Informatics - The Science of Minimal Systems with Maximal Complexity

Andreas Schwill
lnstitutfiir Informatik, Universitdt Potsdam, August-Bebel-Str. 89, D-14482 Potsdam, Germany

schwill@cs.uni-potsdam.de

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Abstract: It is a fundamental idea of computer science to search for, define, analyze, and operate with construction kits consisting of small sets of basic building blocks and a small number of operations to combine the building blocks to larger objects. While the construction kit is mostly simple, it often defines a vast, complex field that consists of all possible objects that'can be built from the building blocks by using any (finite) sequence of combinations of operators. This idea affects and structures many areas of computer science. We present examples from several fields, including imperative and functional programming languages, computable functions, Turing and register machines, Boolean functions, data types, object-oriented programming, characterisations of formal languages along with examples from other disciplines. How can informatics lessons profit? If lessons are oriented towards a fundamental idea, the idea may explain, structure, and integrate many different informatics subjects and phenomena by a single recurring scheme. On the other hand, the construction kit principle belongs to the sphere of everyday thinking so students already have a basic intuition of the concept which may enhance their understanding when entering any field where the idea applies.

1. INTRODUCTION

In recent years we have elaborated Burner's concept of fundamental ideas and made it accessible for informatics lessons (Bruner 1960). Here we consider in detail a fundamental idea of computer science - orthogonalization - and show that it has a wide area of application and may guide many fields of school informatics.

By *orthogonalization* of a field A, following a term in linear algebra, we denote the definition of a number of basic elements A_e of the field along with a set K of operations (K={Ki ,...,K_n}, n small) on the basis each as small and simple as possible, such that every other object of the field may be generated by finitely many applications of operations on the basic elements (Figure 1). The result is a minimal generating system B=(A_e,K), consisting of the basis and the operations, that may be considered as a construction kit for the field.

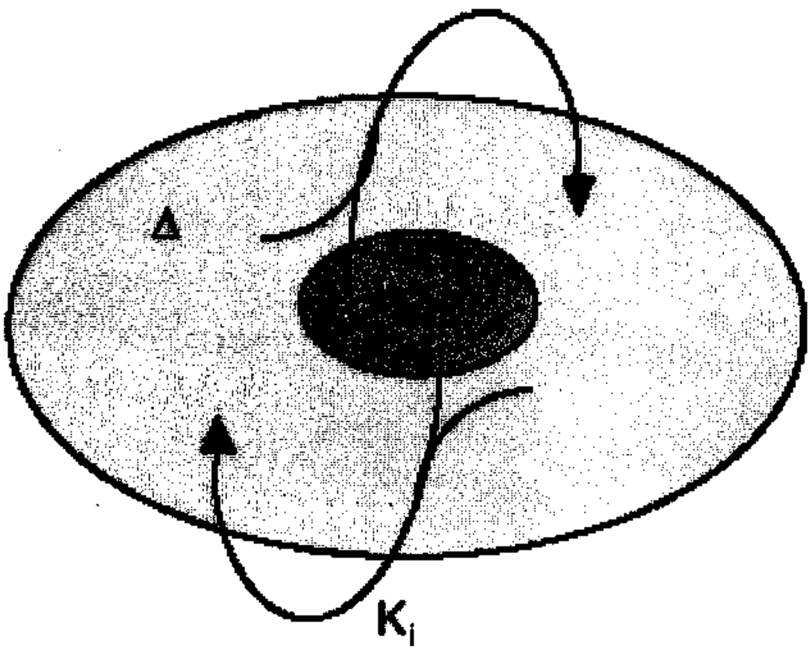

Figure 1. Principle of construction kits

We analyse orthogonalization with respect to didactic criteria and illustrate its relevance by presenting examples and applications in' several areas of informatics.

We use the term *complex* to denote systems that are vast and diverse in their inner structure, while we call descriptions of systems *complicated* if they are vast and varied and hard to grasp. There is no direct relationship between the complexity of a system and the complication of its description. While the system, particularly a real life system, may be complex in nature, it may have a simple, short description. We must avoid complicated descriptions if the systems are simple, and search for descriptions as minimal as possible if the systems are complex, to be able to understand, master, or manage them.

2. BACKGROUND

In 1960 Bruner formulated the teaching principle that lessons should predominantly orient towards the structure (the so-called *fundamental ideas')* of science. In recent years we have adopted the concept, made it and the relevant notions precise, and transferred it to informatics lessons by defining fundamental ideas of informatics (including algorithmization, structural dissection, (artificial) languages and orthogonalization). We have also proposed lessons suitable for teaching certain ideas in school (Schwill 1993; Schwill 1997).

We define a fundamental idea as a schema for thinking, acting, describing or explaining which satisfies the following criteria:

Horizontal Criterion. A fundamental idea is applicable or observable in multiple ways and in different areas of informatics. It organizes and integrates a wealth of phenomena.

Vertical Criterion. A fundamental idea may be demonstrated and taught on every intellectual level - "any subject can be taught effectively in some intellectually honest form to any child at any stage of development" (Bruner 1960). A central methodological means guiding the education of fundamental ideas on different levels of understanding is the *spiral principle.* This recommends three representations of concepts to be learned - *enactive* (lower level), *iconic* (medium level), and *symbolic* (highest level).

Criterion of Time. A fundamental idea can be clearly observed in the historical development of computer science and will stay relevant in the future. Importantly lessons based on fundamental ideas will not become dated as quickly as conventional lessons - a major advantage in teaching informatics which exhibits such dynamic evolution.

Criterion of Sense. A fundamental idea has meaning in everyday life and is related to ordinary language and thinking. Only a precise definition turns an idea "with sense" into an exact concept "without sense". When we teach a fundamental idea early in the student's schooling, we may give a first impression of the idea by using everyday situations as starting points for lessons.