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Identifying regular blocks in valued networks: A heuristic applied to the St. Marks carbon flow data, and international trade in cereal products

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Abstract

While the concept of regular equivalence is equally applicable to dichotomous as well as valued networks, the identification of regular blocks in regular blockmodels is somewhat problematic when dealing with valued networks. Applying the standard procedure for identifying ties in such blockmodels, a procedure perhaps most suited for dichotomous networks, does tend to generate block images and reduced graphs that differ from intuitive notions of such structures.

This paper outlines a formal heuristic procedure for identifying regular ties in valued networks where the “significance” of ties is related to each actor’s role sets. Combined with measures for block criteria fulfillment, the procedure yields reduced graphs, which seem more sensitive to patterns, rather than strengths, of ties.

Two data sets are used as examples in this paper: the St. Marks carbon flow web dataset, and a new dataset containing international trade flows of cereals and cereal products based on Comtrade data.

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Keywords: Network analysis; Regular blockmodels; Valued networks; Regular blocks

1. Introduction

The concept of role-equivalence is one of the fundamentals in social network analysis, perhaps being the best example of the novelty and strength of the network paradigm. The first formally defined method for identifying role-equivalent actors in networks, structural equivalence as introduced by Lorrain and White (1971), has even been considered as a possible foundation for a formal theory of social structure when combined with blockmodeling (White et al., 1976, p. 732;

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Snyder and Kick, 1979, p. 1103). Although such claims of course can be questioned, there is no doubt that the formal procedures for identifying role-equivalent actors are major contributions to the toolbox of social network analysis.

When White and Reitz formalized the concept of regular equivalence in a series of articles (White, 1984; White and Reitz, 1983, 1985), the strict definition of structural equivalence was somewhat loosened: as structural equivalence implies similar relations to the *same actors*, regular equivalence instead implies regular equivalent actors to have similar role sets to actors which in turn are part of the *same regularly equivalent position*. Designed to identify regularly equivalent actors in directional networks, the REGE algorithm has been applied extensively for dichotomous as well as valued networks, the latter of which is of interest in this paper.¹

Once a network has been partitioned into groups of actors (positions) which are deemed to be regularly equivalent, the next step in the analysis is often to find ties within and between positions in the blockmodel, i.e. creating an image graph of the blockmodel. Such ties – regular blocks – differ from ties in blockmodels of structurally equivalent actors: while a perfect 1-block in structural blockmodels consists of a submatrix completely filled with ties, a regular block is instead defined as having at least one tie in each row and column, respectively, in the corresponding submatrix (Wasserman and Faust, 1994, p. 477ff; Doreian et al., 2005, pp. 211–213).

There are two general approaches for identifying regular blocks when dealing with valued networks: either by treating all non-empty blocks² as representing positional ties (similar to how White et al. (1976) identified 1-blocks in structural blockmodels), or a global cutoff value is used to dichotomize the valued data before identifying regular blocks in accordance with its formal definition. Both of these approaches are however problematic when dealing with valued networks with great value spans. Treating all non-empty blocks (i.e. blocks with at least one non-zero value) as regular does not only ignore the characteristic definition of a regular block, but it also makes it difficult to interpret image graphs which, especially for dense, valued networks, most likely would be quite cluttered. The second approach, using a global cutoff value to dichotomize the network prior to finding regular ties, is also quite problematic in valued networks of great value spans. As in and outdegrees might vary greatly between (and within) actors, dichotomizing using a global cutoff value would ignore such variations.

In what follows, a heuristic is presented which tries to address these issues. Using a measure of criteria fulfillment for regular blocks which takes an actor-based perspective on what constitute “significance”, the presentation of this heuristic is followed by it being applied to two datasets: the St. Marks carbon flow dataset (Baird et al., 1998; Luczkovich et al., 2003), and a new dataset on international trade flows in cereal products.³

¹ In an unpublished conference paper, Borgatti and Everett (1991) have looked closer at the REGE algorithm and its behavior when applied to valued networks. Due to the workings of the matching function in REGE, where the algorithm searches for the least common value of flows for the rolesets of would-be equivalent actors, a pair of similar ties of larger magnitudes could very well dwarf several similar ties of lower magnitudes (see also Borgatti and Everett, 1993). As this paper is concerned with identifying regular blocks for *given* partitions, i.e. not the actual partitioning process itself, the assumption is made that the REGE algorithm works reasonably well for valued networks.

² I use the term “block” to denote the submatrix in the blockmodel which corresponds to the two positions of actors as specified in the rows and columns of the blockmodel.

³ Data sheets with full calculation procedures for these two examples are available at <http://www.humecol.lu.se/carl.n/snj/>.

1.1. Measuring “significance” from the actors’ viewpoints

The absolute value on what constitutes a significant in or outflow for an actor may indeed differ from other actors’ significant in and outflows, just as a significant inflow of an actor may be of a different magnitude than its significant outflows. Furthermore, although a specific flow may be significant for the source actor, the very same flow may be insignificant for the receiving actor. Using a global cutoff value to dichotomize valued data would ignore such actor-based perspectives on what constitute “significance”.

We begin by creating two new versions of the original regular blockmodel: an outbound regular blockmodel (ORB) using row-based marginal normalization, and an inbound regular blockmodel (IRB) using a column-based dito. Each row in the ORB represents the outflow profile for the row’s actor, with each cell indicating the outflow to each other actor as a share of total outflows for the source actor. Similarly, each column in the IRB indicates the significance of the different inflows for the column’s actor, where significance is based on total inflows for this particular actor. If an actor has no outbound ties, the values in the corresponding row in the ORB are undefined, just as the case would be in the IRB when an actor lacks inbound ties.

Once the two normalized regular blockmodels have been created, we can dichotomize ORB and IRB using a cutoff value between 0 and 1. Although the same cutoff value is applied globally, the previous normalization procedure, which resulted in separate regular blockmodels for inbound and outbound ties, respectively, guarantees that the notion on what constitutes “significance” for each actor is kept intact. As the mean value in each of the two normalized blockmodels is equal to the inverse of the number of actors in the network, this value could be a suitable cutoff value to begin with, adjusting it as we see fit depending on the properties of the dataset. Applying the formal definitions for row- and column-regular blocks (Doreian et al., 2005, p. 212) in ORB and IRB, respectively, we can create two separate block images (with corresponding image graphs⁴) to depict outbound, respectively, inbound regular ties in the blockmodel. Combining these, we arrive at a block image depicting regular blocks (according to the strict definition of such) while remaining sensitive to what constitutes significant in and outflows for each actor.

1.2. Criteria-fulfillment measures for regular blocks

As partitions of real-world networks most often result in more or less approximative role classifications, blockmodels based on such partitions equally often contain imperfect blocks, which do not conform to the strict definitions of ideal blocks. Although a downward adjustment of the above-mentioned cutoff value could result in more regular blocks, applying the strict definition on what constitutes a regular (or a row- or col-regular) block ignores those which might fulfill the definition criteria to a certain degree. Thus, even when a block contains all significant in and outflows for the actors in question, a single missing tie (or a tie below the cutoff value) would result in the block being non-regular when adhering to the strict definition of such.

Knowing the number of rows and columns in each block allows us to calculate to what degree the definitions of row-regular blocks (in ORB) and col-regular blocks (in IRB) are fulfilled. We

⁴ When visualizing image graphs which demonstrate row-regular or col-regular blocks only, the visual devices presented by Doreian et al. (2005, p. 223) are suitable to underline that these graphs do not depict regular blocks. Another possible visual device could be to keep arrowheads from touching target positions for row-regular blocks and, similarly, keeping arrow-bases a short distance from the source for col-regular blocks.

calculate such criteria-fulfillment percentages by counting the number of rows (columns) that contain at least one tie with a value equal to or above the cutoff value, divided by the number of rows (columns) in the block in question. Formula (1) below is used to calculate row-regular criteria fulfillment for ORB, and formula (2) is used to calculate col-regular criteria fulfillment for IRB:

$$so_{A,B} = \frac{r_{A,B}(\text{cutoff})}{n_A} \quad (1)$$

where $so_{A,B}$ is the share of fulfilled criteria for a row-regular block from position $\{A\}$ to $\{B\}$, $r_{A,B}(\text{cutoff})$ the number of rows in block $\{A\} \rightarrow \{B\}$ in the outbound regular blockmodel which contains at least one outbound tie equal to or above the cutoff value, and n_A is the number of actors in position $\{A\}$.

$$si_{A,B} = \frac{c_{A,B}(\text{cutoff})}{n_B} \quad (2)$$

where $si_{A,B}$ is the share of fulfilled criteria for a col-regular block from position $\{A\}$ to $\{B\}$, $c_{A,B}(\text{cutoff})$ the number of columns in block $\{A\} \rightarrow \{B\}$ in the inbound regular blockmodel which contains at least one inbound tie equal to or above the cutoff value, and n_B is the number of actors in position $\{B\}$.

Combining the above formulas allows us to generate an overall conceptualization of inter- and intra-positional ties – regular blocks – between regularly equivalent actors. As the strict definition implies at least one tie in each row and column for each block, we calculate the share of fulfilled criteria using the following formula:

$$s_{A,B} = \frac{r_{A,B}(\text{cutoff}) + c_{A,B}(\text{cutoff})}{n_A + n_B} \quad (3)$$

where $s_{A,B}$ is the share of fulfilled criteria for a regular block from position $\{A\}$ to $\{B\}$; $r_{A,B}(\text{cutoff})$, $c_{A,B}(\text{cutoff})$, n_A , and n_B are as defined in formulas (1) and (2).

We thus arrive at a collapsed blockmodel containing percentages of fulfilled criteria for regular blocks. These percentages can then be visualized as a reduced graph, either by excluding regular blocks whose criteria-fulfillment percentage is below a specific value, or by visualizing the percentage of fulfilled criteria using different graphical notation, for instance varying arrow widths. When interpreting the latter type of reduced graphs, it is important to stress that the graphical notations of such ties are not indicative of the volume or strength of the tie, but instead refers to the degree of which the strict definition of regular blocks are fulfilled. As the notion of significance is related to each actor's total in and outflows, the occurrences of regular ties are not necessarily correlated to the absolute flows between actors.

Although I have chosen to use formula (3) above in the examples that follows, there are other possible ways to combine formulas (1) and (2) in order to get a measure of criteria fulfillment for regular blocks. Formulas (4) and (5) below presents two such alternative measures for criteria fulfillment, alternatives which stress different aspects of the interplay between row- and col-regularity⁵:

$$\dot{s}_{A,B} = \sqrt{si_{A,B} \times so_{A,B}} \quad (4)$$

⁵ These two measures for measuring the criteria-fulfillment for regular blocks were suggested by an anonymous reviewer of a previous version of this paper; the credit for formulas (4) and (5) thus goes to her/him.

$$\ddot{s}_{A,B} = \frac{(s_{iA,B} + s_{oA,B})}{2} \quad (5)$$

where $s_{iA,B}$ and $s_{oA,B}$ are specified in formulas (1) and (2).

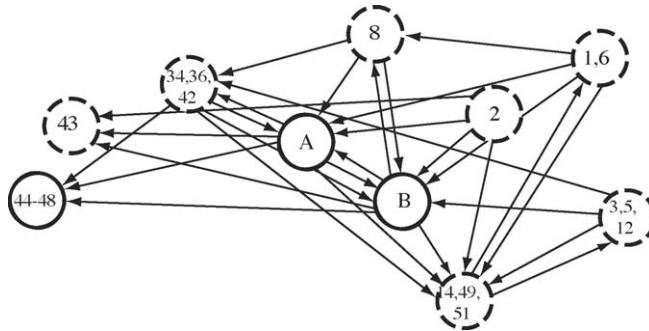


Fig. 1. Reconstruction of the image graph in Luczkovich et al. (2003, p. 315), showing regular ties within and between the 10 isotrophic groupings as conceived by Luczkovich et al. Positional self-ties are indicated by filled circles. See Luczkovich et al. (2003, p. 318) for a complete specie list; also see Footnote 7.

1.3. Example I: the St. Marks Florida carbon flow web

Luczkovich et al. (2003) applied the REGE algorithm to the analysis of trophic food webs in order to test whether the notion of regular equivalence is useful for identifying isotrophic positions. One of the data sets they apply the concept of regular equivalence on is the St. Marks Florida seagrass carbon flow web, data⁶ collected by Baird et al. (1998) containing flows of carbon (measured in mg/m²/day) between 51 different species. The value span for the data set is significant: with a maximum value of 202.701 and a non-zero mean value of 3.295, the non-zero median value is only 0.200. Based on an Anova-style R^2 analysis, the network is partitioned into 10 regularly equivalent (isotrophic) positions, illustrating intra- and inter-positional ties using the image graph in Fig. 1.⁷ Comparing the original data with the image graph seems to indicate⁸ that they use the first general approach for identifying regular ties, i.e. where any non-zero value in a block results in a corresponding positional tie in Fig. 1.

If we instead attempt to create an image graph using the second general approach, i.e. that of applying a global cutoff value on the original network data, the results are quite the opposite from the cluttered image graph in Fig. 1. Either when using the mean value of 3.295 or the median value of 0.200 prior to identifying regular blocks according to the strict definition of such blocks, the resulting image graph only contains a single positional tie: from {3, 5, 12} to {14, 49, 51}.

⁶ Data available at <http://www.drjoe.biology.ecu.edu/publicFTP/StMarks/>.

⁷ Position A contains the species with the following indices: 4, 10, 11, 16, 18, 20, 23, 24, 26, 29, 30, 32, 33, 35 and 37–41. Position B contains the species with the following indices: 7, 9, 13, 15, 17, 19, 21, 22, 25, 27, 28, 31 and 50. For a specification of the species, see Appendix A in Luczkovich et al. (2003, p. 318).

⁸ In support of this is the fact that there is a regular tie from {1, 6} to {A} in Fig. 1 although there is only a single non-zero flow in the 38-cell large submatrix (where $so_{\{1,6\},\{A\}}$ equals about 1% at a cutoff value of zero). Contradicting this however is the fact that although $so_{\{3,5,12\},\{A\}}$ and $si_{\{3,5,12\},\{A\}}$ is around 18 and 1.2%, respectively, Fig. 1 lacks a corresponding tie between these positions.

Table 1
Percentages of fulfilled criteria for regular blocks between and within positions in the St. Marks dataset, applying a cutoff value of 1/51 (~0.020) on ORB and IRB

	8	A	34,36,42	43	44-48	3,5,12	2	1,6	B	14,49,51
8	0	25	25	0	0	0	0	0	7	0
A	0	42	18	5	38	0	0	0	41	86
34,36,42	0	5	0	0	50	0	0	0	13	50
43	0	0	0	0	0	0	0	0	0	0
44-48	0	0	0	0	20	0	0	0	0	0
3,5,12	0	55	17	0	0	0	0	0	75	100
2	0	15	0	50	0	0	0	0	36	25
1,6	67	19	0	0	0	0	0	0	27	40
B	7	50	19	7	22	0	0	0	65	81
14,49,51	0	32	33	0	0	33	0	40	19	50

Lowering the cutoff value to zero, thus treating all 270 ties in the network as 1-cell, only results in a single additional positional tie: from {1, 6} to {8}. Based on such apparently vague role-structural relations, and a low-density dataset, it is perhaps no surprise that the authors chose to define regular blocks as any non-empty block.

Using the heuristic proposed in this paper, calculating ORB and IRB for the St. Marks block-model, subsequently dichotomized using the inverse of the number of actors as cutoff value (~0.020), we end up with the measures of criteria fulfillment for the strict definition of regular blockmodels as found in Table 1 above.

Ignoring all cells with less than 50% criteria fulfillment for regular blocks, Table 1 translates into the image graph below (using the same positional coordinates as in Fig. 1).

Whether Fig. 2 is a better representation of the St. Marks food web than the image graph presented by Luczkovich et al. is quite beyond the skills of the author of this paper to comment about. The resulting image graph, however, does seem to indicate that the proposed heuristic is sensitive to the patterns of rolesets of individual actors and positions, although the value spans in the dataset are very large.

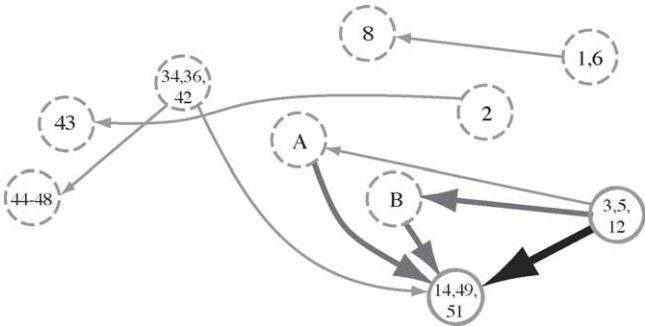


Fig. 2. Reduced graph showing the shares of fulfilled criteria for regular ties within and between isotrophic positions (at their original coordinates) in the St. Marks dataset, using an ORB/IRB cutoff value of 0.020 (1/51). Widths and tints of arrows and positions indicate criteria fulfillment for regular blocks: black indicates 100% criteria fulfillment, dark gray indicates 75–99%, and light gray indicates 50–74%. Dashed positions indicate that the criteria for a regular self-positional tie being below 50%.

Table 2
Partition of cereal trade quantities network into 10 positions

Position	Actors	GrossDeg	Mean GrossDeg
A	Barbados (BRB), Iceland (ISL), Latvia (LVA)	139,622	46,541
B	Brazil (BRA), Egypt (EGY), Japan (JPN), South Korea (KOR), Mexico (MEX)	70,162,158	14,032,432
C	Czech republic (CZE), Slovakia (SVK)	1,261,500	630,750
D	Belarus (BLR), Poland (POL), Slovenia (SVN)	2,410,109	803,370
E	Austria (AUT), Denmark (DNK), Finland (FIN), Greece (GRC), Hungary (HUN), Ireland (IRL), Romania (ROM), Russia (RUS), Sweden (SWE)	15,617,331	1,735,259
F	Albania (ALB), Benin (BEN), Bolivia (BOL), Croatia (HRV), Cyprus (CYP), Estonia (EST), Hong Kong (HKG), Israel (ISR), Kuwait (KWT), Madagascar (MDG), Malta (MLT), Mauritius (MUS), New Zealand (NZL), Nicaragua (NIC), Niger (NER), Norway (NOR), Oman (OMN), South Africa (ZAF), Senegal (SEN), Singapore (SGP), Sudan (SDN), Switzerland-Liechtenstein (CHE), Tanzania (TZA), Togo (TGO), Trinidad-Tobago (TTO), Uganda (UGA)	10,845,882	417,149
G	Belgium-Luxembourg (BEL), China (CHN), France (FRA), Germany (DEU), India (IND), Italy (ITA), Netherlands (NLD), Portugal (PRT), Spain (ESP), Thailand (THA), Turkey (TUR), UK (GBR)	106,638,190	8,886,516
H	Argentina (ARG), Australia (AUS), Canada (CAN), USA	122,523,518	30,630,880
I	Algeria (DZA), Bangladesh (BGD), Chile (CHL), Colombia (COL), Costa Rica (CRI), Ecuador (ECU), El Salvador (SLV), Guatemala (GTM), Honduras (HND), Indonesia (IDN), Jordan (JOR), Kenya (KEN), Malaysia (MYS), Nigeria (NGA), Pakistan (PAK), Panama (PAN), Peru (PER), Philippines (PHL), Saudi Arabia (SAU), Tunisia (TUN), Venezuela (VEN)	48,866,174	2,326,961
J	Lithuania (LTU), Yugoslavia (YUG)	349,022	174,511

Gross degrees equal sums of in and outflows of positional actors; mean gross degree equals gross degree divided by number of positional actors.

1.4. Example II: international traded quantities of cereals and cereal products in 1998

The data set in this example covers bilateral trade in cereals and cereal products between 87 countries for the year 1998. The network is monomodel, containing the aggregate weights (in metric tonnes) of 27 different commodity classes as extracted from the UN Comtrade database (UNSD, 2001).⁹

After running six iterations of the REGE algorithm¹⁰ on the raw data, an Anova density model was applied to test for different partitions (see Luczkovich et al., 2003, p. 310). Based on this, the network was partitioned into 10 positions as specified in Table 2 above. As indicated by the gross

⁹ The dataset used in this paper is derived from PC-TAS 1995–1999 SITC rev. 3 (UNSD, 2001), a CD-ROM containing a low-resolution version of the Comtrade mainframe database for the years 1995–1999. Although each country reports imports as well as exports, the former is used here as it usually is deemed more reliable than export data (UNSD, 1998, p. 20). The 27 different commodity classes can be found in Appendix A.

¹⁰ As previously mentioned (see Footnote 1), we assume in this example that the REGE algorithm works reasonable well for valued networks with large value spans. As the proposed heuristic is concerned with positional role-structure for given partitions, this is of minor concern for the working of the heuristic itself.

degrees, the value span of this network is very large: the dataset has a non-zero mean of 113,690 t and a non-zero median flow of 4623 t. On average, each actor has approximately 19 outbound ties to other actors.

If we choose to use the mean flow value (113,690) to dichotomize the raw data in the regular blockmodel, we end up with a very sparse block image with several perfect zero-blocks. Based on the strict definition of regular blocks, only two regular blocks can be found, both originating from position *H*, with position *B* and *I* as destinations. If we relax the strict definition, instead using the criteria-fulfillment formulas (1) and (2) above (still on the non-normalized regular blockmodel), we end up with the image graph below (Fig. 3). Dichotomizing the non-normalized regular blockmodel using a global cutoff value does seem to favour strength of ties over patterns of ties: position *H* dominates the graph, while the actors in positions *A*, *J* and *F* are deemed as having no “significant” ties whatsoever. Thus, there is indeed a correlation between gross degrees in Table 2 above and the occurrences of positional ties in Fig. 3 below. Although a lowering of the cutoff value would result in more ties being added to the reduced graph below, the reduced graph would be quite cluttered before we would be able to identify any occurrences of regular ties involving positions *A*, *F* and *J*.

Let us now turn to the heuristic proposed earlier. By creating two new marginal-normalized regular blockmodels for outbound (ORB) and inbound (IRB) ties, respectively, followed by utilizing formulas (1)–(3) above, we end up with the reduced graph in Fig. 4 below. Contrasting with Fig. 3 below, the proposed heuristic once again seems to be more qualified to identify patterns of regular ties between positions than what a global cutoff value does. By taking an actor-based perspective on what constitute significant in and outbound ties, the finer details of role-relational

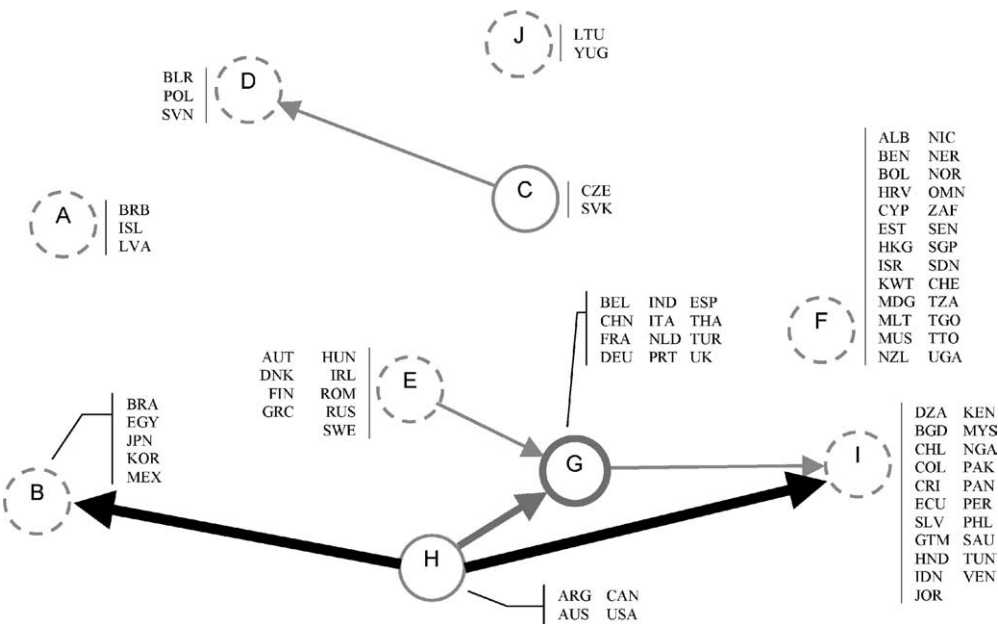


Fig. 3. Reduced graph showing the shares of criteria fulfillment for regular ties within and between positions in the cereal trade dataset, dichotomizing the raw data using the mean (non-zero) flow value. Graphical notation for criteria fulfillment as in Fig. 2. Positional coordinates as in Fig. 4 below.

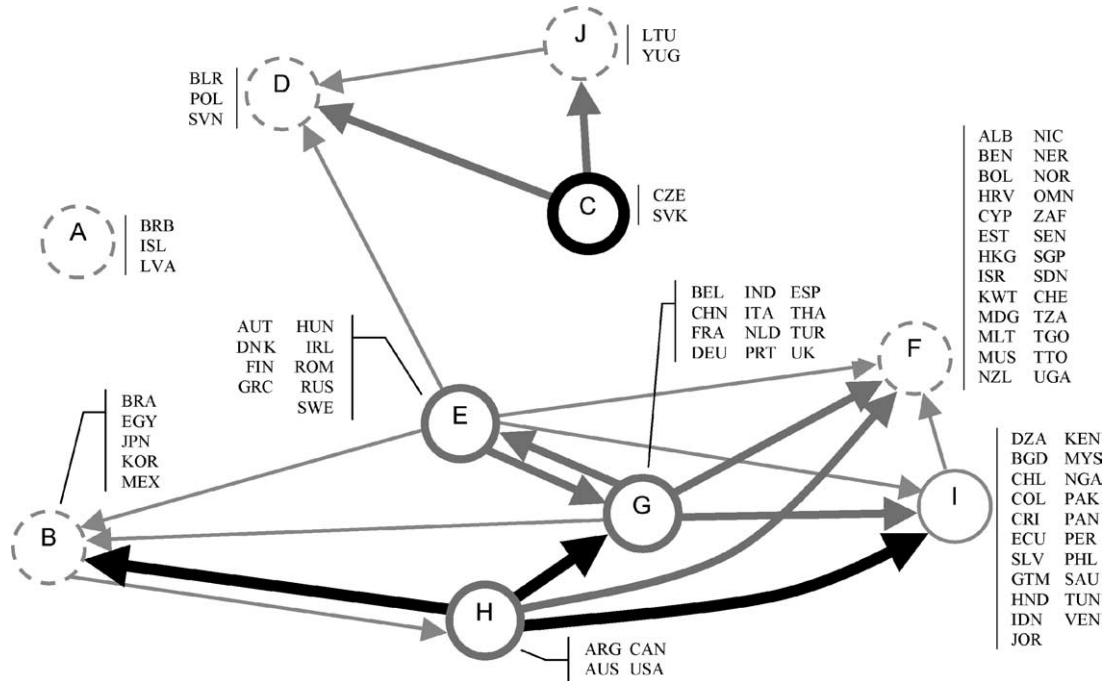


Fig. 4. Reduced graph showing the shares of fulfilled criteria for regular ties within and between positions in the cereal trade dataset, using an ORB/IRB cutoff value of 0.0115 (1/87). Graphical notation for criteria fulfillment as in Fig. 2. Coordinates established using MDS on the underlying image block.

structures in valued networks can be identified as patterns, rather than the mere strengths, of ties are accentuated in this heuristic.

2. Conclusion

This paper has addressed some inherent problems when identifying regular ties in regular blockmodels of valued networks, where large value spans and a strict definition of regular blocks tend to generate block images and reduced graphs that focus more on strength, rather than patterns, of regular ties. The problem seems partly to be based on the lack of a formal notion on what constitute significant flows; applying a global cutoff value in absolute terms does indeed tend to favour the emergence of regular blocks for positions containing actors with large in and outdegrees.

By converting the original blockmodel into two new blockmodels, an outbound regular blockmodel (ORB) which is marginal-normalized with respect to the rows and an inbound regular blockmodel (IRB) normalized with respect to the columns, we can analyze each of these separately. Applying a cutoff value between 0 and 1 on ORB and IRB, we can thus identify which flows, outbound as well as inbound, that are to be considered significant from the actors’ point of view.

By measuring to what degree the criteria for a tie is fulfilled – row-regular, col-regular or (fully) regular – we can choose to define such a tie when the criteria are above a certain threshold, presenting the result either as a block image (containing criteria-fulfillment percentages) or as a reduced graph (indicating criteria-fulfillment using different graphical notations).

Although only applied to two examples in this paper, the procedure seems to be a viable way for establishing role-relational patterns between groups of regularly equivalent actors in valued networks. Further tests are needed to examine how the heuristic behaves for different datasets, perhaps also examining whether the heuristic could be used as an optimization procedure to partition valued networks into regularly equivalent positions.

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Appendix A

The cereals and cereal products dataset covers 87 countries for the year 1998, aggregating the total weight for the following commodity classes (UNSD, 2001):

SITC code	Commodity
Product group BE: cereals	
0411	Durum wheat, unmilled
0412	Other wheat, meslin, unmilled
0421	Rice in the husk
0422	Rice husked
04231	Rice, milled, unbroken
04232	Broken rice

0430	Barley, unmilled
0449	Maize, other unmilled
0451	Rye, unmilled
0452	Oats, unmilled
0453	Grain sorghum, unmilled
04591	Millet, unmilled
04592	Buckwheat, unmilled
04593	Canary seed, unmilled
04599	Cereals, unmilled, not elsewhere specified
Product group BF: cereal products	
0461	Flour of wheat, meslin
0462	Groats, meals, pellets, wheat
04711	Maize (corn) flour
04719	Other cereal flour
04721	Groats, meal maize (corn)
04722	Groats, meal other cereals
04729	Pellets of cereals
04813	Other rolled, flaked grains
04814	Other worked cereal grains
04815	Germ of cereals
0482	Malt, including malt flour
59217	Wheat gluten

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