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Process Innovation through bio-inspired design

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Abstract

In process system engineering, we often adopt a constructivist approach to answer the question "How can we go from parts to a whole system?" To answer to this question we need to propose approach that, based on the knowledge of phenomena at small-scale, allows going up the different scales in order to design process but also to innovate thanks to the creation of new knowledge. In this paper, a bio inspired design approach is presented. It is based on two main principles which intervene repetitively to understand and analyze the passage between scales for living organisms: the juxtaposition of foundational blocks that assemble, and then differentiation. The goal of this paper is to demonstrate that these principles can find a more widespread use and in particular they can be integrated into a process system engineering constructivist approach for innovative design. After defining the fundamental building blocks to initiate the process of juxtaposition and integration, an example on distillation and reactive distillation is used to illustrate the method capabilities in process synthesis.

Keywords: Process Innovation, Bio inspiration, Constructivist approach, Process synthesis.

1. Introduction

Process engineering is becoming more and more complex as our analyses become more efficient. Process engineering has evolved over time through instrumental and modelling developments that have made our capabilities for observations and analysis more efficient. But in his approach for problem solving, engineer tends to divide a problem into levels of understanding. For example the process engineering offers a broad set of methods and tools for efficient problem solving for different scales: molecular, phase and transport, unit operation, process, industrial parks… Similarly, in the manner of nested dolls, life is organised on scales of increasing complexity ranging from the cellular organelle to the eco-system, via the cell, the tissue, the organ, the organism, the population. Figure 1 illustrates this parallel between the decomposition and hierarchization of scales between living organisms and process engineering. But, it is important to keep in mind that any division or hierarchization is arbitrary and offers only an ease of analysis. Therefore, any fragmented analysis of a living or technological system does not make it possible to understand it in details. Indeed, in this approach we isolate the parts, as a consequence we do not consider exchanges between scales and thus we reduce the understanding of the problem.

Multi scale approaches try to restore this dialogue in order to have a better understanding of the system under study. Despite the important advances of these approaches and therefore the improvement of processes, most of the time we reach only incremental innovation. The aim of this paper is to propose a new way to analyse, integrate and cross the scales with a bio inspired approach as the nature is constantly obliged to innovate. The goal is to demonstrate that the physical processes and the principles that appear in the evolution of the living organisms are relevant to be used in the design of new process, and could lead to solutions with a higher level of innovation.

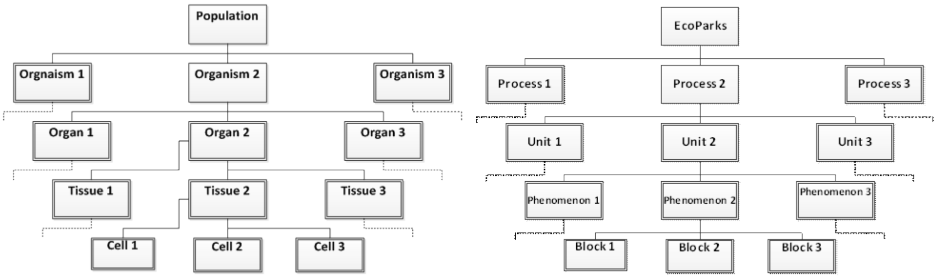

Figure 1 Comparison of scales hierarchization between living organism and process synthesis

2. Backgrounds

Most of the research works in process engineering are based on a reductionist approach, which consists of understanding the fundamental phenomenon. Analyzing a system by focusing on one element moves away from the overall understanding of this system. Thus, focusing on parts takes away from a global vision. Conversely in process system engineering, we often adopt a constructivist approach to answer the question "How can we go from parts to a whole system?" Thus it is easy to understand the difficulty encountered by the process designers: without multiscale integration and systemic approach, the vision of the whole makes the complexity and the relations between the parts invisible. A process (or even at the macroscopic a supply chain) can be seen as a set of nested structures, made up with distinct elements, which juxtapose but which cannot be simply explained by summing the elements. As a result, a process encompasses different scales, each as its own "world" and it is constituted with all those of lower ranks and with which it shares some properties. Thus the elements of a scale serve to constitute the next higher scale. All this leads to the emergence of the complexity, i.e. we cannot reduce the behavior of a scale to the simple addition of those of lower levels. As a result, the large-scale organization comes from a hierarchy of assembly from the smallest to the largest and the interdependence where large scales require smaller ones. The complexity is due to the fact that on the one hand the connections between elements are multiple and that everything is linked, and on the other hand to the passage from one scale to another sometimes accompanied by a paradigm shift. Addressing this complexity and offering systematic solution is the heart of process systems engineering. In conclusion, to have a whole vision of a system, it is necessary to understand what is happening at smaller scales. So, with a constructivist approach, the question that arises is how to do this upscaling.

To continue the parallel with the nature, a starting point for answering to this question was the analysis of complexity of living things made by (Chapoutier and Kaplan, 2011). In the emergence of the complexity for living organisms two main principles seem to intervene repetitively to understand and analyze the passage between scales: the juxtaposition of foundational blocks that assemble, and then differentiation. The two fundamental principles are the juxtaposition of entities of the same order of complexity (and thus of the same scale) and then modification (mutation) of these entities in higher level structures. For example, cells juxtapose then mute to form a tissue, or at a different scale organisms to form a population. Figure 2 gives a schematic interpretation of these principles for two successive scales. Even if theoretically these steps can be repeated indefinitely, in nature they rarely exceed 5 to 6 levels of complexity: from the cell to the animal population.

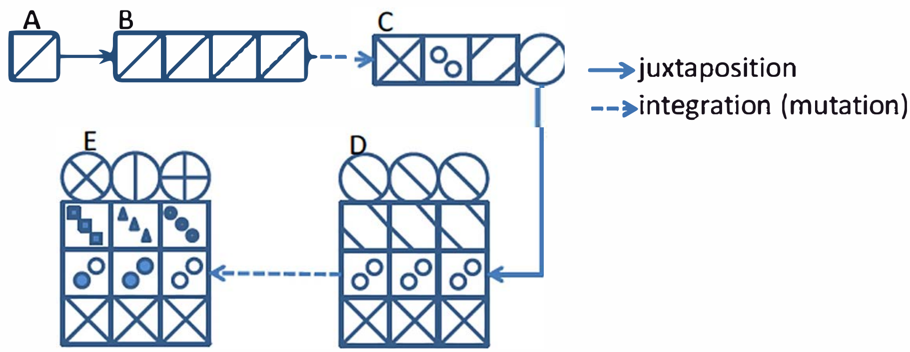

Figure 2 juxtaposition and integration principles (Chapoutier, 2001).

In figure 2, the juxtaposition of element A gives B, where elements do not interact with each other. The integration leads to C where the interaction appears while elements preserve a certain autonomy. Then the process is repeated with the juxtaposition of C to create D and then E by mutation.

For process synthesis, as a first approximation, the juxtaposition can be done linearly and sequentially by appealing not only to elements of the same level of complexity but also to strictly identical elements. Then we find more integrated entities, sometimes more intensified in engineering processes, to form more complex structures. This step is important because in the design of a process, one seeks the maximum efficiency that leads to specialization, which implies to accentuate the integration and the interactions between elements. The purpose is to optimize the transfers, the weight, the form, to make it as compact as possible ... and most often to operate each part to its limits, i.e. to its maximum constraints.

It must be also emphasized that the evolution of living organisms is based on the integration of elements within higher-level elements. The main reasons for the diversification of life and its hierarchical organization are these mutations of individualities at all levels that we have mentioned. As a result, the application of this principle to process synthesis may lead to enhancement of the process performances but also to innovative solutions.

The next step is to identify the initial blocks, i.e. leafs of the tree of figure 1, for process synthesis, which will allow scaling up through the successive repetition of the principles of juxtaposition and integration (also named mutation).

3. Knowledge representation: building blocks

All living organisms are deduced from a four-letters alphabet that are the four nitrogen-containing nucleobases (cytosine [C], guanine [G], adenine [A] or thymine [T]) of the DNA molecule. In the same way as for DNA, it is necessary to determine the constitutive elements that have many degrees of freedom that will thus offer more efficient and sustainable alternatives, but also immense potentialities that can lead to innovations. For process synthesis, these elements must be based on the current process engineering knowledge. Furthermore the knowledge representation chosen must be compatible with the constructivist approach previously mentionned. The fundamental building blocks representation, recently proposed by (Demirel et al., 2017) and (Babi et al., 2015), seems to be a relevant way to represent knowledge. For the former, a bloc is an abstract module that represents a fundamental constituent of a unit operation, which can host single or multiple phenomena. For the latter, a block gathers only one phenomenon. This last definition is well suited for our approach and compatible with the two principles. Relying on the work of (Babi et al., 2015), as most of processes combine, mass, energy, and momentum phenomena, a first set of building blocks could be mixing (M), two phases mixing (2phM), cooling (C), heating (H), reaction (R), phase contact (PC), phase transition (PT), phase separation (PS). These building blocks can be associated with different levels of scale and complexity: process phenomena, tasks, unit operation, etc. In the previous studies, these building blocks are used to formulate a mixed integer nonlinear optimization model to identify process alternatives. Even if some innovative solutions could be reached with this approach, to go deeper in the innovation process, i.e. to find solutions with a higher level of inventiveness, we must propose new principles for the construction. Indeed, there are missing laws to explain consciousness and tacit knowledge.

Let's take the example of (Babi et al., 2015) to detail the proposed approach. The figure 3 depicts the juxtaposition and mutation principles to represent different phenomena and unit operations. First, different building blocks can be juxtaposed in order to generate a feasible phenomenon, e.g. figure 3 is the association of mixing, phase contact, and phase separation. From this point, a first option consists in designing a specific unit where this phenomenon can occur, for the previous example the phenomena can be interpreted as a flash if there is a liquid and a vapor phase. A second option consists in a juxtaposition of the same phenomena. In this configuration if the two phases are liquid then we would find a liquid-liquid extraction. On the other hand, if there is a liquid phase and a vapor phase, i.e. the succession of the same phenomena as the flash vessel, no known unit operation appears clearly. Then the mutation principle can be applied as for example with the addition of cooling and heating at both ends to represent a condenser and a reboiler in order to generate a distillation column. From this point, we can go further in the mutation by adding a reaction block as reaction and separation can occur simultaneously. The reaction block is not added to all the previous blocks but only to some of them, because the mutation does not necessarily apply to all blocks present. This second mutation (or deeper mutation) enables to find the reactive distillation unit operation.

In the same way, at the unit level (figure 1), juxtaposition and integration of unit operations lead to the design of a process alternatives. Indeed, for example the purification section of a process is often composed by successive separation units (juxtaposition). Sometimes this can be improved by the external integration if two different types of separators to fulfil one purification also known as hybrid separation in process intensification (e.g. distillation and membrane, distillation and crystallization). As a result, another strength of the proposed approach is to make more systematic the best process intensification option at the different scales.

It can be also noticed that instead of relying on phenomenon, building blocks could be atoms to generate new groups and then molecules. As a result, the proposed approach is also relevant for computer aided design molecules.

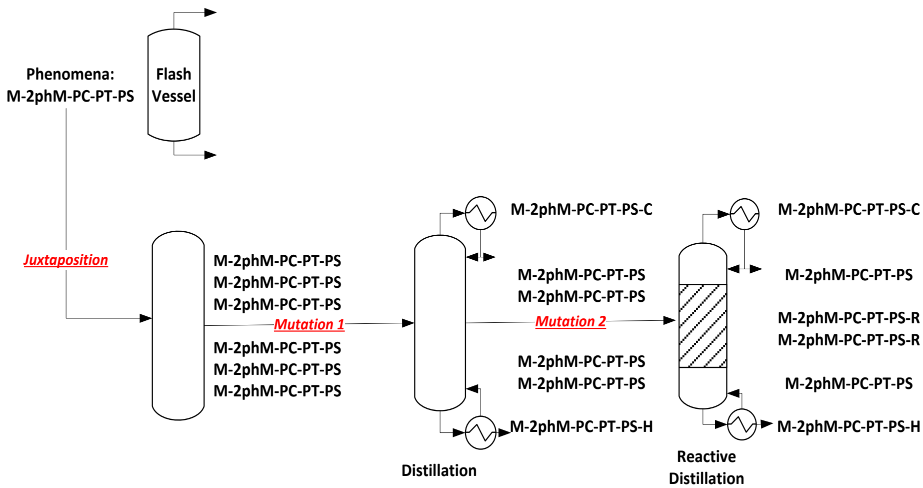

Figure 3: Example of juxtaposition and mutation based on the case study of (Babi et al., 2015)

4. Discussion

In most cases, living organisms are made up of many characteristic units, i.e. cells, so they are in their vast majority multicellular. The objective of the successive integrations of these different cells is also to create specialized structures with particular functions, e.g. heart, liver, nervous system ... for the organs. Likewise, at the same hierarchical level as the organs but on the process engineering side (figure 1), the unit operations also consist of several blocks in order to achieve at least one function. However, a current trend in process engineering is to design multifunctional devices, but this aspect is less present in living organisms. As demonstrated by the example of reactive distillation, more advanced mutations on the process engineering side make it possible to produce multifunctional devices (and more generally more intensified processes and for all scales). But in return, the direct consequence of a further mutation is an increase in the number of possibility of juxtaposition and mutation as the scales rise. As a result, the problem becomes highly combinatory.

Indeed, when dealing with innovation, the search for a solution requires exploring the space of solutions in its entirety, so we must test all possible combinations. For example, during juxtaposition, the number and the type of entity to be juxtaposed are not predefined. When an entity is repeated multiple times, it is difficult to establish when the completion is reached. Moreover, the juxtaposition can be operated with similar or different entities as we have seen in the previous examples. The combinatorial aspect also comes from the principle of mutation. As we demonstrated in the example on reactive distillation, the mutation does not necessarily concern all entities on the one hand, we can also delete, add or replace one or several entities on the other hand. Therefore, all these mutations offer a lot of possibilities. Moreover, for each juxtaposition or mutation, we must verify if the proposed solution is feasible or not. In the previous example, we underline that the multiple repetitions of the phenomenon can lead to none feasible solution when we have a liquid and vapor phases. For living organisms, this question of feasibility does not arise because naturally the steps of juxtaposition and mutation do not allow the creation of non-viable entities. Another direct consequence of this natural selection is the decrease of the combinatorial aspect. For process synthesis, one way to proceed to avoid this drawback could be to define and to use predefine combination rules. Unfortunately, this strategy of adding predefined knowledge would have the detrimental effect of diminishing the innovation potential of the approach. A more relevant solution would be to refine the definition of blocks by adding functional, financial, regulatory etc. aspects. This strategy would also have the advantage of integrating these dimensions from the initial design of the process.

Another crucial point is that we propose only theoretical reflection, strongly supported by examples, but experimental studies should also be proposed to validate the future alternatives created.

5. Conclusions

In this paper, we propose bio-inspired design approach for process synthesis. Nature often evolves and innovates according to a mosaic organization, by using two fundamental principles *juxtaposition* of entities of the same order of complexity and then *modification* of these entities in higher level structures. These two principles permit to understand and to explain the passage between two successive spatial scales. As a result, this vision of mosaic complexity emerging from life, compatible with Darwinian evolution but proposing general principles of progress towards complexity and diversity. The goal of this paper is to demonstrate that these principles can find a more widespread use and in particular they can be integrated into a process system engineering constructivist approach for innovative design in process engineering. After defining the fundamental building blocks to initiate the process of juxtaposition and integration, an example on flash vessel, distillation and reactive distillation is used to illustrate the method capabilities in process synthesis. The main drawback on this approach is that it is highly combinatory. As a result, it is impossible to explore all the possibilities offered. A future perspective of this work would be to incorporate design constraints to limit the space of solutions to feasible alternatives.

References

Babi, D., Holtbruegge, J., Lutze, P., Gorak, A., Woodley, J., Gani, R., 2015. Comp. & Chem. Eng., 81, 218-244.

Chapoutier, G., 2001. Odile Jacob, Paris.

Chapoutier, G., Kaplan, F. 2011. CNRS Editions.

Demirel, S., Li, J., Hasan, M., 2017. Comp. & Chem. Eng., 105, 2-38.