STRUCTURAL ANALYSIS CROSSING DOMAIN BORDERS

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ABSTRACT

There has been a growing recent interest for domain-spanning dependency analysis of product development systems. Several models for depicting these inter-domain relationships have been provided with the Domain-Mapping Matrix (DMM), and the more comprehensive Multiple-Domain Matrix (MDM), but existing methods are often limited to tackle specific problems. This paper points out some general issues regarding structural analysis between domains, and suggests directions for a generic analysis of inter-domain dependencies. Inspired by General System Theory, three structural criteria are converted into indicators that are comparable, also between system and project borders.

Keywords: Structural complexity management, inter-domain dependencies, Multiple-Domain Matrix, structural analysis, General Systems Theory

1 INTRODUCTION

The control of complexity is an increasingly important issue in product development. The Design Structure Matrix (DSM) (Steward, 1981) has become a popular tool to analyse and optimise internal structures in product, organisation, and process domains (Browning, 2001; Birkhofer, 2011, p.148). The Domain Mapping Matrix (DMM) was introduced to structural analysis and deliberately formalised by Danilovic and Browning (Danilovic and Browning, 2001; Danilovic and Browning, 2007), and has been applied to specific problems like the organisation of a multi-project environment (Danilovic and Sandkull, 2005).

DSMs and DMMs are combined in the Multiple-Domain Matrix (MDM) model, for a more comprehensive depiction of complex systems and its interdependencies. Based on graph theory, several structural criteria have also been formulated, as means for developers to optimise system complexity in an approach to design called Structural Complexity Management (Lindemann et al., 2009). Different methods for the MDM have also been developed, including the support of requirements management (Eben et al., 2010) and reduction of waste (Elezi et al., 2011) Specific analysis criteria for dependencies between the domains of product components and project employees (Kortler et al., 2010). General characteristics and applications of inter-domain structural analysis is however little described in literature.

According to General System Theory (Bertalanffy, 1969), domain-spanning dependencies may be of great importance for system behaviour, however, deterministic methods are often insufficient to evaluate such complex systems (Boulding, 1956). A framework that does not implicate a deteriorating simplification of the system information in order to fit a mechanistic model is then needed. As an elaboration of structural criteria (Lindemann et al., 2009), structural indicators are proposed in this paper to extend our ability to describe and compare complex systems.

2 FROM INTRA- TO INTER-DOMAIN ANALYSIS

Networks contained within single domains have been the traditional subject for structural analysis. This type of analysis is characterised by the structural assessment of an element or a network, with respect to specific analysis criteria. According to a certain criterion, dominant structures within a domain can then be identified (Lindemann et al., 2009). The possible application area of structural analysis increases when inter-domain dependencies are taken into account, as the structures no longer are contained within a single domain. However, considering the dependencies of the DMM as ordinary edges between nodes from different domains, networks would have formed, which would have been too large to be analysed. Thus, in order to consider inter-domain dependencies in structural analysis, the concept of dependency-based networks as subsets of the MDM, has to be discussed.

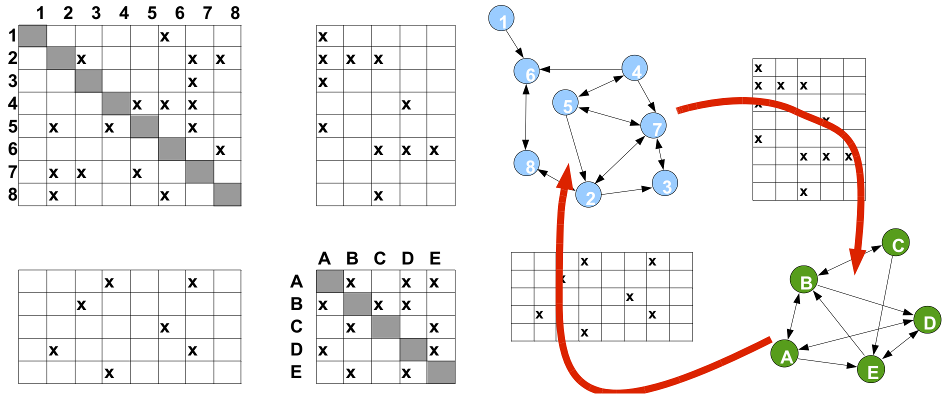

Figure 1. Networks in an inter-domain setting

On the left-hand side in Figure 1, a simple MDM depicts two domains, and the dependencies between them. A network representation of the domains is represented to the right, and it can be seen that all elements of both domains are interconnected. Numerous dependencies between the domains, also indicate a considerable linkage between the two single-domain networks. How the relation between these two networks is characterised is a vital issue in inter-domain dependency analysis. Networks are not given the ability to encompass more domains in this paper, because this complicates already established analysis methods. Besides the structural indicators proposed in this paper, filtering criteria could also be elaborated in order to take care of these complications with networks that span domains.

2.1 System and subsets in inter-domain structural analysis

When the borders of a domain are considered non-permeable, a hierarchy of the system for inter-domain structural analysis can be created as following:

1. Global System
2. Domains
3. Networks
4. Nodes

Hence, nodes are subsets of networks, which again are subsets of domains. The domains, in the MDM represented by DSMs, are further considered as subsets of the global system. All subsets can be assessed in relation to another, and to the global system according to the established norms for directionality. An element may for instance be assessed with respect to its structural importance within its own network, and a whole domain can be evaluated according to its influence on a single node in another domain. Networks, domains and the global system can also be characterised by their internal structures like edge density, and thereafter be compared with similar structures from other projects.

2.2 Comparative basis for inter-domain structural analysis

Dominant structures can be deduced deterministically through the assessment of the respective system, or its subsets. Additionally, they can be identified through comparisons with structures from other domains or other systems. In order to perform this comparison of structures that are not contained by one domain, standardised indicators are needed. With generic indicators, the size of the domain does not influence the values forming the basis for the analysis, thus, structures can be compared across domains and between projects.

3 STRUCTURAL INDICATORS FOR INTER-DOMAIN ANALYSIS

Indicators for the structural characteristics of a system constitute a key feature in the approach to inter-domain structural analysis of this paper. To be able to gather, and compare data from several sources, a consistent framework for the comparison of characteristics between distinct domains and projects is required. The directions of such a framework are suggested in this section of the paper. The three inter-domain structural indicators defined in the following, are based on the graph theory-inspired structural criteria of activity and active and passive sum. (Probst & Gomez, 1991, p. 13; Lindemann et al., 2009, p. 202). The word "relative" is added in order to underline each parameter's independence of the originating subsets.

Relative Active Sum *= determined outgoing dependencies / possible outgoing dependencies.*

Relative Passive Sum *= determined incoming dependencies / possible incoming dependencies*

Relative Activity *= Relative Active Sum – Relative Passive Sum*

The "possible" dependencies represent all cells in the matrix that may denote a relation between the assessed structures. The relative sums are divided by the amount of possible dependencies, in order to give a result between 0 and 1. Hence, they can be compared across domains and systems, and the indicators can be incorporated in a combined analysis, where they are used as weighing factors.

Accordingly, the relative activity is a number between -1 and 1. A negative activity means that the evaluated structure is more susceptible to adopt system adaptations, but not as determinative for the system. A positive activity indicates structures that drives system adaptations, but are less affected by the subset chosen for assessment. When the activity is zero, the sums will have to be reviewed to check if the structure is passive (few dependencies) or carriers of adaptations. A relation between activity of a node, and a model of roles in change propagation (Eckert et al., 2001) can then be suggested as shown in Figure 2.

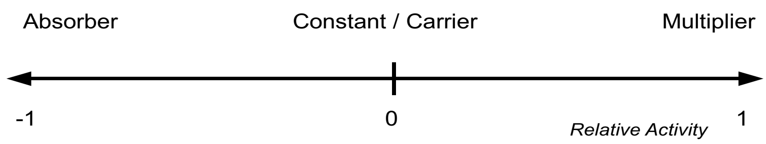

Figure 2. Relation between activity of a subset and its role in change propagation

The main application of structural indicators is however not only to analyse single systems, but to compare different configurations according to their structural characteristics. This will be further explained when the indicators are applied to a test case.

3.1 Structural indicators applied to a test case

In Table 1, the results from the assessment an acoustic guitar are presented with respect to different analysis borders. The dependencies within and between the domains of "components" (system architecture), "important characteristics" and "critical parameters" were assessed, and evaluated according to the structural indicators. The domain of important characteristics is in Table 1 considered as a subset, and evaluated with respect to its involvement in the whole system and the component domain. The network of components called "guitar body" is evaluated with respect to the global system, the domain of important characteristics, as well as to its own domain. The "play ergonomics"-element of the characteristics domain, is evaluated with respect to the global system, the components domain and its originating domain of important characteristics.

Table 1. Structural indicators from test case

	Global			Components – Characteristics			Intra-domain		
Subset	**Active**	**Passive**	**Activity**	**Active**	**Passive**	**Activity**	**Active**	**Passive**	**Activity**
Characteristics (Domain)	0.29	0.27	0.02	0.20	0.14	0.06	-	-	-
Guitar body (Network)	0.25	0.12	0.13	0.40	0.10	0.30	0.24	0.28	-0.04
Play ergonomics (element)	0.28	0.28	0.00	0.09	0.36	-0.27	0.29	0.29	0.00

The most interesting aspect of the structural indicators is perhaps the ability to compare the characteristics of structures from different domains, and even different projects. Being able to compare the structural indicators from one system with others, the indicators may provide a tool to describe and discuss factors which influence performance but not yet have been numerically indicated. Variation in the structural indicators, beside a qualitative evaluation of the performance would help an organisation to generate knowledge on the factors that determines project success.

Different system configurations would give different structural characteristics, and based on experience and a sufficient basis of data, one could distinguish particular configurations that are ideal or critical for the performance of the system, for instance an acoustic guitar. In addition to this potential to comparative analysis as well as to more deterministic analysis like change propagation, the values of Table 1 indicate how the structural characteristics vary when nodes or subsets of the MDM are assessed in regard to different parts of the test model. The values are visualised in Figures 3 and 4, which visually compare the subsets from Table 1 in regard to the three structural indicators proposed in this paper.

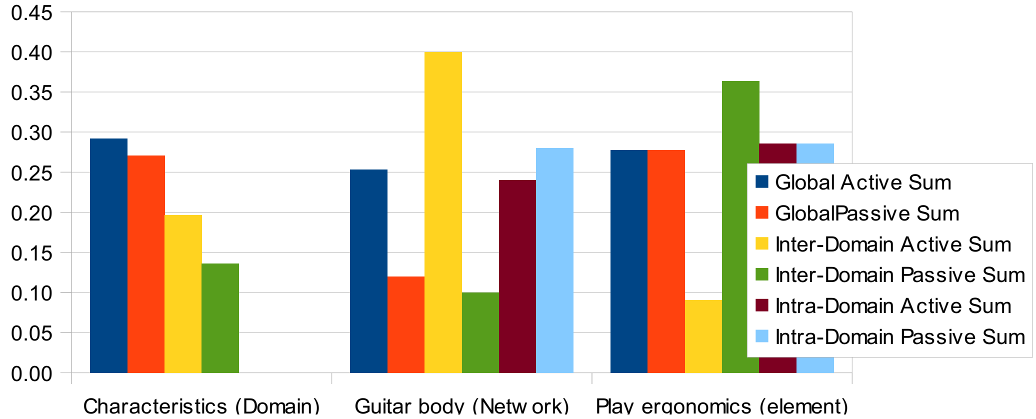

Figure 3. Relative Sums of three subsets from the test case

How the entities are differently connected to the whole system, or to system subsets, is illustrated in Figure 3. It should here be noted that for instance the guitar body network influences other domains in a different way than it influences its own The discrepancy in the projection of the play ergonomics towards the other domains is also worth noticing, and does not surprisingly suggest that the play ergonomics are susceptible to adaptations within the components domain, but on the other side determinative for the critical parameters.

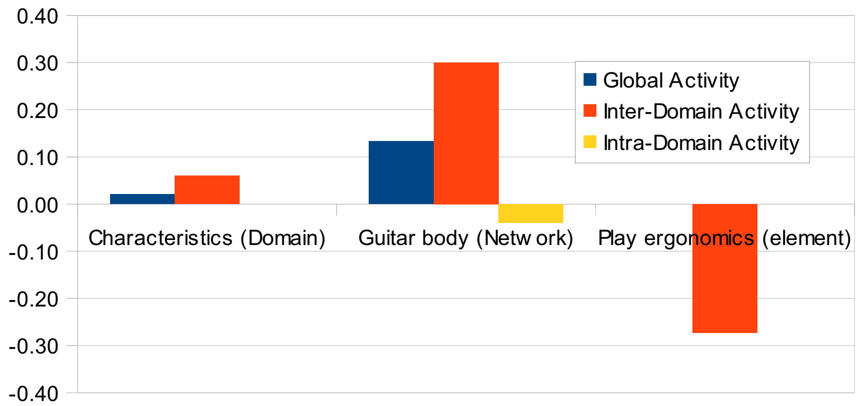

Figure 4. activity of three subsets from the test case

Figure 4 shows even more explicitly that the smaller subsets differ more in their structural characteristic than the larger domain, when they are assessed with respect to different parts of the system. This may be caused by the nature of the relative values from the whole domain, as average values. The more nodes that compose the subset, the more likely is an equilibration of the structural characteristics. Nevertheless, the flow through domains can be evaluated by this type of analysis. When different projects are analysed, similar domains showing distinct structural characteristics from these projects, could help us to determine different different project types and success factors.

The fluctuation in the outcome of the activity indicator for different target subsets, was also smaller for the domain than for the smaller subsets. This should also be expected, because the domains are closer to a system in itself. The activity of the whole system would be zero, which should be comprehensible for a closed system like the MDM.

4 CONCLUSIONS AND OUTLOOK

An expansion of structural analysis was indicated in this work. Responding to a need to describe increasingly more complex structures, concepts from DSM analysis were rationally assessed in an inter-domain setting. However, these deterministic methods and analysis criteria seemed insufficient in order to generically deduce useful information from inter-domain dependencies, therefore a new direction of analysis was suggested.

Inspired by Systems Thinking, structural indicators were proposed and tested in an artificial test case. Within existing frameworks like the MDM, different structural indicators can contribute to a more holistic understanding of the system´s composition. Relating both the domains of the specific system, as well as a possibility to compare different projects according to their structural characteristic, this is an interesting, as well as a demanding direction of future Structural Complexity Management. Three structural indicators were outlined in this paper. However, a much more extensive framework should be developed and discussed before case studies can be carried through.

On the other side, given a consistent and generic framework for the structural analysis, a wide basis of data could be gathered, so that managers and developers could compare indicators from their projects with valid reference values. These indicators could continuously monitor the system, and give feedback on how modifications would affect it. Based on the feedback from such indicators, actions can be taken, or solutions can be tested in order to improve the performance of a system according to a certain criteria.

This paper outlined a new way of thinking in dependency analysis, and intends to start a discussion on the future of structural analysis. If more and more complex structures and systems are to be controlled and optimised, inter-domain dependencies will probably be a more influential part of the analysis. In the spirit of General System Theory, a move towards more generic analysis criteria is then suggested, illustrated by three structural indicators that are generally comparable.

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Structural Analysis Crossing Domain Borders

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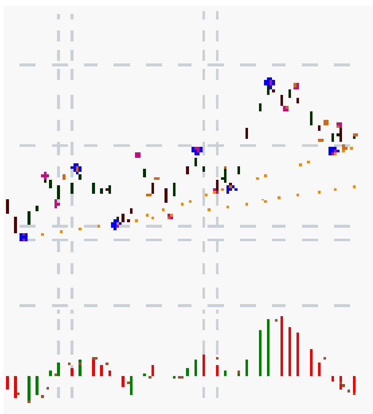
Motivation

- Global competition has led to an increased focus on performance in product development and design.
- New measurement methods are needed in order to:
  - gain more knowledge about the structure of product development projects.
  - predict project performance early in the design and development process.



➔ Indicators can help monitoring the performance of development projects through consultation of reference values. They also provide structural characteristics for evaluating the influence or importance of a subset in different project domains.

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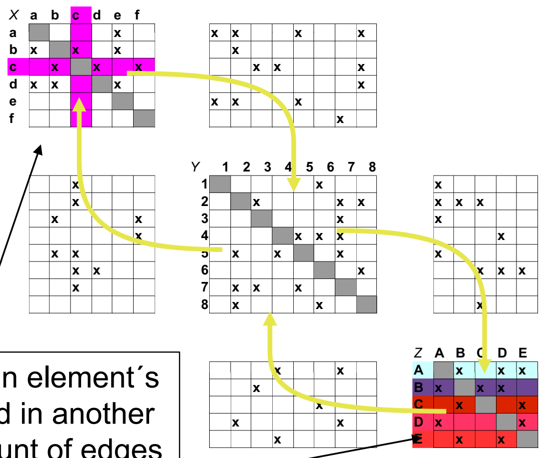
Hierarchy of subsets and directionality

- Several types of subsets can be evaluated according to their set of dependencies, but a hierarchy of subset types needs to be established in order to limit the analysis space. **Networks can easily grow too big!**
- Hierarchy of subsets:
  1. Global System
  2. Domains
  3. Networks
  4. Elements
- All these subset types can be assessed bi-directionally with respect to the others



This example shows how an element´s importance can be reflected in another domain, based on the amount of edges between them. It can be seen that large distances create redundancies.

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Inspiration from System Theory

- Early system theory researchers defined different levels of complexity for describing the systems of the world that surrounds us.

1. Structures. Static depictions like maps or drawings.
2. Simple dynamic systems whose members perform predetermined actions. The solar system is an example.
3. Level of cybernetics. Regulated systems like a thermostat and a heater.
4. Open systems. Throughput is an important characteristic, like it is for rivers or even plant or animal cells.
5. Life begins. At this level, specialised cell structures interact in order to keep the organism alive.

6., 7., 8., 9.... Levels of life and more advanced systems.

Deterministic approaches are limited to the first levels. For the higher levels, only indicators and qualitative evaluations help to predict system behaviour, which is the case for medicine, economics, etc..

Structural Indicators

- Structural Criteria are developed for deterministic analysis of structures in product development projects. They are mostly based on numeric values.
- Standardising these values can not just predict system behavior, but also allows comparison between different products and projects.
- Three structural indicators were suggested in the paper:

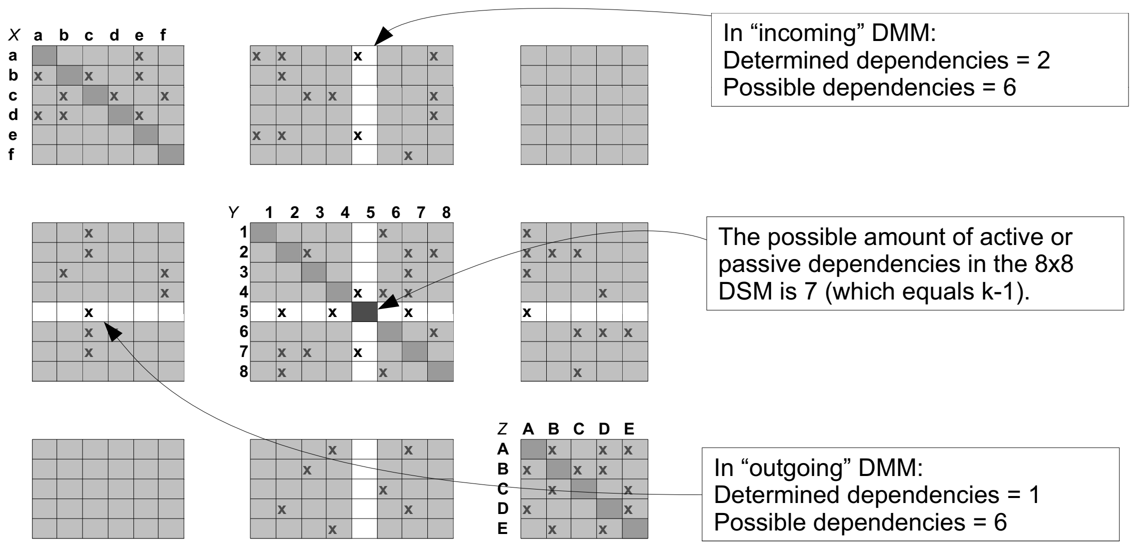
Relative Active Sum = $\frac{\text{determined outgoing dependencies}}{\text{possible outgoing dependencies.}}$

Relative Passive Sum = $\frac{\text{determined incoming dependencies}}{\text{possible incoming dependencies}}$

Relative Activity = Relative Active Sum – Relative Passive Sum

- All values are between -1 and 1 for possible future application in the filtering of dependencies.
- Existing studies on structural criteria can guide further development of structural indicators.

Structural Indicators

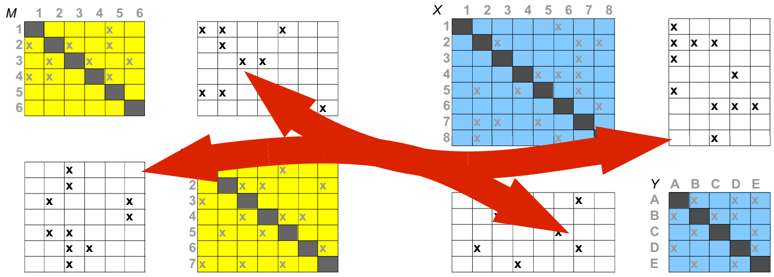


→ Y -->X inter-domain Relative Active Sum of element 5 = 1 / 6

Global Relative Passive Sum of element 5 = 2 / 11

Advantages of Structural Indicators

- Through structural indicators, the structural characteristics of a system can be compared with other similar systems.
- For instance scheduled design improvement processes can be guided by the values of the project´s structural indicators.



A pair of domains from one product.

A pair of domains from another product.

Similar subsets of domains from different projects that have a similar purpose can be identified, and later compared. The “learning organisation” will be easier to achieve when able to compare performance with reference values.

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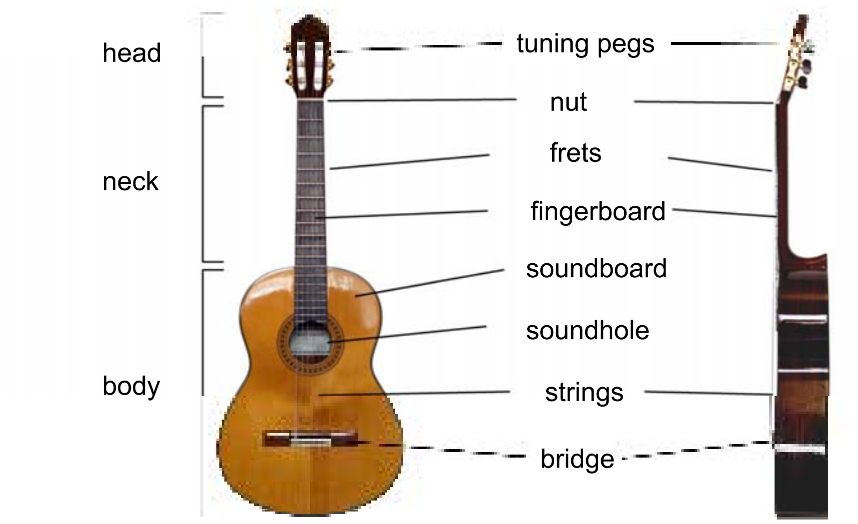
Test Case

- A typical acoustic guitar was used as a test case.
  - A musical instrument with a quite simple build-up, but several complex features.



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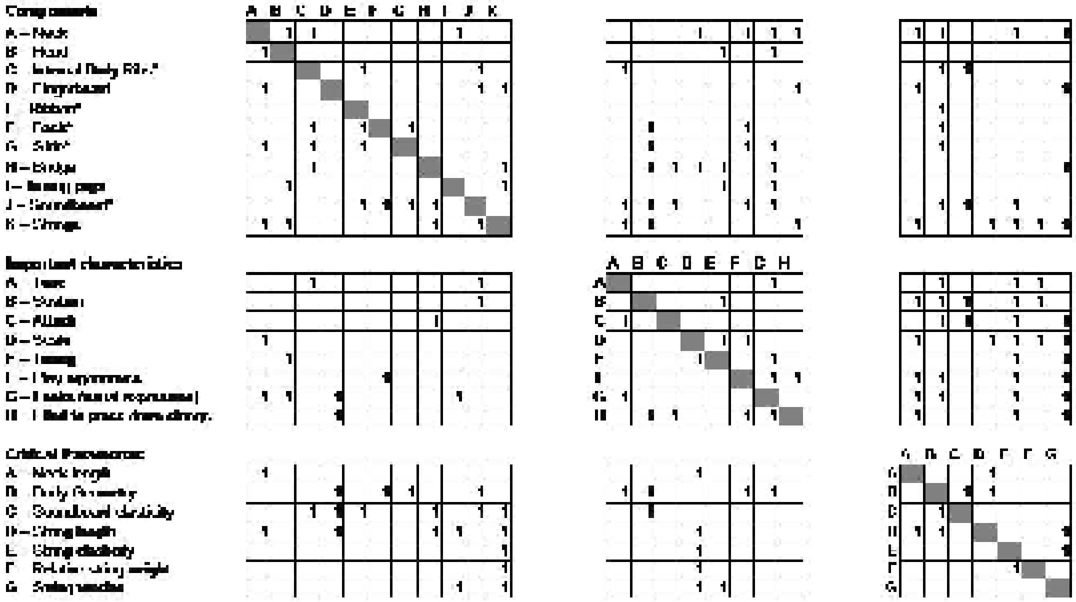
MDM – Acoustic Guitar



- Appropriate simplifications were made in order to map the correlation between the system architecture, critical parameters and characteristics

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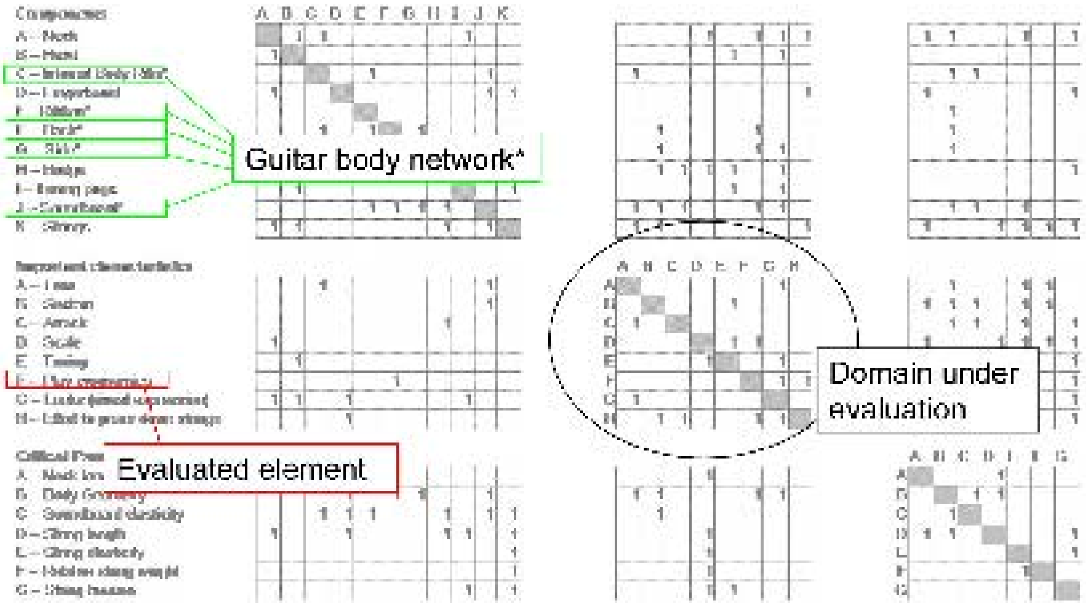
Acoustic Guitar – Evaluated elements



*Comprised by all closest dependencies (distance = 1) of the back-component.

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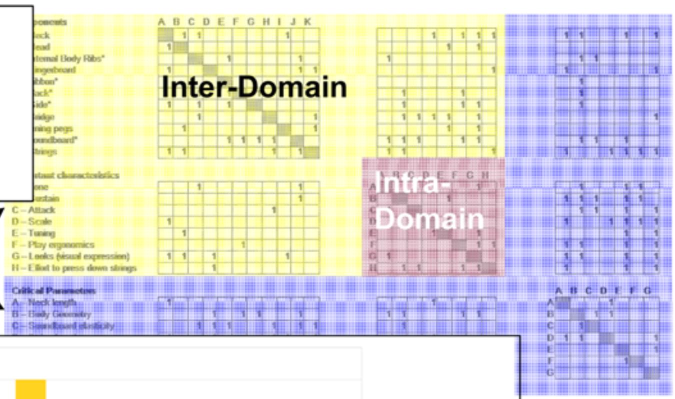
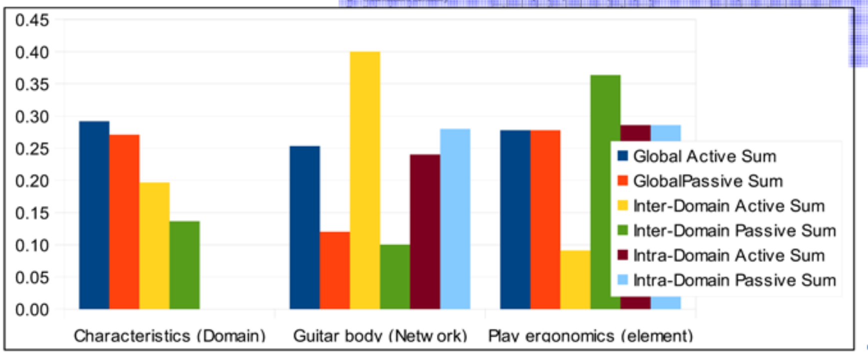
Evaluation Borders with Several Domains

Evaluating the element "play ergonomics" with respect to different subsets in a multiple domain matrix.

Global
(Yellow and Blue)





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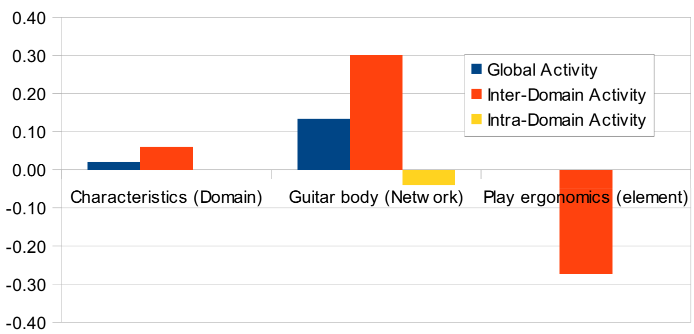
Indicator Values

- Subsets are connected differently to other domains.
- According to structural criteria:
  - play ergonomics are highly affected by the design of the components
  - The guitar body is determinative for the critical parameters.

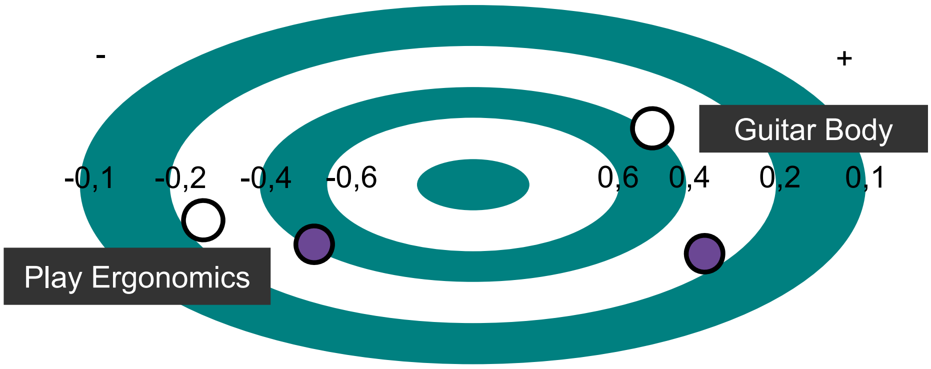


- In a simple test case like the one presented in this paper, the results will have a similar interpretation as structural criteria.

- Subsets can however be compared across domain borders, and here the results of the relative activity evaluation provided.

Values and Alternative Visualisations

- A target diagram can be used to compare the structural characteristics of subsets, like this hypothetical comparison of relative activity.



☐ *Acoustic Guitar* ■ *Electric Guitar?*

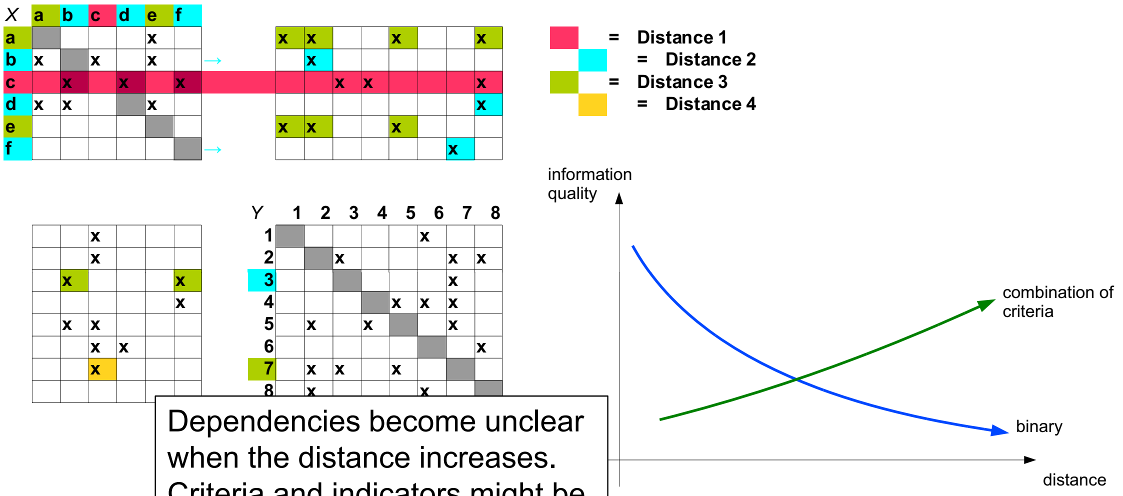
- Comparisons could be made of several similar products, like different acoustic guitars (nylon or steel strings, etc.), electric guitars, base guitars, and so on, in order to gain knowledge of the structural characteristics in guitar development projects.

Importance of Structural Indicators

- The interpretation of results can be equivalent to that of Structural Criteria, since the Structural Indicators proposed in this paper build on the theories of Structural Criteria.
- When evaluating structural criteria of several similar projects, for instance versions or products from different product lines, the indicators from the different projects can be compared and qualitatively analysed in order to see how better performance can be achieved.
  - Could the evolution of Martin guitars have been faster with the guidance, and build-up of knowledge through structural indicators?

Potential Additional Application

- Dealing with distant dependencies
  - Structural Indicators can potentially act as filtering criteria for the consideration of distant or indirect dependencies.



Dependencies become unclear when the distance increases. Criteria and indicators might be combined for better analysis.

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Future Outlook

- Structural indicators may **put values on previously uncountable characteristics**, and this way help the knowledge building within, and between organisations.
- Structural indicators can in this manner be used as reference values for both **monitoring project performance and testing of possible system adaptations.**
- Indicators have long been popular in medicine and economic sciences, but the use of structural indicators has to be learned. An extensive effort is required of academics, who **must establish reference values** which will constitute the basis for comparing the indicators of future models.