

Evaluating Visualizations of Sets and Networks that Use Euler Diagrams and Graphs: Supplementary Material

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1 Introduction

This document is the supplementary material to the “Evaluating Visualizations of Sets and Networks that Use Euler Diagrams and Graphs” paper. It contains data used in the evaluation and how it was obtained, and also contains, for each data set used in the evaluation:

1. the name of the SNAP data set (from which the data were derived),
2. the diagrams drawn by each of the four techniques, and
3. a table showing all violation counts by each technique per property, and runtime information.

The implementations of each technique can be obtained from the following links:

- SetNet: <http://www.eulerdiagrams.org/setnet/> (last accessed 16-December-2019)
- Bubble Sets: <https://github.com/JosuaKrause/Bubble-Sets> (last accessed 16-December-2019)
- WebCola: <https://ialab.it.monash.edu/webcola/> (last accessed 11-December-2019)

2 Data for Visualization

The following describes how the SNAP data was reduced and sampled. To reduce the number of vertices and edges in the SNAP data, firstly, we removed vertices with degree 0 as they do not affect any of the properties being counted because they can be re-introduced post-process after the diagram is drawn⁴. Secondly, we made an assumption that only one non-directed binary relation is considered. In other words, if two vertices have multiple edges between them, then the edges can be reduced to just one. So, we removed all occurrences of multiple edges between any pair of vertices since, in terms of visualizations, the edges would just be drawn on top of each other. We also removed loops (an edge whose incident vertices are the same vertex). Thirdly, we randomly removed vertices using an iterative approach, whilst ensuring that if this created any degree 0 vertices, they would be removed also. The random removal stopped when the number of vertices was in the given bounds. Finally, any produced data sets that had too few vertices or edges were removed from consideration (which can happen through the creation of a degree 0 vertex or removing a vertex with many incident edges).

The operations can be summarized as the following steps:

1. Remove vertices with degree 0.
2. Remove multiple edges.
3. Remove loops.
4. Randomly remove 20% of the vertices (and their incident edges). Remove vertices with degree 0. Repeat this step until the data set is within the bounds or has too few vertices or edges.

This process left us with a set of SNAP data sets, reduced in complexity, from which we randomly selected a sample for our evaluation.

We explain how we randomly selected data sets for the two-set case, with the other cases being similar. We computed the median numbers of zones, vertices and edges. These medians were used to sub-divide the two-set data sets into eight groups: those with a low number of zones, vertices and edges (i.e their numbers were all less than or equal to the median numbers), those with a low number of zones and vertices, but a high number of edges (i.e. more edges than the median number of edges), those with a low number of zones and edges, but a high number of vertices, and so forth. From each of these eight sub-divisions, we randomly selected one data set for visualization. This gave us eight two-set data sets. As we are visualizing two-, four-, six-, and eight-set data sets, this gave us 32 data sets for visualization.

⁴ We acknowledge that the techniques do not work in this way and these vertices could have a profound impact on the layouts.

3 Visualizing Data Using the Techniques

Each of the 32 data sets had to be visualized with each of the techniques in order for us to count violations of the accuracy and effectiveness properties. For each technique, we had to make some choices about how this was to be achieved. Focusing first on SetNet, it cannot visualize vertices that are outside of all curves. To overcome this limitation, we added a ‘dummy’ set, called U (for universal set) to the data: each data item was defined to be inside U . These altered data sets were supplied to SetNet (only), so a circle for U was drawn. This circle was subsequently deleted, since its presence was only necessary to achieve a layout, before we counted the properties. Bubble Sets requires an already drawn graph over which it lays out the closed curves; it does not have an integrated graph layout algorithm. The graphs for Bubble Sets were drawn using the ForceAtlas2 layout algorithm to be consistent with the literature. For WebCola, the size of the vertices needs to be specified: we used the vertex size settings provided on the software website. It is important to note that different choices, such as a different graph layout algorithm or vertex size, could impact the properties possessed by the visualizations.

Given these choices, we attempted to draw each of the 32 data sets using the four techniques. In one case, for the data set with 8 sets, a high number of zones, a low number of vertices and a high number of edges, SetNet could not draw the selected data set. No SNAP data set could be reduced to match the given combination of the number of sets, zones, vertices and edges to replace that data set. Hence, the evaluation we present is based on the remaining 31 data sets.

4 Threats to Validity

The results we obtained are valid within the study constraints. In this section, we consider the threats to the validity of these results and discuss properties of diagrams that cannot be counted, which is why there were not part of our evaluation.

An important factor to consider is that the evaluated theoretical properties act as a proxy to diagram effectiveness. Therefore, the results can only provide a relative effectiveness of the techniques with respect to these properties. We should be mindful that these properties, when possessed by diagrams, do not necessarily ensure effectiveness. However, it is known that violating these properties leads to poor comprehension. Thus, it is important to rank visualization techniques with respect to how well they meet the effectiveness properties, which we have done in this evaluation.

Another important factor to consider is the number and the complexity of selected data sets used in the evaluation. A larger number of data sets, or the original complexity of the network (up to 68413 vertices and up to 1685163 edges) may have produced a different set of results. As explained earlier, it was not sensible to include all data sets with the original network complexity seen in SNAP data sets since the diagrams were to be produced and evaluated manually. So, we used a stratified random sampling method to reduce the number of data sets and we randomly removed vertices to manage the network complexity.

The validity of the results is also limited to the software implementations of techniques we used in the evaluation. Software implementations can use different rendering details, such as vertex sizes, and different heuristics when producing algorithms from theory. Therefore, these alterations can impact the evaluation criteria presented in this evaluation. For example, changing the graph algorithm used for Bubble Sets, or the vertex sizes in WebCola, will likely affect the accuracy and effectiveness properties that arise from graphs.

Our evaluation focused on accuracy and effectiveness properties whose violations can be counted. It is known that other criteria can also impact effectiveness. With regard to Euler diagrams, properties such as zone areas, curve-edge closeness and curve smoothness all impact effectiveness but cannot be easily measured. Illustrative examples featuring these properties are given in Fig. 1 to indicate potential differences in the effectiveness of the layouts produced. The same description was used to produce the diagrams by the techniques. The properties seen in these diagrams typify the techniques by which they were drawn. We can see that zones in Bubble Sets and WebCola diagrams do not have similar areas, whereas relatively, zones in SetNet do. Also, in SetNet the curves do not run closely for large sections and so with regard to curve-edge closeness, they are superior to Bubble Sets and WebCola. All three techniques use smooth curves to a varying degree: SetNet always uses circles, WebCola uses rectangles with rounded corners and in Bubble Sets, smoothness does not appear to be consistent, as can be seen in Fig. 1. Overall, when it comes to these three closed-curve-based properties, it is unsurprising for the techniques that draw the curves first to be superior to the techniques that draw the graph first.

As for graphs, properties like angles, orthogonal layout and symmetry cannot be counted, yet they can also impact effectiveness of diagrams. The graphs in Bubble Sets seem to have a sufficiently large angle between edges leaving vertices. In SetNet, smaller angles between edges can be explained by the constraints imposed by the curves: vertices must be located in their assigned zones. Interestingly, WebCola does not appear to consider the angles property despite drawing the graph first. One can argue that Bubble Sets graphs follow a grid-based placement compared to the other two techniques. As for symmetry, Bubble Sets and WebCola graphs appear to be more symmetrical than those drawn by SetNet. This is likely because the graph layout is produced first by the former techniques. With these three graph properties we can see that the techniques that draw the graph first tend to come out on top.

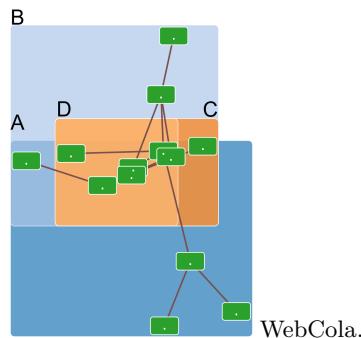
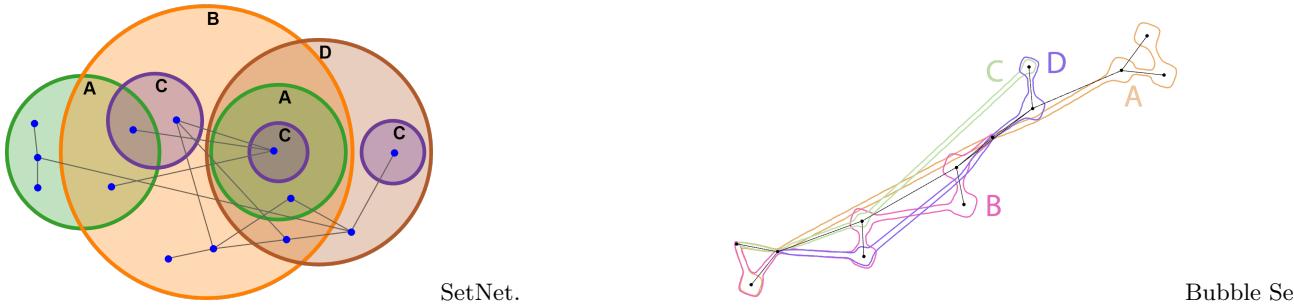


Fig. 1. Properties possessed by grouped network diagrams drawn by different techniques.

5 Counting Property Violations

We now explain how the property violations were counted. We note that for the concurrent curves and triple points properties our counting approach differs from existing literature⁵. There the authors use the Euler diagram to construct a graph whose features are used to count these two properties. As this is done manually and given we have 124 diagrams for the evaluation, it is not practical to count occurrences of these two properties in this way. For this reason we adopted a practical approach for counting concurrent curves and triple points, as detailed below.

- *Edge-vertex intersections*: for each edge, each intersection with a non-incident vertex was counted.
- *Vertex-vertex intersections*: each pair of vertices that intersected was counted. For example, if there are three vertices (v_1, v_2, v_3) placed on top of each other, it is counted as: v_1 intersects v_2 , v_1 intersects v_3 and v_2 intersects v_3 . So the count is 3.
- *Vertices in incorrect zones*: each vertex that was either on a curve or not in its assigned zone was counted.
- *Omitted zones*: each omitted zone was counted.
- *Non-unique labels*: for each curve label, we counted the number of ‘extra’ times it was used on the basis that one curve per set is required. For example, in Fig. 2, the label *C* is used 2 times, so the count is 1. Each label that occurred more than once was made bold in the diagrams.
- *Disconnected zones*: for each disconnected zone we counted the number of extra minimal regions it comprised (i.e. one fewer than the number of minimal regions of which the zone comprised) on the basis that one minimal region per zone is required. For example, in Fig. 3, the zone *A* consists of two minimal regions (labelled *a*), thus adding 1 to the count, and the zone *B* consists of two minimal regions (labelled *b*), thus adding another 1 to the count. So the count is 2. If a zone has more than one region then each region is labelled.
- *Concurrent curves*: we counted the number of (maximal) paths that formed part of two or more curves, including self-concurrency. In Fig. 4, there is a segment of the curve *R* that runs concurrently with the curve *P*, contributing 1 to the count and there is a segment of the curve *R* that runs concurrently with the curve *Q*, also contributing 1 to the count. So the count is 2. In Fig. 5, there is a concurrent path between *P* and *Q* but not *R*, which contributes 1 to the count. There is also a concurrent path shared by all *P*, *Q* and *R*, which also contributes 1 to the count. So the count is 2.
- *Triple points*: each point passed through at least three times by the curves was counted, where at least one of the curves did not run concurrently in a small disc around the point. For example, in Fig. 6, there are two points that are passed through by the curves *A*, *B* and *D* where the curve *D* does not run concurrently in a small disc around the point. These two points are enclosed with red ellipses.

⁵ Stapleton, G., Howse, J., & Rodgers, P. (2010). A graph theoretic approach to general Euler diagram drawing. *Theoretical Computer Science*, 411(1), 91-112.

- *Non-simple curves*: for each curve, each self-intersection was counted. For example, in Fig 7, the curve R self-intersects twice, so the count is 2.
- *Non-circular curves*: each non-circular curve was counted.
- *Extra zones*: each extra zone was counted.
- *Edge crossings*: each pair of edges that crossed was counted.
- *Extra edge-curve crossings*: we counted each ‘extra point’ on a curve passed through by an edge. Given an edge, e , with incident vertices v_1 and v_2 , an *extra point* is one that lies on a curve, c , such that either both vertices are inside c or both vertices are outside c .

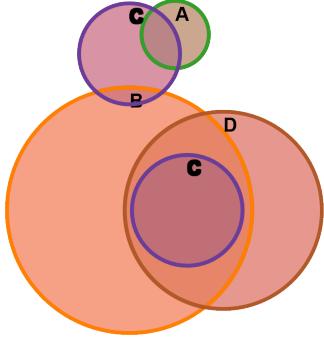


Fig. 2. SetNet: a non-unique label.

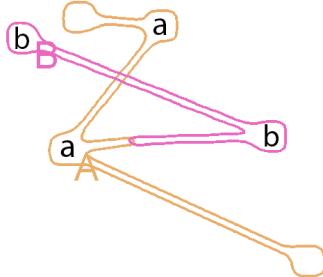


Fig. 3. Bubble Sets: disconnected zones.

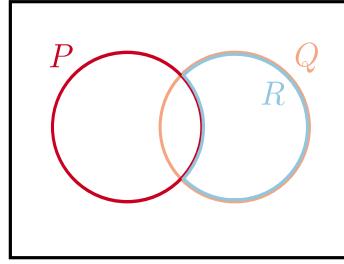


Fig. 4. Concurrency.

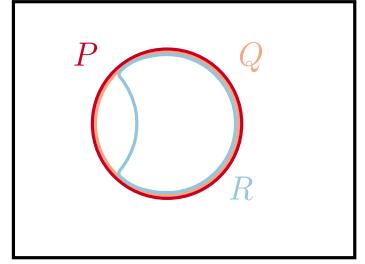


Fig. 5. Concurrency.

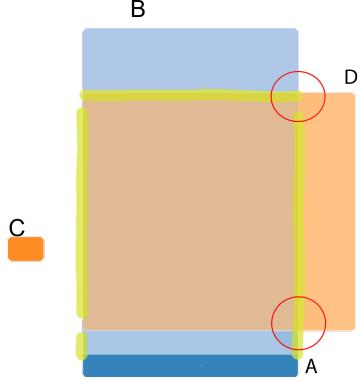


Fig. 6. WebCola: triple points.

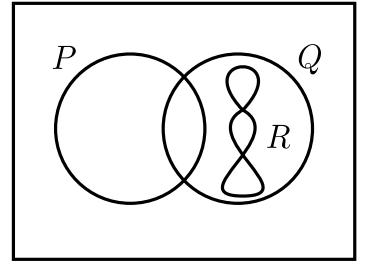


Fig. 7. A non-simple curve R.

In the next section we provide, for each data set, two diagrams for SetNet, Bubble Sets and WebCola: one with the graph omitted and the other with the graph included. The markings for the Euler diagram properties are shown on the diagram without the graph for clarity. The graph property violations were automatically counted by each technique’s software.

6 Produced Diagrams and Results

In what follows, the format is for each data set (as explained in the paper there are 31 data sets):

1. Data set information, including *original* SNAP ID and the *derived* numbers of sets, zones, nodes and edges. To clarify, the original SNAP data set IDs are given, but the numbers of sets, zones, nodes and edges are shown for the derived (reduced) data set.
2. The marked diagram drawn by SetNet, with the graph omitted.
3. The unmarked diagram drawn by SetNet, with the graph.
4. The marked diagram drawn by Bubble Sets, with the graph omitted.
5. The unmarked diagram drawn by Bubble Sets, with the graph.
6. The marked diagram drawn by WebCola, with the graph omitted.
7. The unmarked diagram drawn by WebCola, with the graph.

There was no occurrence of non-simple curves in any of the produced diagrams. Therefore, to avoid clutter, the entry for non-simple curves is omitted from the following tables.

2-set data set 1 SNAP ID: 64619842

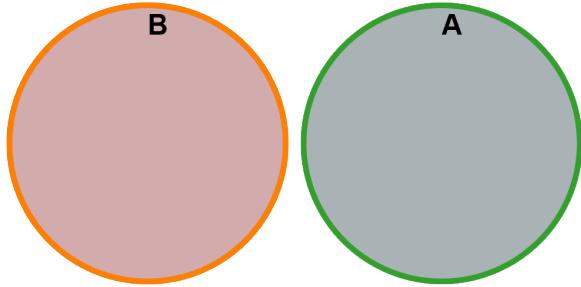
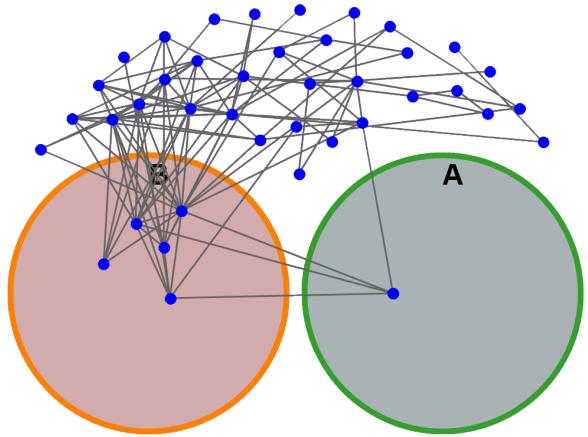
Number of Sets: 2

Number of Nodes: 40

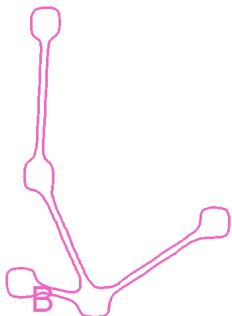
Number of Zones: 3

Number of Edges: 110

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	28	4	126
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	0	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	519	236	591
Edge-curve crossings	0	52	56
Runtime (in sec)	1.769	0.685	6.615

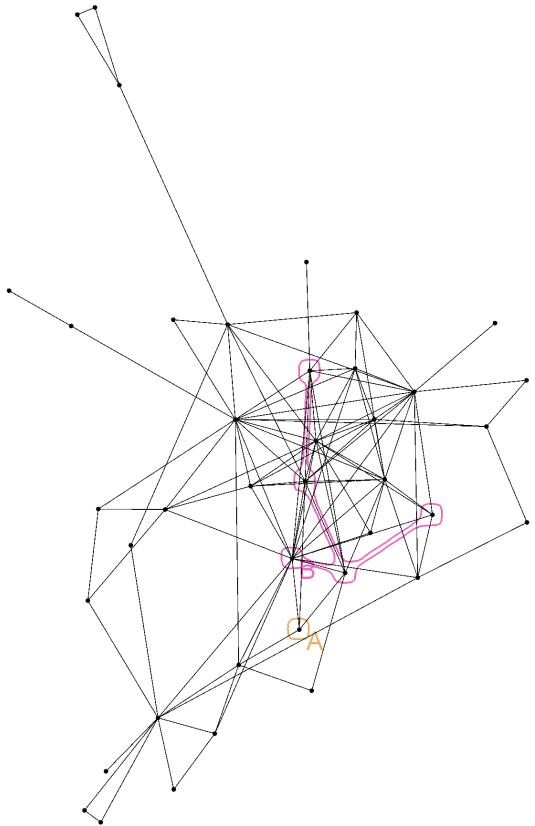
SetNet (without graph)**SetNet (with graph)**

BubbleSets (without graph)

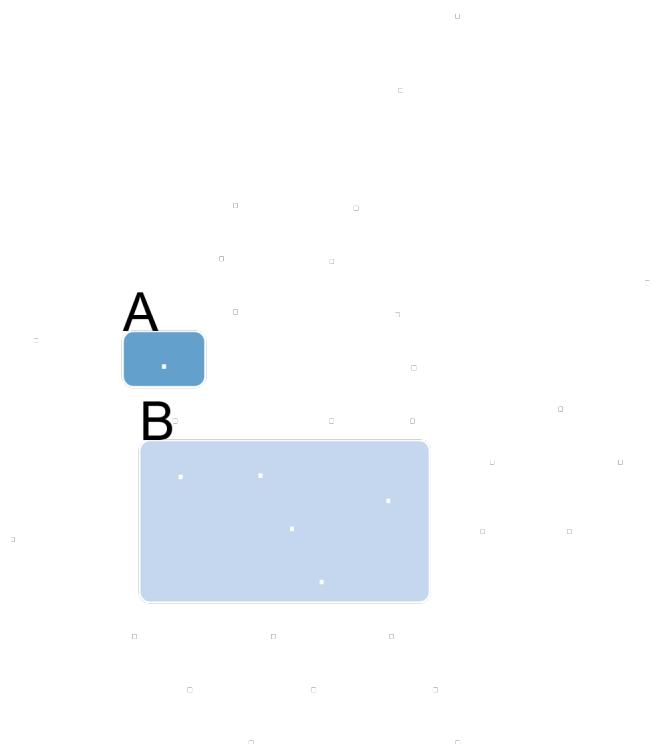


□_A

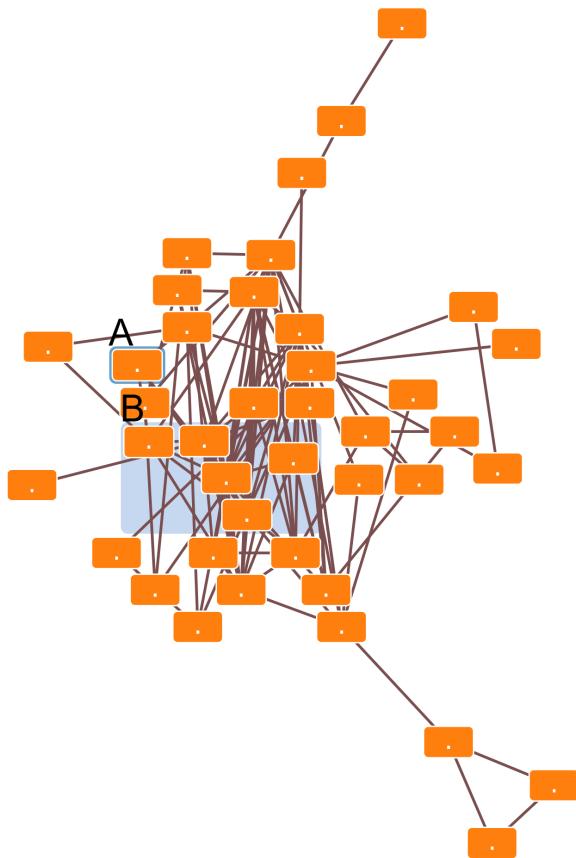
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



2-set data set 2 SNAP ID: 143661263

Number of Sets: 2

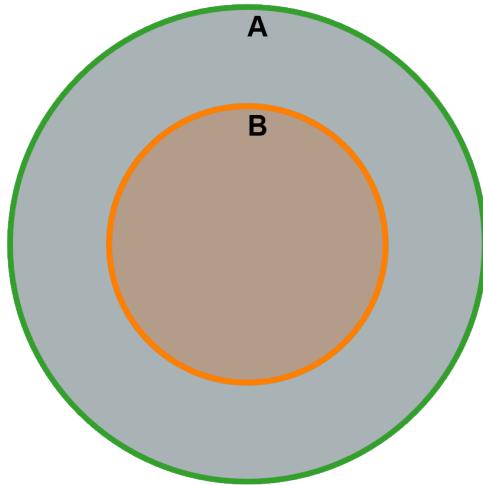
Number of Nodes: 34

Number of Zones: 3

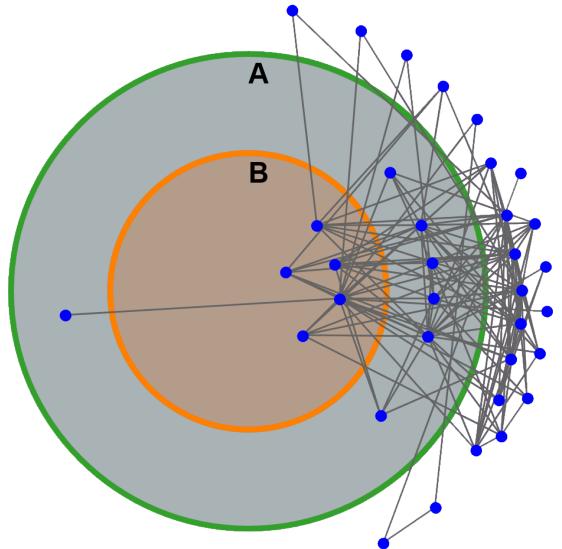
Number of Edges: 133

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	39	11	184
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	2
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	4	0
Curve concurrency	0	0	1
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	6	0
Edge crossings	1430	680	1309
Edge-curve crossings	4	268	35
Runtime (in sec)	1.875	0.754	6.586

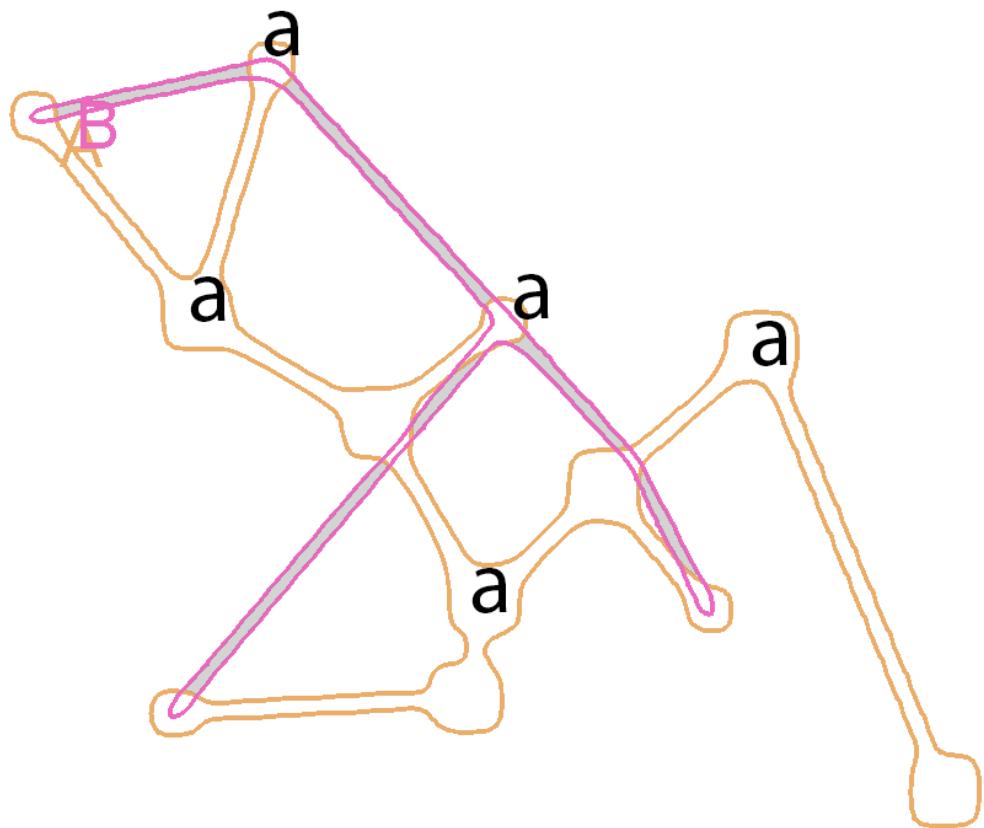
SetNet (without graph)



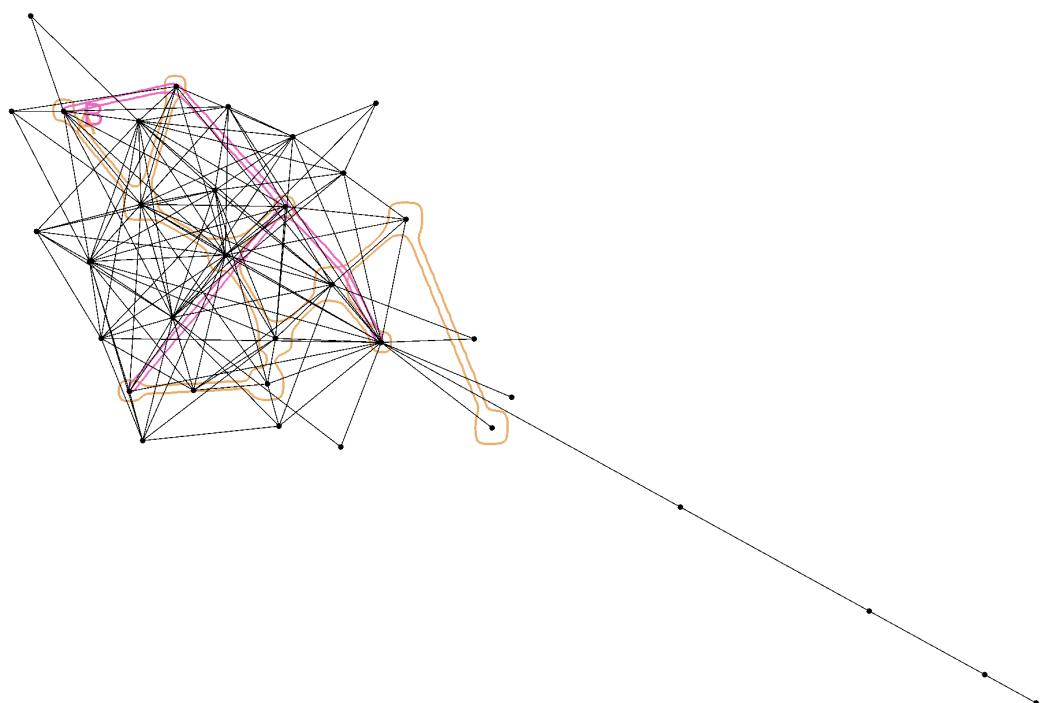
SetNet (with graph)



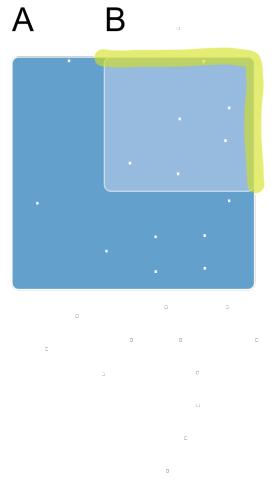
BubbleSets (without graph)



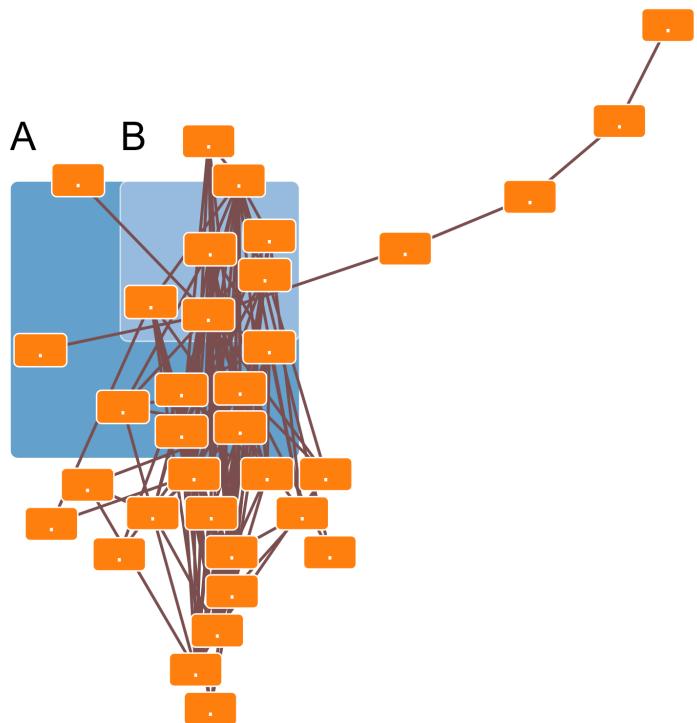
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



2-set data set 3 SNAP ID: 15938936

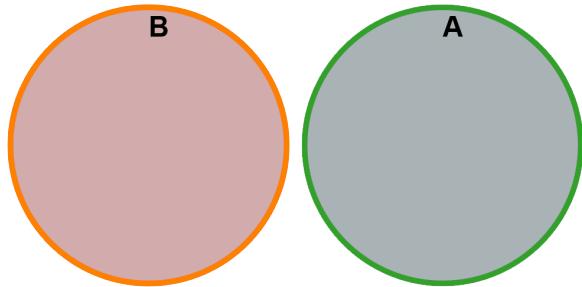
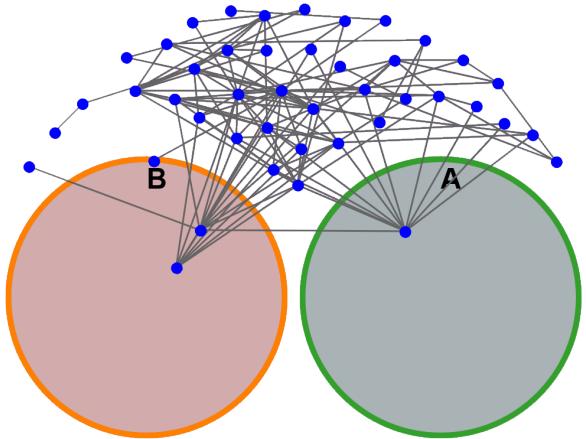
Number of Sets: 2

Number of Nodes: 44

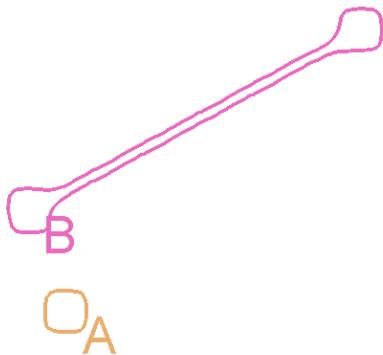
Number of Zones: 3

Number of Edges: 120

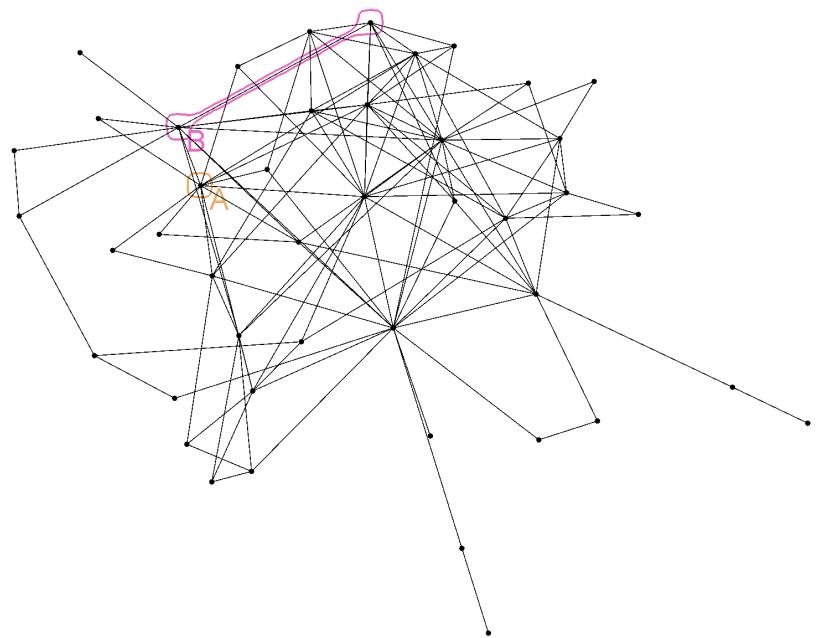
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	48	5	111
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	1	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	0	0
Curve concurrency	0	0	1
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	638	320	687
Edge-curve crossings	1	16	36
Runtime (in sec)	2.069	0.503	6.609

SetNet (without graph)**SetNet (with graph)**

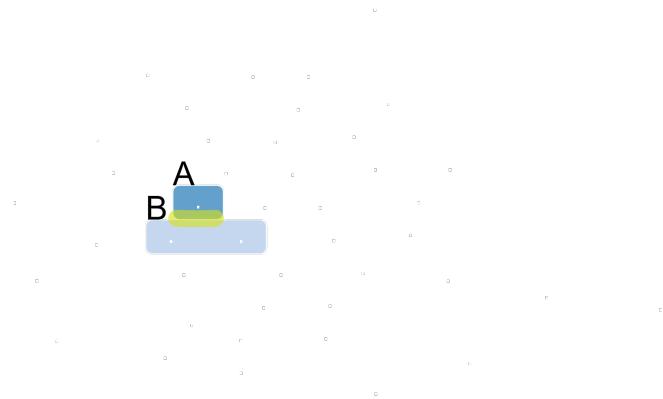
BubbleSets (without graph)



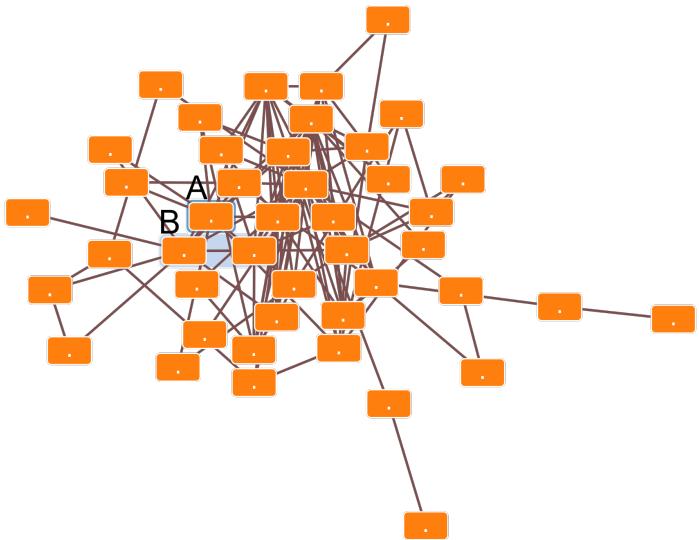
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



2-set data set 4 SNAP ID: 15507297

Number of Sets: 2

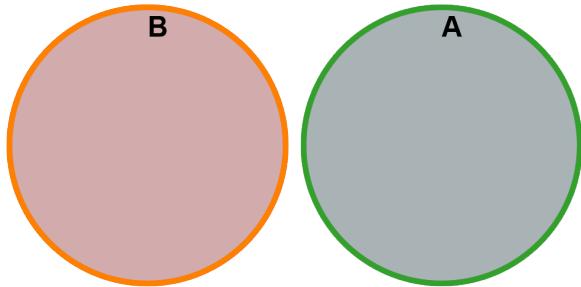
Number of Nodes: 45

Number of Zones: 3

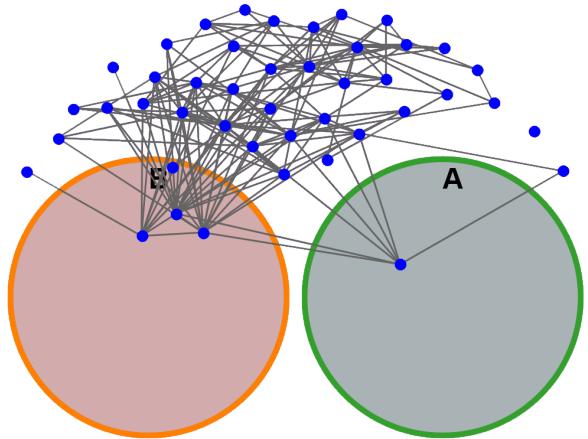
Number of Edges: 163

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	58	11	230
Vertex-vertex intersections	1	0	0
Vertices not in the correct zone	1	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	0	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	1247	638	1049
Edge-curve crossings	1	62	66
Runtime (in sec)	2.774	0.685	6.068

SetNet (without graph)

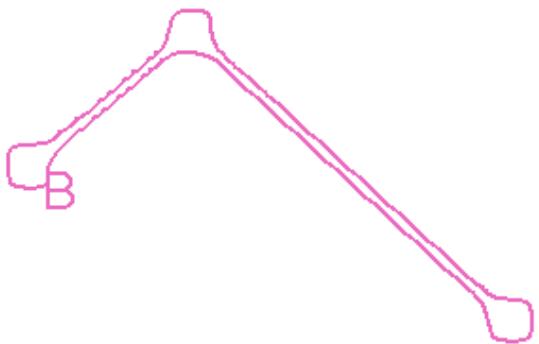


SetNet (with graph)

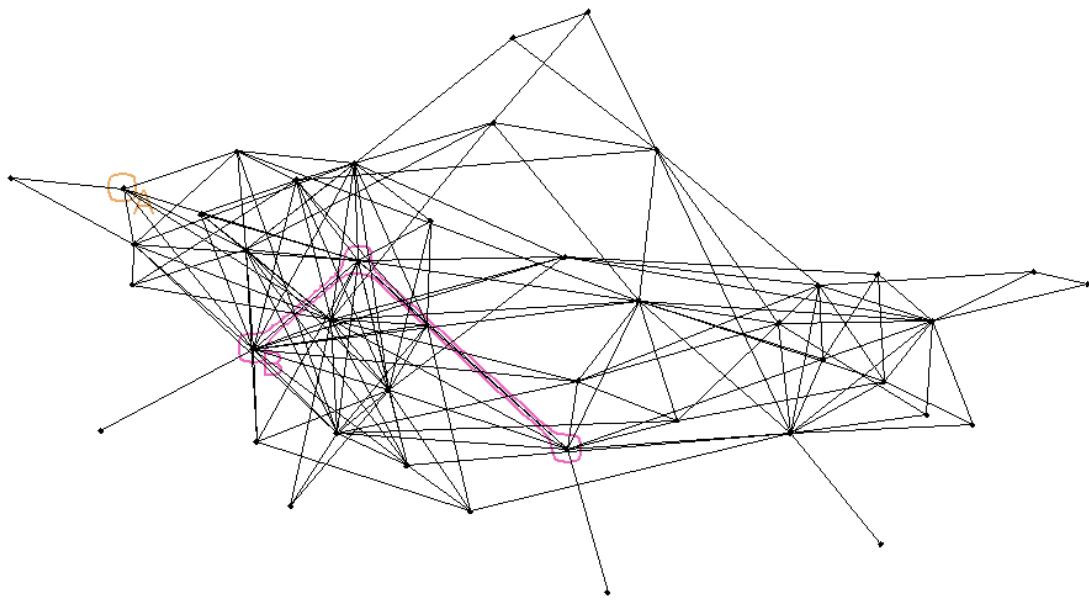


BubbleSets (without graph)

O_A

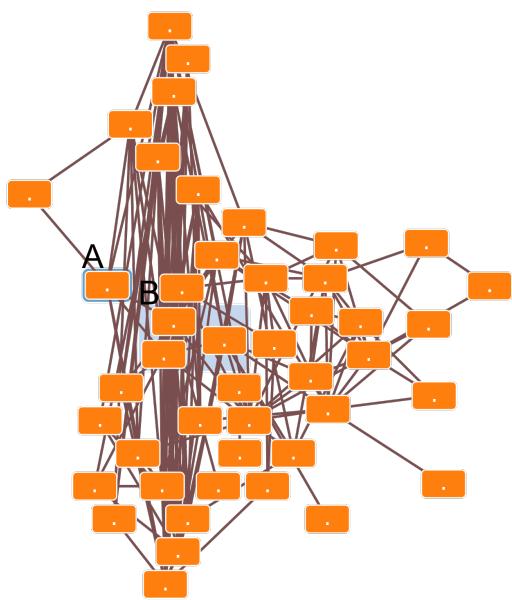


BubbleSets (with graph)



WebCola (without graph)

WebCola (with graph)



2-set data set 5 SNAP ID: 20060293

Number of Sets: 2

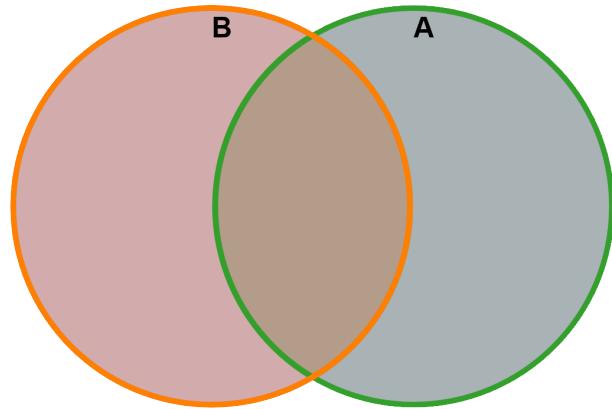
Number of Nodes: 36

Number of Zones: 4

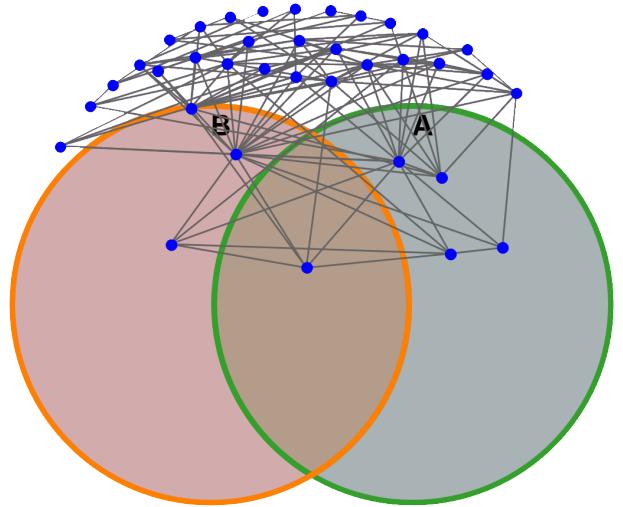
Number of Edges: 111

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	43	6	99
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	1	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	2	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	633	235	621
Edge-curve crossings	20	70	106
Runtime (in sec)	1.745	0.506	6.631

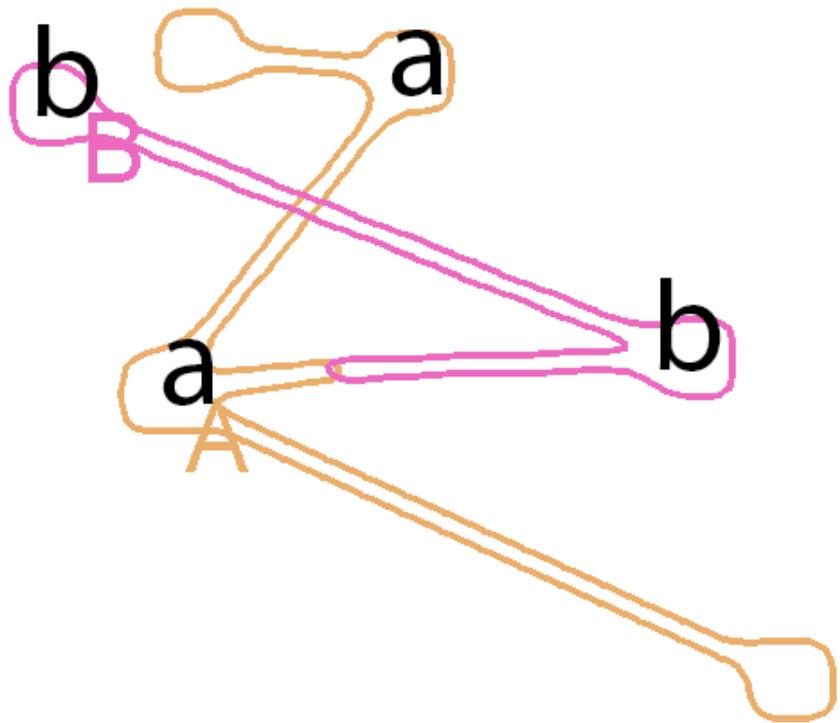
SetNet (without graph)



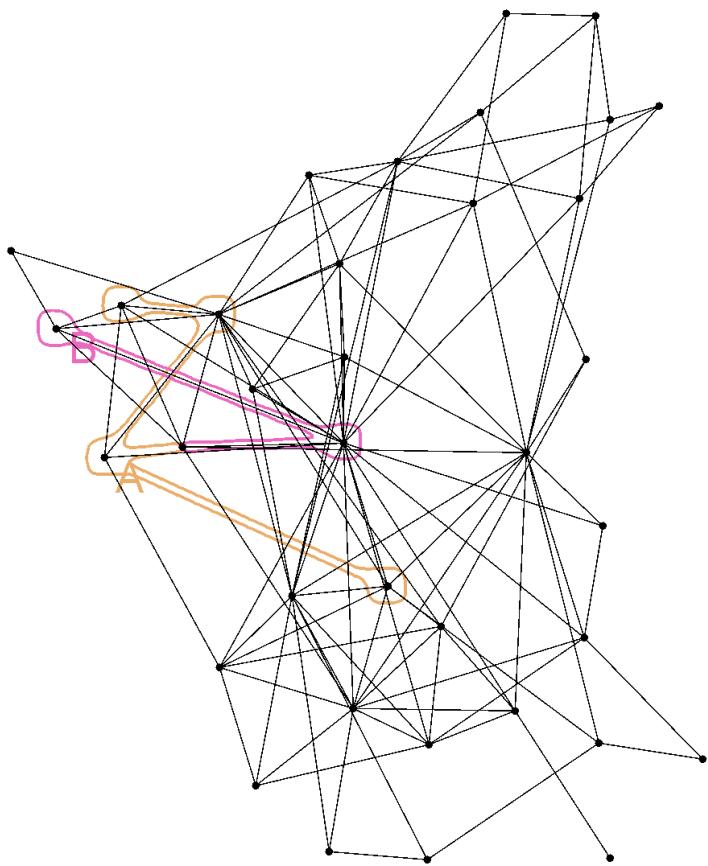
SetNet (with graph)



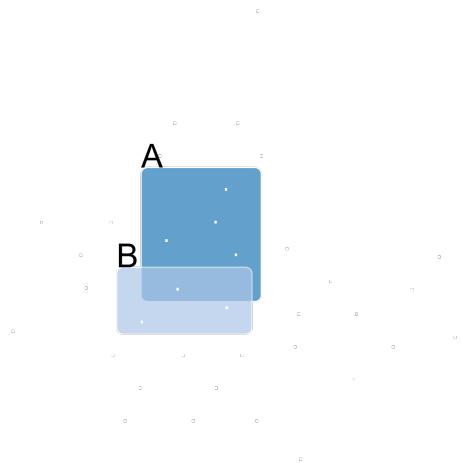
BubbleSets (without graph)



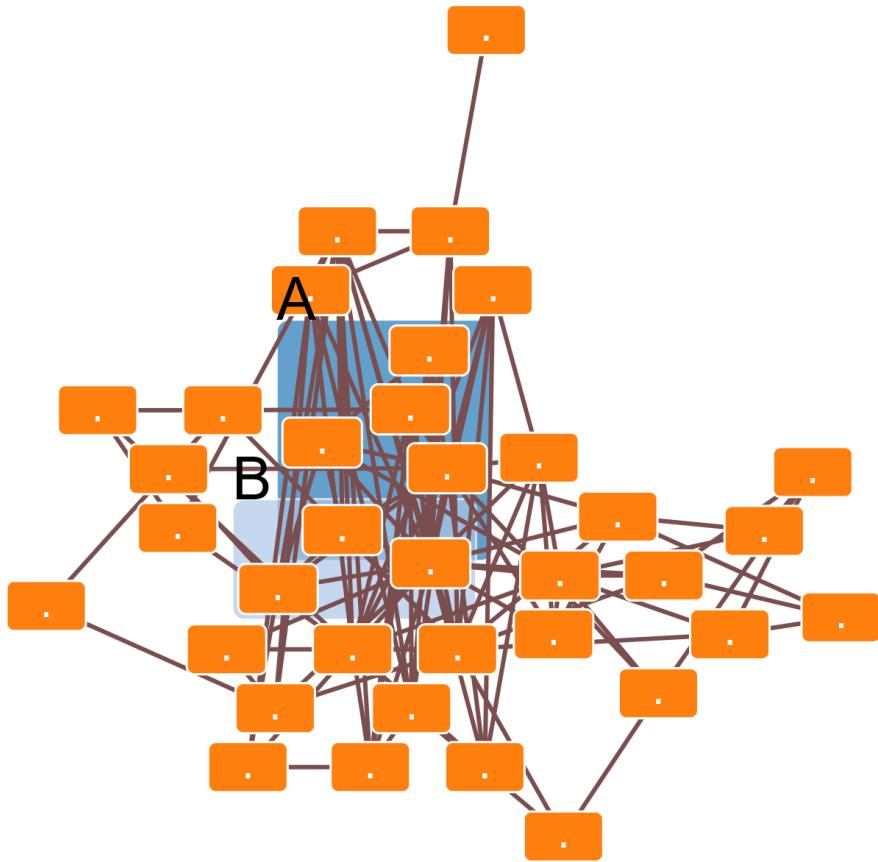
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



2-set data set 6 SNAP ID: 242024994

Number of Sets: 2

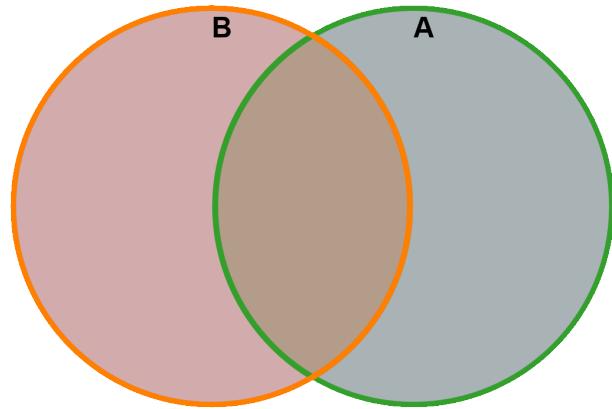
Number of Nodes: 33

Number of Zones: 4

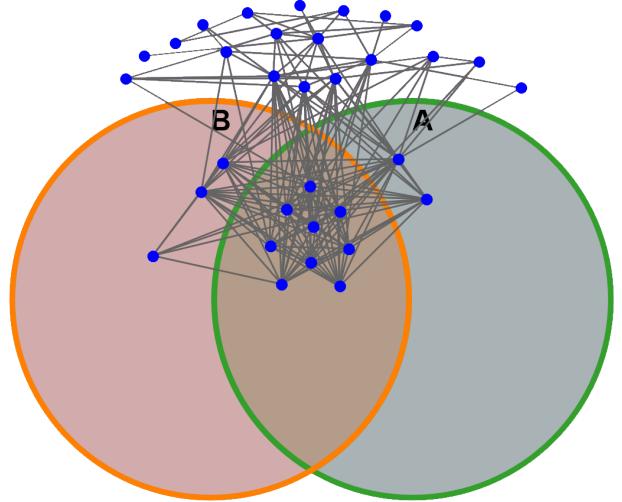
Number of Edges: 170

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	37	16	205
Vertex-vertex intersections	0	0	4
Vertices not in the correct zone	0	0	2
Omitted zones	0	0	1
Duplicated labels	0	0	0
Disconnected zones	0	15	0
Curve concurrency	0	2	1
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	1771	1407	1634
Edge-curve crossings	0	478	33
Runtime (in sec)	2.446	0.525	7.071

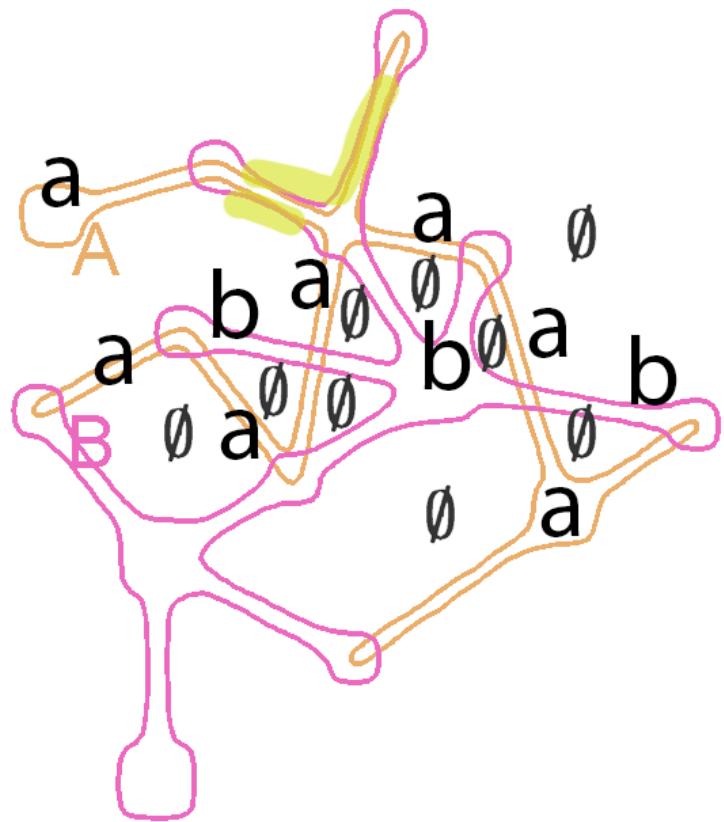
SetNet (without graph)



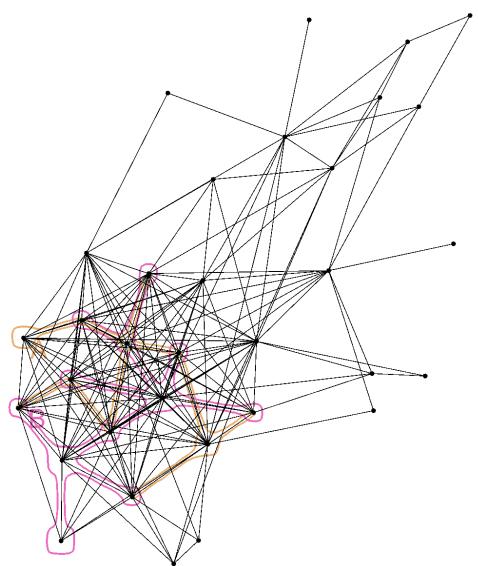
SetNet (with graph)



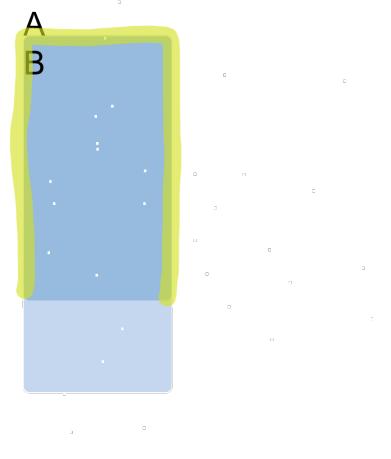
BubbleSets (without graph)



BubbleSets (with graph)

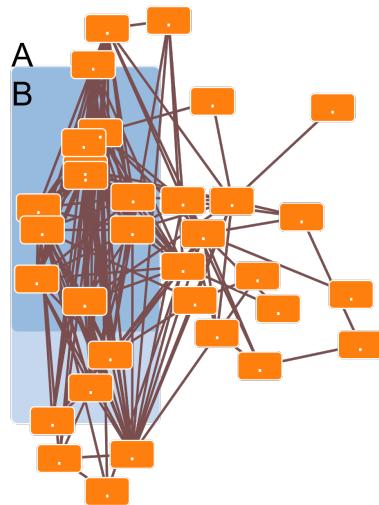


WebCola (without graph)



Omitted zone: A

WebCola (with graph)



2-set data set 7 SNAP ID: 22879382

Number of Sets: 2

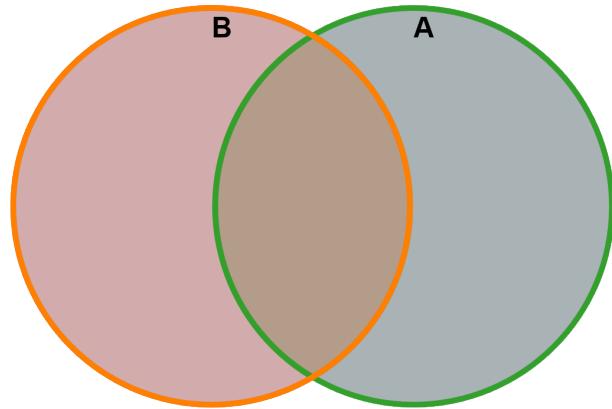
Number of Nodes: 49

Number of Zones: 4

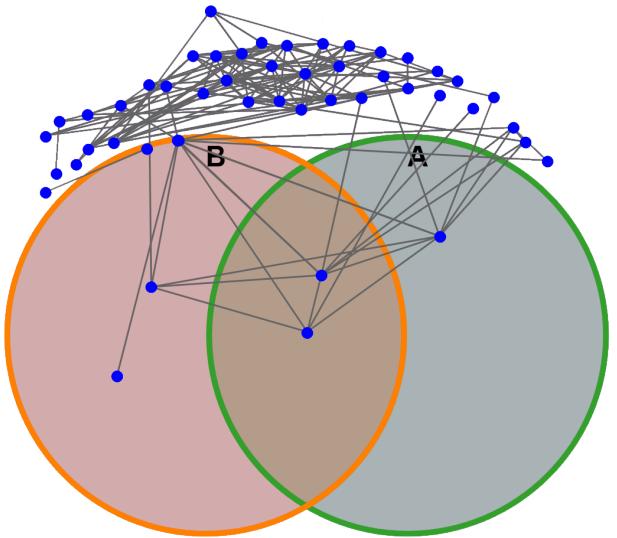
Number of Edges: 138

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	92	9	137
Vertex-vertex intersections	1	0	0
Vertices not in the correct zone	2	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	1	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	911	357	698
Edge-curve crossings	8	25	18
Runtime (in sec)	2.564	0.69	7.098

SetNet (without graph)



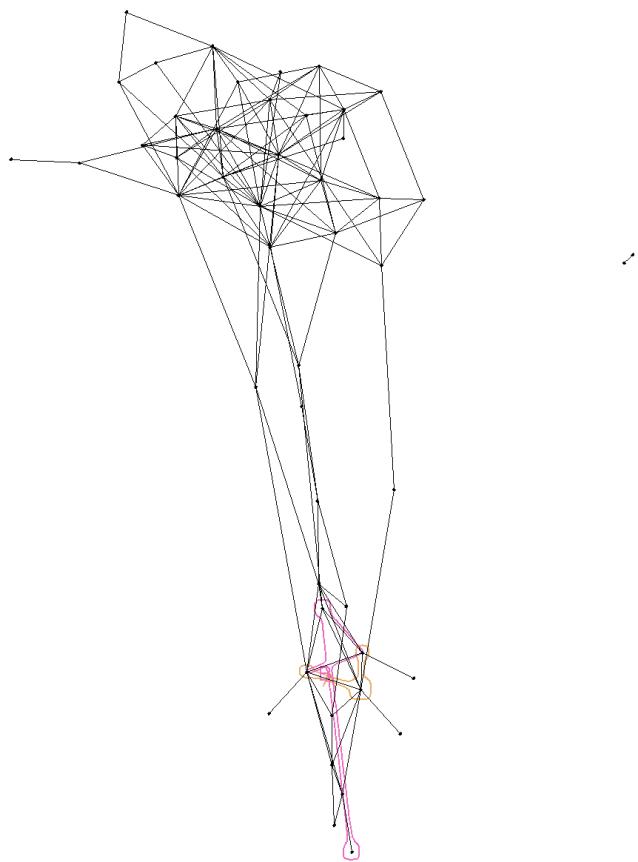
SetNet (with graph)



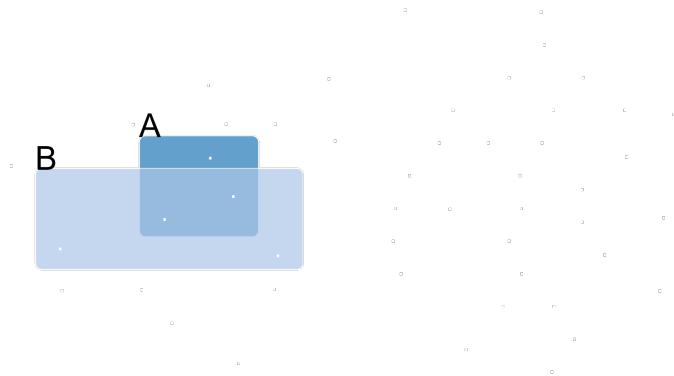
BubbleSets (without graph)



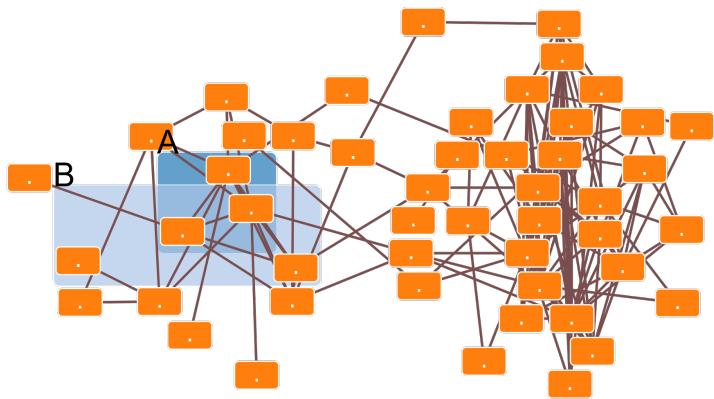
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



2-set data set 8 SNAP ID: 20758393

Number of Sets: 2

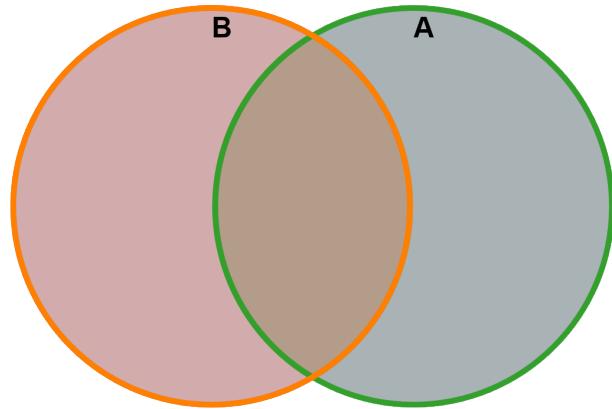
Number of Nodes: 57

Number of Zones: 4

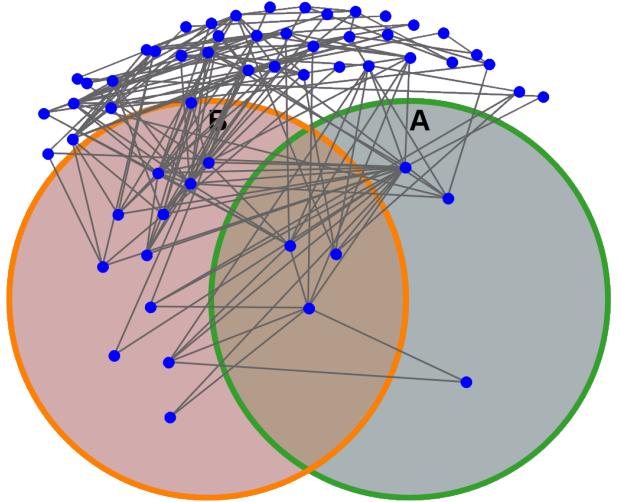
Number of Edges: 165

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	112	4	268
Vertex-vertex intersections	2	0	0
Vertices not in the correct zone	1	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	7	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	2	2
Extra zones	0	0	0
Edge crossings	1807	410	1338
Edge-curve crossings	7	152	128
Runtime (in sec)	3.42	0.561	7.036

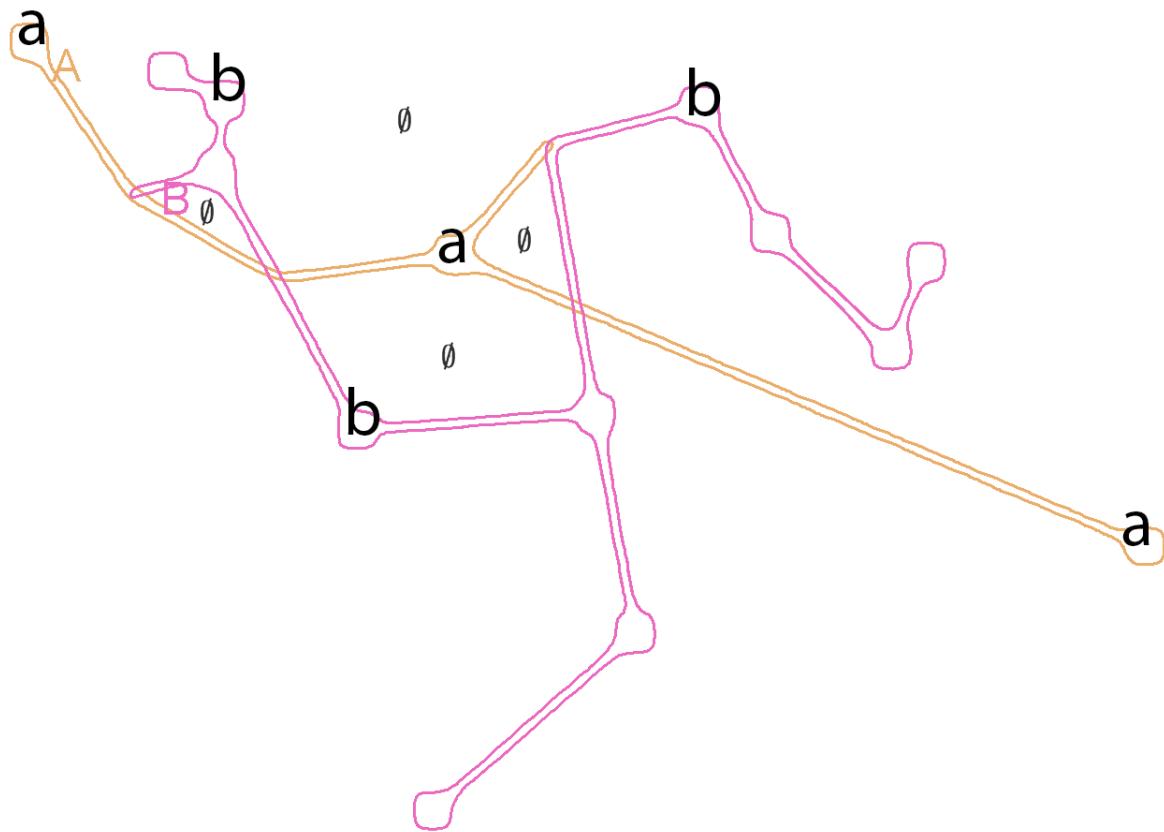
SetNet (without graph)



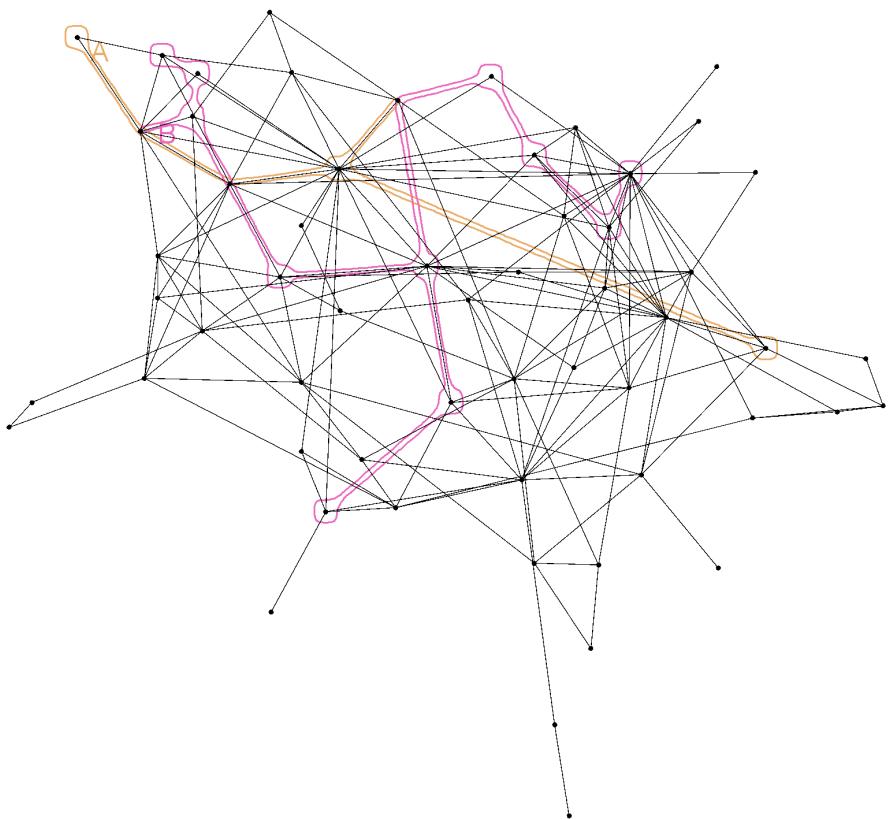
SetNet (with graph)



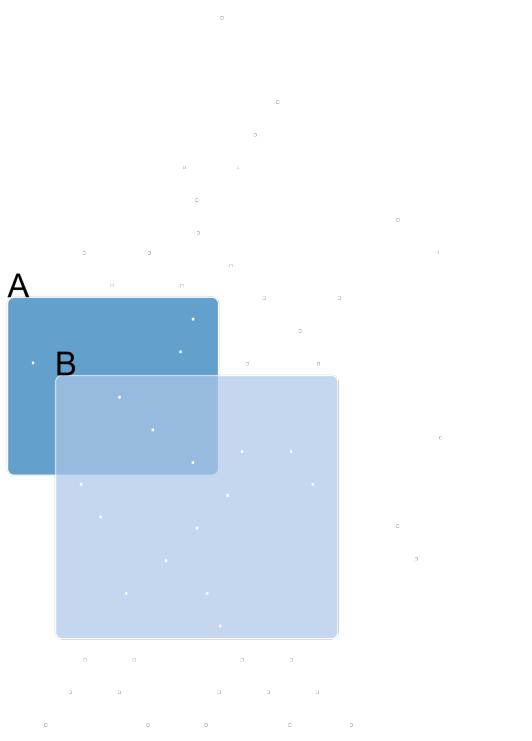
BubbleSets (without graph)



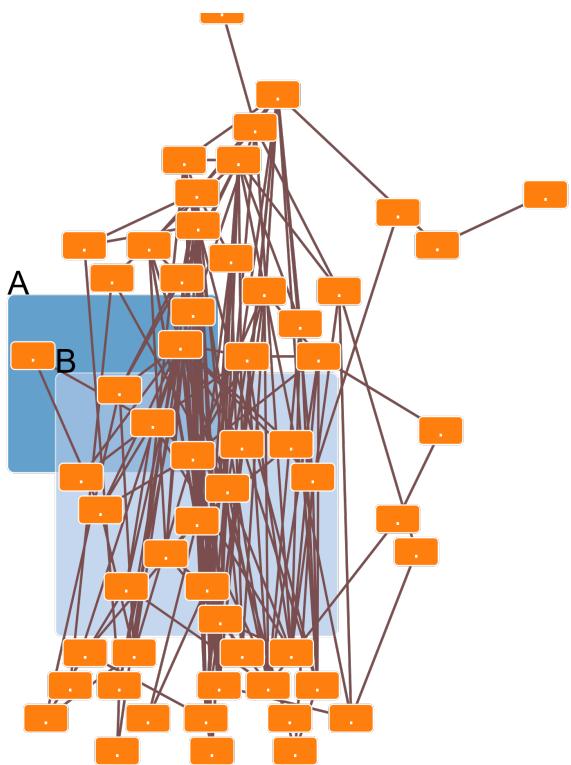
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



4-set data set 1 SNAP ID: 198628427

Number of Sets: 4

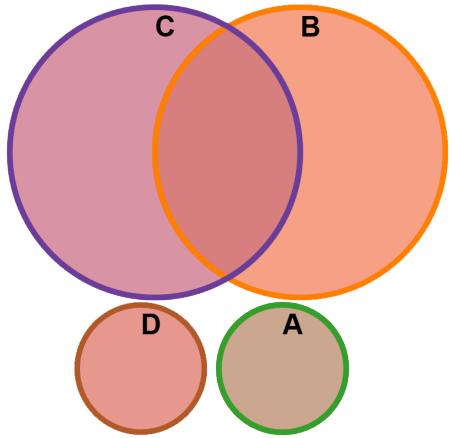
Number of Nodes: 26

Number of Zones: 6

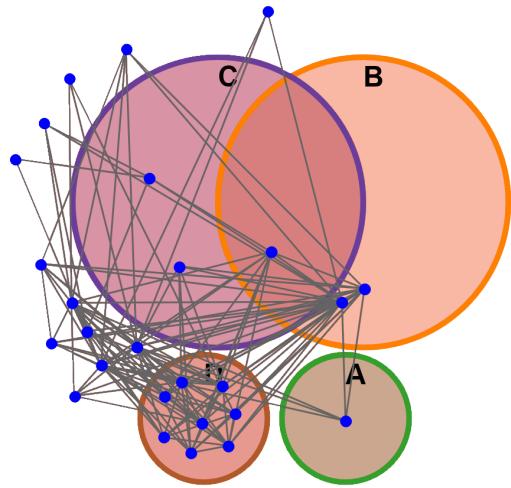
Number of Edges: 133

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	39	6	371
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	11	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	4	4
Extra zones	0	4	0
Edge crossings	1269	861	1088
Edge-curve crossings	29	278	156
Runtime (in sec)	1.947	0.772	3.315

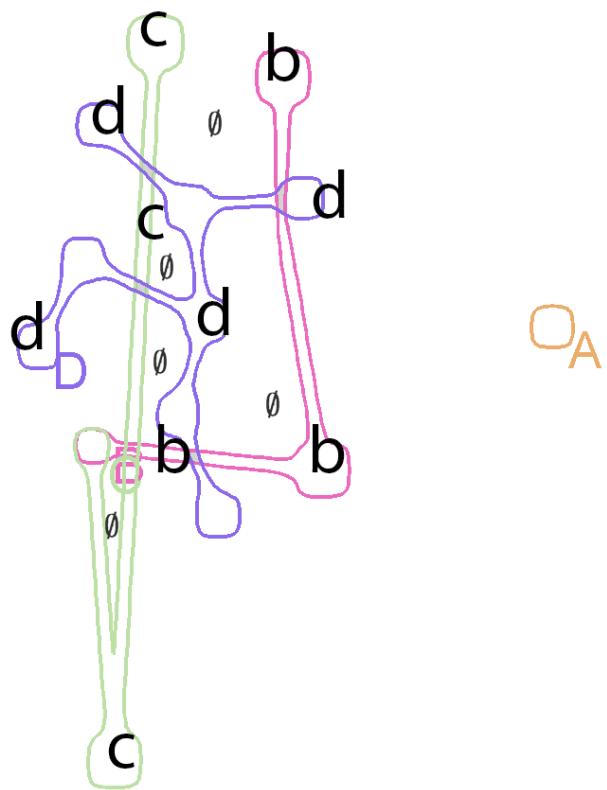
SetNet (without graph)



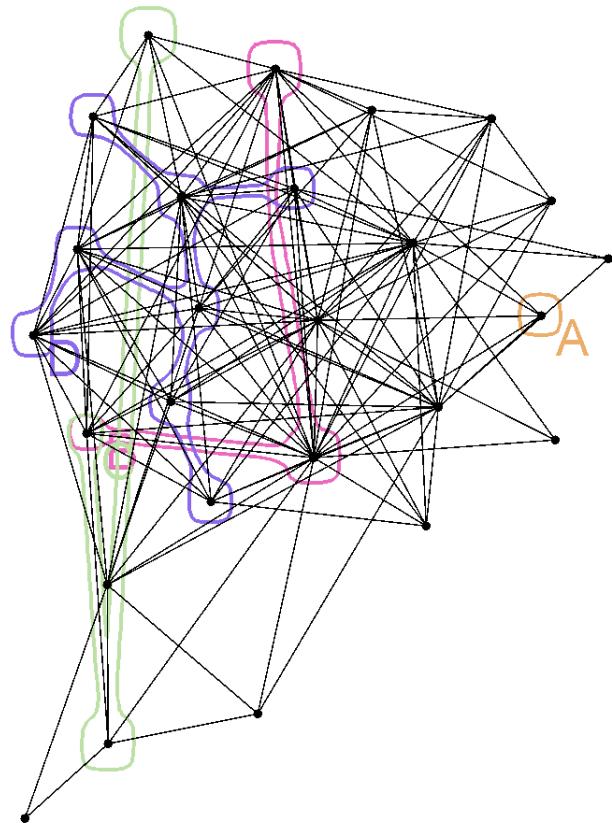
SetNet (with graph)



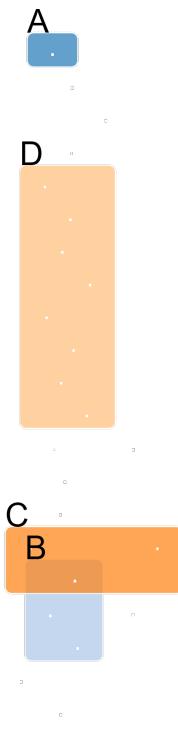
BubbleSets (without graph)



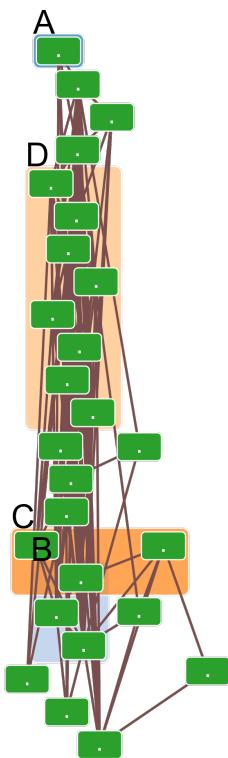
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



4-set data set 2 SNAP ID: 351092905

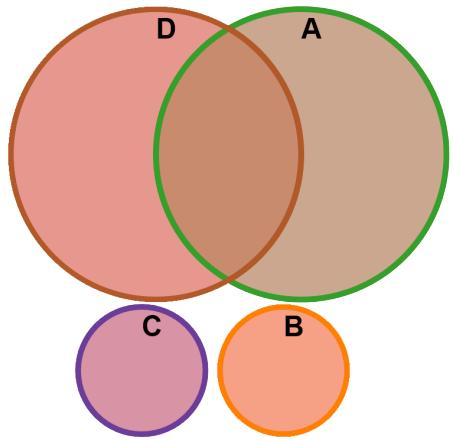
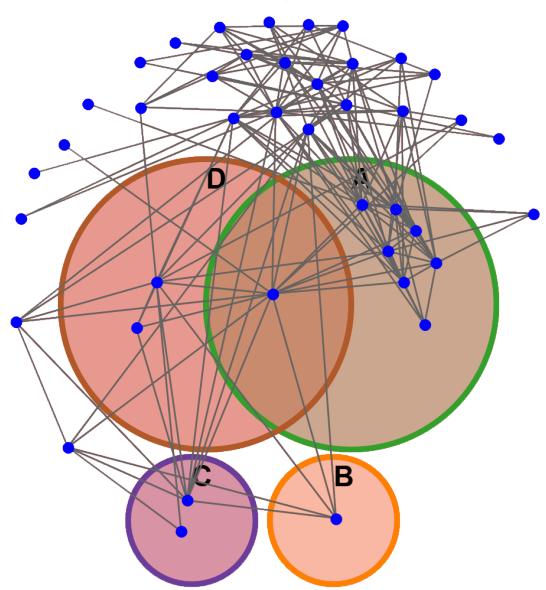
Number of Sets: 4

Number of Nodes: 41

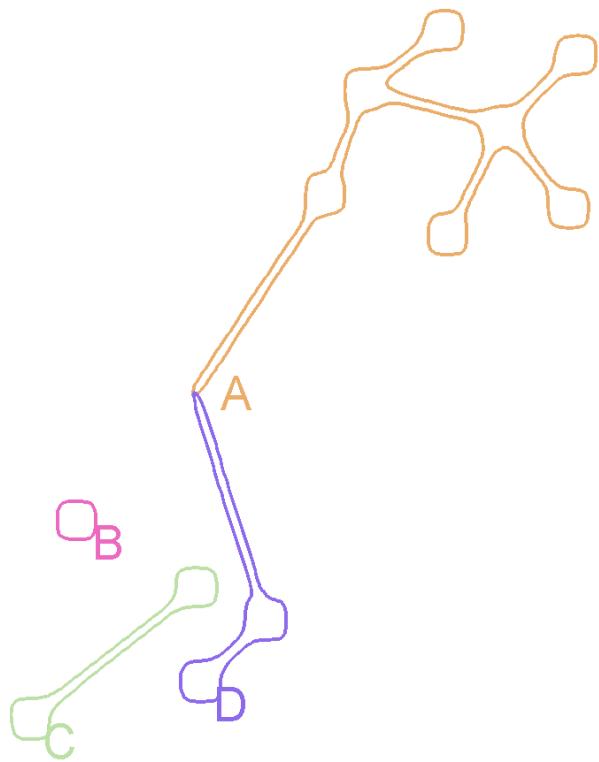
Number of Zones: 6

Number of Edges: 159

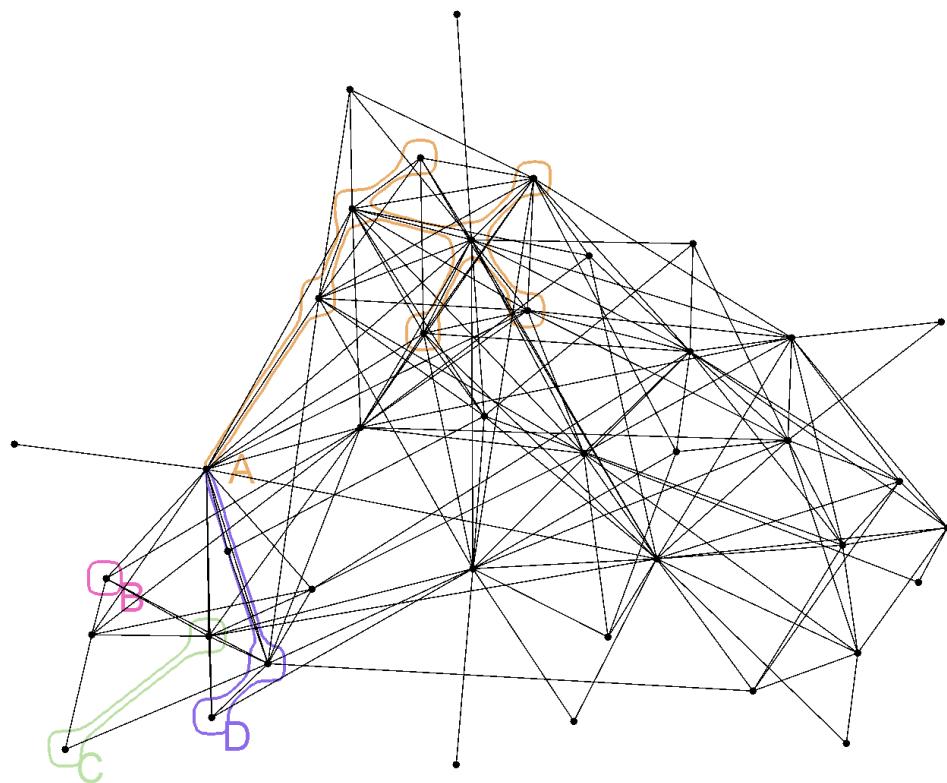
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	38	6	221
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	1	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	0	0
Curve concurrency	0	0	1
Triple points	0	0	0
Non-circles	0	4	4
Extra zones	0	0	0
Edge crossings	1050	639	1175
Edge-curve crossings	15	98	66
Runtime (in sec)	2.782	0.515	6.569

SetNet (without graph)**SetNet (with graph)**

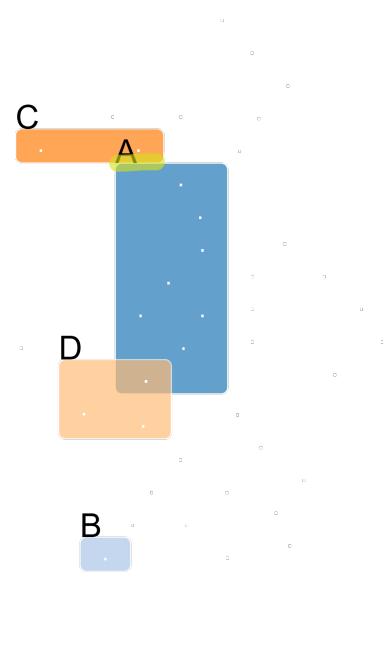
BubbleSets (without graph)



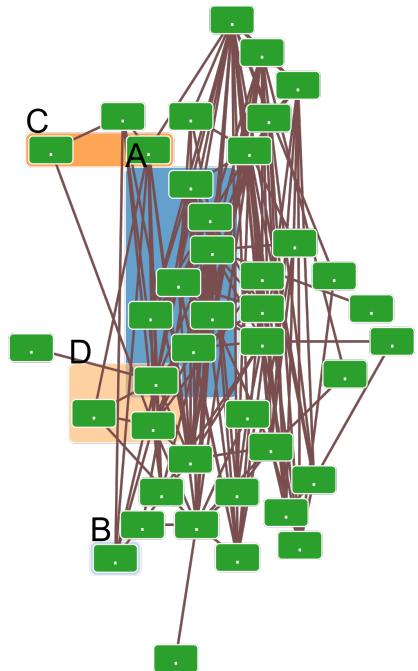
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



4-set data set 3 SNAP ID: 31246395

Number of Sets: 4

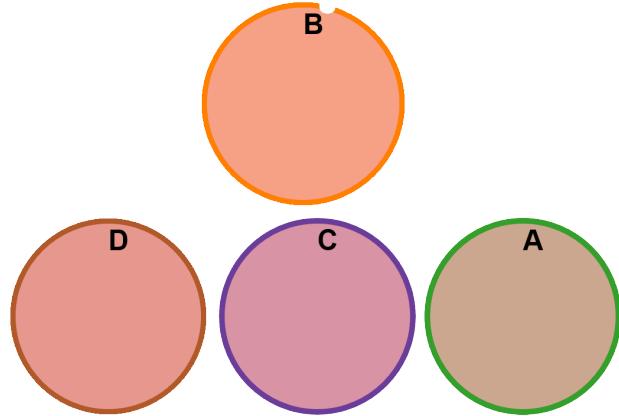
Number of Nodes: 43

Number of Zones: 5

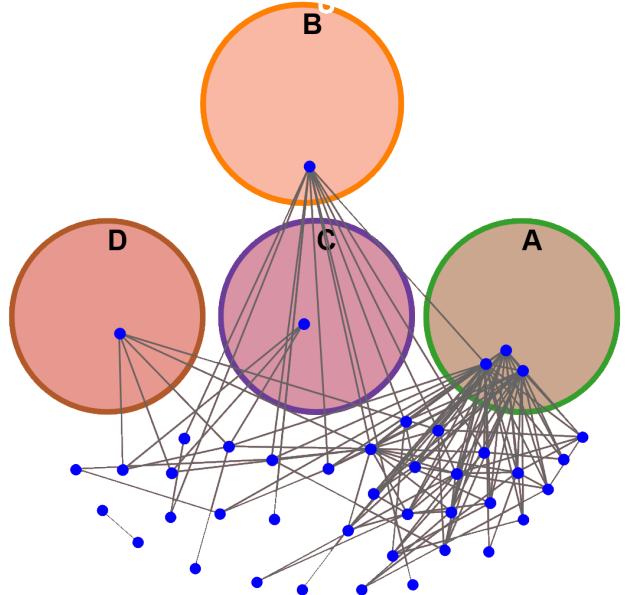
Number of Edges: 132

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	43	7	241
Vertex-vertex intersections	1	0	0
Vertices not in the correct zone	0	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	0	0
Curve concurrency	0	0	0
Triple points	0	0	0
Non-circles	0	4	4
Extra zones	0	0	0
Edge crossings	1018	492	1003
Edge-curve crossings	13	28	42
Runtime (in sec)	2.32	0.503	7.183

SetNet (without graph)



SetNet (with graph)



BubbleSets (without graph)

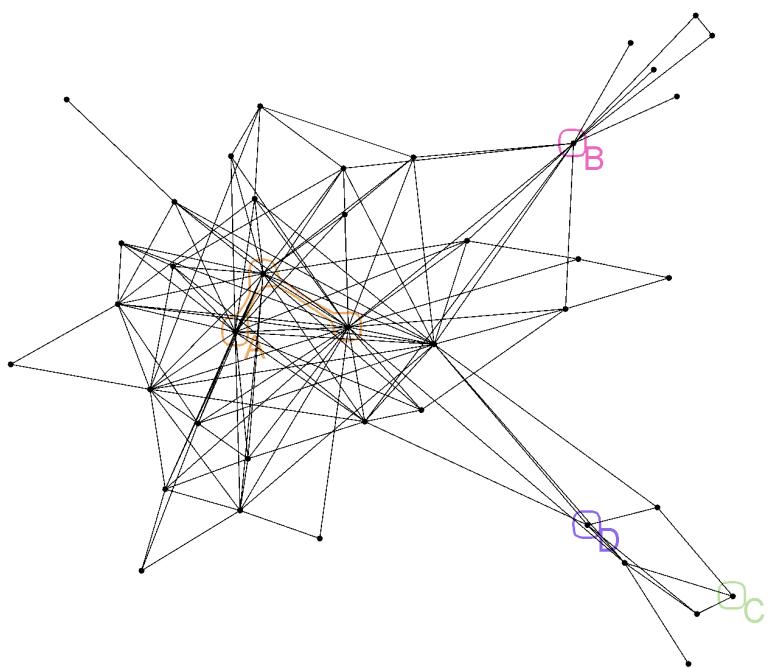
\square_B

\square_A

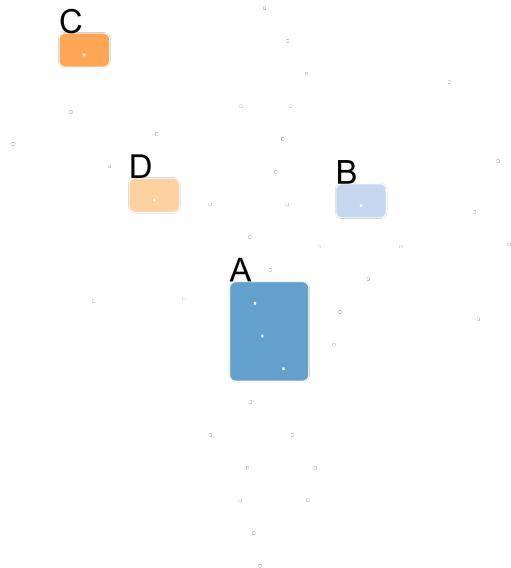
\square_D

\square_C

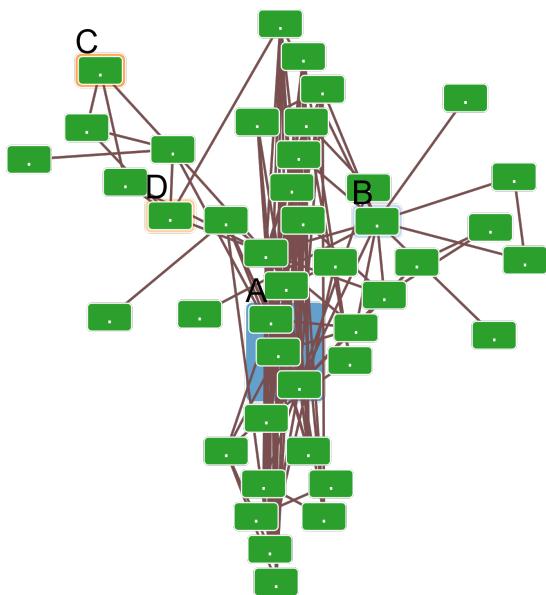
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



4-set data set 4 SNAP ID: 15481789

Number of Sets: 4

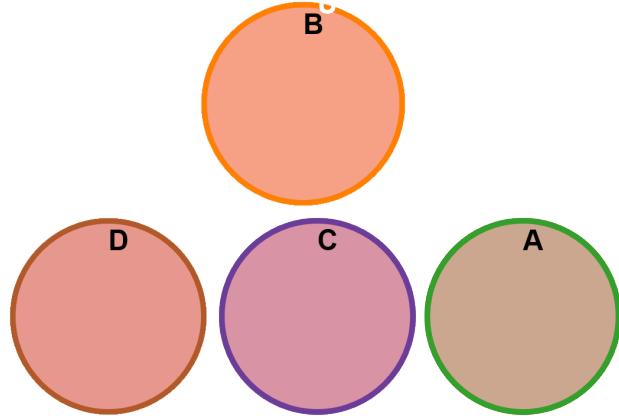
Number of Nodes: 52

Number of Zones: 5

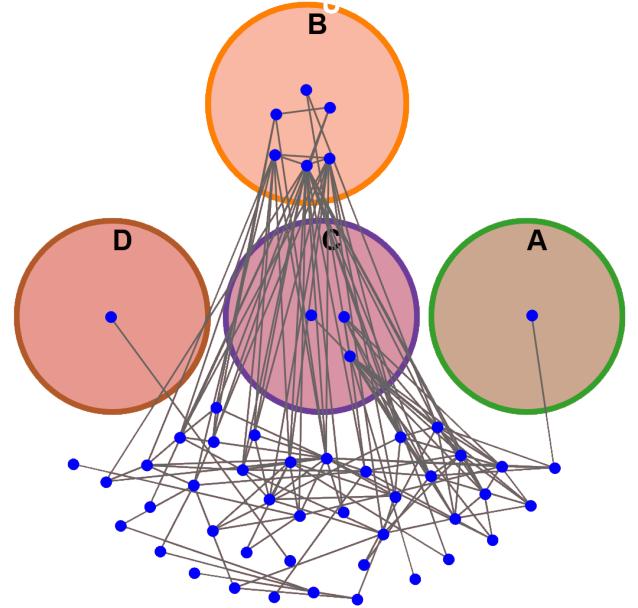
Number of Edges: 145

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	49	4	140
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	2	0
Curve concurrency	0	0	1
Triple points	0	0	0
Non-circles	0	4	4
Extra zones	0	1	0
Edge crossings	821	335	693
Edge-curve crossings	39	96	106
Runtime (in sec)	3.016	0.718	7.506

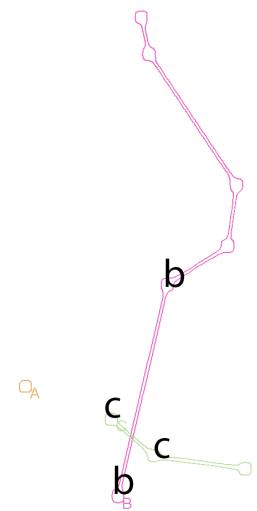
SetNet (without graph)



SetNet (with graph)

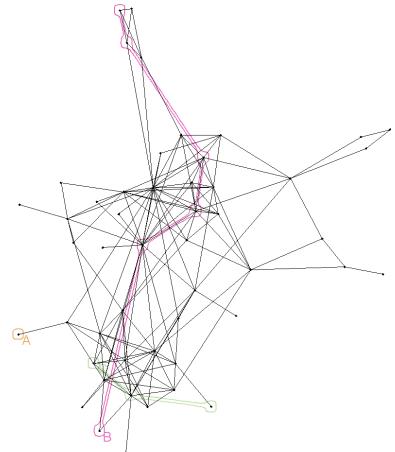


BubbleSets (without graph)



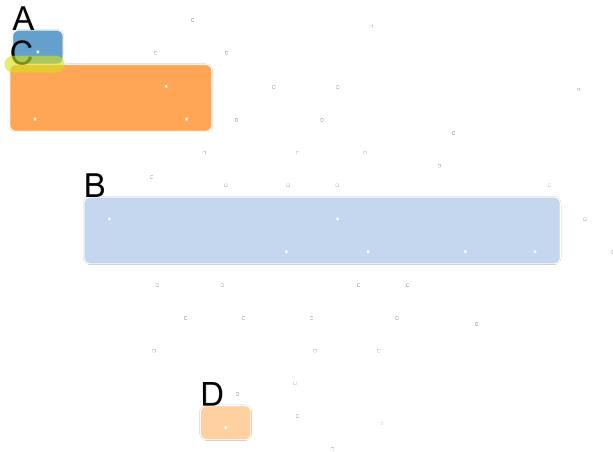
\square_D

BubbleSets (with graph)

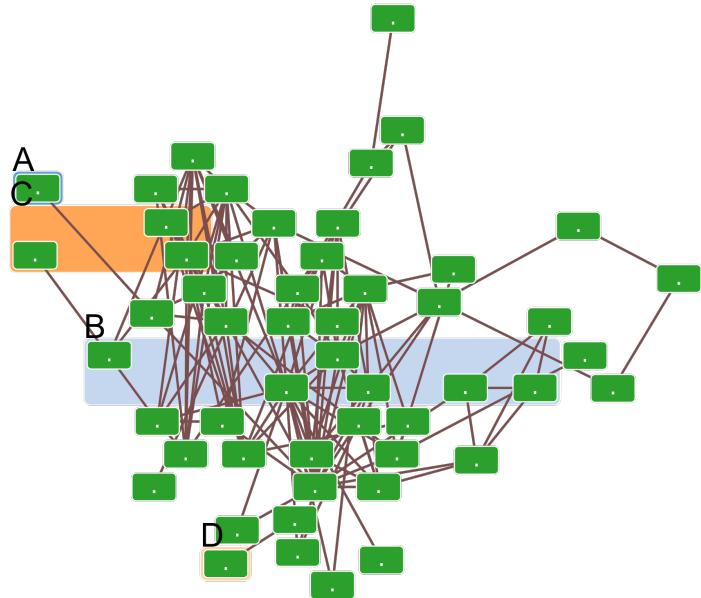


\square_D

WebCola (without graph)



WebCola (with graph)



4-set data set 5 SNAP ID: 428333

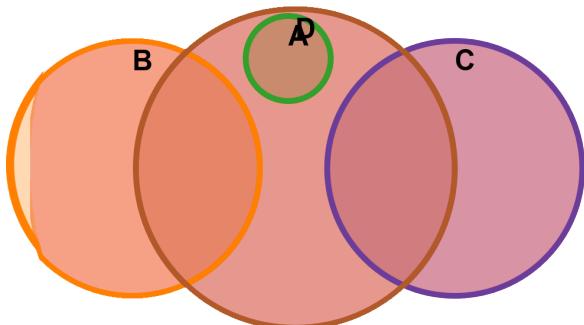
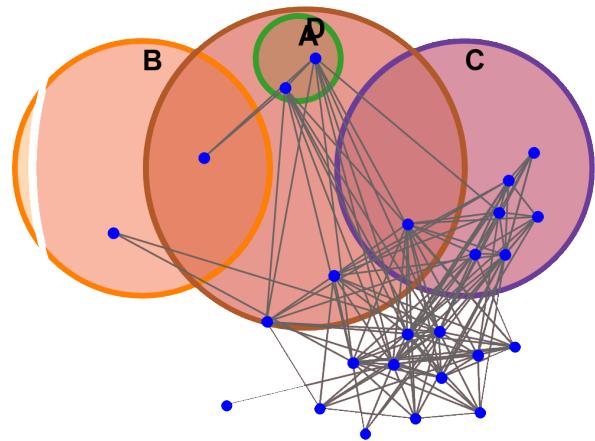
Number of Sets: 4

Number of Nodes: 25

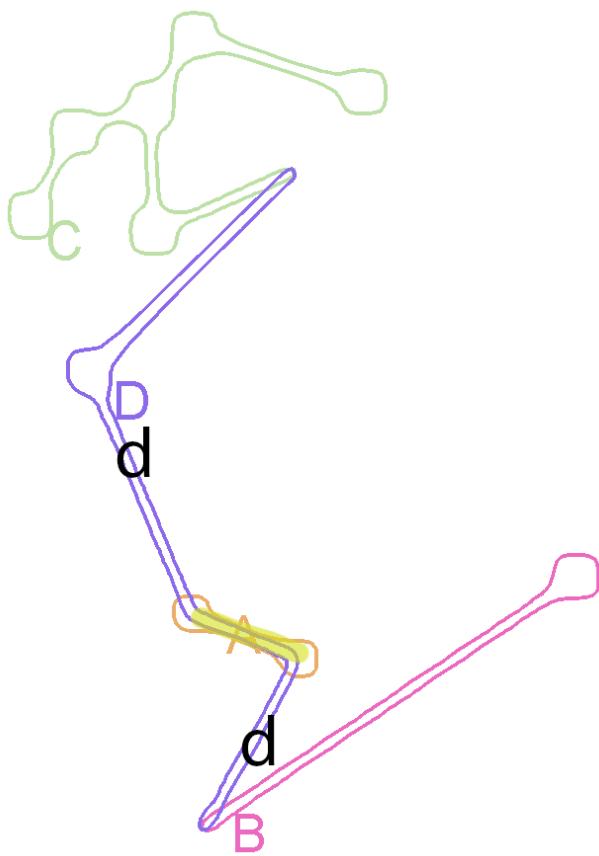
Number of Zones: 7

Number of Edges: 125

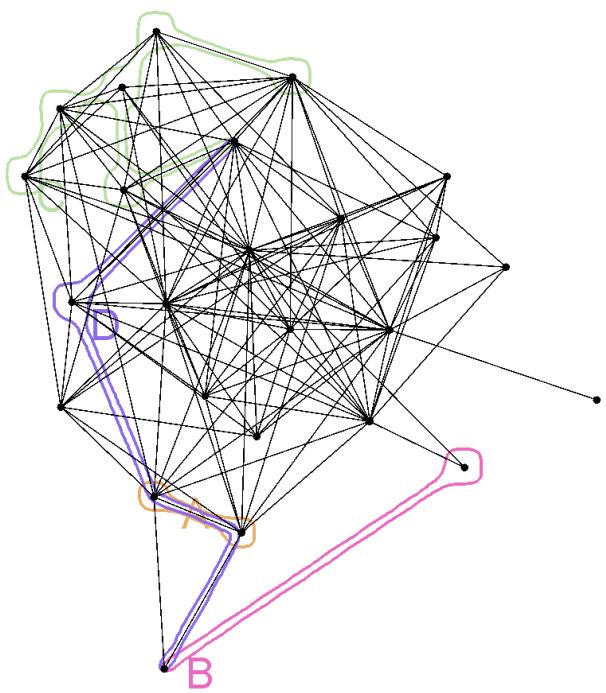
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	29	4	196
Vertex-vertex intersections	0	0	1
Vertices not in the correct zone	1	0	1
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	1	1
Curve concurrency	0	1	4
Triple points	0	0	0
Non-circles	0	4	4
Extra zones	0	0	0
Edge crossings	953	733	1199
Edge-curve crossings	13	99	217
Runtime (in sec)	1.863	0.513	2.881

SetNet (without graph)**SetNet (with graph)**

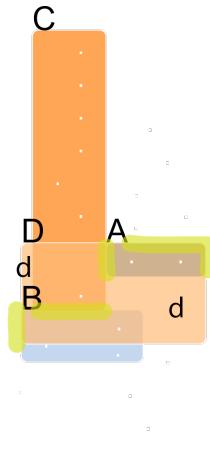
BubbleSets (without graph)



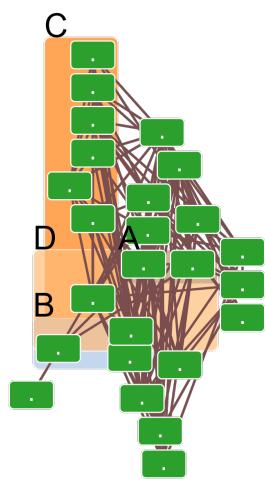
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



4-set data set 6 SNAP ID: 259884200

Number of Sets: 4

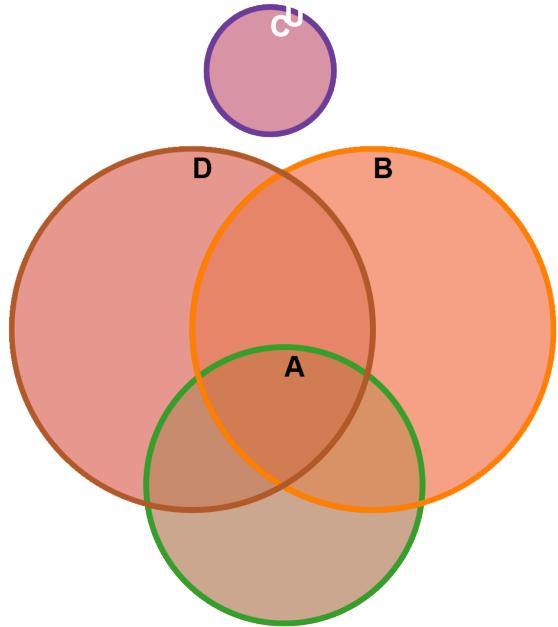
Number of Nodes: 25

Number of Zones: 9

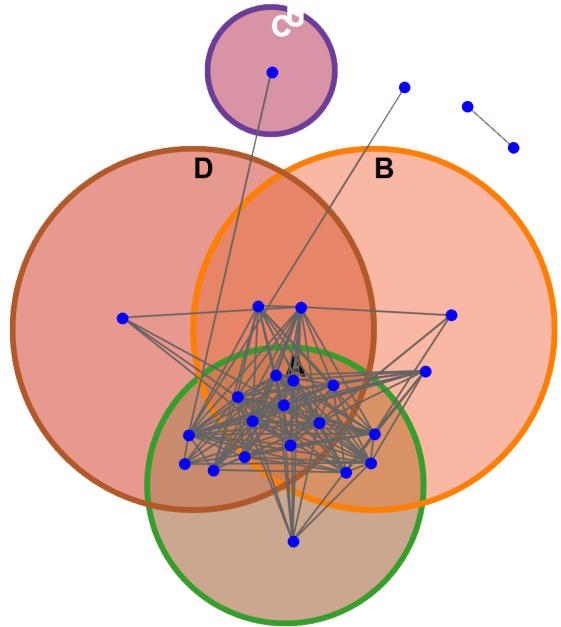
Number of Edges: 145

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	49	7	229
Vertex-vertex intersections	0	0	23
Vertices not in the correct zone	1	0	8
Omitted zones	0	0	2
Duplicated labels	0	0	0
Disconnected zones	0	9	0
Curve concurrency	0	3	4
Triple points	0	4	2
Non-circles	0	4	4
Extra zones	0	0	0
Edge crossings	1662	1388	1590
Edge-curve crossings	11	914	40
Runtime (in sec)	2.057	0.874	6.791

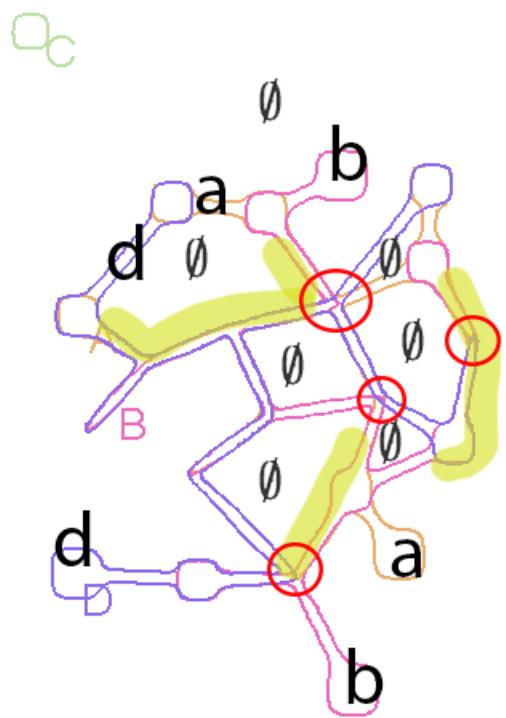
SetNet (without graph)



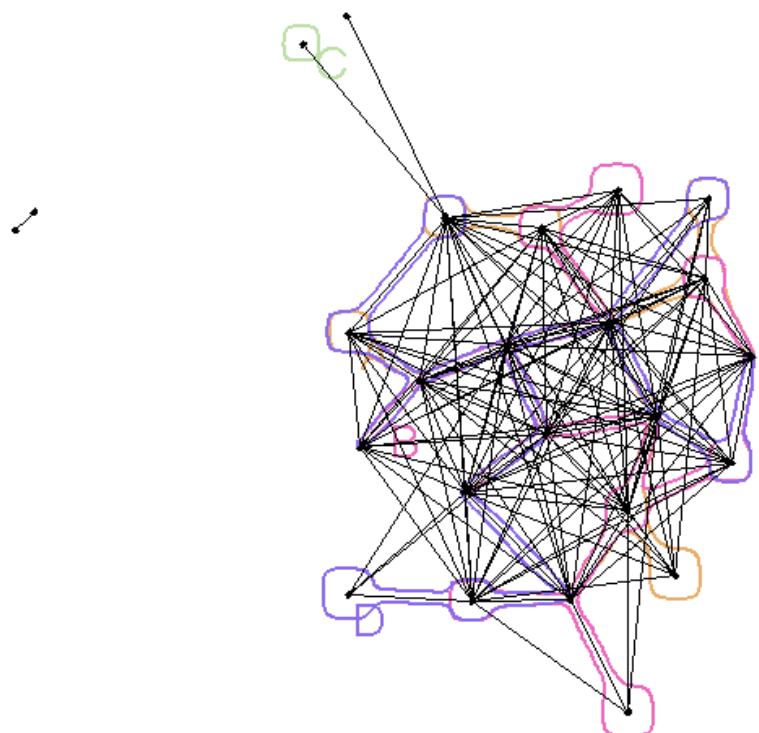
SetNet (with graph)



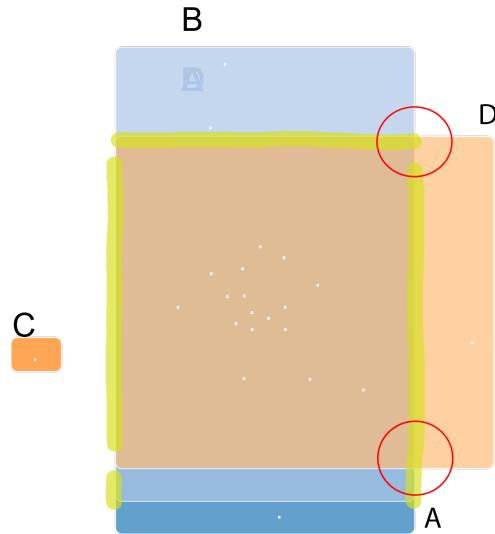
BubbleSets (without graph)



BubbleSets (with graph)

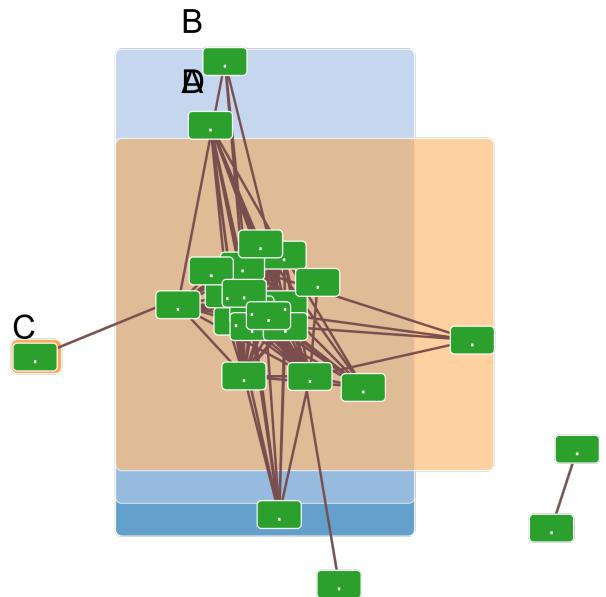


WebCola (without graph)



Omitted zones: AD, BD

WebCola (with graph)



4-set data set 7 SNAP ID: 1548841

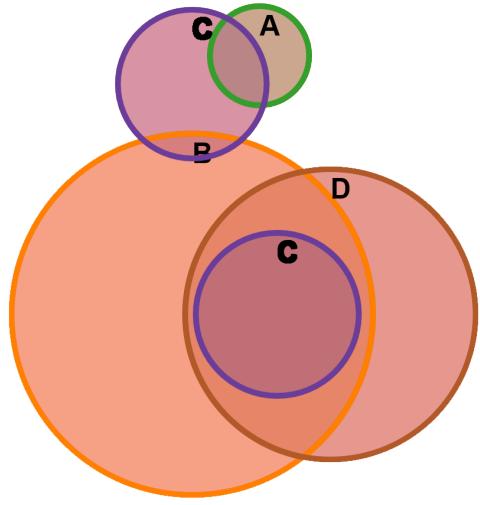
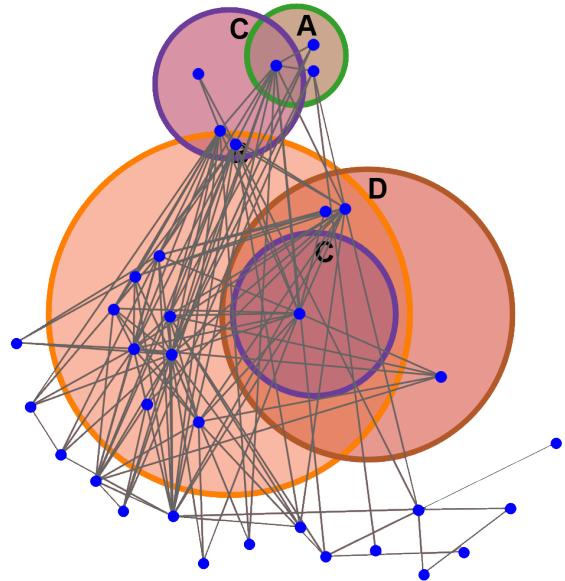
Number of Sets: 4

Number of Nodes: 36

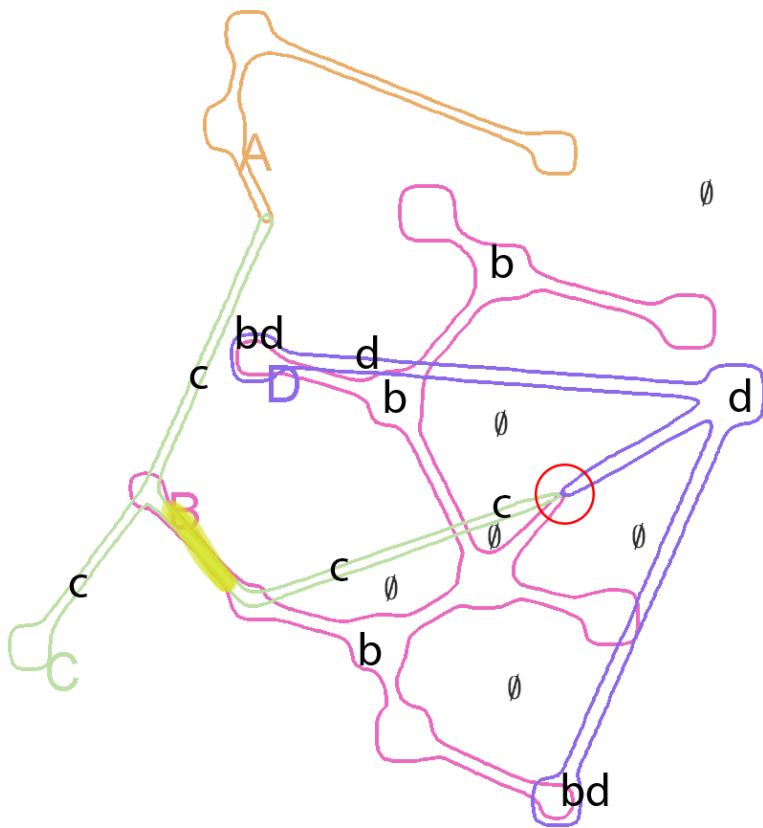
Number of Zones: 9

Number of Edges: 133

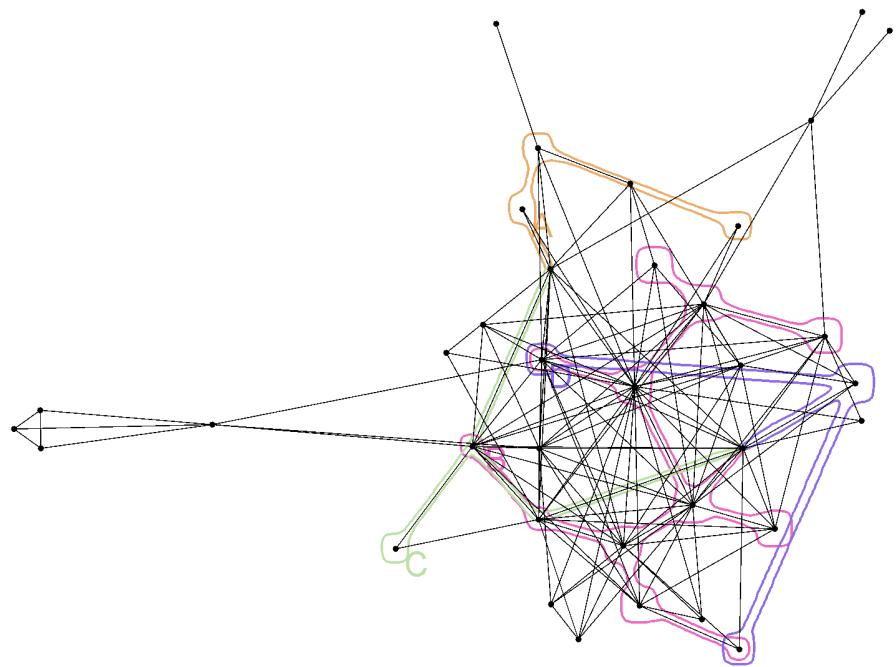
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	33	8	168
Vertex-vertex intersections	2	0	3
Vertices not in the correct zone	0	1	2
Omitted zones	0	0	1
Duplicated labels	1	0	0
Disconnected zones	0	12	0
Curve concurrency	0	1	1
Triple points	0	1	2
Non-circles	0	4	4
Extra zones	0	0	0
Edge crossings	1009	625	1003
Edge-curve crossings	48	301	62
Runtime (in sec)	2.263	0.537	6.689

SetNet (without graph)**SetNet (with graph)**

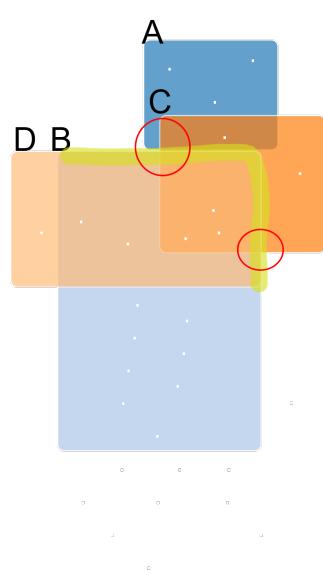
BubbleSets (without graph)



BubbleSets (with graph)

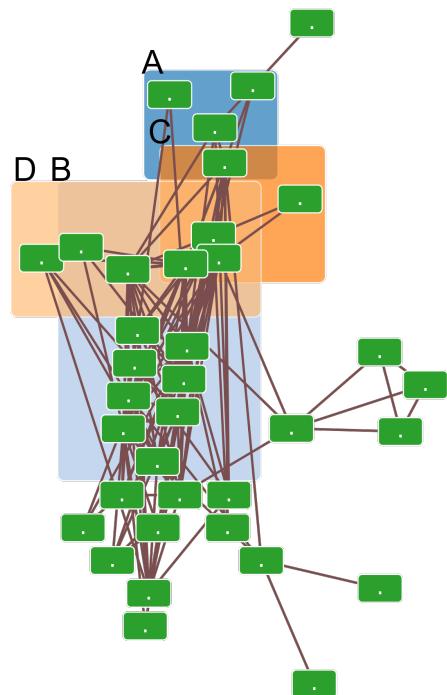


WebCola (without graph)



Omitted zones: BC

WebCola (with graph)



4-set data set 8 SNAP ID: 232006900

Number of Sets: 4

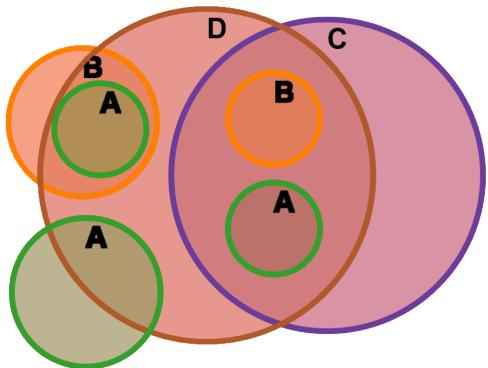
Number of Nodes: 53

Number of Zones: 11

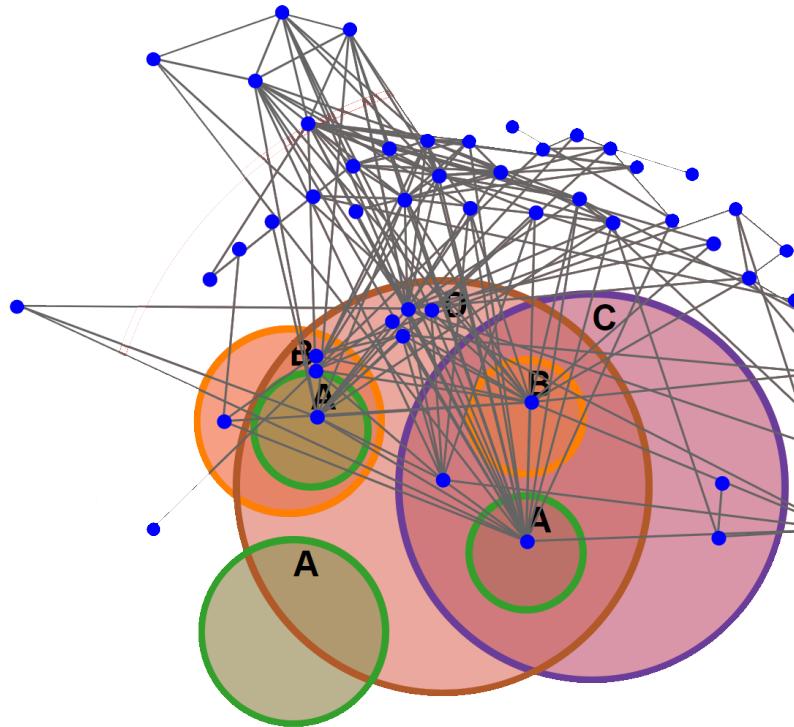
Number of Edges: 168

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	83	10	230
Vertex-vertex intersections	0	0	4
Vertices not in the correct zone	6	1	7
Omitted zones	0	0	2
Duplicated labels	3	0	0
Disconnected zones	0	20	1
Curve concurrency	0	2	3
Triple points	0	3	4
Non-circles	0	4	4
Extra zones	0	0	1
Edge crossings	1623	661	1744
Edge-curve crossings	64	232	275
Runtime (in sec)	3.813	0.543	7.33

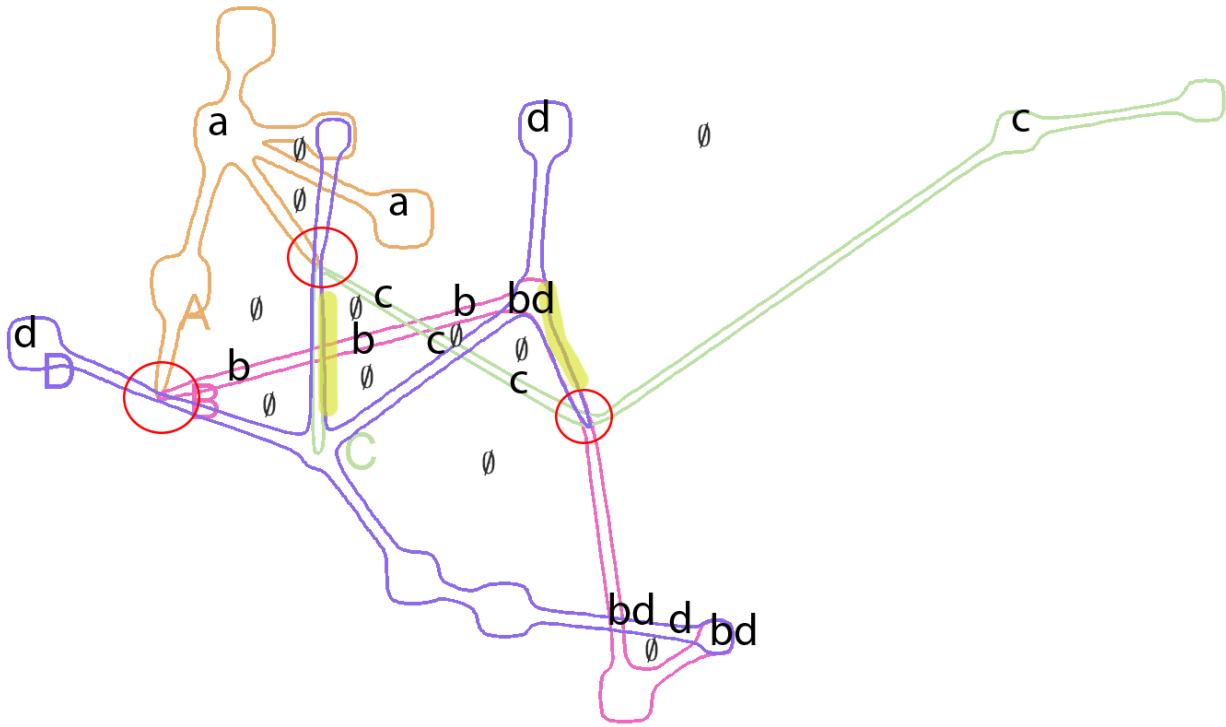
SetNet (without graph)



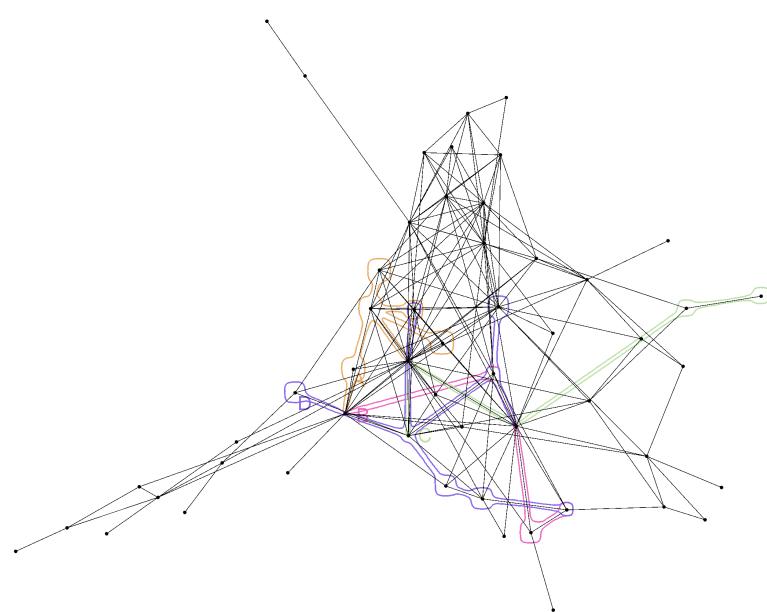
SetNet (with graph)



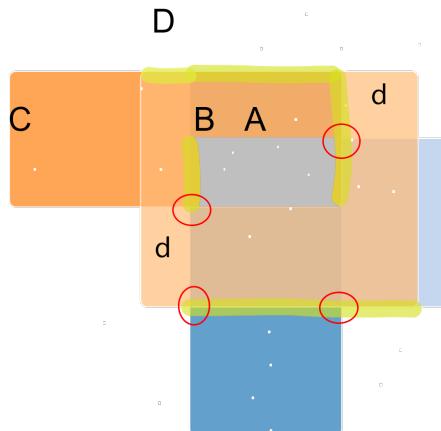
BubbleSets (without graph)



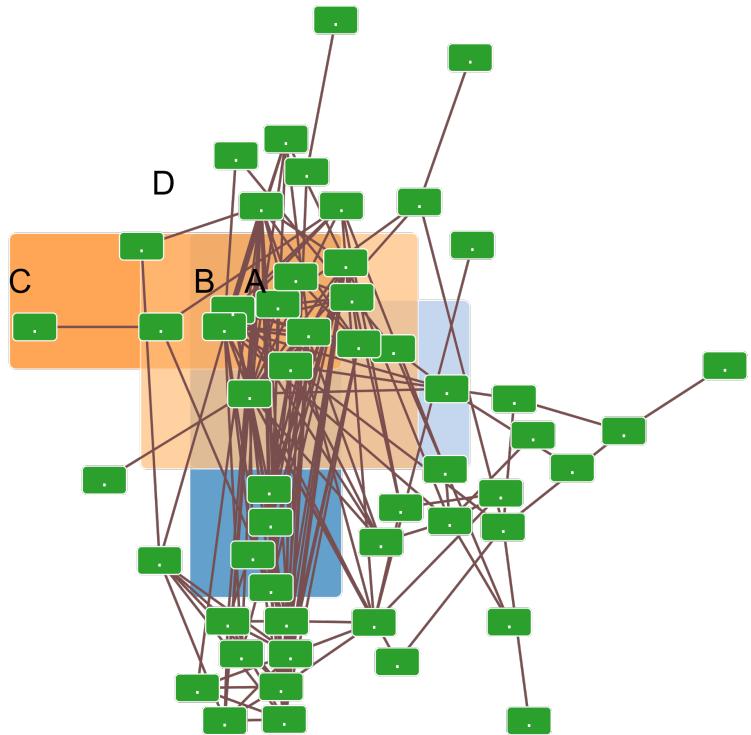
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



6-set data set 1 SNAP ID: 80297299

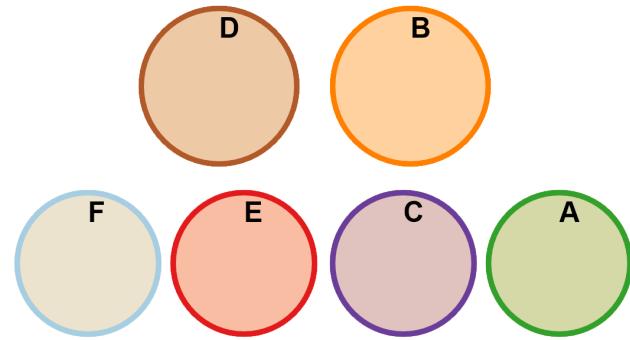
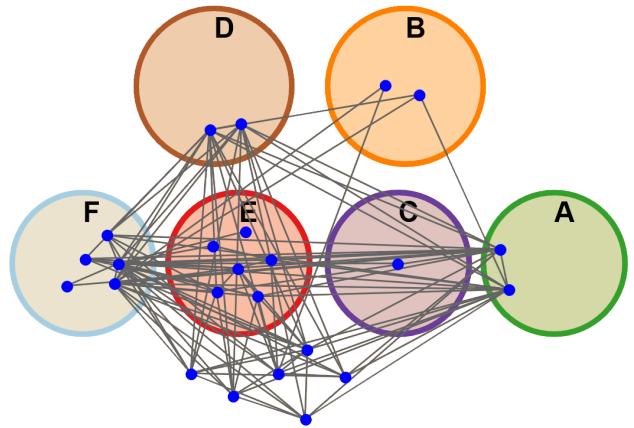
Number of Sets: 6

Number of Nodes: 24

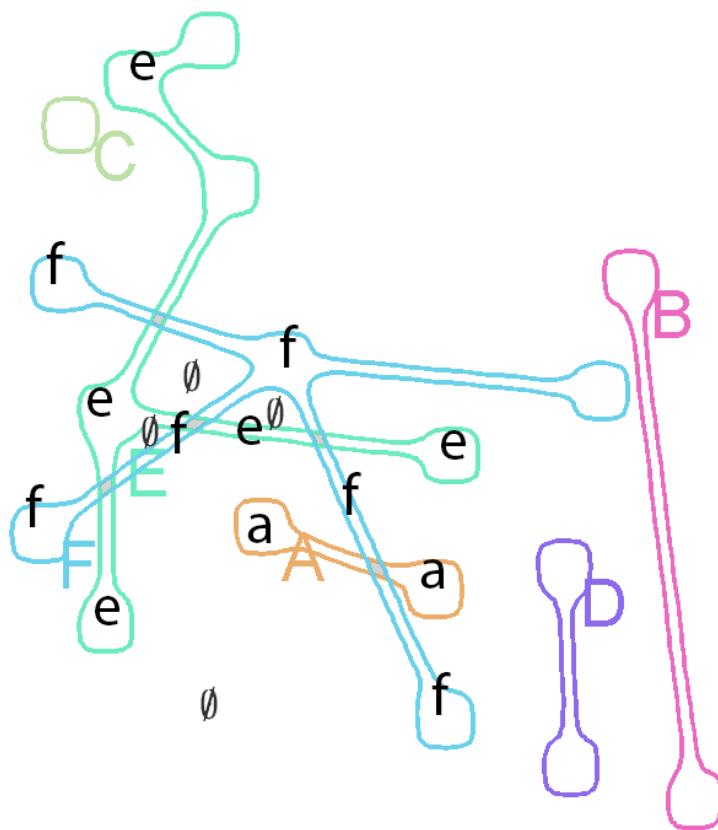
Number of Zones: 7

Number of Edges: 103

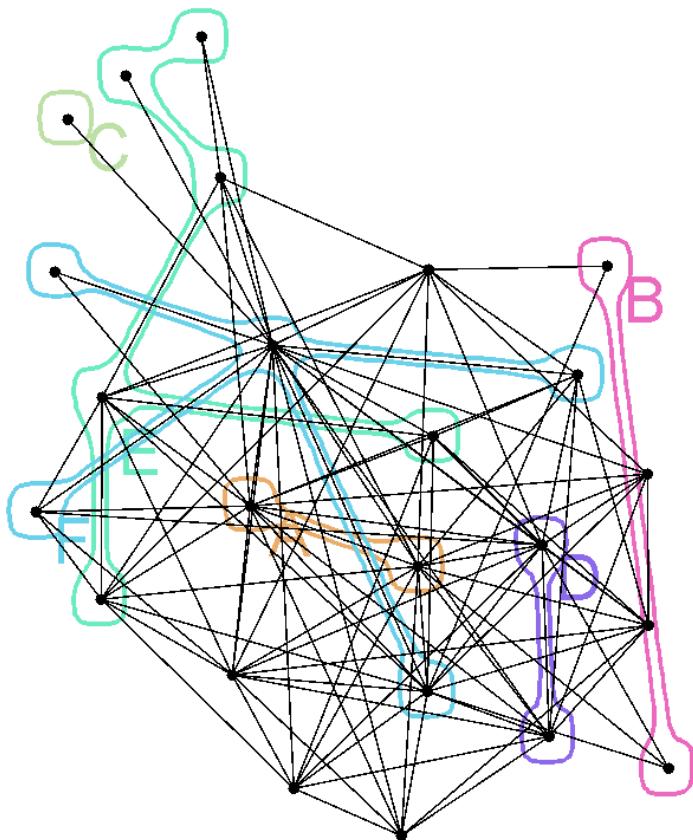
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	36	4	238
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	1	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	12	0
Curve concurrency	0	0	3
Triple points	0	0	0
Non-circles	0	6	6
Extra zones	0	5	0
Edge crossings	938	489	803
Edge-curve crossings	53	200	168
Runtime (in sec)	1.616	0.753	6.999

SetNet (without graph)**SetNet (with graph)**

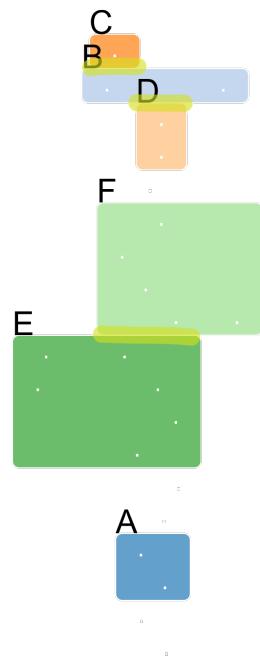
BubbleSets (without graph)



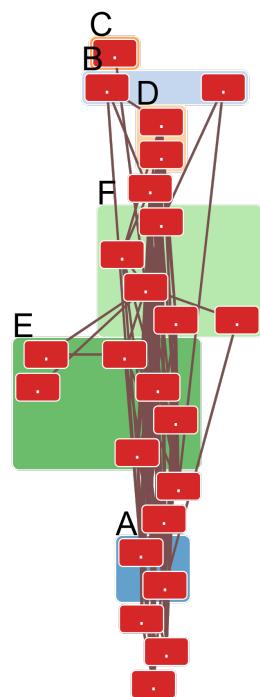
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



6-set data set 2 SNAP ID: 18734310

Number of Sets: 6

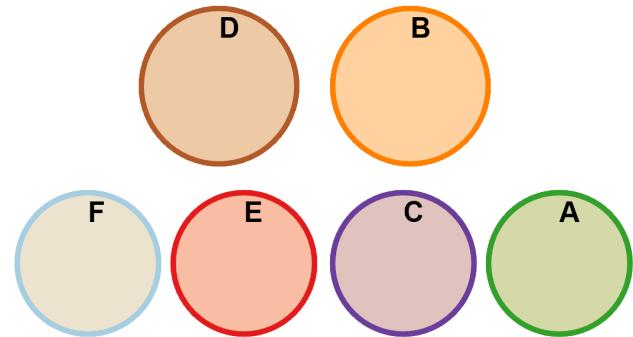
Number of Nodes: 33

Number of Zones: 7

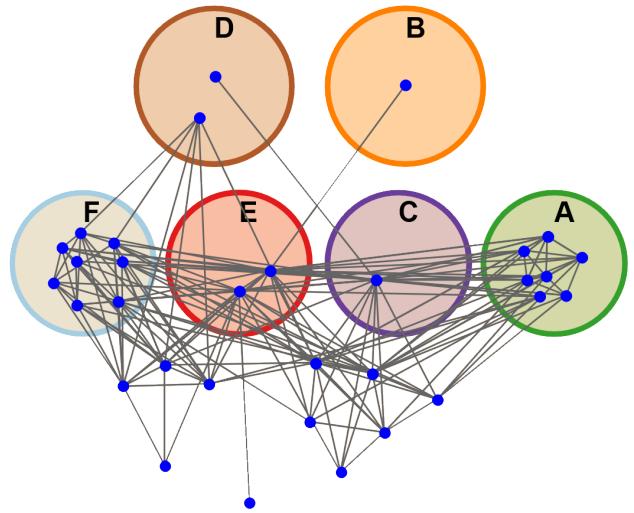
Number of Edges: 160

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	56	6	419
Vertex-vertex intersections	1	0	0
Vertices not in the correct zone	0	1	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	4	0
Curve concurrency	0	1	3
Triple points	0	0	0
Non-circles	0	6	6
Extra zones	0	2	0
Edge crossings	1149	801	1510
Edge-curve crossings	30	301	298
Runtime (in sec)	2.702	0.533	6.789

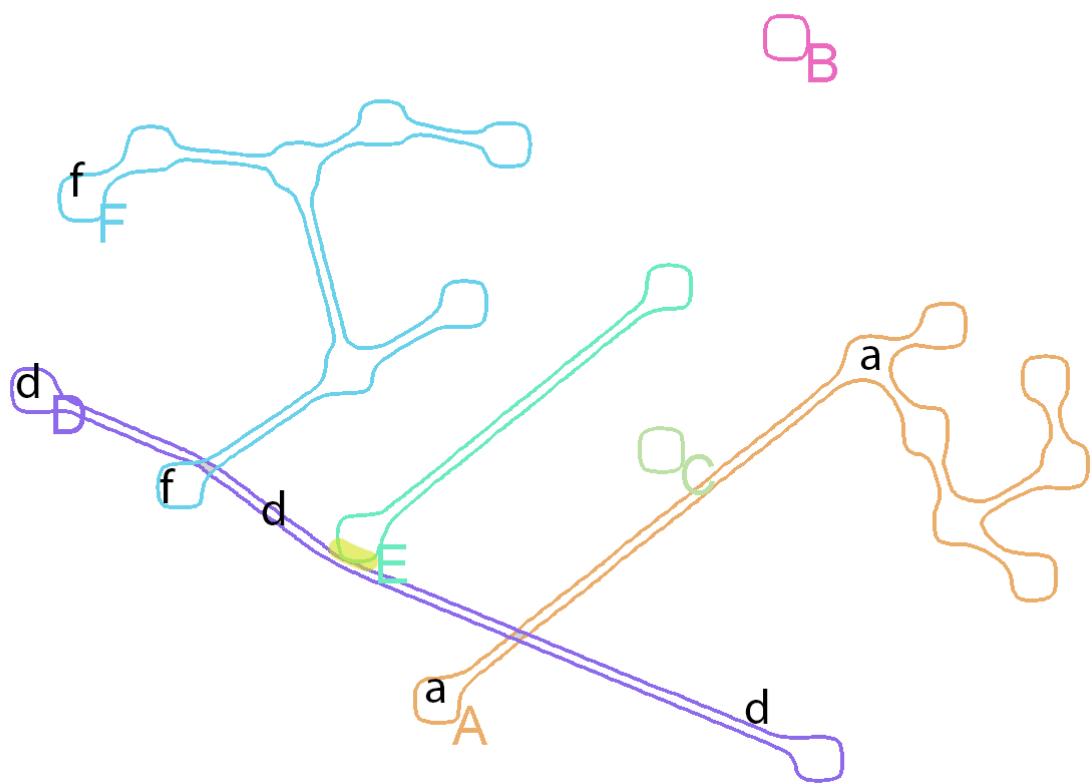
SetNet (without graph)



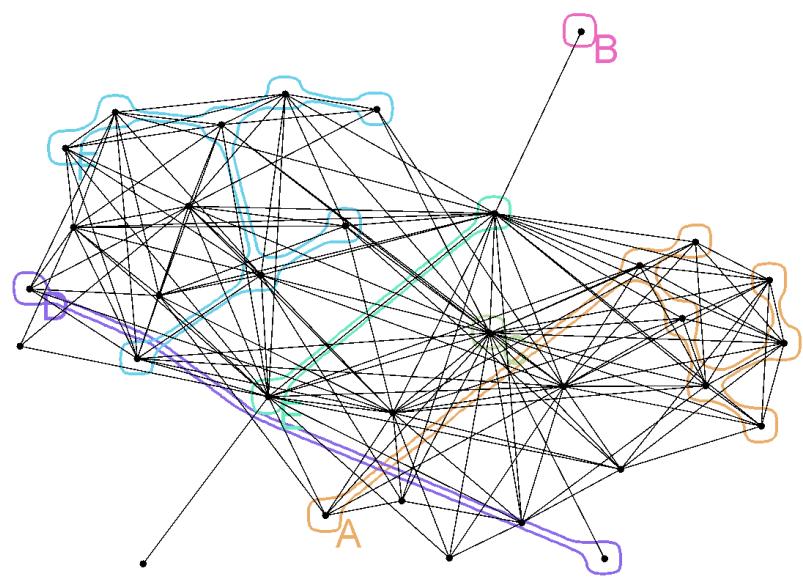
SetNet (with graph)



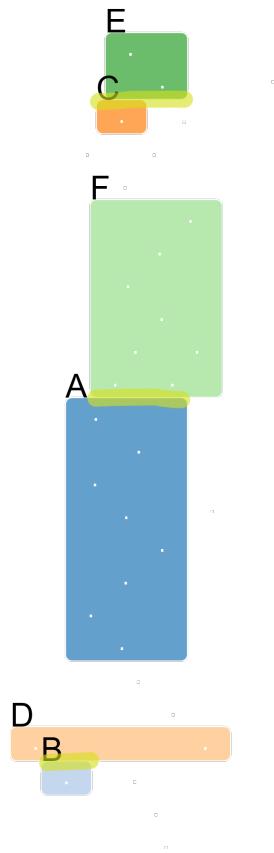
BubbleSets (without graph)



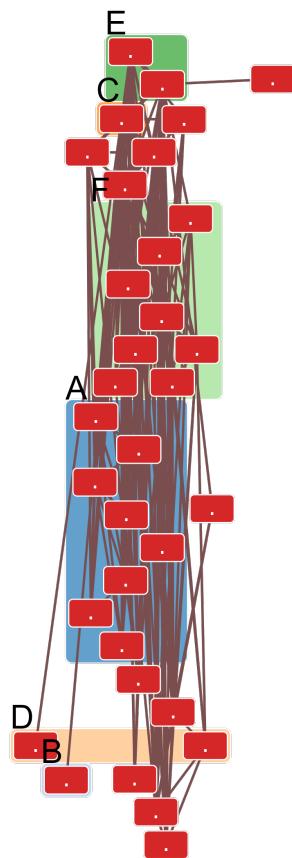
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



6-set data set 3 SNAP ID: 30970675

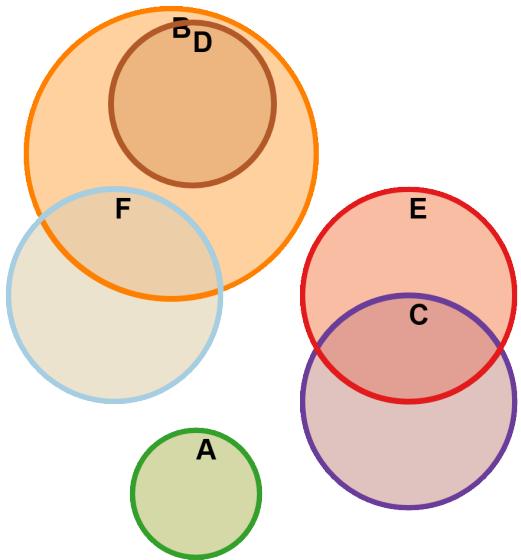
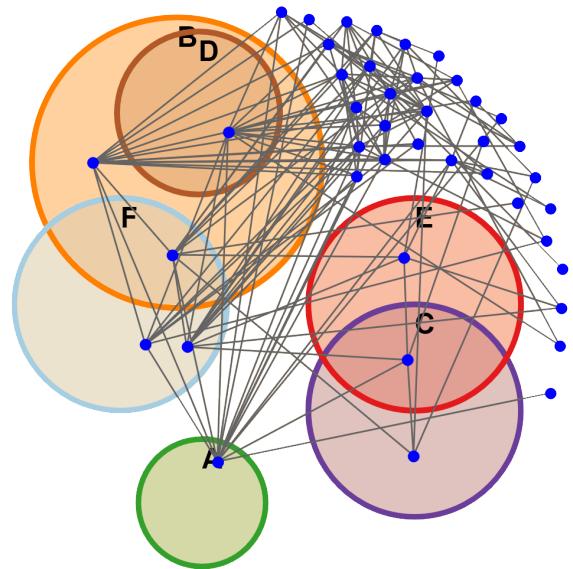
Number of Sets: 6

Number of Nodes: 42

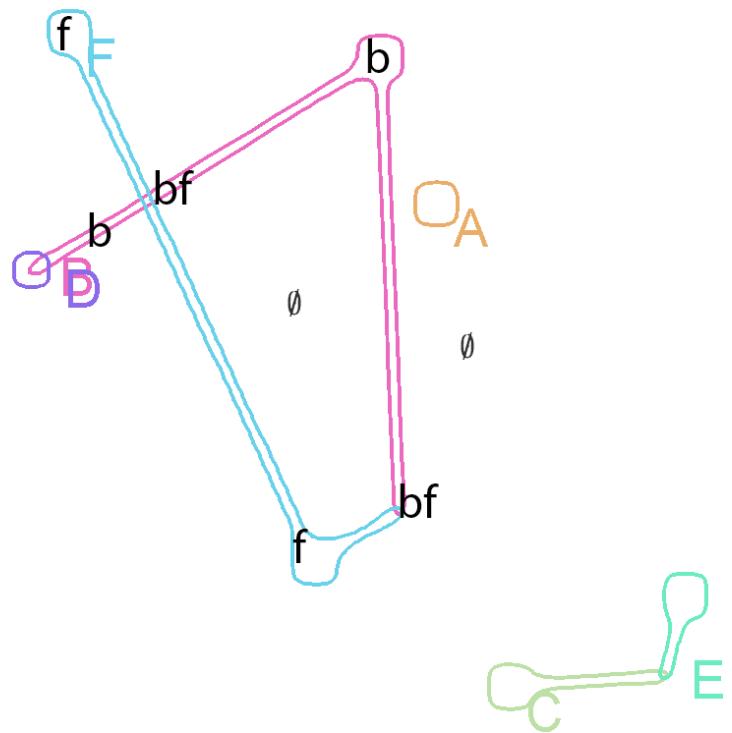
Number of Zones: 9

Number of Edges: 139

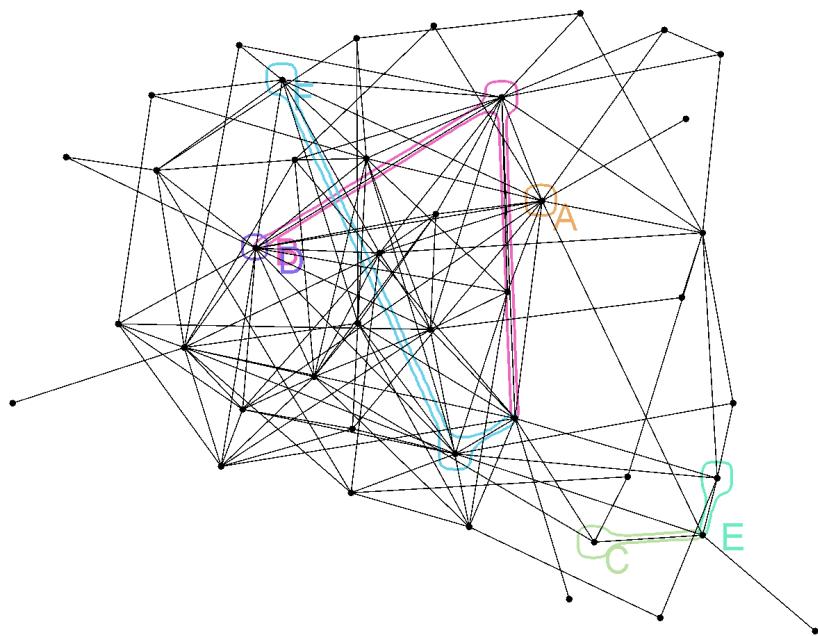
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	42	7	237
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	1	0
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	4	0
Curve concurrency	0	0	2
Triple points	0	0	0
Non-circles	0	6	6
Extra zones	0	0	0
Edge crossings	1330	531	1233
Edge-curve crossings	44	121	250
Runtime (in sec)	2.787	0.512	8.466

SetNet (without graph)**SetNet (with graph)**

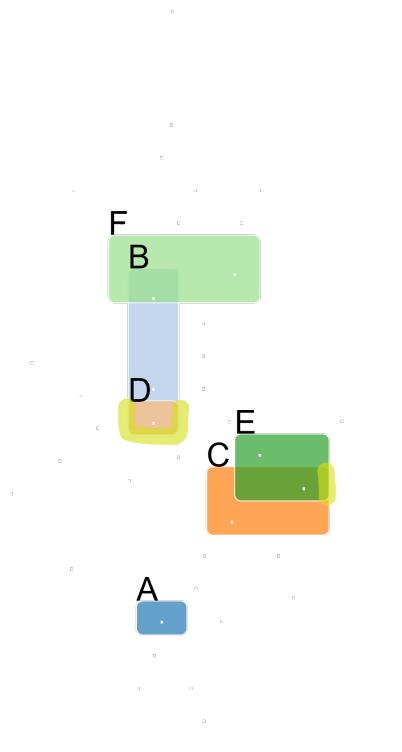
BubbleSets (without graph)



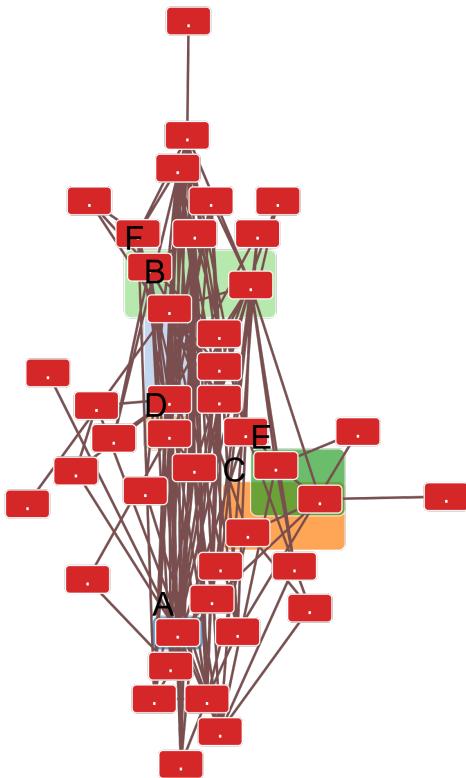
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



6-set data set 4 SNAP ID: 253751053

Number of Sets: 6

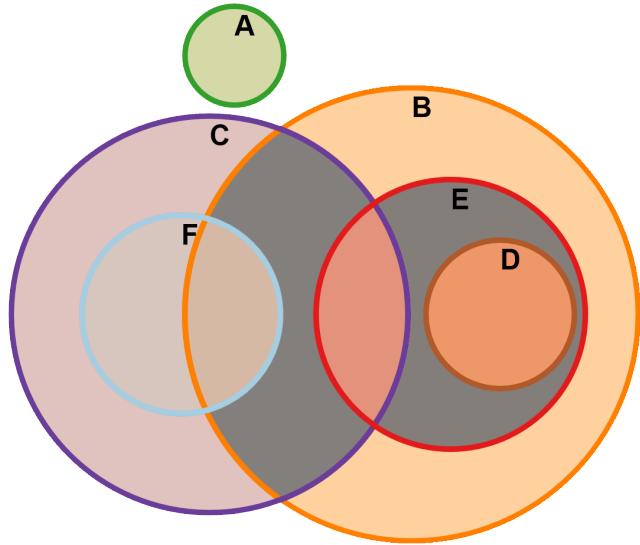
Number of Nodes: 52

Number of Zones: 8

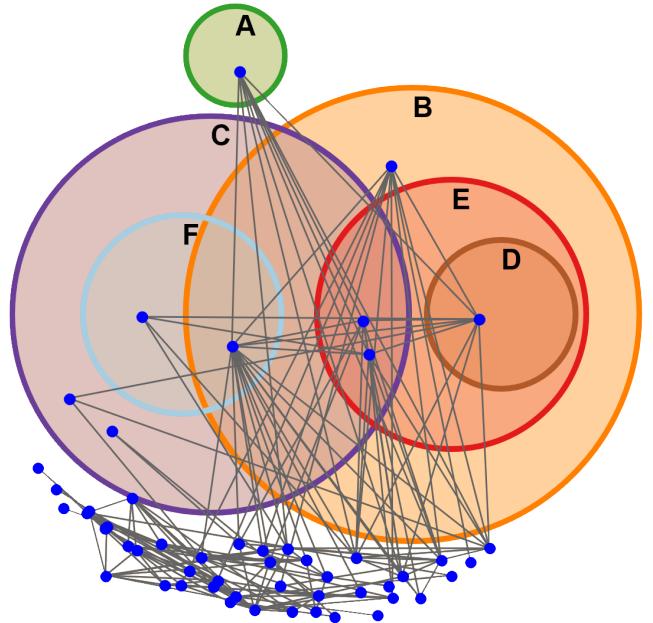
Number of Edges: 156

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	147	9	180
Vertex-vertex intersections	5	0	1
Vertices not in the correct zone	1	2	6
Omitted zones	0	0	1
Duplicated labels	0	0	0
Disconnected zones	0	6	0
Curve concurrency	0	2	3
Triple points	0	2	0
Non-circles	0	6	6
Extra zones	2	6	0
Edge crossings	1228	408	825
Edge-curve crossings	44	213	32
Runtime (in sec)	3.428	0.793	7.345

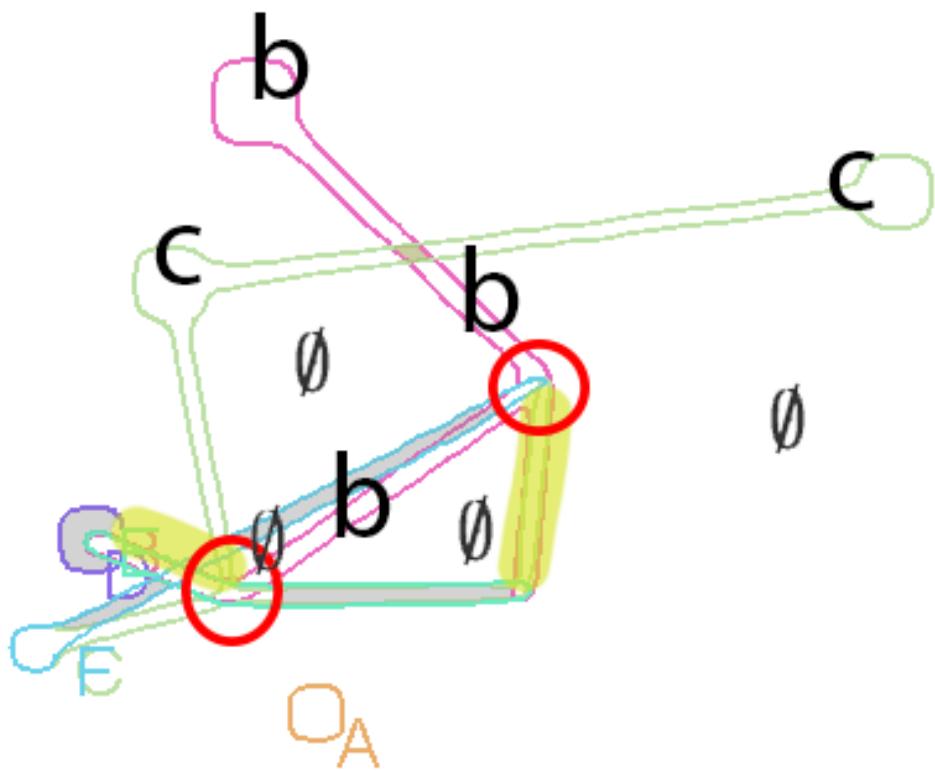
SetNet (without graph)



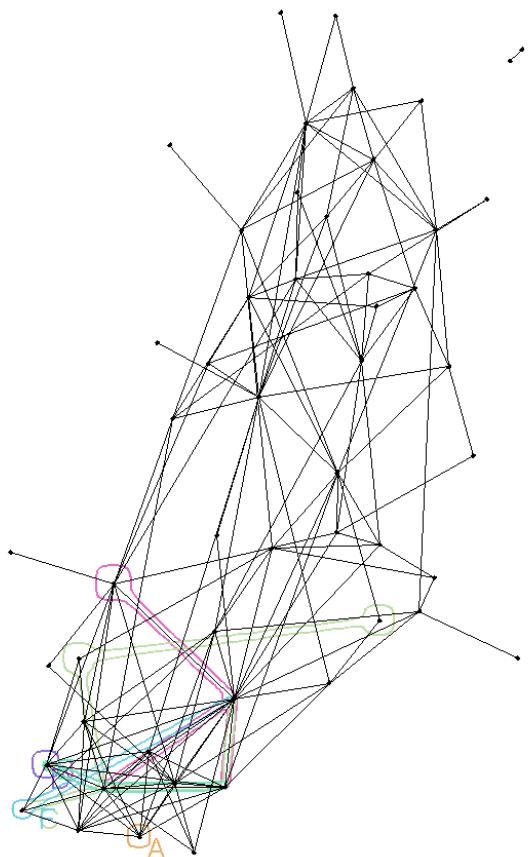
SetNet (with graph)



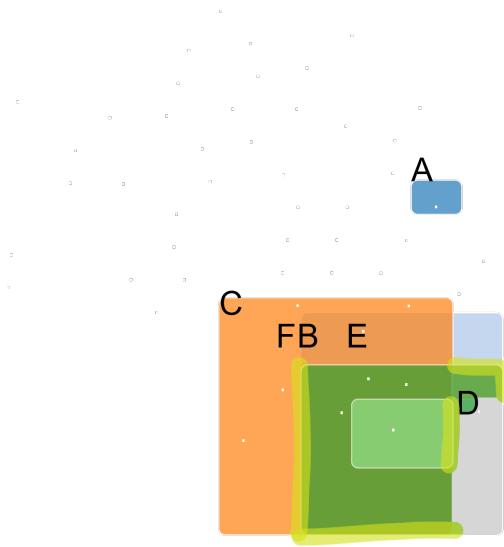
BubbleSets (without graph)



BubbleSets (with graph)

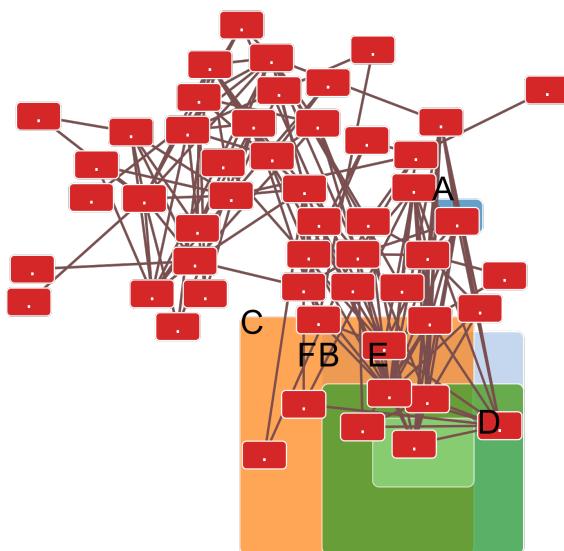


WebCola (without graph)



Omitted zones: BCF

WebCola (with graph)



6-set data set 5 SNAP ID: 204145356

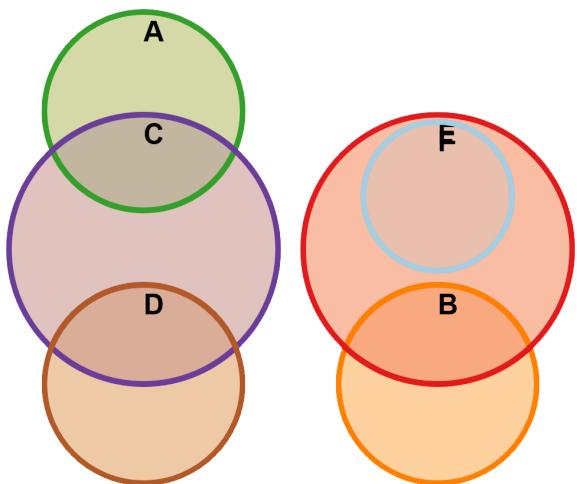
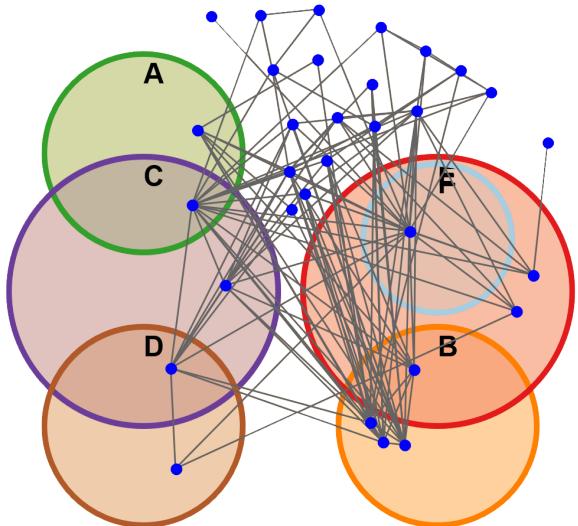
Number of Sets: 6

Number of Nodes: 31

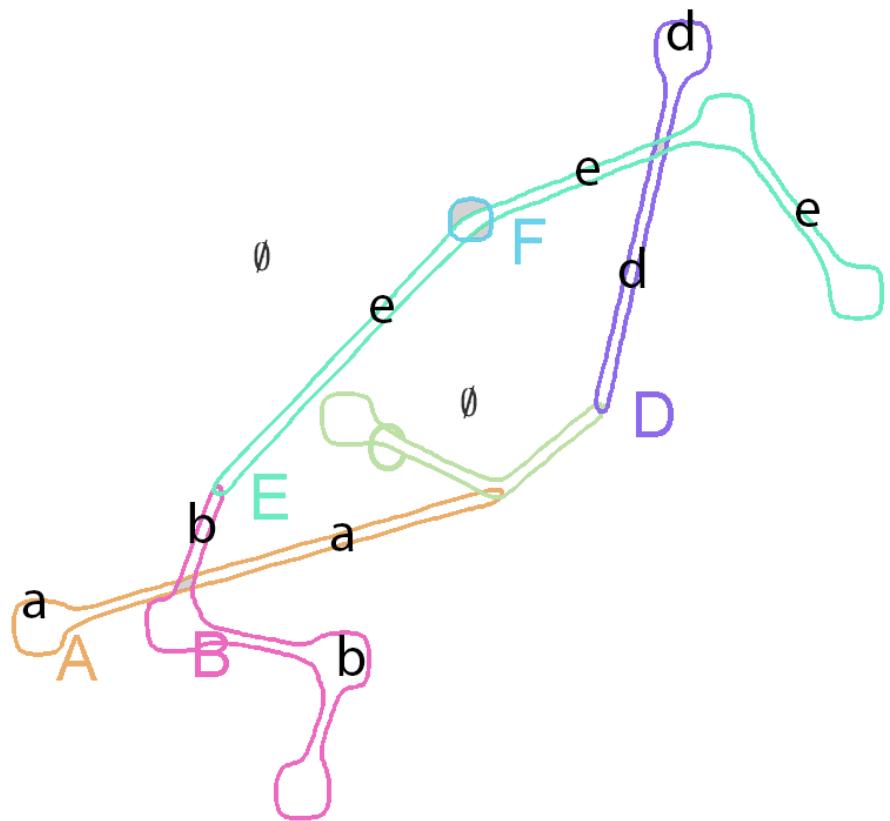
Number of Zones: 10

Number of Edges: 114

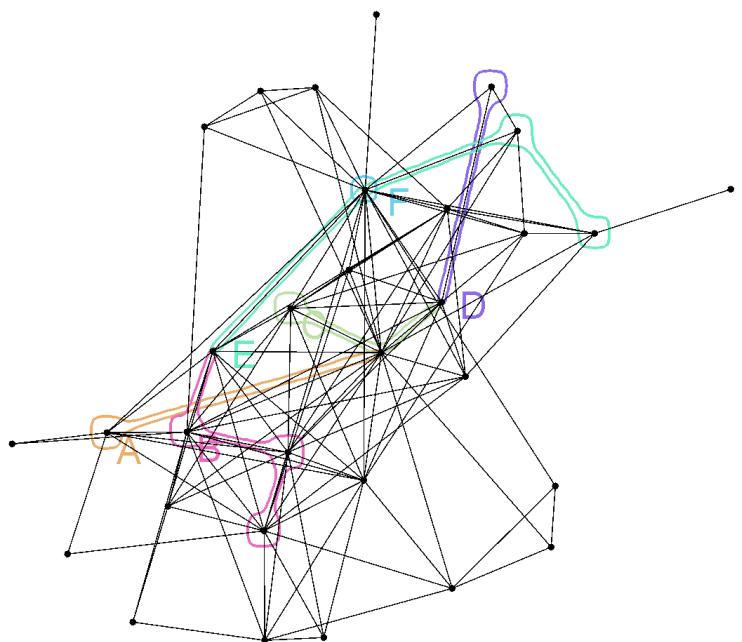
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	32	8	165
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	2
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	6	0
Curve concurrency	0	0	3
Triple points	0	0	1
Non-circles	0	6	6
Extra zones	0	4	1
Edge crossings	1118	366	926
Edge-curve crossings	46	98	170
Runtime (in sec)	1.807	0.508	6.84

SetNet (without graph)**SetNet (with graph)**

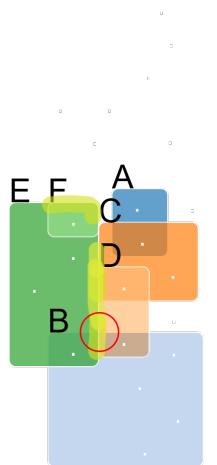
BubbleSets (without graph)



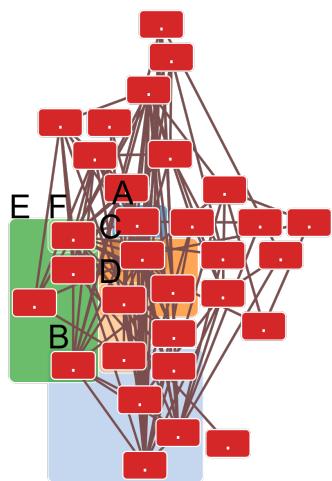
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



6-set data set 6 SNAP ID: 255790981

Number of Sets: 6

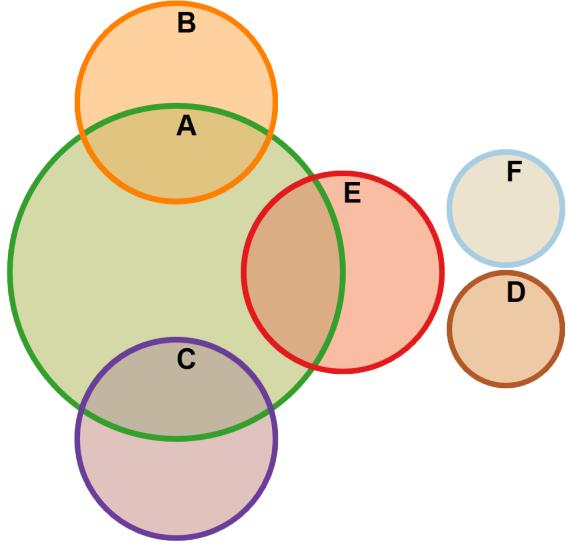
Number of Nodes: 39

Number of Zones: 10

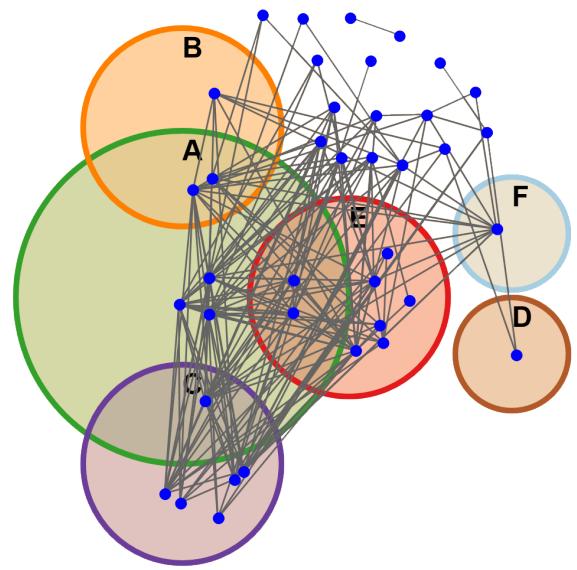
Number of Edges: 167

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	68	7	262
Vertex-vertex intersections	0	0	2
Vertices not in the correct zone	0	2	5
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	26	0
Curve concurrency	0	2	2
Triple points	0	0	0
Non-circles	0	6	6
Extra zones	0	2	0
Edge crossings	2588	1105	2233
Edge-curve crossings	58	460	137
Runtime (in sec)	3.119	0.533	8.35

SetNet (without graph)

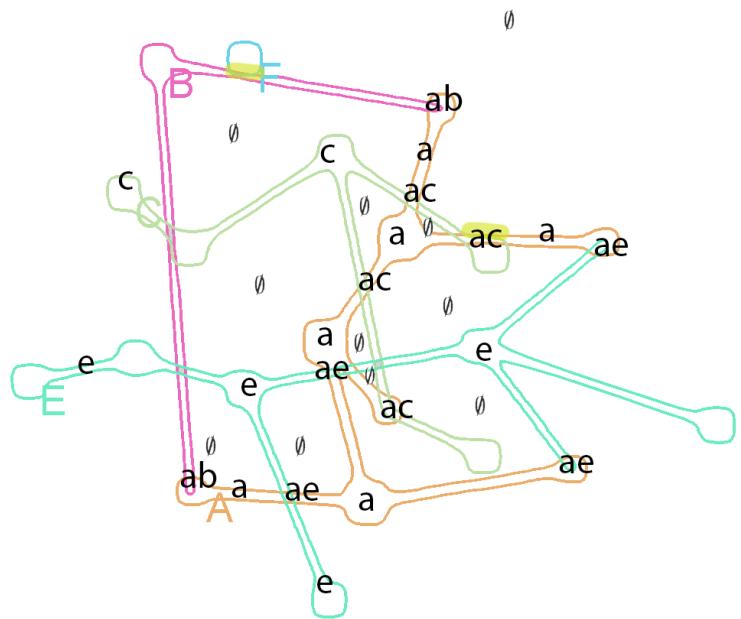


SetNet (with graph)

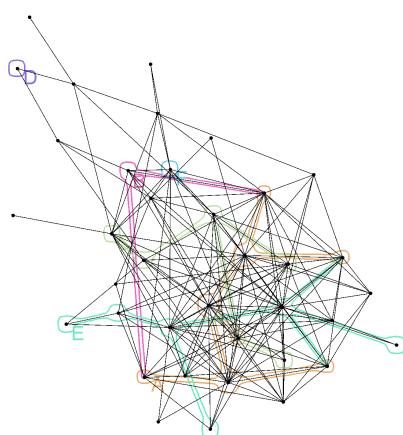


BubbleSets (without graph)

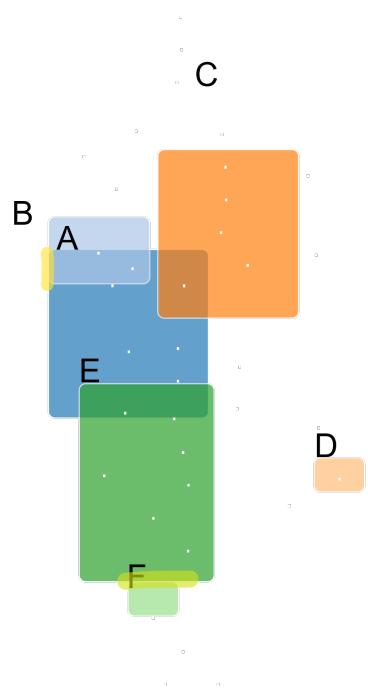
QD



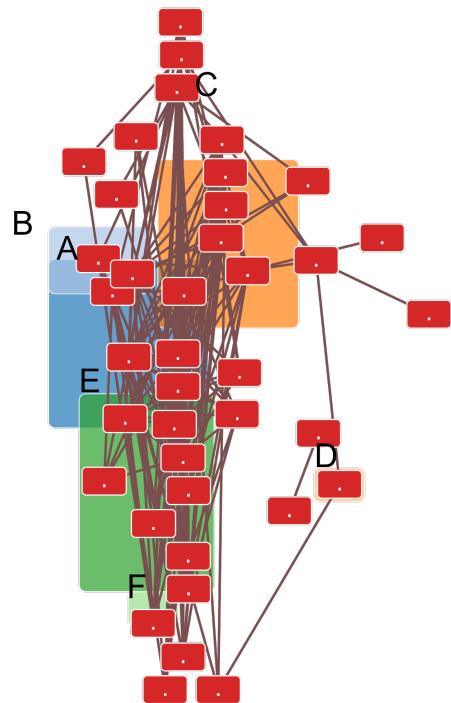
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



6-set data set 7 SNAP ID: 326259198

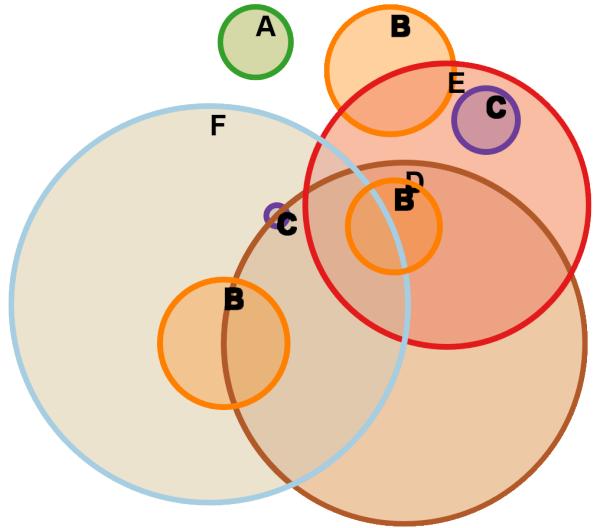
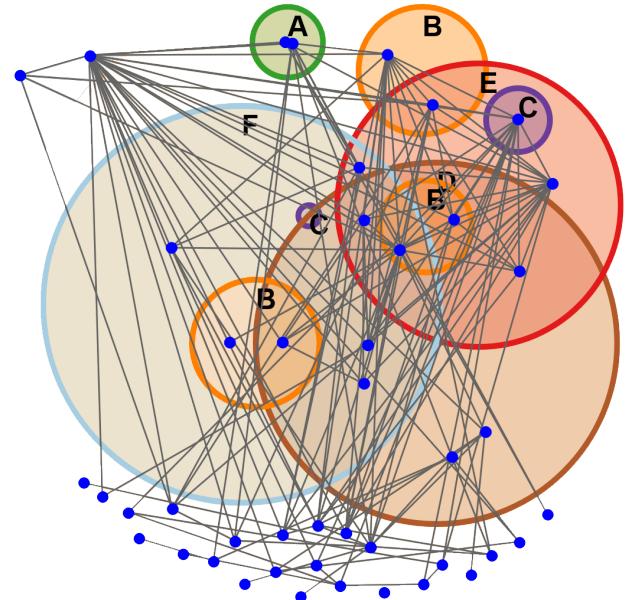
Number of Sets: 6

Number of Nodes: 45

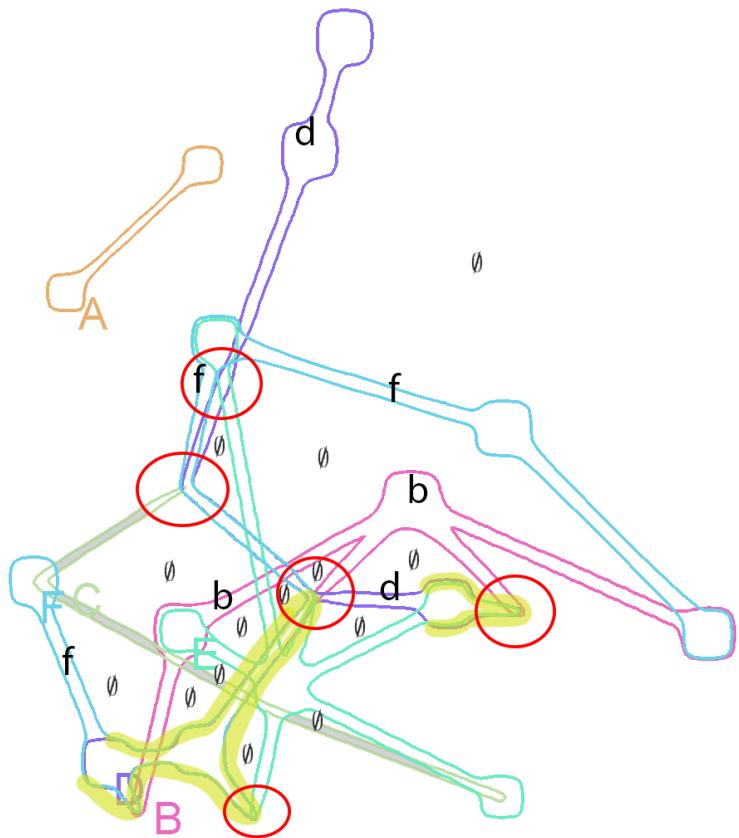
Number of Zones: 18

Number of Edges: 142

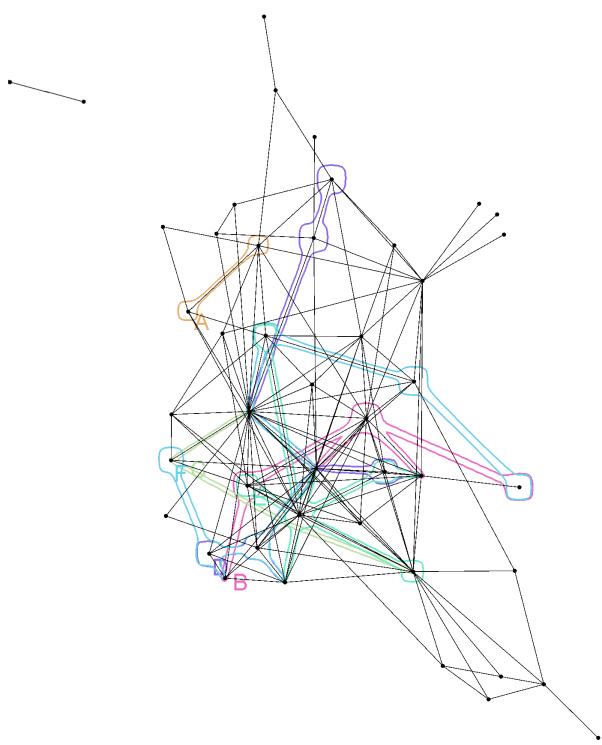
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	40	3	215
Vertex-vertex intersections	2	0	8
Vertices not in the correct zone	2	0	14
Omitted zones	0	0	6
Duplicated labels	3	0	0
Disconnected zones	0	17	3
Curve concurrency	0	2	5
Triple points	0	5	2
Non-circles	0	6	6
Extra zones	0	4	3
Edge crossings	1474	425	1532
Edge-curve crossings	106	411	272
Runtime (in sec)	2.942	0.633	7.167

SetNet (without graph)**SetNet (with graph)**

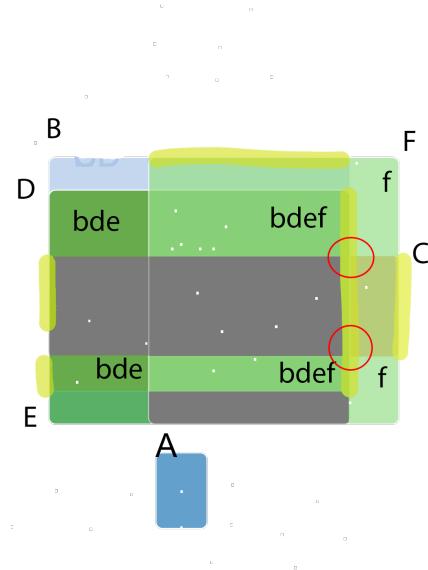
BubbleSets (without graph)



BubbleSets (with graph)

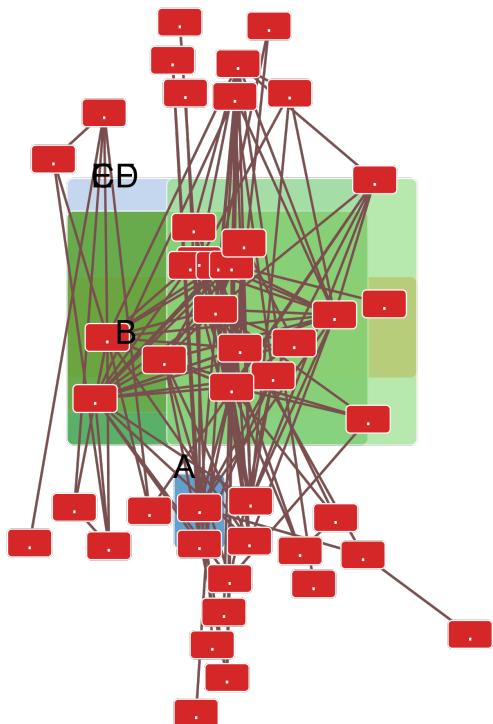


WebCola (without graph)



Omitted zones: D, E, CE, DE, CDF, DEF

WebCola (with graph)



6-set data set 8 SNAP ID: 170729553

Number of Sets: 6

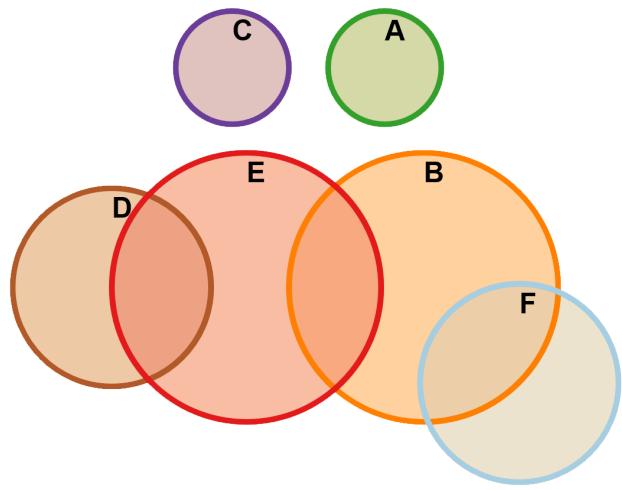
Number of Nodes: 40

Number of Zones: 10

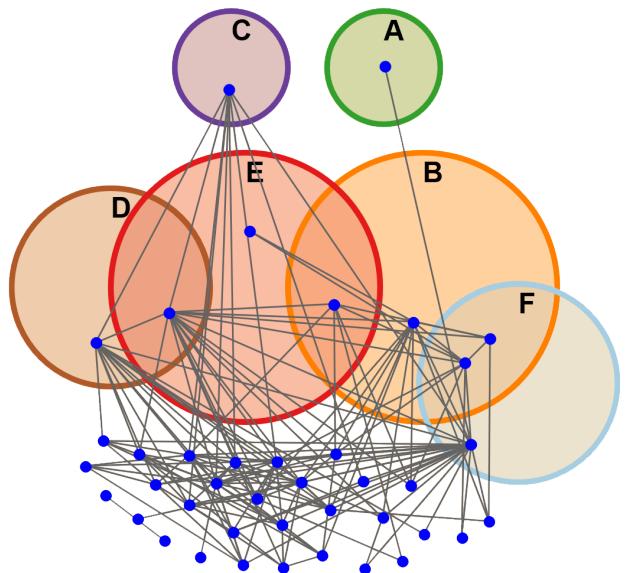
Number of Edges: 152

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	33	5	247
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	1
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	2	1
Curve concurrency	0	1	2
Triple points	0	0	0
Non-circles	0	6	6
Extra zones	0	0	0
Edge crossings	1247	587	1615
Edge-curve crossings	20	80	232
Runtime (in sec)	3.027	0.715	7.873

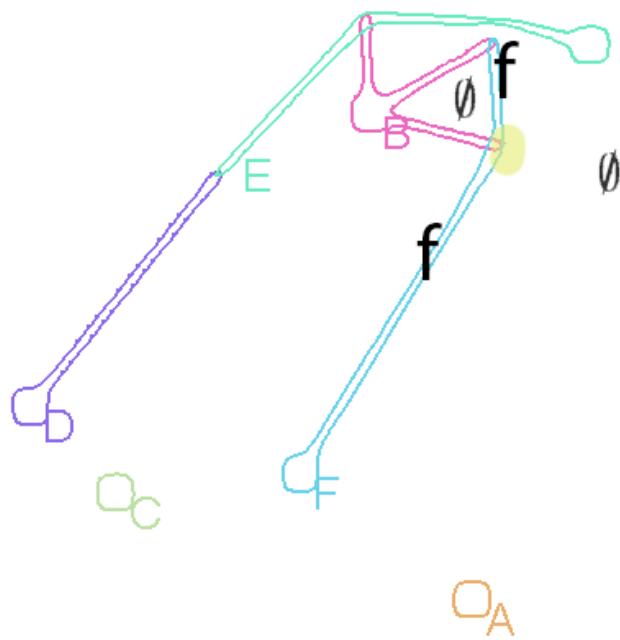
SetNet (without graph)



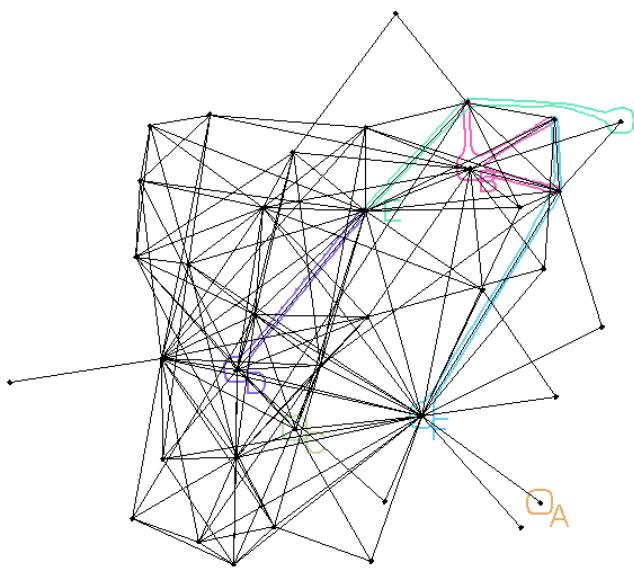
SetNet (with graph)



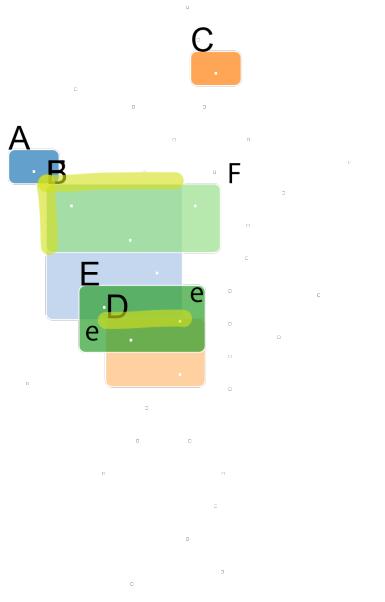
BubbleSets (without graph)



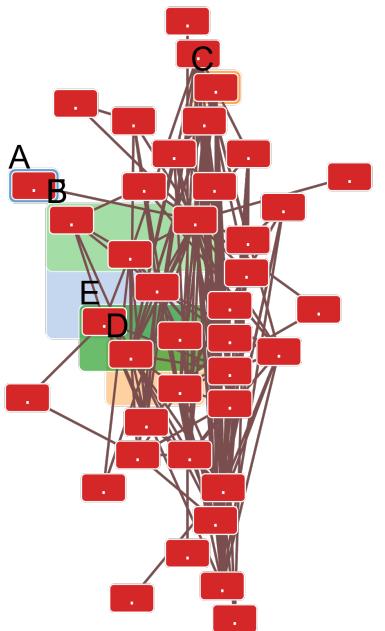
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



8-set data set 1 SNAP ID: 11348282

Number of Sets: 8

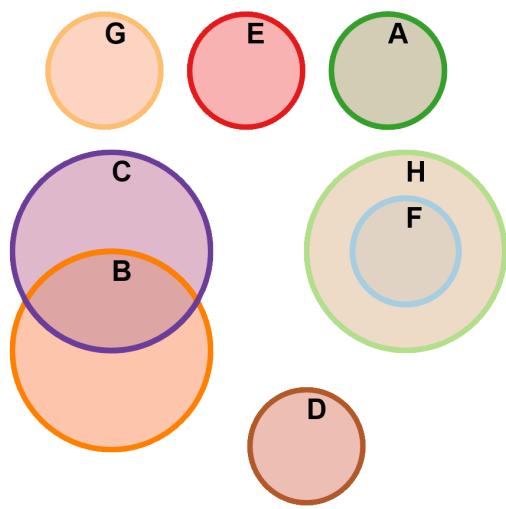
Number of Nodes: 30

Number of Zones: 10

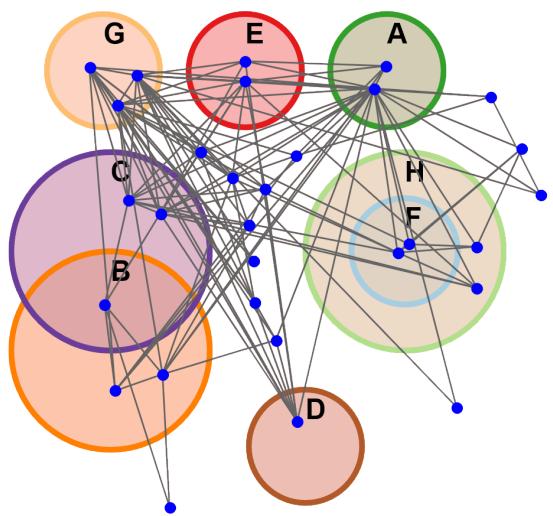
Number of Edges: 118

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	35	4	157
Vertex-vertex intersections	0	0	0
Vertices not in the correct zone	0	0	1
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	4	0
Curve concurrency	0	1	4
Triple points	0	0	0
Non-circles	0	8	8
Extra zones	0	5	0
Edge crossings	854	512	845
Edge-curve crossings	29	153	194
Runtime (in sec)	2.011	0.703	7.014

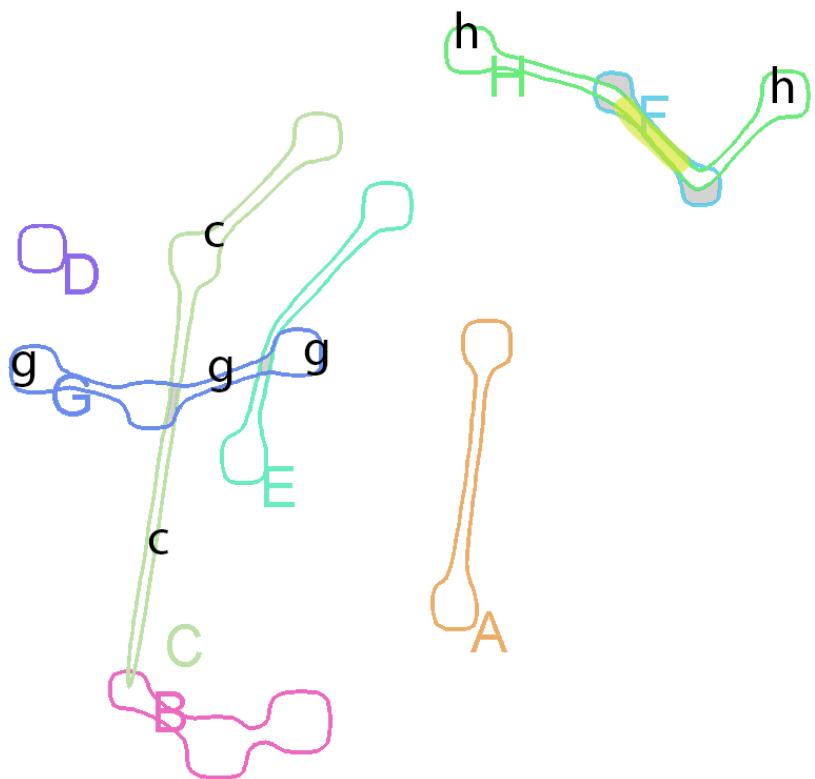
SetNet (without graph)



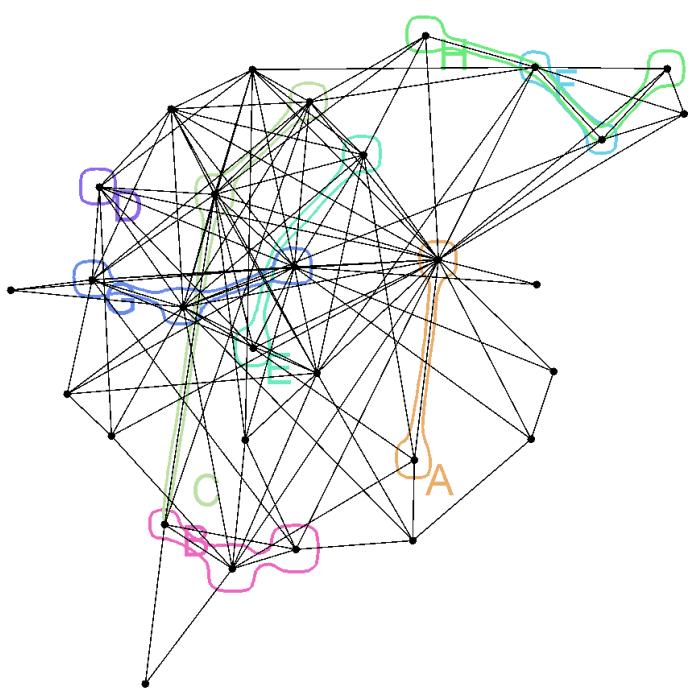
SetNet (with graph)



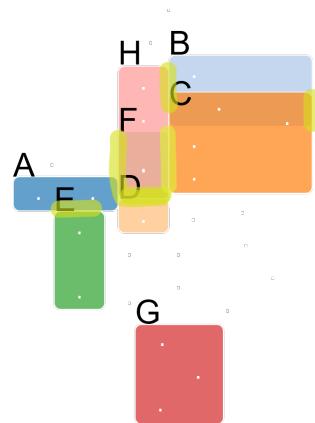
BubbleSets (without graph)



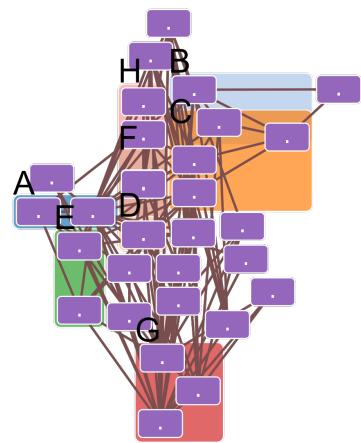
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



8-set data set 2 SNAP ID: 21028234

Number of Sets: 8

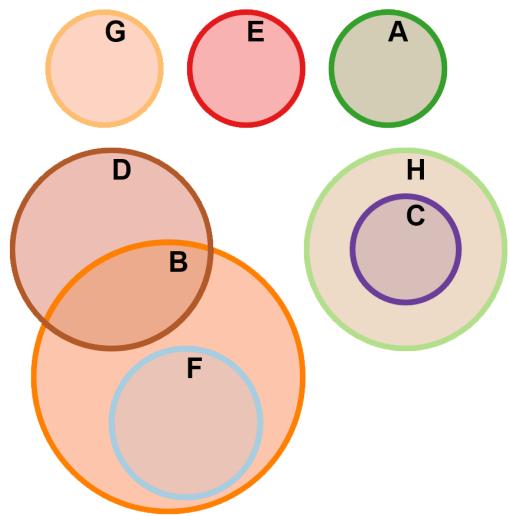
Number of Nodes: 35

Number of Zones: 10

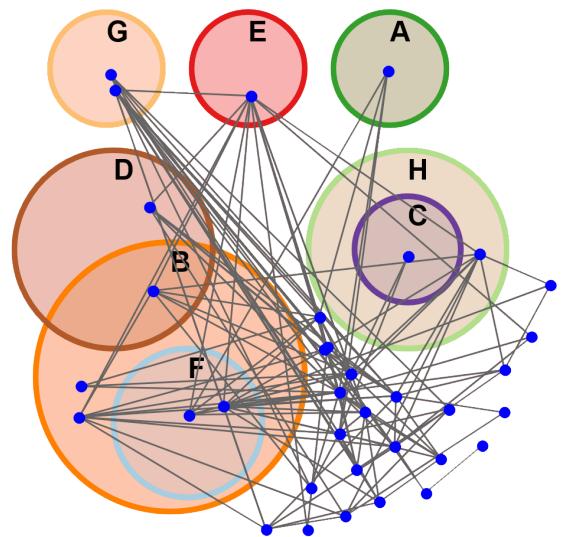
Number of Edges: 128

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	69	9	196
Vertex-vertex intersections	1	0	0
Vertices not in the correct zone	0	1	3
Omitted zones	0	0	1
Duplicated labels	0	0	0
Disconnected zones	0	9	0
Curve concurrency	0	1	2
Triple points	0	0	0
Non-circles	0	8	8
Extra zones	0	3	1
Edge crossings	1372	416	984
Edge-curve crossings	54	196	387
Runtime (in sec)	2.389	0.734	6.552

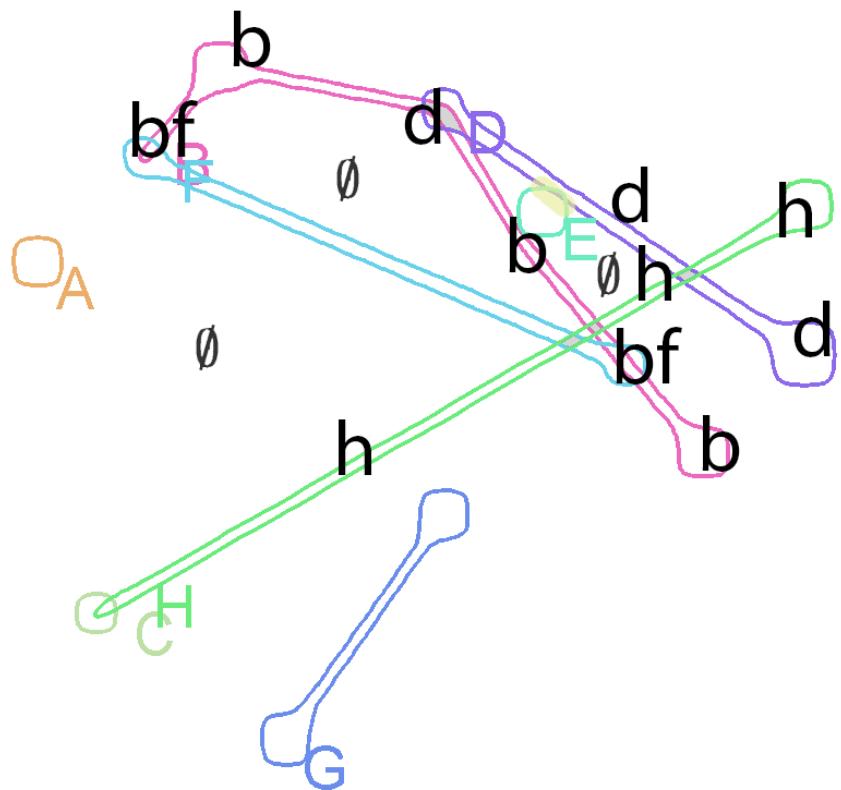
SetNet (without graph)



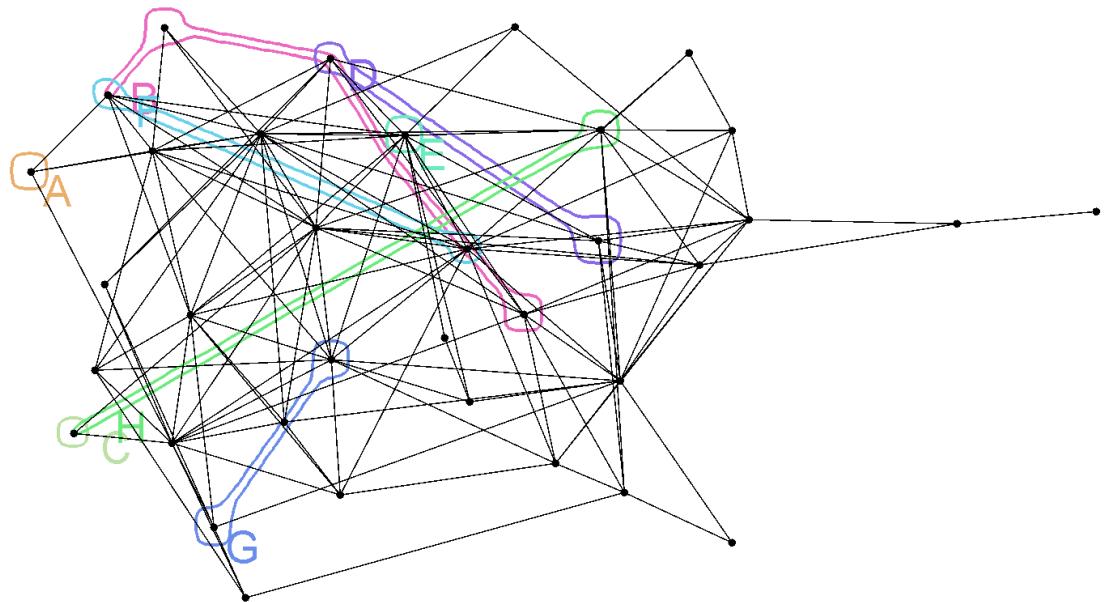
SetNet (with graph)



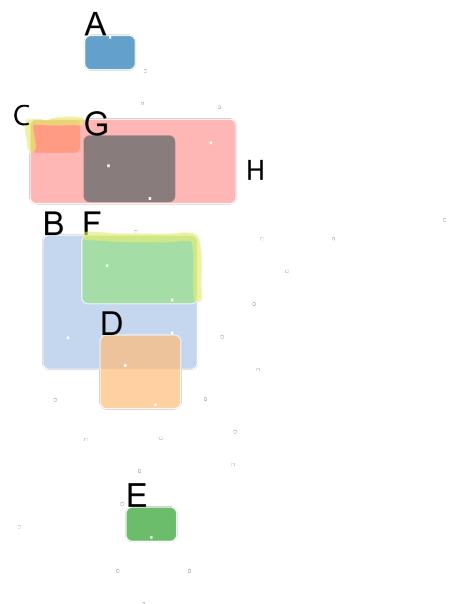
BubbleSets (without graph)



BubbleSets (with graph)

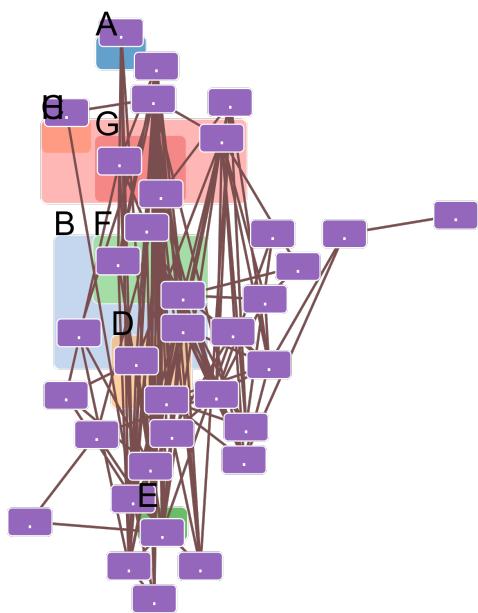


WebCola (without graph)



Omitted zones: G

WebCola (with graph)



8-set data set 3 SNAP ID: 61311054

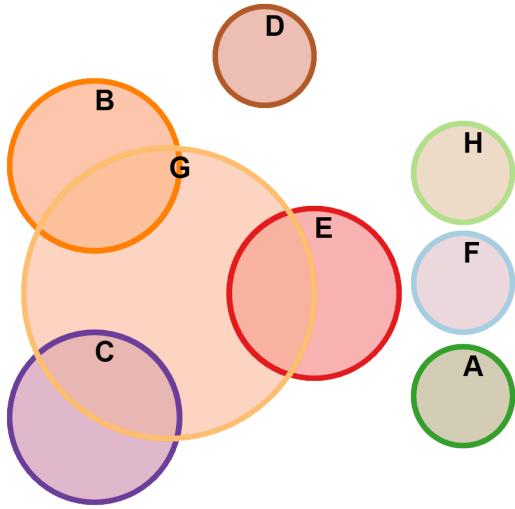
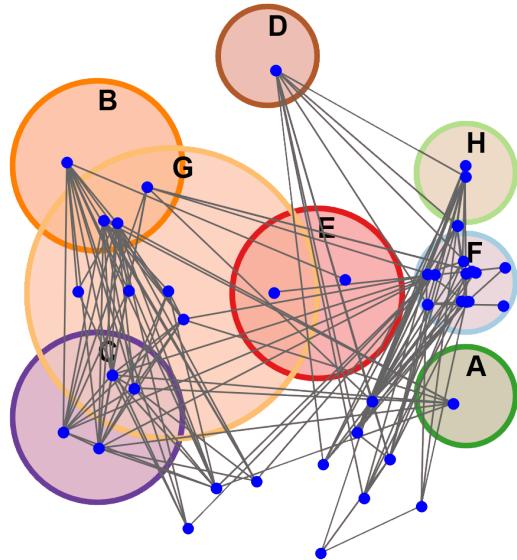
Number of Sets: 8

Number of Nodes: 43

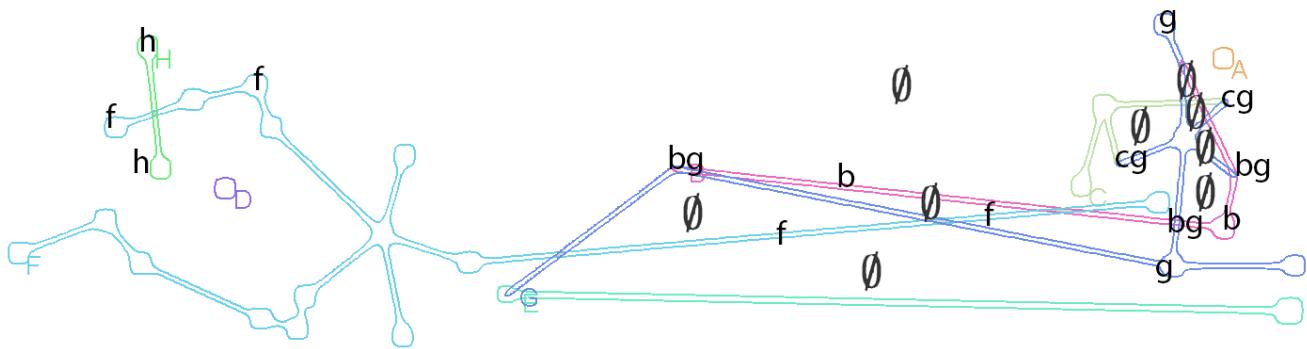
Number of Zones: 12

Number of Edges: 144

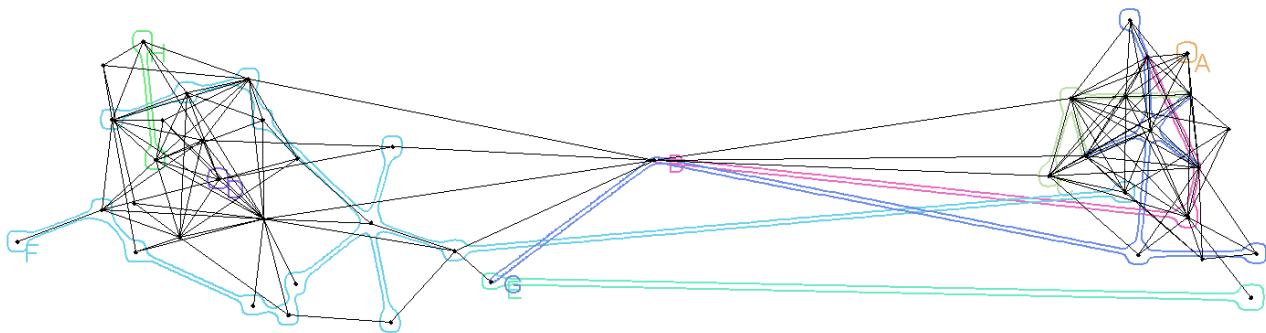
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	139	7	332
Vertex-vertex intersections	11	0	0
Vertices not in the correct zone	1	1	1
Omitted zones	0	0	0
Duplicated labels	0	0	0
Disconnected zones	0	17	0
Curve concurrency	0	0	3
Triple points	0	0	1
Non-circles	0	8	8
Extra zones	0	5	0
Edge crossings	1344	359	1042
Edge-curve crossings	48	218	107
Runtime (in sec)	3.057	0.922	8.481

SetNet (without graph)**SetNet (with graph)**

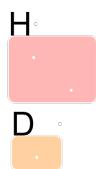
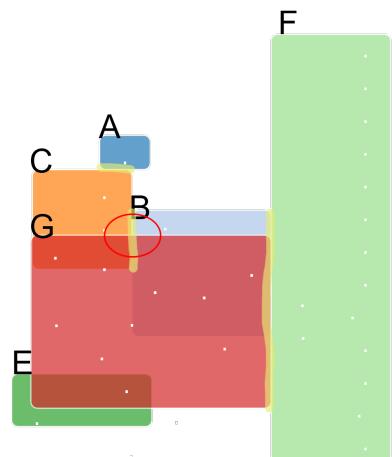
BubbleSets (without graph)



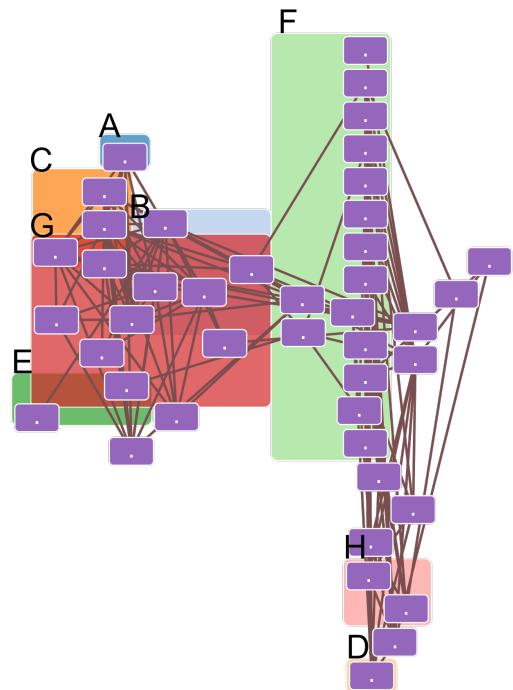
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



8-set data set 4 SNAP ID: 13274152

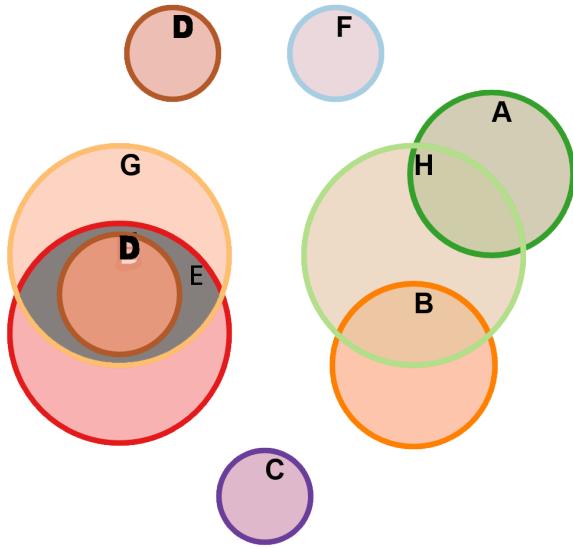
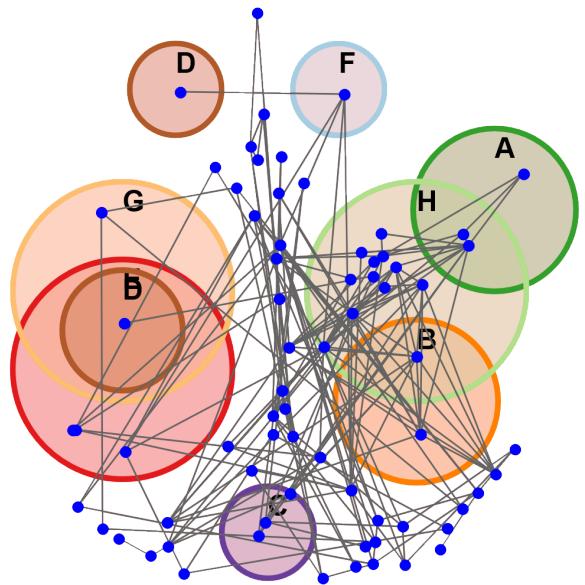
Number of Sets: 8

Number of Nodes: 70

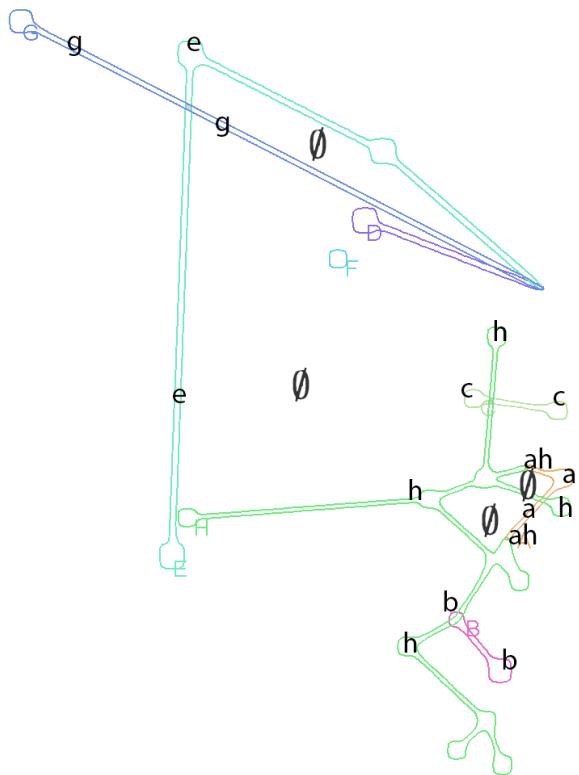
Number of Zones: 12

Number of Edges: 157

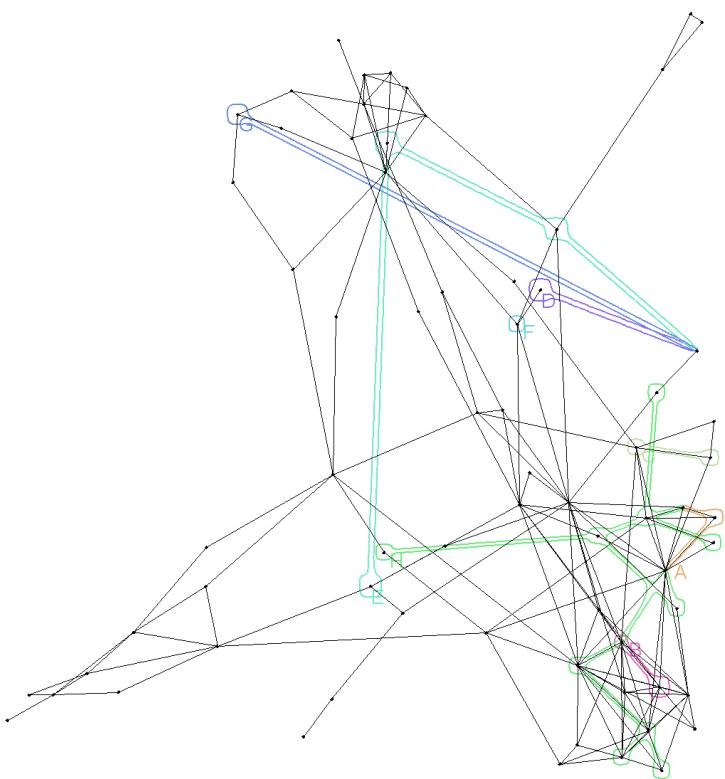
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	133	7	207
Vertex-vertex intersections	3	0	0
Vertices not in the correct zone	2	2	3
Omitted zones	0	0	1
Duplicated labels	1	0	0
Disconnected zones	0	12	0
Curve concurrency	0	0	5
Triple points	0	0	2
Non-circles	0	8	8
Extra zones	1	2	2
Edge crossings	1678	200	881
Edge-curve crossings	61	148	223
Runtime (in sec)	5.141	0.594	9.028

SetNet (without graph)**SetNet (with graph)**

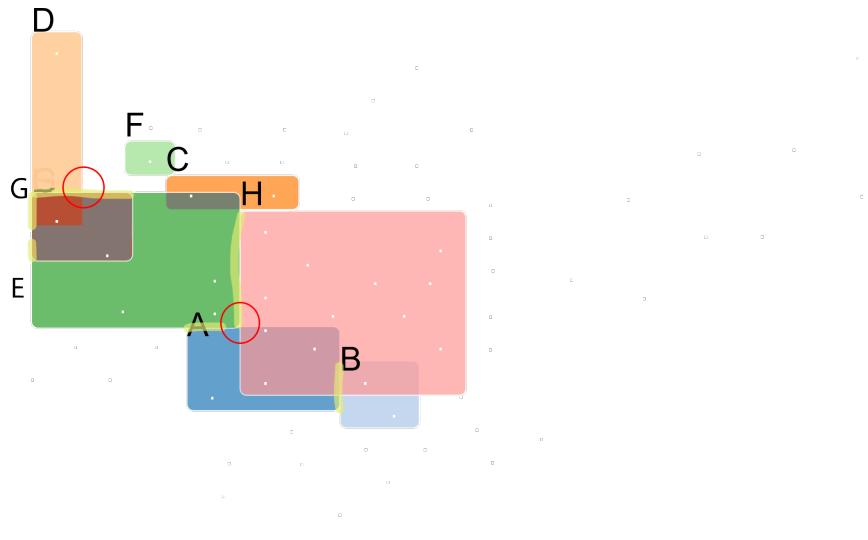
BubbleSets (without graph)



BubbleSets (with graph)

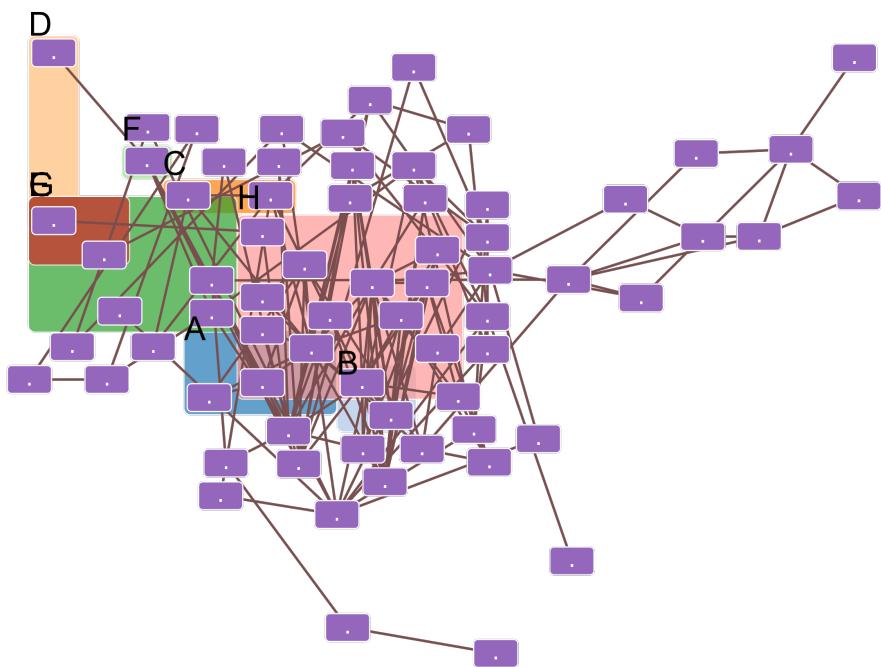


WebCola (without graph)



Omitted zones: G

WebCola (with graph)



8-set data set 5 SNAP ID: 77843323

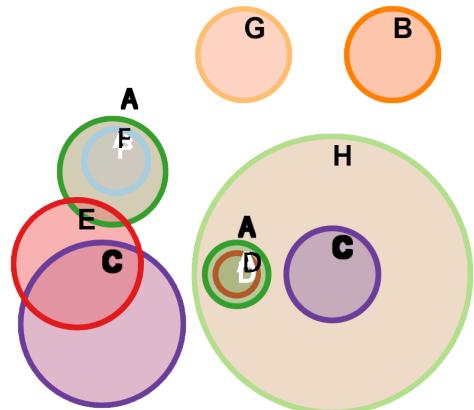
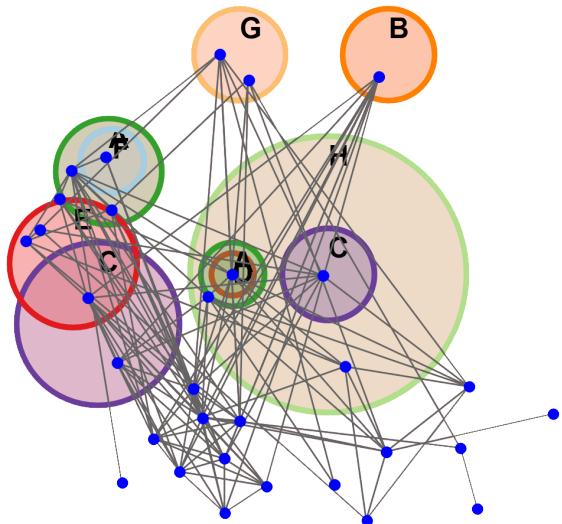
Number of Sets: 8

Number of Nodes: 31

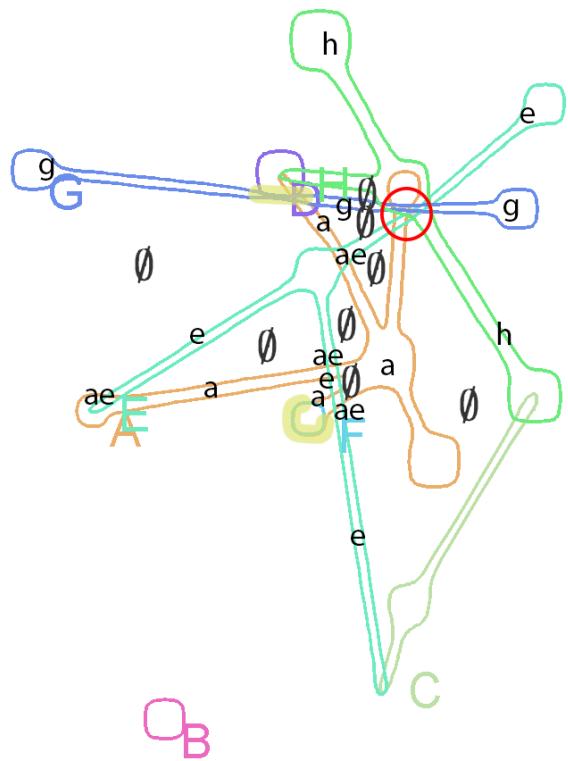
Number of Zones: 13

Number of Edges: 122

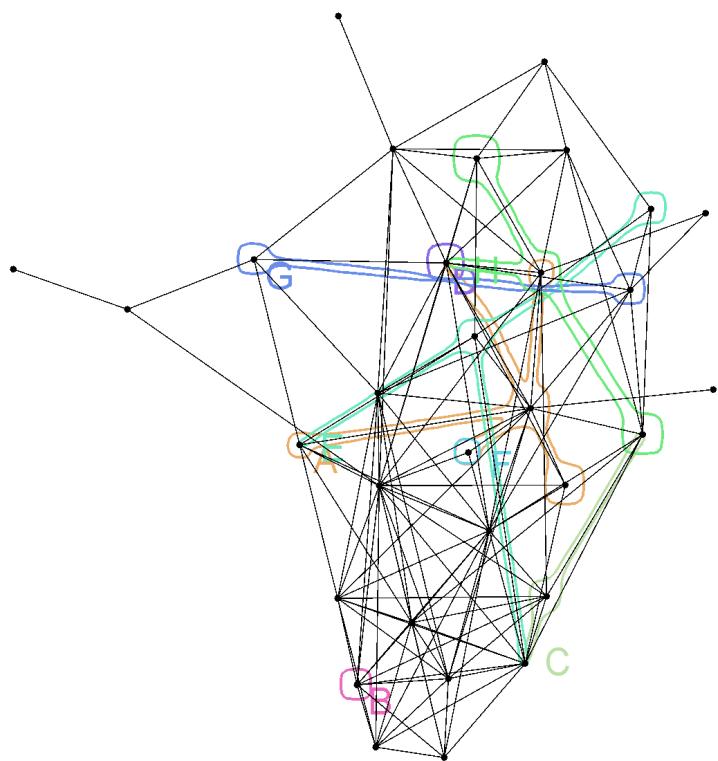
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	26	7	144
Vertex-vertex intersections	0	0	1
Vertices not in the correct zone	3	1	3
Omitted zones	0	0	0
Duplicated labels	2	0	0
Disconnected zones	0	19	0
Curve concurrency	0	2	3
Triple points	0	1	3
Non-circles	0	8	8
Extra zones	0	3	2
Edge crossings	934	411	847
Edge-curve crossings	73	208	188
Runtime (in sec)	2.445	0.515	8.399

SetNet (without graph)**SetNet (with graph)**

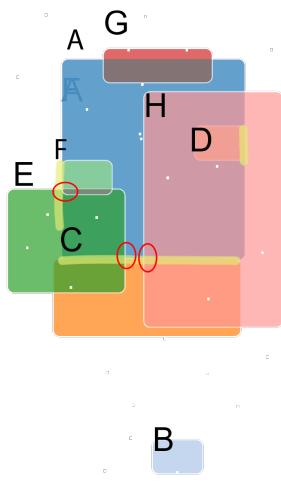
BubbleSets (without graph)



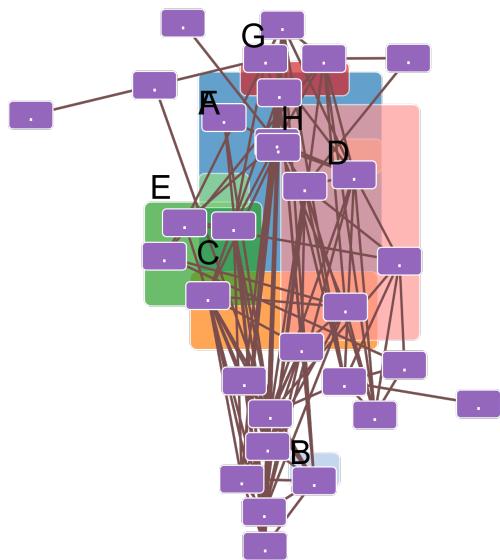
BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)



8-set data set 6 SNAP ID: 45310286

Number of Sets: 8

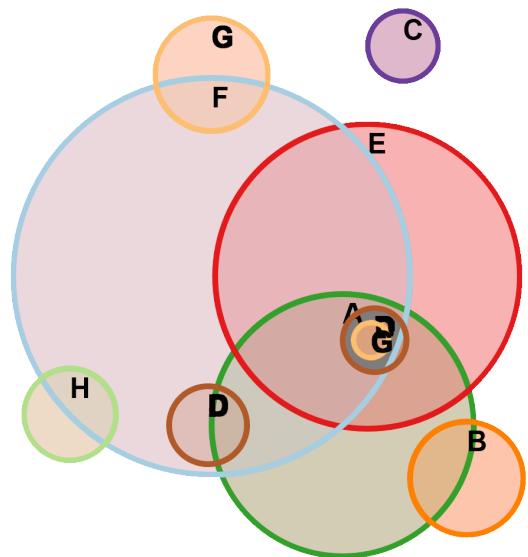
Number of Zones: 19

Number of Nodes: 33

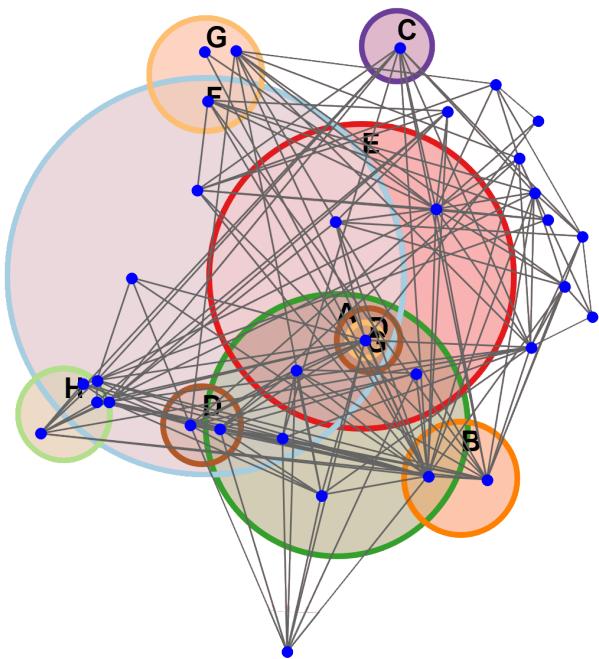
Number of Edges: 148

	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	37	4	203
Vertex-vertex intersections	0	0	10
Vertices not in the correct zone	3	0	13
Omitted zones	0	0	8
Duplicated labels	2	0	0
Disconnected zones	0	25	0
Curve concurrency	0	7	7
Triple points	0	4	0
Non-circles	0	8	8
Extra zones	0	3	3
Edge crossings	1420	595	1477
Edge-curve crossings	90	437	267
Runtime (in sec)	2.844	0.643	7.989

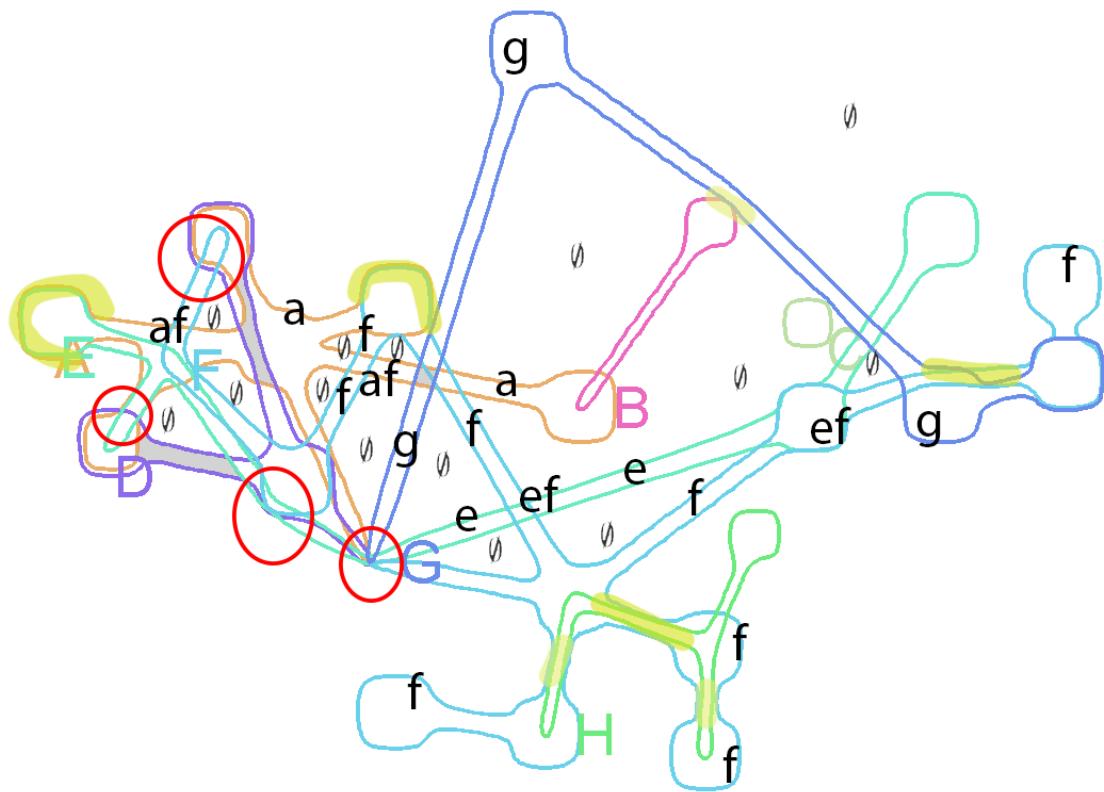
SetNet (without graph)



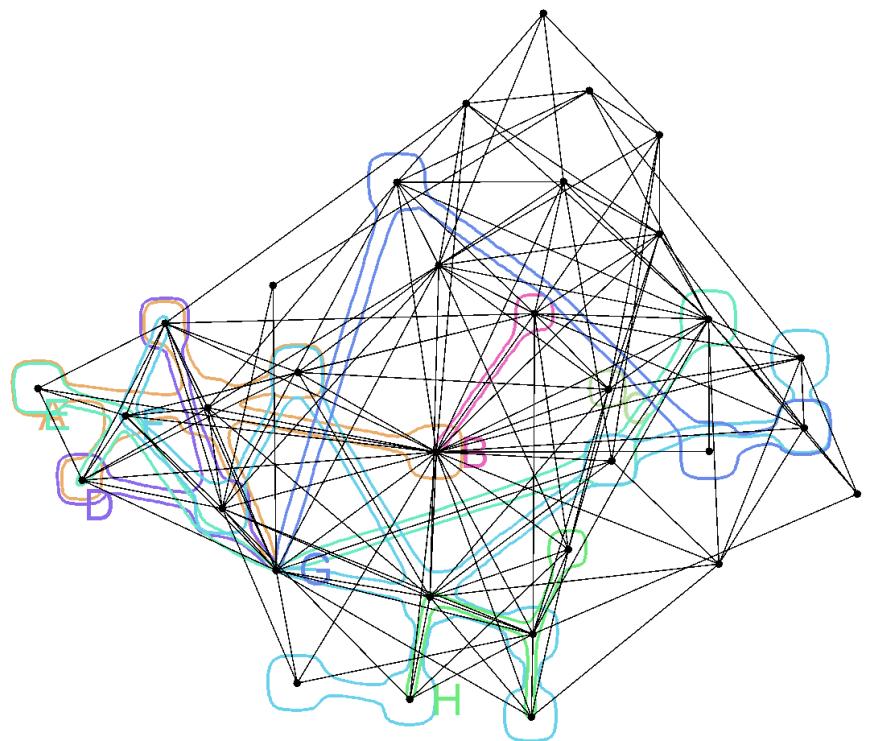
SetNet (with graph)



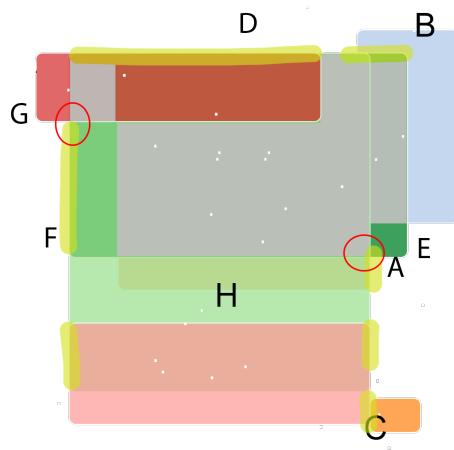
BubbleSets (without graph)



BubbleSets (with graph)

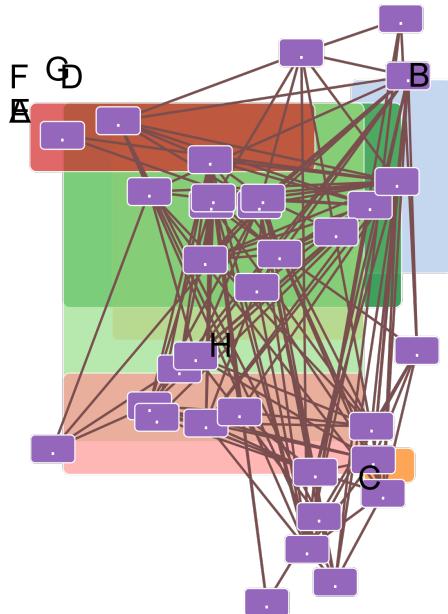


WebCola (without graph)



Omitted zones: A, E, AB, AF, EF, FG, ADE,
ADF

WebCola (with graph)



8-set data set 7 SNAP ID: 16809036

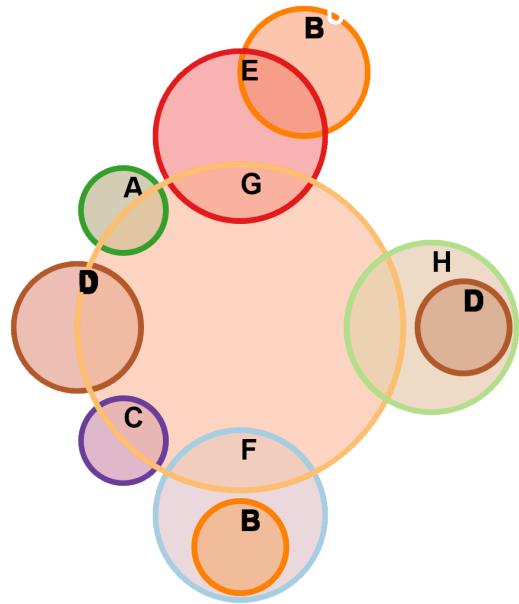
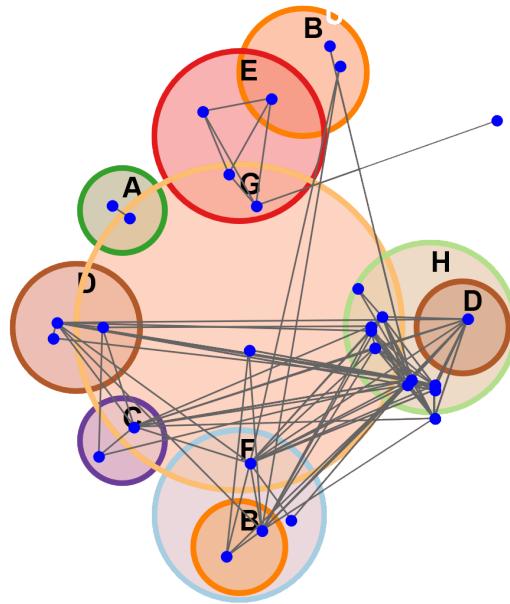
Number of Sets: 8

Number of Nodes: 41

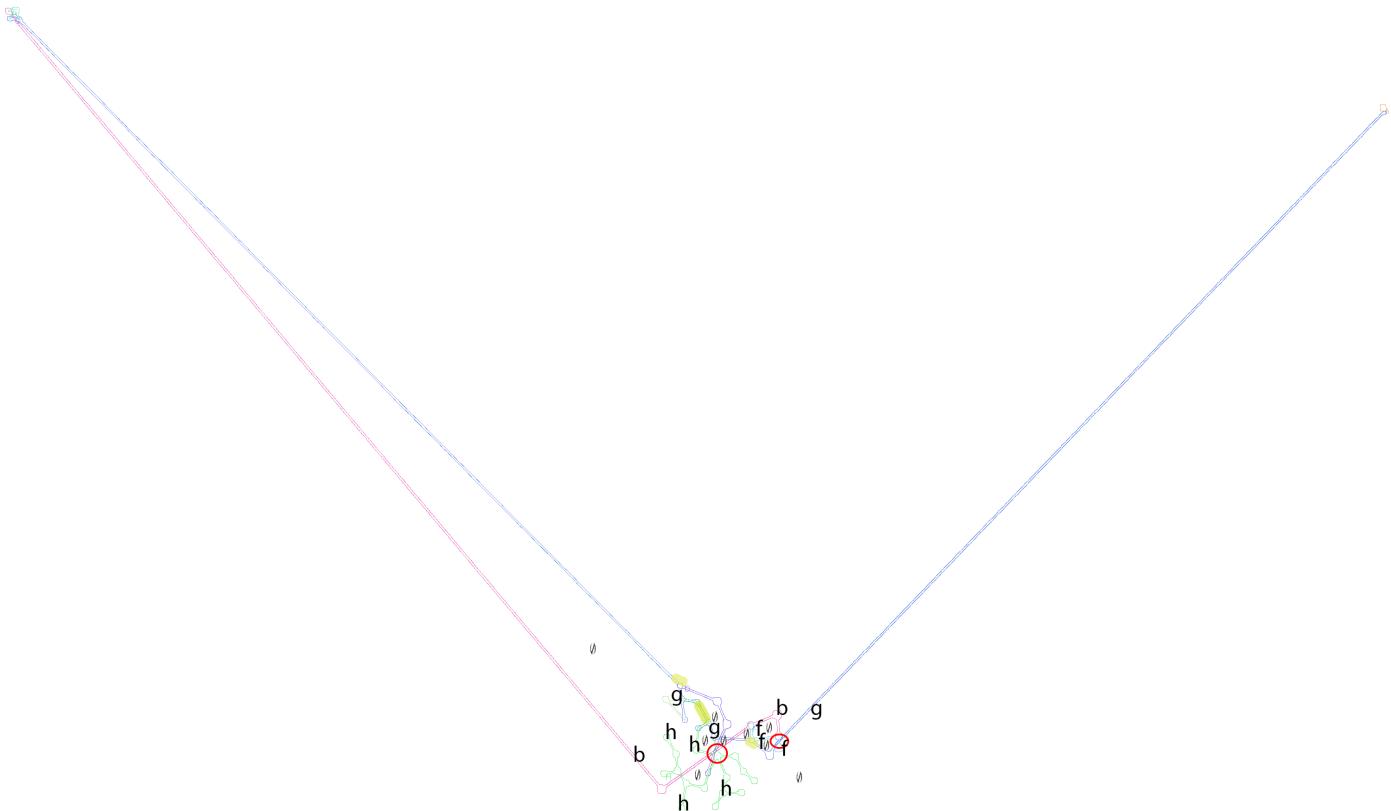
Number of Zones: 18

Number of Edges: 161

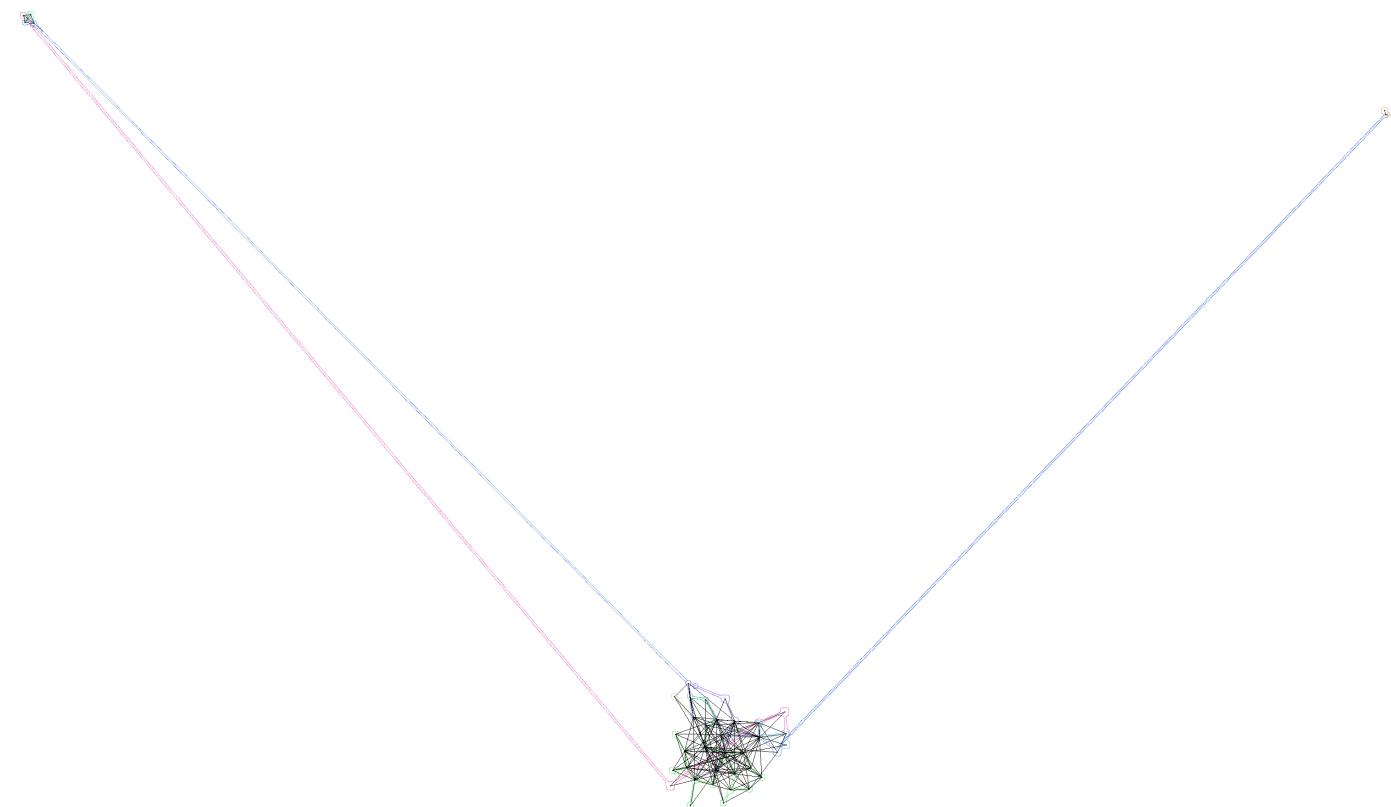
	SetNet	Bubble Sets	WebCola
Edge-vertex intersections	648	10	247
Vertex-vertex intersections	38	0	19
Vertices not in the correct zone	1	1	7
Omitted zones	0	0	1
Duplicated labels	2	0	0
Disconnected zones	0	16	1
Curve concurrency	0	3	4
Triple points	0	2	0
Non-circles	0	8	8
Extra zones	0	3	1
Edge crossings	1307	1019	1588
Edge-curve crossings	51	549	67
Runtime (in sec)	3.488	4.354	8.198

SetNet (without graph)**SetNet (with graph)**

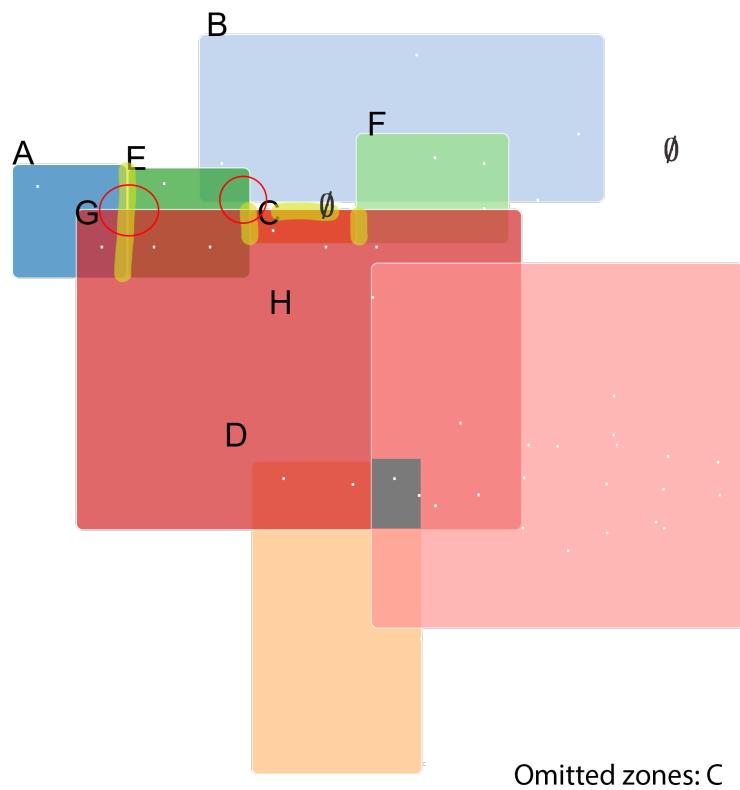
BubbleSets (without graph)



BubbleSets (with graph)



WebCola (without graph)



WebCola (with graph)

