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# Detailing the Algorithm for Improving the Consistency of Structural Interoperability

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**Abstract:** For a collection of agents, information systems, or knowledge components, the level of interoperability and the preferred interoperability structure can be assessed by analyzing the tendency to establish relationships between them. As one possible implementation approach, the concept of structural consistency is proposed. Structural interoperability is based on relationship analysis using a consistency criterion that ensures an optimal level of coherence for the analyzed set of elements. The minimal deviation from an identified consistent structure corresponds to a preferred composition in which interoperability can be achieved with the highest degree of motivation. As a result, a set of potentially interacting elements is partitioned into groups of elements that are mutually motivated to interact. This paper proposes and substantiates an algorithm for determining the closest consistent structure for an arbitrary set of elements, which makes it possible to justify the choice of an appropriate interoperability structure. Examples illustrating the application of the proposed algorithm are provided.

**Keywords:** Interoperability, structural interoperability, consistency, signed graph, connectivity matrix.

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## Introduction

In contrast to the strict requirements for a database regarding data integrity, in a corporate knowledge base the problem of consistency among interacting knowledge elements comes to the fore [*Rozenberg et al.*, 2023]. Hence the need arises to ensure a process of coordinated exchange and acquisition of knowledge, which requires the constant functioning of knowledge base maintenance tools. The development of maintenance procedures is not only aimed at managing the consistency of interrelated elements, but this issue is certainly central. In the context of corporate use of knowledge, the preferred structure of interconnected knowledge elements is of particular importance; in other words, the structure of interoperability of the knowledge system [*GOST R 55062-2012*, 2014; *Ullberg et al.*, 2011].

In [*Rozenberg et al.*, 2023], the influence of the structure of interacting elements on the establishment of interoperability was considered, based on the existing attributes of knowledge elements that determine the preferred structure of interoperability. Such a possible implementation of interoperability was presented in [*GOST R 55062-2012*, 2014] as structural interoperability [*Makarenko and Solovieva*, 2021]. To identify favorable structural conditions for interoperability, determined by the correlation of attributes, a structural interoperability model was proposed.

The work [*Creps et al.*, 2008] describes the interoperability model that has been used to date, developed by the international consortium of organizations NCOIC – "Systems, Capabilities, Operations, Programs, and Enterprises Model for Interoperability Assessment", and in [*Heider*, 1982] a variant of adapting this model to the one presented in [*GOST R 55062-2012*, 2014] is substantiated. The adopted interoperability model [*GOST R 55062-2012*, 2014] is a three-level model consisting of technical interoperability, semantic interoperability, and organizational interoperability.

This paper proposes a description of an algorithm for finding the closest consistent structure, on the basis of which one can draw a conclusion about the choice of the preferred interoperability structure.

**The Terminology and Key Concepts Used**

The motivation for interoperability among interacting elements is determined by the characteristics of the elements that facilitate the achievement of interoperability. The trend towards establishing interoperability in the structure of interconnected elements is characterized by structural interoperability. The approach to assessing the presence of a trend towards interoperability based on the comparison of characteristics is proposed to be implemented on the basis of structural consistency, forming groups of potentially close elements. Let there be a certain set of $N$ elements that can be represented as agents, information systems, or knowledge components. If interaction among these elements is to be ensured, it is necessary to assess the level of their consistency required for interoperability and to determine the preferred structure of interoperability. The proposed approach, therefore, defines the partitioning of the set of elements ready for interaction into groups motivated for interaction.

These elements are represented by a feature vector that allows for the discussion of similarity between them and, consequently, potential motivation for interoperability. The desired structure of interoperability of potentially interacting components determines the partitioning of the set of components that tend to be interoperable. Components are standardly represented by a list of parameters (features) $o_i = (p_1^i, \cdots, p_m^i)$ that allow one to evaluate their similarity.

Let us introduce the similarity function $F$, which takes values from $[0,1]$, where 1 corresponds to the similarity between to similarity $o_i$ and $o_j$, and 0 – to the difference:

$$F\left(o_i, o_j\right) = 1 - \frac{1}{k}\sum_{i=1}^{k} Wml \frac{\left|p_{ml}^i - p_{ml}^j\right|}{\max\left|p_{ml}^i - p_{ml}^j\right|}$$

The transformation of a numeric graph into a signed one is realized by using a threshold value for function $F$, while exceeding the threshold indicates that $o_i$ and $o_j$ are considered similar, and the connection between them is marked with a plus sign, otherwise – dissimilar, and the connection between them is marked with a minus sign. More specifically, when choosing the threshold value $\alpha$ for the function $F$, if $0 \leq F(o_i \text{ and } o_j) \leq \alpha$ – the elements $oi$ and $oj$ are considered dissimilar by $k$ features, whereas in the case $\alpha < F\left(o_i, o_j\right) \leq 1$ – they are considered similar. By assigning a minus sign to connections with $0 \leq F(o_i, o_j) \leq \alpha$ and a plus sign otherwise, we obtain a sign structure that serves as a discrete sign model of a set of potentially interacting elements.

The sign model is visualized by a connectivity matrix. Next, a criterion for the consistency of the sign model of the population is selected in the form of Heider's triangular criterion [*Makarenko*, 2022], on the basis of which the consistent (consonant) or discordant (dissonant) states are analyzed and the problem of consistency of structural interoperability is solved.

The Heider's criterion is a key concept of the proposed approach, as it allows for evaluating not only the similarity between two elements but also correlating this similarity with their relationships to all other elements. The conventional approach to analyzing consistency involves evaluating binary relationships between elements, but for the coordination of elements, it is necessary to consider ternary relationships that define either consistent or inconsistent states, termed consonant (if the positive relationship between any pairs of vertices of Heider's triangle establishes the identity of the connections of these vertices with a third one) and dissonant, respectively. Considering the sign graph as a set of Heider's ternary relationships leads to the possibility of analyzing the structural consistency of interacting elements.

When studying the consistency of a set using the Heider's criterion, it is not difficult to prove that a consonant set $M_k$ (consisting only of consonant Heider's triangles) is formed as two subsets $M_1$ and $M_2 : M_k = M_1 U M_2$, so all elements within any subset are connected by a positive connection, and those belonging to different subsets are connected by a negative connection. The assonant set is amorphous and contains both consonant and dissonant triangles.

Bringing a dissonant set into a consonant state according to Heider means the possibility of representing it in the form of two classes of equivalence of elements [*Dulin et al.*, 2019]. To find a consistent set involving more than two subsets, it is necessary to modify the Heider's criterion to the polyconsonance criterion [*Rozenberg et al.*, 2023]. Unlike Heider's consonance, polyconsonance expands the concept of a coherent state of a set, allowing for more than two subsets. The polyconsonance of degree $P$ corresponds to a coherent state of a set consisting of no more than $P$ subsets, such that the elements within each subset are only positively related, while elements from different subsets are only negatively related.

**Description of the Algorithm**

The algorithm for improving the consistency of structural interoperability consists in analyzing the state of the dissonant set and searching for the nearest consistent state in which the motivation of knowledge components for interoperability is visible. For a dissonant set modeling a body of knowledge, the nearest consonant set is found iteratively by flipping vertices (changing the signs of all connections for a given vertex to their opposites).

The complete set of vertex flips of any consonant set forms the contour of instances of consonant sets; similarly for dissonant sets.

Any configuration (instance) of the set can be reached from any other in no more than $[n/2]$ complete vertex flips.

The algorithm for finding the closest consistent state for a given dissonant set consists of comparing it with consonant sets in order to approach a consonant set based on per-vertex changes to reduce differences in connections.

As a measure of the per-vertex difference, we introduce the vector $(r_1, r_2, r_3, \cdots, r_n) = \overline{r}$ vertex difference (VD) of two sets of the same objects, so that $r_i = \sum_{j=1}^{n} r_{ij} (0 < r_i \leq n-1$, where $r_{ij} = 1$ if $i \neq j$ for $o_i$ and $o_j$ with various connections.

In [*GOST R 55062-2012*, 2014] it was shown that the VD alone does not uniquely define a set. A set can be characterized by a pair $(m, \overline{r})$ where $m$ is a specific instance (configuration) of the set, and, $\overline{r}$ is the VD between $m$ and the target set.

The minimum difference in the sum of connection signs corresponds to the minimum sum of VD components.

Let $M(\varphi)$ be the set of positions in which $\varphi$ two rows of the connectivity matrix have different signs, and $K(M)$ is the number of elements of the set $M$, then $K(M(\varphi)) = \varphi$.

**Statement 1.** If we take three rows with the same number of elements: $m_1 m_2 m_3$ and the number of different values of the elements for each pair of these rows: $r_{12}, r_{13}, r_{23}$, then the following relations are valid:

$$M(r_{13}) = (M(r_{12}) \cup (M(r_{23}))/M(r_{12}) \cap M(r_{23});$$

$$r_{13} = r_{12} + r_{23} - 2K(M(r_{12}) \cap M(r_{23})).$$

**Proof of Statement 1.** The positions of the differences between the rows $m_1$ from $m_2$ and $m_2$ from $m_3$ are defined as $M(r_{12}) \cap M(r_{23})$. If we consider the positions of difference $m_1$ is from $m_2$, but not $m_2$ from $m_3$, or, conversely, $m_2$ is different from $m_3$, but they are not different $m_1$ from $m_2$, then in these positions $m_1$ does not coincide with $m_{13}$. Unconsidered positions record the differences between $m_1$ and $m_2$ and $m_2$ from $m_3$, which means that the values in the lines $m_1$ and $m_3$ for these positions differ. Therefore, excluding from all positions $M(r_{12}) \cap M(r_{23})$, we obtain $M(r_{13})$ as the only set of differences. Since the positions were excluded $M(r_{12}) \cap M(r_{23})$, we can write $K(M(r_{12}) \cup M(r_{23})) = r_{12} + r_{23} - K(M(r_{12}) \cap M(r_{23}))$, which means $K(M(r_{13})) = r_{13} = K(M(r_{12}) \cup M(r_{23})) - K(M(r_{12}) \cap M(r_{23})) = r_{12} + r_{23} - 2K(M(r_{12}) \cap M(r_{23}))$. ■

**Statement 2.** *$k$ iterative vertex changes reshape the VD $\{r_i\}$, $i = 1 \ldots k$; so its components take the form $(n-k) - r_i + 2\beta_i$, where $\beta_i$ is the sum of positions in the $i$ – the row, where the signs of mismatch of $k$ vertices that are fixed in $r_i$.*

**Proof of Statement 2.** Each vertex has $k-1$ signs of connections with other vertices. Let among $k-1$ signs $\alpha_i$ signs are not distinguished and are not taken into account in $r_i$, the rest – $\beta_i$ – are. If you make a vertex-by-vertex change to the $i$-th vertex, its component in the VD will become equal to $(n-1) - r_i$, $\alpha_i$ will turn into the number of differences, and $\beta_i$ – vice versa. Iterative $k-1$ changes to the remaining vertices will reduce $(n-1) - r_i$ on $\alpha_i$, and increase by $\beta_i$, leading to $(n-1) - r_i - \alpha_i + \beta_i = (n-1) - r_i + (\beta_i - k + 1) + \beta_i$, therefore – $(n-k) - r_i + 2\beta_i$. ■

**Statement 3.** *If we produce $k$ per-vertex changes in the set $m_1$ and the same changes in the set $m_2$, having obtained the states $m_1^k$ and $m_2^k$, respectively, then the VD of the set $m_1$ from $m_2^k$ and the set $m_2$ from $m_1^k$ coincide.*

**Proof of Statement 3.** According to Statement 2, for $k$ rows $m_1$ and $m_2^k$, the VD will be equal to $(n-k) - r_i + 2\beta_{i}{}_{i}^{*}$, and for $n-k$ rows $m_1$ and $m_2^k$ the VD will differ by $k - r_i + 2\beta_{i}{}_{i}^{*}$, where $r_i$ – components of the VD $m_1$ from $m_2$. Similarly, for $k$ rows $m_2$ and $m_1^k : (n-k) - r_i + 2\beta_{i}{}_{i}^{**}$ and $n-k$ rows $m_2$ and $m_1^k : k - i + 2\beta_{i}{}_{i}^{**}$. ■

In this case $\beta_{i}{}_{i}^{*}$ and $\beta_{i}{}_{i}^{**}$ are part of the constant signs between $k$ vertices or $n-k$ vertices, therefore $\beta_{i}{}_{i}^{*}$ and $\beta_{i}{}_{i}^{**}$.

This statement allows one to find one of the closest consonant sets for a given dissonant set, moving inside the contour of the dissonant set and fixing vertex flips that lead to obtaining VD components not exceeding $\gamma$ – half of the vertex connections. However, one of the closest approximations of the dissonant set found in this way will not necessarily be the best.

| | | 0:9 | | | | | 5:4 | | | $r_1$ | $r_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **o 1** | + | + | + | + | - | - | - | - | 4 | 0 |
| | + | **o 2** | + | + | + | - | + | - | + | 2 | 2 |
| | + | + | **o 3** | + | + | + | - | + | - | 2 | 2 |
| | + | + | + | **o 4** | + | - | + | - | + | 2 | 2 |
| | + | + | + | + | **o 5** | + | - | + | - | 2 | 2 |
| | - | - | + | - | + | **o 6** | + | + | + | 3 | 2 |
| | - | + | - | + | - | + | **o 7** | + | + | 3 | 2 |
| | - | - | + | - | + | + | + | **o 8** | + | 3 | 2 |
| | - | + | - | + | - | + | + | + | **o 9** | 3 | 2 |

**Figure 1.** Matrix of a dissonant set and its VD with consonances 0:9 and 5:4.

Figure 1 shows an assonant set with VD $(r_1)$ relatively a trivial consonant set of type (0:9) is worse than that characterizing the difference with the consonant set (5:4), since the sum of the VD $(r_1) = 24$ is greater than the sum of the VD $(r_2) = 16$, although for both VD all $r_i \leq \gamma$, where $\gamma = (n-1)/2$.

**Statement 4.** *There are several VDs with components not exceeding $\gamma$ – half the number of connections of the vertex. It should be noted that such sets differ by at least two vertex changes if n is even and by at least three if $n$ is odd.*

**Proof of Statement 4.** Let us take the state of difference of connection, characterized by the vector $\overline{r} : r_i < \gamma$. We carry out $k$ per-vertex changes, so we get the vector $\overline{r}k : r_i^k < \gamma$, $r_j^k < \gamma$. According to statement $2r_j^k = (n-k) - r_j + 2\beta_j$. All components $r^k$ must be less than $\gamma$, hence $(n-k) - r_j + 2\beta_j < \gamma$ and $k > n - \gamma - r_j + 2\beta_j$. $k$ is minimal at $\beta_j = 0$, and $r_j$ reaches the value $\gamma - 1$. So $k > n - 2\gamma + 1$ and it is easy to see that $k > 1$ for even $n$, and $k > 2$ for odd. ■

In Figure 2 a set of eight objects is depicted, equidistant from three consonant sets separated by two vertex changes, so that all $r_i < \gamma$.

| 0:8 | | 2:6 | 4:4 | | | | |
|---|---|---|---|---|---|---|---|
| o 1 | + | + | + | - | - | - | + |
| + | o 2 | + | + | + | - | - | - |
| + | + | o 3 | + | - | + | + | + |
| + | + | + | o 4 | - | + | + | + |
| - | + | - | - | o 5 | + | + | + |
| - | - | + | + | + | o 6 | + | + |
| - | - | + | + | + | + | o 7 | + |
| + | - | + | + | + | + | + | o 8 |

| 0:8 | 2:6 | 4:4 |
|---|---|---|
| 3 | 3 | 1 |
| 3 | 3 | 1 |
| 1 | 3 | 3 |
| 1 | 3 | 3 |
| 3 | 3 | 1 |
| 2 | 0 | 2 |
| 2 | 0 | 2 |
| 1 | 1 | 3 |

**Figure 2.** Matrix of a dissonant set and its VD with consonances 0:8, 2:6 and 4:4.

Figure 3 shows two VD (with components less than $\gamma$) for the assonant set from the consonant sets (0:9) and (4:5). It turns out that a state where all $r_i < \gamma$ cannot guarantee that this particular state should be considered minimally remote.

| 0:9 | | | 4:5 | | | | | |
|---|---|---|---|---|---|---|---|---|
| o 1 | + | + | + | + | - | + | - | - |
| + | o 2 | + | + | - | + | - | - | + |
| + | + | o 3 | + | + | - | + | - | - |
| + | + | + | o 4 | - | + | - | + | - |
| + | - | + | - | o 5 | - | + | + | + |
| - | + | - | + | - | o 6 | + | + | + |
| + | - | + | - | + | + | o 7 | + | + |
| - | - | - | + | + | + | + | o 8 | + |
| - | + | - | - | + | + | + | + | o 9 |

| 0:9 | 4:5 |
|---|---|
| 3 | 2 |
| 3 | 2 |
| 3 | 2 |
| 3 | 2 |
| 3 | 3 |
| 3 | 3 |
| 2 | 2 |
| 3 | 1 |
| 3 | 1 |

**Figure 3.** Two VDs with unimprovable components, but with different total distances.

Thus, to obtain a truly minimally distant state, the vertex difference reduction algorithm must find all locally minimal states and then select the truly minimal one from among them.

A comparison of a certain consonant set with a given dissonant set shows that their VD will contain differences in connections inherent to the consonant set as such, and differences that arose due to residual dissonant connections. That is, the VD contains two types of differences. The nearest consonant set and any other consonant set are in the same circuit, so vertex transfers can only improve the distance to a given dissonant set, but residual dissonant connections will still remain as a minimal set. Iterative vertex transfers are a very expensive procedure because the search is not carried out within types, but among instances of consonant sets, of which there are about $2^{n-1}$.

Within polyconsonance of degree $N$, consider the assonance set and the consonance set consisting of subsets $A_1, A_2, A_3, \ldots, A_N (n_1 : n_2 : n_3 : \ldots : n_N)$ composed of the same objects. Differences in object connections $o_i \in A_1, A_2, A_3, \ldots, A_N$ with an assonant set specifies $r_i$ –

VD component. Take two subsets $A_1$ and $A_2$ from $n_1$ and $n_2$ objects. If $o_i$ has connections with components of subsets $A_1$ and $A_2$, which in total are more than $(n_1 + n_2 - 1)/2$ do not coincide with the connections $o_i$ in the assonant set, then $o_i$ should be moved from $A_2$ to $A_1$, which will reduce $r_i$. Proceeding by analogy with the other components, we reach a state in which none of the rerolls make sense. But this, unfortunately, does not completely eliminate the interconsonant type of difference, leaving only bad dissonant connections. In fact, the inefficiency of the next single vertex transfer does not mean that there is no efficient simultaneous transfer of a group of components to achieve the minimum approximation.

Let us examine in more detail what happens at $k$ top-of-vertex transfers. Let's represent the VD component $r_i$ in the form $r_i = \beta_i + \omega_i + v_i$, where $\beta_i$ is the sum of different signs between variable $k$ objects, $\omega_i$ is the sum of different signs with $n_1 + n_2 - k$ objects of the subsets considered above and $v_i$ – insignia with $n-(n_1+n_2)$ objects located in other subsets. According to Statement 2, after completed $k$ re-throw components of the VD will be equal to $n_1+n_2-k-r_i+2\beta_i+2v_i$. Let's assume that there is no object $o_i \in A_2$, which has connections with $n_1$ and $n_2$ objects $A_1$ and $A_2$ have more than $1/2(n_1 + n_2 - 1)$ differences with the same objects of the assonant set. Let us derive a condition that determines the simultaneous transfer of a group of objects from $A_2$ in $A_1$. In this case $\gamma = 1/2(n_1 + n_2 - 1)$. The signs $v_i$ have no effect. Then we fix $\beta_i + \omega_i$ insignia with all the others $n = n_1 + n_2$ objects. After $k$ transfers of differences became $(n_1 + n_2 - k) - \omega_i + \beta_i$. Initially $-\beta_i + \omega_i \leq \gamma$, accordingly, having carried out transfers, we remain in a state that cannot be improved by a single transfer, which means $(n_1 + n_2 - k) - \omega_i + \beta_i \leq \gamma$. Here you can write for $\beta_i : \beta_{i_i} \leq (k-1)/2$ and for $\omega_i : \beta_i + \gamma - (k-1) \leq \omega_i \leq \gamma - \beta_i$. The situation of minimal sign difference will become better if $\sum^k \beta_i + \sum^k \psi_i > \sum^k (n-k) - \sum^k \psi_i + \sum^k \beta_i$, $\sum^k \psi_i > 1/2(n-k) \cdot k$.

Then $\sum^k \psi_i + \sum^k \beta_i \leq \gamma \cdot k$, and hence, $\sum^k \beta_i < \frac{k(k-1)}{2}$.

Let's assume that $k-1$ the transfer does not lead to the required minimum, i.e., $\sum_1^{k-1} \psi_i \leq \frac{(n+k+1)(k-1)}{2}$. Then the minimization effect from simultaneous transfer $k$ objects will be reached if $o_k$ is found: $\sum^{k-1} \psi_i + \psi_k > \frac{(n-k)\cdot k}{2}$, or $\psi k > \gamma - (k-1)$.

The meaning of the condition $\sum_1^k \psi_i > \frac{(n-k)\cdot k}{2}$ is quite clear: the existence of a group of $k$ objects, which has more than half of the connections with $n-k$ objects differing from the connections of a given dissonant set, indicates that this group is a candidate for transfer to another subset, and this operation will indicate for a given dissonant set the closest consonant set in terms of the difference in connections [*Rozenberg and Dulin*, 2023]. Finding such a group of objects even for polyconsonance of degree 2 is a very difficult task, because it is impossible to determine in advance even the potential possibility of each object being included in the group constructed for the proposed transfer.

**Examples of use**

The methodology for ensuring structural interoperability was implemented in a specialized system called iiProcessor [*Dulin et al.*, 2020; *Ryabtsev and Dulin*, 2025]. This system is designed to create coherent knowledge bases in the fields of social, political, and international sciences. The knowledge bases are built using information provided by various media outlets through their internet servers. The main goal of the system is to accumulate information messages on topics of interest to the user from various sources on the Internet, to integrate this information into a unified knowledge base, to create links between different elements of the knowledge base, as well as to reorganize the knowledge base based on these links. The result of this restructuring is the representation of the accumulated information in the form of a logical system of coherent groups. The overall scheme of the system's operation is presented in Figure 4.

This system uses the CNN website (http://cnn.com) as a source of information. In most cases, information messages are poorly structured text documents. To establish connections between different documents, the previously described method of structural consistency is used. Screenshots of the system's operation are presented in Figure 5. The similarity function classifies the relationships between messages and constructs a connectivity matrix

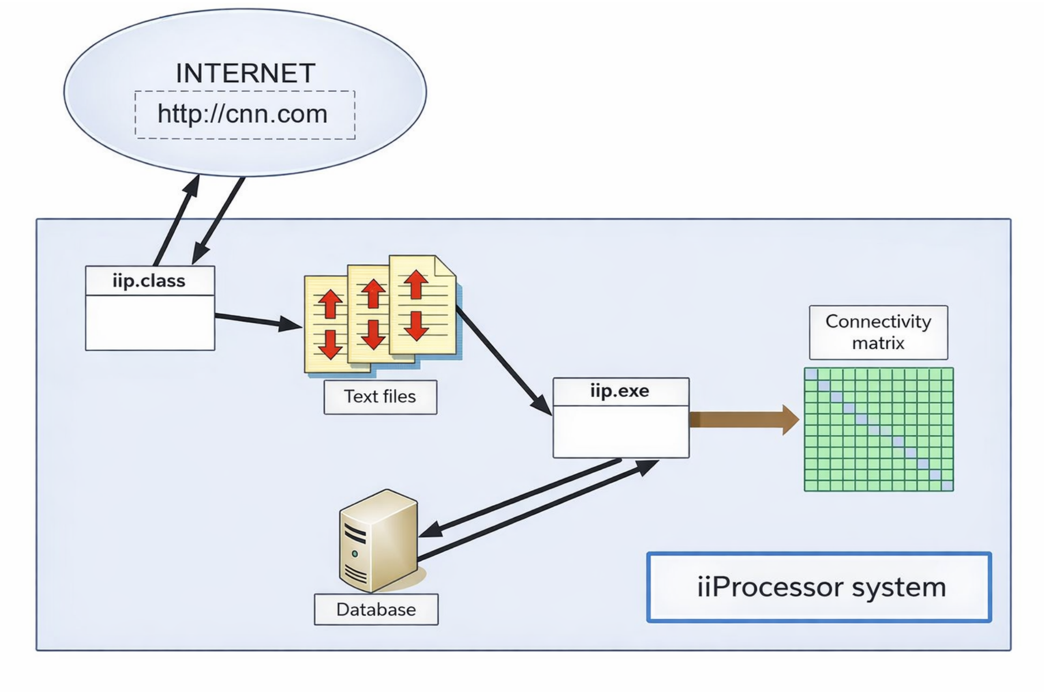


**Figure 4.** Module for consistency control in the iiProcessor system.

on the set of information messages received by the user, after which an algorithm for increasing the consistency of structural interoperability is used.

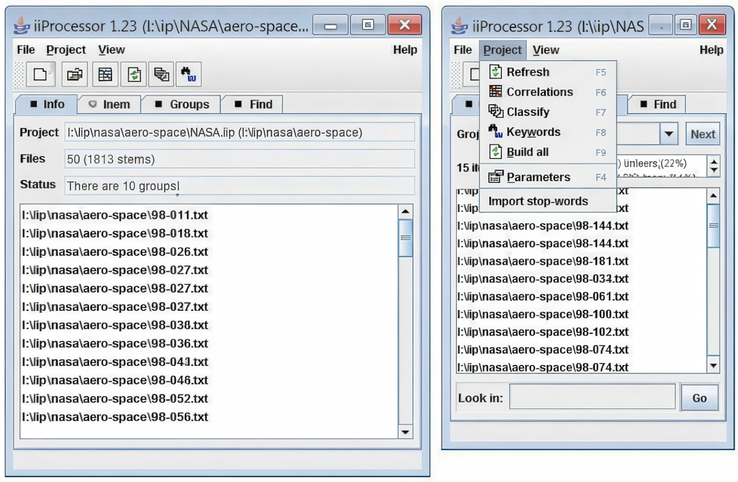


**Figure 5.** Screenshots of the iiProcessor system.

The study [*Leal et al.*, 2019] aimed to find an optimal method, balancing quality, speed, and ease of use, for solving the problem of increasing structural consistency based on the algorithm for improving the consistency of structural interoperability. Several methods are proposed for increasing the consistency of data structure using the example of the problem of searching for groups of identical products on a marketplace [*Ryabtsev and Dulin*, 2025]. Proper grouping of identical products makes it easier to find the most suitable offers in terms of price, rating, or delivery time, and thus improves their interoperability. These groups also allow marketplace sellers to gain insight into the competitiveness of their prices and the attractiveness of their product listings compared to other sellers, so they can make changes if necessary. The main objective of the study is to select the optimal strategy for combining products into groups based on the principle of identity.

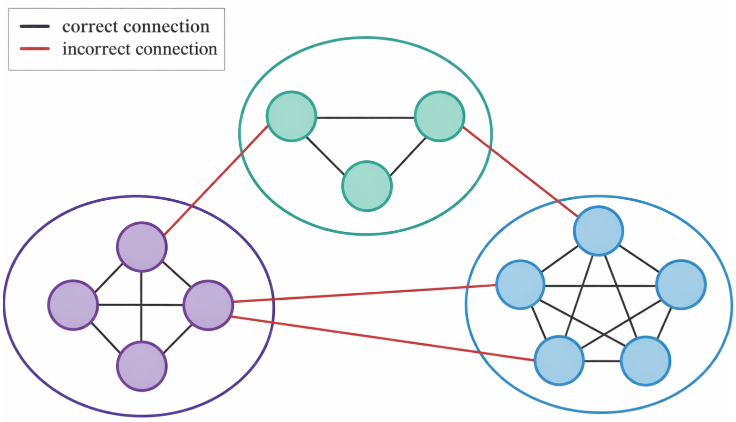


**Figure 6.** Three groups of identical goods mistakenly connected to each other by a small number of edges.

As follows from the analysis of foreign sources, there are several approaches to the formation of interoperability, but most of them are directed towards creating special models [*Makarenko*, 2022]. Each approach has advantages and disadvantages in terms of achieving interoperability in a particular context. The main advantages of interoperability models are the ability to (a) define a common vocabulary that provides semantic consistency and analysis; (b) consider alternatives for the structure of solutions, and finally (c) evaluate new ideas and incorporate various options. Currently, each interoperability model defines a common taxonomy that supports different goals, achieving interoperability in different contexts.

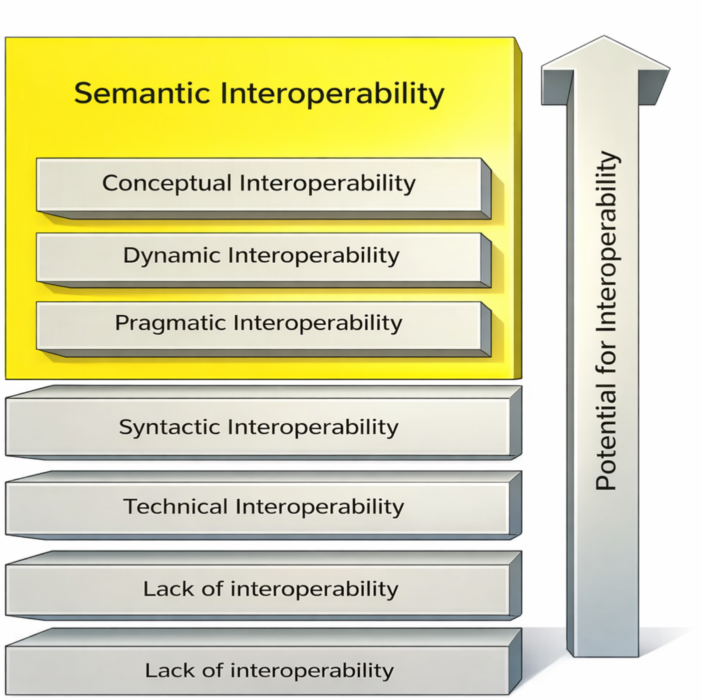


**Figure 7.** Extension of the influence of semantic interoperability to the upper levels of interoperability.

The experience of studying the implementation of semantic interoperability [*Rozenberg and Dulin*, 2023] in the transport infrastructure led the authors of this work to the need to expand the role of semantic geointeroperability by extending it more widely to the upper levels of interoperability of the generally accepted scheme (Figure 7).

As can be seen from Figure 7, the expansion of the role of semantic interoperability consists in considering the pragmatic, dynamic, and conceptual levels under the auspices of semantic interoperability.

Different users should be able to understand the meaning and significance of the information obtained as a result of the exchange. Therefore, the approach based on the algorithm for improving structural interoperability allows for the management of the process of grouping elements motivated towards interoperability, taking into account the simplest modeling of semantics.

The algorithm for improving structural interoperability described above has found its application in information support for the design, construction, reconstruction, and overhaul of railway infrastructure facilities. The Integrated System of Spatial Data of the Railway Transport Infrastructure (ISSD RTI) implements the solution to the problem of geointeroperability on an industry scale [*Russian Railways*, 2021] as a problem of joint coordinated use of geodata obtained from different information sources (Figure 8).

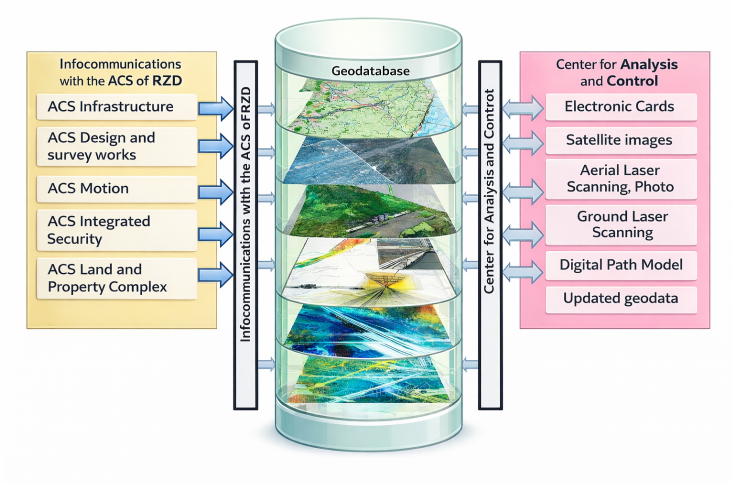


**Figure 8.** Conditionality of geointeroperability in the Integrated System of Spatial Data of the Railway Transport Infrastructure (ISSD RTI).

ISSD RTI is an information technology system for the centralized collection, integration, storage, and analysis of coordinate-referenced information about railway infrastructure facilities. The system is designed to optimize technological processes for monitoring and managing railway infrastructure facilities at all stages of the life cycle. Processing and synthesis of geodata on infrastructure facilities is carried out on the basis of geointeroperability of competent users under the control of a hardware and software complex that collects, processes, stores, and provides geodata for functional applications. It should be noted that achieving the level of semantic geointeroperability is significantly supported by the interoperability structure defined by the algorithm for improving structural interoperability.

## Conclusion

The obtained results demonstrate that multiple acceptable interoperability structures may exist for a given set of interacting elements. Identification of an optimal structure requires either exhaustive search or the use of well-founded heuristics that account for the properties of the connectivity matrix.

Despite the computational complexity of combinatorial transformations, the vertex-difference-based mismatch reduction algorithm provides an effective tool for continuous analysis and control of structural consistency. Its applicability within the polyconsonance framework significantly expands its relevance to complex systems composed of multiple interacting groups.

The proposed algorithm can be used both in theoretical studies of interoperability and in applied tasks related to the organization and coordination of complex information systems, including knowledge bases, geospatial infrastructures, and transport information systems.

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