Chapter 2
Composing a Product Network for Emotional Performance

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Abstract Up to now, we have been discussing performance, focusing our attention on an individual product or a product family at the utmost. But now as Internet of Things, Cyber-Physical Systems, Industrie 4.0, etc., are spreading very quickly, and products are getting more and more connected. So, we have to widen our view and consider products as a society and how each product can contribute to the society and what role it should play. This calls for a new perspective. We have to remember that connecting best performing products does not bring best performing society. We have to assign an appropriate role to each product and to make it serve its function for the society. In short, we need to orchestrate our products to achieve best performance as a team. To achieve this goal, emotion plays an important role, since performance is not just functions, but it means how much emotional satisfaction a product or a team of products provides to our customers. Thus, performance is quickly moving from functional performance to emotional performance, and again, it is no more that of an individual product, but that of a team of products or a product society.

2.1 Introduction

In Chap. 1, it is discussed that as things are getting connected, we have to stop discussing individual products and move toward discussing how products will work together as a network.

But most of the current discussion is how we can *form* a network by putting currently existing products together. But what is stressed in Chap. 1 is that we should go further than that. This approach is still stuck with our traditional product-focused perspective.

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We have to recognize 11 best does not make up a best team, i.e., forming a team with 11 best players does not work. Best 11 is not 11 best. Each player may not be best as an individual, but if they team up in the best way, they can establish a best team [1].

Therefore, we have to change our focus from *forming* a network of best functioning products to *composing* a best functioning network of products. The word *composing* is used in the same sense and meaning as in musical composition. We *compose* music to express our feelings. So *network composition* means we compose a network of products to satisfy our emotions. It is not just an assembly of product functions. It is far beyond that. A team performs far better, if composed appropriately, than a single player does. Team of players produce music that sounds very differently from that of each single player. Thus, we have to move from traditional performance, which focuses on individual products to network performance. We have to move from 11 best toward *best 11.*

2.2 Decomposition

Music may also have started from decomposition, but today, musicians' primary focus is on how to compose music and few, at least to my knowledge, study how the real world is decomposed into music.

In engineering, on the other hand, the necessity of decomposition was realized very early when products became large and complex. In the real world, most physical things are continuous or analog, at least to our eyes. When we made tools or products in the early days, they are quite small and simple. So we designed and manufactured them as we learned from nature. Thus, they remained continuous or analog all the way or all through their life cycle. But after we succeeded in producing such small and simple products, our expectations grew much higher and we moved toward producing much larger and complicated products. Therefore, we could no more produce them as a continuous or analog object. We have to decompose them and break them into smaller parts, which are small enough to deal with.

2.3 Modularization

The word *modularization* is getting very popular and coming to be used widely today. But if we look at it as *discretization,* its history is very long. When products became larger and more complex than we could handle, we broke the object into parts and assembled them into a product. It is our wisdom how we can deal with such large and complex objects with our limited resources.

Decomposition discussed in Sect. 2.2 is one of such examples. Of course, it called for another sophisticated technology for assembling these parts into a final product. But the progress of technology was so rapid that soon we could assemble many different parts into a product as we like. Thus, today, when we say *modularization*, it implies not only discretization, but also assembling of discretized parts. So from now on, let us assume that modularization means both discretization and assembly. In the earliest days, the focus of modularization is on physical sizes or dimensions. We just broke large size products into smaller size parts.

But soon not only sizes but the number of functions increased with increasing complexity. We found out that if we break the product not only into smaller sizes, but into parts with particular functions, we can design more complex products far easier. Thus, modularization soon came to mean functional modularization. And although sizes were not less important, the greatest attention came to be paid on how we can divide functions and allocate them appropriately into parts.

This is the history of modularization of *hardware* products. But when *software* emerged as new technology, it is no more physical so modularization became solely the problem of functional modularization.

With increasing complexities, hardware and software came to be used together as we can easily observe in mechatronic systems. Today, software became an indispensable partner for hardware. So now, we have to consider modularization from both perspectives, physical and non-physical.

Looking at modularization from the standpoint of graph theory, it is nothing other than representing products as a network. Each node has attributes (sizes, functions, etc.), and a link is the interface between the nodes (parts).

But we have to remember that if we look at modularization from a different perspective, i.e., from the standpoint of design, not only we have to consider decomposition for making things easier, but we also have to pay attention to how we can compose them better for design.

We decomposed or discretized our continuous objects into modules, or nodes in graph theory terms, mostly based on our experience from nature. So we did not pay too much attention how attributes can be allocated to modules. Software changed the scene. Software modules are non-physical and it is totally artificial so we have to consider how we allocate attributes to each module. Hardware followed suit, because with increasing complexity of functions, we have to consider how attributes can be allocated best to each module from the standpoint of design. We need to design a module with only attributes needed for its functions.

Modularization is getting wide attention these days in automotive industry, especially in the field of passenger cars. But the history of modularization is very long and how we divide modules depends on how we allocate functions. So if the functions are common to all models, you can use the identical model for all of them. Automotive companies call it a platform and they put on different kinds of modules on top of it to characterize their models. But the same idea was already carried out in truck industry from long time ago (Fig. 2.1).

The identical chassis can be used for all purposes. But the cargo body has to be developed case by case to meet different needs. So truck producers divide the chassis and cargo body, and different companies develop and produce them. Passenger car industries are just following suit.

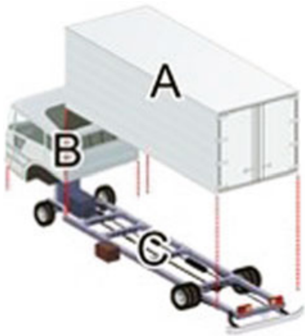

Fig. 2.1 Modularization of a truck

What should be stressed is that modularization in this sense is now going on in every industrial sector. Some deal with very large systems and others deal with very small systems, so modularization is going on very rapidly with products with different sizes with different degrees of complexity.

2.4 Finite Element Method (FEM)

Thus, modularization is modeling a continuum with discrete elements. This expression will remind us of finite element method. Its modularization is very simple and straightforward. As the degree of freedom of a continuum body is infinite, we cannot analyze it as it is. Therefore, we developed a new model and reduced it to finite and calculable degree. FEM is a tool for analysis. So their goal is very clear.

Let us take up FEM of a solid body here. The goal is to calculate stress, strain, and deformation, so they developed a very clever model based on a truss structure. A truss structure is composed of triangular units and each unit has three members connected at the joints or nodes. Each member is two-force member and is subject to either tension or compression.

Just as triangulation is used to survey lands, truss member modeling enabled us to model any shape as an assembly of triangular units. And an analysis can be made very easily if we assume that each triangle is covered with a membrane with no resistance and force (shown in blue in Fig. 2.2) and is only transmitted to members through joints or nodes (shown in yellow in Fig. 2.2) either as tension or compression. In fact, it is a very simple model of a spring (Fig. 2.2).

Modularization as seen in FEM is an excellent idea which revolutionized analysis of a continuum body. In short, geometry is modeled by triangles and stress and strain analysis is made possible by introducing the idea of a truss structure. Today, FEM is used very widely in many industries, and without it, we cannot design and manufacture such very complex and complicated machines, structures, etc. But FEM is

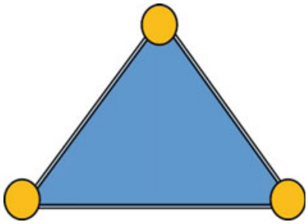

Fig. 2.2 FEM triangular element

used primarily for analysis. Then, what technology will enable us to design a product with the concept of modularization? It is additive manufacturing.

2.5 Additive Manufacturing (AM)

Recently, additive manufacturing is attracting wide attention and is spreading very quickly. It is expected that AM will enable us to design and manufacture any shape without too much difficulty. And in addition, CAD data can be directly realized as a physical entity. This discussion is too much simple. In reality, it is not so straightforward. But we are certainly going in the direction where we can modularize products and attach any attributes to each module as we like, with the emergence of AM.

Interestingly enough, AM not only enables us to attach any attribute to each module, but it will also attach a new meaning to vacancies. They are called chasm, gap, slit, etc., but in most cases, they have been recognized as unfilled or unoccupied and have been regarded as undesired spaces or as spaces that do not serve for any purpose.

Truss structures utilize spaces in a very sophisticated manner, but these empty spaces are result of engineering design to reduce weight and the amount of material. So although they look vacant, they have meanings.

What underlines our traditional design requirements is our experience of physical entities which are found in nature and most of them are continuum and with a *complicated* combination of attributes. It is *complicated*, not complex. If complex, we may be able to separate them into each attribute more easily. Thus, our recognition of physical objects is in most cases continuum bodies with many not-easy-to-separate attributes. Or rather such combinations characterize the nature of physical entities we experience. Thus, it has not been easy for us to decompose attributes and to compose them in a different manner, as we like. AM provided us with such a capability of composing attributes as we like and as we need. Now, we can design a new physical entity by picking up desired attributes and combine them as we wish. AM is a versatile tool to produce unexperienced physical entities.

But as to the separation of attributes, there are other examples we should be aware of. Prof. Shigeru Ban, architect who received the 2014 Pritzker Architecture Prize, developed homes and other architectures using papers. His idea is very much associated with paper folding. Most of us think that thin paper is weak so we cannot build an architecture with it. But weakness is a property related to strength and rigidity is another. But most of us fail to discriminate them. If we design appropriately, we can secure rigidity so that we can build homes, churches, etc., using papers (Photos 2.1, 2.2 and 2.3).

Photo 2.1 Paper homes in India

Photo 2.2 Cardboard cathedral (interior)

Photo 2.3 Cardboard Cathedral (exterior)

Many architects are now paying attention to papers, and they are pursuing paper architecture [2]. This demonstrates how it is important to decompose attributes in a proper way. This idea came from origami, or paper folding. Although we fold papers, most of them are very simple ones (Photo 2.4). We have to know we can fold them into very complicated ones (Photos 2.5 and 2.6). In fact, it is not an exaggeration to say that any shape can be folded.

In addition, origami or paper folding plays a very important role in developing deployable structures, which are required in space.

Photo 2.4 Origami crane

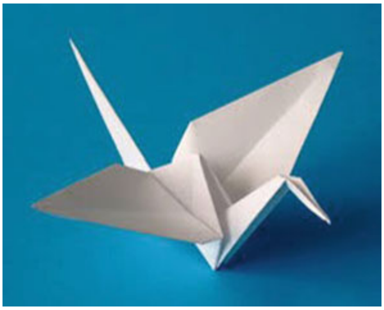

Photo 2.5 Origami serpent

Photo 2.6 Origami tree

These examples are very much interesting as they demonstrate how our traditional culture serves for the progress of engineering. But they are still focusing on tangible attributes. But if we remember the phrase "silence is golden," vacancies or emptiness should have some meanings in our life. Up to now, vacant spaces have been created unintentionally after pursuing to realize the desired functions with desired geometry. Or they were results of engineering design as described in the above with a truss structure example. Anyway, these vacant spaces were leftovers from engineering design, and they were not intentionally created. But if silence is golden, then we have to change our focus from words to silence. That is, from tangible space to intangible space or vacant spaces. At least to my knowledge, we have never tried to design a product by focusing first on vacant spaces. It is certainly important when to keep silent during conversations. Thus, silence has meanings. We have to design when we should keep silent to communicate better. Likewise, vacancies or empty spaces have meanings. But up to now, we only paid attention to words and forgot how to design when to keep silent.

Quite interestingly enough, Prof. Shunji Yamanaka and his group at the University of Tokyo are now starting a project how to design empty space (Photos 2.7, 2.8, 2.9, and 2.10).

They utilize AM, and AM made such an approach possible. AM opened doors to the new world of design where words and silence can be orchestrated, and let them work together harmoniously.

In fact, if we recall Fourier transform analyzes time series and it transforms a function of time to a function of frequency, and further space and time are associated with it, it is reasonable enough that silence is a signal and has a meaning. So is empty space, too.

AM has a potential to let us communicate much better with the outer world than the time when we paid our attention only to *words*. It will make our design much more interactive and communicative. Our designs up to now have been more or less one-way communication.

Photo 2.7 Empty space design-1

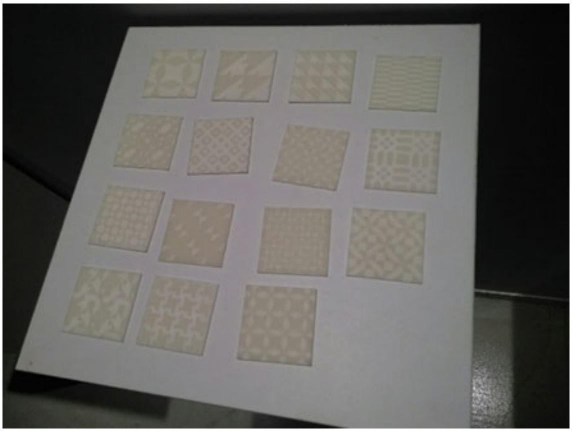

Photo 2.8 Empty space design-2

Photo 2.9 Empty space design-3

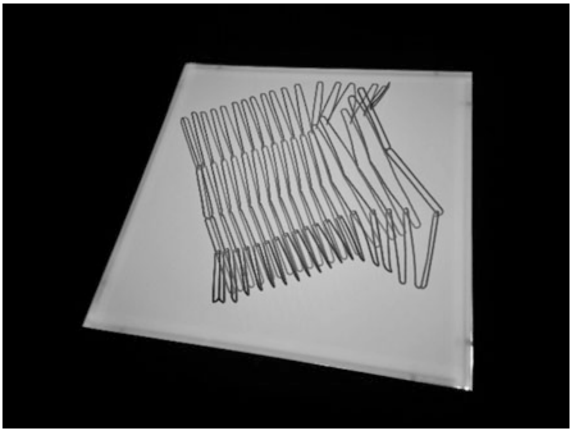

Photo 2.10 Empty space design-3

AM provides us with a versatile tool to design a product by using not only tangible physical attributes, but also intangible attributes. We have to remember again the importance of "silence is golden."

2.6 Visual Words

We discussed in the previous section that vacancy or emptiness has significant meanings. In other words, vacancies or emptiness has meanings because there is substance elsewhere or other portions are occupied or filled.

We can find the opposite example in natural language processing and computer vision. Natural languages are processed based on grammar and word order. But there is an approach called *Bag of Words*, which disregards them and just counts the number of times a word appears.

Long time ago, I attended a meeting of elementary school teachers in the USA. At that time, they were very eager to learn from Japan. But they could not process Japanese on their computers, because theirs were one-byte machines. To process Japanese, they had to have a two-byte machine. In Japan, natural language processing was very much prevalent these days, but all of them processed the language based on grammar. But none of these methods could be applied because their machines were one-byte computers.

What surprised me was one teacher stood up and said that if we note Kanji or Chinese character (Japanese in Chinese characters), their images are very dense or thick, while Hiragana or Katakana, which are Japanese phonetic alphabets, is very sparse or thin. So if we regard Kanji as images, we can pick them up easily. If we classify them as patterns, we can count the number of the appearance of the same Kanji. As Kanji is keywords in Japanese sentence, we can estimate what the sentence means if we make up the histogram of the appearance of each Kanji. You can ask Japanese or someone who understands Japanese what all these Kanji mean. Then, you know the keywords, so now you can guess what the sentence means.

All Japanese know Kanji is an image character, but none of us Japanese noticed there is such a way to understand Japanese sentence. Indeed, this may be the way we all Japanese do in everyday life without being aware of, or this is certainly the way when we read very fast.

This was quite an eye-opener to me and I realized how true it is that outsiders see most of the game. Dense image patches have dense meanings, and sparse image patches have meanings of less importance. This is the spatial relationship among Kanji, Hiragana, and Katakana. This is certainly a very clever feature extraction.

Interestingly enough, image processing researchers expanded the idea. They developed an approach to process images in the same way. Just as we notice Kanji in text and keywords in communication, there are feature portions in images. And they serve for us to recognize the image. They play a role of keywords. The researchers call such feature image portions *Visual Words.* This is just contrary to the idea of how we can make the most of empty spaces described above.

We modularize an image by the degree of importance or the degree of catching our attention. If a very prominent feature can be identified, then we can recognize the image at once. If we cannot, we will go down to the next lower level and look for some other feature portions. Repeating these procedures step by step, we can recognize the whole image.

Although this follows the way of traditional modularization approach, we should realize we can easily extend it to emotional modularization and we can satisfy our customers more. We should remember that traditional engineering modularization has paid its primary attention to functions. Although past engineering design utilized modularization very much, its purpose was only for achieving better functionality, for reducing complexity, or for reducing cost and labor. And we did not pay attention to the problem of how we perceive and recognize. In traditional engineering, modularization has been carried out based on design intentions. It was done with engineering advantages on mind. But in other business fields, modularization focused on perception is being carried out to satisfy their customers emotionally.

2.7 Emotional Modularization

In other business fields, modularization focused on emotional satisfaction has been carried out for a long time. Most typical one is fashion industry.

Let us take a wedding dress for example (Photo 2.11).

Every lady would like to wear a wedding dress just for her alone. But not every lady is rich. So they have to wear rental ones. But rental shops cannot prepare a different wedding dress for every lady. So they hold a wedding dress fashion show and observe which part of the dress ladies are paying attention to. Then, they prepare distinctively individualistic parts which would appeal to ladies with different personalities or preferences. And they prepare the common platform. They

Photo 2.11 Wedding dress

combine them and create personality or uniqueness. So when ladies rent such a wedding dress, they feel this is the dress just for her. Thus, ladies feel very much satisfied.

This idea is fundamentally the same as the one automotive industries are practicing with passenger cars. But automotive companies are focusing their attention on such matters as cost reduction, efficiency, etc. The main interest of fashion industry is to provide emotional satisfaction. Indeed, ladies would not care to pay more, if they are fully satisfied. All fashion industry is practicing such *emotional modularization* and pursuing *emotional performance*.

Engineering companies are now chasing after them. Daihatsu, for example, developed Copen which is composed of changeable parts (Photos 2.12 and 2.13).

At this moment, experts are producing these parts, but it is expected customers themselves can produce such changeable parts and will enjoy changing them in the

Photo 2.12 Daihatsu Copen-1

Photo 2.13 Daihatsu Copen-2

near future with the help of such technologies as AM. Thus, we may have car codes just as we have dress codes. In fact, dress code is a composition of a network of dress parts to meet situational and cultural requirements.

2.8 Composing a Network for Product Society

Up to now, we have been discussing performance from the standpoint of a product or a product family. But now, all products come to be connected. Therefore, we have to widen our view and consider a product society. Each product has a different role in the society, and how we organize them and harmonize them to realize a better society is our next challenge. As described in the previous sections, *emotion* will play a critical role in linking all artifacts together in order to adapt to the fast-changing situations and to provide satisfaction to our customers.

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