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Big Data: Have You Seen It?
Using Graph Theory to Improve Your Analytics

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ABSTRACT

Your data analysis projects can use the SAS® LASR™ Analytic Server and its new HYPERGROUP functionality to mine relationships using graph theory. Discover which data entities are related and, conversely, which sets of values are disjoint. In cases when the sets of values are not completely disjoint, HYPERGROUP can identify data that is strongly connected and identify “neighboring” data that is weakly connected, or data that is a greater distance away. Each record is assigned a hypergroup number and, within hypergroups, is assigned a color, community, or both. The GROUPBY facility, WHERE clauses, or both can act on a hypergroup’s number, color, or community to conduct analytics using data that is “close”, “related”, or more “relevant”. The algorithms that are used to determine hypergroups are based on graph theory. We show how the results of HYPERGROUP allow equivalent graphs to be displayed and useful information to be seen, aiding you in controlling what data is required to perform your analytics.

INTRODUCTION

SAS LASR Analytic Server can handle *really* big data. It does so by distributing data across a grid, and using analytical algorithms specially designed to harness the computing power of a grid, executing in multiple threads on every grid computer. Sometimes data is so big that determining reasonable ways to reduce its size is necessary to reduce runtimes. Also, breaking apart data is sensible in that analytic tasks use data that’s related in some way. You make better business decisions, faster. Crucial data structure can be unearthed and seen. A case study using Facebook data is included in the last section of the paper.

AN APPLICATION

HYPERGROUP is useful in a wide variety of applications. One that springs to mind is a business that makes recommendations to customers as to what they should buy. A LASR table can have a variable containing customer names, and another variable for some commodity they bought, borrowed, or rented, or an offer to which the customer responded. There might be other variables that can be used to separate data such as customer traits (for example, location, age, income) or commodity traits such as model or price. By determining hypergroups, you learn how data has disjoint sets of values for variables, enabling analyses to be conducted per hypergroup.

Imagine a LASR table that has a column for customer names, and another column for vehicles they bought. By hypergrouping these two variables, an output LASR table is produced that is usually similar to original data with the addition of a column called _HypGrp_ that has values 0, 1, 2, ... so that records that belong to the same hypergroup have the same _HypGrp_ value. You can, for example, see the records of vehicle buyers who all bought one or more vehicles belonging to the same set of vehicles. If data has two hypergroups, then there are no records that indicate any of hypergroup 0's customers bought any hypergroup 1 vehicles, and no hypergroup 1 customers bought any hypergroup 0 vehicles.

You do not supply the sets of values. There might be no way you could. Disjoint sets of values are found by HYPERGROUP. In the example, you do not know beforehand whether some customer is a hypergroup 0 customer or a hypergroup 1 customer, nor beforehand whether some vehicle is a hypergroup 0 vehicle or a hypergroup 1 vehicle.

Once HYPERGROUP has been run, imagine a new customer arrives on the scene; you can determine whether he is more like existing customers of either hypergroup 0 or 1 and market vehicles we presume he would prefer to buy belonging to hypergroup 0 or 1 vehicles, respectively. Alternatively, if you manufacture a new vehicle that is similar to either hypergroup 0 or 1 vehicles, you might best expend marketing effort to customers in hypergroup 0 or 1, respectively.

Hypergroup technology is often used in “Recommender” systems. When you are shopping at an Internet retailer, they provide you with items they recommend you also consider buying. That’s based on your previous buying history and, as important, customers like you.

ANOTHER APPLICATION

In customer/campaign/account/insurance policy management applications, and other data cleansing/standardization of data applications, data may have a column for customer names, and another column for address. If these columns are hypergrouped then, for example, records that have these values in the name column: John Smith, J. Smith, John A. Smith, John Smith Jr., Dr. Smith, The Right Honorable John Archibald Smith, Esq., and have the same value, 123 Main St., for the address column, is determined by the Hypergroup action to belong to the same hypergroup.

Now imagine this individual (who goes by several names in your data) owns a vacation home at 456 Beach Rd. This becomes known because of a record in the data that has one of the names he goes by and the value 456 Beach Rd. in the address column, although you’d better check this is not another man named John Smith. Suppose it’s the same guy. Now all records that have any one of the John Smith name variations in the Name Column, and either of the two addresses in the Address column are determined to belong to the same hypergroup.

If that is the extent of the hypergroup, then there are no records that indicate this individual lives anywhere other than these two addresses. There are no records that indicate any other person lives at either of these two addresses.

Now imagine the table has a third column whose values are telephone numbers. Hypergroup all three columns: name, address, and phone number, and interesting associations may be revealed. For instance, if there is a record in data that has address 456 Beach Rd. and phone number 555-1212, then you can imply that phone number belongs to John Smith. If there is a record that has the value J. Smith PhD in the name column and 555-1212 in the phone number column, then that’s another name he has used,… and whenever a new association is discovered, that in turn may cause yet more associations to be discovered.

If there is a record with name Harry Smith and phone number 555-1212, then this could reveal a valid connection, or not, if data was incorrectly entered. In fraud detection applications, such connections are of interest, possibly suspicious. (The Right Honorable Dr. John Archibald Smith, Esq. is using the pseudonym Harry Smith to commit a fraud- surely not?)

Similar applications have been used to detect and investigate criminal and terrorist networks. For managing promotional campaigns, hypergrouping allows you to send offers to only one member of a household.

THE HYPERGROUP ACTION

The SAS program below puts PROC IMSTAT to work determining hypergroups. In the following data set, variables varA to varD are the hypergroup variables, and the remaining variables are other variables you need to appear in an output LASR table.

The varA to varD variable values have values beginning with A and Z, B and Y, C and X, and so on. In our example that distinguishes different hypergroups. However, in real-world data, hypergroups can rarely have such obvious distinctiveness, and can rarely be identified by eye, nor can data for hypergroups reside in consecutive records, on the same LASR server nodes. Hypergroups cannot usually be identified and highlight-colored as in the following DATA step. It's rare that hypergroups can be indicated by WHERE clauses or as ordinary GROUPBY variables without hypergroups first being determined.

```
data arc1;
  input varA $ varB $ varC $ varD $ extra1 extra2 $ extra3 $ extra4 @@;
```

```
     datalines;
A00 A01 A04 Z05 0 A Z 5  B00 B01 B04 Y06 0 B Y 6  C00 C01 C04 X06 0 C X 6
A00 A02 A04 Z06 0 A Z 6  B00 B02 B04 Y07 0 B Y 7  C00 C02 C04 X07 0 C X 7
A01 A02 A04 Z07 1 A Z 7  B01 B02 Y05 Y07 1 B Y 7  C01 C02 X05 X07 1 C X 7
A01 A04 Z05 Z07 1 A Z 7  B01 B04 Y05 Y08 1 B Y 8  C01 C04 X05 X08 1 C X 8
A02 A03 Z05 Z08 2 A Z 8  B02 B03 Y06 Y07 2 B Y 7  C02 C03 X06 X07 2 C X 7
A02 A04 Z06 Z07 2 A Z 7  B02 B04 Y06 Y09 2 B Y 9  C02 C04 X06 X09 2 C X 9
A02 Z05 Z06 Z09 2 A Z 9  B02 Y05 Y07 Y08 2 B Y 8  C02 X05 X07 X08 2 C X 8
A03 Z05 Z07 Z08 3 A Z 8  B03 Y05 Y07 Y09 3 B Y 9  C03 X05 X07 X09 3 C X 9
A04 Z05 Z07 Z09 4 A Z 9  B04 Y05 Y08 Y09 4 B Y 9  C04 X05 X08 X09 4 C X 9
A04 Z06 Z08 Z09 4 A Z 9
D00 D01 D04 W06 0 D W 6  E00 E01 E04 V06 0 E V 6  F00 F01 F04 U06 0 F U 6
D00 D02 D04 W07 0 D W 7  E00 E02 E04 V07 0 E V 7  F00 F02 F04 U07 0 F U 7
D01 D02 W05 W07 1 D W 7  E01 E02 V05 V07 1 E V 7  F01 F02 U05 U07 1 F U 7
D01 D04 W05 W08 1 D W 8  E01 E04 V05 V08 1 E V 8  F01 F04 U05 U08 1 F U 8
D02 D03 W06 W07 2 D W 7  E02 E03 V06 V07 2 E V 7  F02 F03 U06 U07 2 F U 7
D02 D04 W06 W09 2 D W 9  E02 E04 V06 V09 2 E V 9  F02 F04 U06 U09 2 F U 9
D02 W05 W07 W08 2 D W 8  E02 V05 V07 V08 2 E V 8  F02 U05 U07 U08 2 F U 8
D03 W05 W07 W09 3 D W 9  E03 V05 V07 V09 3 E V 9  F03 U05 U07 U09 3 F U 9
D04 W05 W08 W09 4 D W 9  E04 V05 V08 V09 4 E V 9  F04 U05 U08 U09 4 F U 9
;
   proc lasr
         create force port= &pport data=arc1 path="/tmp/";
      performance host= &hhost nodes=3 threads=2;   /* you change */
   run;
   libname mylasr sasiola host=&hhost port= &pport tag=work;

   proc imstat data=mylasr.arc1;
       hypergroup VarA varB varC varD / vars=(extra4 extra3 extra2 extra1)
   save=hyptable;
   run;
```

OUTPUT TEMPTABLES

The HYPERGROUP statement creates at least three temporary LASR tables that are assigned to SAS macros _TEMPLAST_ , _TEMPHYPGRP_ , and _TEMPEDGES_:

The _TEMPLAST_ Temptable

In this example, the HYPERGROUP statement was specified as this:

```
   hypergroup VarA varB varC varD / vars=(extra4 extra3 extra2 extra1);
```

Therefore, the _templast_ temp table has these columns:

- a _HypGrp_ column with values that are hypergroup numbers (0, 1, 2, …).
- the variables VarA varB varC varD specified between hypergroup and the slash, or if there is no slash, the semicolon.
- the VAR=(…) columns--if there are any--extra4 extra3 extra2 extra1. These are columns that are not hypergroup columns that you want to appear in output tables.

```
   table mylasr.&_templast_;
       fetch / from=1 to=150;
   run;
```

```
    Selected Records from Table _T_8651BD0F_7F9390521138
 _HypGrp_ varA varB varC varD   extra4 extra3 extra2 extra1
        0 A00  A01  A04  Z05  5.000000      Z  A      0
        0 A00  A02  A04  Z06  6.000000      Z  A      0
        0 A01  A02  A04  Z07  7.000000      Z  A      1.000000
        0 A01  A04  Z05  Z07  7.000000      Z  A      1.000000
        0 A02  A03  Z05  Z08  8.000000      Z  A      2.000000
```

```
       0 A02  A04  Z06  Z07  7.000000      Z A      2.000000
       0 A02  Z05  Z06  Z09  9.000000      Z A      2.000000
       0 A03  Z05  Z07  Z08  8.000000      Z A      3.000000
       0 A04  Z05  Z07  Z09  9.000000      Z A      4.000000
       0 A04  Z06  Z08  Z09  9.000000      Z A      4.000000
1.000000 B00  B01  B04  Y06  6.000000      Y B      0
1.000000 B00  B02  B04  Y07  7.000000      Y B      0
1.000000 B01  B02  Y05  Y07  7.000000      Y B      1.000000
1.000000 B01  B04  Y05  Y08  8.000000      Y B      1.000000
1.000000 B02  B03  Y06  Y07  7.000000      Y B      2.000000
1.000000 B02  B04  Y06  Y09  9.000000      Y B      2.000000
1.000000 B02  Y05  Y07  Y08  8.000000      Y B      2.000000
1.000000 B03  Y05  Y07  Y09  9.000000      Y B      3.000000
1.000000 B04  Y05  Y08  Y09  9.000000      Y B      4.000000
2.000000 C00  C01  C04  X06  6.000000      X C      0
2.000000 C00  C02  C04  X07  7.000000      X C      0
2.000000 C01  C02  X05  X07  7.000000      X C      1.000000
2.000000 C01  C04  X05  X08  8.000000      X C      1.000000
2.000000 C02  C03  X06  X07  7.000000      X C      2.000000
2.000000 C02  C04  X06  X09  9.000000      X C      2.000000
2.000000 C02  X05  X07  X08  8.000000      X C      2.000000
2.000000 C03  X05  X07  X09  9.000000      X C      3.000000
2.000000 C04  X05  X08  X09  9.000000      X C      4.000000
3.000000 D00  D01  D04  W06  6.000000      W D      0
3.000000 D00  D02  D04  W07  7.000000      W D      0
3.000000 D01  D02  W05  W07  7.000000      W D      1.000000
3.000000 D01  D04  W05  W08  8.000000      W D      1.000000
3.000000 D02  D03  W06  W07  7.000000      W D      2.000000
3.000000 D02  D04  W06  W09  9.000000      W D      2.000000
3.000000 D02  W05  W07  W08  8.000000      W D      2.000000
3.000000 D03  W05  W07  W09  9.000000      W D      3.000000
3.000000 D04  W05  W08  W09  9.000000      W D      4.000000
4.000000 E00  E01  E04  V06  6.000000      V E      0
4.000000 E00  E02  E04  V07  7.000000      V E      0
4.000000 E01  E02  V05  V07  7.000000      V E      1.000000
4.000000 E01  E04  V05  V08  8.000000      V E      1.000000
4.000000 E02  E03  V06  V07  7.000000      V E      2.000000
4.000000 E02  E04  V06  V09  9.000000      V E      2.000000
4.000000 E02  V05  V07  V08  8.000000      V E      2.000000
4.000000 E03  V05  V07  V09  9.000000      V E      3.000000
4.000000 E04  V05  V08  V09  9.000000      V E      4.000000
5.000000 F00  F01  F04  U06  6.000000      U F      0
5.000000 F00  F02  F04  U07  7.000000      U F      0
5.000000 F01  F02  U05  U07  7.000000      U F      1.000000
5.000000 F01  F04  U05  U08  8.000000      U F      1.000000
5.000000 F02  F03  U06  U07  7.000000      U F      2.000000
5.000000 F02  F04  U06  U09  9.000000      U F      2.000000
5.000000 F02  U05  U07  U08  8.000000      U F      2.000000
5.000000 F03  U05  U07  U09  9.000000      U F      3.000000
5.000000 F04  U05  U08  U09  9.000000      U F      4.000000
```

The _TEMPHYPGRP_ Temptable

The _tempHypGrp_ temp table has records pertaining to values of the hypergroup variables. It has at a minimum these columns:

- _Value_ : values of hypergroup variables. These are graph vertex names.

- _Index_ : vertex indices (0, 1, 2, …).
- a _HypGrp_ : hypergroup numbers (0, 1, 2, …).
- _indexH_ : vertex indices (0, 1, 2, …) but only within hypergroup subgraphs.
- _XCoord_ and _YCoord_: the coordinates of vertices.

```
table mylasr.&_temphypgrp_;
    fetch / from=1 to=60;
run;
```

```
   Selected Records from
Table _T_8651BD12_7F9390521158
_Value_ _Index_  _HypGrp_  _IndexH_   _XCoord_   _YCoord_
A00            0         0         0  47.751283  86.484868   …
A01     1.000000         0  1.000000  88.000000  48.243896
A02     2.000000         0  9.000000  65.407182  59.212735
A03     3.000000         0  6.000000  47.026785  67.283859
A04     4.000000         0  2.000000  47.751283  86.484868
B00     5.000000  1.000000         0  69.768578  88.000000
B01     6.000000  1.000000  1.000000  69.768578  88.000000
B02     7.000000  1.000000  9.000000  58.706541  87.376854
B03     8.000000  1.000000  6.000000  70.419826  86.644392
B04     9.000000  1.000000  2.000000  69.768578  88.000000
C00    10.000000  2.000000         0  67.796955  88.000000
C01    11.000000  2.000000  1.000000  67.796955  88.000000
C02    12.000000  2.000000  9.000000  67.485462  86.756084
C03    13.000000  2.000000  6.000000  69.037437  87.019508
C04    14.000000  2.000000  2.000000  67.796955  88.000000
D00    15.000000  3.000000         0  67.613033  88.000000
D01    16.000000  3.000000  1.000000  67.613033  88.000000
D02    17.000000  3.000000  9.000000  71.471194  87.030314
D03    18.000000  3.000000  6.000000  77.220188  86.589432
D04    19.000000  3.000000  2.000000  67.613033  88.000000
E00    20.000000  4.000000         0  82.953739  13.577823
E01    21.000000  4.000000  1.000000  86.255796  14.108228
E02    22.000000  4.000000  9.000000  85.575935  12.750469
E03    23.000000  4.000000  6.000000  83.787772  14.723783
E04    24.000000  4.000000  2.000000  87.366915  12.405042
F00    25.000000  5.000000         0  81.349289  14.107479
F01    26.000000  5.000000  1.000000  82.762365  14.069005
F02    27.000000  5.000000  9.000000  84.532841  13.958093
F03    28.000000  5.000000  6.000000  83.797687  12.575291
F04    29.000000  5.000000  2.000000  84.180868  13.177457
U05    30.000000  5.000000  3.000000  86.281249  13.591267
U06    31.000000  5.000000  7.000000  81.526809  12.205444
U07    32.000000  5.000000  8.000000  85.698858  12.000000
U08    33.000000  5.000000  4.000000  88.000000  13.827690
U09    34.000000  5.000000  5.000000  12.000000  88.000000
V05    35.000000  4.000000  3.000000  85.858098  13.437597
V06    36.000000  4.000000  7.000000  86.547623  12.000000
V07    37.000000  4.000000  8.000000  88.000000  13.256272
V08    38.000000  4.000000  4.000000  85.256010  12.234297
V09    39.000000  4.000000  5.000000  12.000000  88.000000
W05    40.000000  3.000000  3.000000  59.839953  86.752841
W06    41.000000  3.000000  7.000000  88.000000  87.182425
W07    42.000000  3.000000  8.000000  52.710046  86.872934
W08    43.000000  3.000000  4.000000  40.022424  87.408962
```

```
W09   44.000000  3.000000  5.000000  12.000000  12.000000
X05   45.000000  2.000000  3.000000  88.000000  13.990856
X06   46.000000  2.000000  7.000000  86.964785  13.001636
X07   47.000000  2.000000  8.000000  86.129370  12.000000
X08   48.000000  2.000000  4.000000  12.000000  26.614086
X09   49.000000  2.000000  5.000000  12.000000  26.614086
Y05   50.000000  1.000000  3.000000  60.751506  86.896084
Y06   51.000000  1.000000  7.000000  88.000000  87.200911
Y07   52.000000  1.000000  8.000000  79.896879  86.702814
Y08   53.000000  1.000000  4.000000  44.376003  87.405119
Y09   54.000000  1.000000  5.000000  12.000000  12.000000
Z05   55.000000         0  3.000000  28.623736  60.593559
Z06   56.000000         0  7.000000  17.800663  35.110688
Z07   57.000000         0  8.000000  12.000000  12.000000
Z08   58.000000         0  4.000000  49.976991  88.000000
Z09   59.000000         0  5.000000  49.976991  88.000000
```

The _TEMPEDGES_ Temptable

Consider the first record in data:

```
varA   varB   varC varD
A00    A01    A04  Z05
```

This record generates three edges: (A00, A01), (A01, A04), and (A04, Z05).

The _TempEdges_ table has all the variables in _tempLast_, except instead of having the hypergroup variables (in this example, varA, varB, varC, and varD), there are variables: _Source_ and _Target_ that have values associated with the origin and destination of edges, and index and coordinates variables associated with the source and target vertices.

The _tempEdges _ temp table has at a minimum these columns:

- a _HypGrp_ : hypergroup numbers (0, 1, 2, …).
- _Source_ and _Target_ : the names of the vertices the edge connects.
- _Sindex_ and _TIndex_: vertex indices (0, 1, 2, …) of _Source_ and _Target_.
- _SindexH_ and _TIndexH_: vertex indices (0, 1, 2, …) of _Source_ and _Target_ but only within hypergroup subgraphs.
- _XCoordS_ and _YCoordS_: the coordinates of the _Source_ vertex.
- _XCoordT_ and _YCoordT_: the coordinates of the _Target_ vertex.

```
     Selected Records from Table _T_1E114D6E_7FC4D3FB21A0
_HypGrp_ _Source_ _Target_ _Sindex_  _Tindex_ _SindexH_ _TindexH_
       0 A00      A01             0  1.000000         0  1.000000
       0 A01      A04      1.000000  4.000000  1.000000  2.000000
       0 A04      Z05      4.000000 55.000000  2.000000  3.000000
       0 A00      A02             0  2.000000         0  9.000000
       0 A02      A04      2.000000  4.000000  9.000000  2.000000
       0 A04      Z06      4.000000 56.000000  2.000000  7.000000
       0 A01      A02      1.000000  2.000000  1.000000  9.000000
       0 A02      A04      2.000000  4.000000  9.000000  2.000000
       0 A04      Z07      4.000000 57.000000  2.000000  8.000000
       0 A01      A04      1.000000  4.000000  1.000000  2.000000
       0 A04      Z05      4.000000 55.000000  2.000000  3.000000
```

snip

```
 _SourceX_  _SourceY_  _TargetX_  _TargetY_    extra4  extra3  extra2  extra1
 47.751283  86.484868  88.000000  48.243896  5.000000  Z       A            0
 88.000000  48.243896  47.751283  86.484868  5.000000  Z       A            0
 47.751283  86.484868  28.623736  60.593559  5.000000  Z       A            0
 47.751283  86.484868  65.407182  59.212735  6.000000  Z       A            0
 65.407182  59.212735  47.751283  86.484868  6.000000  Z       A            0
 47.751283  86.484868  17.800663  35.110688  6.000000  Z       A            0
 88.000000  48.243896  65.407182  59.212735  7.000000  Z       A     1.000000
 65.407182  59.212735  47.751283  86.484868  7.000000  Z       A     1.000000
 47.751283  86.484868  12.000000  12.000000  7.000000  Z       A     1.000000
 88.000000  48.243896  47.751283  86.484868  7.000000  Z       A     1.000000
 47.751283  86.484868  28.623736  60.593559  7.000000  Z       A     1.000000
```

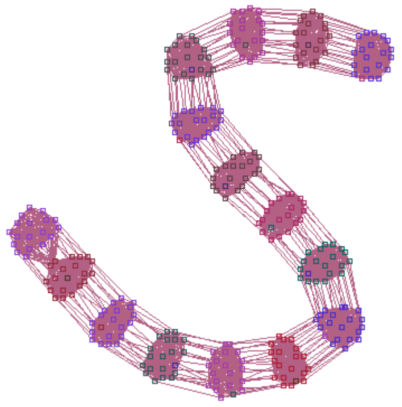
snip

STRONG AND WEAK CONNECTIONS

Big data is messy. Consider the data regarding customers who bought vehicles. Suppose some customers (set C_0) *usually* bought some vehicles (set V_0,), and other customers (set C_1) *usually* bought another set of vehicles (set V_1). These are strong links. However, there might be weak links, related to data that indicates C_0 customers who *occasionally* bought V_1 vehicles, and C_1 customers who *occasionally* bought V_0 vehicles. These purchases are outnumbered by the strong link purchases. If it were not for the weak links, C_0 and V_0 would be one hypergroup, and C_1 and V_1 another hypergroup, but as there are, all data might be one great big hypergroup.

You do not supply the sets of values. There might be no way you could. In this example, HYPERGROUP determines the C and V sets by two different algorithms, and outputs color number or community number 0 for records for C_0 V_0, and outputs a color number or community number 1 for records for C_1 V_1. You do not know beforehand whether some customer is a C_0 or C_1 customer, nor beforehand whether some vehicle is a V_0 or V_1 vehicle.

The algorithms used to determine hypergroups, and strong and weak links (and therefore colors and communities) within each hypergroup, are based on graph theory. Vertices have names that are values of hypergroup variables, and edges that connect vertices ($value_a$,$value_b$) are generated if there is any record in data that has $value_a$ and $value_b$ as values in adjacent hypergroup list variables.



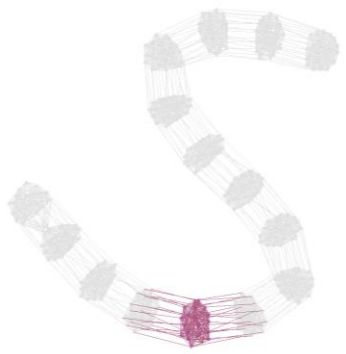
Graphs can dramatically visualize strong and weak connections.

If you zoom into parts of this graph that have vertices with mostly the same colors, you can see the strong connections. Weak connections are usually far fewer in number that connect vertices of different colors.

Therefore, HYPERGROUP formulates the underlying graph, and does the following:

- finds whether data can be broken into separate parts--that is, separate hypergroups. In graph theory terms, HYPERGROUP determines whether the graph has disconnected components.
- within a hypergroup, or the entire graph if there are no separate hypergroups, HYPERGROUP determines coordinates of the vertices so that the graph can be displayed, and can be used to zoom

into a particular part of the graph, consequently be a part of data, and subsequently perform analytics.

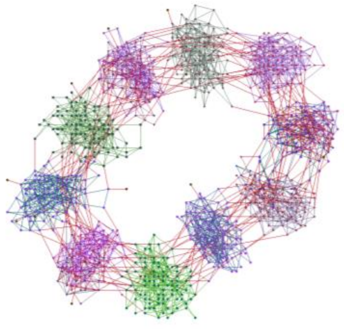
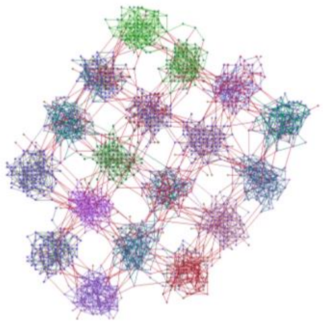
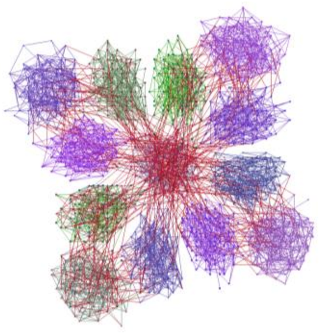


- determines colors, communities, or both, which can be used to color vertices and edges when graphs are displayed, or to zoom into a particular part of the graph and consequently a part of data, and subsequently perform analytics.
- produces structural graphs, as well as coordinates for them, and output details about strong subgraphs (for example, number of vertices strongly connected, and the number of actual edges that make those connections) and weak links (for example, number of actual edges that weakly connect strong subgraphs).
- computes various centrality measures, often used within a social network analysis application, and for other practitioners who wish to further refine what data is to be used by subsequent analytics.

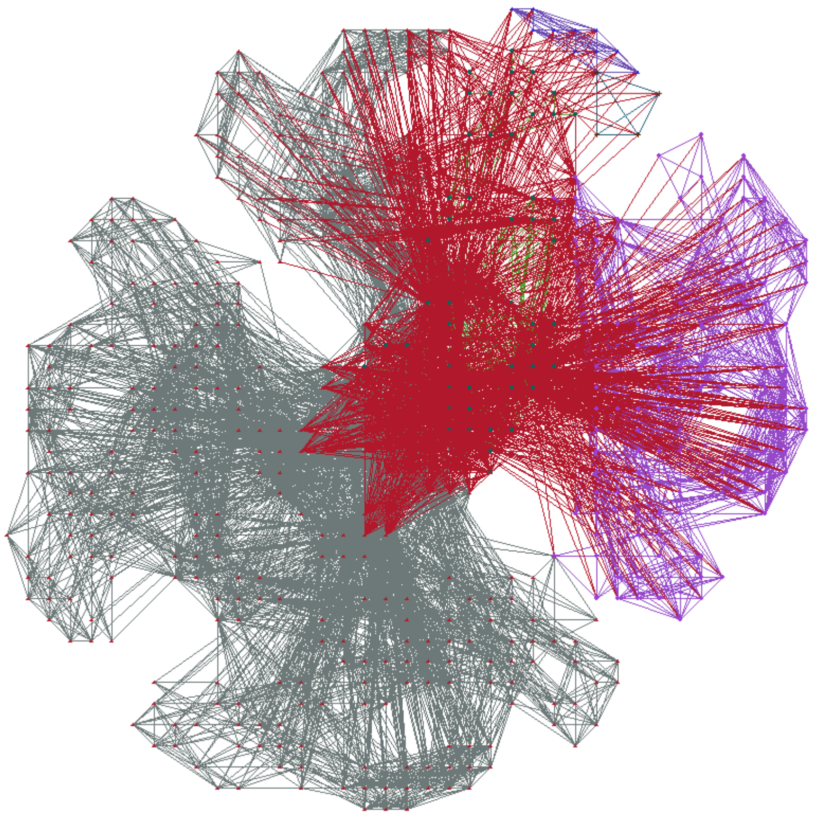
There are many options you can specify in the HYPERGROUP statement to control how layouts, colors, communities, structural graphs, and centrality are performed. The output temp tables will have more columns in them (for example, you've seen the _XCoord_ and _YCoord_ column in _TEMPHYPGRP_). There might also be _Color_, and _Community_, and more. You can also choose to skip some of these tasks that are ordinarily done.

Structural graphs and centrality are covered later in this paper.

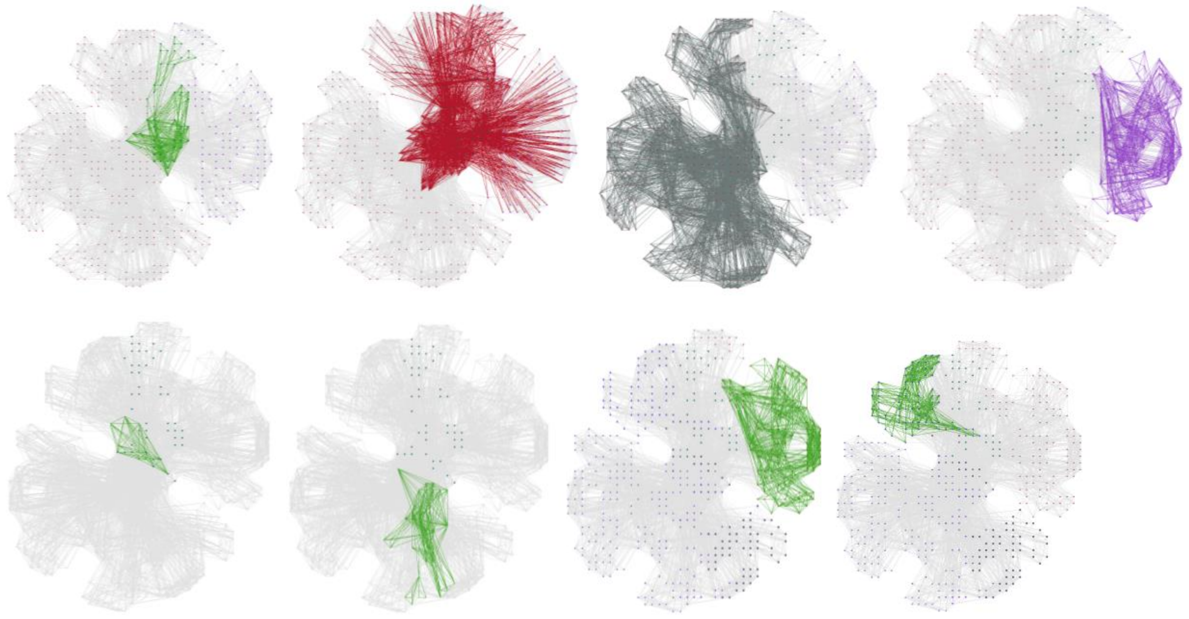
Here are more graphs that have circular, mesh, clover leaf: and later you'll see tree structures:

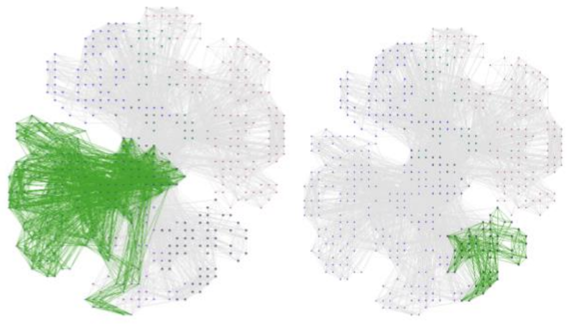




Real data is usually not so structured, although we never cease to be amazed how frequently HYPERGROUP reveals very interesting insights. Consider this graph:



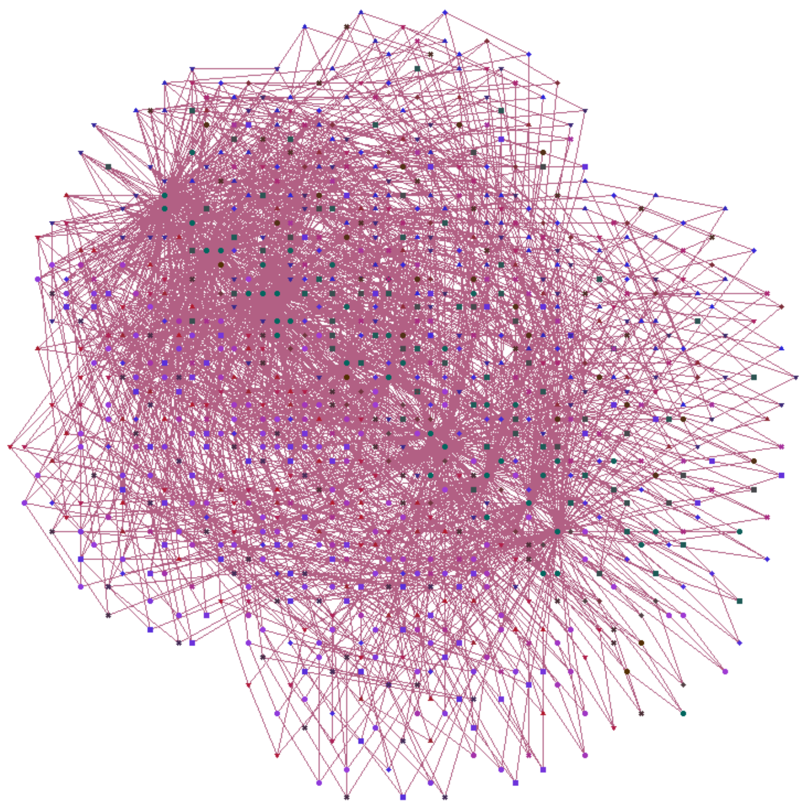
HYPERGROUP allows you considerable control over the way vertex or edge separators are determined, and the resulting graph partitions:





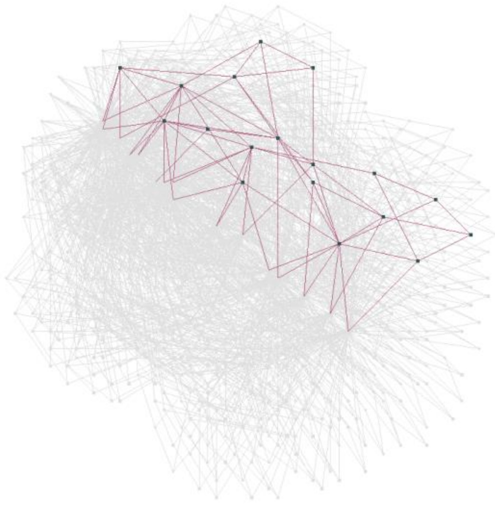
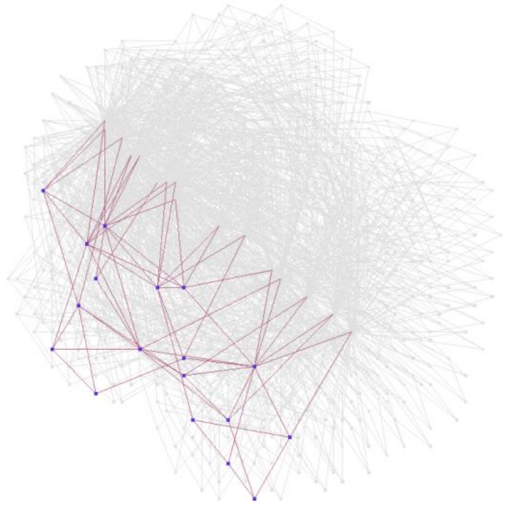
REMOVING NOISE AND CONFUSION

Consider the following graph whose vertices and colors have been determined with HYPERGROUP's default algorithms:

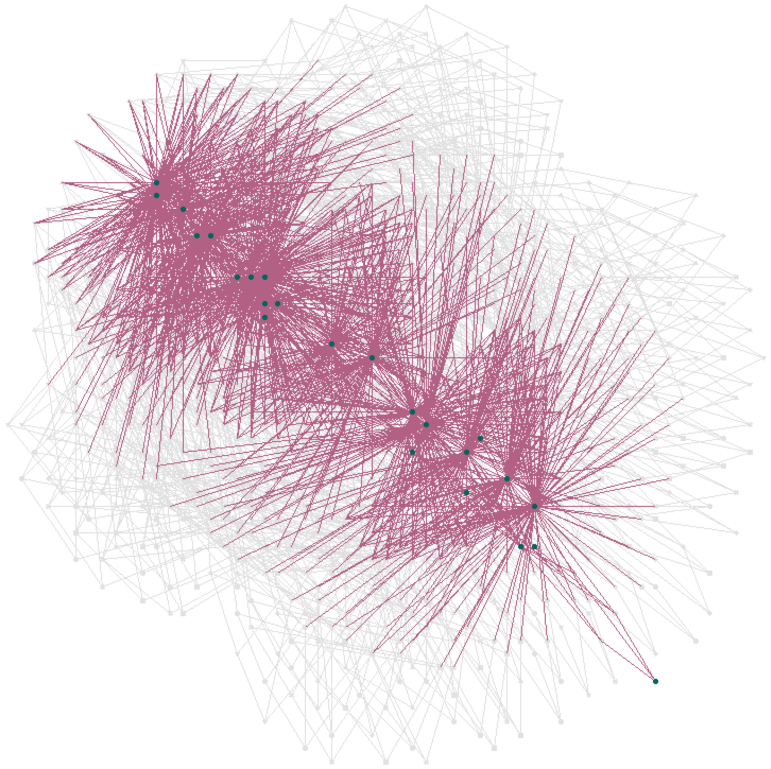


While none of the vertices are laid out on top of each other, which is good, some vertices with the same color are not very close, which is bad. Has HYPERGROUP failed to determine appropriate vertex color numbers? Is this really a graph that has no exploitable structure? You might think so, given the way it looks.

When the graph is displayed so that only vertices with the same color are prominently displayed, we see many subgraphs like these:

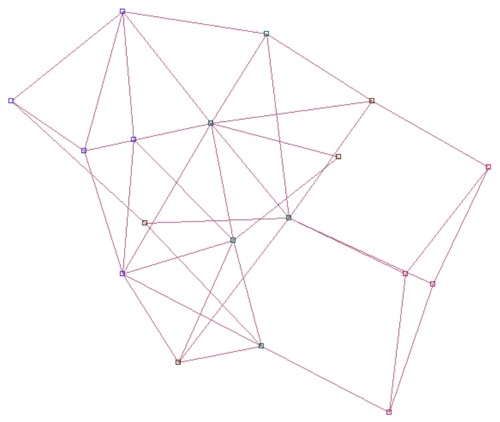



In this example, if you were to draw a line from the top left to the bottom right, the vertices that have the same color are all on one side of that line or the other, and there are edges to vertices with different color that seem to lie on or near that line. These are in the same set of vertices. Only a small number of clicks in the network displayer are required to identify the vertices that have value zero in the _Color_ column, and those that form a separator:



When separators are determined, HYPERGROUP strives to keep the number of vertices in the separator low. However, these vertices can have high degree, and often that is desirable. By the way, the degree of a vertex is the number of edges that have that vertex as one of the vertices the edge connects.

Rerun HYPERGROUP when the separator and edges that are incident onto the separator's vertices are removed; this is very easy to program by using a simple WHERE statement. The result is that HYPERGROUP determines the graph is now many disconnected hypergroup graphs, such as these:



This example illustrates why identifying separators is useful, and that goes beyond making the layout and coloring chores of HYPERGROUP easier.

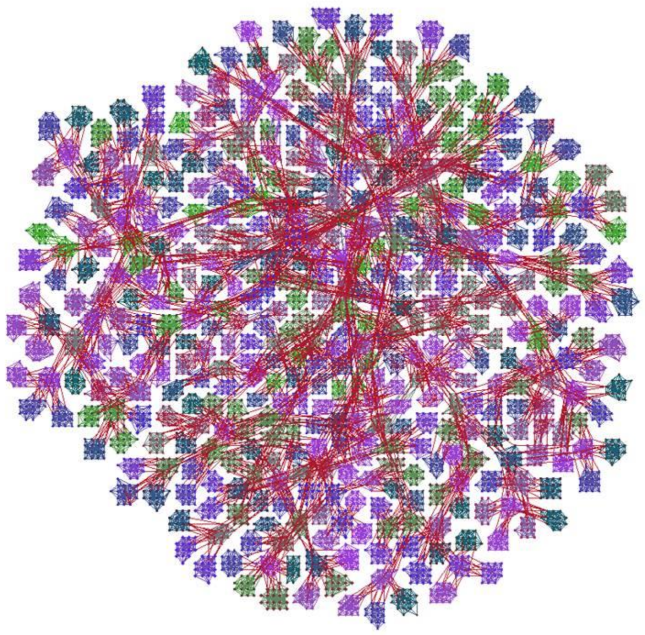
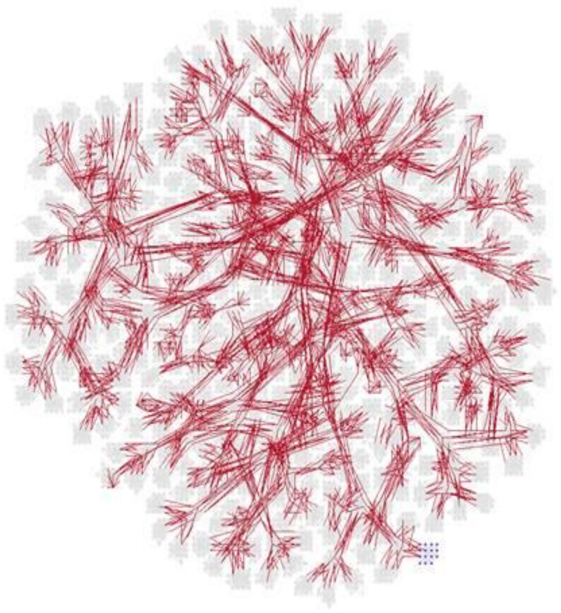
Imagine you are in charge of an Internet retailer. Whenever a customer shows interest in some item of merchandise, other products are shown to him to tempt him to buy one or more products. These recommended products were bought by other customers who have similar buying behavior to the prospective purchaser. However, the least useful data is for customers who seem to have no particular buying behavior; they buy lots of products that were selected from a wide range of product categories. Much better recommendations can be made when data for these "noisy" customers is removed.

Now imagine you are in charge of an advertising budget and must decide on which websites you should advertise. If the vertices in the above graph represent people and websites, then advertising on separator websites could yield the best results.

Obviously, separators separate data into two or more pieces. There is a wide range of applications when breaking apart data in a meaningful way is desired (for example, to improve reliability in communications systems by identifying places where failure would be serious, or to conduct military operations with more efficient interdiction, or simply because the data is too big to be tackled all at once).

WHEN DATA IS BIGGER

Consider data that has been associated with this graph that has one-quarter million edges, 25 thousand vertices, and that has a tree-like structure where every subgraph is weakly connected to three descendant subgraphs and, of course, one parent. The figure on the right shows only the weak edges:

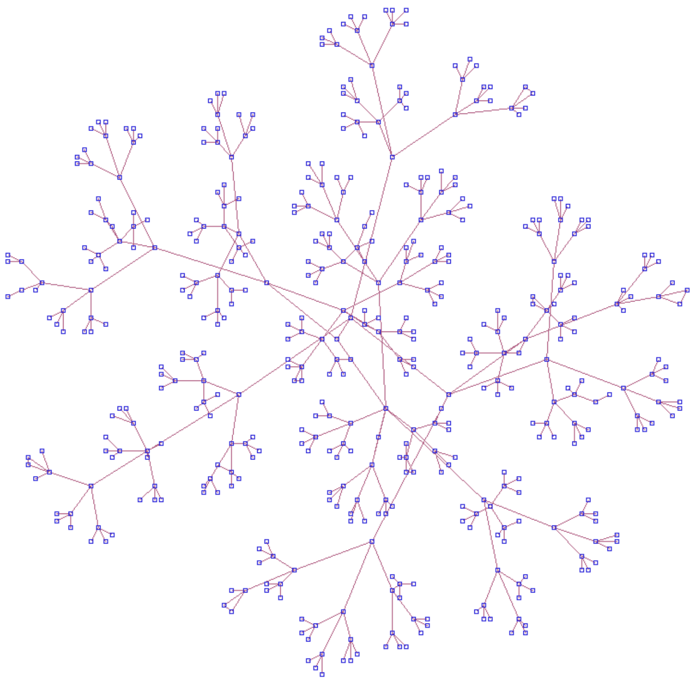



It might be more important to know how strongly connected subgraphs are connected to other strongly connected subgraphs by weak edges, than how strong edges connect vertices within the strong subgraph. Indeed, the latter might be unimportant. Therefore, you can indicate to HYPERGROUP that structural graphs are to be produced. A graph is formed that consists of a vertex for each color (or community)--that is, for each strong subgraph, and one and only one edge for between c_i and c_j if there exists one or more edges in the real graph between any vertex with color (or community) c_i and any vertex with color (or community) c_j. You can do the following:

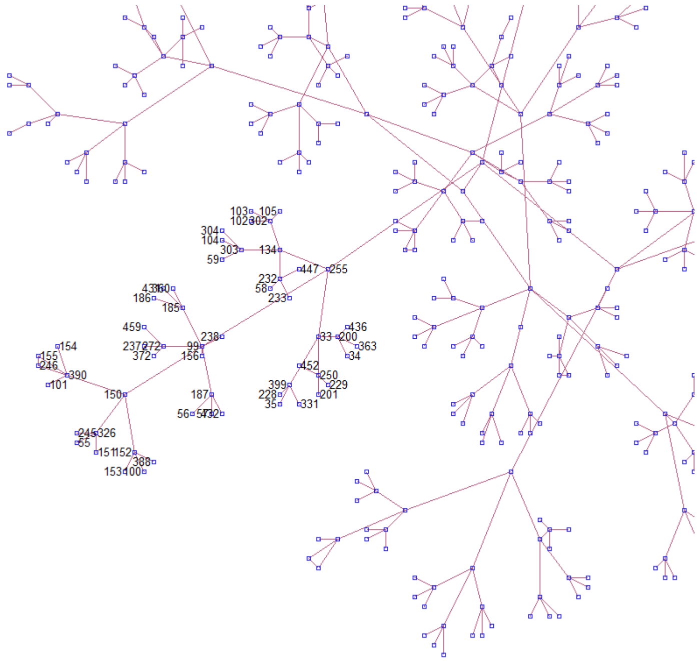
- use HYPERGROUP to determine hypergroups and colors (or communities), but not coordinates, and create the structural=color (or community) graph, and determine the layout of it, and then
- if a particular hypergroup-color (or community) subgraph is of particular interest, use HYPERGROUP again for that hypergroup-color (or community) fell swoop.

This strategy might save time in that only what you need is determined. Also, in effect, only relevant subgraphs are attacked by HYPERGROUP, and even when there are several to be attacked, the overall time might be much less than doing everything all in one ”fell swoop”. You can drill down into parts of the data that are of more interest than other data.

It’s now clear that the structure of the graph is a tree in which vertices have three descendants.



Some of the vertices have been labeled with their colors, and you can easily rerun HYPERGROUP, or for that matter any action, to focus attention onto one or a subset of records that have a particular group-by value combination, hypergroup number, and color values.



FOCUSING UPON DATA FOR PARTICULAR HYPERGROUPS

To identify which hypergroup is associated with a hypergroup variable value, use the WHERE, FETCH, and STORE statements. For example, if analyses are to focus on the hypergroup in which a hypergroup variable has value "C04", do this:

```
table mylasr.&_temphypgrp_;
    where _Value_="C04";
    fetch /  save=fetchTab from=1 to=60;
    store fetchTab(1,cols= _HypGrp_)=hgmacro /
                  left="(" control="_HypGrp_=%" separator=" or " right=")";
run;
%put &hgmacro;
```

In this example, the hgmacro expands to   (_HypGrp_=2)

Now hgmacro can be used in a WHERE statement that governs how _TEMPLAST_ is read to yield output for only the hypergroup with "C04”.

```
table mylasr.&_templast_;    /* or many other tables created by Hypergroup
*/
    where &hgmacro ;
    fetch / from=1 to=150;
run;
```

```
Selected Records from Table _T_8651BD0F_7F9390521138
_HypGrp_ varA varB varC varD extra4   extra3 extra2 extra1
2.000000 C00  C01  C04  X06  6.000000      X      C 0
2.000000 C00  C02  C04  X07  7.000000      X      C 0
2.000000 C01  C02  X05  X07  7.000000      X      C 1.000000
2.000000 C01  C04  X05  X08  8.000000      X      C 1.000000
2.000000 C02  C03  X06  X07  7.000000      X      C 2.000000
2.000000 C02  C04  X06  X09  9.000000      X      C 2.000000
2.000000 C02  X05  X07  X08  8.000000      X      C 2.000000
2.000000 C03  X05  X07  X09  9.000000      X      C 3.000000
2.000000 C04  X05  X08  X09  9.000000      X      C 4.000000
```

Notice that some records do not have the C04 value anywhere in them, yet they belong to the same hypergroup as those that do.

The same techniques can be used to obtain data for even greater granularity; for a particular value combinations of Group-By/Hypergroup/Color, or Group-By/Hypergroup/Community, or Group-By/Hypergroup/vertices that have coordinates in a certain region, or Group-By/Hypergroup/being close by virtue of centrality measures.

We describe the topic of centrality in the next section.

CENTRALITY

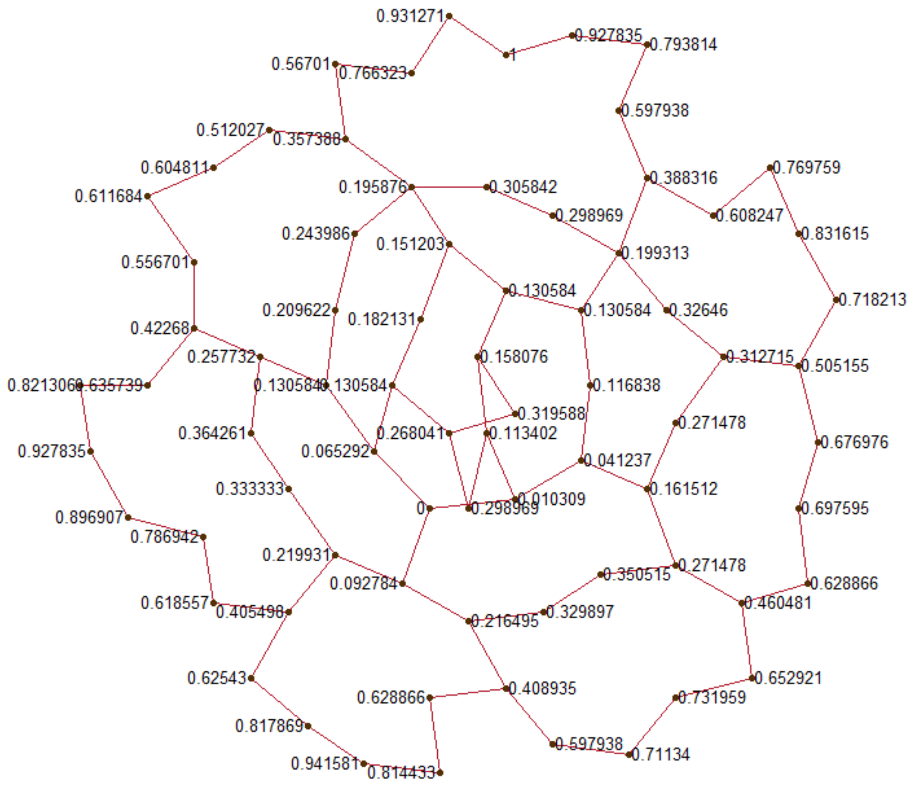
The centrality of a vertex quantifies the importance of that vertex among its peers. Centrality can also be considered a measure of the seriousness of removing a vertex (and edges incident onto it).

There are many ways centrality can be determined, and it’s often the case that one centrality more than another is better suited to some graphs, but for another graph, another centrality is more useful than the first.

Of the dozens of centralities, HYPERGROUP determines four centralities in common use based on shortest paths (Graph Centrality, Stress Centrality, Closeness Centrality, Betweenness Centrality), and another centrality (Centroid Centrality) based on the layout of a graph.

The shortest path between two vertices is the smallest number of edges in a path from one vertex to the other.

The labels of vertices of the following graph are Closeness Centrality:



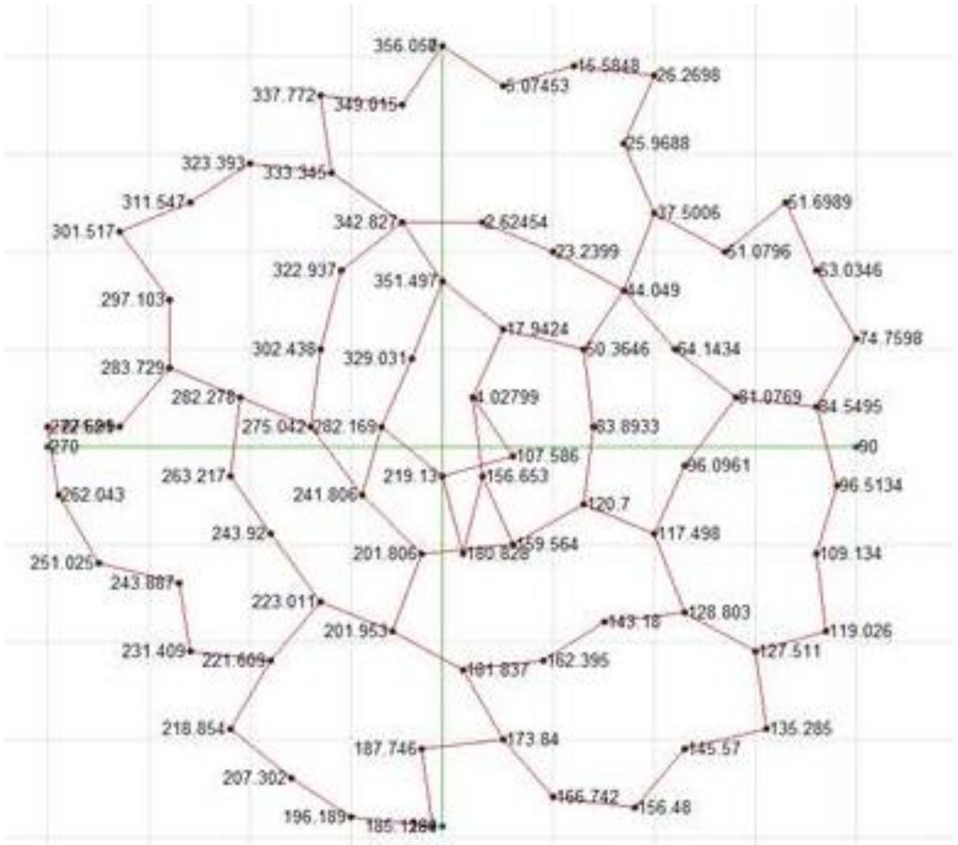
THREE DIMENSIONS

Up until now, we have assumed that only two dimensions are required. If you need to work in three dimensions, simply specify the HYPERGROUP statement’s THREED option (I tried to name this option 3D but SAS won’t allow it). When in 3-D, whenever there are x and y coordinates, there will now be an additional z coordinate. Color, community, and the shortest path-based centrality computations remain much the same as in the 2-D case, but obviously the layout algorithms are different, as are the centroid centrality results. Graphs are often seen to be more compact as space between vertices is obtained by using the extra dimension.

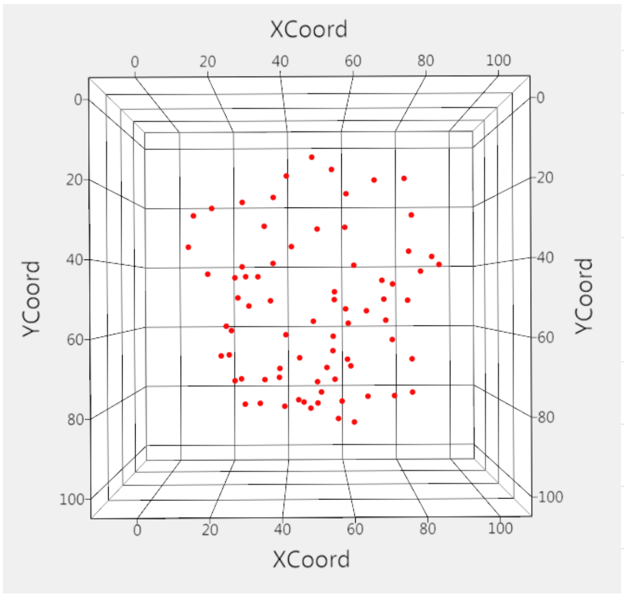
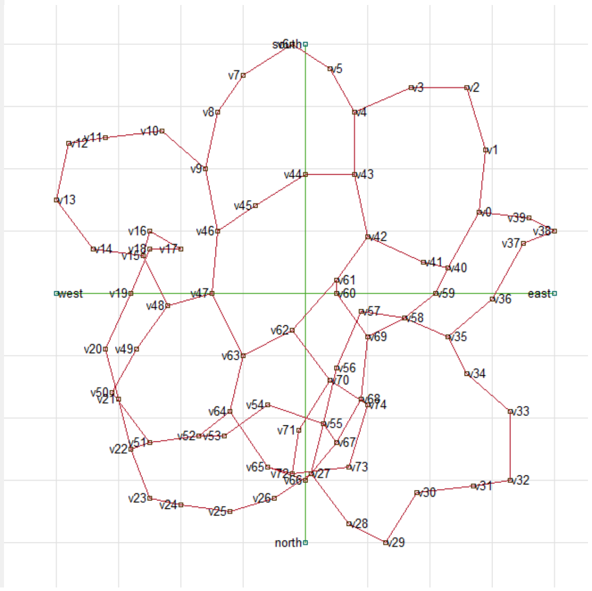
At the moment, SAS software products do not have a 3-D graph renderer, but visually appealing and informative details of 3-D graphs can be realized by the following:

- continuing to use 2-D graph renderers that are available in SAS such as SAS/GRAPH® NV Workshop, which has been used for all 2-D graphs so far in this paper,
- using 3-D scatter plotters to display vertices: I've opted to use the JMP® 3-D plotter that has the feature that 3-D scatter plots can be tilted and rotated interactively, or
- running a JMP script that plots vertices onto a 3-D scatter plot, and then adds vectors for every edge you want displayed.

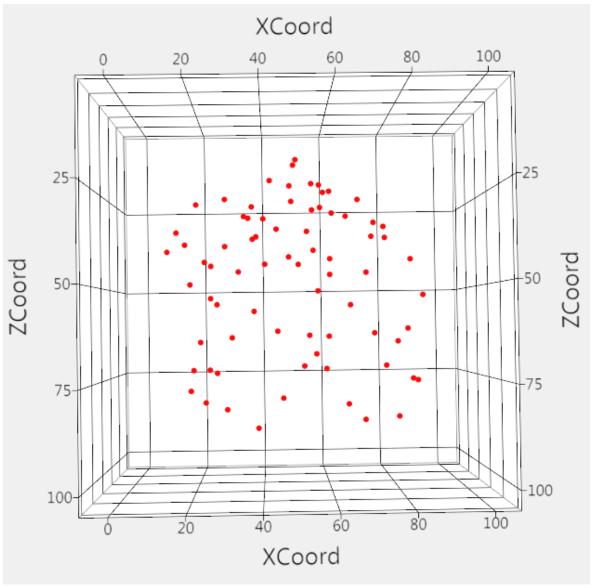
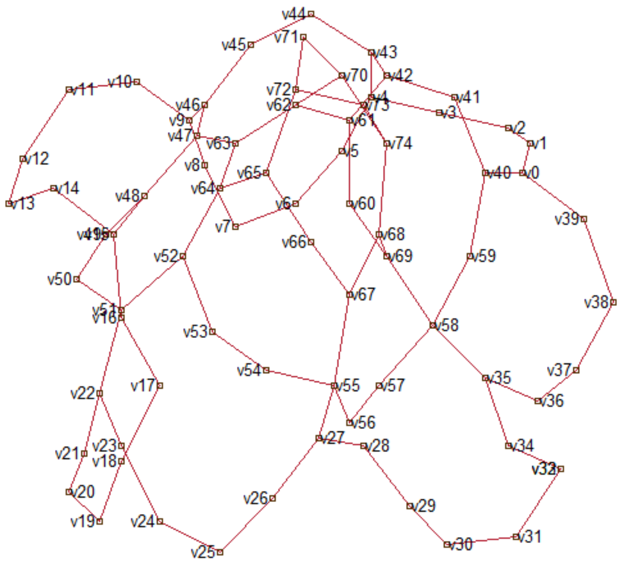
Consider the graph from the last section (here shown are centroid centrality's angles with respect to the graph's centroid):



Looking down from the positive z-axis (using the JMP 3-D scatter plotter) (left), and using SAS/GRAPH NV Workshop, using only the _Xcoord_ and _Ycoord_ columns (right).

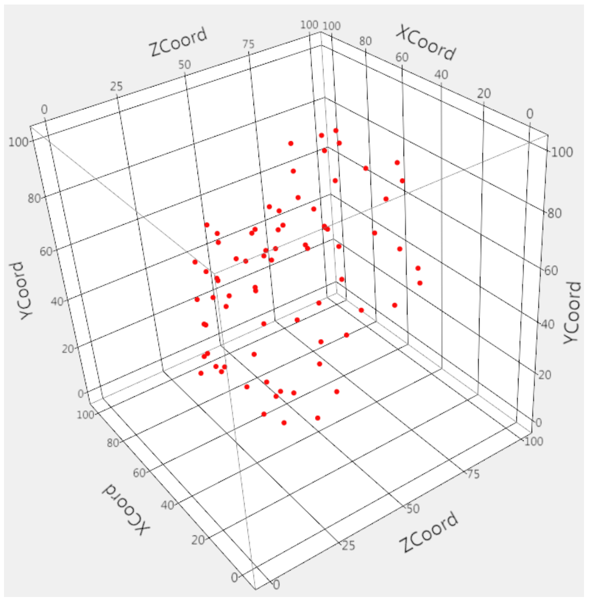



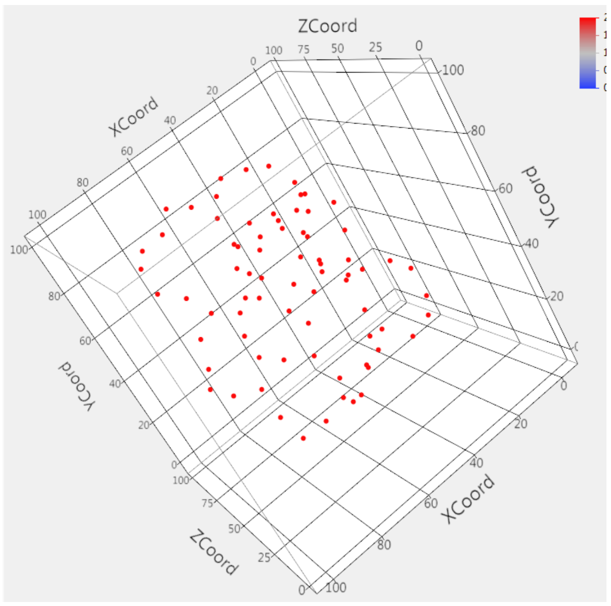
Looking down from the positive y-axis (using the JMP 3-D scatter plotter) (left), and using SAS/GRAPH NV Workshop, using only the *_Xcoord_* and *_Zcoord_* columns (right).

To save space, we've omitted the illustration that looks down from the positive x-axis.

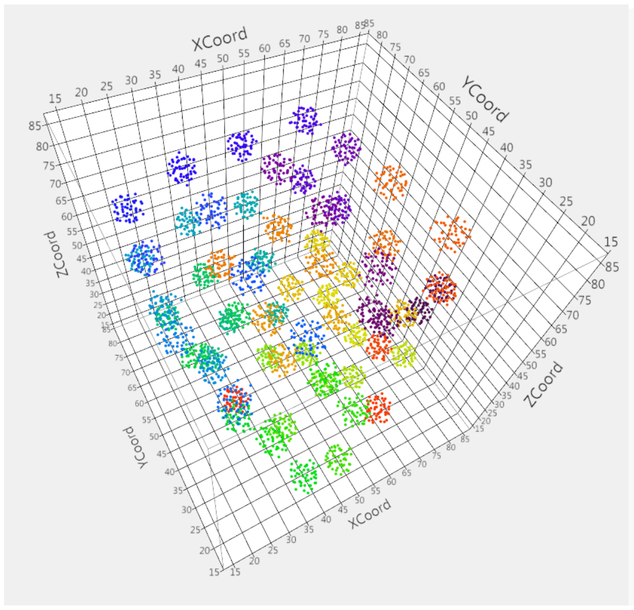
Here are screen shots when axes are tilted and rotated:

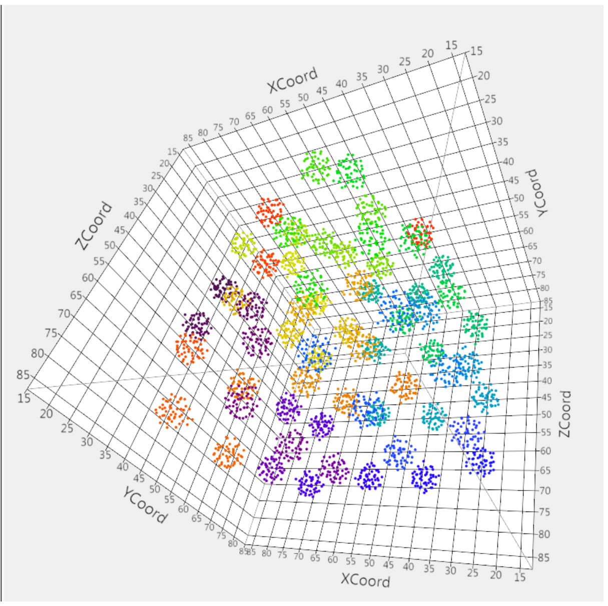




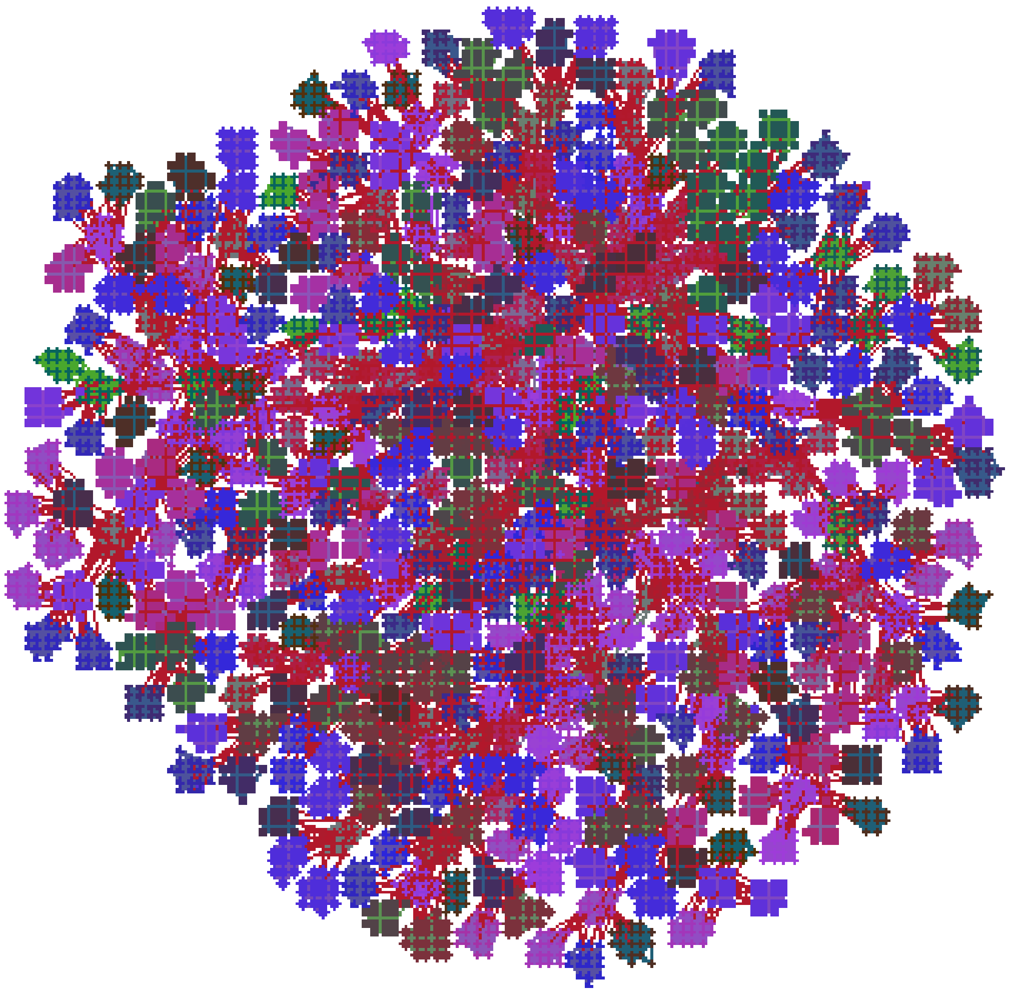
For the next few figures, the coordinates HYPERGROUP uses are the JMP 3-D scatter plotter to plot vertices. The communities HYPERGROUP determines are used by the scatter plotter to set the colors of the vertices.

Another example, a 4x4x4 mesh: There are 64 strong regions, each having 50 vertices connected by 1000 edges. There are 144 sets of weak edges, each having 5 edges.

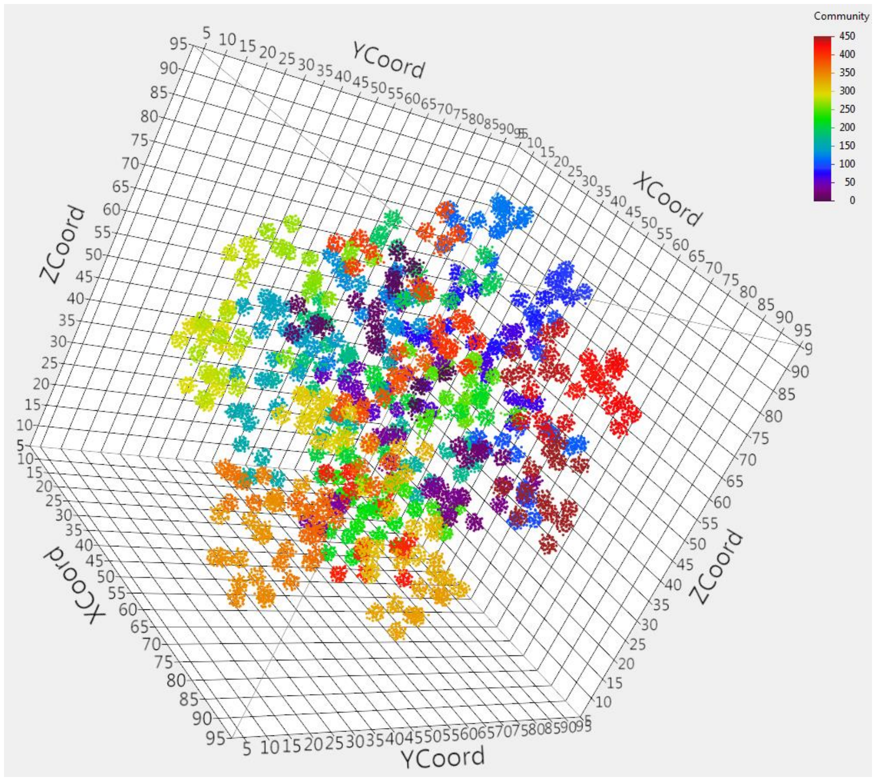


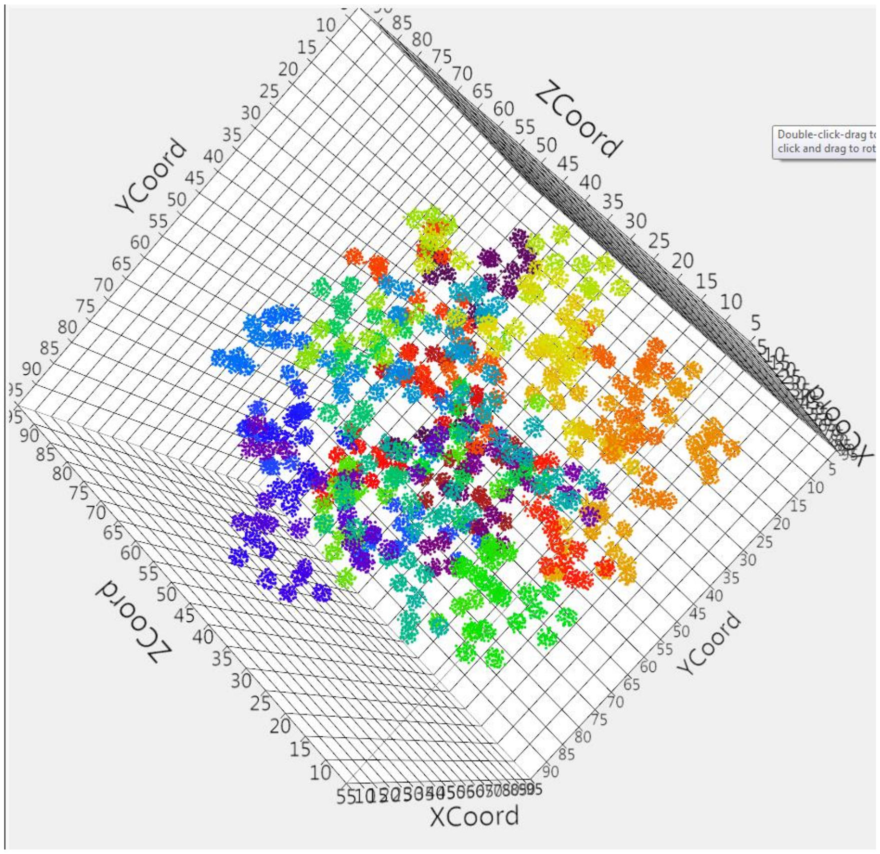


In previous sections, this graph was used. It has 23 thousand vertices and about one-quarter million edges. There are 460 strong subgraphs that on average have 50 vertices and 533 edges. These strong subgraphs are connected by 459 sets of weak edges that have on average 10 edges.



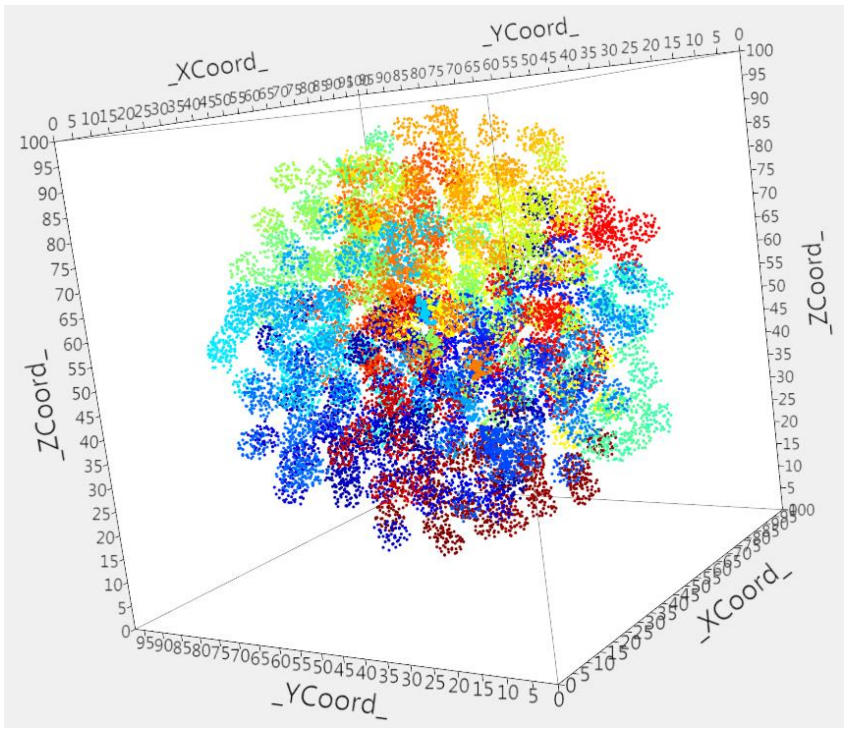
The structure is that of a tree with vertices having three descendants. Here are screen shots of it in 3-D:


Community
450
400
350
300
250
200
150
100
50
0
XCoord
YCoord
ZCoord


XCoord
YCoord
ZCoord
Double-click-drag to
click and drag to rot

You can control how the layout is determined so that strong subgraphs are more compact, or less compact, trading off space between strong subgraphs.

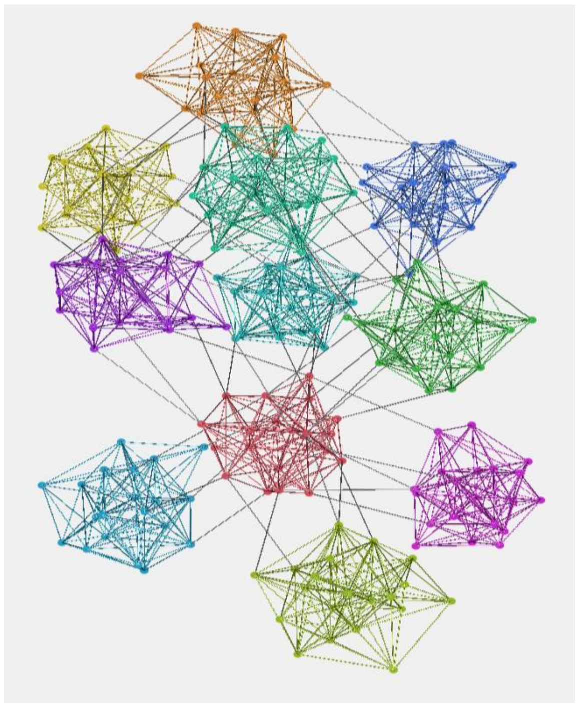
Here's the same graph with layout tuning parameters that have been tweaked:

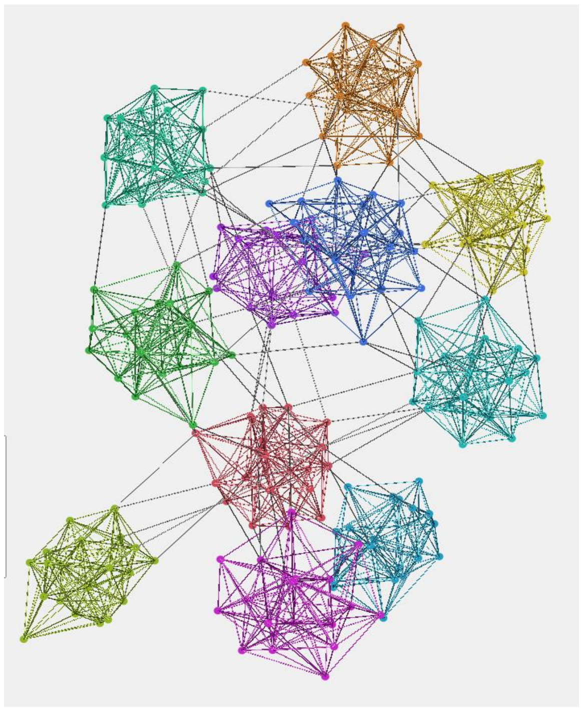


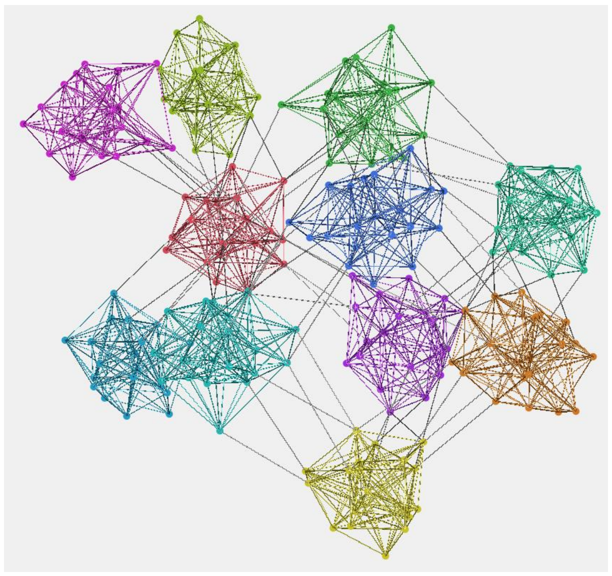
SEEING EDGES IN 3-D GRAPHS

A JMP script must be written (contact me if you want it) so that graph edges can be seen. Here are screen shots of a small 3-D graph with all edges shown. Note that strong edges are colored the same as the vertices they connect. Weak edges are black.

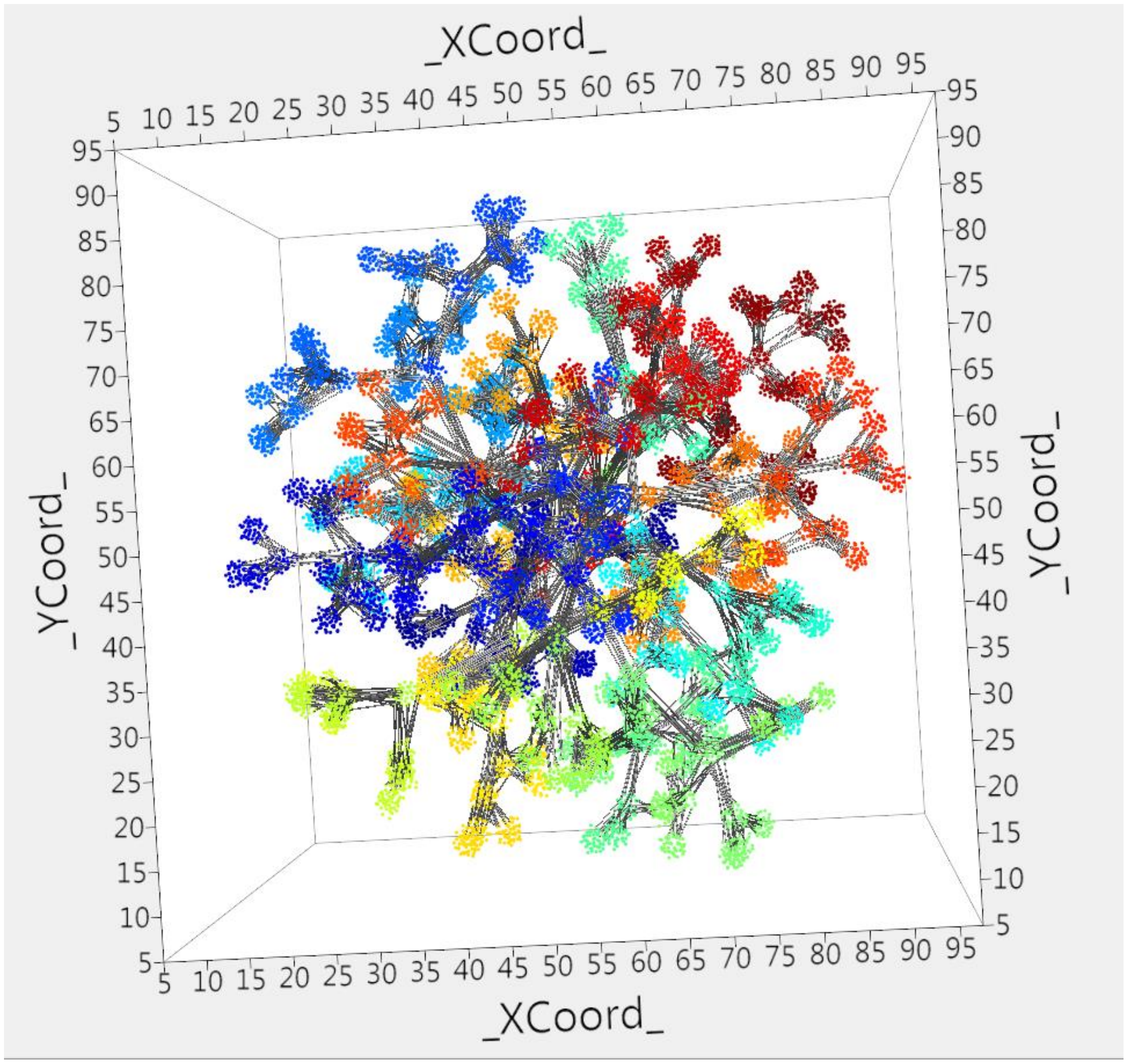
It's a pity this doc is not like pictures in books and newspapers, and portraits on walls in Harry Potter movies that move, because then you'd see the screenshots tilt and rotate, and you'd clearly see the 3-D graph with squadrons of vertices flying together in formation and performing amazing aerobatics, as if on broomsticks playing Quidditch!



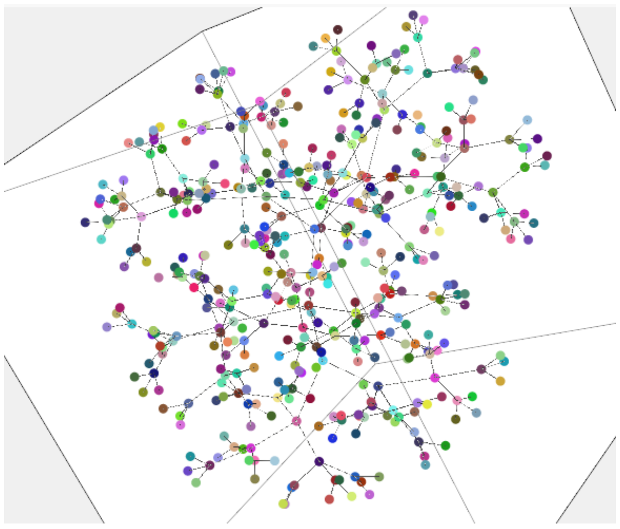


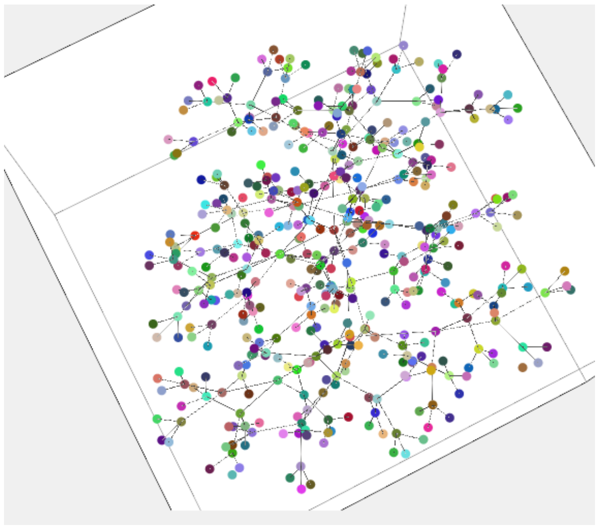


Even for graphs that are quite small (and just as it is the case with 2-D), larger graphs become indistinct when too many edges are shown. It’s often better to show all vertices, but only weak edges:



If this is still too cluttered, HYPERGROUP can, as an option, create structural graphs based on partition, community, or both. One vertex represents an entire partition or community, and an edge represents all weak edges between two of them. Coordinates are also determined in 3-D.





A CASE STUDY USING FACEBOOK DATA

DATA

In this session, we are going to present a case study using data from Facebook to show how to apply HYPERGROUP to real data. Bear in mind that the HYPERGROUP action can do much more than what is demonstrated in the case study. HYPERGROUP can be used in many applications other than social networking.

The data set is Facebook "friends" data from Stanford Network Analysis Project. (http://snap.stanford.edu/data/egonets-Facebook.html). All of the user information is anonymized. There are 4039 nodes in the data set, of which each node is a Facebook account. They are indexed from 0 to 4038. There are 88,234 edges, which means if two Facebook accounts "friend" each other, there is an edge between them. So obviously, it is very dense network data, which is not surprising considering how people use Facebook (often, a user has a large circle of friends). There are only two columns in the data set, _from_ and _to_, which are the index of the source account of the edge and the index of the target account of the edge. For example, if a row value of _from_ is 178, and value of _to_ is 303, then that means there is an edge between the account who indexed 178 and 303. In other words, account index 178 and user index 303 are "friends".

DETAILS

With this "friendship" network data, we are going to show how to do the following tasks in just one HYPERGROUP statement.

- Determine the layout of the social network for visualization.
- Conduct graph partitioning that partitions the data into several subgraphs so that the users in each subgraph are strongly connected, though they might not directly "friend" each other. The subgraph number is indexed as '_color_' in the result table.
- Conduct community detection. It is similar to graph partitioning in the above point, but uses a completely different algorithm. The community is indexed as '_community_' in the result table.
- Measure the centralities of the user and identify the most influential users.

Assuming you have already started a LASR server and loaded the data into it, you can use the following PROC IMSTAT code to run HYPERGROUP in SAS® In-Memory Statistics.

```
proc imstat;                                                   /* 1 */
table mylasr.facebook_edges;                                   /* 2 */
    hypergroup ( _FROM_ _TO_ ) / structural=both centrality    /* 3 */
        layout=walshaw  niters=100 scalecoords nopendants      /* 4 */
        width=101 length=99 margin=2                           /* 5 */
        graphpartition highdegree=1 maxnodes=150 separator=edges /* 6 */
        commiters=25 commalg=LLsemisynchronous                 /* 7 */
;
run;
table mylasr.&_temphypgrp_;                                    /* 8 */
    fetch / orderby=(_Betweenness_ ) descending=_Betweenness_; /* 9 */
    distinct _HypGrp_ _Color_ _Community_;                     /* 10 */
   promote temphypgrp;                                         /* 11 */
run;
quit;
```

In line [1], the IMSTAT procedure is invoked. It is an interactive procedure that keeps running until you quit it by issuing the QUIT statement or starting other procedures or DATA step sessions. After you terminate PROC IMSTAT, the data is not removed from the LASR server memory. You can start a new IMSTAT procedure to continue your analytics without reloading data. However, temporary tables will be removed when the IMSTAT procedure ends.

In line [2], the TABLE statement indicates to the SAS LASR Analytic Server which LASR table you want to work on. Before the next TABLE statement is claimed, all actions will run on this table. Therefore, you can run several actions on the same LASR table, without specifying the LASR table again and again.

In line [3], the HYPERGROUP statement uses two input variables in the parentheses, _from_ and _to_. The STRUCTURAL option specifies which structural analysis you want to conduct, graph partition, or community, or both, or even none. In this case, both graph partition and community detection are conducted. The CENTRALITY option tells HYPERGROUP that you want to calculate centrality measures of vertices.

In line [4], the options determine the layout algorithms and parameters of the algorithm.

In line [5], the options determine the width, length, and margin of the layout.

In line [6], the commonly used parameters of the graph partition algorithm are specified.

In line [7], the algorithm and the number of the iteration of community detection are specified.

Please note that all the options after the slash '/' in a HYPERGROUP statement are irrelevant to the order they are specified.

In line [8], the TABLE statement tells SAS LASR Analytic Server that we want to work on the temporary table _temphypgrp_ produced by HYPERGROUP.

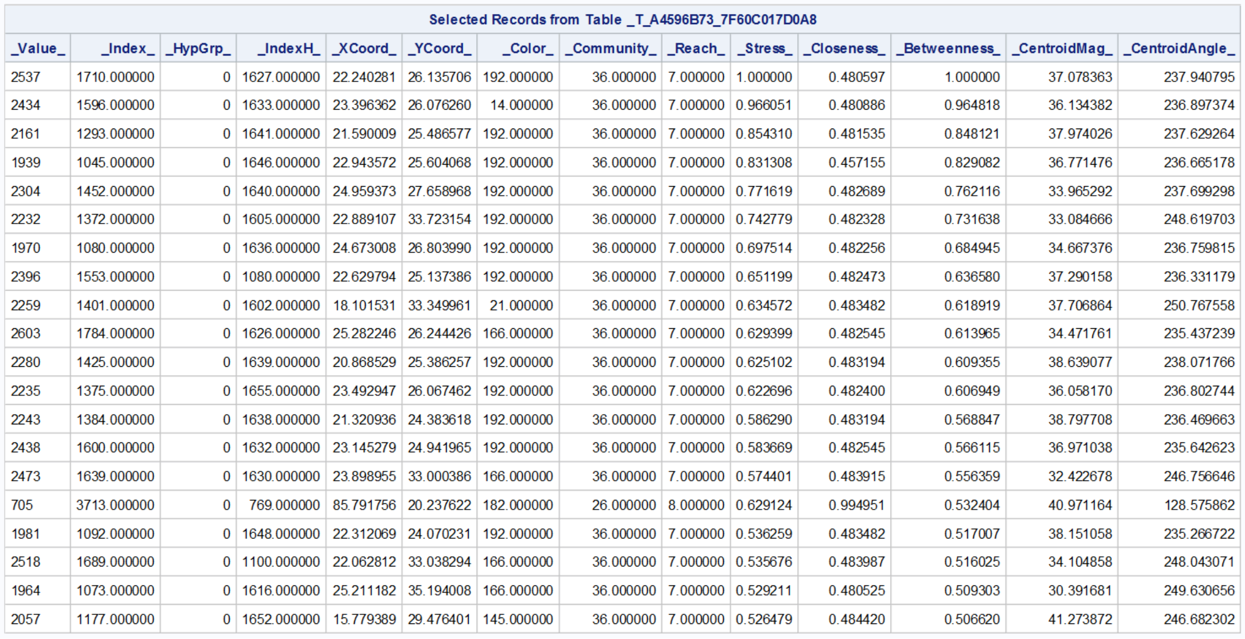
In line [9], the top 20 vertices with the largest values of betweenness centrality measure are printed in descending order.

In line [10], distinct counts of _HypGrp_, _Color_, and _Community_ are calculated.

In line [11], the temporary table is promoted as a 'permanent' LASR table in memory.

OUTPUT TABLES

The following table shows the first 20 rows in the _TEMPHYPRP_ temporary table. The vertices are ordered by betweenness centrality so that these are the top 20 most influential Facebook accounts by betweenness centrality. You can also find hypergroup numbers in column _HypGrp_, X and Y coordinates in column _XCoord_ and _YCoord_, subgraph number in _Color_, community number in _Community_, and the centrality measures.



Selected Records from Table _T_A4596B73_7F60C017D0A8

Value	_Index_	_HypGrp_	_IndexH_	_XCoord_	_YCoord_	_Color_	_Community_	_Reach_	_Stress_	_Closeness_	_Betweenness_	_CentroidMag_	_CentroidAngle_
2537	1710.000000	0	1627.000000	22.240281	26.135706	192.000000	36.000000	7.000000	1.000000	0.480597	1.000000	37.078363	237.940795
2434	1596.000000	0	1633.000000	23.396362	26.076260	14.000000	36.000000	7.000000	0.966051	0.480886	0.964818	36.134382	236.897374
2161	1293.000000	0	1641.000000	21.590009	25.486577	192.000000	36.000000	7.000000	0.854310	0.481535	0.848121	37.974026	237.629264
1939	1045.000000	0	1646.000000	22.943572	25.604068	192.000000	36.000000	7.000000	0.831308	0.457155	0.829082	36.771476	236.665178
2304	1452.000000	0	1640.000000	24.959373	27.658968	192.000000	36.000000	7.000000	0.771619	0.482689	0.762116	33.965292	237.699298
2232	1372.000000	0	1605.000000	22.889107	33.723154	192.000000	36.000000	7.000000	0.742779	0.482328	0.731638	33.084666	248.619703
1970	1080.000000	0	1636.000000	24.673008	26.803990	192.000000	36.000000	7.000000	0.697514	0.482256	0.684945	34.667376	236.759815
2396	1553.000000	0	1080.000000	22.629794	25.137386	192.000000	36.000000	7.000000	0.651199	0.482473	0.636580	37.290158	236.331179
2259	1401.000000	0	1602.000000	18.101531	33.349961	21.000000	36.000000	7.000000	0.634572	0.483482	0.618919	37.706864	250.767558
2603	1784.000000	0	1626.000000	25.282246	26.244426	166.000000	36.000000	7.000000	0.629399	0.482545	0.613965	34.471761	235.437239
2280	1425.000000	0	1639.000000	20.868529	25.386257	192.000000	36.000000	7.000000	0.625102	0.483194	0.609355	38.639077	238.071766
2235	1375.000000	0	1655.000000	23.492947	26.067462	192.000000	36.000000	7.000000	0.622696	0.482400	0.606949	36.058170	236.802744
2243	1384.000000	0	1638.000000	21.320936	24.383618	192.000000	36.000000	7.000000	0.586290	0.483194	0.568847	38.797708	236.469663
2438	1600.000000	0	1632.000000	23.145279	24.941965	192.000000	36.000000	7.000000	0.583669	0.482545	0.566115	36.971038	235.642623
2473	1639.000000	0	1630.000000	23.898955	33.000386	166.000000	36.000000	7.000000	0.574401	0.483915	0.556359	32.422678	246.756646
705	3713.000000	0	769.000000	85.791756	20.237622	182.000000	26.000000	8.000000	0.629124	0.994951	0.532404	40.971164	128.575862
1981	1092.000000	0	1648.000000	22.312069	24.070231	192.000000	36.000000	7.000000	0.536259	0.483482	0.517007	38.151058	235.266722
2518	1689.000000	0	1100.000000	22.062812	33.038294	166.000000	36.000000	7.000000	0.535676	0.483987	0.516025	34.104858	248.043071
1964	1073.000000	0	1616.000000	25.211182	35.194008	166.000000	36.000000	7.000000	0.529211	0.480525	0.509303	30.391681	249.630656
2057	1177.000000	0	1652.000000	15.779389	29.476401	145.000000	36.000000	7.000000	0.526479	0.484420	0.506620	41.273872	246.682302

Let us take a closer look at the result by calculating the distinct counts of _HypGrp_, _Color_, and _Community_ columns. The following table shows there is only one hypergroup, which means all of the Facebook accounts are somewhat connected. In other words, any two accounts are linked together through some path or paths. Within the hypergroup, there are 219 subgroups and 49 communities.

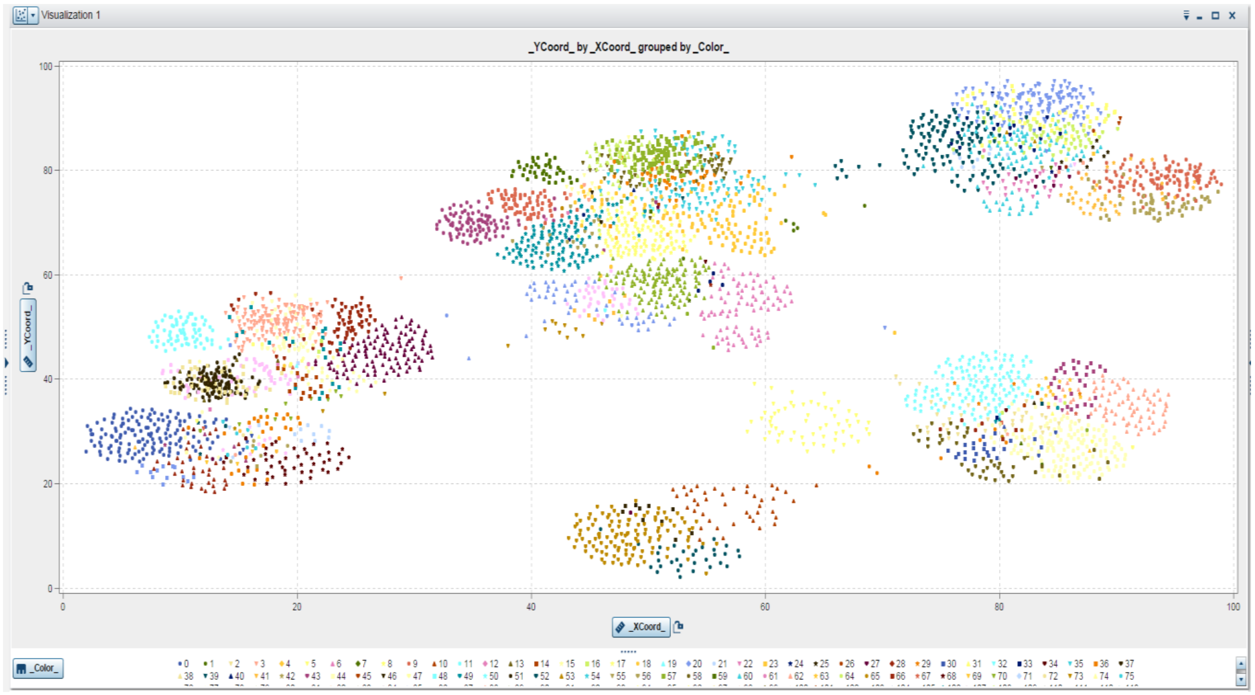
Number of Distinct Values in Table _T_A4596B73_7F60C017D0A8		
Column	Number of Distinct Values	Number of Missing Values
HypGrp	1	0
Color	219	0
Community	49	0

PLOTS

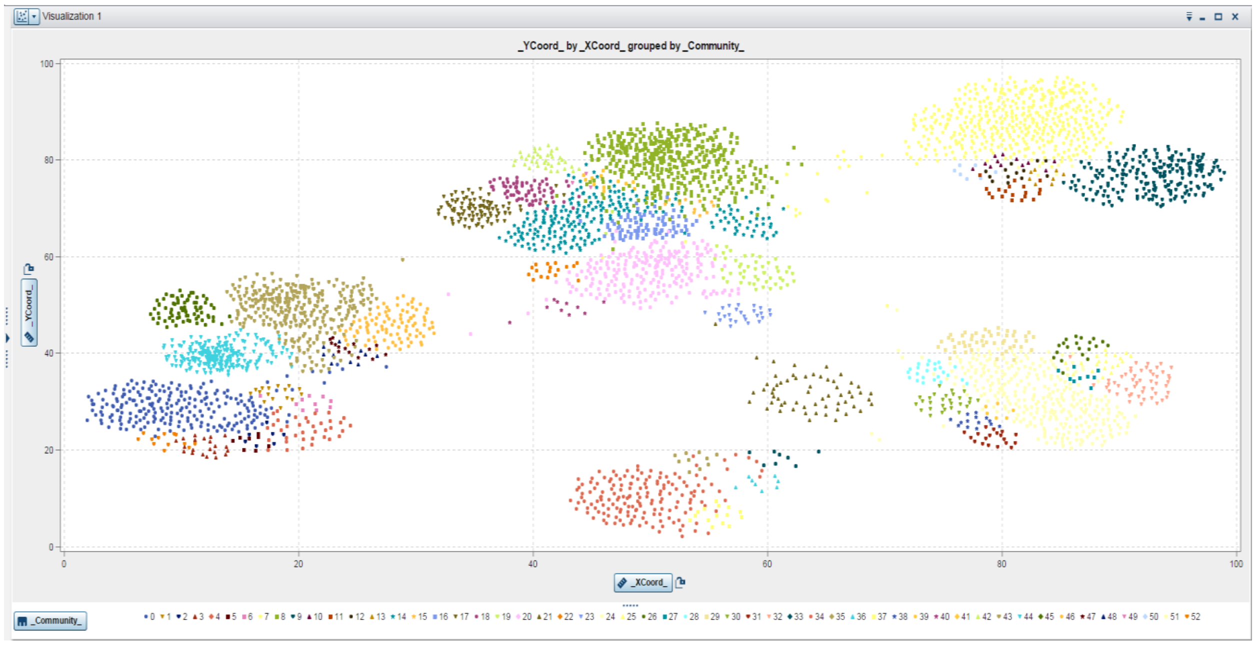
There are many ways to render results of HYPERGROUP. They can be rendered in the following:

- SAS® Visual Analytics.
- SAS/GRAPH NV Workshop.
- Some SAS procedures such as SGPLOT, G3D, SAS JMP and so on.
- Any other tools that can render coordinates, colors, or edges.

The following two plots are rendered by scatter plot nodes in SAS Visual Analytics. The vertices are nicely distributed across the diagram, with colors specified by _color_, which is subgraph number, and _community_, respectively.



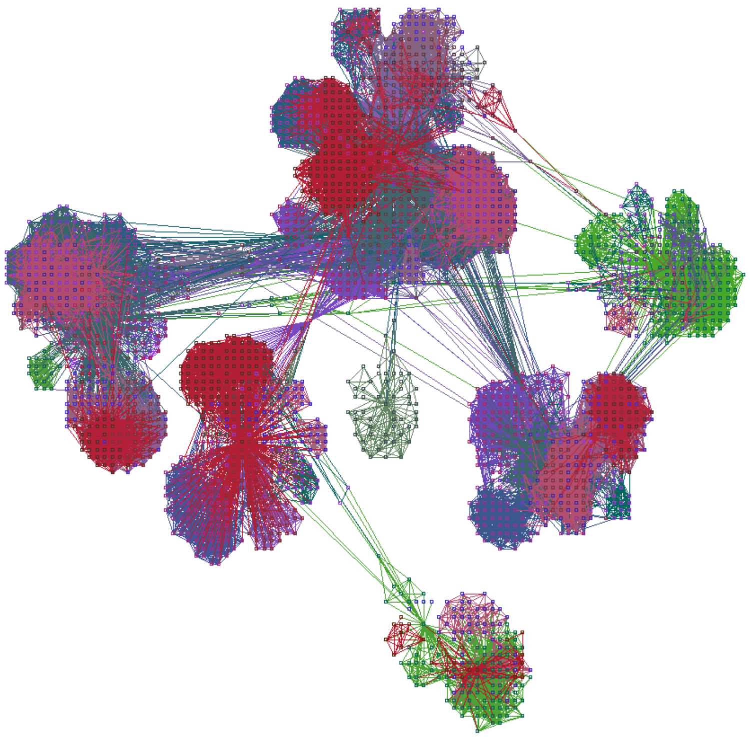
Graph Partition



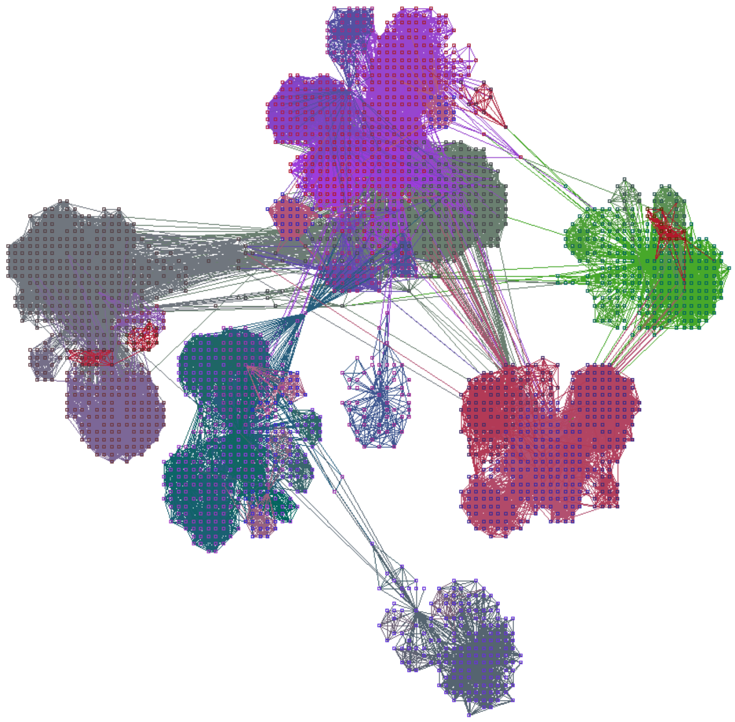
Community Detection

The following two plots are rendered by scatter plot nodes in SAS/GRAPH NV Workshop. Because this software product is dedicated to displaying networks, it can render edges, which scatter plotting procedures cannot, except that JMP's scatter plot can be called by a JMP script to superimpose edges. Hence, it would be easy to visualize the accounts that play as critical roles.

For example, some vertices have many connections within their subgraph and community. Some vertices not only have many connections, but also they are very critical in the way that many paths go through them so that they link two big clusters of vertices together. In the example, colors of edges are determined by color of source vertices. It is very obvious from the following two results that the graph partition algorithm partitions the graph into many more subgraphs than the community detection algorithm.

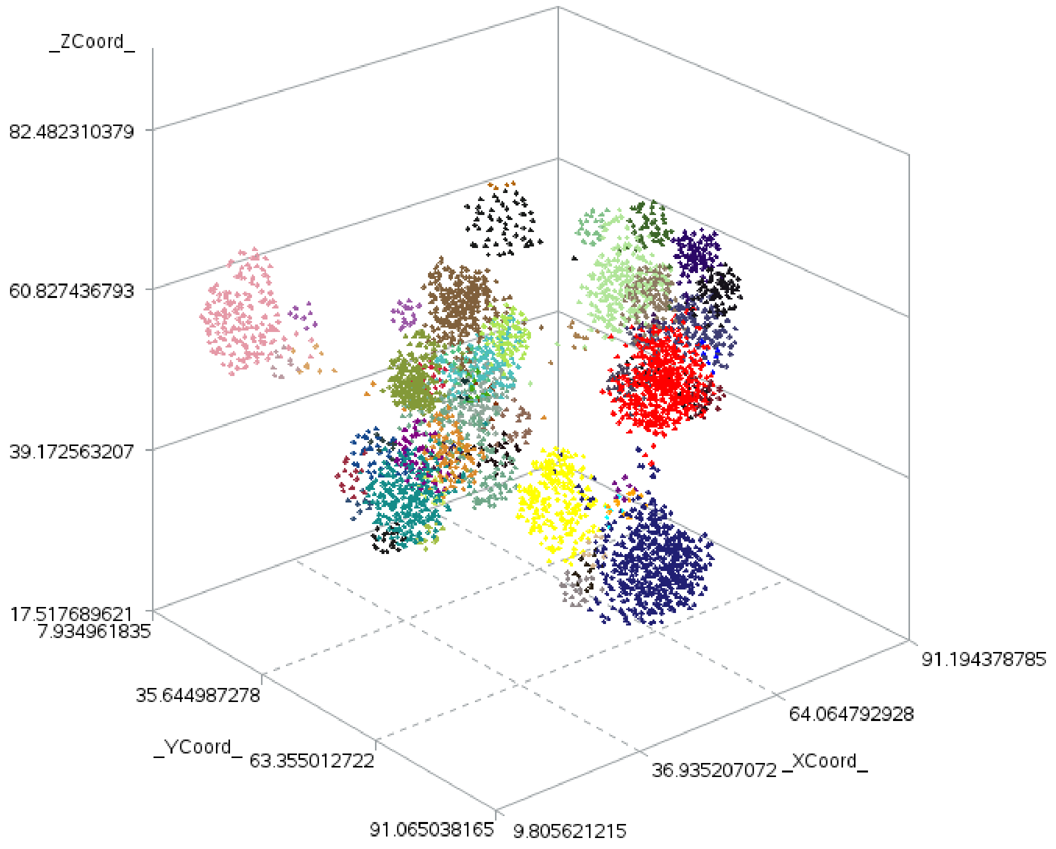


Graph Partition



Community Detection

The following plot is rendered by the G3D procedure where each color represents a community. In a three-dimensional plot, the vertices can spread out to reduce overlap of communities in the visualization so that the visualization is much clearer.



CONCLUSION

The algorithms used to determine hypergroups are based on graph theory. HYPERGROUP functionality generates one or more graphs based on your data, and produces results so that the graphs can be displayed and useful information can be derived. Data structure can be unearthed. You can control what data is supplied to analytics.

HYPERGROUP determines graph coordinates, colors, communities, structural graphs, centrality measures, whether for two-dimensional or three-dimensional graphs.

HYPERGROUP functionality for SAS LASR Analytic Server uses this powerful new tool to discover how data can be classified or assigned, so that records have columns that have disjoint sets of values. In cases when the sets of values are not completely disjoint, HYPERGROUP can identify data that is strongly connected, and identify “neighboring” data is weakly connected, or data that is farther away than that.

Each record is assigned a hypergroup number, and within hypergroups a color, community, or both. The GROUPBY facility, WHERE clauses, or both can act on hypergroup number, color, or community in order to conduct analytics using data that is “related” or more “relevant”. Your analysis is better, results can be obtained faster, and you really do have SAS®... THE POWER TO KNOW®.

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