Heuristics for Solving Technical Problems – Theory Derivation Application

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Heuristics for Solving Technical Problems – Theory, Derivation, Application

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Dedicated to those who enjoy the

intellectual challenge of problem solving.

Heuristics for Solving Technical Problems – Theory, Derivation, Application

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Abstract

Heuristics used by engineers and scientists in solving design-type problems are the non-algorithmic, empirical tricks, tools, and techniques learned academically and from experience. They do not solve problems. Instead they give pause to look at problems in different ways for new insights. An axiomatic basis consisting of six assumptions, inferred from the physical world of interacting objects, is used for a first-time derivation of heuristics. The derivation leads to a surprising number of heuristics.

As the axioms are couched in generic terms, independent of a particular field's argot, the resulting heuristics are also generic. Hence, a particular derived heuristic can be adapted to a specific field by wording it appropriately. This allows personalization of derived heuristics. Conversely, it provides a unified system for cataloging personal heuristics in a generic classification.

These derived heuristics and their underlying strategies constitute a new problem-solving methodology. The resulting methodology presents problem solvers an attribute-centered methodology in contrast to conventional object-centered methodologies.

Heuristics for Solving Technical Problems in Three Parts

This discourse is in three parts. It is a somewhat theoretical discussion aimed at problem solvers experienced in, or just interested in, the use of heuristics for structured-type problem solving. This includes experience such as gained using TRIZ, USIT, SIT, and/or ASIT. Please read Part I if you are unfamiliar with this type of problem solving. The derivation of heuristics in Part II is directed toward discovering new heuristics and using them to embody new focus for structured, problem-solving methodology. They are designed to provide new perspectives to problems and thus serve as tools for innovative inspiration. Their application is demonstrated in Part III.

Part I: Use of Heuristics in Problem Solving

Part I covers a background of heuristics, describes examples, demonstrates their use in solving technical problems, and explains how selected heuristics are used in the second part to derive new heuristics. Those familiar with heuristics in problem solving and with structured, problem-solving methodologies may wish to skip Part I.

Part II: Derivation of Heuristics

Part II is devoted to the derivation of heuristics at an abstract level. An attribute-centered approach to problem definition is described in a graphic model. Three solution strategies are found and given graphic models. Their application is demonstrated.

Part III: Demonstration of Derived Heuristics

Part III demonstrates the application of heuristics derived in Part II to a problem of invention. While it uses USIT heuristics for problem definition and analysis, it uses the newly derived heuristics for problem solution.

PART I

Use of Heuristics in Problem Solving

Part I – Use of Heuristics in Problem Solving

Introduction

Heuristics imbue all areas of problem solving, both technical and non-technical problems. We will look first at what they are and give a few examples of some rather common heuristics. We will see how they are used, who uses them, and point out that they have been amassed empirically from the lore of problem solving. This brings up the derivation of heuristics for solving technical problems – the main topic of this writing. The method to be used for deriving heuristics will be discussed and demonstrated before engaging in their derivation. Uses of the derived heuristics will be demonstrated. It will be seen that the derived heuristics are abstract. An interesting implication of this fact is that they may be applicable to non-technical problems. However, this implication is not proven here.

Heuristics in Mathematics

Twelve classical heuristics used in mathematics provide a familiar introduction to heuristics (1):

1. Search for a pattern.
2. Draw a figure.
3. Formulate an equivalent problem.
4. Modify the problem.
5. Choose effective notation.
6. Exploit symmetry.
7. Divide into cases.
8. Work backwards.
9. Argue by contradiction.
10. Check for parity.
11. Consider extreme case.
12. Generalize.

These are not derived heuristics. They have been developed over years of trial-and-error solving of mathematical problems along with insightful introspection. Evidence of these heuristics will be seen in this writing. However, the heuristics derived here are motivated by non-mathematical, engineering design-type problems.

Definition of heuristics and intuition

Heuristics are the non-algorithmic tools, techniques, and tricks that are used in problem solving. However, unlike algorithms, they do not solve problems. Instead they give pause to look at problems in different ways to find new insights. Problem solvers use heuristics to “seed” their subconscious during the search for new concepts. Many of the heuristics commonly used do not have names and may not be recognized as heuristics. They are recalled as simple rules; i.e., phrases indicating a possible thought process. Consequently, problem solvers often are unaware how dependent they are on the use of heuristics.

Probably the main reason for professional problem solvers’ lack of realization that they use heuristics is their dominant reliance on intuition. It may also reflect a lack of momentary introspection to analyze the actual mental process of problem solving being used. Intuition uses heuristics so practiced and ingrained in one’s subconscious that they come into action instantaneously without conscious summons.

Examples of some heuristics and suggested generic names for them are shown in Table (1). Those who know and use these heuristics probably recognize them as being similar to the quoted phrases. Names, or even references to being heuristics, are rare.

Table 1. Examples of heuristics used by technologists in problem solving (some generic names are suggested).

	Generic heuristic	Common references
1	Simplification	"divide a complex problem into small parts"
2		"reduce duplicate objects to a minimum set"
3		"take small steps"
4		"reduce assorted objects to a minimum set"
5		"eliminate an object"
6		"combine functions"
7		"eliminate extraneous information"
8	Ambiguity	"generify object names"
9		"eliminate metrics of attributes (use no dimensions)"
10		"use generic metaphors"
11	Contrarian view	"whatever change is suggested also try the opposite"
12		"whatever heuristic is applied also try its opposite
13		"think outside /inside the box"
14	Extremes	"vary attributes to their extremes (+/- infinity and zero)"
15		"multiply and divide objects to extremes"
16	Focus	"search root causes for solution concepts"
17		"search technological contradictions"
18		"examine areas of contact of objects"

Heuristics seed the subconscious

Technologists have learned to solve problems, a creative cognition process, without an understanding of how the brain does it. An idea arises from the subconscious while examining the details of a problem. It is clarified, defined, and subjected to an appropriate algorithm for verification, and further improved in generating a viable solution. Multiple algorithms may be used in the engineering-scaling process to eventually validate the original concept. Thus, technical problem solving is itself a two-part mental problem: finding an idea and finding an algorithm. Finding an algorithm succeeds from years of training in mathematics, and the conscious selection and application of its algorithms. Finding an idea is less tractable because it relies on the subconscious to recall past experience and offer ideas for conscious reasoning – a process lacking understanding or algorithms for its logical manipulation.

How to induce the subconscious to offer ideas is one of the more interesting problems technologists have solved without the use of algorithms. It is done using heuristics. They seed the subconscious to spark ideas. We all use heuristics, sometimes automatically, and often without recognizing the act.

The simple, reliable process of repeated seeding, by stepping through the alphabet to recall a person's name, is a well-known heuristic. A mnemonic for remembering pi to a large number of digits is another kind of heuristic. *"How I need a drink, alcoholic of course, after the heavy lectures involving quantum mechanics. All of thy geometry, Herr Planck, is fairly hard."* (The number of letters in each word yields pi to 24 significant figures: 3.14159 26535 89793 23846 264 [I]) That sound intensity decreases inversely as the square of the distance from its source is an example of a rule-of-thumb heuristic. "Think outside (or inside) of the box", is one of the slogan-like heuristics suggested for creative thinking. Koen discusses the importance and ubiquity of heuristics in all manner of applications. (2) His thesis is that heuristics constitute the engineering method.

In this discussion, I divide the technical problem-solving process into two parts: concept generation and engineering-type scaling. I treat the two parts as independent activities in structured, problem solving. Heuristics are used in both activities. Our focus is on the derivation of heuristics for concept generation.

The use of heuristics in problem solving

Heuristics (and intuition) play a dominant role in the creative thinking involved in problem solving. [II] They are so widely used and relied upon that for decades heuristics have been searched, collected, named, categorized, computerized, and taught in problem solving classes. Yet, they are not nearly as generally accepted, as are algorithms in the scaling phase of problem solving. This, I think, is due in part to a misunderstanding leading to unrealistic expectations of heuristics, or how it may be regarded that they are used.

Heuristics are often referred to as techniques for finding conceptual solutions, and inventive ones at that. Hence, they may be incorrectly thought of as algorithms for formulated production of ideas from the (intractable) subconscious. This is a self-contradictory idea. Nonetheless, heuristics are gaining recognition, as methodologies that explicitly use them are becoming known. Structured, problem-solving methodologies make heavy use of

[I] Source unknown.
[II] The words "creative", "inventive", and "innovative" are used freely without definition. They are so subjective that they may serve the reader best through personal interpretation.

heuristics. These methodologies are marketed both in the form of training classes teaching a methodology and in the form of expertise of professionals who apply their methodology to solve client's problems. Some engineering schools teach them in senior design classes. Informally, they are taught throughout our academic experiences – an elementary school example teaches how to multiply by 9's on your fingers.

Unstructured brainstorming

Organization of problem-solving tools into a logical structure that guides a thorough process toward solution concepts is not common lore of technologists. Most technologists are so practiced at problem solving that they have their own intuitive steps, which may vary with each problem situation.

Initial mental approach to a problem often is instantaneous reaction to offer an intuitive solution. It is quick. This type of reaction is commonly referred to as "brainstorming". (3) We all do it. It works, to a degree, and we are good at it.

Knee-jerk-type brainstorming, such as this, is performed without organization, analysis, or conscious use of heuristics. It is productive although an unstructured and unguided, intuitive process. After this initial mental activity subsides consideration may be given to a more organized process. Or, a common occurrence, the problem solver may delay any organized effort and decide to let the problem incubate a while (a heuristic) and have another brainstorming session later. By then, a heuristic may have been remembered to try. This unorganized process attests the reliance we have on the capabilities of our intuitions. It also suggests an opportunity for a structured methodology based on a self-consistent set of derived heuristics.

Background

Structured problem-solving methodologies

The methodology called unified structured inventive thinking (USIT) (4,5) is used in this discussion. It is an offshoot of systematic inventive thinking (SIT, now known as advanced systematic inventive thinking [ASIT (6)]). SIT is an offshoot of the theory of solving inventive problems (TRIZ) originating in Russia in 1947. (7) TRIZ followers have been active in the continued search of the patent literature to glean new examples of inventive ideas and heuristics. These methodologies all are devoted to the use of heuristics. Ball has published an excellent collection of heuristics for use in TRIZ, although not named as such. (8)

Origin of heuristics

Historically, heuristics have been discovered in personal experience, taught in problem-solving classes, and gleaned from the literature. They may be viewed as being anecdotal. They have not achieved the status or acceptance of algorithms, which often are backed by generations of research. Heuristics have not been derived in a logical procedure analogous to the derivation of algorithms. And no algorithms exist for that purpose. Nonetheless heuristics continue to be used by technologists. They are effective.

Cognitive psychologists have recognized that heuristics play a significant role in creative cognition during problem solving. In the last decade or so, they have begun serious study of creative cognition, an area neglected in the past because of unscientific connotations and uncertainty regarding how to conduct definitive experiments. (9) As these barriers have been overcome, research is contributing to a better understanding of the creative processes in problem solving. Their research emphasizes the "creative" part of creative cognition. Here interest is more on the side of "cognition". Heuristics will be used to obtain as many solution concepts as possible whether or not they are creative. This is an important issue for adoption of a structured problem-solving methodology in industry – multiple concepts lead to alternative solutions.

A simple model of cognition

I use a simple, naive model of the creative cognition process employed in problem solving. [III] It is intentionally superficial in order to grasp a few essentials of the process without the detail. The simple model:

When in need of an idea, the mind can consciously seed the subconscious. Subsequently, recall and association of past experience may occur resulting in a trial concept for conscious testing.

Recall is a critical component of the model. Recall means to make a subconscious association of past experience with a conscious concept. There

[III] This naïve model is mentioned only to clarify references here to seeding and subconscious recall. It has no direct impact on the outcome of the results to be described.

is no magic involved. Past experience must already exist otherwise recall is meaningless. Our mental store of experience builds from every imaginable conscious interaction with the physical world. Solving technical problems depends heavily on training, practice, knowledge, and on-going curiosity to build a functional base of experience.

It is assumed further that the lag time between a thought, involving observation, recall, association, and modification, is very brief. Thus, it becomes instantly available for recall in the next mental iteration of trial-and-error seeding. The consequence of this assumption is that memory is refreshed dynamically during problem solving – experience is constantly updated.

An interesting aspect of recall, for problem-solving concepts, is the age of the information being recalled from memory – milliseconds to decades. Another interesting aspect is the nature of what is needed in recall. It is not facts, or data and specifications, but ambiguous associations with the simplest of artifacts (man-made objects) to the most complex high-tech device, from the simplest living organism to the most complex biological system, from subatomic particle interactions to cosmological phenomena. And most interesting is the trickery of recall using ambiguous stimuli from our senses.

Perspectives and biases in problem solving

Although problems arise from misbehaving functions, their understanding begins with the source objects. Engineering design refers to the formalized conceptualization of artifacts. Conventional, engineering-type problem solving can be characterized, in its analytical phase, as developing levels of abstraction of objects. At the initial level, the problem solver may have “in hand” a malfunctioning component – an object, either simple or complex. There may also be available photographs, a working prototype having most of the current features, a non-functional scale model, and blue prints; all serving as various metaphors of the original object. Ensuing discussions will generate simple pictorial sketches readily recognized as the subject. As the objects become more familiar, in the problem solving process, sketches become less detailed, even crude. Occasionally a simple labeled box will represent the original object. Thus, object expression can gradually lose definition but the object is still in one’s mind: real object ► photograph ► prototype ► model ► blueprints ► sketches ► labeled box and, even as abstract as an unlabeled box (discussed later). Similar abstraction occurs in verbal and written reports. The device initially is referred to by its full name. This will quickly be simplified to one or two words, then to an acronym, and then to a nickname, or even a comical name. The point is that our technical training, used for description and analysis in problem solving, is object oriented at all levels of abstraction.

The second most important feature in technical problem solving is a function. When an object is understood, understanding of its function follows. Functions are the purposes for the existence of objects. Considerable care is taken to understand functions; this can lead to extensive mathematical abstraction.

Third in importance in features of technical problems are the attributes of the objects. These are usually summarized in lists of materials and in design specifications of the objects. They may be accepted as conditions of solutions and, as such, serve as filters to cull solution concepts. Minimal abstraction, if any, is involved for attributes.

The point of this somewhat simplified view is that objects are the center of focus in conventional problem analysis and solution. Furthermore, the abstractions of objects used in discussion and analysis often retain graphic semblances to the original object. These create a biased perspective of the problem. Such bias is a limited view that can dissuade a problem solver from broader investigation.

It is the objective of structured problem-solving methodology to draw the problem solver away from such a (subconsciously) biased perspective and suggest ways of finding new perspectives. Of course, these will have their own biases; but they have not yet been exploited for new insights. An obvious opportunity for a new perspective is an attribute-centered system of analysis and solution. The heuristics derived in Part II will be seen to take advantage of this opportunity.

Object-oriented bias is desirable in the scaling phase of problem solving. In the idea-generation phase one needs as much freedom of association with past experience as can be evoked in the subconscious for unusual recall. An excellent heuristic for this purpose is the use of "*ambiguity*". One form of ambiguity is known as "*generification of object names*" (Table 1, No. 8). That is, referring to objects not by their commercial names but by generic names that reflect their functions. For example, a mechanical screw might be named a clamp, a fastener, a marker, an adjuster, a pivot, a support, a pump, a balance weight, a point of reference, a hole filler, or a propeller, according to its main use in a given problem.

Each generic object name becomes a seed to spark the subconscious. At this juncture, minds diverge through individual-dependent backgrounds of experience. The generification of an object's commercial name according to its application will produce rather similar results among different problem solvers, but the subsequent sparks of imagination can vary in surprising ways. As an example, consider one of the above generifications of a mechanical screw; say, a "fastener". In quick succession (without filtering), these ideas came to my mind: a gate latch, a staple, a railway spike, a Cleco button, a safety pin, a straight pin, a tack, a ratchet, Velcro, a belt buckle, a mechanical detent, a cog, a knot, a welded joint, a bottle cap, a shoe string, a skewer, a shoe stuck in mud, a rivet, a friction joint, a differential thermal-expansion joint, and … (I quit when the rate of ideas slowed). Note that some of the “sparks” produced sequences in which one idea gave rise to the next. Hence, a particular idea may appear to be disconnected from the original one. The purpose of this demonstration is to show that some resulting associations may seem logical to the reader and others may not. All were logical to me for specific reasons. Such variability among individuals should be borne in mind when judging whether a proffered solution concept follows logically from a specific heuristic.

A major benefit of the use of ambiguity to invoke broad associations is to suppress the rigor of engineering-type analysis. Presumably, when a problem solver has reached the point of applying a structured problem-solving methodology, rigorous engineering-type thinking has been already exploited and useful ideas captured. The strategy now is to shift to an unconventional approach that is not whimsical and retains phenomenological validity.

Abstraction of heuristics

The heuristic to “*simplify*” a problem, without identifying what to simplify, sounds very abstract. But it is only applied when the problem solver has begun to formulate verbal and graphic metaphors and complexity has been recognized. Most often the complexity relates to the number of objects, repeated patterns, or extraneous information. Once complexity is recognized, simplification may come to mind intuitively or as a practiced discipline of problem solving. At this point, when complexity has been recognized, the problem solver has physical world images to deal with.

“*Reverse the order of functions*” and “*reverse the order of objects*” are less abstract heuristics because they are worded to make their point of application specific and mentally visible. “*Reverse order*”, would be a more abstract level of thinking. In any case, the problem solver usually will mentally translate a heuristic to the specific situation at hand, making object and function associations relevant to the physical world. At this point the heuristic assumes the bias associated with the physical world objects in its new wording and images. This facilitates execution of a heuristic. At the same time, it may reduce its potential scope. In the derivation of heuristics it will be seen that they can be executed at an abstract level that widens their scope.

Comments on the method

Because no algorithms exist for deriving heuristics it will be necessary to call on heuristics to assist the process. Heuristics selected for this task must be reasonably well known and accepted, or at least tolerated while postponing judgment in order to see the outcome. Procedural steps will include creation of a well-defined problem, use of assumptions composing a set of axioms, and logical deduction of heuristics (while applying known heuristics throughout the process).

Note that the eighteen heuristics listed in Table (1) are all abstract, meaning that a specific physical-world object, attribute, or function is never mentioned. Such abstraction poses no mental problem in applying the heuristics to physical-world problems because the necessary associations are obvious. In fact, their history usually involved reduction or generalization of similarities seen among multiple real-world problems. However, their application to an abstract problem might be troublesome on first encounter.

A well-defined problem will be established following the guidelines of USIT. [4, 5] One requirement for a well-defined problem is a single unwanted effect. [4, 5] Since the to-be-derived heuristics will be used to produce solutions to technical problems, the unwanted effect will be the existence of a technical problem, although an undefined one.

It is also required that an unwanted effect be defined in terms of objects, attributes, and functions. Furthermore, it is recommended to introduce ambiguity through generification of objects' names. In this case – the derivation of heuristics – the problem is abstract and ambiguous from the beginning because no physical-world components are referenced whose names would be generified. To complete the well-defined problem, verbal and graphic statements of the problem are constructed.

Notice that a well-defined problem requires a single-unwanted effect. It might occur to define the lack of derived heuristics as the unwanted effect, since the target is to obtain derived heuristics. This would imply that the solution to the abstract unwanted effect, lack of derived heuristics, is derived abstract-heuristics, which smells of a trap in circular reasoning.

Mathematical algorithms are not derived from mathematical algorithms. Instead a class of problems is characterized by a set of axioms designed to permit their translation into a generic (abstract) equation, such as a quadratic polynomial, for example. A general solution of the equation is deduced, which becomes an algorithm for solving future quadratic equations. In other words, a generic problem is solved of the class needing an algorithm. A general algorithm is deduced from its solution.

An analogous procedure can be applied here. We define a generic problem of the type needing heuristics and from its solution deduce the target heuristics. Hence, we will create an unwanted effect as a generic problem composed of objects, attributes, and functions, find its solutions and deduce “derived” heuristics from the results.

The method for derivation of abstract heuristics

We will first analyze a physical-world problem using known heuristics in order to observe how the application of heuristics can work on a “real” problem. Next, we will apply heuristics to the same problem cast in abstract form; i.e., divested of its specific physical-world identities. This will enable comparison of the application of heuristics to real and to abstract problems.

As the application of heuristics unfolds, note the phase of problem solving where each heuristic is introduced: problem definition, analysis, and solution. Note also the nature of each heuristic, the ideas it evokes, and how they differ between two minds (yours and mine).

Application of heuristics to a physical-world problem

Problem-definition phase

The problem:

> “Hand held binoculars produce blurring of images resulting from motion of the binoculars caused by breathing.”

This problem statement has specific objects identified including, binoculars, image, and hand. Other objects are implied including light, the components of binoculars, lungs, the components connecting hand to retina, and retina (the image-encoding object).

Several known heuristics were applied in constructing this problem statement:
1) *include objects, attributes, and functions* (the function to form an image is implied);
2) include a single unwanted effect (blurring of image);

3) *include root cause* (motion of lens relative to eye caused by lung expansion and contraction), and
4) *identify object-object interactions* (e.g., hand holding binoculars, light forming an image on the retina, lung moving chest, shoulder moving arm, etc.). Another heuristic is
5) *include a simple sketch* (an example is shown in Fig. 1).

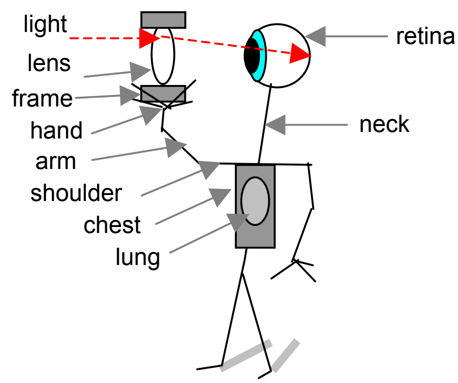


Figure 1. Simple sketch of hand-held binoculars showing light passing through a lens and forming an image on the retina of an eye. Eye is treated as a single compound object. The binoculars are shown connected to the source of motion, the lungs, through lens frame, hand, arm, shoulder, and chest.

A heuristic that applies to both verbal and graphic statements is
6) to *simplify*.
In this case, we see in the sketch that all of the physiological components from shoulder to hand, plus the lens frame, perform the same function, namely to support. A simplification of the sketch would be to combine these into one object (see Fig. 2). Another heuristic is to
7) name objects for their functions
rather than use their common or their manufactured names. In this case the unified element in Fig. (2) is named support.

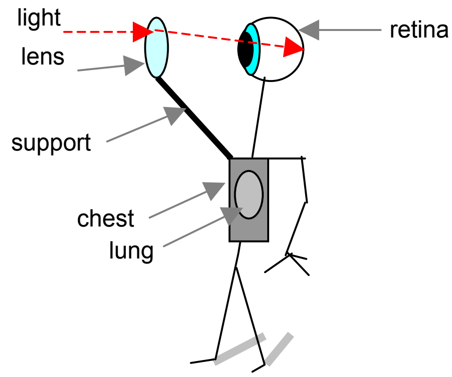


Figure 2. Simplification of Fig. (1) that combines components from shoulder to lens as a single object, the support.

Further simplification comes to light on examining the simpler sketch in Fig. (2). Since lung is the source of motion, and the motion moves lens relative to eye, other objects can be eliminated, as illustrated in Fig. (3), without loss of the problem – the unwanted effect. Note that eye includes its lens and its retina, which together form an image. They are combined into one object, eye, since neither is seen as root cause. This follows the heuristic to
***8**) eliminate unnecessary objects* (and further simplification).

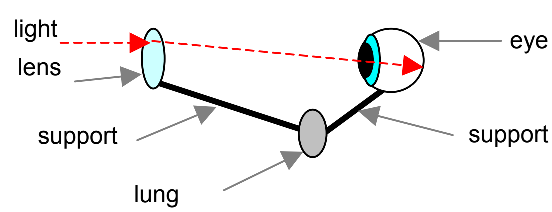


Figure 3. Simplification of Fig. (2) by eliminating unnecessary objects without loss of the unwanted effect.

Although not defined explicitly in the figure, this sketch has components that are graphic metaphors for smaller components. The mind readily deals with them once they have been defined. And it does not forget them.

Problem analysis phase

A problem is ready to be analyzed once it is reasonably simplified both verbally and graphically. A first tool for this purpose is to construct an object-function diagram to identify the beneficial functions of each object. A heuristic advises one to
9) construct a hierarchical diagram of objects linked by their single most important functions [IV].
The object-function diagram is illustrated in Fig. (4). [V]

As shown in Fig. (4), eye, light, and image have been combined as an image-forming system that is inaccessible to the problem solver. [VI] Lens is beneficial to this combined system in that it collects and focuses the incoming light. Support is beneficial to lens, being designed to align lens and eye. This construction reveals that lung, which is a vibrator, has no beneficial function to any of the objects.

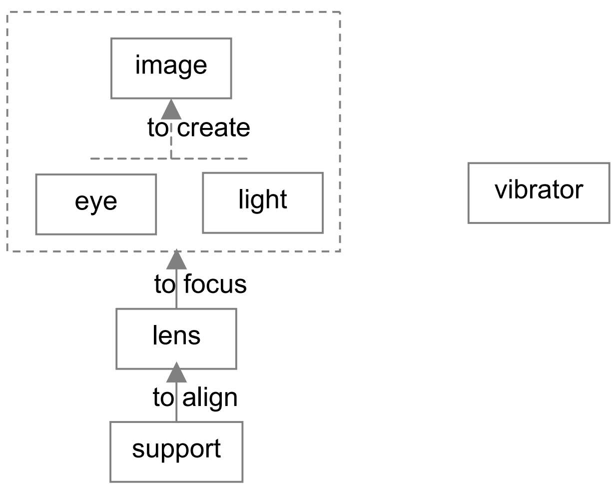


Figure 4. Object-function diagram illustrating the beneficial relationship of object-object interactions in a hierarchical relationship. Vibrator, the lung, has no beneficial function to any of the objects and is set to the side in the diagram.

[IV] This tool is know as the closed-world diagram and is adopted from ASIT.
[V] This and other USIT tools to be discussed all have rules for their construction. Each is a heuristic. They are not all mentioned here but can be found in the textbook, "Unified Structured Inventive Thinking – How to Invent", that is cited in the Bibliography. (4)
[VI] Image is a form of information. It is defined as an object in ASIT and USIT. It could also have been placed at the top of the diagram as a separate object.

The sketch should be examined for further simplification opportunities using ideas learned from the first analysis before moving to the next analytical tool. It is evident that the binocular lens focuses light for the purposes of forming an image. However, we see now that focused light has nothing to do with blurring of image. Both a focused and an unfocused image can be blurred by motion. The critical factor is the alignment of the axes of the two optical elements, lens and image forming system, "eye". This axis is emphasized in Fig. (5).

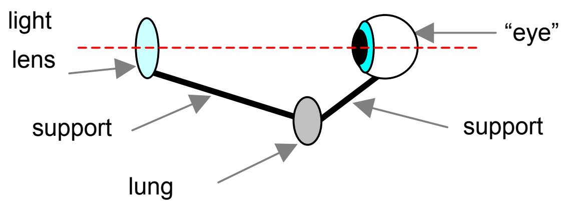


Figure 5. Simplified version of Fig. 3 in which the optical axes of lens and "eye" are aligned. The two supports have been further qualified to distinguish them.

The next phase of problem analysis requires
10) examining interactions between pairs of objects, and
11) identifying one attribute from each object and a function they support.

Another heuristic for problem definition is to
12) identify plausible root causes of the unwanted effect.
This is done using a
13) plausible root causes diagram
shown in Fig. (6) as a proforma diagram. Each double-layer row has a cause related to the effect in the row above it. Each cause is treated as an effect for the double row below it. The hierarchical diagram terminates on active attributes. The diagram is annotated for the blurring of image problem in Fig. (7). Note in the figure that 'coupling to support" refers to "degree" or "strength" of coupling.

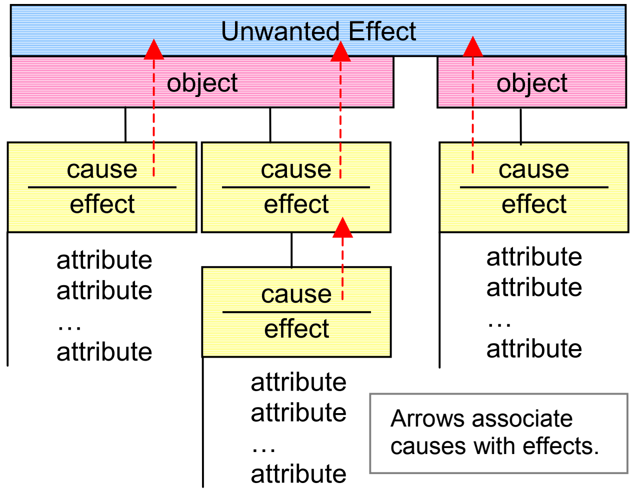


Figure 6. Proforma diagram for a plausible root causes analysis.

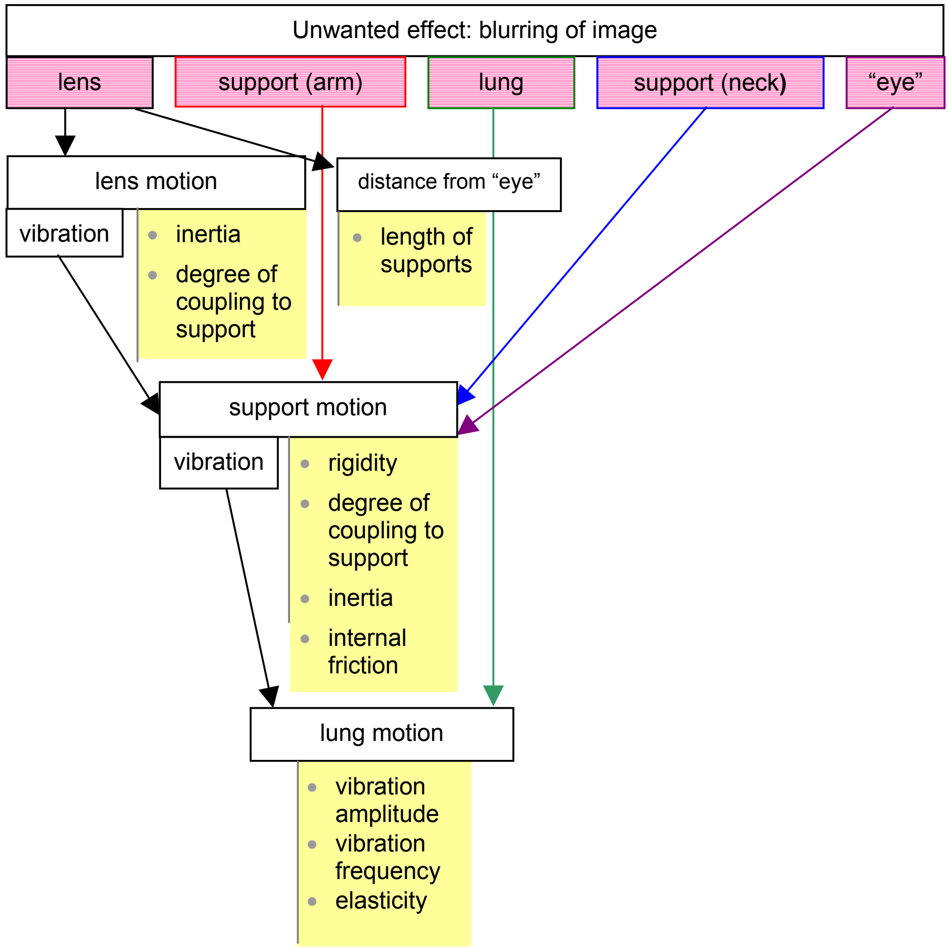


Figure 7. Plausible root causes diagram for the blurring-of-image problem.

After active attributes of objects are identified the next step in analysis is to
14) determine attribute trends; i.e.,
15) determine whether increasing or decreasing their intensities causes an increase or decrease in the unwanted effect.
16) Construct qualitative-change graphs [(VII)]
for this purpose, as illustrated in Fig. (8). The objects light and "eye" are not included in Fig. (8) since their attributes can be considered fixed.

Vibration amplitude has three components: along-axis, off-axis, and tilt. Along-axis vibration is immaterial, whereas both off-axis and tilt components are detrimental in the same sense and have been combined in Fig. (8).

[VII] From ASIT and USIT

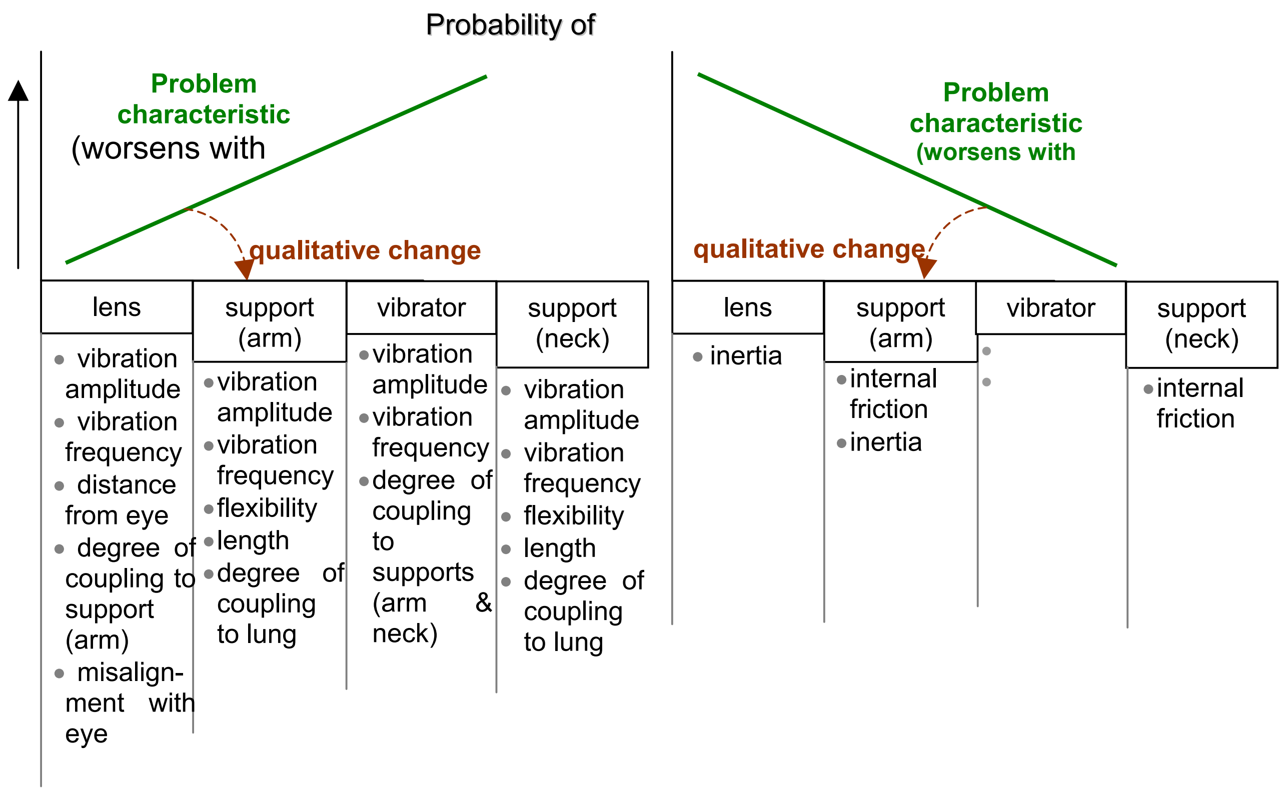


Figure 8. Qualitative-change graphs for probability of blurring.

From the identified attributes, Fig. (7), and attribute trends, Fig. (8), it is evident that the two supports behave identically. This suggests that they can be combined in the sketch as one object and further simplify the sketch.

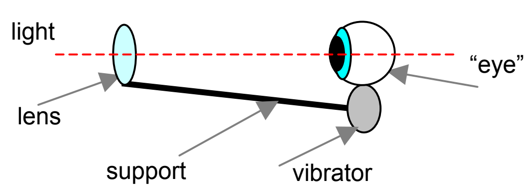


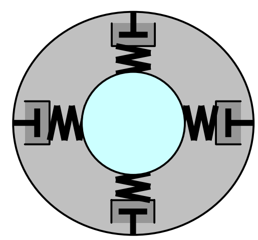
Figure 9. Simplification of Fig. (5) by combining supports into one object. Vibrator now moves support relative to "eye". (Vibrator and support could have been reversed.)

Problem-solution phase

We move now from problem analysis to the application of solution techniques, which are also heuristics. The process actually begins with completion of the QC-diagrams. Solution concepts may be found using these graphs by
17) considering a worsening trend as working against us and finding ways to make it work for us.
Solution concepts may also be found from the graphs by
18) considering the implications of making a particular attribute trend have a zero slope [VIII], i.e., …
19) eliminate an attribute.
Elimination of an attribute means to make an active attribute inactive by discontinuing its use.

Solution techniques

Make an unwanted effect work for us (***#17***). [**S1**] Construct the lens and support as a spring-and-damper assembly mounted within an outer enclosure that is handheld. The inner lens will then lag the motion of the outer enclosure and dampen its motion.



Reduce an attribute's characteristic slope to zero, Fig. (8) and heuristic (**#18**).
The characteristic of vibration amplitude of vibrator could be reduced to zero by [**S2**] holding one's breath. This is a known solution that works for short periods.

The degree of coupling of vibrator to support can be given zero slope by [**S3**] adding a new support between head and lens to bypass the vibrating support. A particular embodiment of this concept could be binoculars mounted to a head frame, which eliminates need of handholding.

Eliminate an attribute. (***#19***) Lens alignment with 'eye' can be eliminated by [**S4**] combining lens and "eye". This suggests a contact lens that would move with the "eye" and whose curvature could be altered electronically – such as a "fluid lens". (10)

Uniqueness

20) identify unique features of a system and examine them for solution concepts.

VIII See ASIT and USIT

Note that the lens has rotational and three translational degrees of freedom with respect to the path of light: translation includes horizontal and vertical plus longitudinal motions. The latter, longitudinal, has little effect on blurring (but a large effect on focusing). Both transverse motions affect blurring adversely but do not affect focus.
[**S5**] This uniqueness suggests stabilizing the lens in at least two directions. Stabilization can be accomplished using a built-in, battery-operated gyroscope mounted to an optical element, such as, an internal lens, prism, or mirror. This is a known solution that is available in commercial products.

Multiplication of objects

21) *Multiplication of objects* allows one to introduce copies of existing objects and employ them differently.

[**S6**] Multiplication of supports brings to mind two, hinged supports containing a vibration dampener between them. An example is illustrated in Fig. (10). Vibrations are transmitted through the arm to the lower leg of the hinged support. The damper connecting the two legs attenuates vibration transmitted to the upper leg of the support. A second damper could be used to attenuate vibration in an orthogonal direction. Hinges provide mechanical connectivity. This function could be incorporated in the dampers. [IX]

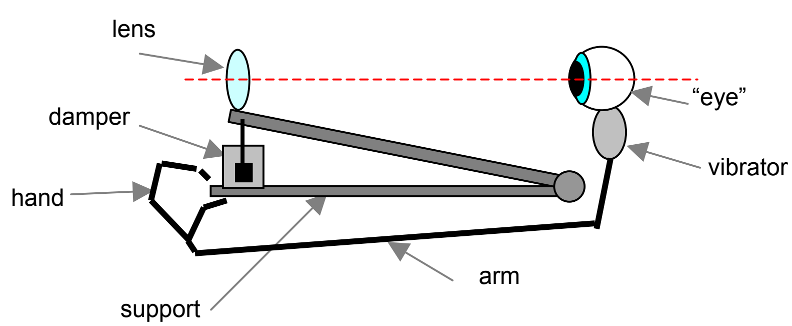


Figure 10. A hinged support containing a damper on one leg and the lens attached to the other leg is held by hand to align the lens and "eye".

Division of objects

22) *Division of objects* allows use of the parts differently.

[**S7**] Division of lens into quadrants, with each quadrant being coated with a transparent, light-sensitive material, or coated on its rim (or bezel), would enable detection of lens motion in two transverse directions by differential

[IX] Idea courtesy C. H. Stephan

measurement of light intensities on opposing pairs of quadrants. This information could be fed back to transducers coupled to an internal optical element (lens, prism, or mirror) to be moved in direction and amplitude so as to cancel motion that would cause blurring.

Distribution of functions

***23**) Distribution of functions* suggests moving functions to different objects.

[**S8**] Could, for example, "support's function to align" be moved to "eye" (Fig. 4)? For "eye" and light to perform alignment suggests recording sequences of digital images, then comparing and correcting successive pairs of images, and playing back the motion-corrected image on a viewing screen on the binoculars.

Transduction

Transduction suggests
24) considering the addition of attribute-function-attribute links to construct a solution concept.
To visualize the process first
25) construct a block-type diagram of interacting objects, a pair of their attributes, and the unwanted effect they support, with its affected attribute (as shown in Fig. 11).

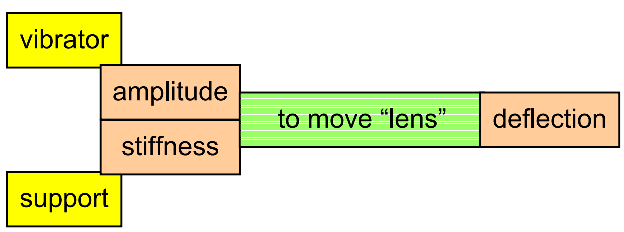


Figure 11. Amplitued of vibration of vibrator and stiffness of support interact to support the unwanted effect of "lens" motion affecting "lens" position.

An attribute-function-attribute link suggests
26) using the affected attribute (deflection) as an input attribute to another function that would affect some other attribute of an object in a useful way.
27) Multiple A-F-A links are allowed.

An example is illustrated in Fig. (12).

[**S9**] An A-F-A link of [internal friction of support] –to– [dampen motion] –to– [deflection of support] has been added to the system of Fig. (11).

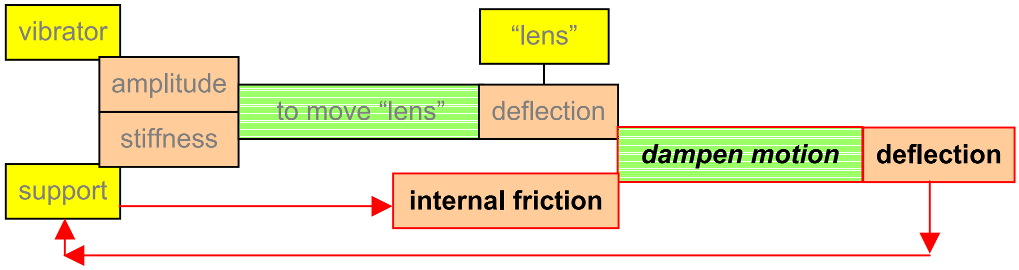


Figure 12. Addition of an A-F-A link (internal friction – to dampen motion – deflection) to Fig. (11) to produce dampening of the deflection of the support.

This completes the demonstration of heuristics used in problem solving following the USIT methodology. Heuristics used in this demonstration problem are summarized in Table (2). Although nine solution concepts were found (S1 – S9) this was not a thorough execution of the methodology. More phenomenology could have been discussed, more heuristics applied, and more solution concepts found. However, it is sufficient to illustrate a variety of heuristics and to show where they play a role and how they work. In all cases they work as seeds to spark ideas.

Table 2
Summary of heuristics used in the blurring of image problem.

#	Heuristics used in problem solving – USIT style	O	D	A	S
1	Include objects, attributes, and functions.	O	D		
2	Include a single unwanted effect.		D		
3	Include root cause.		D		
4	Identify object-object interactions.	O	D	A	
5	Include a simple sketch.	O	D		
6	Simplify.	O	D		
7	Name objects for their functions.	O	D		
8	Eliminate unnecessary objects.	O	D	A	
9	Construct a hierarchical diagram of objects linked by their most important functions.	O		A	
10	Examining interactions between pairs of objects.	O	D	A	
11	Identifying one attribute from each object and a function they support.	O	D	A	
12	Identify plausible root causes of the unwanted effect.		D	A	
13	Plausible root causes diagram.	O	D	A	
14	Determine attribute trends.	O		A	
15	Determine whether increasing or decreasing their intensities causes an increase or decrease in the unwanted effect.	O		A	
16	Construct qualitative-change graphs.	O		A	
17	Conside a worsening trend as working against you and find a way to make it work for you.				S
18	Consider the implications (for solution concepts) of making a particular attribute trend have a zero slope.	O			S
19	Eliminate an attribute (discontinue use of an active attribute).	O			S
20	Identify unique features of a system and examine them for solution concepts.	O			S
21	Multiplication of objects allows to introduce copies of existing objects and employ them differently.	O			S
22	Division of objects allows to use the parts differently.	O			S
23	Distribution of functions suggests to move functions to different objects.	O			S
24	Consider adding attribute-function-attribute links to construct a solution concept.				S
25	Construct a block-type diagram of interacting objects, a pair of their attributes, and the unwanted effect they support, with its affected attribute.				S
26	A-F-A link: Use the affected attribute as an input attribute to another function that would affect some other attribute of an object in a useful way.				S
27	Multiple A-F-A links are allowed.				S
Keys to columns:					
O designates direct object focus required to execute the heuristic.		O			
D designates heuristics used in problem definition.			D		
A designates heuristics used in problem analysis.				A	
S designates heuristics used in problem solution.					S
	Shaded cells indicate graphic-type analysis and solution heuristics.				
#	Shaded number cells (#) indicate heuristics that can be applied to an abstract problem				

The twenty-seven heuristics in Table (2) make up a part of the structure of USIT.

Abstract heuristics – no physical-world references

You probably noted apparent redundancies in some heuristics being named as well as listed again in an explanatory form or even repeated in different words. Such is the method of using heuristics. Since they are seeds to spark mental action, they have no unique proforma of expression that is guaranteed to work for all problem solvers. Or even to work for the same problem solver on different occasions. For this reason, heuristics tend to take on personalized wording to the liking of an individual. They also take on the argot of particular fields of use.

Of particular interest is that none of the heuristics in Table (1) cites a specific, physical-world object, attribute, or function; consequently all of the heuristics are abstract. When heuristics are applied to a specific problem, the problem solver gives objects, attributes, and functions identities belonging to the problem. This observation implies that heuristics should be transportable to various fields. In fact, they should be transportable to any field in which problems can be couched in terms of objects, attributes, and functions. That begs the question of appropriate definitions for objects, attributes, and functions in non-technical areas.

Specific physical-world objects became immediately obvious as heuristics were introduced in the process of defining, analyzing, and solving the demonstration problem. Then came identification of functions (object-object interactions), and finally, perhaps with more effort, came the identification of object attributes (heuristics were used to identify these). In fact, without these direct associations between the abstract words, *object*, *attribute*, and *function*, and physical-world examples of the problem, some readers would find the heuristics too abstract to understand. On the other hand, once it is understood how abstract heuristics work, i.e., how they spark the thought process, it is proposed that they can be used to solve abstract problems. This is the process used in the derivation of heuristics in Part II. To see how this might work, I will cast the demonstration problem in abstract form, determine which heuristics can be applied, and apply them to solve the abstract problem.

There is a working level of logic that ties together *object*, *attribute*, and *function* allowing their definitions and realistic associations in the physical world. It is that functions affect attributes by changing or maintaining their degree of intensity. Objects are the carriers of attributes and are characterized by their active attributes. Pairs of active attributes interact to support functions. This circle of logic, while stated in the abstract, is readily satisfied in the physical world.

Application of heuristics to an abstract problem

Problem definition phase

The original physical-world problem statement:

> “Hand held binoculars produce blurring of images resulting from motion of the binoculars caused by breathing.”

This problem statement is to be elevated to an abstract form. When cast into abstract form, by stripping the statement of specific, physical- world references, the problem can be written as follows.

> “An object interacts with another object causing an unwanted effect in a third attribute as a result of a causal attribute of an object.”

This statement incorporates heuristics (1 – 4) in Table (2). A simple sketch is an additional need for a well-defined problem. This is done readily for real-world objects, but how is it to be done for abstract objects? Solution heuristic, 25) “Construct a block-type diagram of interacting objects, a pair of their attributes, and the unwanted effect they support, with its affected attribute.” in Table (2), is useful for this purpose and is substituted for #5, as shown in Fig. (13). Although the components are all abstract, their general relationships to one another are clearly illustrated.

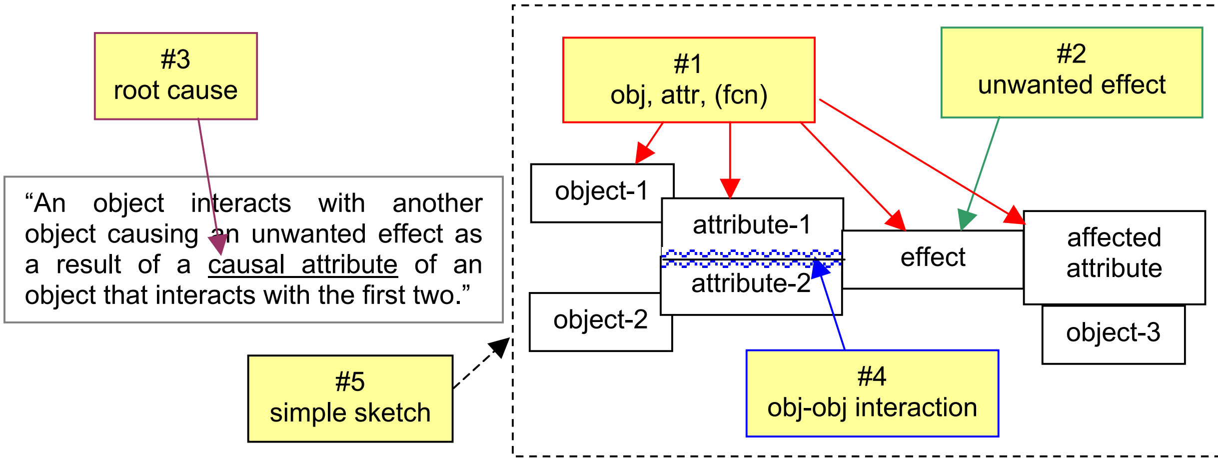


Figure 13. Problem statement and simple sketch (block diagram) for an abstract problem using heuristics (#1 - #5, #27) of Table (2) as indicated. Wavy lines indicate the zone of interaction of input attributes A_1 and A_2.

The abstract verbal statement and abstract block diagram constitute an abstract problem definition not associated with a particular field, or even a particular problem. The diagram in Fig. (13) is a graphic heuristic, H_1. ($H_{(x)}$ identifies new heuristics by subscript number.)

Problem analysis phase

The only analytical heuristic in Table (2) that can be used without specific information about objects and attributes is heuristic (#5), "*a simple sketch*", which has been cast in the abstract in Fig. (13) using heuristic (#27). Thus we move on to the solution phase.

Problem solution phase

Solution-phase heuristics (#17, 18, 20, and 23) in Table (2) require specific details about objects and attributes. Hence, they cannot be used for the abstract problem. Heuristics (#19, 21 – 22, and 24 – 27) can be used. These are illustrated in the following figures.

Heuristic #19: eliminate an attribute.

Three attributes are available to select for elimination (A_1, A_2, and A_m, the affected attribute). These constitute three new heuristics ($H_2 – H_4$ for removing $A_1 – A_m$ respectively.) [X]

H_2) Eliminate active attribute A_1 of object O_1 by moving, removing, or reshaping O_1.

H_3) Eliminate active attribute A_2 of object O_2 by moving, removing, or reshaping O_2.

H_4) Eliminate the affected attribute A_m of object O_3 by moving, removing, or reshaping O_3.

The consequences of eliminating an attribute are to render its associated object useless, for supporting the unwanted effect, thus eliminating the unwanted effect (if the object has only one attribute supporting the unwanted effect). One choice of eliminating an attribute is shown in Fig. (14).

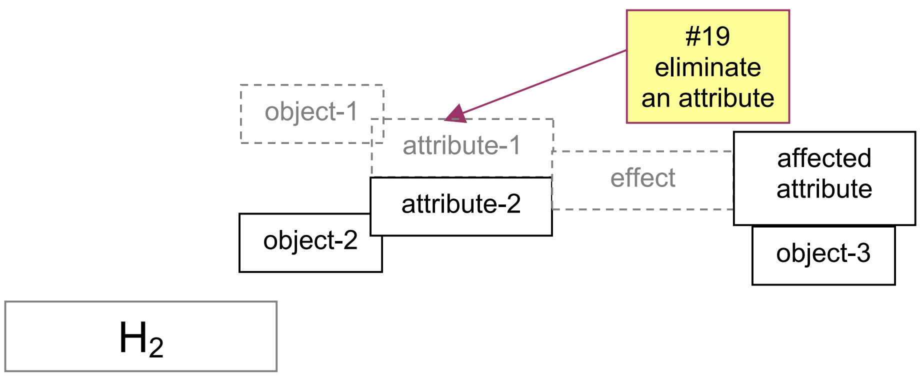


Figure 14. An unwanted effect can be eliminated by eliminating an input attribute.

Figure (14) illustrates one of three new graphic heuristics for solving an abstract problem, H_2. They have been derived from a known heuristic; (#19) “*eliminate an attribute*”. The three graphics represent solutions of the original abstract problem (Fig. 13). Thus, the abstract problem has been solved.

To apply these three solution heuristics to a physical-world problem, first construct the block diagram inserting the specific objects, attributes, and unwanted effect of the problem. If its components have the same relative relationships as shown in the abstract problem of Fig. (13) then Fig. (14) represents a solution. The problem solver, at this stage, studies the physical-world block diagram just created and considers the consequences of eliminating object-1. If the heuristic has the desired effect the problem solver will discover solution concepts involving removal of attribute-1. The process is repeated for removal of the other two attributes, one at a time.

The identification of pairs of interacting attributes is a tool of USIT designed to simplify problem analysis. There can be multiple pairs of attributes supporting

[X] Heuristics labeled (# numeral) are Table (2) heuristics and those labeled (H numeral) are Table (3) heuristics.

the same function. There may also be multiple functions at the same point of object-object contact. The closed-world diagram heuristic is used to identify the most important function. Others can be ignored (and should be) during analysis of the most important one.

Heuristic #21: Multiplication of objects
With three potential objects to choose from (O_1, O_2, and O_3), multiplication of objects brings three more graphic heuristics ($H_5 – H_7$). Multiplication of an object refers to using a copy of it in a different way [XI] by activating a new attribute to support a useful function when joined with an existing attribute (see Fig. 15).

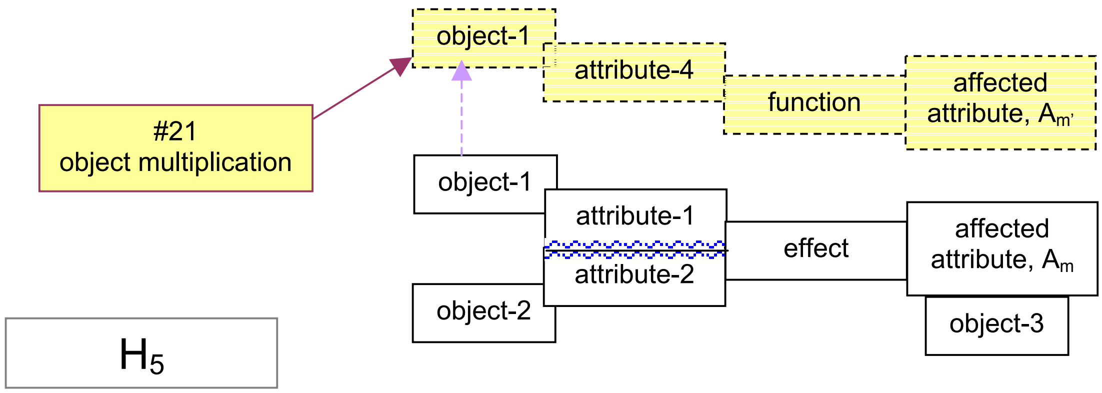


Figure 15. Object multiplication introduces a copy of an existing object ($O_1 – O_3$) having a new active attribute, A_4, which combined with an existing attribute (A_1, A_2, or A_m) supports a function that is useful as a solution to the problem through its affected attribute.

Figure (15) is a graphic heuristic (H_5); it illustrates the starting point – multiplication of an object, O_1. The next step in this example of multiplication is to consider which attributes the new attribute (A_4) will interact with (A_1, A_2, or A_m). The interaction of A_4 with A_1 is illustrated in Fig. (16) where the function, the interaction supports, modifies the original attribute, A_m, so as to counteract its unwanted effect. In this manner twelve graphic multiplication heuristics are created; see Table (3) (heuristics $H_5 – H_{16}$).

[XI] Logging in deep forests provides an example of multiplying objects and using the copies in different ways. Felled trees, stripped of limbs, are drug or slid to lower collection points. Previously felled trees can be used as rollers and slides.

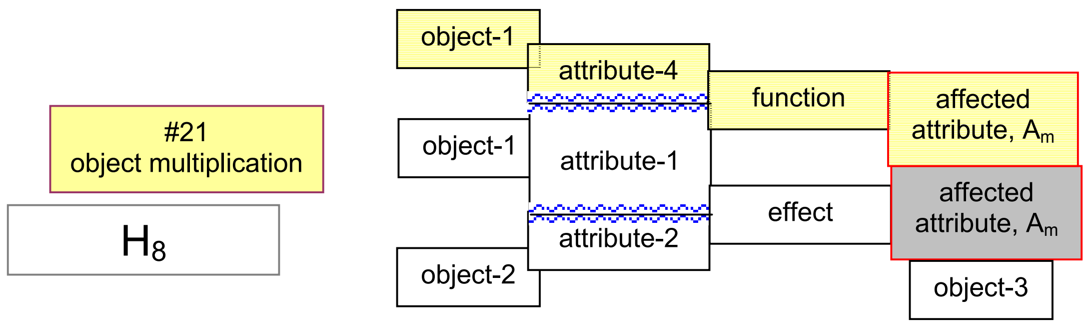


Figure 16. Attribute A_4 of multiplication object O_1 is allowed to interact with attribute A_1 to support a function that affects the original unwanted-effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

Heuristics, $H_5 – H_7$, can be subsequently combined with any one of the three attributes to form a total of nine new graphic heuristics ($H_8 – H_{16}$). [XII]

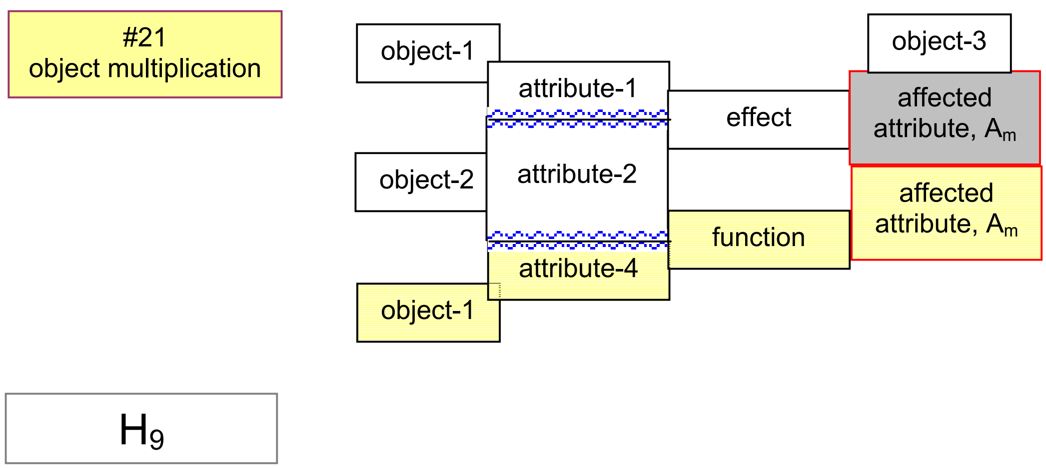


Figure 17. Attribute A_4 of multiplication object O_1 is allowed to interact with attribute A_2 to support a function that affects the original unwanted effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

[XII] The rapid pluralization of heuristics, where three might seemingly be combined into one generic heuristic, is an issue of heuristic naming, which is discussed in a later section.

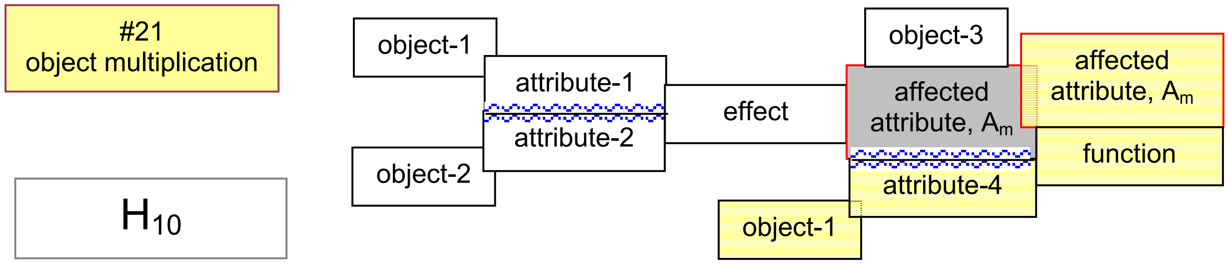


Figure 18. Attribute A_4 of multiplication object O_1 is allowed to interact with attribute A_m to support a function that affects the original unwanted effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

Figures (17) and (18) illustrate multiplication of object O_1 followed by interaction of attribute A_1 with A_2 (Fig. 17) and A_m (Fig. 18).

Heuristic #22: Division of objects
Division of an object allows using its parts differently by activating new attributes in the parts. This is particularly useful for compound objects where finding different functions for components may be useful. Division of O_1 is illustrated in Fig. (19).

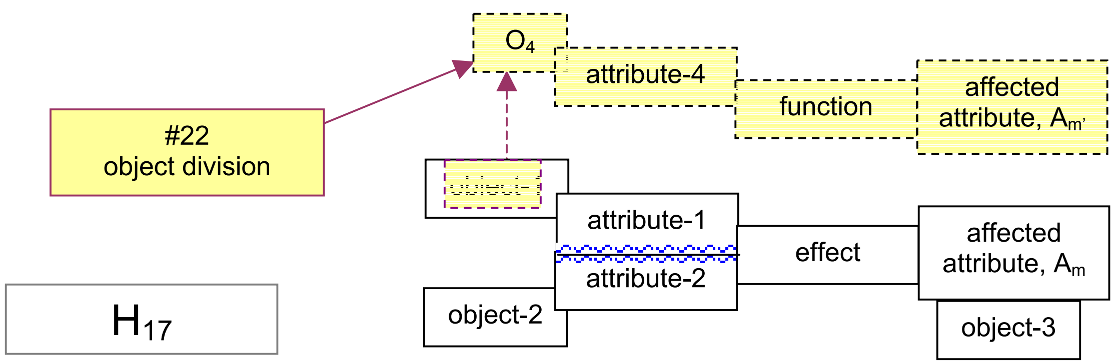


Figure 19. Object division introduces a part of an existing object (O_1 – O_3) having a new active attribute, A_4, which combined with an existing attribute (A_1, A_2, or A_m) supports a function useful as a solution to the problem through its affected attribute.

Again, three new heuristics arise, one for each object to be divided (H_{17} – H_{19}). The second step, selecting which of the original attributes to interact with, produces nine more heuristics (H_{20} – H_{28}). One is illustrated in Fig. 20.

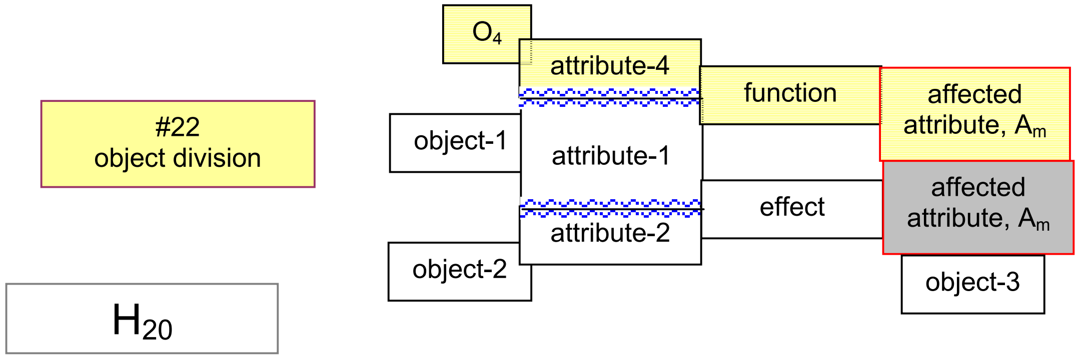


Figure 20. Attribute A_4 of division object O_1 is allowed to interact with attribute A_1 to support a function that affects the original unwanted-effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

Heuristic #29: Add attribute – function – attribute links
Attribute-function-attribute (A-F-A) links connect the affected attribute in an unwanted effect to support a useful function. This is illustrated in Fig. (21). Adding an A-F-A link allows introduction of a new object and an active attribute from the new object (H_{29}). Multiple links can be used (#26 of Table 2).

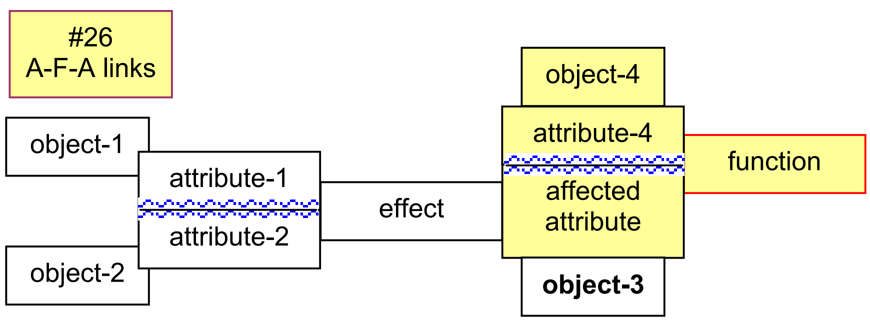


Figure 21. An A-F-A link has been introduced to the problem diagram through a new object, O_4, and its active attribute, A_4, to support a new function through interaction of A_4 with A_m.

The newly found graphic heuristics for solving an abstract problem are summarized in Table (3).

Table 3. Summary of new graphic heuristics for an abstract problem.

	Graphic Heuristic		Object	Attribute
H1	Problem statement			
H2	Attribute elimination (Ax)			A1
H3	“			A2
H4	“			A3
H5	Object multiplication (Ox)		O1	
H6	“		O2	
H7	“		O3	
H8	Multiplication → attribute-attribute interaction	O1→	H5	A1
H9	“	O1→	H5	A2
H10	“	O1→	H5	A3
H11	“	O2→	H6	A1
H12	“	O2→	H6	A2
H13	“	O2→	H6	A3
H14	“	O3→	H7	A1
H15	“	O3→	H7	A2
H16	“	O3→	H7	A3
H17	Object division (Ox)		O1	
H18	“		O2	
H19	“		O3	
H20	Division → attribute-attribute interaction	O1→	H17	A1
H21	“	O1→	H17	A2
H22	“	O1→	H17	A3
H23	“	O2→	H18	A1
H24	“	O2→	H18	A2
H25	“	O2→	H18	A3
H26	“	O3→	H19	A1
H27	“	O3→	H19	A2
H28	“	O3→	H19	A3
H29	A-F-A links			

Abstract heuristics for abstract problems

The solutions of the image-blurring problem, a physical-world problem, were accomplished using twenty-seven known heuristics. All of the solution heuristics used are abstract in that they have no specific objects or attributes mentioned in their wordings. The image-blurring problem was then stripped of specific object, attribute, and function references to convert it to and equivalent abstract form. Thirteen of the original heuristics were used to formulate abstract solutions. In the process, twenty-nine new graphic-type solution heuristics were discovered. This exercise demonstrates how new heuristics can be derived from abstract problems.

Although the abstract formulation of the image-blurring problem came from a physical-world problem, it has no specific relationship to the physical-world problem except through similarity of its abstract graphic representation to its physical-world graphic representation. Similarity refers to the graphic arrangement of generic objects, attributes, and unwanted effects. Many other yet to be found problems may have the same abstract representation. Consequently, when such a physical-world problem is found, regardless of its field, the newly found solution heuristics can all be used to spark solution concepts.

This demonstration gives an overview of the procedure to be used in the more thorough derivation of heuristics in Part II.

Graphic representation of heuristics

Heuristics exist under various names with modifications fitting personal taste and the argot of a particular field. This occurs for lack of comprehensive cataloging and standardized nomenclature. Heuristics are rarely labeled as such. Consequently, it is difficult to know whether a "new" heuristic is really new.

It is evident from the foregoing demonstration that a graphic representation of a heuristic may provide a standardized method of cataloging heuristics for future reference. Such graphics would be independent of argot and special terminology.

A problem consisting of an unwanted effect, UE, evidenced in an affected attribute, A_m, in an object, O_m, supported by two interacting attributes, A_1 and A_2, contained in two objects, O_1 and O_2, could be represented graphically as shown in Fig. (22).

```
O1 – A1
        \
         UE – Am
        /      |
O2 – A2        Om
```

Figure 22. Graphic representation of a problem consisting of an unwanted effect UE, three attributes, A_1, A_2, and A_m, along with their associated objects, O_1, O_2, and O_m respectively.

A graphic representation of the solution of a problem using the attribute-elimination heuristic is illustrated in Fig. (23). Parentheses around O_m in the figure remind that m can designate one of three possible objects.

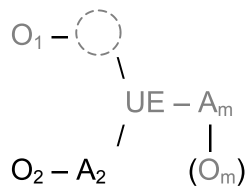


Figure 23. Graphic representation of a problem solution, using attribute elimination is illustrated where the attribute A_1 has been eliminated.

These ideas will be further elaborated in Part II.

We turn now to the abstract derivation of heuristics for abstract problems.

Comments on the Adaptation of Derived Heuristics to Other Fields

Since the heuristics derived here are abstract, and were derived in solving an abstract problem, there are no a priori reasons to limit their application to physical-world problems. Hence, it is proposed, but not proven here, that they can be applied to non-technical problems as well as technical problems in diverse fields. A few comments follow on how this might be done.

Several steps are recommended for investigating the adaptability of the derived heuristics to non-technical problems:

- Assemble an assortment of solved problems representative of the non-technical area of interest.
- Examine the solved problems for analogies with objects, attributes, and functions used to define physical-world problems.
- Test modifications of the definitions of objects, attributes, and functions that may be needed to create analogies between well-defined problems in the new field and those in the physical world.
- Determine whether these analogies are sufficient to compose a statement of an unwanted effect.
- Convert solved problems into well-defined problems using the newly found analogies to objects, attributes, and functions.
- Generate graphic models of the problems in terms of interacting objects, pairs of attributes, and an unwanted effect as shown herein.

- Model the solutions in a similar fashion. This is a crucial step. The goal is to find similarities in solution strategies among diverse problems. Without such similarities every problem will appear to be unique and inert to application of heuristics.

Examination of the collection of solved problems will provide a basis for discovering what constitutes the simplest statement of an unwanted effect. Some caution will be needed, as has been learned in analyzing physical-world problems. Too often what seems to pass as an adequate problem statement is anything but a well-defined problem. The most important features of a well-defined problem in the physical-world are a single unwanted effect described in terms of interacting objects. Identifying a single unwanted effect is often difficult until practiced. A good approach is to start with any obvious unwanted effect in the problem situation and see how many unwanted effects it can may contain. Rank these, pick the most important, and repeat the exercise until successive reductions and rankings identify a single unwanted effect for focus. Object minimization is an excellent test of convoluted unwanted effects.

Another caution is to observe how large problems can become in their description. Eliminating extraneous information and reducing a problem to its essentials is the key to unraveling complex problem statements. Simplification is the mantra for this work.

In search of analogies, it will be helpful to reduce the definitions of objects, attributes, and functions to their essentials. A useful starting point is the graphic axiomatic model for interacting objects shown in Fig. (24).

$$\begin{array}{l} O_1 - A_1 \\ \qquad\quad \backslash \\ \qquad\qquad F \rightarrow A_m - (O_m) \\ \qquad\quad / \\ O_2 - A_2 \end{array}$$

Figure 24. An axiomatic model of two interacting objects, O_1 and O_2, having attributes, A_1 and A_2, supporting a function, F, that affects another attribute, A_m, existing in a parent, O_1, O_2, or another object, (O_m).

This axiomatic model is an example of extreme simplicity having only three, and possibly just two, objects. The use of only two interacting attributes is another degree of simplification. It is a powerful metaphor for points of action. The definitions of object, attribute, and function used in physical-world problems may need modification for non-physical world applications. Their physical-world definitions are as follows:

Object

An object exists of itself, occupies its own space (defined by the space its mass occupies), and can make "contact" with another object to enable pairs of their attributes to interact. The ability to bring attributes into interaction range is the most important feature of objects.

Information as an object

A very useful ploy for analyzing physical-world problems is to define information as an object. This is especially effective, for example, when dealing with transducers in control systems where their basic physical properties are not of interest. A strain gauge may be sold as a shaped wire in an insulating package that can be fastened to a flexible object. When the flexible object bends it stretches (strains) the strain gauge. Electrical current passing through the strain gauge will change in intensity in proportion to the amount of strain. Those are the physical details. However, a particular problem may be better analyzed in terms of the meaning of the variation of electrical properties rather than physical details of the variation. Thus, viewing a strain gauge as an object that creates a new object called information becomes a simplification of analysis offering unusual perspectives. This object, information, has defining attributes, it can interact with another information object to create a function or produce an unwanted effect (such are the vagaries of feedback control systems).

Information is the input to transducers and the output from sensors. It also can be the input and output of both.

Using information as an object raises the question of whether information occupies space, as required of the physical-world definition. Information as imprinted in the attributes of physical objects occupies the space of the objects. Information imprinted in the human mind can be seen as specific neural maps occupying the space of the activated neurons.

Note that information, in the physical world, covers all forms of recorded or stored knowledge. These include neural nets in the brain; character and graphic patterns printed, shaped, embossed, and carved in matter; magnetic, electric, chemical activity, and chemical composition patterns encoded in matter; arrangements of individual pieces of matter; dynamic density patterns in matter; and patterned electromagnetic waves, as examples. They all occupy space. One information object can interact with another information object to alter or sustain an attribute of information. Hence, information is a viable object in problem analysis.

In practice, the use of information as an object in physical-world problems is relatively easy to adopt without undue quarrel over rigor of definition – these are tools for inspiration.

A “for thought” example: The following sentence illustrates information as a possible object. “A law can interact with a jury’s vote to affect a suspect’s future.” In this example “law” is offered as an information object characterized by rules. Suspect is a second object characterized by past action. When considered in juxtaposition by a problem solver (judge or jury), they are brought into interaction in the problem solver’s mind. The resulting decision can activate one of two latent attributes, guilty or not guilty, and thereby affect the suspect’s future.

```
     law – rule
                \                        guilty
          to determine guilt →    (or not      – suspect
                /                        guilty)
suspect – past action
```

Figure 25. Two objects, law and suspect, have interacting attributes, rule and past-action, which interact in a judge’s or jury’s mind to activate the attribute guilty or not guilty, which affects the future of suspect.

Attribute

Attributes characterize objects so as to distinguish one object from an otherwise similar one. The attributes of interest are those represented in the axiomatic model; they support a function. Attributes that support a function are referred to as being “active”. All other attributes can be ignored except when being “turned on” (activated; or “off” for deactivation) to support a new function. An attribute’s use for pairing with another to support a function is the most important characteristic of attributes in problem solving.

Function

Functions either alter or sustain an attribute of one of the interacting objects or of a third object.

Object abstraction

We often think of higher mathematics as abstraction. Yet concepts in mathematics are symbolized by language characters and even by invented graphics. As such, they are written, printed, etched, and visualized mentally. These forms are information objects. They can be combined to create other information objects. They are characterized by attributes and support functions.

As an example of attributes, consider the use of subscripts and superscripts in tensor analysis. These attributes may remain the same or be modified in tensor operations.

Note on Mathematical Heuristics

In closing it is interesting to review the twelve mathematical heuristics mentioned in the introduction. They have direct and intuitive relevance to the use of known and derived heuristics. Comparisons are illustrated in Table (4).

Table 4. Comparison of twelve mathematical heuristics with known and derived heuristics

	Mathematical heuristic	Heuristics used herein
1	Search for a pattern.	• Characterize a problem as a verbal O-A-F template. • See the A-F-A solution technique in Part II.
2	Draw a figure.	Make a simple sketch of interacting objects.
3	Formulate an equivalent problem.	Symbolize an unwanted effect as an O-A-F graphic diagram.
4	Modify the problem.	• Reduce problem to a single unwanted effect. • Minimize the number of objects.
5	Choose effective notation.	Use objects, attributes, and functions in a problem definition, analysis, and solution.
6	Exploit symmetry.	See • spatial and temporal heuristics, • solution by transposition, • paired spatial | temporal attributes in Part II.
7	Divide into cases.	See solution techniques utilization, A-F-A linking, nullification, and elimination in Part II.
8	Work backwards.	Apply a contrarian view: • to every concept proposed; • to every restriction; • to every deduction; • to every change.
9	Argue by contradiction.	Annihilate an unwanted effect with a function.
10	Check for parity.	See spatial and temporal dependencies of effects in Part II.
11	Consider extreme cases.	Multiply and divide to extremes.
12	Generalize.	Use ambiguity: • Generify object, attribute, and function names. • Eliminate metrics for attributes. • Use generic metaphors.

Conclusion of Part I

Heuristics have been demonstrated as common tools used for problem solving. The roles of objects, attributes, and functions in problem definition, analysis, and solution also have been demonstrated. The latter are themselves sophisticated heuristics. Heuristics have been demonstrated in their abstract form, being striped of specific real-world references. This discussion is in preparation for the derivation of heuristics in the next part.

It has been proposed that heuristics used in solving physical-world problems may be adaptable to non-physical world problems by using them in their abstract form. This conjecture has not been proven.

PART II
Derivation of Heuristics

Part II – Derivation of Heuristics

O-A

\

$(U \equiv “\mathbf{F}”) \rightarrow A_m$

/ |

O-A (O_m)

Derivation of Heuristics

In the conceptual phase of problem solving, prior to engineering-type scale-up, many ideas come quickly to mind and are culled according to specifications of the problem and other criteria. Some are mentally recycled for improvement. As new ideas wane one resorts to heuristics to prod one's thinking toward fresh insights.

A generic problem-solving strategy for deriving heuristics is demonstrated that is based on a set of definitions and assumptions. These constitute the axiomatic basis for a generalized, self-consistent derivation. The axioms are generalizations, which allow deductions of useful methodology. Derivation is done by constructing and analyzing graphic metaphors of interacting objects without identifying specific objects.

Following a few definitions to set up the axioms, known heuristics to be used will be discussed and the search for new heuristics begun. As they arise they will be printed in italics and distinguished as previously known heuristics (*KH*), new heuristics presented here (*NH*), or heuristics found in the derivation process (*DH*).[XIII] Note that definitions are heuristics, which often we refer to for clarification of thinking.

Definitions

Physical-world problems are visualized as being composed of interacting objects. For example, a specimen resting on a glass slide experiences a reactive force that stabilizes its vertical position. Conceptually, we see that these objects interact. Weight of specimen and elasticity of slide interact to stabilize vertical position of specimen affecting specimen's attribute of location. [XIV]

Interaction of objects is defined to mean that one object modifies or preserves an attribute of the other. More generally, interaction includes two parent objects in which one attribute of each affects an attribute of one, or of a third object. Implied directionality of interaction is intentional. [XV] Abutting, overlapping, and fused (or mingled) attributes characterize the state of interaction of objects. Desirable

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[XIII] While being new to the author, they may be known already to others.

[XIV] This is a proforma sentence structure used to identify three essential components of a well-defined problem: objects, attributes and functions; it is a heuristic. *(Attribute) of (object) and (attribute) of (object) interact to (function) affecting (attribute) of (object)* (*KH*) – a heuristic device taken from USIT. It is used to facilitate learning how to discover active pairs of attributes.

[XV] Directionality is intended as a simplification focusing on one half of an otherwise two-part action-reaction phenomenon.

interactions are defined to be functions. Interaction of objects involves their functional contact – i.e., effects that modify or sustain attributes of acted-upon objects – with or without their physical contact. Attributes, such as fields, can extend beyond the mass boundaries of parent objects.

A well-defined problem also contains objects, attributes, an unwanted effect, and root causes. Root causes are defined as causal attributes that can be linked to an unwanted effect. An example of a well-defined problem: "The lead of a mechanical pencil, pressed against paper while writing, tends to break as a result of length of unsupported lead and elasticity of the paper." It is well defined in the sense that it contains the necessary elements required of the methodology selected for its solution. This problem statement can be further improved for idea generation by adding ambiguity: A rod in a mechanical holder, when pressed against a solid, tends to break as a result of length of unsupported rod and stiffness of the solid.

Axioms

The strategy for deriving heuristics has the following basis. Six assumptions (Ax_1 – Ax_6) that arise from self-evident truths, experience, and intuition, are selected to support simplification of analysis. They constitute the axiomatic basis for this discussion and are referred to individually as axiomatic heuristics –

Ax_1. Problems can be analyzed in terms of interacting objects.

Ax_2. Interacting objects can be simplified to pairs of objects.

Ax_3. Interaction of objects can be reduced to one attribute from each object supporting an effect that is acting on a third attribute (of an initial object or of a third object).

Ax_4. Attributes require no metrics in a conceptual analysis. (Dimensions and numerical values are filters used later in culling and scaling concepts.)

Ax_5. Effective simplification for problem analysis and solution can be achieved with a minimum set of objects.

Ax_6. Problem situations must be reduced to unwanted effects of which one is to be solved at a time (the mind cannot solve two problems simultaneously).

An axiomatic model of interaction, constructed of these axioms, is shown in Fig. (1) with an example in Fig. (2). [XVI]

[XVI] All illustrations in this writing are graphic heuristics. The axioms are axiomatic heuristics, labeled Ax_1 – Ax_6.

O_1 - A_1
\
$F \rightarrow A_m - (O_m)$
/
O_2 - A_2

Figure 1. An axiomatic model of two interacting objects, O_1 and O_2, having attributes, A_1 and A_2, supporting a function, F, that affects another attribute, A_m, existing in a parent, O_1, O_2, or another object, (O_m).

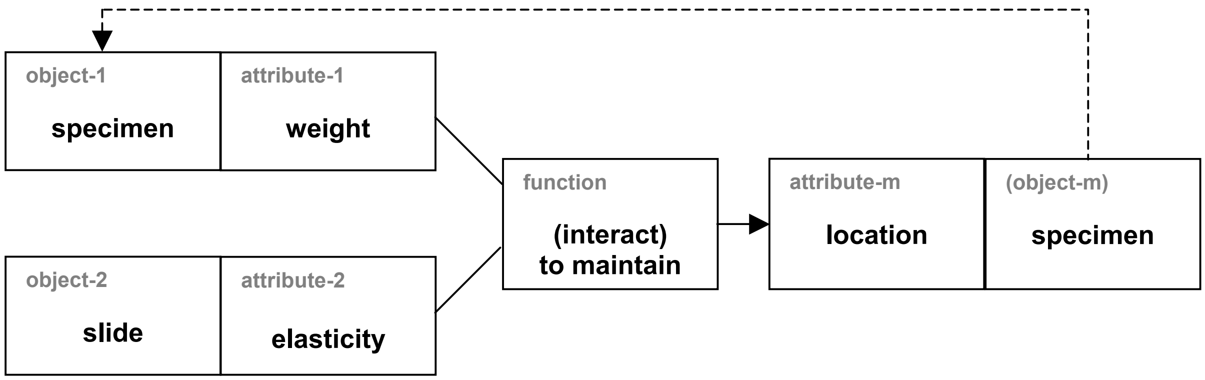

Figure 2. An axiomatic model having the acted upon object as one of the interacting objects.

Five specific objects have been cited above: specimen, slide, holder, solid, and rod. They likely are recognized and accepted as objects without second thought. Yet, “object” has not been defined. For most recognizable physical things this does not present a problem. However, these axioms are not limited to the physical world. Objects may be conceptual “entities” having attributes that can interact in the sense of modifying or sustaining an entity’s attributes. (From Part I: “A rule of a law can interact with a suspect’s past actions to effect a suspect’s guilt or lack of guilt.”) Thus, the following analysis allows derivation of heuristics at an abstract level (as represented in Fig. 1), from which they must then be translated to the practical level for application in a specific field (Fig. 2), with possible rewording in appropriate argot (“*translate* heuristics using appropriate *argot*”). *(NH)*

Known Heuristics

Heuristics are ubiquitous in problem solving, and since this derivation is a problem-solving exercise, heuristics will be used, both consciously and subconsciously. They play a significant role and the obvious ones are italicized for identification.

One known heuristic is to *name physical objects for their generic functions* (*KH*) rather than use their marketing name. This induces alternative mental associations for objects. Similarly, attributes can be named ambiguously. *Name an attribute for its most generic property* (*NH*). [XVII] *Effective attributes use no metrics* (such as dimensions and numbers) and thus are more conducive to ambiguity for creative thinking (*KH*). [11] A very common heuristic, of unknown origin, is to "*think contrarily*" (*KH*). That is, whatever solution concept comes to mind, or step in the process, consider its opposite. Another heuristic is to "*use known solutions as templates*" (*KH*) for new concepts – "*analyze known solutions for underlying phenomenology and improve them* (*KH*)". [5]

These heuristics, and the others previously mentioned, operate at the abstract level using the metaphors of "object", "attribute", and "function". A problem solver makes ad hoc physical-world associations when applying a heuristic. This observation offers an important clue regarding how and what to look for during derivation of heuristics. A problem-state graphic (see below) is composed of metaphors and their relationships to each other. A solution-state graphic will bring new relationships to light at the same abstract level. Derivation then becomes an exercise in deduction of guidelines for manipulating the metaphors to create the solution state (still in the abstract). An expected advantage of working at the abstract level is that one is free of the bias of experience. That is, the process is allowed to discover new ideas rather than the analyst forcing desired solutions, whether consciously or subconsciously.

Abstraction

Definition of an unwanted effect, in the abstract, is done using unspecified objects, attributes, and functions to define metaphorically its "space", to enable description of object-object interaction producing the "effect", and to characterize its "time" of existence, which formulate its mental image. This abstraction is intentionally independent of a particular discipline. [XVIII] Resolution of an unwanted effect uses

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[XVII] Some names given to attributes in this text may seem to be minor rewording of another one, or essentially obviously identified with another. The reason for this is discussed in the section on phraseology.

[XVIII] While such independence may be intentional, the engineering mind, due to years of physical-world thinking, may subconsciously make physical-world associations for all components. In fact, this discourse is sprinkled with physical-world examples to assist easier understanding of new concepts. Thus, this will these definitions and other heuristics to formulate a well-defined problem, analyze its root causes, and discover solution concepts. [XIX]

Problem state

An unwanted effect, like a function, maintains or modifies an attribute. Two objects in contact enable at least two of their attributes (usually more but selected in pairs, Ax_3) to interact producing an effect that modifies or maintains an attribute in one of the interacting objects or in another object (Fig. 3). While objects have many attributes, it behooves the analyst to identify pairs of "active" attributes; meaning attributes in active support of the effect. This is a useful simplifying heuristic expressed in Ax_3. [4] A specific example of Fig. (3) is illustrated in Fig. (4).

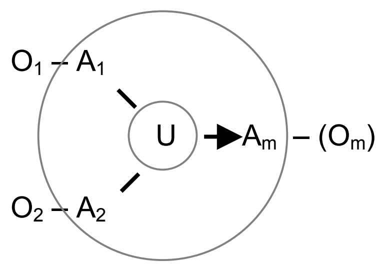


Figure 3. Schematic of an unwanted effect, U, with input and output attributes, A_1, A_2, and A_m, and their host objects, O_1, O_2, (and possibly O_m) . The unwanted effect is central to a ring of three attributes that is inner to a ring of objects.

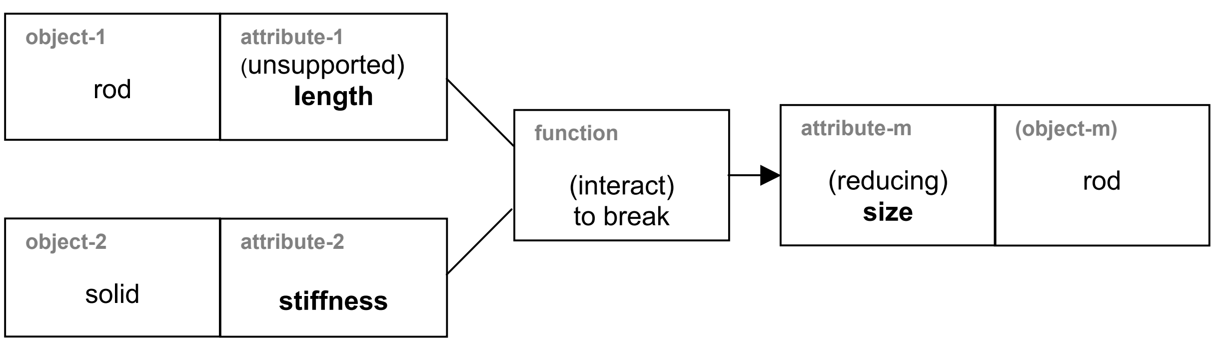


Figure 4. Schematic of an unwanted effect following the proforma graphic of Fig. (3).

be an initial mental block to translation of the results found here to other fields. Heuristics may be needed to facilitate such translation.

XIX Details of a USIT-style well-defined problem may be found in references (3) and (4).

The order of constructing an unwanted effect schematic begins with the unwanted effect, adds output- and then input-attributes, and ends with the host objects, as shown (working from center outward) in Figs. (3) and (4). Such order shifts emphasis from objects to attributes in order to create an alternative perspective. This proforma procedure is a heuristic, "*work from effect-to-attribute-to-object*" (*NH*), for constructing a well-defined problem. As a well-defined problem it requires causal attributes.

If causal attributes of the unwanted effect cannot be found, this suggests that the unwanted effect may not be a unique effect. *"When causal attributes are not found look for multiple, entwined effects"* (*KH*, from USIT). *Since unwanted effects entail two or three objects, the more objects used in a problem definition the more unwanted effects may be lurking in a convoluted problem statement*. (*NH*) Minimization of objects may help to untangle and discover multiple effects. "*Eliminate objects lacking involved attributes*" (*NH*) – object minimization heuristic.

Problem-state – to – solution-state strategies

A problem state is that of an unwanted effect. The first zone of attack on a problem state, as seen in its graphic heuristic, contains the effect itself, U. The second zone contains the attributes (Fig. 3).

The process of solving a problem has three self-evident tactical routes: *utilize the unwanted effect, nullify it, or eliminate it*. *(NH)* Utilization converts an unwanted effect to a beneficial one, a function. Nullification introduces a counter effect. Elimination annihilates an unwanted effect. Utilization and elimination operate directly on the unwanted effect. Nullification attacks the unwanted effect through the attribute it affects. Obviously, any ideas to modify the affected attribute necessitate modification of its object. However, ideas can originate without conscious concern for objects; hence, a non-object-oriented perspective.

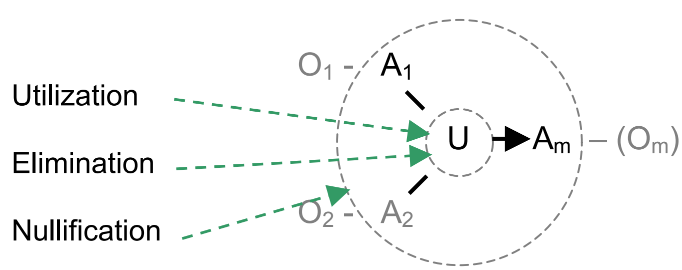


Figure 5. Utilization and elimination operate directly on the unwanted effect. Nullification attacks the unwanted effect through the attribute it affects.

A problem-state and the three solution states are illustrated in Fig. (6). A state comprises an arrangement of objects in space interacting in time to support an effect –

utilizing three compositional concepts: space, time, and effect. Verbal and graphic heuristics play different mental roles in finding new perspectives of a problem.

Problem state graphic model

O-A
\
$U \rightarrow A_m$
/ |
O-A (O_m)

Solution state graphic models

O-A
\
$(U \rightarrow \text{“F”}) \rightarrow A_m$
/ |
O-A (O_m)

Utilization

O-A
\
$U \rightarrow A_m \leftarrow F$
/ |
O-A (O_m)

Nullification

O-A
\
(_)
/
O-A

Elimination

Figure 6. Graphic-heuristics representing a problem state and three solution states: utilization, nullification, and elimination.

In the following discussion examples of applying the solution state concepts are given using physical-world problems. Sketches represent various solution states. Keep in mind that solution state sketches (Fig. 6) also contain the original problem state consisting of objects, input attributes, unwanted effect, and acted upon attribute. This may be a little confusing when studying the examples. When examining a sketch think of it as being constructed in two stages: look first for the unwanted effect and its supporting attributes. Once they have been identified, consider how the indicated solution-state components were added to resolve the problem. See Fig. (7).

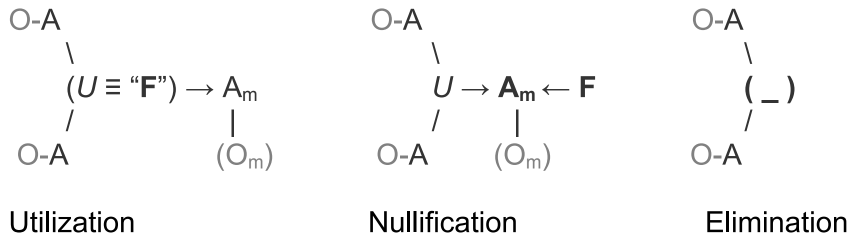


Figure 7. State sketches containing the original problem (italics) and the solution (bold font).

Characterization of attributes

Before analyzing these solution states it will be useful to examine attributes as adjustable parameters for constructing solution concepts from the solution states. Attributes characterize specific objects, distinguishing them from other objects. Since objects are not specified at the abstract level, we need to consider how to characterize attributes abstractly in order to understand better their roles in the various solution states.

An ambiguous view is to consider the kind of characteristics attributes have that can be subjected to alteration. Three are – intensity, location, and time – which, on reflection, have further subdivisions. In fact, a hierarchy of characteristics of a single attribute can be constructed, as illustrated in the physical-world example of Fig. (8).

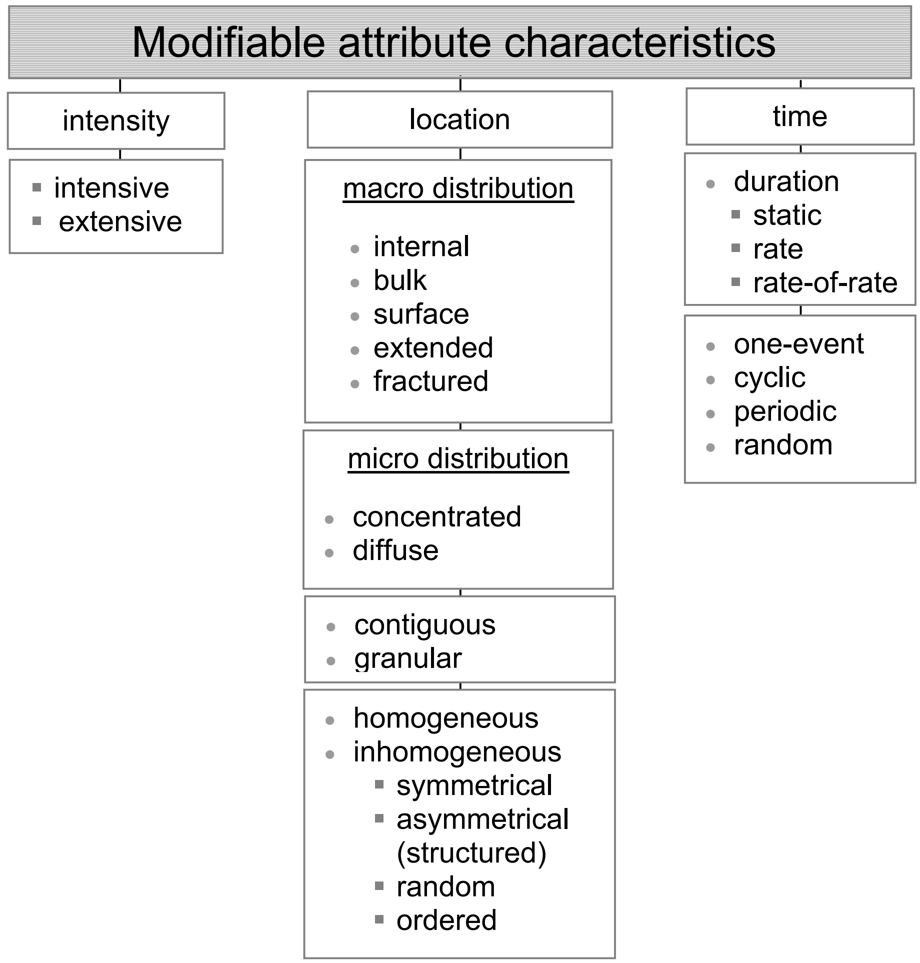


Figure 8. Hierarchy of modifiable attribute characteristics with physical-world examples.

Attributes characterize or classify objects generically. Metrics give specific intensity or extent to attributes to define specific objects in the same classification. Attributes can be classified as being extensive or intensive. Metrics of extensive attributes define the spatial or size characteristics an object in space; i.e., its volume, weight, shape, etc. Metrics of intensive attributes define an object independently of its spatial extent. Physical properties such as density, specific heat, conductivity, and many more, are examples of intensive attributes. Metrics introduce a finer classification of objects having the same attributes.

A sketch of an object outlining its shape indicates where its mass exists and where it does not exist – its macro distribution. Within its macro distribution of shape its mass may vary in density – its micro distribution, possibly including holes of zero density. An internal attribute lies within the object’s shape boundaries. A surface attribute lies on (or contains) the boundaries, while an extended attribute extends to the possible limit of infinity. A fractured, macro-location attribute could characterize a divided object or a compound object. Examples of spatial types of attributes are listed in Fig. (9) for physical-world objects. Thousands of combinations follow from the list in Fig. (8).

Attributes of Physical Objects

- An interior-localized attribute of a car seat could be its stiffness (intensive);
  a surface-localized attribute, its texture (intensive – the same for every element of area);
  a bulk attribute, its elasticity (intensive); and
  an extended attribute, its odor (extensive).

- An interior-localized attribute of a golf club could be the mass of an inserted counter-weight (extensive for the counterweight, intensive for the club head);
  a surface-localized attribute, its polished finish (intensive);
  a bulk attribute, its stiffness (intensive); and
  an extended attribute, the sound it makes on high speed contact with a ball (extensive – varying within its occupied space).

- An interior-localized attribute of a lion could be its rate of heartbeat (intensive, depending on factors other than size of the lion);
  a surface-localized attribute, the fineness of its mane (intensive, the same for each elemental area of mane);
  a bulk attribute, its weight (extensive); and
  an extended attribute, its roar (extensive).

Figure 9. Examples of spatial ranges of attributes in physical objects.

Examples of attribute-attribute interactions of two physical objects are given in Fig. 10.

Attribute-Attribute Interactions of Physical Objects

- Interaction of two abutting objects through their bulk attributes:

  Stiffness of a pipe and hydrostatic pressure of a liquid interact to contain the liquid affecting location of the liquid.

- Interaction of two abutting objects through a bulk attribute of one and a surface-localized attribute of the other:

  Weight of a block and coefficient of friction of a ramp interact to determine the tendency for sliding of block affecting stability of block.

- Interaction of two objects through the localized attribute of one and the extended attribute of the other:

  Magnetic permeability of a bar magnet and the magnetic field of a solenoid interact to move the bar magnetic affecting position of bar magnet.

Figure 10. Examples of attribute-attribute interactions of two physical-world objects.

Within the shape boundaries of an object an attribute may have a concentrated location or be diffused. Either may be contiguous or granular. And the latter may be homogeneous or inhomogeneous. If inhomogeneous and contiguous or granular, component(s) may be located with symmetry, with structured asymmetry, randomly, or ordered. (Labels used in Fig. (8) are representative of physical world applications.)

Attributes have a time duration in which their intensity may be static or change as derivatives of time. During their duration they may occur as a single event, multiple cyclic events, periodic, or random ones.

The mathematical combinations of modifiable attribute characteristics, as suggested in Fig. (8), constitute a large number. However, little gain for this discussion is seen in attempting to organize these possibilities in more detail than the overview in Fig. (8).

Analysis of solution states

In the following analysis of solution states, attributes will provide a major opportunity for new insights. The challenge will be to understand their characterization details and then search opportunities for their modification.

Solution by Utilization

Since, as indicated in the utilization solution state, Fig. (11), content of the innermost circle remains the same effect, the first line of action for finding solution concepts is to address the active attributes. These too remain the same attributes but they provide opportunity to scale their intensities using their space-time dependencies.

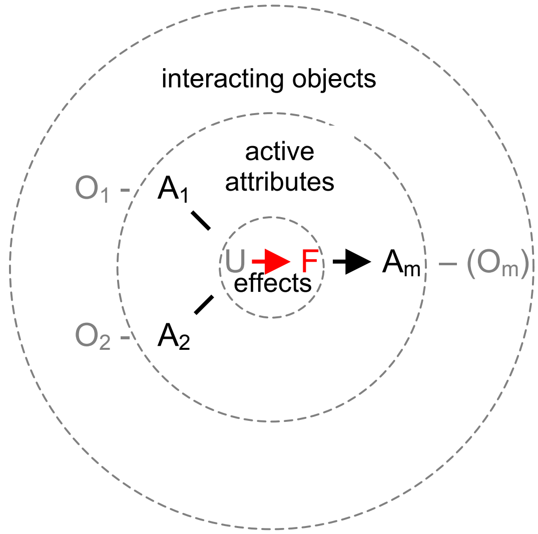


Figure 11. Interaction zones of objects, attributes, and functions in the utilization scheme of solution concepts. The innermost zone is the effects zone (beneficial and unwanted). Utilization converts the unwanted effect, U, to a useful function, F. Objects are grayed in order to give preferential emphasis to attributes.

The "unwanted" aspect of an effect has spatial, temporal, and input-/output-attribute implications. Alteration of any one of them may lead to solution concepts ("*alter attributes in intensity, space, and time* (*NH*)."). Contrarily, don't alter anything ("*status quo*" heuristic (*NH*).); use the modified attribute (or unwanted effect) in a different way or use it for a different purpose ("*effect utilization*" heuristic (*NH*)).

A space-time graph of the unwanted-effect – to – function transition illustrates the desired outcome.

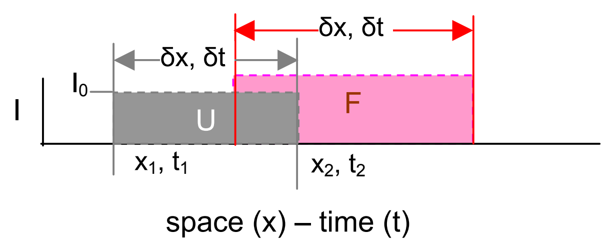


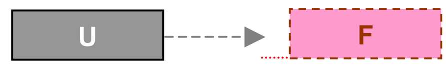
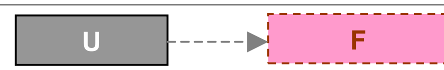
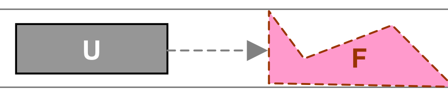
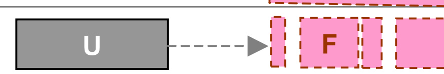
Figure 12. Available modifications of space or time dependence of intensity, I, of an unwanted effect, U, to produce a useful function, F, are illustrated with similar rectangles.

Modifications of the unwanted effect, suggested in Fig. (12), to produce a useful function, could involve changes …

in initial location (x_i), and/or in initial time (t_i),

in width (δx) and/or duration (δt),
in strength (I_0),
in spatial dependence of intensity, $I_0 \cdot f(x)$, where f is a function of x, and
in time dependence of intensity, $I_0 \cdot g(t)$, where g is a function of t,
of the space-time rectangle. These are summarized graphically in Table (2). Each active attribute, shown in Fig. (11), offers a point of application for this attribute-modification strategy.

Table 2. Space-time attribute modifications for solution by utilization

Space-time attribute modifications				
	generic attribute	modification	contrarian modification	graphic space-time representation of a modification (column 3)
1	location	shift	fix	
2	width	lengthen	shorten	
3	strength	intensify	weaken	
4	structure	modulate (shape)	sustain	
5	continuity	pulsate		

Generic attributes listed in column (2) can be altered by the modifications suggested in column (3), and *contrarian* modifications in column (4), to find solution concepts by utilization. Their graphic representations are illustrated in column (5).

An attribute's activity can be shifted (or fixed) in space or time. Width in space or time can be lengthened or shortened. Strength of an attribute can be intensified or weakened. Structure of an attribute can be modulated in space or time. And continuity of an attribute in space or time can be broken with variable gapes between breaks. A heuristic: *sketch space and time dependences of effects with a common rectangle drawn on common axes* (*NH*). *Test modifications of a space/time rectangle from starting point, width, intensity, structure, and continuity* (*NH*). Contrarian modifications must also be considered as well as combinations of these modifications. Recognizing space-time similarities simplifies their memorization and recall.

The possible modifications of attributes constitute an abstract view of solution by utilization. Final embodiments of the possible attribute modifications will lie in specific objects having the modified attributes. This transition brings us to their realizations in the physical world. Here we address engineering scaling concepts to achieve the abstract modifications.

Utilization transition, U ≡ “F”, implies that the modified attribute is used beneficially (it is “defined” to be a function) or is ignored. It can be ignored when solution of a larger problem mitigates it.

There are three evident tactics for using an unwanted effect beneficially:

(1) “*use an unwanted effect as-is*”, that is, “*use an unwanted effect in a different location, at a different time, or for a different purpose (NH)*”;

(2)“scale an unwanted effect” to greater or lesser intensity (magnitude, distribution, etc.); or

(3) “link an unwanted effect” as a causal attribute of another function. Scaling can benefit from a similar heuristic used in mathematics when analyzing the behavior of functions: “*scale to extremes* (*KH*)” heuristic (+/- infinity, and 0).

Examples of Solution by Utilization

U ≡ F
U → F
U → ~~F~~
U → F F …
A–U–A–F–A

Combustion of air and gasoline vapor in an internal combustion engine allows oxygen to react with both the fuel and nitrogen producing NO_x pollutants – an unwanted effect.

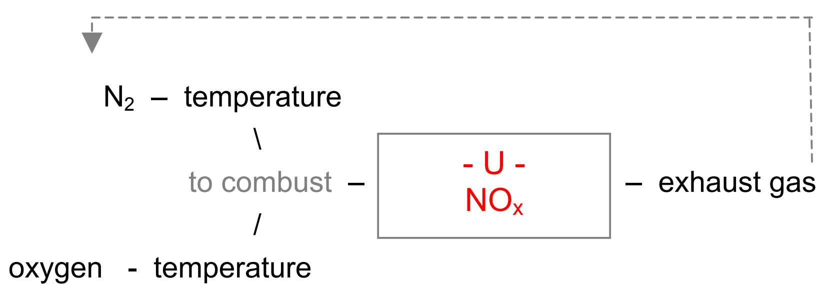


Figure 13. Example of NOx in internal combustion engine exhaust as an unwanted effect and its solution by utilization of the exhaust gas.

An approach to reducing NO_x in output exhaust gas of an internal combustion dngine is to reduce combustion temperature to favor fuel combustion. Addition of an inert gas having useful heat capacity would reduce combustion temperature. A useful attribute of exhaust gas is the heat capacity of its non-combusted nitrogen. Thus, exhaust-gas recirculation can reduce NO_x emission (as illustrated in Fig. 13).

Examples of Solution by the Utilization continued

U ≡ F
U → **F**
U → ~~F~~
U → F F …
A–U–A–F–A

- Use it as-is in a different manner: U ≡ F

  Printing waste salvaged: Misprinted postage stamps command higher than face value as a result of their rarity.
  Manufacturing scrap: Parts out of specification may be used for less critical applications.
  Post-it notes (® 3M Company) salvaged poorly adhering glue.

- Scale it: U → **F**

  Fishing line: The refractive index of monofilament line makes it visible in water – good for fish, bad for fisherman. Matching the filament's refractive index to that of water makes it nearly invisible in water but visible in air – bad for fish but good for fisherman.
  Immunization: The oral polio vaccine consists of live vaccines (although attenuated in strength) so that it stimulates antibody production without causing polio.

- Divide it (simultaneous use): U → ~~F~~

  Bed of nails: Dividing the load and distributing it among many points of contact can lessen the pain of a single sharp point.
  Parts of a compound object can be used for new functions.

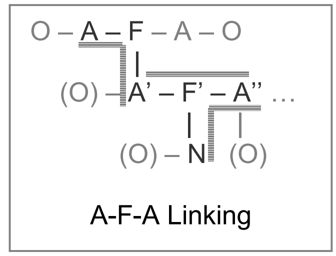
- Multiply it (sequential use): U → F F …

  Driving a nail through a glass object may shatter it on the first blow. Multiplying nail-to-glass contact duration into many sequential events of lower intensity enables drilling without shattering.

- Link it: $A - U - A_m - F - A \ldots$

  Feedback control: Inattention to accelerator pedal pressure allows vehicle speed to drift from a desired value. The differential speed (actual minus desired) can be fed back to the throttle plate to produce a constant speed using automatic speed control.

Solution by A-F-A Linking



Linking derives from noting a common feature in the problem-state and solution-state graphic heuristics: namely that they involve internal A-F-A – type connections with functions or unwanted effects. This suggests solution states based on chains of A-F-A links terminating in a useful solution state (“*form* A-F-A *links* (*KH*)” heuristic [XX]); see Fig. (14). Inserting a new link introduces a new attribute (N_3) and its optional host object (O_3); that is, the attribute can exist in any of the four objects (“*attribute’s optional object* (*NH*)” heuristic).

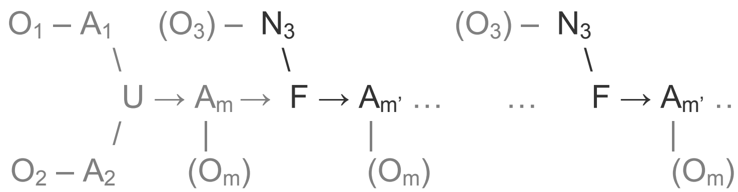


Figure 14. Illustration of A-F-A Links: Initial links A_1–U–A_m and A_2–U–A_m, solution link A_m–F– $A_{m'}$, and the link it introduces, N_3–F–$A_{m'}$. Note that each added link allows one new function, F, an attribute, N_3, with its optional object, (O_3), and an affected attribute, A_m, with its optional object.

Each A-F-A link allows addition of a function, an attribute, its optional object, and an affected attribute (*NH*). This heuristic enables one to think first of stepping from attributes to functions to attributes repetitiously until an attribute is reached that is recognized as being available. Then the intermediate attributes are addressed to determine if they are available in the existing objects, with possible modification, or whether to introduce optional objects (fewer is preferred).

XX The A-F-A link heuristic has been recognized previously in USIT [4, 5], but without some of the nuances found here.

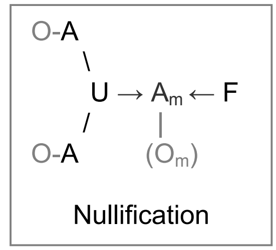
Example of Solution Using A-F-A Links

O_1 A_1
pedal – *throttle angle(t)*
\ U $A_m(t)$
to accelerate(t) – affecting *speed*
/ \ F’ $A_{m'}$
driver – concentration to differentiate (subtract) – affecting *error*
O_2 A_2 /
speed reference
/ N_3
O_3 control unit

Figure 15. Example of solution by utilization for a vehicle speed control problem.

A driver depresses accelerator pedal, O_1, to attain desired vehicle speed, A_m. Pedal position is linked mechanically to throttle angle, which determines amount of air allowed to enter combustion chambers. Lack of driver attention allows speed to drift in time, $A_m(t)$ – an unwanted effect. The attribute time-dependent speed, $A_m(t)$, can be subtracted from a reference speed, N3, to produce an error signal for speed control, Am’. This involves two links: $A_m(t)$ – F’ – $A_{m'}$ and N_3 – F’ – $A_{m'}$.

Solution by Nullification



Nullification suggests countering an unwanted effect using another effect, a function. The graphic of this heuristic is illustrated in Fig. (16) with the affected attribute sandwiched between opposing action arrows: one causal, one nullifying. The new function requires supporting attributes (N3, N4) that may be accompanied with optional objects (O3, O4).

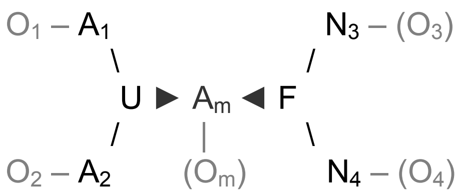


Figure 16. Schematic showing possible locations of causal attributes, A, nullifying attributes, N, and optional objects, (O), for a nullifying effect (function, F).

Two new attributes (N3, N4) can exist in any of five objects, the two or three initial objects and two optional ones (O3, O4), but not in the same object (see Ax3); "*try new, attribute pairs in different objects* (*NH*)". These conditions allow 20 configurations of the two new attributes ("*test multiple locations of nullification attributes (NH)"* heuristic). Simplification cautions to favor fewer objects.

Examples of Solution by Nullification

- **Two-object solution state**: Polymer processing leaves stretched chains resulting in polarizing films – an unwanted effect for optically isotropic products (U = to polarize = F, in Fig. 17). Nullification can be produced with distributed local changes in optical activity having opposite birefringence – a one-object concept. A proof of concept uses a distribution of small strontium carbonate crystals selected for proper birefringence – a two-object embodiment. In this

```
polymer – birefringence                    birefringence – strontium carbonate
                        \                 /
                         U → polarization ← F
                        /                 \
                location                   location
```

Figure 17. Polymer and strontium carbonate provide a two-object solution state for nullifying birefringence.

example, $A_1 = N_3$ = birefringence and $A_2 = N_4$ = locale; similar attributes that are scaled differently in their final embodiments. Note that A1 and A2 belong to the first object, the polymer, while N3 and N4 belong to the second object, distributed strontium carbonate. Reference: SCIENCE, Vol. 301, p729, 8 August 2003.

```
          belt – rate                      rate – belt
                     \                    /
             to drop → location ← to hold
                     /        |           \
swabs – orientation         swabs          location – swabs
```

Figure 18. Two-object solution state for swabs.

- **Two-object solution state**: Automated production of single-ended cotton swabs ends with hand packaging. Picking up randomly orientated swabs from a moving conveyor belt, while managing a hand full of swabs, leads to dropped swabs that can't be reused. Gradually slowing the conveyor-belt rate as hand fills with swabs eliminates dropped swabs (Fig. 18). (Ref. Design News, 08.18.03)

```
front wheel – angle                       angle – front wheel
                   \                     /
                    U → turn radius ← F
                   /         |           \
rear wheel – separation   vehicle         angle – rear wheel
```

Figure 19 Three-object solution state for turn radius.

- **Three-object solution state**: Turn radius of a vehicle is limited by the angle of a front wheel and the separation of the front and rear wheels, an unwanted limitation (U = to turn = F, in Fig. 19). Turn radius can be shortened by rotating about a point between front and rear wheels when the attribute of angle is activated in the rear wheel.

```
cell – accessibility                 accessibility – cell
                    \               /
                     U → exposure ← F
                    /       |        \
   blood - location        cell       hole –- silicon
```

Figure 20. Three-object solution state for pancreas cells.

- **Three-object solution state**: Foreign pancreas cells placed into a new host's blood system are exposed to attack by the host's immune system (U = to expose = F, in Fig. 20). However, pancreas cells secured into tiny holes in silicon cannot be reached by the immune system. Hence, the unexposed cells can produce insulin, which the blood can access. Reference: Popular Science, p86, September 2003.

Larger than three-object embodiments are obviously possible, allowed, and useful, but they are less interesting from an innovation perspective and are not illustrated here.

Solution by Elimination

Elimination of an unwanted effect suggests annihilating it: U → (   ). One or more objects can be moved to eliminate interaction of their attributes thus eliminating the effect. ("*move object to annihilate unwanted effect* (*NH*)"). "*Reshaping an object, permanently or temporarily, may uncouple a localized surface or internal attribute* (*NH*)." Relocation of an object can be temporary or permanent depending on the time character of the unwanted effect ("*temporary object relocation (NH)*", and "*object elimination*" heuristics).

```
O-A
    \
     ( _ )
    /
O-A
```

Elimination

Rearranging or modifying attributes can change attribute coupling and accomplish elimination. Rearranging suggests relative displacement or rotation. Modification can include change in intensity (high/low) or distribution of an individual attribute as summarized in Fig. (21). Modification includes temporal characteristics. In general, "*alter an attribute's intensity, location, and time, to effect elimination* (*NH*)". (See Fig. 21 in next section.)

Example of Solution by Elimination

- Car radios can be seen through the windows of locked cars producing a potential enticement to thieves (an unwanted effect). Removal of the array of tuning buttons on a car radio reveals a non-functioning radio, eliminating the enticement. The driver can hide or carry away a removable button array. This reduces perceived profit of theft, eliminating the unwanted effect.

Graphic metaphors as solution heuristics

So far, graphic heuristics have made use of alphabetic characters as metaphors for objects, attributes, and functions (O, A, and F, as seen in Fig. 1 and others). It is also common to use labeled boxes as graphic metaphors in making simple sketches during problem analysis. Another useful metaphor, one step more abstract, is to use unlabeled boxes. These can represent attributes as well as objects or functions. They are convenient to work with when thinking of as many ways as possible to arrange and modify attribute interactions. Without labels they are more ambiguous and less restrictive to intuitive negation while creating different arrangements.

Consider two attributes of contacting objects supporting an unwanted effect. Suppose we opt to use elimination to solve this problem. We will try to decouple, weaken, or modify the interaction of the two supporting attributes. And, contrarily, we will consider strengthening the coupling. This can be tested graphically, to see what ideas come to mind, by finding new representations of two squares. Some possible arrangements and modifications are illustrated in Fig. (21).

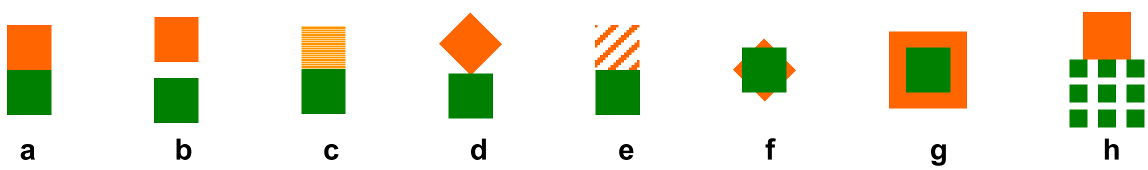


Figure 21. A small sample of some graphic ways to arrange or modify two attributes represented initially as contacting squares in (a).

The exercise illustrated in Fig. (21) began with arrangement (21a) making the obvious movement of one square with respect to the other (21b). Next, (21c) by weakening the intensity of one square the strength of its coupling was reduced. Then the interaction was weakened by minimizing area of contact (21d). In the remaining graphics (21e – 21h) a different approach was taken.

It was noted that an idea of the meaning of decoupling preceded each sketch: (21b) separate, (21c) weaken intensity, and (21d) minimize contact area. Reflecting on this process led to the idea that it was not very creative. The sketches merely served as notations of existing thoughts. Why not create the sketches randomly and see what ideas they produce? [XXI] So metaphorical pre-intent of the squares was ignored and the exercise became one of simply creating new arrangements and modifications of two squares for no reason other than difference from previous arrangements; thus, producing sketches (21e – 21h).

[XXI] This exercise led to the hierarchy of attribute characteristics shown in Fig. (8).

The exercise turned to examining the random arrangements and deducing plausible associations with attributes. Non-homogeneous weakening of an attribute came from (21e). Overlapping, or saturation, came from (21f). Engulfing, or entraining, came from (21g). And fracturing into parts came from (21h). This exercise has been performed a number of times, always producing surprising and useful results. Clearly, the possible modifications and arrangements of two squares is a larger number than shown in the sample in Fig. (21) and was discussed under characterization of attributes. The representation of attributes as squares was intended to subdue focus on shape, which is an attribute itself. *“Make arbitrary arrangements of squares to stimulate new concepts for interacting attributes (NH)”.*

Examples of attribute characteristics applied to physical-world objects. (See Fig. 8)

- Homogeneous refers to a uniformly distributed attribute such as uniform density. Inhomogeneous might be a density gradient.
- Inhomogeneous symmetrical could be a bi-symmetrical chemical concentration gradient.
- Micro-distribution that is diffuse and granular might recall a patterned impurity implanted in an annealed polycrystalline semiconductor.
- And extreme – macro-distribution – fractured – with micro-distribution – concentrated – contiguous – and ordered could recall pulverized, radioactive crystalline solids.

This is an exercise in personal recall that validates and installs these metaphors in one’s memory.

In the case of two attributes, the forgoing attribute characteristics apply to each plus contact area and overlap volume. Zero contact area (or overlap volume) implies complete separation of attributes. Contact area has several non-zero extents: a minimal point, partial area, and full overlap.

As discussed earlier, the hierarchy of attribute characteristics allows many possible strings of characteristics, over 2000 for each attribute. Each is an abstract heuristic, and each can have associated verbal and graphic metaphors.

An example of a two-attribute configuration: a “macro-bulk, micro-diffuse, granular inhomogeneous characteristic” could describe a colloid having a dispersed phase in a continuous phase.

The last sketch in Fig. (21) brings up an issue of spatial complexity. This figure has introduced two-dimensionality as a fragmented array of small squares. In the name of simplification it would be judicious to work only in one dimension and, when needed, infer higher dimensionality characteristics from one-dimensional ones.

Spatial and temporal heuristics

Functions and effects have both spatial and temporal characterizations. A simple heuristic for examining temporal characteristics is to *represent the time dependence of active attributes as "on/off" rectangles on a time plot* (*NH*). An example for two periodic functions is shown in Fig. (22).

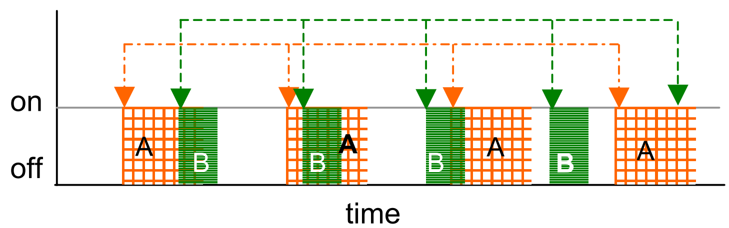


Figure 22. Two attributes having periodic on-states of two different durations are illustrated: A, shown in patterned shade, has the longer on-time; B, shown in transparent shade has the shorter on-time. Arrows indicate the start of each on-state. The amount of time for attribute interaction varies as the amount of overlap of the attributes during their on-states.

The sketch in Fig. (22) serves as a graphic metaphor from which certain kinds of information can be inferred. From the analytical perspective, we see that two attributes, having periodic but asynchronous on-states, can exist individually for a greater amount of time than they can interact. Interaction, supporting an effect, occurs only during their temporal overlap or abutment. Sometimes they neither overlap nor abut, in Fig. (22). The figure also reveals that the sequential periods of overlap have variable durations. This could be relevant in portraying a real-problem situation in which an unwanted effect has to last longer than some threshold value before becoming unwanted. It could also be fitting where the effect is only unwanted when B interacts with the leading edge of A, of the mid-section, or the trailing edge of A.

If Fig. (22) represented a real unwanted effect, we would dwell on the figure and mentally test variations of the placements of the rectangles to spark solution concepts. We would also divide the rectangles to allow sequential activity of each attribute individually in areas that would otherwise have overlapping configurations. We might change periodicity of one such that overlaps occurred only near the leading edge of the other (or mid section, or trailing edge, or never). What we are doing mentally is rearranging simple rectangles as graphic metaphors to spark ideas of other graphic metaphors.

Interestingly, this abstraction has its counter part in spatial arrangements of metaphorical rectangles. Some of these are illustrated in Fig. (21). This observation suggests *introducing further ambiguity by treating temporal and spatial displays of rectangles in analogous fashions to discover potential solution concepts in space and in time* (*NH*).

Solution by Transposition

At the abstract graphic level, space and time dependencies seem to have analogous depictions that offer heuristic value. This can be captured as a heuristic of ambiguity by, in effect, equating time and space representations of rectangles. In other words *give each graphic arrangement of attribute-rectangles both spatial and temporal interpretations* (*NH*).

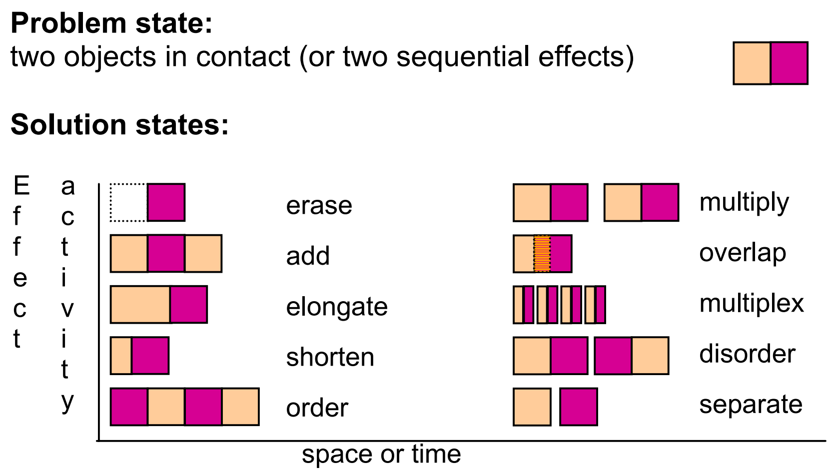


Figure 23. Activity rectangles represent where or when effects are active in space or time (on or off). Operations are labeled.

Effects have spatial and temporal character according to where or when certain attributes are active. Simple one-dimensional plots of spatial and temporal arrangements of effects shown as rectangles bring out some graphic similarities; effects show when their supporting pairs of attributes are active. These are evident when one considers how to make a transition from a problem state to a solution state in such graphs. "*Consider alternative arrangements of rectangles in space and time, representing attributes and functions that produce solution states, as being similar (NH)*." This brings out a heuristic to "*think of solution states as all possible operations on rectangles in space or time to see what ideas come to mind*" ("*space | time similarity* (*NH*)" heuristic for object | function arrangements). Some examples are shown in Fig. (23). The possible heuristics are numerous.

Generalization of this space-time transposition heuristic can "*expand space | time similarities to any pair of conjugate spatial | temporal attributes* (*NH*)". Special opportunities will be recognized in different fields. Some of many possible physical pairs are suggested in Table (3).

Table 3. Paired spatial | temporal attributes.

random	raucous	repeat period	repeat period
superposed	simultaneous	size	duration
curvature	chirp (frequency slur)	slope	rate
phase	phase	hole	lull
alternate	multiplex	order	scale (music)
sequence	sequence	color	sound

Such analogies in conjugate attributes suggest to "*transpose space/time conjugate attributes* (*NH*)". This action is, in effect, a mapping of one attribute onto another[XXII] – "*map a spatial attribute onto its temporal conjugate and vice versa (KH)"* – to see if that perspective sparks new concepts: a transposition or mapping heuristic. Useful sensibility can be maintained by working with pairs of attributes of interacting objects, rather than attributes from unrelated object pairs.

Consider other types of mapping and what ideas might follow:

- angle of a slice of cake onto sugar content of the slice of cake → different levels of sweetness in different sections of a cake (to share with a diebetic person);
- gasoline antiknock onto color of men's trousers → category coding for an automotive contest;
- fracture strength of glass and viscosity of ink in a writing pen → (?).

These three examples go from realistic, to plausible (but a bit of a stretch), to questionable. Useful sensibility can be maintained by working with pairs of attributes of interacting objects, rather than unrelated object pairs, as in the last two examples.

Some interaction-related conjugates[XXIII]:

- The slope of a road is conjugate with speed (coasting) – slope, a spatial derivative and speed, a time derivative.
- The irregularity of a solid surface produces chirp when machined in the lathe – spatial irregularity conjugate to temporal pressure waves.
- The spatial pattern of two interfering sound waves is conjugate to their temporal phase shift.
- Talking on a public telephone requires protection against the external noise (lull in time) by means of an enclosure (holes in space).

[XXII] Mapping is used here as a metaphor associating conjugate attributes. Of course this is more poetic, and hence more provocative, than rigid functional mapping of mathematics.
[XXIII] The five examples are courtesy of Juan Carlos Nishiyama and Carlos Eduardo Requena of UTN FRGP, General Pacheco, Argentina.

- A molecular example of spatial-temporal conjugate attributes is in ketone ⇄ enolic tautomerism, an equilibrium state involving two isomers. In this example, a hydrogen atom has conjugate space-time sequences of association with a carbon atom and a heteroatomic oxygen atom.

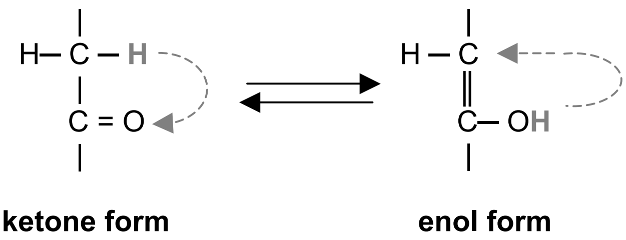


Figure 24. Tautomeric relationship of ketone and enol showing the spatial-temporal sequencing of a hydorgen atom's position.

Attribute mappings, as a heuristic, are recommended to "*first use space | time conjugate pairs and then to try pairings of other interaction-related attributes* (NH)".

While time can be treated as inviolate from field to field of application, space may take on other analogies. Time is not an attribute – it is not tied to an object – but it adds dimension to attributes through their time-dependent intensity (past > present > future), location, rate of change (speed), and derivative of rate-of-change (acceleration). Time characterizes effects ("*time-dependent attributes help to characterize effects* (*NH*)"). For example: Concurrence of length (size) of exposed rod and duration of deflection risks breaking rod (example from Definitions section, Part II).

An opportunity to apply transposition occurs in problem analysis when characterizing "synchronous" versus "asynchronous" features (quote marks emphasize both temporal and spatial connotations) of multiple effects (e.g., U and F in nullification). Time | space uniqueness of effects can be illustrated on two one-dimensional graphs of simple rectangles representing where and when different effects, U, are active (Fig. 23). These graphs make evident such space | time characteristics as order | periodicity, superposition | simultaneity, size | duration, and other attribute pairs (some are shown in Table 3). Arranging one graph above the other exhibits relative space | time graphic-characteristics. Rearranging the rectangles in either graph can create solution states. Rearrangement heuristics are the same for either graph – hence, space | time graphic similarity.

A one dimensional space- or time-plot of effects can depict a problem state and enable visualization of a solution state – yielding solutions by erasing, adding, elongating, shortening, moving, dividing, multiplying, overlapping, multiplexing, separating, ordering, disordering, and reordering rectangles (Fig. 23) – a host of heuristics (*NHs*).

Summary of Heuristics for Problem Statement, Analysis, and Solution

1. Translate heuristics using appropriate argot
2. Create an alternative perspective.
3. Analyze points of interaction of objects (Ax_1).
4. Analyze object interactions in terms of object pairs (Ax_2).
5. Identify pairs of attributes, one from each object, to support an effect (Ax_3).
6. Use no metrics for attributes (Ax_4).
7. Minimize the number of objects (Ax_5).
8. Unravel a problem statement to contain a single unwanted effect (Ax_6).
9. Use ambiguity for creative thinking (known).
10. Name objects for their generic functions (known).
11. Name an attribute for its most generic property.
12. Think contrarily (known).
13. Use known solutions as templates (USIT).
14. Analyze the underlying phenomenology of templates and improve on them (USIT).
15. Construct a well-defined problem graphic working from effect-to-attributes-to-objects.
16. When causal attributes are not found look for multiple, entwined effects (USIT).
17. The more objects used in a problem definition the more unwanted effects may be lurking in a convoluted problem statement.
18. Eliminate objects lacking involved attributes.
19. Use attributes first in resolving an unwanted effect.
20. To resolve an unwanted effect:
    a. *utilize* it as a beneficial function,
    b. *nullify* it with a countering function, or
    c. *eliminate* it by annihilation.
21. Graphic heuristic for a problem state:
22.

O-A
\\
U → A_m
/ |
O-A (O_m)

23. Graphic heuristics for solution states

O-A
\
(U → “F”) → A_m
/ |
O-A (O_m)

Utilization

O-A
\
U → A_m ← F
/ |
O-A (O_m)

Nullification

O-A
\
(_)
/
O-A

Elimination

24. Examine attributes as adjustable parameters for constructing solution concepts.
25. Intensity, location, and time are three abstract variables of attributes.
26. A hierarchy of characteristics of a single attribute: begin with intensity, location, and time. See table of Modifiable Attribute Characteristics for details.
27. Recognize attributes as being intensive or extensive.
28. Alter attributes in intensity, space, and/or time.
29. Status quo: for every change considered consider also not changing it.
30. Use an unwanted effect in a different way or for a different purpose.
31. Sketch space and time dependences of effects with a common rectangle drawn on common axes
32. Test modifications of a space/time rectangle from starting point, width, intensity, structure, and continuity.
33. Ignore an unwanted effect when solution of a larger problem mitigates it.
34. Use an unwanted effect as-is: at a different location, time, or a different purpose.
35. Scale an unwanted effect” to greater or lesser intensity (magnitude, distribution, etc.).
36. Link an unwanted effect” as a causal attribute of another function.
37. Scale to extremes (+/- infinity).
38. Form A-F-A links.
39. Attribute’s optional object. (A-F-A links offer optional objects for new attributes.)
40. Each A-F-A link allows addition of a function, an attribute, its optional object, an affected attribute, and its optional object.
41. For A-F-A linking, step from attributes to functions to attributes repetitiously until an attribute is reached that is recognized as being available.
42. For nullification, try new, attribute pairs in different objects.
43. Examine multiple locations for nullification attributes.
44. Move object to annihilate an unwanted effect.

45. Reshaping an object, permanently or temporarily, may uncouple a localized surface or internal attribute."
46. Eliminate an unwanted effect by temporary object relocation.
47. Eliminate an unwanted effect by object elimination.
48. Alter an attribute's intensity, location, and time, to eliminate an unwanted effect.
49. Represent the time dependence of active attributes as "on/off" rectangles on a time plot.
50. Give each graphic arrangement of attribute-rectangles both spatial and temporal interpretations.
51. Consider alternative arrangements of rectangles in space and time, representing functions and attributes that produce solution states, as being similar.
52. Think of solution states as all possible operations on rectangles in space or time to see what ideas come to mind.
53. Expand space | time similarities to any pair of conjugate spatial | temporal attributes.
54. Transpose attributes.
55. Map a spatial attribute onto its temporal conjugate and vice versa.
56. First use space | time conjugate pairs and then to try pairings of other interaction-related attributes.
57. Time-dependent attributes help to characterize effects.
58. *Cast heuristic phraseology in appropriate argot to make it as relevant as possible for its rapid recognition and ease of application.*
59. Interpretation of heuristics from graphic models averts the tedium of their rote learning.

Phraseology in words and graphics

Close examination will show that some of the derived heuristics are related and with only a little imagination could be combined under more generic names. On the other hand, they could just as well be expanded and divided into multiple heuristics. For example, the “*optional object*” heuristic could be worded to address each option as an individual heuristic.

The practical application of heuristics in problem solving methodologies seems to take the latter direction. There are efforts to discover, characterize, and tabulate as many empirical heuristics and examples for them, gleaned from the literature and experience, as can be found. It is also noted that a heuristic in one field may have an analog in another field, but in different wording. This points to an evident need in practice to “*cast heuristic phraseology in appropriate argot to make it as relevant as possible for its rapid recognition and ease of application* (*NH*)”.

The axiomatic models are graphic heuristic tools. They can be used as proforma structures to simplify layout of problems. Thus, they provide condensed, logical heuristics for the formation, analysis, and solution of a well-defined problem. Furthermore, “*interpreting heuristics from graphic models averts the tedium of their rote learning* (*NH*)”.

Phraseology poses a problem. Should heuristics be subdivided into multiple, slightly variable expressions with different wordings for each field of application? Or should they be generalized by eliminating small variations of expression and assembled into a minimal collection of generic expressions independent of field? If current practice prevails they will continue to multiply into variant wordings specialized for particular fields. Problem solving methodologies usually grow from this basis. However, individuals seeking simplification for the memorization and application of heuristics may prefer smaller collections composed of generic wordings and generic sketches from which specific examples can be deduced. *The highest level of generification offers the broadest base for seeding recall. (NH)*

Conclusion of Part II

For the first time a logically related collection of heuristics for solving problems has been derived from a common axiomatic basis. A self-consistent process for discovering heuristics, based on six axioms, has been demonstrated. The process is generic consisting of abstract components, axiomatic models, and logic that produced a surprisingly rich supply of heuristics. Ideas underlying the axioms came from experience in solving physical-world problems. The process and results demonstrate an abstract justification for heuristics not limited to a specific field.

The shift of focus from objects to their attributes has been discussed as a ploy to bring an unusual perspective to problem solving. Three strategies were found for resolving unwanted effects using attributes; their utilization, nullification, and elimination. Simple graphic models were developed to serve as proforma templates for applying each strategy.

It has been demonstrated that by representing attributes as undefined boxes (simple graphic metaphors for attributes), and then arranging the boxes in arbitrary ways, the new arrangements can be interpreted as heuristics for resolving unwanted effects. [XXIV] The facility of using graphic metaphors for attributes led to both spatial and temporal interpretations for the same linear arrays of graphic elements (unlabeled boxes) – space/time transposition. This led to the pairings of space/time conjugate pairs of attributes as another problem-solving tool.

Dozens of heuristics were identified and thousands implied. For theoretical study of heuristics, it will be useful to reduce these to a small number of generic models; such as, the graphic models for solution states plus rules for working with graphic metaphors exhibited here. For field-specific adaptations it is expected that heuristics will be expanded into larger numbers as specific applications call for their wordings in relevant argot.

[XXIV] If this sentence sounds a little like reading tea leaves, please reread the section titled, “Graphic metaphors as solution heuristics”.

Part III
Demonstration of Derived Heuristics

Table of Contents

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O-A
   \
    U → Am ← F
   /       |
O-A      (Om)
```

Introduction

Applications of the heuristics derived in Part II are demonstrated in this section.

Derivation of heuristics and application of heuristics in problem solving have different goals requiring different mental processes and expectations. The difference suggests left-brain and right-brain functions. In the process of deriving problem-solving heuristics our attitude is that of critical judgment of logic in the process and plausibility of the resulting heuristics. Application of heuristics, on the other hand, is a process designed to spark recall and stir creative thinking. Critical judgment and creative thinking are akin to different brain-hemisphere activities

Heuristics are effective when recall and creative thinking result. However, while logic is readily evident in the first process it sometimes is illusive in the second. That one idea sparks an apparently unrelated idea is common experience but difficult to justify logically. This may be seen in the following as I apply heuristics and discover concepts, which lead sometimes to seemingly non-related new concepts. Meanwhile, you will have thought of even different concepts during the same demonstration. I see this phenomenon as the “surprise and delight” of structured problem solving (to borrow an automotive industry design strategy).

Two types of problems may be used to demonstrate a problem-solving methodology. One is, what I call, the “fix-it” type. In this situation, an incremental solution may suffice. The second is a problem situation in need of an invention.

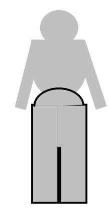
I have selected a problem of the invention-type for a demonstration of using the newly derived heuristics in solving a real-world problem. Although this is not the usual type of problem most engineers and scientists deal with on a daily basis, it is usually the type of general interest in the classroom. By far the more common problems to be solved are not of the inventive type but of the type requiring only incremental change in design or of the type, “it’s broken, fix it!” Most of the example problems I have published are of the fix-it type. On the other hand, innovative ideas for solution concepts are always welcome and expected when solving problems of either type.

As we go through this demonstration bare in mind that an engineered product is not our goal. Rather, we desire to discover concepts that can be engineered – a pre-engineering goal.

Inventing a belt – a problem to be solved

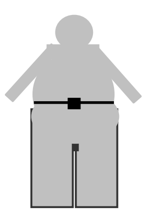
Suppose we are consulting for a manufacturer of men's clothing and are asked to invent a new type of belt for men's trousers. (XXV) We first define the problem and then turn to the heuristic methodology and use heuristics derived earlier to develop solution concepts. In order to define the problem, let us begin by understanding the intended functions of a belt for trousers.

Deduction of problem definition information

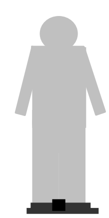


Trousers are usually designed with waist circumferences smaller than hip circumferences so that they do not fall off when buttoned or zipped. Properly sized trousers for appropriately shaped torsos do not fall off. Hence, in these cases, belts may be more functional as information creators than as trouser supporters. The information they create is an expression of style. Since we are being consulted as technologists and not as stylists, this function will be ignored.

This strikes me as a questionable decision; i.e., to ignore styling problems. And it is. However, I have more experience in analyzing and solving technical problems than styling problems. And I suspect the readership of this discourse also is somewhat shy of such experience. Nonetheless, there appears to be no a priori reason not to attack styling problems using the same derived heuristics. Here the decision is a judicious choice of the more promising benefit to this readership.



Torsos having larger (or equal) waist circumference than hip circumference offer no natural support for trousers. Belts provide one type of solution to this problem. Suspenders provide another. Belts snugged to the body produce an indentation in the body contour that serves to "lock" in place the otherwise insecure trousers. This concept relies on the elasticity of the torso. If neither shape nor elasticity is available, such as in a shapeless manikin, a belt may need to be cinched tightly to create a large area of friction for opposing the force of gravity on the trousers.



Cinching a belt sufficiently tight to indent one's torso requires working against the elastic response of the torso. Thus, a belt is put into a state of internal stress, which it must maintain during the period required to keep trousers suspended. Maintenance of

XXV A belt for men's trousers is so ordinary an object as to seem past its prime for new invention. Why pick this problem? The reason is to simulate a problem-solving situation where brainstorming has waned of ideas. This may demonstrate better claims made for USIT.

the state of stress in a belt is accomplished by securing it with a buckle. It also requires insignificant creep of the belt material; i.e., no relaxation.

Belts for men's trousers are known in at least three forms: cords threaded through belt loops and their ends tied in knots (one-object solution – cord), flat belts threaded through belt loops and connected at their ends with various types of buckles (two-object solution – belt and buckle), and elastic bands sewn into trousers plus hooks to create a buckle also sewn into the trousers (three-object solution – band, hook, and trousers).

[B0] An idea comes to mind of a belt having no buckle. This could be an elastic band to be expanded enough to be slipped into place and then relaxed to a less expanded state where it provides sufficient force to indent the torso. (In case you wonder about belt loops, that's another problem that can be addressed separately.) (XXVI)

An obvious function of a belt is implied in its name, "belt". That is, to be able to be wrapped around and to be conformable to the shape of something.

An unwanted effect as a strategy for invention

The problem of invention can be treated in a manner similar to fix-it problems by identifying an unwanted effect to focus on. In the case at hand, that means to examine the needed functions of a belt, select one, and convert it into an unwanted effect. This strategy enables application of the same USIT methods as used in other problems.

We've found five functions for a belt: to be wrapped, to be conformable, to be cinched tightly, to be locked in place (sustaining the cinched state of elastic energy) and to create information. Is there an opportunity for invention here?

One aspect of invention is being unconventional. Being able to be wrapped and being conformable are conventional traits of many kinds of ribbons, bands, cords, strings, etc. Sustaining a cinched state for a stretched band is a matter of having sufficient yield strength and low enough creep rate. These are simple specifications of two engineering-type attributes.

The conventional solution of a belt being locked in place is a locking device, a buckle, which introduces another object. Perhaps belts without buckles could be invented. This presents the situation of being able to draw tight a belt, hand-held at both ends, but then being unable to release the ends and retain the desired stressed state since no

[XXVI] Belt solution concepts are numbered in the form, [Bxx].

buckle is available for this purpose. Obviously, a solution concept is to incorporate the function of a buckle into a belt – a buckle-less belt.

If we choose to invent a "buckle-less belt" what are the interacting objects? Having no buckle, there remains only the belt and trousers. Actually this situation can be analyzed at least at three points of contact between object pairs: belt-to-buckle, belt-end-to-belt-end, and belt-to-trousers. The first retains the buckle and the belt as interacting objects. The second treats the two ends of the belt as different objects, since they are placed in contact and together modify or sustain an attribute of belt (internal stress of belt and belt-end are the same). I'll elect the first in order to force myself to discover the desirable functions of a buckle and a belt before trying to eliminate the buckle.

An unwanted effect could be stated in various ways as. Here's a first draft:

Belts without buckles do not retain cinched-state of stress.

Graphic problem statement

The generic graphic of a problem is shown in Fig. (1).

O_1 - A_1
\
$U \rightarrow A_m$ – (O_m)
/
O_2 - A_2

Figure (1). Two objects in contact, O_1 and O_2, have two interacting attributes, A_1 and A_2, which are causal of an unwanted effect, U, that acts on an attribute, A_m, of an object, (O_m).

This graphic is a model for formulating the unwanted effect to be analyzed and solved. The two objects are belt and buckle. The unwanted effect is tendency to loose a cinched state, which affects the attribute internal stress in belt.

belt – A_1
\
tendency to lose cinched state → internal stress – belt
/
buckle – A_2

Figure (2). Graphic model of the belt problem without identified causal attributes. Objects are grayed and attributes bolded to show their relative importance in applying derived heuristics.

A plausible root causes diagram helps to identify causal attributes. This is illustrated in Fig. (3). The unwanted effect is tendency to loose a cinched state.

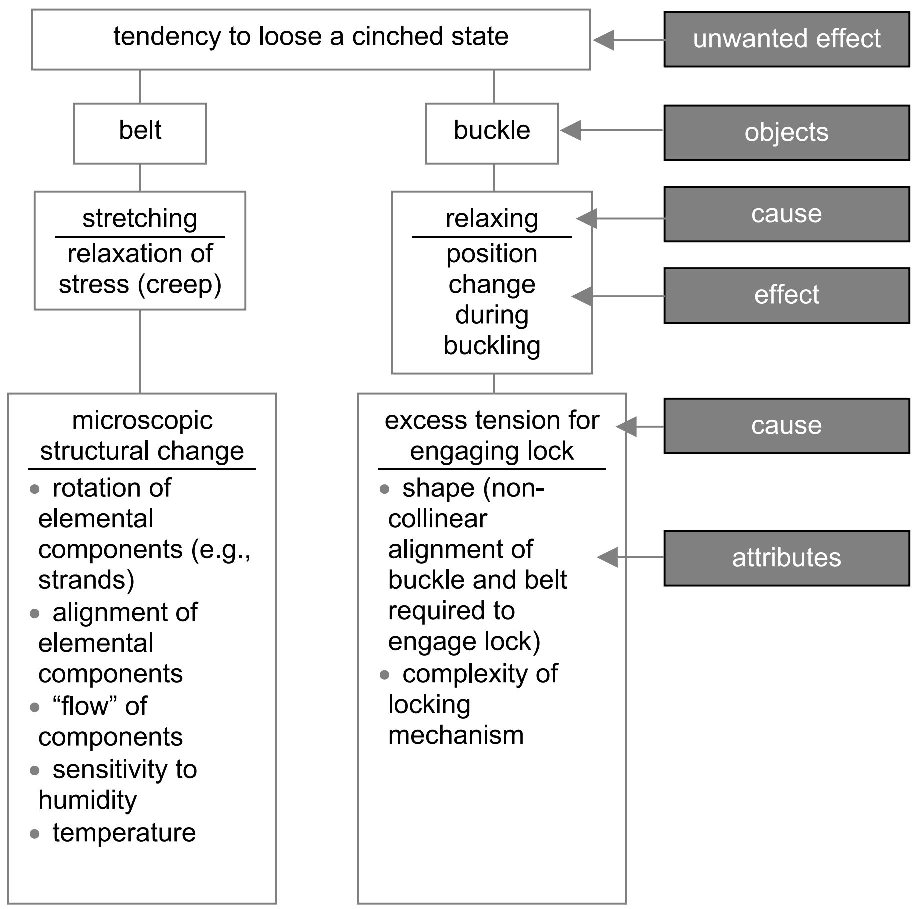


Fig. (3). Plausible root causes diagram for a belt and buckle having a tendency to loose a cinched state of elastic energy.

Stretching of belt, after cinching and releasing, can be the cause for a tendency to loose its cinched state – a time-dependent phenomenon. The effect of stretching can be caused by relaxation of internal structure of belt material – known as creep. Attributes of belt materials that may lead to creep through structural rearrangement are those related to size changes, such as, sensitivity to stress, to humidity (sorbing and desorbing of moisture), and to temperature. Stress sensitive attributes include phenomena such as rotation of elemental components (e.g., molecules, cross-linked groups, and nano-strands), alignment, and "flow" of these components, and others.

Relaxation after locking and releasing a buckle can be the cause for a tendency to loose a cinched state. Such relaxation could occur through out-of-alignment positioning, of buckle relative to belt, required to engage the locking mechanism. This may due to a shape attribute involving complexity of the locking mechanism. Positioning and engaging a buckle may necessitate an initial excess of stress in the belt. The excess stress would relax when the buckle is locked and the belt released.

Solution by utilization

In solution by utilization, both the unwanted effect and causal attributes remain the same (see graphic model in Fig. (4)). However, scaling of attributes is permitted to produce solution concepts.

belt

A_1 Causal attributes

- rotation of elemental components (e.g., strands)
- alignment of elemental components
- motion of components
- sensitivity to humidity
- sensitivity to temperature

\\
tendency to loose post-cinched state → **cinched state** – belt
/

buckle

A_2 Causal attributes

- shape (non-collinear alignment of buckle and belt required to engage lock)
- complexity of locking mechanism (including shape and multiplicity of parts)

Fig. (4). Graphic model of the belt problem with the unwanted effect and its causal attributes is shown explicitly. Attributes are to be selected in pairs; one from each box.

Spatial and temporal plots of function activity help to characterize the activity of causal attributes. These are illustrated in Fig. (5).

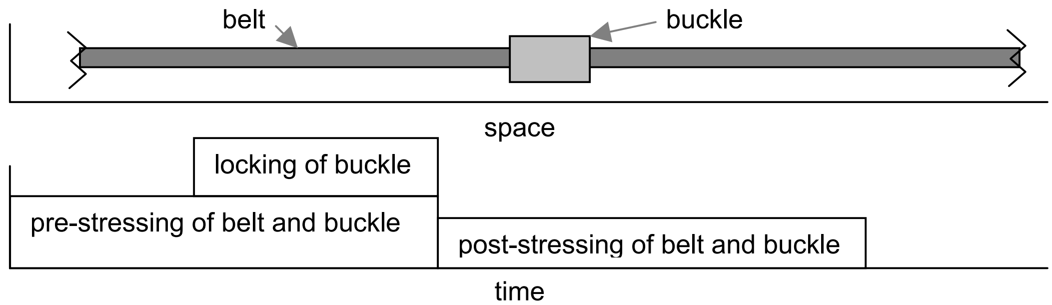


Fig. (5). Spatial and temporal plots of belt buckling process. The unwanted effect occurs during the post-stressing of belt and buckle. Height differences between pre-stressing function and post-stressing function are intended to indicate a decrease in excess stress after locking of buckle.

The purpose of the above analyses is to create a definitive, phenomenological view of the problem. This view is then approached with the derived heuristics to inspire creative ideas for a belt design having no buckle while utilizing the unwanted effect of the tendency to loose cinched state of the belt. Obviously, this entails incorporating the functions of a buckle into a belt. Thus, two functions must be accomplished: locking the ends of a belt together and managing the amount of post-stress elastic energy that might be lost during the period of a belt's application. Ideas for these two independent functions may be found separately and later combined to produce a belt having no buckle.

Solution by utilization suggests heuristics such as: alter attributes in intensity, space, and time; don't alter anything (contrarian view); and use an unwanted effect for a different purpose.

[B1] A simple engineering solution to a tendency to loose cinched state is to scale the intensities of the time-dependent attributes so that the amount of loss of stress during the period of belt application is acceptable.

[B2] Locking can be accomplished with a Velcro®-like interface in a region of overlap of the belt ends.

[B3] This brings to mind to slice one belt end laterally, but not quite edge-to-edge, to form a slot into which the other end (cut to be narrower) can be inserted for locking.

[B4] The inserted end could be serrated for engaging matching notches inside the slot.

A gradually changing cinched state might be used for …

[B5] information creation in the sense of a novelty of style, or

[B6] as an indication of the current state of stress. These could be constructed in the form of a stress-induced color change in the coating on a belt, or

[B7], a stress-induced change in polarization of reflected light.

[B8] This brings to mind a money belt with a built-in alarm. When the stress is suddenly relaxed the released energy could be used to trigger an alarm. This is also an example of linking an effect to a new function.

Ignoring the unwanted effect and taking advantage of it suggests

[B9] a belt for a clown's trousers having a calibrated creep rate to allow the pants to fall from the torso at a predictable instant.

Solution by utilization using A-F-A linking

The strategy of A-F-A linking is to connect effects through attributes that enable conversion of an unwanted effect into a useful one, a function.

The graphic model for A-F-A linking is shown in Fig. (6).

A_1 N_3 N_3

\ \ \

$U \rightarrow A_m \rightarrow F \rightarrow A_{m'} \ldots$ $\ldots$ $F \rightarrow A_{m'} \ldots$

/

A_2

Fig. (6). Graphic model of A-F-A linking to connect an effect beneficially to a new function supported by the final attribute in the link. Objects have been omitted.

This model can be applied to the case of the new belt design as illustrated in Fig. (7). In the figure the unwanted effect has been abbreviated to "relaxation" and the affected attribute to "stress state". The attribute, stress state in a physical object, can be expressed as internal stress, strain, or strain energy (the integral of stress-strain).

stress
\
relaxation → **stress state** → F → $A_{m'}$ …
/
creep

Fig. (7). Graphic model of A-F-A linking applied to the belt design problem. Stress and creep are represented as causal attributes.

[B10] Internal stress can be coupled to a proportionate electromotive force (e.m.f.) through the phenomenon of piezoelectricity. The associated e.m.f. created by piezo-electrification could be coupled to a threshold voltage of an alarm system, as shown in Fig. (8). This leads to ideas for an electronic belt. Various novelty products may unfold from this electronic-based technology.

stress / strain / impedance
\ / \ / \
relaxation → **stress state** → piezo-electrification → **e.m.f.** → alarm → threshold voltage
/
creep

Fig. (8). Graphic model of A-F-A linking applied to the belt design problem. Stress state is mapped on to threshold voltage through A-F-A links.

A-F-A linkage of internal stress energy to an e.m.f. opens the way for electronic-based technology. There other internal stress-energy linkages become possible. An obvious one is elasticity, the coupling of stress and strain. For example, stress can be coupled to strain in a diffraction grating that shifts the peak order in the diffracted beams. A variety of stress-induced effects can be found in the technical literature including stress-induced polarization, temperature change, resistivity change (e.g., strain gauges), voiding (in Al and Al-alloy films), phase change, and many more. Identification and characterization of stress-induced phenomena is an active area of materials science.

A-F-A links used as a problem-solving tool work to advantage when they cause one to recall a variety of phenomena. One can easily filter chains of links for fear of undue engineering complexity. However, this defeats the purpose of cued recall. If, for example, stress-induced polarization, although potentially useful for novelty products, should be filtered for complexity the value of linking cues is lost. Once the idea of stress-induced polarization is discovered, its adaptation in a product might not involve stress or polarization, but lead instead to incorporation of decorative or functional optical components in a specialty belt, for example.

Solution by nullification

Nullification suggests countering an unwanted effect using another effect, a function. The graphic of this heuristic is illustrated in Fig. (9) without objects. The new function requires supporting attributes (N3, N4) that may be accompanied with optional objects.

A_1 N_3
\ /
U → A_m ← F
/ \
A_2 N_4

Figure (9). Schematic showing causal attributes, A_1 and A_2, and nullifying attributes, N_3 and N_4, for a nullifying effect (function, F).

Nullification allows support of a new function using new attributes. Their sources can be decided after nullifying functions and their attributes have been identified. In this case, state of stress can be nullified by a reacting stress, as shown in Fig. (10).

causal attributes N_3
\ /
U → state of stress ← reacting stress
/ \
causal attributes N_4

Figure (10). Schematic showing a reacting stress as a function used to nullify a state-of-stress attribute.

Reacting stress brought to mind an over-riding stress, one that is stronger than that of the belt. This could eliminate creep.

[B11] Introduce a spring having greater strength (N3) and lower creep rate (N4) than the belt.

[B12] This brought to mind a buckle designed to produce and maintain stress with only in-plane action. The buckle could be a flat reel and ratchet that winds and locks a cord or thin ribbon attached to the loose end of the belt. The excess stress needed to lock a conventional belt buckle would be eliminated. (No, this is not a “buckle-less belt” concept.)

The expression, “reacting stress”, suggests the dynamics of the state of stress. State of stress should change with different activities of the person wearing a belt. We’ve seen above that A-F-A linking brought up the idea of added electronics.

[B13] Thus, a "smart belt" could be designed with electronics to monitor the state of stress and a feed-controlled reel used to adjust reacting stress as needed. This could make trousers more comfortable after eating a large meal.

Solution by elimination

Elimination of an unwanted effect suggests annihilating it: U → ( ). Elimination of causal attribute interaction is a recommended procedure. Figure (4) is repeated below (as Fig. 11) to recall the causal-attribute resources for this strategy.

belt

A_1 Causal attributes

- rotation of elemental components (e.g., strands)
- alignment of elemental components
- motion of components
- sensitivity to humidity
- sensitivity to temperature

\

tendency to loose post-cinched state → **cinched state** – belt

/

buckle

A_2 Causal attributes

- shape (non-collinear alignment of buckle and belt required to engage lock)
- complexity of locking mechanism (including shape and multiplicity of parts)

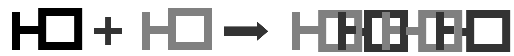
Fig. (11). Graphic model of the belt problem with the unwanted effect and its causal attributes shown explicitly.

Eliminating or rearranging attributes can eliminate attribute interaction. This may entail reshaping or moving objects.

In our case, having two ends of the same belt being treated as individual objects, the elimination of one seems to lead to a continuous belt loop, such as the elastic band of concept [B0]. What if both ends are eliminated? (Contrary thinking.)

Elimination of both ends seems to imply elimination of belt leaving only buckle. But we're trying to eliminate buckle by placing its function into belt. Now contrary thinking brings to mind to eliminate belt and place its function into buckle. Basic differences between buckle and belt come to mind as rigidity of the former and flexibility of the latter. Of course, flexibility of rigid objects can be designed from small linked or hinged components. These can be multiplied to a useful number.

Elimination of creep of belt material can be accomplished with linked “buckle” segments.

[B14] Construct belt of interlinked rigid segments. 

[B15] Separation of internal stress and creep suggests a layered structure. An internal layer can be designed to have miniscule creep under expected loads while in other layers creep is of no consequence. A flat “I”-beam cross section comes to mind, having a thin central member of non-creeping metal covered by decorative inner and outer layers.

Conclusion of Part III

The problem-solving heuristics derived in Part II have been demonstrated for application in invention. It is shown that invention can be couched in terms of an unwanted effect. Consequently the problem definition and analysis heuristics of USIT are applicable without modification.

The three major strategies for problem solving used in Part II, utilization, nullification, and elimination, constitute a thorough approach to problem solving. Each strategy contains other heuristics; such as, A-F-A links used in utilization.

It is expected that individual problem solvers applying these three major strategies will bring into the process his or her favorite heuristics as sub sets of the three. The three strategies provide a simple and convenient overview of the problem-solving phase**.**

In the process of solving the belt problem, without allowing filtering, some seemingly (at first sight) illogical results came to mind. This reflects the power of the metaphor of generic names – ambiguity.

Acknowledgements

The author is indebted to Dr. Craig Stephan, Senior Technical Specialist of the Physical and Environmental Sciences Department, Research Laboratory, Ford Motor Company for years of joint teaching structured problem solving in Ford, for in-depth discussions, critical comments, and creative suggestions regarding ideas presented here and for his critical review of the manuscript.

Gratitude is also expressed to Juan Carlos Nishiyama, Consultant in Organization and industrial engineering in the Centro Tecnológico UTN FRGP, and Carlos Eduardo Requena, Professor in General and Applied Chemistry in UTN FRGP, General Pacheco, Argentina. Together, these colleagues translated the manuscript draft into Spanish, found errors, tested ideas, and made recommendations which, they then translated into English for my benefit.

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O-A
    \
  ( _ )
    /
O-A
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Glossary

attribute: An attribute characterizes an object distinguishing it from an otherwise similar object. Attributes are characteristics such as weight, size, shape, color, conductivity, etc. (from SIT and ASIT).

active …: An active attribute is an attribute that supports an active function (or effect) or is acted upon by a function.

removal of (deactivation, annihilation) …:
In USIT an active attribute is rendered inactive (removed, deactivated, or annihilated) when its use is discontinued in a problem situation.

algorithm: An algorithm is a series of steps, a set of rules, or a recipe for systematically producing a solution for a well-defined problem. (See problem-solving methodology.)

argot: The special vocabulary and idioms of a particular profession or social group.

axiom: An axiom is a self-evident truth requiring no proof.

brainstorming: Brainstorming is used here as an intuitive, instantaneous process of recall in producing solution concepts.

cognition: Cognition is the act or process of knowing.

concept, solution concept:
Solution concepts are the first, somewhat nebulous ideas that come to mind as potential solutions to problems. A concept requires engineering scaling for verification as a viable solution.

creativity: Creativity (innovation and invention) is a subjective term left undefined for personal adaptation of the reader.

effect: Effect, like a function, maintains or modifies an attribute.

function: A function modifies or maintains an attribute of an acted-upon object. Functions are desirable effects.

distribution of …: Distribution of functions is a USIT solution technique in which functions are moved to other objects in the problem set to see if solution concepts occur.

generification: Generification of an object's name replaces its commercial name with a function-type name determined by its specific use in a problem situation.

heuristic: Heuristics, as used here, are the non-algorithmic tools, techniques, and tricks that are used in problem solving.

innovation: Innovation (invention and creativity) is a subjective term left undefined for personal adaptation of the reader.

intuition: Intuition is the use of heuristics so practiced and ingrained in one's subconscious that they come into action instantaneously without any need of conscious seeding.

object: A physical-world object, as used in USIT, occupies space, exists of itself, and can interact with another object through its attributes (from ASIT, and USIT). An object is defined by its active attributes – without active attributes it has no function and therefore doesn't exist. This condition allows its removal for new insights.

division of …:
Division of an object is a solution technique wherein physical-world objects are divided and their parts used differently.

multiplication of …:
Multiplication of an object is a solution technique wherein physical-world objects are multiplied and the copies used differently.

problem: A convenient definition of a problem is any unanswered question.

well-defined …:
A well-defined problem is defined to be a problem constructed appropriately for the methodology to be used to solve it.

problem-solving methodology:
A problem-solving methodology is a guide to solving problems made up of heuristics for defining, analyzing, and searching

solution concepts. It is less systematic than an algorithm. (See algorithm.)

qualitative change: A qualitative change refers to the graphic representation of a problem characteristic in which the slope of the characteristic is reduced to zero (from SIT and ASIT).

root cause: Root causes are defined as causal attributes that can be tied directly to an effect.

scaling, scale-up, engineering scale-up:
Scaling includes the clarification, modification, modeling, algorithmic analysis, and testing needed to validate an otherwise tentative solution concept.

state: A state comprises an arrangement of objects in space interacting in time to support an effect – utilizing three compositional concepts: space, time, and effect.

transduction: Transduction is a USIT problem-solving technique in which attribute-function-attribute elements are inserted in a graphic representation of a problem so see what solution concepts come to mind.

Bibliography

1 http://www.arbelos.org/ProblemSolving.html, and
"Mathematics and Plausible Reasoning", G. Polya, Vol. 1 and 2, Princeton University Press, 1954.

2 "Discussion of the Method – Conducting the Engineer's Approach to Problem Solving", Billy Vaughn Koen, Oxford University Press, New York, 2003. (This work would include algorithms as heuristics.)

3 This is close to, but not quite what Osborne had in mind as brainstorming: "Applied Imagination", A. Osborne, Charles Schribner's Sons, New York, 1953.

4 "Unified Structured Inventive Thinking – How to Invent", Ed Sickafus, Ntelleck, LLC, Grosse Ile, MI, USA, 1997.

5 "Unified Structured Inventive Thinking – an Overview", Ed Sickafus, Ntelleck, LLC, Grosse Ile, MI, USA, 2003 (free ebook available at www.u-sit.net).

6 www.start2think.com

7 "Creativity As An Exact Science – the Theory of the Solution of Inventive Problems", Studies in Cybernetics Series, Genrich Altshuller (translated by Anthony Williams) Gordon and Breach, New York, 1988.

8 "Breakthrough Thinking – a Linear Sequencing of TRIZ Tools", Larry Ball, 2002 (available at www.triz-journal.com).

9 "Creative Cognition – Theory, Research, and Applications", Ronald A. Finke, Thomas B. Ward, and Steven M. Smith, The MIT Press, Cambridge Massachusetts, 1996.

10 "The Lens as Aquatic Gymnast", Ian Austen, The New York Times, E7, Circuits section, Thursday, March 18, 2004; also
Appl. Phys. Lett. **85**, 1128 (2004).

11 "Creative Cognition – Theory, Research, and Applications", Ronald A. Finke, Thomas B. Ward, and Steven M. Smith, The MIT Press, Cambridge Massachusetts, 1996.

About the Author

Ed. Sickafus is an inventor, industrial scientist, teacher, author and a puzzle enthusiast.

Academic background: His academic experience ranges from graduation with a Ph.D. in physics from the University of Virginia, Visiting Lecturer in Physics, Sweet Briar College, Associate Professor of Physics at the University of Denver, to instructor in sign language at Madonna University. He studied transmission electron microscopy at the Cavendish Laboratory of Cambridge University, Cambridge England. He also aided development of surface science research, and gave seminars at universities in Spain and Brazil.

Industrial background: Ed's industrial background ranges from assembly line manufacturing experience as an automotive welder, an ordnance inspector, and an aircraft riveter, to laboratory studies of air bearings and molecular pumps, and to design and modeling of miniature sensors and actuators.

Industrial positions: His industrial positions include senior staff scientist, manager, corporate technical specialist, and president of Ntelleck, LLC. He served on the Industrial Board of the Sensors and Actuators Center of the University of California – Berkeley.

Basic research: His basic research studies include internal friction of metals, growth morphologies of layered structure crystals, microcalorimetry, mechanical and electron scattering from surfaces of atomically clean metals, and secondary-electron spectroscopies.

Publications: Ed has published over 70 scientific papers and articles on a wide range of topics, three books on USIT, and maintains a website (www.u-sit.net) where he publishes free lectures on USIT. He has lectured in Spain, Brazil, China and South Korea. He holds twelve patents.

Management: His management experience includes Acting Head of the Physics Division of the Denver Research Institute, Manager of the Miniature Sensors and Actuators Department and the Physics Department of the Ford Motor Company Research Laboratory.

Professional Societies: Ed was former President of the American Vacuum Society, member of the Governing Board of the American Institute of Physics, and served on various society committees.

Civic service: He was an interpreter for the deaf while living in Denver.

Hobbies: Ed spends spare time traveling around the world photographing anything of interest. He prints and sells his photographs locally. He enjoys cycling and hiking.

USIT: He introduced SIT into the Ford Motor Company through monthly, three-day courses and weekly user-group meetings. This led to his development of USIT, which he now teaches in on-site classes for industrial corporations. Classes in USIT have been given in North America, Europe, South Korea, and Australia.

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