

TECHNOLOGY PATTERNS

TOM HINRICHS

Northwestern University, USA

1. Introduction

Throughout history, across all engineering disciplines, the same abstract patterns reappear over and over. Yet, there has been little serious effort to systematically exploit these patterns to scaffold conceptual design. Performance-support tools for engineering are for the most part special-purpose applications for routine, detailed calculations. The research literature on technological design is largely descriptive and anecdotal. There is a fertile middle ground that can be explored by formalizing, extending, and operationalizing these descriptive accounts.

This paper describes an ongoing effort to develop tools to support conceptual design of technological systems. The long-term goals of the project are to support more systematic exploration of design spaces, to facilitate the identification of analogues and precedents, to help standardize problem categories, and to place problems in their historical contexts. The short-term focus is on identifying technological design patterns in a manner similar to software design patterns (Gamma et al. 1995) and TRIZ cases (Altshuller 1999), while emphasizing the historical evolution of these patterns. A key difference in our approach is that it focuses on patterns of refinement along a set of dimensions, and explicitly distinguishes subject matter concepts from the evolutionary and historical context, in a manner similar to the evolutionary schemas of scientific knowledge in RA (Swaminathan 1990). A main research question is to determine if understanding the contextual preconditions, barriers, dead-ends, and refinements of a prior technology can shorten the refinement process of analogous new technologies.

2. Design Spaces

Because technology in general is such a broad area, a monolithic catalog of patterns would likely be enormous and not terribly useful. Consequently, we decompose the technological design space into subspaces, identify categories within those spaces, and try to partition the spaces for the purpose

of discriminating and accessing individual innovations and analogous precedents. To do this, we make three main assumptions: 1) There are only a few domain-independent dimensions along which a design can be improved. 2) For each such dimension, there is a small canonical set of barriers to improvement. 3) These barriers derive primarily from physical laws, geometry and combinatorics. We then define a technological design pattern as a tuple consisting of a function, a problem or barrier to refinement, and a strategy for surmounting the barrier, where function plays a relatively minor role in discriminating strategies.

If we look at the evolution of a technology, most time and effort is spent making the technology practical by refining devices and processes along a few critical dimensions, such as efficiency, power, physical scale, or durability. By structuring the problem space around these refinement dimensions, we can support more systematic search of design spaces while avoiding premature commitment to implementations. These problems of refinement are more bounded, have clearer metrics, take more development effort, and benefit more from cross-domain analogies than do problems of ab-initio invention.

The second subspace is the function space, which captures the intended purpose of a material, device, or process. In order to be useful for retrieving and operationalizing strategies, the functional categories must completely partition the space of possible functions. The approach we have taken is first to consider all technological processes as transformations of energy, matter, and information in location or form. Conversion processes of all sorts fall naturally out of this breakdown. Next, we consider symmetry groups to capture particular invariants representing functional categories such as repeatability and reversibility (translational and mirror symmetries in time, respectively), containment (reflexive symmetry), amplification (scale symmetry), process initiation (temporal asymmetry), etc. These symmetries can be seen as conversions of space-time, rather than of energy, matter, or information and provide a categorization scheme that is orthogonal to the conversion functions.

The third subspace is the strategy space, consisting of structural, process, and environmental design operations for addressing barriers to design improvement. Currently, we have identified about 40 abstract strategies, such as interlock, indirection, and surrogacy. This set is incomplete, and depends strongly on the level of abstraction at which they are described. As with the function space, the challenge is to identify properties that partition the space, rather than to identify interesting islands of solutions. Strategies can be indexed by problem categories, and further discriminated by function, operating principle and physical constraints. Moreover, strategies are domain-independent and loosely coupled, even with respect to refinement

problems. So for example, James Watt's use of modularity in separating the condenser from the boiler addressed a different problem (efficiency) from Lee DeForest's intent in separating the heater from the cathode in the vacuum tube (reducing thermal noise to improve accuracy). Analogies are more likely to be useful when the strategies address the same refinement problem, e.g., stirring the melt to ensure a uniform index of refraction in optical glass vs. stirring the melt to ensure uniform doping in semiconductors.

3. Current Status

In order to develop and validate these design patterns, we have created a knowledge base of over 1000 cases consisting of both conceptual and episodic knowledge. The conceptual knowledge contains the design pattern tuple, the operating principle, physical quantities, field of study, and explicitly reified analogy relationships. The episodic information contains the date and agent information, the type of innovation (e.g., invention, refinement, experiment, etc), and typed preconditions, such as resource, technique, knowledge and need preconditions. We have also developed software tools for accessing, browsing, and visualizing cases in the context of their technological evolution, via categorized timelines and precondition graphs. At this phase of the project, the tools are intended more for data mining, validating and extending categories than for design assistance. The next phase of the project is to develop and refine task models for conceptual design and support the systematic exploration of design spaces and problem reformulation. The focus on large-scale evolutions of designs does not eliminate the need for task-based support for individual designers, but helps to identify potential long-term problems and possible solution strategies.

References

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