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Standardization in information systems

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Standardization in Information Systems

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Abstract

On a very abstract level, an information system consists of a set of system elements which communicate with each other. Communication is an unproductive operation, so the time needed to communicate data should be kept as short as possible and, to put it in monetary terms, the opportunity costs for communication should be kept small. Now, communicating data is more than just transmitting it, but it consists in large parts of converting data structures that are used by one system element into data structures that are used by another system element. Such conversion can be avoided, if the system elements use a common standard of data structures. Since establishing a standard at a system element incurs standardization costs, a decision maker has to check, if the cost savings gained by standardized communication outweigh the costs for installing the standard. In a recent paper, it is claimed that this so-called standardization problem is an \mathcal{NP} -hard optimization problem. We will demonstrate that this is not true, but in fact the standardization problem can be solved in polynomial time by solving a minimum cut problem.

Keywords: Standardization, Enterprise Resource Planning, Client/Server-Architecture, Information System, Network Flow, Minimum Cut

1 Problem Definition

Consider an information system consisting of n system elements which communicate with each other. Each system element can be operated in one out of two modes. In the first mode, a system element uses data structures which are unique to this particular system element. In the second mode, a system element uses a common standard. Introducing the standard at system element i incurs standardization costs $s_i > 0$. If two system elements communicate with each other and at least one of them is not operated in the standardized mode, total communication costs $c_{ij} > 0$ incur. So, the decision problem is to figure out the optimum degree of standardization in the information system and to decide for which system elements the common standard should be established. We can use two types of binary decision variables to formulate the problem mathematically:

$$x_i = \begin{cases} 1, & \text{if system element } i \text{ uses the common standard} \\ 0, & \text{otherwise} \end{cases}$$
$$y_{ij} = \begin{cases} 0, & \text{if both system elements } i \text{ and } j \text{ use the common standard} \\ 1, & \text{otherwise} \end{cases}$$

The following mathematical program states the standardization problem precisely:

$$\begin{aligned} \min \quad & \sum_{i=1}^n s_i x_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^n c_{ij} y_{ij} \\ \text{s.t.} \quad & \\ & x_i + x_j \geq 2 - 2y_{ij} \quad \begin{matrix} i = 1, \dots, n-1 \\ j = i+1, \dots, n \end{matrix} \\ & x_i \in \{0, 1\} \quad i = 1, \dots, n \end{aligned}$$

$$y_{ij} \in \{0, 1\}$$

$$\begin{aligned} i &= 1, \dots, n-1 \\ j &= i+1, \dots, n \end{aligned}$$

Buxmann et al. [4] claim that the standardization problem is an \mathcal{NP} -hard optimization problem. Consequently, they propose to use heuristics to attack this problem. A simulated annealing procedure is described in detail by Buxmann [3], but unfortunately, an in-depth computational study is not published.

Note that in this problem we face a phenomenon that is known in microeconomics as network externalities where one system element's consumption (=standardization) directly influences the utility for standardization of other system elements. To the best of our knowledge, the microeconomics literature has not dealt with the aforementioned standardization problem so far. So, we only give two references which, we believe, present the microeconomic point of view neatly: Besen and Farrell [2] and Farrell and Saloner [6].

The subsequent text is organized as follows: Section 2 proves that the standardization problem is of practical interest and discusses so-called Enterprise Resource Planning systems a bit by means of the SAP R/3 example. Section 3 then shows that the standardization problem can in fact be solved in polynomial time, because it can be transformed into the problem of finding a minimum cut in a specific network. Finally, Section 4 provides some computational results to reveal that large instances can now be solved optimally.

2 A Sample Application: Enterprise Resource Planning

To demonstrate that the standardization problem is indeed of practical interest, we will discuss a sample application to some extent: Enterprise Resource Planning (ERP). Given that particular functions of a firm require input data from other functions and produce output data that is to be used by other functions, the basic idea of Enterprise Resource Planning is to facilitate communication by maintaining a database accessible by all functions to provide the necessary data in (almost) real-time. It is therefore appropriate to implement a client/server-architecture where the clients support specific functions and access a database operated by the server (see Figure 1 for an illustration).

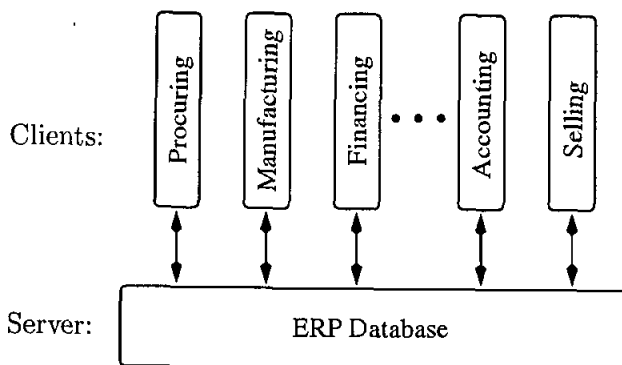


Figure 1: Client/Server-Architecture of an ERP System

Commercial ERP software packages like, for instance, SAP R/3 Enterprise Resource

Planning therefore provide a bunch of modules which support specific functions (see Figure 2).

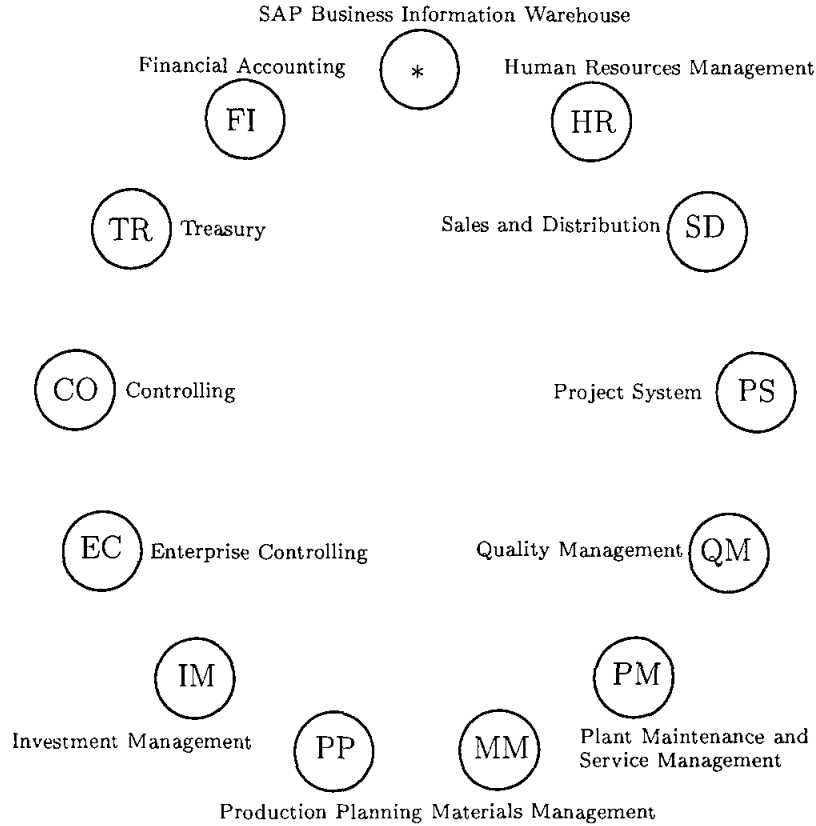


Figure 2: Software Modules of the SAP R/3 Enterprise Resource Planning System

Those who consider to implement such an ERP system, need not buy all software modules, but may opt for just a few of them. So the costs for introducing the, say, SAP R/3 standard for a particular function (= system element) are mainly the costs for purchasing the corresponding software module user licenses, the costs for buying adequate hardware (if not already existent), the costs for teaching the users SAP R/3, and the costs for converting existent data into SAP R/3 format. On the other hand, once two functions use the SAP R/3 standard, they can communicate data in (almost) real-time. Those functions which use a tailor-made software solution instead of an SAP R/3 module cannot communicate data that easily, so communication costs incur.

3 Network Flow Interpretation

Now we will show that the standardization problem can be converted into a minimum cut problem which is known to be solvable in polynomial time (see Ahuja et al. [1]). To illustrate this idea clearly, we use a small example with $n = 3$ system elements as shown in Figure 3.

Given an instance of the standardization problem, we construct a network Γ with

$$n + 2 \text{ nodes}$$

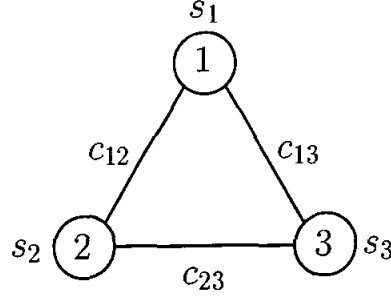


Figure 3: An Example with $n = 3$ System Elements

numbered as $i = 0, \dots, n + 1$ and

$$\frac{1}{2}n^2 + \frac{3}{2}n - 1 \text{ arcs}$$

as follows (see Figure 4). Let $s = 0$ be the source node and $t = n + 1$ be the sink node in the network. We then introduce an arc emanating from the source node 0 and pointing to each of the nodes $i = 1, \dots, n - 1$. The arc coefficient for such an arc $(0, i)$ is defined to be $\sum_{j=i+1}^n c_{ij}$. Also, we introduce an arc from each of the nodes $i = 1, \dots, n$ and pointing to the sink node $n + 1$ with an arc coefficient of s_i . Finally, we have an arc emanating from each node $i = 1, \dots, n - 1$ to each node $j = i + 1, \dots, n$ with an arc coefficient c_{ij} .

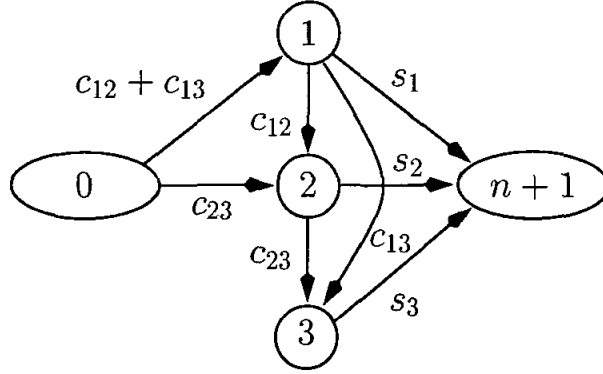


Figure 4: Network Γ with $n + 2$ Nodes and $\frac{1}{2}n^2 + \frac{3}{2}n - 1$ Arcs

The basic idea of this network is that, if we consider an s - t -cut in the network Γ , such a cut represents a feasible solution of the standardization problem in the following manner. By construction we have that every s - t -cut contains at least one of the arcs $(0, i)$ or $(i, n + 1)$ but not both for each $i = 1, \dots, n - 1$. And, an s - t -cut contains the arc $(n, n + 1)$ or it does not. Now, the interpretation of arc $(i, n + 1)$ being contained in the s - t -cut is that system element i is standardized, otherwise it is not.

Consider, for example, the s - t -cut shown in Figure 5 (note: a dotted arc indicates that the arc is not contained in the cut). From the set of those arcs which point to the sink node, arc $(3, n + 1)$ is the only one contained in the cut. That is, system element $i = 3$ is the only one that uses the standard. Therefore, the objective function value of this solution is $s_3 + c_{12} + c_{13} + c_{23}$ (compare Figure 3). This, however, equals the sum of arc coefficients of all arcs in the cut. Noteworthy to mention that introducing the

standard at just one single system element would never be an optimum solution, because standardization costs incur, but no communication costs can be saved.

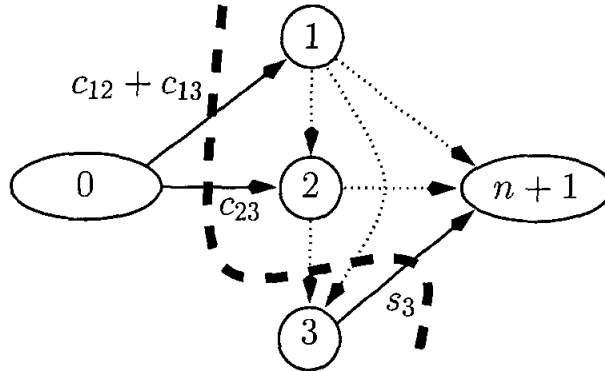


Figure 5: An s - t -Cut Representing System Element $i = 3$ being Standardized

As a second example, let us examine the feasible solution where system elements $i = 1$ and $i = 3$ use the common standard (compare Figure 3). The objective function value of this solution apparently equals $s_1 + s_3 + c_{12} + c_{23}$. This, however, is exactly what comes out when we consider the s - t -cut that corresponds to this solution (see Figure 6).

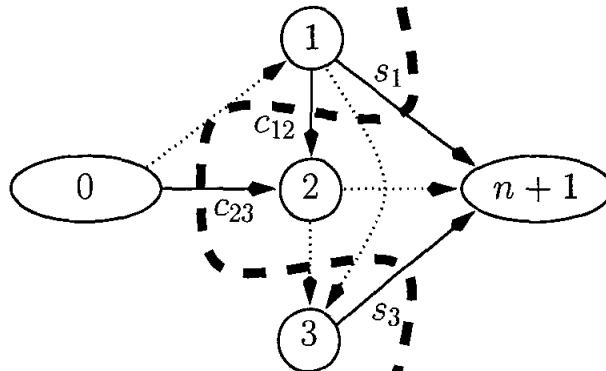


Figure 6: An s - t -Cut Representing System Elements $i = 1$ and $i = 3$ being Standardized

In summary we have that the standardization problem can be solved in polynomial time, because solving the standardization problem is equivalent to computing a minimum cut in the network defined above.

4 Computational Study

The minimum cut problem is a well-known network flow problem and efficient algorithms are available. We have used the implementation by Cherkassky and Goldberg [5] to test our approach to solve the standardization problem. We run the minimum cut procedure on a Pentium III computer with 450 MHz and a Linux operating system.

The testbed consisted of instances with

$$n \in \{5, 50, 500, 1000, 1500, 2000\}$$

system elements. The communication costs c_{ij} were randomly drawn out of the interval $[1; 100]$ with uniform distribution. This was combined with two sets of standardization costs s_i . The first test set (H) used high standardization costs which were randomly drawn out of the interval $[n; 100n]$ with uniform distribution. The second test set (L) used low standardization costs which were randomly drawn out of the interval $[n; 10n]$ with uniform distribution. For each parameter level combination, a set of 10 random instances has been used.

The average run-time needed to solve the standardization problem optimally is given in Table 1. All figures are measured in CPU-seconds.

Test Set	n					
	5	50	500	1000	1500	2000
(H)	0.00	0.00	0.08	0.36	0.79	1.49
(L)	0.00	0.00	0.22	0.95	2.22	3.92

Table 1: Average Run-Time (CPU-Seconds) to solve the Standardization Problem Optimally

As we can see, instances with up to $n = 2000$ system elements can be solved optimally in just a few seconds. It turned out that instances with high standardization costs (test set (H)) are easier to solve than instances with low standardization costs (test set (L)).

5 Conclusion

We have shown that the so-called standardization problem is not \mathcal{NP} -hard as claimed in the literature. In fact it can be solved in polynomial time by converting it into a minimum cut problem. A computational study revealed that instances with up to 2000 system elements can be solved optimally in just a few seconds.

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