MODULAR PRODUCTS

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Outline

• INTRODUCTION
• MODELING PRODUCT MODULARITY
• FORMING MODULES
• DEVELOPMENT OF MODULES
• SUMMARY
Modular Products and Components

- Modular products refer to the products, assemblies and components that fulfill various functions through the combination of distinct building blocks (modules).

- Modular components refer to components whose functional, spatial, and other interface characteristics fall within the range of variations allowed by the specified standardized interfaces of a modular product.

- Modularity in products implies the use of common units to create product variants.

Modular Product: Nippondenso Panel Meter

288 different products
Modular Computers

Modular Bike Breaks
Modular Watches

VOLVO Sweden

- Product (VOLVO 80) modularity
- Manufacturing process modularity
- “Human resource modularity” (teams)

Restored company’s market position
Potential Benefits of Modularity

- Economy of scale
- Increased feasibility of product/component change
- Increased product variety
- Reduced order leadtime
- Decoupled risks
- Easier product diagnosis, maintenance, repair, and test
- Environmental friendliness

Unrealized Potential of Modularity
Potential Costs of Modularity

- Redundant physical architecture (due to decreased function sharing)
- Excessive capability due to standardization (designing for the most rigorous application)
- The potential for static product architectures and excessive product similarity

Question:

Does the product modularity concept apply to areas other than engineering design?

If yes, give an example.
Modular architecture vs Integrated architecture

Two models of domestic furniture

Modular
- 4 modules are used

Integrated
- 7 blocks are used

Component swapping modularity

Component sharing modularity

Bus modularity

Selectional modularity

Fabricate-to-fit modularity
Modular Products

Modularity depends on two characteristics of designs:

1. similarity between the physical and functional architecture of the design, and

2. minimization of incidental interactions between physical components

Modeling Modularity
Matrix Representation of Modularity

- Interaction matrix, $A = [a_{ij}]_{m \times m}$, is a component-component incidence matrix, where $a_{ij}$ represents the interaction between component $i$ and component $j$; $i$ and $j$ in $C$.

- Suitability matrix, $B = [b_{ij}]_{m \times m}$, is a component-component incidence matrix, where $b_{ij}$ represents the suitability of components $i$ and $j$ for inclusion in a module; $i$ and $j$ in $C$.

- $A' = [a'_{ij}]_{m \times m}$ be the matrix with the rows and columns rearranged by the decomposition algorithm presented for easy identification of modules.

- $B' = [b'_{ij}]_{m \times m}$ is the matrix with the rows and columns arranged in the order as the rows and columns of $A'$.

- Modularity matrix is defined as $[A'|B']_{m \times 2m}$.

Interaction Matrix

$n = \text{Set of components considered for modules}$
Interaction Matrix

- Frequency of interactions (integer number)
  - unidirectional (e.g., force)
  - bidirectional (e.g., force and signal)

- Yes - No relationship (0 - 1 number)

Modular Desk Lamps

Lamp components:
- 1 and 4 are different covers of the lamp
- 2 and 7 are the internal and external electrical cord, respectively
- 3 is an internal connector
- 5 is the lamp stand
- 6, 9, and 10 are different bulbs
- 8 is the switch
- 11 is the base
Two matrices for the components of the lamp

- 1 and 4 are different covers of the lamp
- 2 and 7 are the internal and external electrical cord, respectively
- 3 is an internal connector
- 5 is the lamp stand
- 6, 9, and 10 are different bulbs
- 8 is the switch
- 11 is the base

Frequency of interactions (components 3 and 7 interact in five products)

Interaction matrix

Suitability matrix

NOTATION

- Each nonzero integer entry denotes the number of times the corresponding components are used in different products

- "a" denotes suitability of two components for inclusion in a module

- "u" indicates undesirability of two components for inclusion in a module
Decomposed Modularity Matrix

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Modularity Algorithm

1 and 4 are different covers of the lamp
2 and 7 are the internal and external electrical cord, respectively
3 is an internal connector
5 is the lamp stand
6, 9, and 10 are different bulbs
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Hint:

A good way to determine modules for a matrix with general integer entries is to use a threshold value, e.g., $\tau = 3$ for the previous and replace each entry $\geq \tau$ with an *.

The new matrix can be transformed with a modularity algorithm, which is in essence a modification of the triangularization algorithm.
The Modularity Matrix

<table>
<thead>
<tr>
<th>Design phase</th>
<th>Product type</th>
<th>Entry interpretation</th>
<th>Column name</th>
<th>Entry interpretation</th>
<th>Entry interpretation</th>
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</thead>
<tbody>
<tr>
<td>Conceptual phase</td>
<td>All</td>
<td>Functional interactions</td>
<td>Mechanism/Subsystem</td>
<td></td>
<td>a: strongly desired</td>
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<tr>
<td>Detailed phase</td>
<td>Electrical</td>
<td>Signal flow</td>
<td>Mechanism/Subsystem</td>
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<td>e: desired</td>
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<td></td>
<td>Mechanical</td>
<td>Force flow, thermal flow, functional interactions, etc.</td>
<td>Component</td>
<td>Integer number: number of applications</td>
<td>u: undesired</td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
<td>Force flow, thermal flow, functional interactions, etc.</td>
<td>Component</td>
<td>Integer number: number of applications</td>
<td>o: strongly undesired</td>
</tr>
</tbody>
</table>

**Entry interpretation**

- A: strongly desired
- E: desired
- U: undesired
- O: strongly undesired

**Axiom 1: Component-swapping Modularity**

Let $C_i$ be the set of columns corresponding to entries "1" of row $i$.

If

1. row $i$ corresponds to module $M$, and
2. columns $j$ in $C_i$ do not correspond to any other module,

then

the component-swapping modularity occurs.
Component-swapping Modularity

\[ M = \{M' + 7\} \]

(a) Modular products  
(b) Matrix representation

Different product variants are generated by applying components 1, 2, and 3

Axiom 2: Component-sharing Modularity

Let \( C_i \) be the set of columns corresponding to entries "1" of row \( i \).

If

1. row \( i \) corresponds to a basic component, and
2. each column in \( C_i \) corresponds to a different module,

then

the component-sharing modularity occurs.
Component-sharing Modularity

(a) Modular products  (b) Matrix representation

Product 3 (monitor) is shared by modules (products) M1 and M2

Axiom 3: Bus Modularity

Let $C_i$ be the set of columns corresponding to entries "1" and $R_i$ be the set of rows corresponding to entries "1"

If

1. the set of rows $R_i$ corresponds to module M, and
2. all columns $j$ in $C_i$ do not correspond to any other module,

then

the bus modularity occurs.
Bus Modularity

Modular products

Components 4 and 5 of bus M interact with components 1, 2, and 3 belonging to different products

Modularity Problem

Decompose a component-component interaction matrix into mutually separable submatrices (modules) with:

(1) the minimum number of non-empty high value entries outside the block-diagonal interaction matrix, and

(2) the maximum number of strongly desired entries (denoted as a) and minimum number (possibly zero) of strongly undesired entries (denoted as o) included in the submatrices of the block diagonal suitability matrix

subject to the following constraints:
Constraint C1: Empty modules of components are not allowed
Constraint C2: The number of components in a module can not exceed the upper bound, Nu
Constraint C3: the total cost of the components duplicated can not exceed, B.
Modularity Algorithm

Step 0 (Initialization)
Establish the interaction and suitability matrix. Specify an upper bound NU on the number of components in a module and budget B.

Step 1 (Triangularization)
Transform the interaction matrix A into matrix A' with the triangularization algorithm.

Step 2 (Rearrangement)
Rearrange the suitability matrix B into matrix B' so that sequence of columns and rows in matrix B' is same as in matrix A'.

Step 3 (Merge)
Merge matrix A' and matrix B' into the modularity matrix \([A'|B']\). Identify modules corresponding to the groups in A'.

Step 4 (Deletion)
Remove a component from a module that satisfies Rule 1, and place it in the last column of the modularity matrix. Repeat this step until no more components can be removed.

Step 5 (Duplication)
Duplicate a component that satisfies Rule 2, and repeat this step until no more components can be duplicated.

Step 6 (Classification)
Analyze the modularity matrix and classify the modules based on the three axioms.

Step 7 (Termination)
Stop and output the results.
Rules

Rule 1

Remove a component, say k, if the following conditions are satisfied:

1. Component k and any other component, l, in the same module are strongly undesired for inclusion in the module, i.e., an entry in the submatrix of matrix B' is set to "o".

2. Component k interacts with the remaining components in the module to a lesser degree than component l, i.e., the total of row entries corresponding to component k is smaller than the total of row entries corresponding to component l in the matrix A'.

3. None of the submatrices will violate constraints C1, C2, and C3.

Rules (cont'ed)

Rule 2

Duplicate the component if the following conditions are satisfied:

1. The component is strongly desired for inclusion in two modules simultaneously, i.e., some entries in the matrix B' are set to "a".

2. None of the submatrices corresponding to the two modules will violate constraints C1, C2, and C3.
Electrical circuits
(Yes- No interaction between 14 components)

Example

Eight products P1 - P8, each with 14 different components

Interaction matrix and the suitability matrix

Notation:
1 - comp-comp interaction
a - suitable
u - undesired
o - strongly undesired

Matrix A
Matrix B
Decomposed Modularity Matrix

Too large module

Suitability constraint violation

Component Duplication

Component 13 was randomly selected
Decomposed modularity matrix with component 13 duplicated

Matrix A'

Matrix B'

No duplication of components

Component 13 duplicated
Five Modular Circuits

Matrix and solution
### Mechanical products
(Frequency of Interactions)

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<tr>
<td><strong>Interaction and suitability matrix for 10 products and 14 components</strong></td>
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Decomposed Modularity Matrix

Matrix A'  Matrix B'

Decomposed modularity matrix with component 14 excluded from module M1

Matrix A'  Matrix B'
Six Modular Products

Matrix and corresponding modular products
CONCLUSIONS

• Methodology was developed for determining product modules with the consideration of performance and cost.

• Components making up different products were represented with an interaction and suitability matrix.

• The components of a module were determined by a decomposition approach.
CONCLUSIONS (cont’ed)

- The approach was illustrated with numerous products built with traditional components as well as multichip modules (MCMs)
- For the module components known, a fuzzy neural network approach can be used to analyze the tradeoff between performance and cost of generic modules