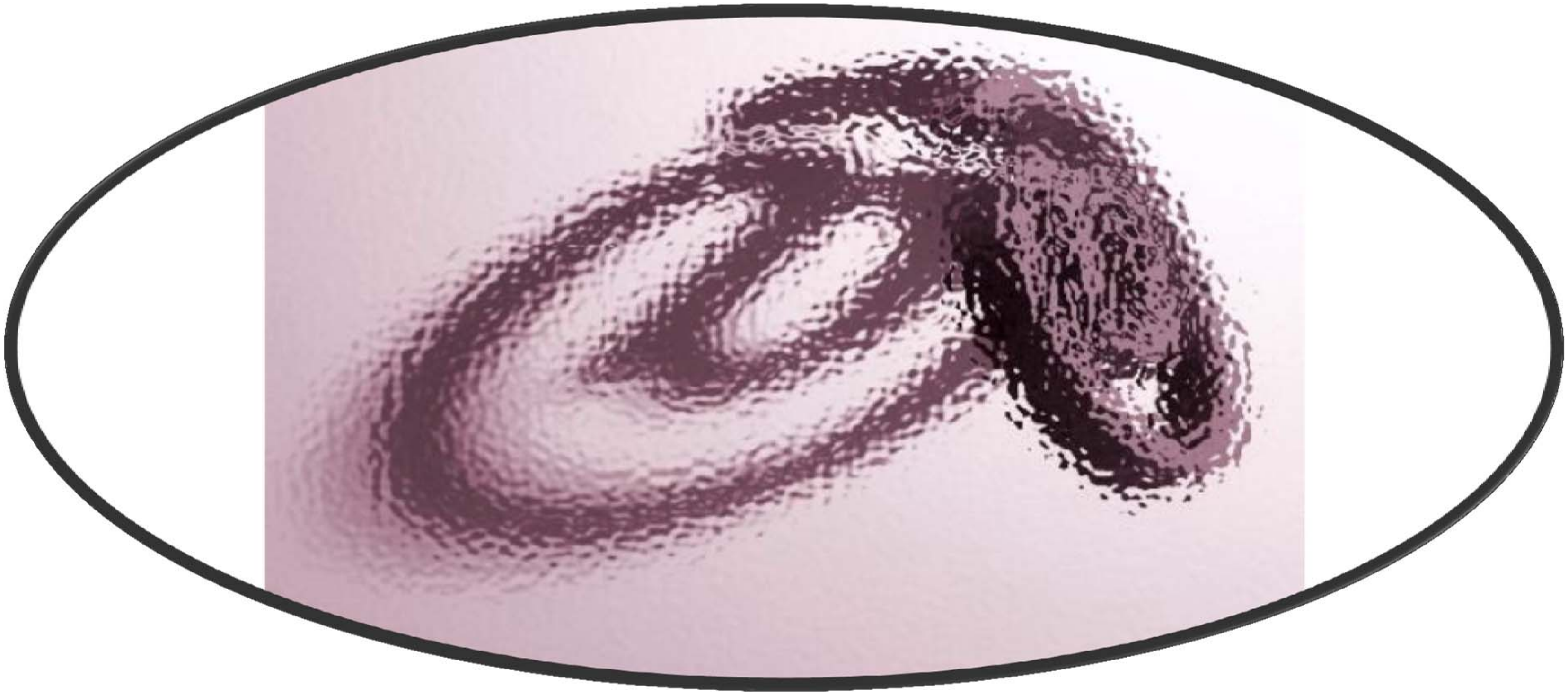
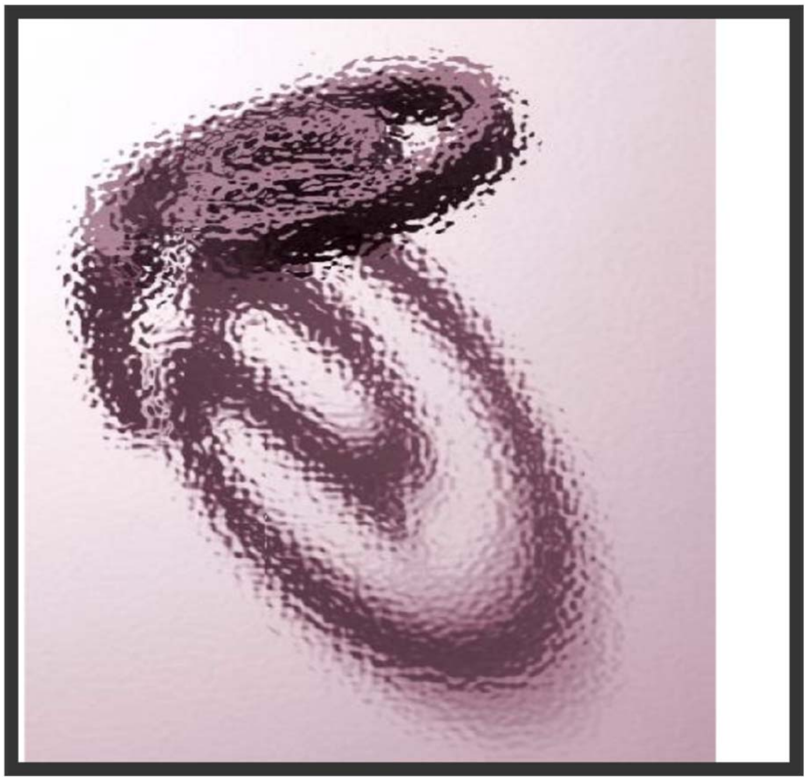
Different Perspectives and reflections



A better understanding

From this:



Transposed to this:

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But How?

- Information is related through multidisciplinary approaches.
- Different areas to look for a common thread:
  - Communication theory
  - Network traffic patterns
  - Complexity science & Chaos theory
  - Topology:
    - braid / knot theory relationships
    - Topological relationships to multi-agent control
    - Clusters and dimensional reduction methods
    - Quantum entanglement
  - Stigmergy (collective self-organization in nature)
  - Sparse data effects in ecosystems

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Highlights of References (1)

1 Paxson and Floyd: Large-scale network ***packet traffic does not follow*** the anticipated model of ***a Poisson distribution***, ***but*** instead has ***a fractal*** quality in the way that the packets self-organize into clusters, producing'burstiness'.

2 Mandelbrot: Observed scaled [self-] similarity (currently called fractal topology) pattern in communication error clusters for signals on telephony transmission lines.

3 Kurlin: Algorithm using topological aspects of ***braid theory*** plans the ***motions of large numbers of robots***. His objective: robots to ***traverse*** a connected graph or '***map***' of connected paths, ***without collisions***.

4 Huebschmann: ***Braid theory*** and its mapping as multiple strings which cross, which he refers to a "crossed module structure". He later describes what he calls a "permutahedron" as an overlay of a shape originating from a ***polyhedron*** that is ***mapped to higher dimensions***.

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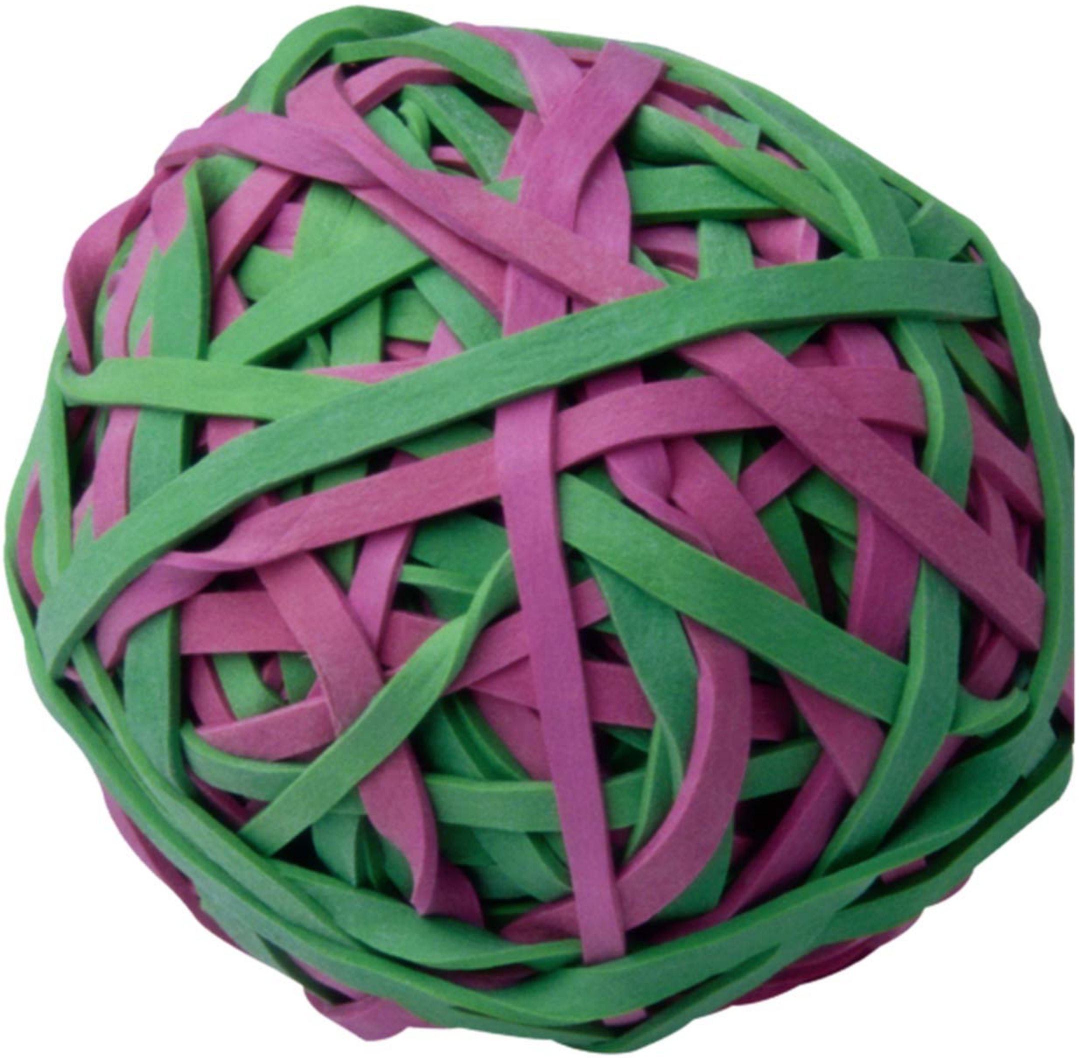
Topological relationships

Knot or Braid Theory can show the shared points as intersections or overlaps between linear data sets. These points shared in common between multiple data sets ***might be*** a representation of the same observed object, or may indicate some sort of constraint to the systems as a whole.



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Highlights of References (2)

5 Holden, Karlsen and Risebro: Initially starting from differing locations / trajectories, ***nonlinear weakly coupled*** degenerate parabolic ***systems*** eventually form an 'orbital' state around an attractor. Gives proof of ***random yet topologically constrained systems self-organizing towards an attractor***.

6 Stremler, Ross, Grover, and Kumar: Reciprocal effort to Holden, et al. - provide a method for the ***analysis of chaos using a topological approach*** - in this case, braid theory to bound the topological space.

7 Jordache: ***Nature can cause rules to be created from multi-agent systems interacting with their environment, by a consensus of information***, i.e. constraints and convergence for random data in general.

8 Larsen and Speckman: When clusters are not independent, or the clusters are ***not homogeneous*** relative to selected ***dependent variables***, this creates a ***need*** for ***multidimensional scaling***.

9 Tashkova, Šilc, Atanasova, and Džeroski: Models of ***ecosystems*** that are ***high dimensional and nonlinear with sparse data*** are tested, and it is shown that ***global methods are superior*** to localized methods in this type of case.

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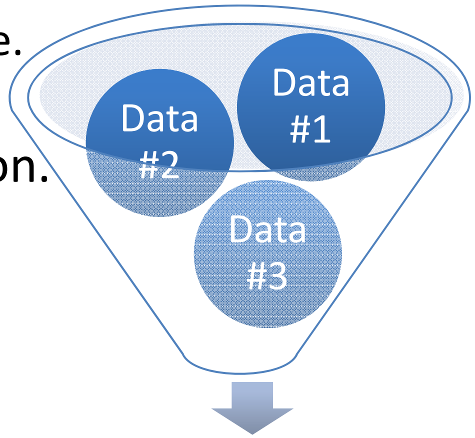
The high dimensional data problem

- Heterogeneous data from many sources – each has its own perspective.
- Composite information is formed from data, but is intractable – why?
  - Because differing time / space observations & sensor resolutions creates multiple, different representations of any object.
  - Each representation may be reduced to a unique dimension, capturing all relevant information. Many representations = many dimensions.
  - Mathematically, n-dimensional matrices computationally hard.
  - N-dimensional topologies are even harder to conceptualize.
- Need to capture relevant details, yet reduce dimensions.
- Algebraically challenging, but possible topological solution.



Composite / aggregate data.

Highlights of References (3)

10 Mosseri and Ribeiro: High dimensional {Hilbert} space may include remotely linked systems or information, defines ***quantum entanglement***.

11 Solomon: Similar ***topological entanglement*** = vector cross products shows that entangled state of vector / topological spaces is linked to Braid theory.

12 Marseguerra and Zoia: ***Multiple inputs from various sensors create a high dimensional*** problem space for signal processing. In order to reduce the dimensionality so as to create a more tractable lower dimensional problem space, an autoassociative neural network is chosen.

13 Yuksel: ***Focused information sharing across distributed systems***, while avoiding some of the dimensionality issues. (Stochastic nestedness). Method uses a Markov chain of distributed information, and incorporates a 'belief' system to supplement missing information. This creates ***a recursive optimization pattern of minimum information***. Note that a this type of ***recursive pattern is computationally similar to a fractal***. Issue: open question as to whether the selected beliefs would prove valid and sufficient in all cases.

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Highlights of References (4)

14 Masoumi and Meybodi: For ***multi-agent systems*** of learning automata, a ***stigmergic learning algorithm*** with entropy based adaptation can be an improvement over general algorithms.

15 Sukumar, Jayakumar and Geetha: ***High-dimensional problem*** & methodology - Multiple web services compared, to select the best for certain tasks. Comparisons are made on multiple simultaneous parameters producing mappings that create clusters, each of which represents different criteria (high-dimensional problem).

Dimensional reduction is done using space-filling curves (SFC). The SFC can be thought of as a projection of some higher dimensional data set containing clustered subsets that map to portions of the curve (***Fractal structure***).

Choosing best SFC: Hilbert SFC shortcomings discussed - limited scalability and mapping irregularities, and failing to successfully map exact cluster patterns. Previous paper cited that mathematically proves the Peano SFC to be superior to the Hilbert SFC.

{Lays groundwork for investigation of novel / adaptive SFCs for better 'fit'.}

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Conclusions

- Various approaches to large-scale distributed information.
- Topological approaches provide some mathematically tangible methods.
- Fractal curves both can be dimensional reduction of high-dimension space, and provide bounding conditions for multi-cluster relationships.
- Current fractals are statically limited, use an adaptive fractal method.

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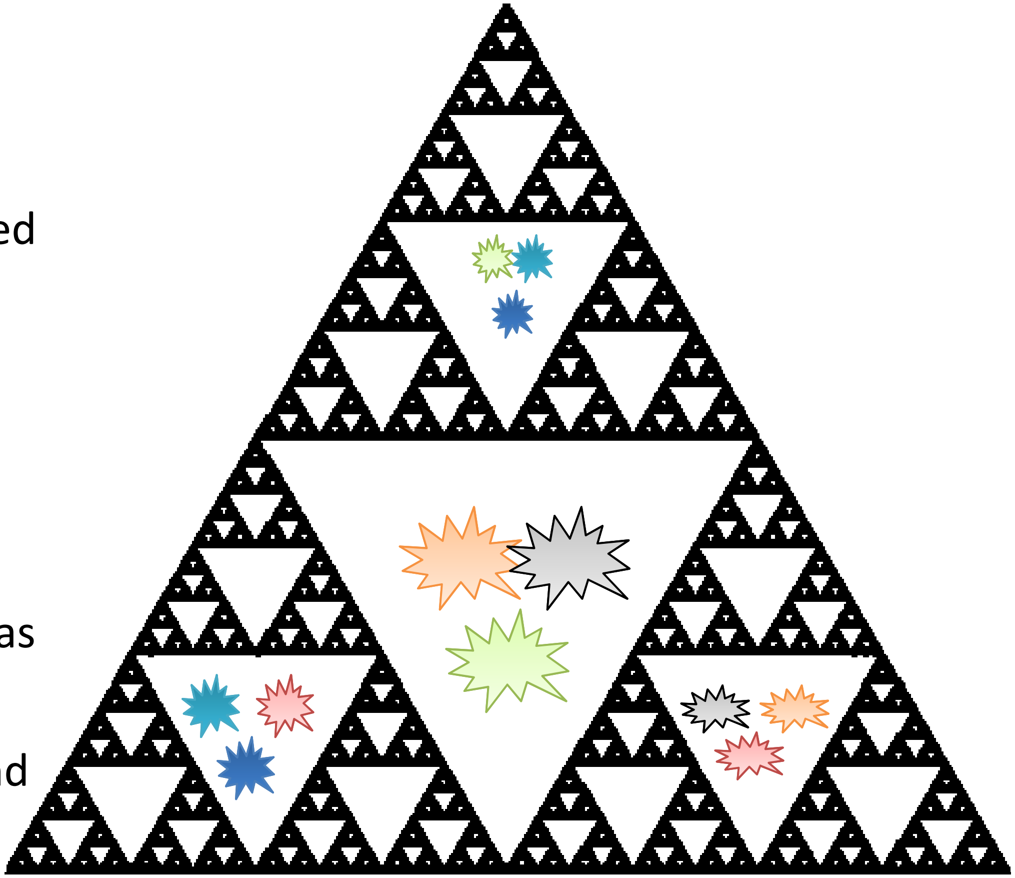
Non-overlapping topology relationships – multiple clusters

Capturing relationships for multiple cluster-of-cluster topologies, while reducing dimensionality:

- Non-stochastic solution is needed (preserve interrelationship details).
- Possible non-integer resulting dimensionality.
- Various self-similar curves have had success in the past – e.g. fractal models.
- Resulting curve / map emerges as the abstraction of complex collective interrelationships, dictated by world constraints and objectives or goals the autonomous systems .



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Acronyms

- SoS – System of systems
- SFC – Space-filling curves

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