Heuristic Innovation

Engaging both brain hemispheres in rapidly solving technical problems for multiple solution concepts

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by

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Dedication

To ...

problem solvers
quizzing,

ponderers
thinking,

wonderers
puzzling,

former students
asking,

questioners
doubting,

puzzlers
riddling,

posers
baffling,

cogitators
awing,

teachers
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Contents

E x a m p l e s – Ideas, partial demonstrations, completed exercises, etc.

(More examples are found in Ref. 1)

To All Problem Solvers

Welcome to all manner of problem solvers, especially to professional problem solvers, inventors, puzzlers, and those who are intellectually titillated by confounding problems. Heuristic innovation is a new methodology for solving problems requiring fresh insights, inspiration, and clever concepts.

Direction

There are two kinds of problem solving that we engage in. One is algorithm-type and the other is design-type problem solving. Algorithmic driven problem solving is a “crank turning” exercise that is tedious for humans but ideal for computers. It is not creative. Design-type problem solving is very creative. This applies to engineering design, art, poetry, and mathematics, among many other fields.

Mathematics, for example, requires creative insight when generating new algorithms, when reducing a problem to a mathematical formulation (for solution by crank turning), when cracking a problem with a clever approximation, when testing function behavior, when proving theorems, and in many other ways. Engineering design is a creative process requiring unusual insights to resolve an unwanted effect with an inventive concept. Engineering of a design, on the other hand, is not creative; it is a crank turning process of concept scale-up to a specific application. Engineering scale-up of a concept uses handbook procedures of accepted practice.

The above bit of hyperbole should get every reader’s attention. I use it to make the point that there is something fundamentally different between following the dictates of an algorithm or a recipe in problem solving and in creating a new concept. The former has documented precedence; the latter has no precedence for guidance. Creation of a new concept, invention, or innovation is the greatest intellectual challenge of problem solving.

Our two hemispheres of cognition have their own dominant specialties they bring to problem solving. In algorithmic-type problem solving …

we use words to describe and define,
we figure out things step by step,
we condense information into symbols,
we let a small bit of information represent a whole thing,
we keep track of time, sequencing one thing after another,
we draw conclusions based on reason and facts,
we use numbers as in counting,
we draw conclusions based on sequences of logical steps or conclusions, and
we think in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion

– all are thinking traits of the language-oriented hemisphere.

In design-type problem solving, as exercised by an artist for example,
we use nonverbal cognition to process perceptions,

- we put things together to form wholes,
- we relate things as they are, at the present moment,
- we see likenesses among things; understanding metaphoric relationships,
- we have no sense of time,
- we do not require a basis of reason or facts,
- we have a willingness to suspend judgment,
- we see where things are in relation to other things and how parts go together to form a whole,
- we make leaps of insight, often based on incomplete patterns, hunches, feelings, or visual images,
- we see whole things all at once; perceiving the overall patterns and structures, often leading to divergent conclusions

– all are thinking traits of the image-oriented hemisphere.

These two paragraphs are also exaggeration but perhaps in a little more subtle way. Your cognitive hemispheres probably chafed a bit as you saw the two lists of thinking traits assigned to two different fields while recognizing some of both in your own thinking habits. Nonetheless, I suspect that technologists reading these two lists will identify more with the language-oriented hemisphere list than with the non-linguistic hemisphere list. A tendency of technical-problem solvers and many others to prefer logic is my first premise in support of heuristic innovation. They are, after all, highly trained, practiced, proficient, rational, problem solvers.

Not all aspects of problem solving succumb to logic – it has its limitations. For example, brainstorming a problem in a group of technologists (think of technical logicians), a common industrial ploy, is a highly logical process. The reason is that every idea proposed is immediately attacked with a logical argument. This is a logically self-regulating system. It's a well proven method for quickly gathering low-hanging fruit, but it always sputters and prematurely runs out of momentum. Unfortunately, when the flow of ideas ebbs brainstorming has reached the limits of its usefulness and the problem team could well be disbanded. Lacking in this ploy is a technique for discovering the buds not yet recognizable as "low-hanging fruit". These concepts need culturing to see what fruit is produced, not pruning for lack of logical maturity.

My second premise in support of heuristic innovation is that we could be much more creative and inventive in solving design-type problems. We could be if we could easily activate our non-linguistic, image-oriented thinking traits. Unfortunately thinking traits are not tractable. We cannot control them. Thinking involves conscious planning, organizing, and structuring. Simultaneously, the two cognitive hemispheres subconsciously exercise their thinking traits according to their preferences. The final results can be marvels of human imagination. Yet the process remains unknown.

Given this introduction it should be evident that to explain, understand, and test heuristic innovation, as a creative problem solving methodology, will require some introspection.

We will be treading a path between the knowable and the unknowable. We will be looking for plausible cause-and-effect associations with known thinking traits – an uncertain process. To complicate matters further, you and I have two different brains with different interests, practices, preferences, procedures, and cognitive-hemisphere influences. Communication will be a challenge.

To address the complexity of introspection required to understand the methodology, I feel obligated to expose my own introspection (as best I can recall it) in demonstrating heuristic concepts. You will recognize these efforts as first person dialog appearing in the text. You should challenge for credibility each assertion they make or imply. Then you should put yourself in the situation being described and see what your own thinking would produce. Of course, I hope we come out on the same track in the end.

Design Problems

Heuristic innovation is presented as a generic problem-solving technique but is demonstrated using specific engineering design-type problems. What are design-type problems? All artifacts, man-made things, had a design rational justifying their existence. If something goes awry in the performance of a device someone is called upon to produce a design modification. If a new device is proposed, someone must design it. These are design problems.

Your boss calls you in and explains that the new toaster, just out on the market, has had several returns with complaints that the crumb-tray jams on removal or insertion – "Fix it! And when that is done begin design of a new toaster; we've been notified that our current design may have infringed a competitor's patent." These are engineering-design problems.

Engineering-design problems can be examined generically and reduced to interacting objects, effects, and causal attributes of the objects. Objects, their attributes, and the functions they support constitute a design. When a function fails it becomes an unwanted effect. This generalization renders problems in many fields accessible to the tools of heuristic innovation when they are analyzed in terms of objects, attributes, and unwanted effects.

Targeted Audience

All technical problem solvers, engineers, scientists, technicians, managers, and others involved with technical problems can utilize heuristic innovation for speed and efficiency in creating multiple solution concepts. Non-technically trained fanciers of problem solving will find the techniques of heuristic innovation intellectually rewarding.

If you enjoy solving problems, try heuristic innovation. It will simplify your view of all problems while expanding your understanding and use of heuristics. For example, the key heuristic of the methodology is complete focus on the most difficult part of problem solving, namely problem definition. It shows how to greatly simplify problem definition. It then continuously examines, modifies, tests, elaborates, abstracts, and simplifies the definition iteratively without ever leaving this step. There is no other structure to the method. In this process it uses heuristics to enable you the problem solver to engage both of your hemispheres of cognition for optimum creativity.

P R E F A C E

Why is *problem solving* so profoundly gratifying?*
Problem solving is a pleasure. Well, it is for some people but not everyone. Those who enjoy problem solving may do it as an avocation or as a profession. Creative problem solving, as in invention, carries a badge of recognition called a patent. With or without recognition problem solving entails intellectual challenges that bring personal satisfaction – mental stimuli that bring us back for more.

This book teaches how to think and discover insights while solving a problem. It takes a counterintuitive approach to innovative thinking as compared with that of more conventional, structured, problem-solving methodologies. Structure is de-emphasized. Intuitive insight is emphasized.

Logic and creative thinking
Problem solving methodologies designed to foster creative thinking have long emphasized prohibiting criticism as ideas arise. Such criticism is known as filtering, judgment, and other terms. Having thusly dealt with criticism, by disallowing it, they proceed to teach logical methods of analysis and solution to find creative ideas. Criticism is a hindrance to creative problem solving and should be treated properly. However, squelching filters and postponing judgment are only passive approaches to the negative influence of criticism. The root cause of criticism hindering creative thinking is the continual struggle of intuition and logic. By understanding this struggle active methods can be developed and applied to spark creative thinking accompanied by filtering. Such methods are presented in this book.

Problem solving is usually separated into three parts: definition, analysis, and solution. Each of these parts consists of problems. Professional problem solvers spend much of their academic years and a part of later years in learning and practicing rote techniques for problem solving. Rote training and practice is an accepted and well-developed part of technical learning.

Rote is a bit too pejorative for describing the mathematics we have learned to love. Mathematical methods have their mechanical parts that we refer to as “turning the crank”, which, indeed, churn out desired results. And our ability to use the parts successfully gives us pride. On the other hand, these methods require up front innovative thinking in order to prepare and organize problem information in a well-defined format for each method to be applied. This preparation is less rote. It is confronted as a “word” problem. Learning to unscramble a word problem and reduce its information to a well-defined, tractable problem is, for some young students, an insurmountable problem. Innovative thinking in formulation of word-problem information into a well-defined problem distinguishes creative mathematics from rote arithmetic.

Rote is not too pejorative in reference to industrial training in how to invent. Various structured problem-solving methodologies are used to teach how to invent. They all have a rote composition built around their underlying “structure”. Such structure is usually captured in a flow chart. Tools for executing the sequential steps of the flow chart make up most of the methodology. Given our years of academic training and experience in application of mathematics, with its underlying arithmetic rote (by now resting unawares in our subconscious), we are susceptible to erroneous expectations. It is natural for terminology such as “how to invent”, “flow chart”, “sequential steps”, “structure”, “tools”, “methodology, and others – typical crank-turning terminology of structured problem-solving methodologies – to instill our subconscious of rote practice and results. Such unawareness can hinder learning and practicing of innovative problem solving. It is one of the motivations for searching ways of bypassing as much structure as possible and dispelling subconscious “turn the crank” expectations.

Considerable investments are made in industry to give technologists, already professional problem solvers, continuing education especially in creative problem solving, including learning how to invent. The methods learned are applied to routine problems, incremental improvements in products, and to inventing new products. Problem solvers in this line of profession have enviable jobs that bring intellectual satisfaction with monetary reward – doubly gratifying stimuli that bring them back for more.

It is curious that problem solving, considered a stressful exercise by many and one to be avoided, can be a pleasurable experience for others. Why is this? Why or how does the brain derive pleasure from problem solving?

A plausible clue may be found in a recent publication of two neuroscientists who study cognition and perception (Appendix A1). Biederman and Vessel posed the question, “Why is *acquiring information* so profoundly gratifying?” To answer this question they first discuss physiological and neurochemical evidence to demonstrate how gratification can arise from viewing and recognizing photographic images. Then they performed experiments on groups of people who were shown photographs and their reactions recorded. One group gave verbal assessments of their relative preferences among the images. The second group was asked no questions but had their brains scanned by fMRI while viewing the same images. The preferences between the groups correlated. I draw analogy between this work and the pleasure we experience in problem solving.

Heuristic innovation is designed to eliminate misleading crank-turning-like structure of formalized problem solving and replace it with natural modes of thinking we have already perfected.

Organization of

Heuristic Innovation in Three Parts

Any technical problem solver can be an inventor. Surely this is counterintuitive to unsuccessful aspirants. However, as will be seen, the difference between inventors and aspirants of equivalent training and experience is not large. It mostly hinges on differences in subconscious thinking during problem solving – differences escaping our awareness. Such differences are addressed in heuristic innovation by introducing heuristics for reversing ingrained thinking that emphasizes logic over intuition. These heuristics are discussed theoretically, demonstrated on real-world problems, and incorporated in logical, but sometimes-counterintuitive methodology.

Underlying development of heuristic innovation is the goal of rapidly creating multiple solutions to technical problems in any discipline amenable to the fundamental model of problem definition.

This book is divided into three parts.

Part A: **Overview of heuristic innovation and problem solving**

Part A presents an overview of the mental processes used in problem solving and how they relate to heuristic innovation. Assumptions, models, and techniques used in heuristic innovation are given a brief overview. This overview is intended especially for academics and industrial management; it covers the methodology with limited theory and little background.

Part B: **Theory, Derivation, and Application of Heuristics**

Part B discusses the thinking traits in which our two brain hemispheres excel. Their involvement in the application of heuristics to solve problems is demonstrated with example problems.

Part C: **Application of Derived Heuristics**

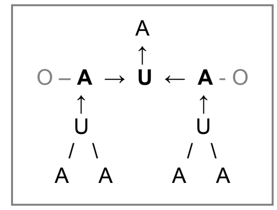
Part C brings a unifying viewpoint to heuristics for problem solving through a first principles derivation of heuristics based on the underlying model of unified structured inventive thinking (USIT, from which heuristic innovation was derived). It is divided into three sections: theory, derivation, and application of newly derived heuristics.

Appendix A2 **For Managers**

"Strategic partitioning of problem-solving resources" is a discussion of a counterintuitive use of problem-solving resources when structuring ad hoc "fresh-eyes" teams.

Exercises are included at the end of the book and a few appear in the text.

A Mental Problem Solving – How the Mind Solves Technical Problems



Heuristic innovation is an improvement over existing structured, problem-solving methodologies including unified structured inventive thinking (USIT, developed by the author). USIT itself was as an improvement over previous structured, problem-solving methodologies. It is not that these methodologies are wrong or inadequate. Rather it demonstrates that as they are practiced new ideas come to light for simplifying them. Many of the concepts used in USIT are used here. [1]

A lesson learned in teaching and practicing structured problem solving is that a methodology is not a "one size fits all" bargain. Individual practitioners develop their own versions of a methodology by finding parts that work best for them. To address this practice constructively a methodology needs fewer specialized techniques and more generic ones offering flexibility for adaptation to specialized needs. This enables a user to maximize the benefits of time spent learning and to optimize personal skills.

This book is about developing a theory and methodology for solving well-defined problems. The principles are generic to many fields. Discussion and examples will usually involve problems having characteristics of basic engineering. Exemplary cases always involve objects, their attributes, and an unwanted effect they support (nomenclature from USIT, not common in engineering but mostly self evident). Before getting into the details I will briefly discuss the goal, procedure, basic assumptions, and models underlying heuristic innovation. Later chapters will elaborate these.

Goal of heuristic innovation

From the start, problem solving is partitioned into two independent, sequential phases: pre-engineering where solution concepts are found using no metrics or quantitative specifications, and engineering scale-up of pre-engineering concepts. The goal of the new methodology is to capitalize on simplifications that enable finding pre-engineering solution concepts quickly, including inventive ones. The method does not address engineering scale-up. Although problems encountered in engineering scale-up are prime for treatment using the methods taught here. Problem partitioning is the first example of applying the heuristic *simplification*.

Emphasis on no metrics or specifications enables a large audience of problem solvers to benefit from the methodology. Its practice requires only a phenomenological understanding of mathematics, physics, chemistry, and engineering. No sophisticated

[1] Terms taken from USIT and other terms are defined in the Glossary and Appendix A3.

calculations are essential. It educes fundamental analysis from the depths of each problem solver's experience. Many more heuristics follow.

Procedure

Achieving the stated goal entailed, in part, reducing the amount of structure in previous methodologies including, for example, eliminating a flowchart.

Lessons learned from our natural thinking in problem solving are adopted. One lesson is that it is natural for technologists to filter every solution concept that comes to mind or is presented by another person. It is un-natural to consciously set filters aside. Here we will encourage filters and adopt them as useful insights to the problem-solving process.

Engaging both logic and intuition in all phases of problem solving is emphasized. This is accomplished by giving intuition preference over logic, which may sound sacrilegious to technical readers. If it does, bear in mind that we are involved in finding pre-engineering conceptual solutions to problems. Hence, there is plenty of time to work out any technical kinks in new ideas before adopting them. In this phase of problem solving we need to spark intuitive insights. In fact, working out the kinks in questionable concepts is a valuable technique endorsed here. In subsequent engineering scale-up and modeling, evaluation is done to cull impractical concepts.

Without the pseudo constraints of a flowchart we can let our contemplation oscillate between logical analysis and intuitive reactions. One brain hemisphere directs our logical linguistic formulation of a problem and its analysis while the other, non-linguistic hemisphere, rapidly searches intuitive meaning.

Assumptions

Assumptions basic to this discussion are summarized here in a pseudo sorites. All are motivated by a search for simplification. They are elaborated in the text.

- **Need**: An effective methodology is needed for quickly finding multiple and innovative solution concepts to technical problems.
- **Insights**: Innovative solution concepts are often evasively arising, if they do at all, from unusual perspectives. Means are needed to produce unusual perspectives.
- **Partitions**: Solving technical problems can be partitioned into two phases of action: finding solution concepts without concern for metrics or quantitative specifications (pre-engineering) and scaling of concepts using metrics (engineering scale-up). An implication of non-scaled solution concepts is a potential for greater robustness because they have not been subjected to engineering tradeoffs.

> **Pre-engineering insight**: The audio signal of speech varies slowly compared with the frequency of digital clocks in computers. Occasional digital sampling of an audio signal at computer clock frequency is sufficient for later reconstruction of the original signal using digital-to-analog conversion.
>
> **Engineering scale-up**: Companding of an audio signal compresses it for transmission and expands it on reception, thus producing greater apparent dynamic range in transmission – more messages in the same time period, as in up-down satellite links.

- **Counterintuitive measures**: *Counterintuitive measures of simplification* can awaken new insights. These constitute a unifying logic that is applied consistently throughout the methodology and serve to keep one subconsciously on a fast track. Some of the measures are summarized as follows:
    - Analyze only one unwanted effect at a time. In the case of systems problems, this means to identify all unwanted interacting effects and choose a single one to investigate (at a time).
    - Restricted budget, resources, tools, time, and environment inspire creativity – thinking inside of a closed world.
    - Describe an unwanted effect in terms of pairs of objects in contact, two interacting attributes (one from each object), and the unwanted effect they cause.
    - Analyze a single point of contact of two objects.
    - All of problem analysis and solution strategies can be done using only one tool – a graphic, proforma condensation of a well-defined problem (Fig. A1) – based on the last four statements:
    -

Object – Attribute
\
Unwanted effect – Attribute – Object
/
Object – Attribute

Figure A1. Graphic proforma for a well-defined problem.

> **Example graphic proforma of a well-defined problem:**
>
> Automobile trunk lid – momentum
> \
> Explosive airbag deployment when trunk lid is slammed shut – unnecessary disorientation – driver
> /
> Air bag transducer – electrical signal
>
> **Exercise**:
> Convert the information above into a complete, verbal problem statement.

  - The tool is made simpler and more exploratory by de-emphasizing, but not eliminating, objects (grayed print in above graphics).
  - A solution concept is found when one of three conditions is met: the unwanted effect is utilized, eliminated, or nullified. Each is a solution strategy of heuristic innovation.
- **Models**: Several models of thinking in problem solving are used to provide mental reference in assuring plausibility of each technique used.
  - Brain lateralization: Brain lateralization engages one hemisphere for language-oriented logical expression in problem solving. This asymmetry produces a kind of dominance over the other hemisphere, which has no language and functions intuitively. Both hemispheres receive the same problem information at the same time but process it differently according to their complementary strengths. The dominant logical hemisphere may prematurely squelch ideas offered by the intuitive hemisphere.
  - Metaphoric cues: Verbal and graphic metaphors contained in problem description and definition cue instantaneous intuitive recall of personal experience. Personal experience supports abinitio construction of solution concepts. Such experience may entail an actual solution (already known), may discover sufficiently close association to make a new solution obvious, or may provide the starting point for developing a new one. Metaphoric cuing is referred to as seeding the subconscious.

I’ll digress here to give a demonstration using a real-world problem.

Example – Erasure smudge: Consider the problem statement:

> "The eraser retains particles of lead picked up in previous applications and smudges the paper in its next application."

Possible cues are: "eraser", "retains particles of lead picked up in previous applications", "smudges the paper", and elements of these.

My instant reaction was recalled images of

1. An eraser smudge on paper,
2. A yellow wooden pencil with a fixed, exposed eraser on its end,
3. A mechanical pencil with an eraser hidden under a metal cap,
4. A handheld white-colored plastic eraser, and
5. A hanheld tan-colored gum eraser.

In a few moments of thought (with these fresh in my mind) there followed images of

6. An eraser that can be mechanically extended and withdrawn from its sheath,
7. A battery-operated vibrating eraser,
8. An electrical, rotating eraser with a power cord, and
9. A thin, metallic eraser shield used in mechanical drawing.

An intuitive solution concept came to mind along with the images:

> [ES-1] Make an eraser of friable material for wiping clean with one's finger before using it.

Filter: It would never be accepted because of the mess it would create! (Filters will be discussed later.)

I recognize this solution concept as related to my experience in using white-colored plastic erasers when I rub the end of one with my thumb to clean it. (I suspect, but can't confirm, that I may have given thought to this problem sometime in the past.)

These were intuitive thoughts requiring no analysis, discussion, library search, or other investigation for information. I was impressed with how quickly the first five ideas came to mind – as quickly as I could type them. On examining these images I was struck by how few there were: only six immediate images and four more in half a minute or so. Only one solution concept came to mind with them. I suspect that the problem statement was so specific that it narrowed my mental focus.

I then considered how to generify the cues. To do that I simply looked at the list of cues and made a generalization for each. (The third column below shows ideas that came to mind while thinking of a generalization.)

eraser	➔ cleaner	ink eradicator, broom
eraser smudge	➔ ugly mark	scratch on a car door
retains particles of lead	➔ portable dirt supply	muddy tracks
	➔ tacky material	fly paper
picked up in previous applications	➔ accumulated dirt	air fliter on a clothes dryer
smudges the paper	➔ deposits dirt	finger print

I am always impressed with how quickly intuition proffers some kind of response to cues, whether or not they are relevant. It is easy to ignore the third column above as being irrelevant to erasure smudges (a filter). On the other hand, they can be thought of as having latent relevance that sparked their intuitive association. Hence, they should be analyzed for attributes that might be transferrable or spark other relevant attributes for the eraser-smudge problem. Don't sell short intuition.

Now back to the model for metaphoric clues.

- Intuitive reaction to metaphoric cues is quick but of limited productivity. Rewording and resketching expands their productivity.
- The brain is excessively lively during problem solving as it makes uncontrolled jumps between problem definition, analysis, and solution without logical connectivity between them. This tendency is encouraged for more natural thinking by eliminating flow charts and replacing them with incremental iteration of problem definition.
- Rewording of objects, attributes, and unwanted effects can develop metaphoric cues. With practice, generification of these words is effective.
- Intuition based on academic and professional practice of technology is less amenable to artistic-type “freethinking”. Consequently, thinking tends to be logically constrained – policed by the logical brain hemisphere.

The above thinking models are offered without apology but with a word of caution. I am not a neuroscientist.

We do not know in sufficient detail how the brain functions to understand thinking. Yet understanding brain function is essential to building, testing, practicing, and teaching heuristics for problem solving. Fundamental to these activities is the creation of models by which we can understand and communicate our understanding of mental problem solving. However, this lack of understanding doesn’t stymie us from formulating hypotheses about mental problem solving and testing them. Unfortunately, it does limit depth and scope of laboratory experiments we can perform with any acceptable degree of credibility. What are we to do?

How can we develop sufficient understanding to even organize a problem-solving methodology? Part of the answer is to apply the well-established practice of trial and error. We can postulate procedural steps and try them to see if they work. Criticism will arise about the assumptions involved in the test and the interpretations used on the results. We examine them internally while others will be more public. Resolving this dilemma is itself a problem. Our main method of formulating and testing needed hypotheses begins with introspection – a time-honored method. It is also suspect of being too personal to apply generally and of lacking sufficient objectivity to qualify as scientific. (I state this up front to caution both of us to be on guard for accidental fallacies.)

Exercise: Practice metaphors
In 30 seconds list as many words, phrases, and concepts as you can that come to mind on reading each word; <u>tape</u>, <u>nail</u>, <u>airplane</u>, <u>alien</u>, <u>tree</u>, <u>dam</u>.

The models discussed above are my guides for plausibility in interpretation of introspection. They fit my limited readings of the neuroscience literature. However, the models are not the test of the methodology being taught. Functional success using the methodology is the test. Constructive criticism of these models is welcome.

Analogy of visual cues and problem-solving seeds

The building of image recognition along a neural pathway requires successful associations of image elements with known elements, those already in memory. Association can be thought of as resulting from successions of logic AND gates comparing two inputs (A & B), one a stage of image development, the other a known element. If when ANDed they produce "true", meaning recognition with experience, the developing image proceeds for further development.

Optical stimuli, arriving to the cortex from the retina, are processed first for recognition of simple features. These cue further analysis as each stage of image development succeeds in recall of known features. Ultimate recognition ends as perception and cognition produce association of the developed image with recorded experience (memory). This recognition is understanding that produces gratification (*a la*, Biederman and Vessel [2]) and reinforces mental recording.

Unsuccessful associations anywhere along the optical processing pathway prior to ultimate gratification probably end with temporary recording of the latent image components in short-term memory. In which case, a subsequent or parallel stimulation of the retina could initiate image processing, which at some point could reinforce the previously aborted latent image, if it is still available in short-term memory. This combination and, possibly, other stimuli arriving before it is lost from short-term memory, could amass sufficient strength to create a record in long-term memory.

Problem solving may involve cues from each of the five senses plus written and oral words and phrases along with sketches, photographs, physical models, and full-scale parts. This scope of cues does not invalidate analogy of problem solving with optical image cognition. Instead it would seem to bring more statistical opportunities for cues to arise that can strengthen associations under test with other cues. Furthermore, the neurochemistry of image recognition and gratification can be expected to be the same in problem solving as in optical image recognition. Evolution would benefit by multiple applications of the same physiological and neurochemical components.

[2] See Reference 2 and Appendix A1.

Using seeds

Seeds, as used here, are forms of sensorial cues generated by problem statements, ancillary information in photographs, sketches, and other formats, provided by someone else. They are forms also of non-sensorial cues created when we imagine them. As we mentally formulate wording of a problem definition, or imagine the next component to add to a sketch, our brain is simultaneously testing metaphorical value of the words, phrases, and sketch components.

Just how to define a seed from first principles is not yet determined. I'll examine some seed-creating situations to see what we can learn about them. We create seeds with every verbal and graphic problem statement. Each modification of wording and a sketch produces new seeds. Intuitive response to seeds produces seeds.

Seeds seem to have some kind of interplay between our conscious and subconscious thinking. We are aware of our conscious mulling and can construct seeds logically; a process that simultaneously can stir intuitive thinking. Our non-verbal intuitive thinking must lie mostly in the subconscious. Our conscious can play with words and images through logical synonymic and generic associations to provide variants of seeds. The subconscious interprets these metaphorically enabling surprisingly useful insights (along with irrelevance).

In the erasure-smudge example five intuitive reactions occurred as quickly as I could type them (Numbers 1 – 5 in Fig. A2). Four more (Numbers 6 – 9, printed in gray shade) followed with additional time to think.

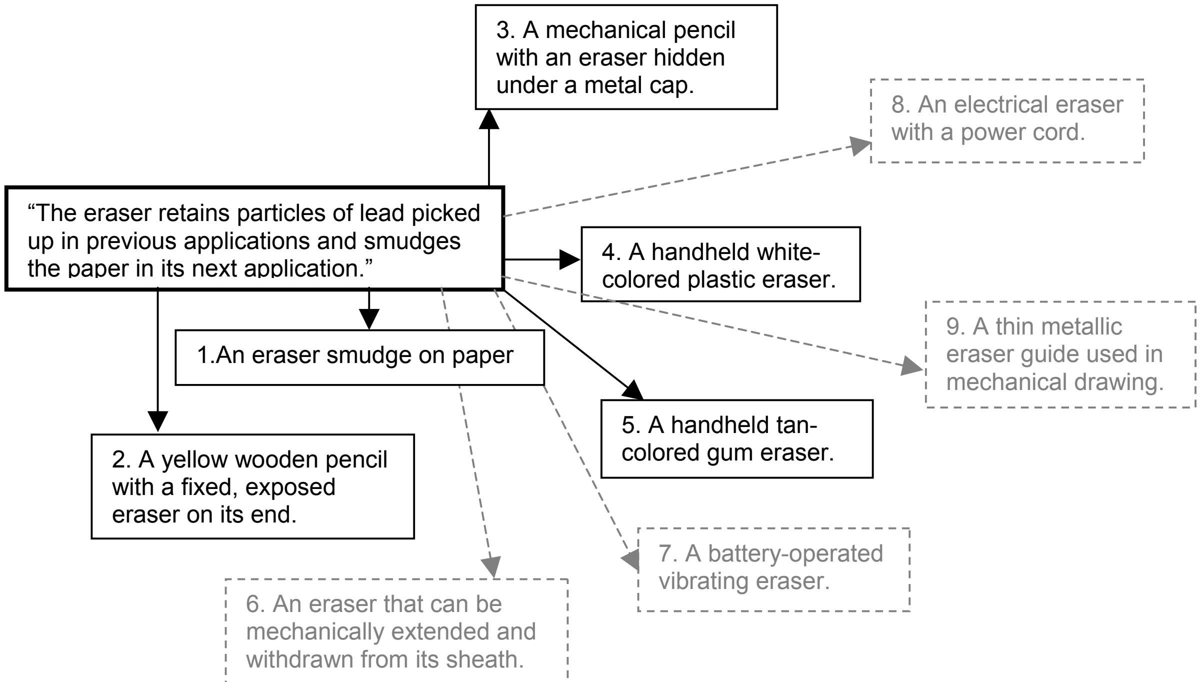


Figure A2. Intuitive reactions to the erasure-smudge statement.

Understanding and creating problem-solving seeds is an essential aspect of heuristic innovation. However, in the above example it is not clear how to associate specific inspiration with its causal seed. Arrows are drawn from the original statement to the first five intuitive results, in Fig. A2. This seems reasonable but rather general. It is likely that only parts of the original statement sparked a particular reaction. But we can’t discern this from the drawing alone. What about the next set of reactions, shown in gray? Were they inspired by the first set, by the original statement, by specific parts, or by unknown combinations of the available information? In the above sketch connections were drawn between the original statement and all responses. It may be that some of the connections should be between the first group of responses and the second. This is inaccessible information. (On rereading the list of reactions I could imagine how the first group sparked No. 6 and then how each successive reaction could have sparked its successor.)

Several observations can be drawn from the example:

- A small number of intuitive images were generated
- Inspiration came in two waves. The second wave took a few more seconds of subconscious thought than the first. (I was not consciously mulling any particular clues during this period.)
- Intuitive images were rather narrowly related to the original statement, as though controlled by its context

The important issue here is to identify what in the original verbal statement constitute seeds that spark association with experience? Comparing the original statement and my responses, recorded as soon as I thought of the problem statement and was typing it and my responses, can identify plausible connectivity.

The **eraser** retains particles of lead picked up in previous applications and **smudges** the **paper** in its next application.

1. An **eraser smudge** on **paper**.
2. A yellow wooden pencil with a fixed, exposed **eraser** on its end,
3. A mechanical pencil with an **eraser** hidden under a metal cap,
4. A handheld white-colored plastic **eraser**, and
5. A hanheld tan-colored gum **eraser**.
6. An **eraser** that can be mechanically extended and withdrawn from its sheath,
7. A battery-operated vibrating **eraser**,
8. An electrical, rotating **eraser** with a power cord, and
9. A thin, metallic **eraser** shield used in mechanical drawing.

Figure A3. Associations between reactions and components of the original erasure-smudge statement.

Eraser had nine direct associations, smudges had one, and paper had one; as shown in Fig. A3. Eraser is a common object in my experience.

Handheld was not mentioned in the problem statement but occurred twice in the responses. This condition seems to be implied or associated with my experience in how I use erasers. In fact, the images recalled were of handheld erasers or handheld objects having erasers, except for No. 8.

The problem statement has four objects: eraser, particle, smudge, and paper (nouns). It has four effects: to retain, to be picked up, to apply, and to smudge (reworded as infinitives). And it has specified, implied, and inferred attributes of objects: eraser (hand graspable and dirty), lead (particulate), and paper (susceptible to smudging).

The responses had an interesting collection of objects, effects, and attributes. These are listed in the Table A1. My inferences are shown in parentheses.

Table A1. Analysis of erasure-smudge responses in terms of objects, effects, and attributes.

	Object	Effect	Attribute
1	Smudge Paper	(to create information) (to wipe dirt from eraser)	(unsightly) (susceptible to smudging)
2	Pencil Eraser		yellow, wooden fixed position
3	Pencil Eraser Cap	 (to hide eraser)	mechanical metallic
4	Eraser		handheld, white color, plastic
5	Eraser		handheld, tan color, gum
6	Eraser Sheath	to be moved mechanically (to hide/protect eraser)	extendable and retractable (hand graspable)
7	Eraser	to vibrate	battery operated
8	Eraser Power cord	to rotate	electrical
9	Shield	(to limit erasure area)	thin, metallic

Note, in No. 2 in the table, that eraser is "exposed", but this is not an attribute of eraser. Visibility of eraser could relate to attributes of an otherwise blocking object; namely, it being *transparent* or its projected *size* being smaller than the eraser. In No. 3 in the table, eraser is hidden, but this too is not an attribute of eraser.

At this point it is evident that the eraser problem statement caused intuitive reactions in my mind. It is not evident that any of these are relevant to new insights or novel solutions, with the exception of the friable eraser idea. When I wrote the nine recalled images to the eraser problem I was disappointed with both the small number of ideas and their limited scope. These points will be discussed further, but first I'll discuss what a solution concept is.

Solutions

The previous discussion of seeds may be misleading to some. It may be if one infers that seeding the subconscious produces finished, ready to apply solution concepts. This is not the intended meaning. Such finished solutions are not ruled out. When they occur they likely are already in one's experience or they require only obvious modification to be applicable solutions. Intuitive concepts are the brain's attempt to create understanding out of seeds.

Intuition is a source of insights relevant to creating novel solution concepts. Seeding the subconscious can spark innovative insights. Creating solution concepts, creating a well-defined problem, and plumbing the depths of one's phenomenological understanding of a problem are all rewarding experiences having us craving for more. However, this begs the question, what is a solution concept for a problem? How do you determine that a problem has been solved? And this begs the question, what is a problem? In fact, what is a well-defined problem? To these questions I offer my working definitions, without much justification.

I define a problem to be an unanswered question. If the questioner knows the answer to the question being asked, but the one being questioned doesn't know it, it belongs in the category of a puzzle. This definition of problem is selected for its all-encompassing breadth, which puts it at some risk of challenge. For example, not all questions have answers. This may not be true for religion but it is true for science. There are innumerable questions that can be posed that have no scientific answers.

This weakness in the definition of a problem shows the need for a well-defined problem. A well-defined problem is a problem couched in terms suitable for clear understanding and logical analysis. It is "well defined" for the methodology to be used to solve it. Being well defined does not guarantee that it has a solution, only that it is amenable to an established protocol of logical analysis. The protocol of the problem-solving methodology has conditions defining a solution.

Causes and effects in a well-defined problem

From USIT we have a simple proforma graphic for displaying an abbreviated, well-defined problem. It has two objects (O) in contact, each having an (input) attribute (A), which interacts with an attribute of the other to cause an unwanted effect (U). An unwanted effect maintains or modifies the intensity of a third (output) attribute in one of the original two objects or in a third object; see Fig. A4.

```
O – A
      \
       U ➔ A – O
      /
O – A
```

Figure A4. Simplified proforma graphic of a well-defined problem as used, with variations, throughout the text.

This graphic makes the definition of a solution obvious: a solution must prevent the affect of U on the output attribute A (U ➔ A). How this can be done is the subject of the section of the book on solution strategies. One way to solutions is through plausible root causes.

Example – Erasure smudge continued:

To apply the proforma graphic to the eraser problem we start by identifying a point of contact between two objects for analysis. The eraser situation inspires thoughts of two points of contact: one is hand in contact with eraser and the other is eraser in contact with paper. The later is the logical choice since it contains the unwanted effect, a smudge.

```
Eraser – A
          \
           to create ➔ Unsightly – Information (smudge)
          /
 Paper – A
```

A smudge is a form of information, which is an object (*a la* USIT). It has the attribute of being unsightly. The unwanted effect, an undesired action expressed as an infinitive, is *to create*.

Completing the graphic to this point, that is, leaving open the casual attributes, brings one to in-depth analysis of cause and effect. Here the analyst is expected to search pairs of casual attributes that *logically* and *plausibly* complete the graphic. Identification of pairs of casual attributes challenges the problem solver to stretch personal experience and technical understanding.

The caveat *plausibly* is used to distinguish proven root causes from perceived ones. Establishing proof of root cause can be a major hurdle for industrial problems and can stymie creative investigation. In USIT and heuristic innovation it is encouraged to use plausible root causes in order not to stymie progress. Remember that we are searching solution concepts yet to become products or in-place solutions. These are ideas needed to kick-start the engineering scale-up phase. In addition, plausible root-causes analysis can be used to identify variables to be examined in a designed experiment – a formal root causes analysis.

Example – Erasure smudge continued:

Obviously, eraser and paper have many attributes, but we are only interested in relevance to causing a smudge. As I look for relevant attributes I first try to break the process in to smaller effects. In my mind I see

- an eraser being rubbed on the surface of paper and lead particles on the eraser being transferred to the paper in a smudge. This image causes further thought about actions:
    - How does the eraser collect and store lead particles?
    - How does the rubbing process transfer particles from eraser to paper?
    - How do particles become a smudge on the paper?

Examination of these thoughts brings to mind more definitive effects. How the eraser collects and stores lead particles brings to mind

- collection as a process of removing a previous smudge and retaining its lead particles until the next application. The idea came to mind that successive removal, transfer, and smudging could gradually divide particles into smaller particles. (Maybe in time they would become too small to be seen, but I doubt it.)

Storage brings to mind two images,

- one being an image of particles sticking (weak bonding) to an otherwise smooth surface, and
- the other an image of particles being imbedded within the surface roughness of an eraser.

Rubbing transfer of particles brings to mind

- roughness of paper engaging particles sticking out from a smooth surface of eraser (breaking bonds) and an image of
- particles being squeezed from pores in a rough eraser surface.

These two images seem to follow the previous two, the former inspiring the latter.

How particles become a smudge brings to mind

- mashing particles into smaller particles that adhere to or imbed in paper.

The process of dwelling on effects for a few moments brought to mind plausible details of the phenomenology of smudging. These can be examined for casual attributes and for convoluted effects. For example, the first image of eraser collecting and smudging was that of particles being ground into smaller particles. Now I see that this involves eraser in contact with particles not in contact with paper – a new effect has been uncovered that is convoluted with the former one.

This discovery illustrates how the graphic being used can shed light on complexity as well as causality. It also exposes the reason a well-defined problem should have a single unwanted effect, not one convoluted with others. Need of a single unwanted effect should not cause hesitation in initial wording of a problem because as multiple unwanted effects are discovered rewording of the problem statement follows. This is an iterative process that supports speed and clarity in problem solving.

The last set of reactions (framed) convinces me that here I am mulling specific effects and looking for relevant attributes. Seeds are more evident in these examples.

Exercise: Iterate for ambiguity
Rewrite the sentence, "The tape doesn't work", as a problem having an unwanted effect. Include objects, causal attributes, and an unwanted effect that you create for the purpose. Then rewrite the sentence four times, each time generifying one of object, attribute, or the unwanted effect. Create a simple sketch for each problem statement to see if changes in the sketches are implied with wording changes.

Example – Erasure smudge continued:

Iteration of the graphic for analysis of eraser-particle contact gives the following sketch.

```
          Eraser – A
                    \
                     to create ➔ Small (size) – Particle
                    /
         Particle – A
```

Note the intentional generality used for eraser and particle of lead. We do not need specifics about what kind of eraser or what kind of particle. However, they are not forgotten and will come to mind to affect and modify our ideas. This is the beginning of generification. Its effectiveness will become more apparent as other problems are analyzed.

What are the attributes of eraser and particle that lead to small particle? Pressure of eraser and shear strength of particle are two obvious attributes. I'll examine these without looking for others.

```
      Eraser – Pressure
                      \\
                       to create ➔ Small (size) – Particle
                      //
Particle – Shear Strength
```

Points of focus for resolving this unwanted effect are illustrated with double bolded lines and a bolded arrow. My first idea is

- to eliminate either eraser or the contacting particle. These ideas followed:
  - 1. Use a scraper to lift particles rather than mash them. This replaces eraser and eliminates mashing pressure.
  - 2. Annihilate particle during storage on eraser before the next application of eraser. (Note that this idea came to mind without further elaboration. How to annihilate particle was not evident. If no ideas come to mind quickly, the new issue can be aborted, or set up as another problem with its own proforma graphic having particle in contact with an unknown object or with eraser but having a new output attribute.)

My second idea is to eliminate shear strength of particle. This resolves the unwanted effect of further division of particles during subsequent erasures. It raises in my mind the question of what determines shear strength? As I thought about that it arose that now the type of particle comes into play. Pencil lead is composed of graphite and clay. Attributes of graphite provide the visible contrast between paper and smudge while attributes of clay modify its shear strength enabling ease of smudging. Eureka! I now see that mashing of lead particles is not the cause of smudging. Clay holds the particles while in the pencil and during smudging. A smudge is a thin layer of clay with embedded particles. This new insight can be used to introduce another proforma graphic:

Example – Erasure smudge continued:

Graphite – Color intensity
\\
to create ➔ Unsightly – Smudge
//
Clay – viscosity

More ideas come to mind:

- 3. Lift-off smudge without rubbing or scraping.
- 4. Eliminate clay and make pencil lead of lightly sintered, hard graphite particles. The particles need to be small enough to easily engage and be retained in the roughness of paper. Another idea follows from this.
    - 5. Coat particles with a chemical that enables bonding with paper so that paper roughness is not an issue.

Before moving on, note how narrowing focus onto attributes supporting the unwanted effect quickly produced more solution concepts. These included essentially complete concepts along with some needing further development. Also note how the problem statement took on new light when an underlying unwanted effect was discovered, and again when erroneous thinking was discovered. These occurrences are common in problem solving and support emphasis being placed on the iterative development of problem stages.

You may have questioned focusing on eraser-particle contact after starting with eraser-paper contact as being too detailed, or an insight only some people would notice. Obviously, your insights and analyses will differ from mine. At issue here is the demonstration of how discovering points of contact between two objects can force one to look for new attributes and to rationalize their roles.

Yes, eraser presses on smudge, which transfers pressure to paper and on to the table beneath it (and on and on through a series or actions and reactions) and, yes, pressure is distributed over the entire interface between eraser and smudge and between smudge and paper, etc. All the components of smudge are subject to the same pressure. Note that this line of reasoning is typical physics we are all aware of – therefore, we can expect nothing new in perspective of a problem. On the other hand, since all points of these interfaces act the same, they can be reduced to one representative point as simplification suggests. Furthermore, intentionally searching for hidden or unnoticed points of contact brings yet more opportunity to discover effects and their associated attributes.

This example of application of the proforma graphic to resolve an unwanted effect is sufficient for now. More details will follow later.

Plausible root-cause analysis

The proforma graphic expands straightforwardly into a proforma plausible root-cause analysis tool.

The proforma graphic, the root of all heuristic innovation analysis,

```
O – A
     \
      U → A – O
     /
O – A
```

on counter-clockwise rotation and flattening of inputs becomes a convenient layout for plausible root-cause analysis:

```
                      Object
                        I
                    Attribute
                        ↑
Object – Attribute → Unwanted effect ← Attribute – Object
```

Figure A5. Proforma graphic rearranged for plausible root-cause analyses.

In this graphic (Fig. A5), the two lower objects each are causal of the unwanted effect through a pair of interacting attributes. We now look at the input attributes (bolded) independently and ask, are there effects that maintain or modify these attributes? If so they are unwanted. When a lower level unwanted effect is identified it is then analyzed as being supported by two causal attributes. To show this the enclosed A-U-A group in the above diagram is repeated under each subsequent attribute. These results are illustrated in the following graphic (Fig. A6).

```
                      Object
                        I
                    Attribute
                        ↑
Object – Attribute → Unwanted effect ← Attribute – Object
            ↑                            ( ↑, similarly for this attribute)
            U
           / \
   Attribute   Attribute = PRC
       ↑
       U
      / \
Attribute  PRC
   ↑
   …
```

```
            A
            ↑
O → A  →  U  ←  A ← O
    ↑           ↑
    U           U
   / \         / \
  A   A       A   A
```

Figure A6. Example extension of cause/effects as attribute/plausible-root-cause-associations from one of the original causal attributes. The inset is a simplified proforma representation of a plausible root cause analysis.

The terminating attribute of each subsequent lower branch (underlined in the figure) is defined to be a plausible root cause (PRC). In principle it might appear that application of this graphic could expand into unmanageable complexity. In practice, it usually has only two or three levels, and those in only one or two branches. Such simplicity results from first selecting a point of contact (of only two objects) for analysis and searching relevant effects.

Attributes in each sub-branch below one of the two initially interacting attributes belong to the same object as their parent attribute.

Example – Erasure smudge continued:

To demonstrate how the plausible root-cause analysis works, I'll apply it to the eraser smudge problem.

Smudge
I
Unsightly
↑
Eraser – **Attribute** → to create ← **Attribute** – Particle
↑ ↑
U U

Particle contributes to the smudge through its attribute of color contrast, which, in this case is the color of graphite. The color results from the electronic properties of the particle. Graphite looks black because it absorbs most of the light incident on it. Contrast implies color difference between particle and paper. If they were the same color a smudge would not be unsightly and might go unnoticed.

Smudge
I
Unsightly
↑
Eraser – **Attribute** → to create ← **color contrast** – Particle
↑ ↑
U to absorb light
/ \

As I was typing the right-hand side of the diagram to examine cause of color contrast it occurred to me that pressure of eraser during erasure is transferred to particle but has only been seen as cause of smearing, being coupled to the viscosity of the clay content of a particle. This led to the idea that

6. a new kind of particle could be developed that looses its light absorbing attribute by pressure change of its electronic band gap.

to create ← **color contrast** – Particle
↑
to absorb light
/ \
band gap pressure

This attribute would need to have a threshold of pressure such that soft sliding of paper on paper would not affect light absorption but hard rubbing during erasure would. Thus the particles would loose their blackness on initial pick-up onto the eraser.

I'll stop this demonstration here. This shows how working one's way down the plausible root cause analysis brings new perspective to a problem. You might enjoy expanding further on my start by trying attributes that come to your mind. Remember not to reject ideas by filtering. We'll be examining filters and how to use them later.

Forms of the proforma graphic

It is useful to pause here and review the graphic model and its derivations. The model begins with the definition of a well-defined problem (Fig. A7):

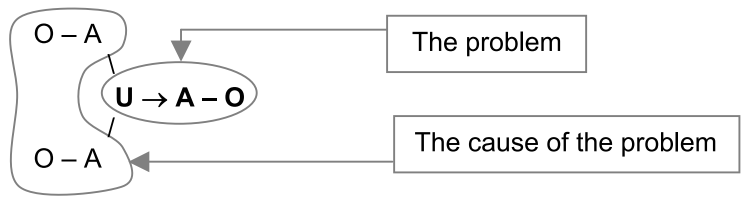


Figure A7. Division of the problem-statement proforma into problem and cause components.

In order to emphasize different perspectives of a problem, we shift attention to attributes, which does not remove the objects from our short-term memory. This is illustrated in the simple unit that makes up all other diagrams, the A-U-A unit (Fig. A8).

A – U – A

Figure A8. The elemental core of all proforma graphics and analyses.

Two of these units are seen in the problem-definition graphic sharing a common unwanted effect. Multiples of these units form the plausible root-cause analysis graphic – as many units as needed to reach plausible root cause in each branch (Fig. A9):

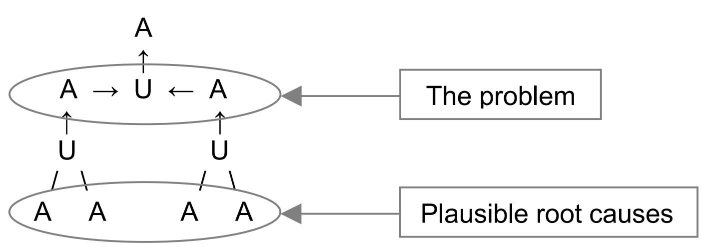


Figure A9. Rearrangement of the graphic in Fig. A8 to include plausible root causes to their first sublevel of attributes.

Focus on Attribute → Unwanted effect ← Attribute units

The AUA unit of the proforma graphic is basic to all analyses. Focusing on attributes instead of their objects is not as natural for technically trained problem solvers as is focus on objects. Hence, AUA becomes a device for shifting one's more common approach to a problem to a somewhat uncommon one – new perspective. Thinking of attributes in pairs also is not a common practice. It too is a device for creating new perspective. You may use the tool anyway that works for you, object or attribute first. But you are encouraged to test attribute-first focus and discover the impact on your thinking.

The complete plausible root-cause graphic (i.e., without objects) is used for teaching and understanding how the components fit together and to show its underlying logic. In practice of problem solving we take many short cuts through territory that is familiar. In particular, we tend to short cut formalities. The AUA element alone is a shortcut through the more tedious full-structured plausible root cause graphic.

Exercise: Plausible root cause
Construct a plausible root-cause analysis for the problem, “The tape doesn’t work”.

Orphan attributes

An interesting and opportune occurrence, when thinking of attribute pairs and ignoring objects, is the arrival of an orphan attribute, an attribute not obviously characteristic of the two initial objects. This is another opportunity to see the problem in a new light. An orphan attribute is examined to understand why it came to mind, in what way can it address the unwanted effect? If the orphan attribute is seen as resulting in a solution concept a search is made for an available object having that attribute.

The newly identified object and its useful attribute offer a valid solution concept but may introduce more complexity if adopted to resolve the problem. As is typical in problem solving, solution concepts are often accompanied with new problems. In this case an opportunity for innovation exists by finding a way to activate the new attribute in one of the original two objects, or to use the new attribute to suggest an alternative attribute that can be linked to the original unwanted effect. Such A–E–A links are referred to as solution by transduction in USIT.

Questions having answers / Problems having solution concepts

As already discussed I draw an analogy between a question having an answer and a problem having a solution concept. The processes of finding an answer and finding a solution concept both require a search for information that resolves the issue being posed. Interestingly, neuroscientists have demonstrated that acquiring information is a gratifying experience that brings us back for more; by analogy, so does problem solving.

A perplexing part of mental problem solving that I cannot fathom is the speed with which intuitive ideas reach the conscious. It seems that while logically considering an aspect of a problem an idea suddenly, quietly, and without fanfare, is present for consideration. I did not consciously put it there, but there it is. In other words the transition between conscious and subconscious cannot be sensed or interrogated introspectively. Nonetheless it is boldly clear to me that pondering nouns, adjectives, verbs, and graphics induces mental inspiration that otherwise would lie dormant. Simple rewording of a problem statement and focus on an attribute of an unwanted effect always induce subconscious insights not consciously invented. It seems that good problems have to be created through variation of cues.

Inventing problems

I am amazed at how often students are unable to bring a problem to class when warned that one was expected. The most common excuse for not doing so is, “I couldn’t think of one!” I should say that I used to be amazed. I changed my attitude when one day I sat down to solve a problem and had to think of an example to work on. Nothing seemed to come to mind. I decided that this is a problem – that is, finding a problem is a problem – one that I should solve. Here is the reasoning I used to solve it.

Seeding had long been a familiar practice for me so I wondered what kind of seed could be constructed that would inspire the subconscious to provide an unsolved problem. On thinking about this it seemed a little strange to expect my brain to have a long-term database of unsolved problems to select from. I soon realized that this approach, waiting for my subconscious to do something, was going nowhere. So I decided that an unsolved problem needed to be created. I must admit that the idea of how to do this did not come for some days.

I was working with the plausible root cause diagram when I realized that the problem I was dealing with could be thought of as an unwanted effect in an artifact – a manmade, mandesigned object all of which exist for a purpose. Then the enlightenment – an unwanted effect can be imagined for any manmade thing! Now creating problems to be solved is sort of fun. I can randomly select anything within sight (or out of sight) and quickly imagine an unwanted effect in one of its uses, which may also have to be imagined. The eraser lying in front of me on my desk gave rise to the eraser-smudge problem.

A sorites for this thought process is as follows:

- All manmade objects have an intended function (otherwise man would not have made them).
- Functions of manmade objects are subject to design inadequacies, materials limitations, manufacturing limitations, and other tradeoff issues.
- All functions can have perceived malfunctions.
- Perceived malfunctions can be used as unwanted effects to be resolved.

How do seeds work?

These are interesting observations but they still don't define the characteristic of an effective seed or explain how it works. How a seed works is a question for cognitive psychologists. But identification of seed characteristics should be evident in the conditions we erect that lead to ideas. Let's look at what types of seeds may have led to the six ideas for the eraser-smudge problem and at my rational for the ideas.

Solution concept Nos. 1 and 2 arose after constructing the proforma graphic for eraser-particle interaction (Fig. A10):

```
        Eraser – Pressure
                          \\
                           to create ➔ Small (size) – Particle
                          //
Particle – Shear Strength
```

Figure A10. Proforma graphic for the pressure-shear strength pair of causal attributes.

In this case pressure on particle gave me an image of mashing a particle. This seems to have led to No. 1: “Use a scraper to lift particles rather than mash them.” My image was of pushing the smudge parallel to the paper rather than mashing it into the paper – I was seeing pressing as perpendicular force onto paper being reacted by paper’s support and pushing as a transverse force against eraser with friction being the only restraint.

Number 2 was an obvious way to break up the unwanted effect in the diagram by doing away with particle to eliminate smudge. No. 2: “Annihilate particle during storage on eraser before the next application of eraser.” “Doing away with particle” was captured in “Annihilate particle”. But the solution concept went on to elaborate on doing it *before* creating a smudge. This preempts “to create a smudge” implied in the diagram. But what seeded the need to define *before* as “during storage on eraser”, specifying both time and place? Did these questions arise in the subconscious as the conscious was verbalizing the solution?

Concepts Nos. 3, 4, and 5 came to mind after constructing the proforma graphic for graphite-clay interaction (Fig. A11). Previous graphics probably still had some influence.

```
Graphite – Color intensity
                          \\
                           to create ➔ Unsightly – Smudge
                          //
        Clay – viscosity
```

Figure A11. Proforma graphic for the color intensity-viscosity pair of causal attributes where color intensity is causal of smudge being unsightly.

Number 3. “Lift-off smudge without rubbing or scraping.” This idea came to mind as I was logically thinking about how pressure and viscosity control smearing. Lift-off arose as a way to counter mashing by substituting lift for press.

Number 4. “Eliminate clay and make pencil lead of lightly sintered, hard graphite particles. The particles need to be small enough to easily engage and be retained in the roughness of paper.” Sintering eliminates the need of clay as a binder to hold graphite during storage and transport transport. Particle size addresses a way of holding the particles onto the paper without using clay as a matrix. These ideas seem to be most related to elimination of clay.

Number 5. “Coat particles with a chemical that enables bonding with paper so that paper roughness is not an issue.” This idea arose from No. 4 when considering roughness of paper for holding particles in place.

Number 6. “A new kind of particle could be developed that looses its light absorbing attribute by pressure change of its electron-energy band gap.” (See Fig. A12.) This idea arose directly from seeing the phrase “to absorb light” in the last graphic of the example discussion:

to create ← **color contrast** – Particle
↑
to absorb light
/ \
band gap pressure

Figure A12. Plausible root cause analysis of the attribute color contrast to one sublevel of attributes.

Some of the seed characteristics in these examples are evident but not all. A synopsis is shown in the next table.

Table A2. Synopsis of the six solution concepts for the erasure-smudge problem.

	Concept	Seed	Comment
1	Scrape instead of mash	Pressure implies mashing	Negates the action of mashing
2	Annihilate particle	Eliminate the problem	Preempts smudge
3	Lift-off smudge	Pressure implies mashing	Shifts mash to lift
4	Eliminate clay	Source removal	Preempts smudge
5	Coat particles	To hold without roughness	Avoids roughness mentioned in #4
6	Modify light absorption	Color contrast	Preempts light reflection

On first examination of this table I could not find a particularly satisfying generalization of seeds and their inspirations. I reread the previous pages and discovered a sentence that may be biasing my search: “Nonetheless it is boldly clear to me that pondering nouns, adjectives, verbs, and graphics induces mental inspiration that otherwise would lie dormant.” The statement is true but in my search for generalization I was misinterpreting *pondering* and thus biasing my search to types of words. While again reading the table, it occurred to me that it is not the words specifically that I ponder, but the mental images they create. Every entry in the table creates an instantaneous image in my conscious. This must be the work of the intuitive brain hemisphere as it deals with metaphors, shapes and images, spatial relationships, and puts things together to form a whole.

This observation helps to explain why iteration of problem definition, analysis, and solution, in small steps with word and graphic modifications, enriches one’s invention of solution concepts. Here, personal experience distinguishes one problem solver from another. Seeding the subconscious brings insights to the conscious from which we draw inspiration. How the seeds couple to underlying experience, and to what they are associated, begins as a personal difference in recorded experience.

This discussion has not succeeded in defining the specifics of seeds or how they work. But it has been demonstrated how seeds can be prepared and that they produce inspiration. Most importantly, without introspective interrogation of the subconscious-to-conscious linking process, and without definitive work by cognitive psychologists, we are left to our own devices for plausible understanding. In other words, we each have to experience this process for ourselves and make appropriate adjustments for its success.

So far, we have seen specifically phrased problem statements and graphics produce focused intuition. Now we'll look at generification of previous specifics.

Generification of problem definition

Seeding can be looked upon as direct association of words and images with their instantiations in recorded experience. But the brain also makes metaphoric associations with experience. We can create opportunities to spark this mode of thinking by resorting to generic terminology in problem definition and analysis. A hint of the process was given in the first frame of the eraser-smudge problem (Page A5). It is repeated in Table A3.

Table A3. Original reactions to erasure-smudge statement with generifications.

	Specific wording	Intuitive reaction	Generification
1	Eraser	cleaner	ink eradicator, broom
2	Eraser smudge	ugly mark	scratch on a car door
3	Retains particles of lead	portable dirt supply	muddy tracks
4		tacky material	fly paper
5	Picked up in previous applications	accumulated dirt	air fliter on a clothes dryer
6	Smudges the paper	deposits dirt	finger print

I'll redo this analysis of the problem statement with the target of generifying individual objects, attributes, and effects (stated, implied, and inferred), as shown in the next table. Generification can be as broad as intuition leads. To keep this manageable, I'll limit the generifications to a reasonable sample; Table A4.

Table A4. Expansion of Table A3 with added generic terms.

	Object	Attribute	Unwanted Effect	Generification
1	Eraser			cleaner, eradicator, sweeper, vacuum cleaner, broom, sandpaper, solvent
2		dirty (implied)		wet, inky, dusty, gritty, sticky
3			to smear (paper)	to spread, -flow, -scatter, -disperse, -eliminate
4	Paper			surface, substrate
5		susceptible to smudging		rough, porous, friction, rigidity
6			to clean (eraser)	to abrade,
7	Smudge			mark, spot, stain
8		unsightly (inferred)		visible, reflectivity, contrast
9			to draw, -distract	to disturb, -trouble

To apply generic wordings as seeds they can be inserted in the graphic proforma to see what results, Fig. A13. This is a mental process of thinking, for example, "cleaner in contact with surface has the attribute dirty that interacts with the attribute rough of paper to smear causing an unsightly spot". In other words, the linguistic hemisphere of the brain is inserting the generic words into to a logical proforma that simulates a well-defined problem. While putting these concepts together the other brain hemisphere is trying to make intuitive sense of them presumably using the images they bring to mind and their associations with experience. Pressing the process logically, the dominant hemisphere can consciously focus on specific parts of the graphic and the things they represent.

```
Cleaner – dirty
                \
                 to smear – unsightly – spot
                /
Paper – rough
```

Figure A13. Proforma of the erasure smudge statement using generic terminology.

The first sentence in the last paragraph was ended with a somewhat misleading phrase: "… to see what results". This is a bit too passive. Actually you need to mentally iterate the wording of the proforma in your mind as you test different generic words, as you think of the point of contact between the two objects, as you mull the meaning of the action occurring, as you visualize the way the interacting attributes maintain or modify the state of the output attribute, and as you continue logically to sustain focus. When we get to problem-solving techniques later, other thought-provoking methods will be found that can be used in this process such as extremes of attribute intensities.

Contents of the previous table have been combined in the next table and rearranged into the proforma graphic order. This is an aid to scanning the possible combinations as one

Table A5. Rearrangement of Table A4 in the form of a complete proforma graphic.

	Object	**Input Attributes**	**Unwanted Effect**	Output Attribute	Object
O	cleaner, eradicator, sweeper, vacuum cleaner, broom, sandpaper, solvent ser				
A		wet, inky, dusty, gritty, sticky			
U ↓ A ↓ O			to spread, -flow, -scatter, -disperse, -eliminate, to abrade,	unsightly	paper
A		rough, porous, coefficient of friction, rigidity			
O	surface, substrate				

mulls different aspects of O–**A–U–A**–O images. Most ideas arise out of the Input Attributes column of the last table because this column contains causes and plausible root causes. In fact, the last two columns can be omitted.

When I examined the A–U–A combination, *sticky–to disperse–friction,* a solution concept came to mind:

> [ES-2] Make a spherical eraser on the end of a pencil that is rotated while being rubbed on paper and cleaned as the moving surface rotates from the paper into a housing where the dirt is wiped away.

I started to work on the attribute *wet* and immediately had an intuitive idea from that word alone:

> [ES-3] Make a two-sided sponge-type device that has cleanser-dispersing properties on one side and cleanser-absorbing properties on the other side. A little pressure on one side enables wetting and scrubbing and then press-and-release dabbing on the other side does the removal of dirty liquid.

This demonstrates the use of generic terms with logical focus maintained through the graphic proforma. You may enjoy substituting your own generic terms into the table and inventing new conceptual solutions.

Ideas will come to mind when using generic terms that introduce new objects and sometimes involve questionable attributes or effects. These are not to be filtered. Rather, they should be examined to understand why they came to mind. Is there a useful connection by way of metaphoric interpretation of the generic objects, attributes, and effects that can be modified and adopted for a relevant solution concept? How did intuitive thinking make the proffered association?

A variety of the techniques of mental problem solving have been discussed along with examples. We need also to examine the executive branch of this enterprise to see how the process is regulated for quality control – it is not a pretty picture!

Iteration in mental problem solving

As educated problem solvers we take pride in our training, our abilities, and our accomplishments, including peer recognition, in problem solving. The entire world and nearby space manifestly attest our technological accomplishments gained through logical thinking and fundamental understanding of nature. We especially pride our skill in orderly, logical thinking as we pursue knowledge. However, it could appear to the prying eye that a sham is at play. We are not orderly, logical thinkers!

That we are not orderly thinkers is evident in what we write, draw, paint, speak, and think that requires correction, reorganization, culling of irrelevance, editing, and doing it again (and again, and …). Most attempts at such forms of communication do not originate in finished, presentable, pride-inducing form.

That we are not logical thinkers is evident in false starts, retractions, fallacy, whim, vagary, and many other distractive facets of thinking. A little introspection during problem solving easily reveals the capricious and erratic nature of our thinking. Our minds wonder from logic to whimsy making disconnected leaps to think momentarily about unrelated things.

Then when are we logical?

We are logical in communicating including teaching. We learn from logical presentation of new ideas. Syllogistic presentations are compact, rationally sequential, and readily assimilated by our impatient brains. We communicate through logical discourse. We lose credibility when our arguments stray from logic.

This realization of how our thinking works suggests reconsideration of the philosophy of structured-problem solving methodologies. Structure in these methodologies gives them distinction. Modifications of structure lead to new methodologies. Clearly structure is essential to learning and some structures are better for this purpose than others. But structure can be a false restraint to creative thinking.

Heuristic innovation presents a different emphasis on structure. A minimum of structure is used in teaching and communicating its methods. No structure is advocated for thinking. Rather logical creation of seeds, the rapid, subconscious response of intuition, and the natural interplay of logical and intuitive thinking are emphasized. These are simple heuristics without structure.

The modes of thinking are encouraged through iteration of problem definition, analysis, and solution between alterations of metaphors. There is no recommended order of definition, analysis, and solution. Jumping from idea to idea in any phase of the problem-solving process is a natural process.

Heuristic innovation scrimps on structure to unencumber the mind of unnecessary procedure. With fewer extraneous details to worry about more time is available for truly creative thinking. Most of the foregoing discussion has demonstrated how that time can be creatively spent in iterative definition and analysis. Another aspect of problem solving, in all phases, is the innovative selection and application of heuristics. A brief discussion of these follows.

Natural Thinking in Problem Solving

Natural thinking is a term I use when describing our mental mode of solving problems. Reference is made to academically trained, experienced, professional problem solvers. We are trained to be highly critical, well-organized, logical thinkers. Of course, we are not!

Through our academic training we have learned to be logical. This requires organized, rational thinking. It would suggest that we proceed through problem solving as illustrated in Fig. A14.

Figure A14. The logical order of developing and solving a technical problem.

We like to think that this is what we do, but we don't. We don't even proceed as illustrated in Fig. A15.

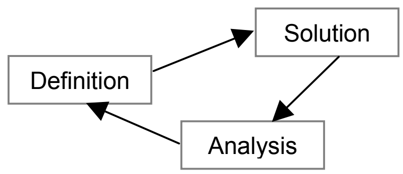


Figure A15. An improved order of problem solving (using iteration) but still one we don't follow.

More typical of our natural mode of thinking while solving problem is illustrated in Fig. A16.

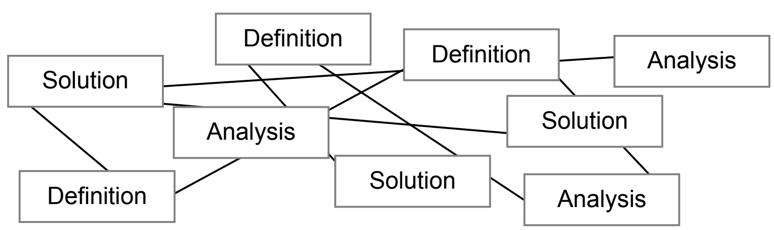


Figure A16. A disordered, non-logical, intuitive process typical of our mode of thinking when solving problems.

The disordered, non-logical (not illogical) intuitive process illustrated, I claim, is typical of how we think. It is our natural mode of thinking. The drawing is intended to illustrate spontaneous skipping about and intuitively reacting to newly encountered metaphors interspersed with sips of coffee, phone calls, and other distractions including daydreaming (the latter are not shown).

This is not to say that we are not logical. Rather it is to point out that logic and intuition have different places and roles in our thinking. Logic is necessary in rationalizing intuitive associations, formulating order, communicating, learning, and teaching. We do not always think logically. Ideas arise to our conscious from our intuitively inspired subconscious in unpredictable associations and incomplete formulations, but sometimes insightful and at other times whimsical or having undetectable relevance. This mode of thinking is effective in discovery of multiple opportunities, we are good at it, and we should encourage it. Subsequent treatment of these ideas requires logic to organize, verbalize, and communicate them – we are also good at this.

One bit of evidence for this situation is summarized in the old saw, “Put a problem on the table and everyone present will instantly try to solve it!” This is intuitive reaction of highly experienced technologists. It is natural.

To explain my position on natural thinking I’ll review several factors that influence our natural thinking: the neural chemistry of mental problem solving, brain lateralization, and the struggle between intuition and logic.

The neural chemistry of problem solving

We don’t know how our minds work in problem solving. But that doesn’t stop us from constructing and testing plausible models. A useful model can be drawn by analogy with recent research of neural scientists studying vision.

It is curious that problem solving, considered a stressful exercise by many and one to be avoided, can be a pleasurable experience for others. Why is this? Why or how does the brain derive pleasure from problem solving? A plausible clue may be found in a recent publication of two neuroscientists who studied cognition and perception. (See Appendix A1. “Infovores Crave Information”)

Biederman and Vessel posed the question, why is *acquiring information* so profoundly gratifying? I would like to parallel this with the question, why is *problem solving* so profoundly gratifying?

Problem solving is a pleasure. Well, it is for some people but not everyone. Those who enjoy problem solving may do it as an avocation or as a profession. Creative problem solving, as in invention, carries a badge of recognition called a patent. With or without recognition problem solving entails intellectual challenges that bring personal satisfaction – stimuli that bring us back for more.

Biederman and Vessel tested the hypothesis that acquiring information is gratifying by examining the neural chemistry of pleasure produced by optical stimuli and certain images they create. They characterize humans as infovores craving certain types of stimuli.

First they established a model of neural chemistry that predicts a gradual increase in pleasure as optical signals are processed along the optical path in the ventral cortex. Pleasure is modulated along this path as endomorphins attach to mu-opioid receptors. Along the path of neurons mu-receptors gradually increase in surface density on the neurons. As information passes along the optical path it is processed for recognition of simple image elements initially, then progressively more complex elements, until finally an image is developed that associates with experience. The amount of endomorphinmodulated pleasure increases with increasing density of mu-receptors that are activated with the development of increasing pattern recognition. Some associations are more pleasurable than others.

Second, they used functional magnetic resonance imaging (fMRI) to image blood flow (oxygen delivery) along the optical path as subjects were shown photographs. They tested image-induced pleasure by showing a series of photographs to two different groups of subjects. The first group (without fMRI imaging) was asked to rate their relative preferences among the photographs. The second group was shown the same photographs while individually being examined using fMRI. This group was not asked about their preferences. As predicted, the preferences of the first group correlated with higher rates of blood flow in the image-association areas of the cortexes of the second group. From this correlation was inferred support of the hypothesis that acquiring information is gratifying. The neural chemistry model explained why.

This research suggests, to me, a correlation between the pleasure of acquiring information and the pleasure of problem solving. Problem solving can involve stimuli from all five senses in recognizing and defining a problem. It is certainly a more complex mental process than image recognition stimulated by one sense. Technical problems typically involve many images to be processed for understanding. Evident similarities between these two activities include:

- Both are neurological forms of problem solving.
- Both are initiated by sensory stimuli.
- Both are searching meaning derived from association with experience.
- Both build progressively complex solutions to reach resolution.
- Both are subconscious activities.
- Both are intellectually rewarding.

Thus, it is plausible that our brains are electrically and chemically wired to produce pleasure in problem solving analogous with the neural chemistry of reward associated with visual perception. Then why doesn’t everyone enjoy problem solving?

The enduring reward of problem solving, as with the reward of image recognition, comes with successful association of processed, stimuli-generated information and experience. One factor in attaining reward must bear on the scope and depth of one’s mental database of experience. That is, the more understanding one has accumulated, the more success one can have in acquiring new understanding through problem solving.

Intellectual pleasure is one aspect of understanding problem solving. Another involves the modes of thinking that we consciously and subconsciously invoke while problem solving. These modes of thinking characterize the strengths or preferences of our two brain hemispheres. They are the essence of brain lateralization.

Brain lateralization

Brain lateralization is not a sequential division of labor. Both brain hemispheres receive the same stimuli at the same time and process them simultaneously but with different protocols and interests. Consider logic and intuition. Logic tends to be the preferred thinking mode of the language-dominant hemisphere whereas intuition tends to be preferred by the other hemisphere.

Logic is critical in communicating, defining, and analyzing a problem. It is so important to technologists that we are trained to eschew irrational intuition and whimsy. We have a variety of heuristics at our disposal to encourage logical thinking in problem solving; these include methods of constructing well-defined problems, methods for analyzing problem phenomenology, techniques for finding solutions, and flow charts for unifying overview of the process. We are so good at logical thinking we are regarded as lacking the creative skills of artists. Of course we regard ourselves as being very creative and bristle if thought otherwise.

I have two clues to the “otherwise” gained from industrial experience in organizing and leading “fresh-eyes” teams.

One clue arose from an informal survey conducted in a company to determine whom to invite to participate as inventors volunteering to mentor young engineers. To the surprise of the conductors of the survey and their manager, a small percentage of the division’s engineers had patents. This was the assumed metric of their innovative skills.

A second clue arose multiple times in leading fresh-eyes teams charged to solve quickly a particularly important problem. These teams were organized using two selection criteria: reputation for specialized experience and creative thinking. Individual performance in these teams exhibited very non-uniform creative thinking: all individuals were capable of incremental improvement of ideas proffered by someone else; all individuals were capable critics of ideas proffered by someone else; few consistently had intuitive insights of merit; and few consistently produced leaps of insight. My surmise of the reason for such non-uniformity in creative thinking capabilities is an overpowering, subconscious stress placed on logic at the expense of intuition.

Heuristic innovation addresses the problem of logic overpowering intuition with heuristics for addressing the struggle between intuition and logic that can reverse this effect.

The struggle between intuition and logic

Acquisition of information to begin formulation of a problem statement is an intuitively driven process – we seem to know in advance the kinds of information that will be needed. It is also a logically driven process as we examine the information at hand to evaluate its completeness and validity in order to determine whether more information may be needed. In this acquisition process there are occasional moments of satisfaction on *recognizing* that facts are beginning to fit together (recognition is key). This increases one's *anticipation* encouraging further pursuit of the unsolved problem – inklings of pleasure to come.

We have seen that perceptual preferences of photographs arise in the association areas of the brain as connections are made with stored information – recognition. Presumably, analogous association areas influence pleasure in problem solving as newly collected information and associations with experience hint at success to follow.

In addition to recognition and anticipation in problem solving there are other causes of satisfaction. One is *intuitive leaps of insight* and another is *development of logical order*. Intuition and logic are two independent modes of thinking usually assigned to different hemispheres of the brain. They play complementary roles in problem solving. Both bring rewards.

During problem solving, logic is in the driver's seat. Logic decides where to go and not go, what to try and not try, what to accept and not accept, and other control-type decisions. The dominance of logic in problem solving has been associated with language; they both reside in the same brain hemisphere. Logic and language are conscious activities.

While logic is busily producing pleasure through rational order the subconscious is actively using intuition to solve the same problem. Intuition produces pleasure in the discovery of new insight and the speed in doing so (in team-like competition). The two modes of thinking are in competition as they crave pleasure-generating contributions to solutions. Logic, bolstered with language, can build persuasive arguments for squelching intuition. Intuition, unfettered by rational, rapidly tries many associations of problem components, sometimes with near instantaneous insights for solution concepts.

Logic employs words and graphics as it rationally steps through its resources of knowledge and meticulously builds rational understanding. This requires time consuming checks and cross checks between assumptions and experience. The product is pleasurable.

Intuition, on the other hand, is sparked into action by the metaphorical power of the same words and graphics. It wastes no time on logic. Consequently, solution concepts arise in a sporadic mix of the reasonable and the whimsical. New insights and leaps of insights are most pleasurable.

So why doesn't everyone enjoy problem solving? And why are not all problem solvers successful inventors? There may be as many reasons as there are anti-problem solvers. A common factor must begin with the initial realization or awareness of a problem. This is a conscious activity. Its understanding comes through its logical perception. Anti-problem-solvers seem to show antipathy toward grinding through logical reasoning. What about some (even professional) problem solvers not being inventors? This could relate to their having never developed awareness and controls for throttling logic's overriding influence on intuition. Hence, these problems solvers may be more rewarded by logic, having had less experience with the thrill of leaps of insight.

Whatever the reason for fewer inventors there is little reason for not learning how to invent. Problem solving methodologies are available that teach how to solve technical problems with inventive concepts. They are very uneven, however, in their treatment of concerns raised above.

It should be noted that corporations employing technologists as problem solvers are well aware of the limited resources for creativity that exist among typical technologists. Evidence for this is the frequent need to assemble fresh-eyes teams of "specialists" to tackle tough problems or produce a sudden increase in intellectual property. It is also evident in the industrial need of textbooks, special training, and consultants in structured problem solving.

Resolving the struggle between intuition and logic

The sporadic nature of our natural, subconscious thinking uncovers unexpected insights and interesting solution concepts. The logical club of our trained, conscious thinking beats down hints of undisciplined procedure and instantly filters intuition. Clearly there is value in directed intuition. But we have no control over our subconscious. How then can intuition be directed?

Logic can be directed with practiced use of verbal and graphic diagrams based on rational we have been taught – structured problem-solving methodology. Intuition reacts to verbal and graphic metaphors, which seemingly could lead anywhere – whence comes unwanted whimsy. Heuristic innovation combines guidance of logical words and a simple diagram with metaphors that inspire intuition while encouraging natural thinking.

If we don't know how the subconscious works how can we select effective metaphors? The assumption of heuristic innovation is that problem solving is a form of information gathering involving interpretation and recognition of stimuli. The stimuli of problem solving are the words and images contained in problem description. Recognition involves recorded experience from which associations are discovered. Producing a well-defined problem brings logical focus of the conscious to a simplified, but critical set of stimuli regarding an unwanted effect. These stimuli spark the subconscious into action.

Well, maybe they do. Couldn't a slightly modified set of words and changes in drawings have better (or worse) effects? And shouldn't the effectiveness of metaphors vary with individuals? Yes, to both questions.

Such variance is addressed with the ploy of iteration. A well-defined problem is developed gradually with small changes in words and graphics between frequent iterations. No logical hindrances are applied to direct one's thinking, such as flow charts;

the mind is allowed to jump about exploring every spark of intuition. Definition, analysis, and solution happen in uncontrolled sequences. This style of problem solving optimizes the use of one's natural thinking capabilities. It encourages an effective interplay of logic and intuition.

Brain divergence

Another aspect of cognitive psychological studies that is relevant to this discussion is "the idea of semiotic evolution from the right-hemispheric 'archaic' mentality towards the left-hemispheric 'modern' is presented in neuropsychological developmental and cross-cultural aspects". (Ref. 8) In essence, right-hemisphere's experience-based thinking is considered to have primitive origins in human biological evolution while left-hemisphere's logic-based thinking originates in cultural evolution.

Brain lateralization refers to the varied and complimentary modes of thinking preferred by the brain hemispheres. Brain divergence refers to two styles of thinking; one is empirical thinking considered to be prelogical or primitive as compared with more recently developed theoretical thinking. Brain divergence studies, by Deglin and Kinsbourne (Ref. 9), used electroconvulsive therapy (ECT) to suppress one or the other hemisphere. While psychiatric patients were recovering from transitory suppression of one hemisphere they were given syllogisms to solve. "While the right hemisphere was suppressed, syllogisms were usually solved by theoretical, deductive reasoning even when the factual answer was known a priori, the premises were obviously false and the conclusions were absurd. While their left hemisphere was suppressed, the same subjects applied their prior knowledge; if the syllogism content was unfamiliar or false, they refused to answer." In other words, the right hemisphere lacks logical reasoning.

These two references are included because they show a different way of looking at brain function in a specific type of problem solving using information obtained while a brain was temporarily functioning with only one hemisphere. In other studies, discussed in Part B, commissurotomy patients ("split brain") were studied to identify the thinking modes of the hemispheres.

Of particular interest to the goal of heuristic innovation is the concluding prediction in Chernigovskaya's paper: "However, in spite of an overall 'left-oriented' vector we probably face the next stage of mental development – a tendency to evaluate the world and to process information in a Gestalt, right-hemisphere way. So, we still have a long way to go before we master our own potential skills". I presume that this refers to potential skills in problem solving.

Transition from structured to unstructured problem solving

Heuristic innovation's resolution of the struggle between intuition and logic appears to eliminate structured problem solving. It does, but only for those trained in structured problem solving. For those of us who practice structured problem solving it is a significant transition to desirable simplification. For novices to innovative problem solving it is a shortcut to effective practice. However, most of the heuristics of structured problem solving are retained.

Many of the components of heuristic innovation are carried over directly from USIT. These are shown in the following table.

Table A6. Association of components of heuristic innovation with original USIT components.

Problem Activity	USIT Components	Heuristic Innovation
Situation description	Objects, Attributes, Unwanted effects	Objects, Attributes, Unwanted effect
Definition	Well-defined problem in one step	Well defined problem in small increments
Analysis	Object-Attribution-Effect diagram; Closed world, qualitative-change graph, solution-problem morph diagram, particles	Object-Attribution-Effect diagram with extrapolation to plausible root causes
Solution	Six heuristics: Uniqueness, Dimensionality, Pluralization, Distribution, Transduction, Generification	Three solution strategies: Utilization, Nullification, Elimination
Flow chart	Sequential Definition ➔ Analysis ➔ Solution	None: Iteration of Solution, Definition, and Analysis in any sequence
Mental process	Sequential (logical) application of tools for definition, analysis, and solution	Iterative mix of logic and intuition involving verbal and graphic metaphors using natural thinking

New heuristics

In developing heuristic innovation it was discovered that new heuristics could be derived from a simple set of axioms and three solution strategies. These are discussed in Part C. Before looking at this work we will first examine, in Part B, how heuristics are applied in problem solving and how traits of our lateralized brains participate.

Exercises (See pp. xx –xx for more exercises.)

A. Consider the problem situation, “The newly laid asphalt sticks to vehicle tires and splashes onto vehicle parts making a mess that is difficult to clean.”

1. Reword the statement for clarity and replace “vehicle” with a specific example.
2. Identify points of contact of objects in your description.
3. For each point of contact identify a pair of active attributes and construct a proforma graphic.

B. Invent a problem for a flag pole.

C. What is the difference between a solution to a problem and a solution concept? Give an example.

B Application of Heuristics

```
          A
          ↑
O – A → U ← A - O
    ↑       ↑
    U       U
   / \     / \
  A   A   A   A
```

Preface

Stored inside of our craniums are two amazing machines of cognition – our personal resources and tools of knowing. Sensory data are transmitted simultaneously to both of them from five outlying information-gathering centers. Never idle, they continuously sort, store, and process these data. They have their own memory storage, organization, recall procedures, curiosities, and limits of concentration. They have their own preferences for method of processing data. They approach problem solving differently and they sometimes get different answers. Should there be clashes, and occasionally there are, an interconnecting mediator resolves any issues. They are two hemispheres of our brains and they communicate through their joining corpus callosum (the mediator).

Cognitive psychologists have shown that the brain hemispheres can be characterized by their preferred approach to processing information. Terms like analytical, abstract, rational, logical, and linear resonate with images of how we problem solvers think. We easily find examples of our problem-solving methodologies that enable us to lay claim to all of these traits. In fact, we are quick to defend them.

Another information processing method should be mentioned, one that is more important than those above. It is verbal cognition – the use of words to name, describe, and define. At this, we professional technologists are expert. Successful communication with others requires logical use of well-defined words to explain our linear, rational reasoning.

When problem solving our minds jump uncontrollably to many relevant and irrelevant areas. Ideas come to mind, sometimes haphazardly, and are instantly filtered; some are discarded, some are kept, while some are modified and kept. This happens even though we may have in mind a rational, strategic path to follow involving problem definition, analysis, and solution – the logical stuff. Later we sort through these findings and figure out how to string some of them together to support rational conclusions – a trial-and-error procedure. This disorganized collection of ideas is assembled rationally as we prepare to communicate our conclusions to ourselves and to other technologists. Logic sets in. Many concepts pass through our minds as we momentarily grasp one, test it, and look for another. It is a chaotic, intense, challenging period of thinking. Our mental processing procedures, named above, come and go without conscious control. A common reaction to a problem-solving session is to express mental tiredness.

The thought process just described is so rapid and intense as to be nearly intractable consciously. For example, it is common to proffer solutions even before a problem has been fully stated. Is this logic in action?

Part B examines the thinking traits we use of our lateralized brains and our applications of conventional heuristics in solving real-world problems. Example problems and solutions are presented along with introspection of the problem-solving process. These examples are presented to establish a basis for a theoretical treatment of newly derived heuristics, their derivation, and their application in Part C.

I think that the most challenging part of problem solving is definition. The most interesting part of problem solving is prediction. And the most rewarding part of problem solving is confirmation. We will focus on the first part to learn techniques for accomplishing the other two.

Origins

The transition from structured problem solving to non-structured problem solving is discussed briefly to clarify expectations of such methodologies and of heuristic innovation.

Introduction of the problem-solving methodology known as TRIZ in 1947 (Ref. 3) led to a number of spin-off methodologies. Their development was motivated by the need for simplification of TRIZ. Among these appeared ASIT (Ref. 4), SIT, and USIT (Refs. 1, 5, and 6), and others, each reaching for further simplification of the previous one (acronyms are explained in the introduction). They all are sequential descendants of the original TRIZ. TRIZ began as an empirical methodology without a unifying theoretical backing. Its empiricism is based on a continuing growth of amassed patents from which are gleaned examples of problems that fit the TRIZ scheme of deduction.

It is important at the outset to understand the desired efficacy of structured problem solving and the consequential expectations of heuristic innovation. When and why do we turn to structured problem solving? There are at least two motivations. The most common occurs when, in addressing routine problems, our intuitive methodology wanes and we essentially run out of ideas. [1] The second motivation occurs when we desire creative insights with potential for inventive solutions. Neither of these two reasons necessitates a structured methodology. The first motivation, the waning of conventional methodology, implies that a concerted effort has already been expended in solving a particular problem. The second motivation implies that invention has been separated from routine problem solving.

The strategy of heuristic innovation is based on five assumptions:

1. The problem solver has already addressed the problem using intuitive methodology (i.e., exhaustion of ideas by brainstorming).
2. The need for solutions of routine problems and the need of invention are the same need.
3. Routine solutions and inventions differ only in current filters used to judge their value.
4. The most important concern is the need for new insights into an already examined problem situation.
5. New ideas come to mind when the subconscious is stimulated with new seeds.

Conventional structured, problem-solving methodologies divide the process into three sequential phases: problem definition, problem analysis, and the application of solution techniques. These are reduced to one phase in heuristic innovation – iterative problem

[1] This situation, exhaustion of ideas, is key to appreciation of the power a problem-solving methodology. It is created in USIT classes by having students name every known solution to a problem they can think of before beginning a USIT treatment of a problem. You are encouraged to do the same.

definition. During iteration of problem definition the problem solver creates solution concepts using three simple solution strategies and other heuristics.

Structure is introduced in problem-solving methodologies in the form of algorithmic-like procedures, which include graphs, hierarchical diagrams, and flow charts. Some have codified databases of solved problems. These involve procedures for classifying a problem to be solved that enable its codification and aid searches of the database for relevant examples. Some use computer software for analysis and database searches. A common complaint of such structure is that it makes the methodology too complex and tedious. It seems that structure begets structure with encroachment of complexity.

Heuristic innovation emphasizes our natural mental processes of problem solving. It includes minimization of logic in strategic places to allow one's brain the freedom of natural illogical skips and jumps in arriving at useful concepts. Structured methodologies, by design, are guided by the logic of their structures. These may unconsciously curtail illogical forays of our imagination. Heuristic innovation uses simple heuristics designed to seed the subconscious and spark innovative insights from both cognitive hemispheres. Heuristics are the tools for discovering new thought paths.

Proof of efficacy

A common shortfall of all problem-solving methodologies designed for innovation, heuristic innovation included, is lack of proof of their efficacy. How do you know they work? That they have logical structure and logical tools is no proof that they work. Results obtained using a problem solving methodology may or may not have been generated by the methodology. Since the creative results we seek are subconscious inspiration that suddenly appears in the conscious their roots are unknown. In short, we don't know how our brains work to invent. Consequently, offering proof based on the use of engineering designs and solved problems as examples of what a problem-solving methodology is capable of is syllogistic reasoning. Too often these examples were solved without the benefit of the methodology in question.

Furthermore, case studies in which a particular methodology was applied are no proof that the methodology works. Rather they show to what kind of problem the methodology was applied, and to a degree, how a problem solver applied the methodology, and the results obtained. Yet, the problem solver cannot claim that the inspirational results belong to particular tools or techniques of the problem. We simply do not know what goes on in our subconscious during problem solving. Yet we do know subjectively that our problem-solving skills are improved using problem-solving methodology. Until cognitive psychologists do definitive research that settles this issue we are left to our subjective feelings.

Proof of the efficacy of heuristic innovation is limited to personal testing and subsequent introspection.

Introduction

The structured methodologies that led to heuristic innovation are compared briefly.

Problem solving skills, invention skills, and the aura of mystique accompanying inventors are within the reach of anyone trained in modern methods of structured problem solving. Unfortunately, this type of training is relatively new and only slowly being recognized in technical academia. Resistance to its adaptation is mostly due to complexity of early methodologies, a lack of theory to support them, and a lack of proof of their efficacy.

Creative problem solving, with invention as a practical spin-off, is the topic of heuristic innovation. The goal is efficiency that produces multiple solution concepts in minimal time. The strategy is to adapt heuristics to the special interests of our cognitive hemispheres and to our natural, sometimes non-logical, thinking process. Anyone having an innate interest in problem solving and training at the introductory level in engineering and science will benefit from this methodology.

Structured problem solving from TRIZ to USIT

Structured problem solving, since 1947, has been influenced by the work of the inventor, Genrich Altshuller, of the former Soviet Union. He developed a methodology for solving inventive problems known by its Russian acronym, TRIZ, pronounced “trees” (Ref. 3). By 1980 TRIZ had begun to appear in the United States as a hirable expertise of a few emigrant engineers and scientists trained in the former Soviet Union. Since the 1990’s this methodology has been taught in only a few schools.

A major complaint of TRIZ is its difficulty to learn and complexity to practice. This has led to the development of a group of consultants who market their expertise as TRIZ specialists. Training is also available from some consultants and specialized TRIZ software is marketed to aid its application.

In the late 1980’s and early 1990’s Roni Horowitz and his professor (Ref. 4) began developing a simpler version of TRIZ now called advanced systematic inventive thinking (ASIT). The method has proven to be easier to learn and apply and has a good following. Course information is available on the worldwide web.

An earlier version of ASIT was introduced into Ford Motor Company in 1995 and modified for use in the automotive industrial environment. This version was named structured inventive thinking (SIT). Upon retirement from Ford I began developing new tools and teaching unified structured inventive thinking (USIT), to non-Ford interests, using a textbook published with Ford’s permission. (Ref. 1) Teaching of USIT in industrial settings inspired further development of tools and pedagogy to facilitate learning and application of this type of structured problem solving. This history led to the development of heuristic innovation.

The structured problem-solving methodologies ASIT, SIT, and USIT have a common heritage in TRIZ. All four methodologies justify their procedures not on a fundamental theory but on a syllogistic type of deductive reasoning.

The origin of TRIZ lies in an early recognition of apparent similarities in selected patents authored by inventors in the former USSR. Although the subject matter of the patents differed the general approach to their unique discoveries had similarities, as identified by deduction of the catalogers. As these similarities were recognized and cataloged, along with their solutions as examples, a large set of heuristics was developed that simulated the deduced approach to problem solving.

The resulting methodology works as follows: a real world problem is structured in standardized terms allowing recognition of standard patterns by which selected patents have been previously cataloged. A particular pattern then yields cues to tabulated examples of patents having generic similarities. The examples provide cues for potential solutions to the original problem. The method provides heuristics for analyzing a problem. These heuristics also do not have a theoretical basis. They have metamorphosed from the historical lore of problem solving into a common terminology.

Although not justified by theory, TRIZ derives credibility by association with a large number of patents. Patents are assumed to reflect a high level of creativity. The volume of cataloged patents continues to grow and catalog searches can be performed on computers.

ASIT, SIT, and USIT are relatives of TRIZ that are simplified versions of TRIZ, and sequentially of each other. They use a smaller number of heuristics for analyzing and solving a problem and do not reference cataloged patents. However, their heuristics can be seen as modified versions of TRIZ heuristics although they may have been developed independently.

Apparent similarities of the heuristics used in these four methodologies are a natural consequence of the field of application. All four methodologies were developed originally for the same type of problems, namely engineering design-type problems. They even have most of their initial development based on mechanical engineering examples. The language and imagery of mechanical engineering imbues each of the methodologies with a similarity of logical reasoning.

Heuristic innovation, by comparison, has no underlying catalog of patents or solved problems for reference. It is based on a theory of heuristics for solving technical problems that was derived from a set of six axioms. These axioms are self-evident truths derived from experience in the application of heuristics to solve technical problems. They are strongly influenced by the author’s experience in developing and teaching USIT.

Consequently, heuristic innovation has similar language and imagery of its forgoing methodologies.

Heuristic innovation has a fully generic representation built into it that is expected to support its application to diverse fields. However, this remains to be demonstrated.

The methodology makes frequent use of a simple cognitive model of inspiration; namely, that creative ideas arise from unusual insights. Furthermore, “seeding” the subconscious with language and image metaphors to engage both the left- and right-cognitive hemispheres of one’s brain can create unusual insights. This model does not derive from cognitive psychology research. Instead it is an assumption justified by introspection.

The Model of heuristic innovation

The model used in heuristic innovation for solving problems is composed of simple concepts of how we think about problems, how we can discover new insights through ambiguity, and how we can stimulate both of our cognitive hemispheres to generate new concepts. It has techniques for evading the critical rigor of logic while involving both logical and intuitive cognition. It is designed to make the most efficient use of personal thinking traits of both brain hemispheres.

A common thinking trait is our lack of logical control as our minds jump about. The rigor of logic is overridden in heuristic innovation by encouraging rapid leaps between concrete characteristics of a problem and ambiguous metaphors. Logic is needed to organize the results of our thinking for communication to others. Logic is not needed to seed our subconscious and reap useful results. A lack of logic might be inferred as a process lacking focus, but keen focus is established and maintained in the subtleties of object minimization and point-of-contact analysis – two problem simplification heuristics.

Problem solving begins after collection and organization of definitive data from which a general problem statement is constructed. Heuristic innovation starts with a verbose problem statement that is as comprehensive as the problem solver wishes. Iteration of problem definition begins with this problem definition and moves incrementally towards a simple statement having a single unwanted effect and a minimum set of objects. Through iteration a well-defined problem statement develops gradually. During these iterations solution concepts are created as the process of simplification uncovers new insights. The dynamics of iteration – gradual change toward ambiguity – allow each metaphor variant to seed new ideas.

A problem statement has verbal and visual renditions. The statements have four critical parts: objects, attributes, unwanted effects, and root causes. Each critical part is a potential point of iterative modification for variety of renditions. The effectiveness of their modifications lies in the power of their metaphoric renditions to spark new insights in a problem solver’s mind. But effectiveness cannot be predicted. Therefore we iterate through words and sketches to test many variants.

Intuitive problem solving – seed and reap

Intuitive problem solving (brainstorming) works and we are all good at it. At the very first reading, or hearing of a problem, we immediately attempt to think of a solution. Phrases create instant mental images, and both phrases and images seed the subconscious producing relevant and irrelevant associations in our conscious state. Relevance is a judgment resulting from filtering. As experienced problem solvers we are experts at judging solution ideas – especially when filtering other people’s ideas.

Intuitive problem solving can happen without conscious effort or we can induce it with verbal and graphic seeds. Because it is natural, effective, and we are so good at it, its principles are maintained in heuristic innovation. Our purpose will be to exploit it to its fullest. One method of doing this will involve verbal and graphic metaphors.

Example of intuitive problem solving using seeding

Consider this problem:

> "Why does …"
>
> > Note how this interrogative phrase immediately prepares your mind for a question. A problem is an unanswered question. However, not every question poses a solvable problem.
>
> "Why does sticking a pin …?"
>
> > As the problem unfolds one's mind rapidly creates images from the printed words. The phrase, "… sticking a pin …", causes me to see a hard, pointed object in motion toward something yet to be defined. The word and the image it creates activate both language- and image-oriented thinking.
>
> "Why does sticking a pin into a balloon …?"
>
> > Now I see a balloon as the target and the pin piercing it. In fact, my initial image, as just described, caused immediate question about whether the balloon was inflated (logic), which was my initial assumption. I then saw an un-inflated balloon lying on a table. And I wondered of what material it was composed, rubber, plastic, or some other elastomer?
>
> "Why does sticking a pin into a balloon cause it to burst?"
>
> > As the question ends a solution comes immediately to mind. "Because the pin is sharp!" This answer required no conscious effort; it just came to mind automatically – an intuitive idea. To some it is a logical answer; to others it may not be.
>
> It seems obvious that the answer given came from a mental databank of experience. If I had never seen a balloon burst when stuck by a pin I probably could have deduced a plausible answer. However it would have required conscious effort. And it would have been possible only if my databank held information generically characterizing pin and balloon.
>
> As the answer came to mind it struck me as being too glib. It doesn't satisfactorily address the issue of why the balloon bursts. The problem did not state that the pin was sharp; that was an assumption (based on memory of a generic pin). And if it was sharp, how does sharpness cause bursting? These thoughts bring to mind an image of a pin-shaped object causing an increasing depression in an inflated balloon as the action of "sticking"

progresses. That image raised the question of whether a blunt pin would also burst the balloon? And another; Does the balloon need to be inflated? If so, how much? More images and questions are being formed.

I carried the thinking process much further, even into the molecular level of wondering how an elastomer generates and responds to local stress. You may enjoy seeing how far you can pursue root causes of bursting in your own mind.

The purpose of this example is first to see how words create images and together they seed the subconscious and spark ideas that instantly rise to the conscious as intuition.

The purpose of heuristic innovation is to aid us in creating effective metaphors for seeding our subconscious databanks when intuition has been exhausted. Three mental processes are involved: problem definition, seeding with metaphors, and reaping results. These are illustrated in Fig. B.1.

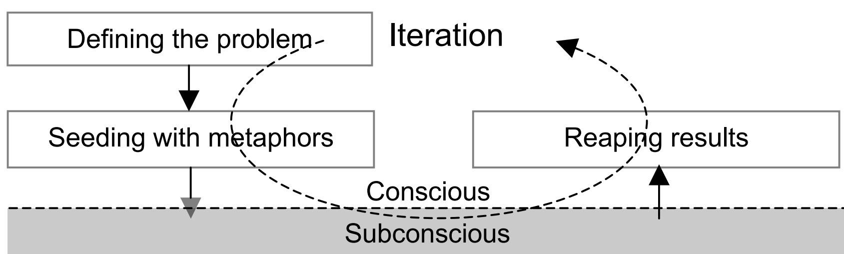


Figure B.1 Three mental processes used iteratively in heuristic innovation: defining the problem, seeding the subconscious with metaphors, and reaping the results.

Note: A former criticism of USIT may be useful to comment on.
"USIT assumes that all solutions to engineering problems already exist in one's head!"
Of course, this is not true. What exists in one's head is an enormous data bank of experience. The process of seeding prods both cognitive hemispheres metaphorically to find relevant information. How they find it, and what they do with it, is unknown. What is known are the amazing ideas they present to one's conscious.

Logical problem solving – a linear path

We also are good at solving problems logically. Reading of the above example sparked an intuitive response while at the same time raising logical questions of cause and effect. Questioning the cause of an effect and searching plausible associations is a process of linear reasoning.

Technologists are trained to understand phenomena. The curiosity they engender and the subsequent explanation they generate give considerable intellectual satisfaction. An explanation that is not forthcoming presents a challenging problem. A natural response is to search plausible causes and effects. Technologists bring large databanks of phenomenological information to bear on problems.

Their reasoning process compiles multiple phenomena and then organizes them into a logical, linear sequence – from the effect to its cause. The end is accepted as a satisfactory explanation. The process flows as follows: If A then B, if B then C, etc.

> Consider one's logical reactions in the example (language-oriented logic):
>
> | | |
> |---|---|
> | "Why …", | causes expectation of a coming question. |
> | "… does sticking a pin …", | is inferred as action beginning an effect mentally formulated in an image of a moving object that looks like a pin (whatever image pin invokes). |
> | "… into a balloon …", | sufficiently completes the action to bring experiences to mind related to sticking a balloon. |
>
> Image associations at this point are immediate although no problem has been stated. These images from memory carry with them their original situations, which may have been problem situations. Already the mind is primed to offer an intuitive answer when the problem is completely stated, if of course, experience fits the new situation. Inappropriate or illogical responses also occur.
>
> | | |
> |---|---|
> | "…cause it to burst?" | "Because the pin is sharp!" (An intuitive response.) |
>
> Conscious logic following this response begins the mental assembly of a linear series of causes and effects usually prompted by questions or observations of fact. For example:
>
> - Pin is sharp, sharp cuts; balloon is softer than pin and is cut by pin.
> - Burst implies suddenness, why is balloon cut suddenly? Balloon is thin. Balloon is pressurized to near its point of bursting. Pin has momentum allowing rapid penetration of balloon to a point of bursting.
> - Is momentum the whole story? Does any amount of momentum produce suddenness?
> - …

And so on, as conscious logical questioning leads the search of rational solution concepts.

Intuitive and logical responses work together. Intuition starts the problem-solving process with a proposed concept. Logic critiques, tests, rejects or modifies the concept for further testing. Herein lies a potential problem for technologists trying to invent. Assertive, language-based, logic driven critique can veto image-based, intuitive ideas.

Problem definition – the heart of heuristic innovation

It is well recognized that problem definition is the most important part of solving a problem. Unfortunately it too often gets scant or inept attention at the hands of many problem solvers including some experienced problem solvers. The most probable reason for this shortcoming is the lack of an effective definition of a well-defined problem. Definitions bound logic. Lack of a definition leads to any problem statement being acceptable without testing its adequacy. A secondary reason may be a tendency to rush through the formal phase of structured problem solving to get to the more interesting application of solution techniques. Whatever the reason, experience in teaching structured problem solving (USIT) has shown that students who execute a problem definition without prompting from the instructor tend to do so in too glib a fashion to appreciate and realize its benefits.

This shortcoming is eliminated in heuristic innovation by building the entire problem-solving process around one phase – problem definition. Moreover, developing solution concepts is encouraged throughout the procedure. This obvious omission of the linear logic of problem definition, problem analysis, and then solution is, in fact, more similar to an inspired creative mind that jumps uncontrollably, but inspirationally or curiously, from one step of the process to another without conscious reason. For this purpose we adapt the USIT definition of a well-defined problem and then spend our entire time developing one. Solution concepts occur during the creation and iteration of the well-defined problem.

Example of a not so well defined problem
"Why does sticking a pin in a balloon cause it to burst?" This is not a well-defined problem, but it is part way to one. Yes, we were able to solve it, so why is it not well defined? We gave an intuitive answer to the question but we did not address the problem at the level of its characteristic attributes. Why not? It is because no attributes were stated in the problem that could aid relevant or specific focus. *A well-defined problem is stated in terms of interacting objects, pairs of causally active attributes* [2]*, a single unwanted effect, and root causes. It is sketched in the form of contacting objects.*

[2] * The use of interacting objects having attribute pairs is a ploy for generating new analytical perspectives of a problem. It is not based on theory.

Example of a well-defined problem

"Why does pressing a sharp pin into an inflated balloon cause it to burst suddenly?" This statement with its accompanying sketch produces a well-defined problem. It has interacting objects, *pin pressing on balloon*, active attributes, *sharpness and rigidity of pin (implied) along with pressure and elasticity of balloon*, and a single unwanted effect, *bursting of the balloon*. And it has a simple sketch of two contacting objects (Fig. B.2). In this case, the problem posed is to identify root cause of bursting to answer the question, "Why?" In other problems root causes are required to complete a well-defined problem statement.

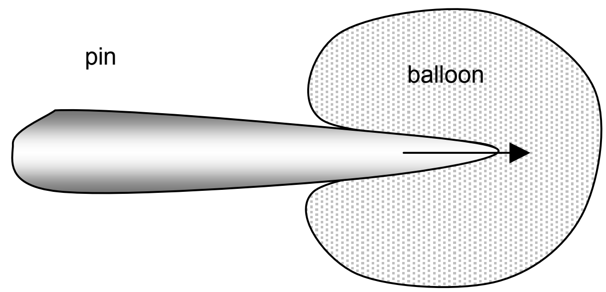


Figure B.2 Sketch of a sharp pin pressing on an inflated balloon.

Notice that the sketch is simple, having only two interacting objects. The shape of one object and the vulnerability of the other bring focus to the actual point of their contact. It is a plausible representation of a mental image the verbal statement might create. However, a discerning problem solver will recognize a major shortcoming of this sketch – it contains the objects of concern, it represents their interaction, but it does not contain the problem! How would you fix that?

[If you give up on the answer, here it is. Gnitsrub noollab eht wohs. (Don't write like this while standing. You may become dizzy from looking back over your shoulder.)]

Engaging Both Hemispheres of Cognition

Metaphors – thought starters

As we hear or read the description of a problem its metaphors enable subconscious construction of mental images by associations with our past experience. If these are deemed inadequate (logical critique) then new images, not from past experience, may be constructed consciously.

When you first read, “Why does sticking a pin …?”, you had time to form an image of pin before encountering the rest of the problem. Since no sketch had been provided, you created your own images. What image or images came to mind? Did you think of a straight pin, a cotter pin, a linchpin, a diaper pin, a safety pin, a fraternity pin, a wristpin, a tiepin, a clothespin, a hairpin, a belaying pin, a duckpin, or others? Did you think of homonyms (pig pen, fountain pen)? Did you think of different parts of speech (pin the tail on the donkey)? Did whimsical images come to mind (letting the air out of a windbag)? Such simple metaphoric insights are starting points of thinking paths.

Upon encountering the word pin in the opening phrase of the problem statement it creates some kind of mental image that may or may not be the intended one. For the originator of the problem the word pin is a metaphor for a concrete object. The reader may or may not translate the metaphor into a graphic replication of the original object. Yet the reader, on hearing the complete problem statement, will create a mental image sufficient for personal understanding, unless, of course, there is no familiarity with the objects named or the unwanted effect. Furthermore, this understanding will suffice to produce an intuitive answer to the question.

Example of effective metaphors

Note the increasing generality of the following three statements.

1. Pressing a sharp pin into an inflated balloon may cause it to burst.
2. Pressing a sharp object into a fragile object may cause it harm.
3. Pressing one object into another may cause damage.

On reading the third sentence what examples come to mind (in 30 seconds)?
You go first.
I thought of the following:

A collision of two automobiles
Swatting a piñata
Pricking a blister
Tossing a water-balloon
Slicing butter
Puncturing a bicycle tire
Biting an apple

Sinking of the Titanic

> It is important to understand that all three of the numbered statements preceded discovery of the above eight examples. The last of the three statements, the more general one, might have produced the same results, but the exercise was not conducted that way. The process of iteration with increasing generality gave all three sets of metaphors a chance to influence my search for examples. This is the way heuristic innovation is conducted, through increasing ambiguity.

Generally a problem statement begins as a verbose description of a problem situation accompanied with detailed illustrations. Its purpose is to capture adequate information to give the problem solver comfort and assurance to continue. From this point on the problem solver gradually identifies and pares away unnecessary detail to simplify the problem statement.

Paring of problem details requires thoughtful rational. The problem solver must mentally justify this rational within the ability of personal training and experience. Rational, thus created, is new insight to the problem. Discovering and selecting a single unwanted effect and then searching its root causes identifies unnecessary detail. Gradually the problem is reduced or focused ideally on a single point of contact. The process is iterated until the problem is finished. Throughout this iteration metaphors are introduced, tested, and modified.

The effectiveness of a metaphor lies in its ambiguity. That’s right, rich metaphors are ambiguous! If ambiguous, how can metaphors be allowed in solving technical problems? Doesn’t this degrade technical precision? It smells of poetry!

The answer to this apparent contradiction arises in understanding the overall purpose of heuristic innovation and its execution, which lie in the magic of poetry. The answer follows in the section on hemispheres of cognition.

Note: Ambiguous metaphors may provide multiple paths to the same concept. However, this does not mean that ambiguity is convergent. Should multiples paths reach the same concept it is likely that subconscious constraints are in effect that reflect familiarity with the subject plus the influence of logical thinking.

Awareness images

Can we “see” images without naming their contents? Yes. For example, walk through a familiar room or scan your eyes from area to area in a familiar room (say in your home). As you do this you can move or scan too rapidly to name a particular object yet you are aware that familiar images are passing by; shapes, colors, sizes, relative proximity are all accepted without stopping your eye movement. This must be intuitive-seeing without language. It probably results from intuition’s quick holistic recognition of familiar space.

Have a strange object placed in view in the room, or move an object to a new position, then enter the room and try rapid scanning without stopping. Intuition will call attention to the object, halting the scan, and logic will identify its name.

Or, walk through your house while reciting a poem and concentrating on its words. You are always aware (mental images) of your surroundings without focusing on any particular object. Focusing on an object causes the linguistic hemisphere instantly to name (identify) the object.

Metaphorical images

Language metaphors can be written, spoken, spelled, coded, and manually signed. All forms produce mental images, as do non-language metaphors. Note the following examples with my first reactions to the listed language metaphors. What are your reactions?

Table B.1 Example reactions to different kinds of metaphors.

Language metaphor	**Reactions**	
	Verbal	**Image**
Word	Flower	Blossom
Non-language metaphors		
Visual	Silhouette	A famous person
Sound	Rustling	An intruder
Smell	Hot grease	Fried chicken
Tactile	Itching	A mosquito
Taste	Popcorn	A cinema

Metaphors are the lifeblood of creative thinking – poets cherish them, logicians abhor them.

Hemispheres of cognition – two innovation resources

Poets and artists know that hint, suggestion, vagueness, and allusion arouse creative communication. Metaphor is the tool of their trade. Scientists and engineers know that precision of language sustains technical communication. Logic is the tool of necessity. Cognitive psychology has revealed that creative and logical thinking are accessible to the same brain, but are active for the most part in separate cognitive hemispheres.

Recognition of this distinction has been adapted to aid in training aspiring artists in the use of RH function.[3] Dr. Betty Edwards has shown how much beginning students in drawing can progress in a five-day class when taught tools for engaging RH creativity while intentionally thwarting LH logic. (Ref. 7) Comparison of first-day sketches by students of their own faces with sketches made at the end of her five-day course makes an impressive demonstration. The beauty in her demonstration is captured in the satisfaction of both student and teacher (and this reader). Most importantly the student proves to his or her personal satisfaction that the techniques they have learned actually work (authenticated efficacy).

Goal of studying cognitive-hemisphere modes of thinking

This dissertation relies heavily on introspection to discern personal activity in one's cognitive hemispheres – a tricky path that threads its way between the knowable and the unknowable. An overview is needed here to clarify the desired goal. It is not claimed that we know how we think. But it is deemed advantageous to understand what research of cognitive psychologists has revealed since 1968 about how our brain hemispheres process information. This understanding is used here to design problem-solving heuristics that engage participation of both hemispheres in problem solving.

The terms "LH" and "RH", as well as "logical" and "intuitive" (or "creative"), are used as labels to designate dominant modes of thinking. But this dominance is not to the exclusion of their compliments. For example, technologists may be LH logical but they are also RH creative. And, artists are RH creative yet they also are LH logical. Of course, RH and LH are only appropriate for a majority of the population, not for everyone. I am heavily LH so that is my point of reference in this discussion. I ask the RH readers to make appropriate switches of LH and RH when necessary.

Cognitive psychology research unveils different modes of thinking of the two cognitive hemispheres. Positron emission tomography (PET) scans of brains actively performing tasks is a recent advancement in cognitive psychology. (Ref. 10) Results show that LH is more active in using numbers, logic, solving word puzzles, sequential tasks, and analysis.

[3] Dr Edward's work has influenced part of heuristic innovation. As in Edwards work, an intentional effort is made to engage the intuitive hemisphere while thwarting the logical hemisphere. Furthermore, its credibility lies in personal satisfaction – that is, you have to experience it to appreciate it.
Edwards and other authors refer to the linguistic, logical hemisphere as the left hemisphere (LH) and the intuitive, nonlinguistic hemisphere as the right hemisphere (RH). The division is typical but not true of all people. When used here, you may need to reverse these if your linguistic hemisphere is the right hemisphere.

In comparison, RH is more active in activities involving music, imagination, colors, or creative expression. Right-hemisphere seems to have a global bias while LH has a local bias. That is, RH sees holistically while LH sees components.

It is quite possible that we do not use the abilities of both of our cognitive hemispheres efficiently in solving technical problems. It is also possible that heuristics can be devised that alleviate this shortcoming. It is assumed here that technologists make better use of their logical thinking capability than of their creative thinking capability. Both are addressed, but a leaning toward improving creative skills will be seen. It is assumed that LH problem solvers can benefit form RH participation and from understanding better LH functions.

What our two cognitive hemispheres have to offer

Cognitive psychology has revealed that creative and logical thinking are accessible to the same brain, but reside for the most part in separate cognitive hemispheres. Some thinking characteristics of these hemispheres are listed in Table (B.2).

Table B.2 Thinking Characteristics of Cognitive Hemispheres (adopted from Ref. 7)

	Left Hemisphere		Right Hemisphere	
1	Verbal	Using words to name, describe, define	Nonverbal	Using non-verbal cognition to process perceptions
2	Analytic	Figuring things out step-by-step and part-by-part	Synthetic	Putting things together to form wholes.
3	Symbolic	Using a symbol to stand for something. For example, = for equal and ∑ for sum.	Actual, real	Relating to things as they are, at the present moment.
4	Abstract	Taking out a small bit of information and using it to represent the whole thing.	Analogic	Seeing likenesses among things; understanding metaphoric relationships.
5	Temporal	Keeping track of time, sequencing one thing after another.	Non-temporal	Without a sense of time.
6	Rational	Drawing conclusions based on reason and facts.	Non-rational	Not requiring a basis of reason or facts; willingness to suspend judgment.
7	Digital	Using numbers as in counting.	Spatial	Seeing where things are in relation to other things and how parts go together to form a whole.
8	Logical	Drawing conclusions based on logic: one thing following another in logical order – a mathematical theorem of well-stated argument	Intuitive	Making leaps of insight, often based on incomplete patterns, hunches, feelings, or visual images.
9	Linear	Thinking in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion.	Holistic	Seeing whole things all at once; perceiving the overall patterns and structures, often leading to divergent conclusions.

It has been known since the Napoleonic wars that language resides in the LH. Understanding of the source of language came from noting that RH injuries did not cause loss of language but LH injuries did. Further elaboration of hemisphere distinctions awaited the Nobel Prize work of R.W. Sperry (beginning in 1968). (Ref. 11)

Sperry and his colleagues studied a small set of commissurotomy patients ("split brains") who had undergone a radical brain operation as a last resort in curing their epilepsy. The operation severed their corpora callosa and associated commissures. To everyone's satisfaction the operations cured their epilepsy. Then to everyone's amazement the patients showed little adverse effects. Their demeanor and coordination appeared to be natural in casual observation.

The patients were subjected to a series of subtle but definitive experiments that revealed differences in brain-hemisphere functions. They found that each hemisphere's cognition of reality differed. They also found that in both split- and whole-brain subjects the language-hemisphere usually dominated.

Our five senses serve both hemispheres simultaneously with the same information. The hemispheres process this information with different emphasis, and interest. Some of our reactions to these sensory signals are evident in body-side preferences[4]: handedness, nostrilness, eyedness, earedness, and footedness, for example.[5] Our cognitive procedures are to process these signals in two brain hemispheres in order to make sense of them. Since processing emphasis differs between the hemispheres conflicts of deduction are possible. Such conflicts are mediated through the corpus callosum.

One of the experiments with split-brain subjects involved a man trying to assemble a small jigsaw-like puzzle made of wooden pieces. Attempts to assemble the pieces using his right hand failed (poor spatial cognition by LH). Furthermore conflict occurred as the left hand tried to interfere (good spatial cognition by RH) causing the right hand to knock the left hand away. He stopped the interference by sitting on his left hand. When trying to solve the problem using both hands the right hand interfered causing the left hand to knock it away (driven by RH's spatial cognition).

One important distinction in the above table is LH's cognition through verbal use of language as opposed to RH's non-verbal cognition. Recognition of this difference, and recognition of our conscious state of reasoning being language oriented, raises a concern that LH's logical rational may dominate our thinking. That is, RH's contribution to reasoning, as in problem solving, may receive short shrift. LH seems to have veto power by virtue of its singular control of logical communication through language (internal reasoning and external communication).

Another distinction shown in the table is how RH processes comparative spatial information with a holistic awareness of overall patterns. It uses image-oriented cognition in processing sensor information. Images can be introduced with graphics or they can be word inspired.

These two distinctions, LH language orientation and RH image orientation lead to the deduction that verbal and image metaphors can be tailored to stimulate both hemispheres into cognitive action. This seems to offer a degree of control (or initiation of action) of

[4] Right-hand sidedness of physiological functions is controlled by LH, and left-handed sidedness by RH.
[5] These may not all be words, but you can understand the intended parallels to handedness.

one's subconscious thinking during problem solving via the content of metaphors. It does not present an obvious means of combating LH's veto power.

It also appears that time captures the interest of LH but not of RH. But RH is interested in space while LH is not.

It is interesting, and a bit puzzling, that the table contrasts RH's understanding of metaphor with LH's abstraction of a small bit of information to represent the whole. The dictionary definition of metaphor is a verbal suggestion. That, it seems, should entice LH abstraction. Metaphor is used here to mean suggestion in word or image. This definition gives metaphors two degrees of freedom in their design.

It is also shown in the table that RH makes intuitive leaps of cognition based on incomplete patterns and images that can lead to divergent conclusions. By contrast, LH uses cognition based on linear sequences of logical steps capable of convergent conclusions.

In general, the LH characteristics shown in the table are attributed to technical-type thinking. The RH characteristics are attributed to creative thinking as evidenced in artists. Of course, both types of thinking are available to everyone having normally functioning brains. Both types of thinking are evidenced in technologists and artists. Logical-thinking technologists use intuition in solving problems and creative-thinking artists use logic in solving their problems. They may differ in degree of influence of one cognitive hemisphere over the other.

From these characteristics of brain-hemisphere cognition, we can distinguish the attributes of metaphors needed to stimulate one or the other hemisphere.

By way of review, the characteristics of the table can be summarized in the language of heuristic innovation where attributes are generic concepts enriched with ambiguity.

- LH metaphors use words, symbols, time, facts, numbers, and logical phrases to suggest the generic attributes verbal, analytic, symbolic, abstract, temporal, rational, digital, logical, and linear.
- RH metaphors use images, instantaneity, similarity, space, relative shape, hunches, and overall patterns to suggest the generic attributes nonverbal, synthetic, actual, analogic, non-temporal, spatial, intuitive, and holistic.

These two summations constitute a heuristic for creating effective metaphors in heuristic innovation.

Reminder: Statements distinguishing LH and RH thinking traits are not to be taken as denoting black and white differences. They simply associate dominance of a particular trait with a particular hemisphere. The same trait is expected of the other hemisphere but of less ascendancy.

When do we use both logical and intuitive thinking traits?

If hemisphere dominance does not exclude the other hemisphere's participation in problem solving then both should be participating in the exercise. It would aid our understanding of their efforts if such participation could be detected. It is tempting to examine a simple mathematics problem to see where LH and RH traits might occur.

Here's a problem example, one my grandfather gave me to work (ca. 1930's).

> At the intersection of two streets are four saloons, one on each corner. A man enters one; he pays $1 for admission, spends half the remaining money in his pocket, and pays $1 to leave. He goes to each of the remaining three saloons and repeats the same process: pays $1 to get in, spends half the money remaining in his pocket, and pays $1 to get out. After paying to leave the fourth saloon he discovers that he has no more money. How much money did he have to start with?
>
> This problem statement has only words, satisfying LH that created them.
>
> Right hemisphere, not to be left out, immediately creates completely satisfactory images to understand the problem.
>
> RH or LH (?) has an "Ah ha!" moment noting that only the last value is known. LH agrees and tags that final state with a value of zero.
>
> RH sees a pattern: the same procedure occurred during each saloon visit.
> LH agrees but suddenly decides to attack the problem head on, step by step (LH veto of RH?):
>
> Let x = the amount money at the start.
>
> Leaving the 1st saloon he has in his pocket (x-1)/2-1.
> Leaving the 2nd saloon he has ((x-1)/2-1-1)/2-1.
> Leaving the 3rd saloon he has (((x-1)/2-2)/2-1-1)/2-1.
> Leaving the 4th saloon he has ((((x-1)/2-2)/2-2)/2-1)/2-1.
>
> Leaving him broke or (((((x-1)/2-2)/2-2)/2-2)/2-1= 0
>
> LH thinks that the equation defines the problem and is ready to quit. From here to a numerical answer is a matter of turning the "algebra crank".
>
> LH(?) or RH(?) notices that a rearrangement of the last equation by stacking the terms would make it easy to mentally visualize reduction of the equation to the value of x.

$$\cfrac{\cfrac{\cfrac{\cfrac{x-1}{2}-2}{2}-2}{2}-2}{2}-1 = 0$$

> LH begins working from the bottom dashed line upwards to each successive dashed line. At the bottom dashed line, the –1 is moved across the = sign and multiplied by 2 showing that the remaining stack is = 2. Removing the next dashed line the remainder = 8. The next remainder is = 20, and the last remainder yields x = 45.

Of course any elementary school child can solve this problem using addition and multiplication without the algebraic theatrics. But the person applying algebra may have a different goal. An algebraic solution is a general solution that can be extrapolated to any number of saloons. Such generalizations are a part of the value of algebra and the enjoyment of mathematics. Is this a pleasure experienced by both LH and RH? Contrarily, could it be possible that the person steeped in algebra and far removed from simple arithmetic may not think of the simpler approach?

Review of the mental process:
The inset paragraphs above are a bit confusing to understand their underlying mental activity. LH is initially in control, since everything is verbal at the beginning. LH searches for and comes up with a simple problem from memory. [*When the problem came to mind, I began to write but words were not coming to mind in the most logical order. On realizing this, I decided to write to the end of the problem statement and then edit for logic.*]

The words being written created various images of the intersection of two streets, corner saloons, man, man entering a saloon, within, and leaving a saloon, and man looking at an empty wallet (even though wallet was not mentioned). [*This raises a question of simultaneity. Was I ever conscious of a noun, and the image it invoked, at the same time? I had no trouble being conscious of an image, but were LH and RH multiplexing my conscious attention – flipping back and forth between word and image – or can both a conscious view of the noun being typed and its associated image be in the conscious simultaneously? I can't answer these questions. (But, I suspect not. I can't convince myself of simultaneity.)*]

In the remaining assertions there are some confusing steps.

- RH has an "Ah ha!" moment noting that only the last value is known.

LH agrees and assigns a value 0. This is language in action (LH).

Then LH seems to take over, ignores RH, and starts an algebraic analysis. Why? RH's start seems (in hindsight) to be simpler. The algebraic approach doesn't seem to be a logical choice, yet LH, the source of logic was supposedly in control.

Though confusing and illogical, this is the sequence of events that I recall. However, they came so quickly and continuously to the end of the problem that I can't feel with any certainty that my description is anything more than rationalization of foggy recall. Of course the whole process of assigning specific thoughts to LH and RH is pure speculation. But such is the way of introspection – sometimes the rational is satisfying and sometimes it is not. Yet, given these caveats, introspection continues to provide useful insights.

> Here's an interesting exercise that may cause some initial RH and LH conflict – which one comes up with the winning approach to solving the problem? You probably know the problem, but may not have thought about RH and LH conflict arising in solving it. [6] As you solve it, pay attention to when you are focused on language and when you are considering images.
>
> Two trains traveling at 50 miles per hour approach each other on parallel tracks. When they are 75 miles apart a bumblebee leaves the engine of one train and flies to the engine of the second train at 100 miles per hour. On arrival at the second engine he reverses direction without loss of time and flies back to the first engine. He repeats this process until the engines meet and pass each other. When they meet how far will the bumblebee have flown?

Ambiguous metaphors

Without further explanation, take thirty seconds to list any ideas that come to mind from the following image (Fig. B.3):

Figure B3 What ideas come to mind?

It doesn't matter what is seen. Rather it is simply interesting that one sees anything in particular. Nothing real was intended in making the sketch. But it is a natural reaction of intuitive thinking to make something meaningful out of retinal images. This is the

[6] I thank Dr. Craig Stephan for suggesting this problem.

motivation for using graphic metaphors, to inspire RH. Instantaneous intuitive response is likely more metaphorically induced than by language-based logic; i.e., more RH than LH.

Although RH does not use language in the cognitive process it does understand language. Obvious examples are the images that come to mind as you read an object's description. Hence, words can be used to stimulate image formation in the right cognitive hemisphere.

It is simple to assign some semblance of logic through language to the above sketch– namely, through the attributes of the image. Names tend to bring a feeling of acceptance.

Try it.

Name the *attributes* of the image and see what new images come to mind. Then read on.

…

My reactions:
For example, the sketch has *contrast* making it discernable from its background. It has *shades of gray* making it appear three dimensional, it has *no definite outline* making it seem to rise out of the background and to be *moving* from left to right. It has *shape* resembling a baseball mitt, a clam, a ventriloquist's fist, a handheld stapling machine, and a computer game icon. (You probably thought of others.) This exercise is similar to our childhood experience of seeing animals in clouds and the man in the moon. Conscious translation of an image into words invokes language and logic and may involve more LH than RH thinking.

Filters

Heuristic innovation selects a single unwanted-effect from which multiple solution concepts are created. Filtering of unwanted effects occurs before heuristic innovation while filtering of resulting solution concepts occurs after heuristic innovation.

Multiple Problems ➔ **Filters** ➔ $\underbrace{\textbf{Single \underline{Unwanted effect}} \to \textbf{Multiple \underline{Concepts}}}_{\textbf{Heuristic innovation}}$ ➔ **Filters** ➔ **Single Solution Engineering**

Problem solving has three fundamental parts: a problem statement, one or more solution concepts, and an engineered solution. Pre-filtering isolates a single unwanted effect from many producing the problem to be solved. Post-filtering selects solution concepts to be engineered.

Here's an example:

Problem situation:	Several unwanted effects are noted when a pin is pressed into a balloon. • The balloon bursts. • The balloon makes a disturbing noise when it bursts. • Seeing a pen pressed into a balloon is threatening to children.
Filtering:	Of these unwanted effects, the balloon bursts was selected as being the more fundamental issue.
Problem:	“The balloon bursts when stuck with a pin. Fix it!”
Solution concepts:	• Increase rupture strength. • Halt air leakage. • Change the current elastomer to polyester like Mylar©. • Test the rupture strength of the balloons and fill them to a pressure that still allows one side of a balloon to be pressed to its opposite side without bursting. • Line balloons with self-healing puncture sealant.
Filtering:	Filtering, often based on business decisions, for example, will cull most solution concepts leaving a few for engineering consideration.

This example illustrates how solution concepts precede engineered solutions in technical design-type problems. Concepts are pre-engineering. They need no numbers, materials specifications, or other engineering metrics. Thus finding conceptual solutions is free of assumed limitations of technology. Here we can use poetic or ambiguous metaphors. Post filtering culls concepts acceptable for further engineering.

Engineering can be thought of as the process of scaling a concept to a set of metrics. Engineering abides by the technical limitations of specifications and accepted practices.

Heuristic innovation is about creating concepts that are devoid of metrics. This realization leads to the restriction that no filtering of solution concepts is allowed during creative problem solving. An immediate benefit of no filtering is more concepts in shorter time – efficiency. Another benefit is robust solution concepts. Following post-filtering, however, robustness may be sacrificed later in engineering tradeoffs between ideal and practical details.

Filtering is appropriate and necessary in selecting a problem worth the investment of resources to solve. Filtering is again appropriate in selecting from among multiple solution concepts those to be carried forward into engineering evaluation. However, filters have limited lifetimes. Thus unfiltered solutions concepts need to be treated as intellectual property and book shelved for future reference.

Two objects – ultimate focus

A common concern of students is the insistence on selecting a single unwanted effect by reducing the number of objects in a comprehensive problem description. Concern is further exacerbated upon realizing that such reduction is extended (eventually) to two objects. Their reluctance is based on two fears: one, the fear that the baby may be thrown out with the wash and, two, the fear that solution of one problem may cause another somewhere else in the system.

Regrettably, perhaps as a result of technical training, we tend to construct system-like overviews in a problem statement hoping not to overlook what may become an important feature. Of course, this is a desired goal in system analysis, which is common training for industrial technologists. It wouldn't be regrettable (in fact it is encouraged for comprehension in heuristic innovation) if we could then readily identify and shed unnecessary objects to focus on a particular problem. But many students balk at shedding objects.

Consider this problem situation:

> A mean ogreish person, wielding a sharp pin, is bent on attacking an inflated balloon floating aloft on a ribbon held by a small child, and bursting the balloon.

This statement contains several potentially unwanted effects: small child in the presence of an ogre, ogre with sharp pin, and sharp pin aimed at an inflated balloon, to name obvious ones. Notice in this list that three unwanted effects, in the same problem situation, are each described in terms of different pairs of objects: ogre and child; ogre and pin; and pin and balloon. In these examples focus on a single unwanted effect has been established by minimization of objects to two (pen and balloon).

Minimization of objects is a heuristic used to extract individual unwanted effects from a convoluted problem statement. It is executed by first thinking of the problem statement as <u>describing</u> a problem situation having multiple unwanted effects. Identify these and select one. Then examine the objects in the problem statement and select a minimum set that <u>contains</u> the selected unwanted effect. If the minimum set contains more than two objects, be suspicious of remaining unidentified unwanted effects. Examine points of contact of pairs of the remaining objects to see where the unwanted effect can be localized. Such two-object localization, or point of contact, is a useful heuristic for isolating a single unwanted effect. Of course it is possible for more than one unwanted effect to exist at the same point of contact, but this is rare.

What about concern for throwing the baby out with the wash? Nothing so drastic as this metaphor may suggest is occurring. Objects are not thrown out of our minds. They are imbedded in our short-term memories as we develop and simplify our description of a problem. After reducing a problem to two objects, and while iterating the problem description using these two objects, the other objects will pop into your conscious from time to time offering potential use where new attributes or functions are desired. They come to mind because the reduced set of objects becomes a metaphor for the original set.

> Try this.
> *A dip of rich vanilla ice cream served on top of a warm slice of fresh baked apple pie and topped with butterscotch syrup.*
>
> Examine this statement as though it were describing a problem situation. Write one plausible unwanted effect involving just two of the objects, ice cream, pie, and syrup. (This is an important step. It builds a metaphor.) Then see if you can forget the other object by the end of this chapter.

And what about solving one problem only to create another? We intentionally sharpen focus to see only one problem. One can't solve two problems at the same time. Furthermore, it works against efficiency during concept generation to spend time determining whether a particular solution concept is a threat elsewhere in the system (culling ideas is not allowed during problem solving). Hence, the answer to this concern is to generate as many solution concepts as possible for every unwanted effect addressed as though others do not exist. If an important idea is a threat elsewhere in the system, treat it as a new problem and solve it – the tools for this task are at hand.

Introduction of thought paths

In this section methods for creating thought paths are examined and their use to generate solution concepts is demonstrated.

Reduction of an originally verbose problem statement to two objects brings one to an effective point of focus with isolation of a single unwanted effect. From this vantage point we begin the search for thought-paths – starting points for pondering cause and effect phenomena (LH action) that spark intuitive insights (RH action).

Thought paths begin in either the verbal or visual rendition of a problem and with any of the basic components of a problem statement: objects, attributes, effects (unwanted effects and functions), and root causes. For example, pairing two attributes, one from each object, supporting the unwanted effect, identifies thought-paths. Examining the point of contact of two objects is a thought path. Wondering how a desired function became an unwanted effect is a thought path. One proceeds along a thought path by asking questions.

Selecting attributes in pairs, one from each of two interacting objects, is not a mainstream thought process of physical science. It is a viewpoint heuristic encouraging in-depth mental analysis of phenomena in ways to reveal better understanding. It does not violate physical science (necessarily). Although anyone can, in using the method, unknowingly compose physically inaccurate interactions. Is this bad? Probably not, because you will recognize when you are reaching the limit of your own understanding and will naturally terminate further analysis or flag it for confirmation by a specialist. That self-limiting effect will minimize fruitless digressions.

It sometimes happens that one makes an intelligent guess about an effect and invents names of relevant attributes. This can happen, for example, when a physicist tries to pry into the depths of some chemical synthesis process outside the realm of personal understanding. The outcome may be a clever solution concept but requires an attribute the physicist does not know exists. This simply requires flagging the uncertainty and then later consulting an expert. It may also be an embarrassing flop.

The utility of this process is that it encourages one to investigate areas that might otherwise seem intimidating for lack of familiarity. It may also lead to the discovery of research opportunity. And since it is tailored to personal thinking, it still serves to spark new ideas in spite of incomplete understanding of fundamental facts. It identifies where and what kind of assistance is needed or study to be done. And it prepares one for an informed discussion with an expert.

By the way, before rejecting less than perfect understanding of a solution concept, consider how many successful inventions waited years for their full understanding.

Examples of thought paths found through attribute pairing
We can examine attribute pairing in the pin-balloon contact to see how iteration enables probing. In the process we can expect to realize other active attributes.

I'll start by selecting the attribute sharpness of pin as a seemingly obvious cause for a balloon to burst. As I write that sentence I have a mental image, somewhat like that shown in Fig. B.2, of a point depressing a balloon. Now an interacting attribute from balloon is needed. Suppose the attribute color of balloon were randomly selected. Color is an attribute of visible objects, but no plausible way for sharpness of one object to interact with color of another comes to mind. They might seed an idea if I were working on a whimsical concept for a cartoon. Let's try another attribute.

Obviously this random selection of balloon attributes could go on a long time as the many attributes of balloon come to mind. To select relevant attributes (active attributes) we need to ask ourselves what can sharpness do to balloon? This step sends us on our way to understanding the phenomenon of bursting a balloon.

To answer the question just raised about the effect of sharpness, think also of the effect of bluntness (contrarian view). The obvious difference in depressing a balloon with sharpness versus bluntness is that the former produces local concentration of *stress* in balloon.

> Once the contrarian heuristic is exercised it sets the stage for considering the extremes heuristic. This means to take attributes to their extremes of intensity, time interval, etc. For example, sharpness could become an atomic point or a flat plane.

You might have thought of local *strain* (stretching) instead of stress. That's fine; it's your decision. Pick the word you best understand. Remember though that it helps to deepen understanding by questioning the specific meaning of each such metaphorical attribute – the contrarian-view heuristic can bring self-generated enlightenment. The goal is not technical accuracy but the mental commitment of what you have in mind for an attribute's meaning. This commitment supports further rational.

The goal is also to engage RH thinking. While technical accuracy is good for LH, RH may ignore it.

The observation that sharpness produces localized stress begs the next question. How does local stress lead to balloon bursting? Why doesn't pressing a pin into a balloon cause the depression to deepen until the elasticity of the balloon produces sufficient reaction to halt further motion of the pin? To burst, the balloon must separate, but where and how and why? Now things are becoming interesting. Details can be tracked using proforma graphic of object-attribute-effect statements and diagrams illustrated generically in Fig. B.4.

Causal attribute of *object* interacts with causal *attribute* of *object to (an unwanted effect)* affecting *attribute* of *object*.	O – A \\ U – A_m – (O_m) / O – A

Figure B.4 Generic proforma object-attribute-effect statement and diagram: two contacting objects, (O), provide one causal attribute each, (A), to support an unwanted effect, (U), that affects attribute, (A_m), of one of the contacting objects or a third object, (O_m) .

What do we know about the active attributes of an inflated balloon?

- We know that a balloon has some *strength*; it supports the pressure it contains without bursting.
- We know that an inflated balloon is expanded by *stress*; it is larger than when not inflated.
- We know that an inflated balloon's *internal stress* and *thickness* are uniform; its shape is *spherical*.
- We know also that a balloon's strength has an upper limit because we have pressurized a balloon beyond its *yield strength* to the point of bursting.
- We know that a rubber balloon is mostly *elastic*; on deflation it returns close to its un-inflated shape.

The italicized words are active attributes of an inflated balloon.

Hence, strength of the material of the balloon is a relevant attribute. And strength can be paired with sharpness in a plausible way. The associated object-attribute-statement and diagram are shown in Fig. B.5 – the zeroth iteration of this problem statement (I_0).

I_0: Sharpness of pin interacts with strength of balloon to burst balloon affecting continuity of balloon.	pin – **sharpness** \\ to burst – **continuity** – balloon / balloon - **strength**

Figure B.5 OAU statement and diagram for the pin-balloon interaction of sharpness and strength attributes.

Three thought-paths are introduced, for example in pairings of sharpness, strength, and continuity.

I_1

On second look, the pairing of sharpness and strength seems to present a rather macro view of the bursting phenomenon. What actually is going on at the physical point of contact between pin and balloon? The OAU diagram does represent the physical point of contact. However, the depth of understanding of the phenomenon at that contact depends on the metaphorical power of the selected attributes.

Iteration of the attributes in the OAU statement introduces new information. Instead of considering balloon's bursting strength, maybe its thickness is non-uniform leading to weak spots and pin just happened to hit a weak spot. Hence, sharpness can be paired with non-uniform strength.

This first iteration adds another thought-path: non-uniform thickness.

I_2

Maybe other things can occur at the point of contact. Does something prevent sliding and thus hold pin at a given spot on balloon as depressing of balloon proceeds? If so, could it be friction of balloon?

The second iteration adds friction as a thought-path.

I_3

The idea doesn't immediately sit well in my mind because friction, at least static friction, seems to require roughness to engage two moving surfaces and prevent sliding. Sharpness implies, to me, a keen, uninterrupted edge. This is more of a geometrical ideal that must break down under high magnification. If we mentally enlarge the point of contact to where sharpness begins to look like dullness, the balloon's surface is still something pin can slide on, i.e. not be forced into a local spot unless roughness of both objects allows engagement. Actually roughness of balloon seems to be a more likely way that sharpness of pin could be engaged and thereby localize the action of pin. Yes, roughness is similar to non-uniform thickness, if you see it that way. Different wordings of attributes are the purpose of iteration that toys with the effectiveness of metaphors.

The third iteration adds roughness as a thought-path.

I_4

Now I question roughness of balloon. What does roughness of an elastomer mean? And on what scale is it rough? We need a roughness course enough to engage (the dull part of magnified) sharpness of pin. Sharpness engaging roughness is like a lock-and-key kind of engagement. This means that local areas of both surfaces are somewhat compliant in shape enabling one to nestle slightly into the other and resist their sliding motion in the tangent plane of contact.

Compliance becomes a thought-path.

I_5

Maybe localization of pin on balloon is caused by sticktion. Sticktion refers to resistance to sliding caused by partial sticking that begins after two objects come into contact and before sliding is induced (an idea to be checked with experts).

Sticktion becomes a thought-path.

I_6

I just noticed that the path being followed in iteration concerns localization of pin on balloon to enable stress build up to the point of rupture. Localization is one issue but what's going on at the point of rupture? How does balloon rupture under pressure from pin? This question brings me back to the same mental image of a solid point depressing an elastic body. Maybe it would help to visualize the microscopic region between the sharp edge of pin and the reacting area of contact of balloon.

A simple model of a point penetrating an elastic material without rupturing it is shown in Fig. **B**.6. The rounded-tip wedge represents a pointed object seen in magnified cross-section (a pin). The gray region represents an elastic membrane being bent around a small radius. The outer layers of the membrane are under tension while the inner layers are under compression. This creates a shear force across a median plane indicated by the broken line.

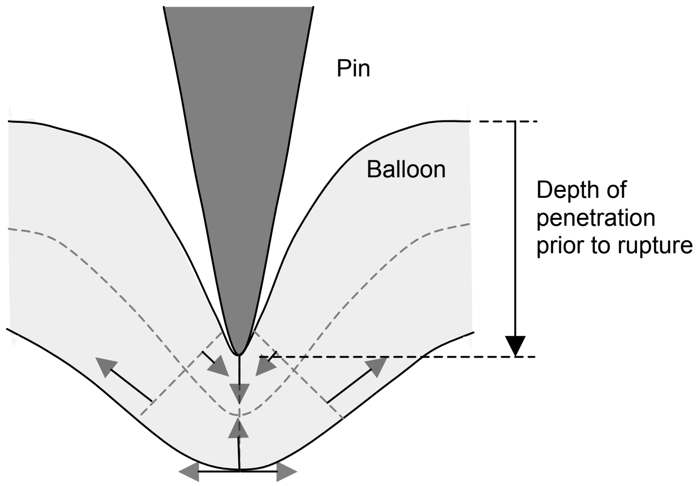


Figure B.6 Bending of an elastic membrane around tip of a pin is illustrated. The broken, gray line separates inner regions under compression from outer regions under tension. Inward pointing pairs of arrows indicate compression while outward pointing pairs indicate regions of tension. Depth of penetration of pin prior to rupture of balloon is indicated

This sketch suggests that the outer layer of the elastic membrane, directly under the pin, experiences the greatest tensile stress and therefore is the probable point of initiating separation when the material strength is exceeded. The radius of the tip of the pin and the depth of its penetration prior to rupture of the membrane are relevant attributes. Taper of pin may be an attribute for wider tapers than shown in the figure. Note: this figure is my plausible rendition of a stressed membrane. It is not the result of mathematical modeling.

Prior to rupture of a balloon depressed by a pin, regions under stress store potential energy. As rupture starts, in the outer layer of curvature (inside surface of balloon), tensile stress in the balloon is spread across a decreasing cross-sectional area of material. The rate of rupture increases while the pressure within the balloon sustains the driving stress. As the cross-section becomes thinner the balloon expands creating an outward motion.

Upon rupture of continuity, the balloon can no longer sustain its internal stress and cannot prevent air escaping. The balloon collapses with a gush of escaping air. Regions of stored energy relax in a pulse of shock waves that initiate catastrophic failure of the balloon. Shards of balloon are sent flying with the escaping and expanding air.

Pin radius of tip curvature and shaft taper become thought-paths.

Strength becomes a thought-path.

I_7
Can we carry this investigation any deeper? The next level that occurs to me is to think about microscopic structure of balloon. Does it have any? Metals, for example, have

microscopic grain structure separated by grain boundaries. Grains and grain boundaries behave differently. But I don't know how polymer chemists model the mechanical structure of elastomers. So I'll make my own stab at it and check with an expert later.

I have always thought of balloons as being made of rubber. Modern balloons may be made from several materials. Rubber is an amorphous polymer. At room temperatures it is above its glass transition temperature, the temperature separating a low temperature range of brittle behavior from a high temperature range of flexibility. Rubber, the solid, can be made from liquid latex by vulcanization using sulfur. Above the glass transition temperature the long molecules of rubber have considerable freedom of motion accounting for rubber's elasticity. My image of the resulting material is a highly convoluted matrix of molecules linked at sulfur-rubber bonding nodes. I infer from this that shear strength may be directly associated with degree of vulcanization. (Consult an expert)

Vulcanization becomes a thought-path.

I_8
A second look at vulcanization of rubber and volume of pin seems to lack any logic of contact. Sulfur contacts the rubber molecules it bonds. It doesn't bond to pin material. Does it bond to any attribute of pin? There are none that come to mind. If there were any bonding of sulfur to pin it might prevent bursting. Another view may be better than this one; namely, that stress of rubber interacts with vulcanization of rubber.

Stress and vulcanization have been added as thought-paths.

I_9
I think we're getting closer to the root cause of balloon rupture. It is plausible to me that the breaking of sulfur-rubber bonds at the nodes of the matrix might explain rupture of rubber. Hence the strength of sulfur-rubber bonds is an active attribute. (Expert opinion needed here.) Contrarily, if sulfur bonds are nodes of strength in the matrix then anti-nodes midway between sulfur bonds could be points of weakness.

Inflation of a balloon implies an increasing state of tensile stress sufficient to balance the internal pressure of the balloon as its volume increases. A penetrating pin, prior to bursting, deforms the balloon causing its internal pressure to increase and consequently the balloon's tensile stress to increase. Of course, increasing tensile stress is greatest at the point of pin contact, but internal pressure is distributed throughout the volume of the balloon. This suggests that pressure could exceed shear strength at a weak point of the balloon not under the point of the pin. Maybe a balloon could rupture elsewhere than at the point of contact.

Three more thought-paths added: uniformity of balloon thickness, depression volume and pressure.

This surely is not an exhaustive search. At each level of iteration others will find additional attribute pairs to consider and carry the iteration still further. But for the pedagogical purpose of this demonstration nine iterations will suffice. There is no required or recommended level to attain. Rather the value of iteration lies in the depth of understanding that can be generated and the multiple thought-paths produced. The demonstration was carried to nine iterations to satisfy the curiosity of readers. In practice, you adopt this process to your needs. A clearer picture of the process will develop after solution strategies have been presented.

In the demonstration of iteration on attribute pairs we did not stop to generate new solution concepts. In actual problem solving we stop at every opportunity to reap innovative ideas.

Depth of understanding of an effect

You may have been hoodwinked in the discussion of the last section. Compare the following causal statements found in iterations I_0, I_1, and I_5:

> I_0: *Sharpness* of pin interacts with *strength* of balloon to burst balloon thus affecting *continuity* of balloon.
>
> I_2: *Sharpness* of pin interacts with *friction* of balloon to burst balloon thus affecting *continuity* of balloon.
>
> I_6: *Radius of curvature* of pin interacts with *strength* of balloon to burst balloon thus affecting *continuity* of balloon.

Each statement ostensibly deepens our understanding by using more technical and insightful metaphors. Yet each of these three statements can be seen as variations of "it happens because it happens", i.e., they don't seem to reach root cause. To the unsuspecting, the statements may appear increasingly more impressive. But look closely and you see there are still unanswered questions. A physical process by which atoms once joined no longer form bonds is not yet offered. How does stress, a bulk attribute, translate to electron energy states, an atomic attribute of broken bonds? Should we have ventured into atomic physics and quantum mechanics for deeper understanding? How far do we pursue this search?

This is where LH logic may become technical nit picking. Our goal in the above exercise is to find points of view expressed in new words and images that spark our imagination.

How far do we pursue this exercise? Quit when you run out of ideas. This is not an exercise in fundamental research. Rather it is an exercise in generating effective metaphors for unusual points of view. Furthermore, it is most effective when you are effective; i.e., adapt it to your experience and interests.

Using thought paths

Recall how thought paths were found through attribute pairs. Selection of attribute pairs began with filtering lists of randomly selected attributes of the contacting objects using two filters: first, F_1, requiring a plausibly causal relationship to the unwanted effect, U, and second, F_2, requiring a plausibly causal interaction with A_1. The method is condensed into Fig. B.7. These logical filters bring some focus out of the random attributes.

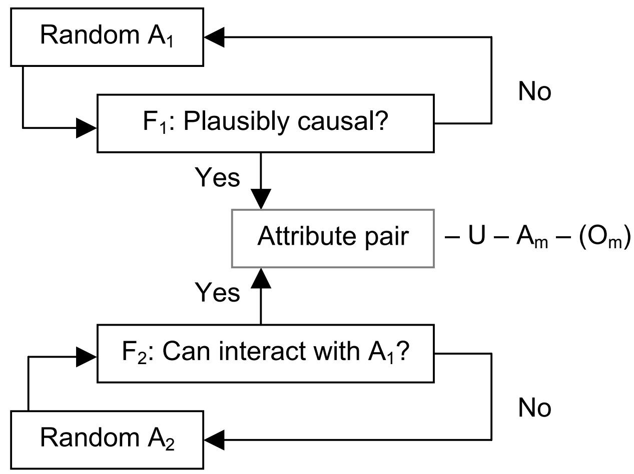


Figure B.7 Selection of attribute pairs begins with filtering random lists of attributes of the contacting objects; first according to, F_1, a plausibly causal relationship to the unwanted effect, U, and second, according to, F_2, a plausibly causal interaction with A_1.

The attributes that pass these filters become starting points of thought paths. They can be pondered singly, in pairs, or in triplets that include the affected attribute. This arrangement should appeal to LH logic.

You will find as you ponder a triplet, for example, that each attribute's parent object is readily evident and consciously tied to its attribute. Furthermore, the association affects your thinking process. That happens because the attribute pairs were found by examining an OAU connection with the objects used to identify the attributes. Such automatic association of the filtered attributes with specific objects is not necessary for innovation. In fact one can focus on the unwanted effect and causal attribute interactions without concern for parent objects. Such object-independent attribute pairings can uncover attributes not readily associated with the parent objects. They might be available in other objects in the system. Recall that some objects were culled during object minimization. This would offer yet another thought-path; i.e., association of attributes with other objects of the system.

Solve Exercise E.11.

Attribute pairing in ambiguous effects

Another approach to attribute pairing can be investigated using an ambiguous description of an effect. A concrete effect is generalized and used to produce intuitive images of a wider range of concrete effects with concrete objects. From these can be deduced new attribute pairs.

Let inflated balloon become pressurized enclosure, for example, and look for causal attributes for loss of pressure. This should invoke a greater variety of phenomena with new attributes, some of which may be accessible in the given system.

```
A
  \
   loss of pressure – continuity – enclosure
  /
A
```

Figure B.8 OAU diagram for an unwanted effect, loss of pressure, by an enclosure caused by two undefined attributes.

In a few moments of thought a variety of images come to mind (all having concrete objects): the Hindenburg dirigible catastrophe, a bomb, an explosive rivet, a puffball (fungi), a water balloon, a submarine, a tank of oxygen, a soap bubble, and a pressure cooker. Some of these are desired effects. On wondering why these came to mind, I thought about their modes of pressure loss. Thus, abstraction led to new concrete phenomena, which offer new thought paths. The following came to mind.

> The Hindenburg dirigible was pressurized with hydrogen that caught fire internally and burned through the enclosing skin without catastrophic instantaneous collapse. A bomb builds pressure from the inside following a chemical reaction and ruptures catastrophically. An explosive rivet, on being heated, also builds pressure from the inside as its explosive chemicals react. A puffball bursts and releases spore when struck by an object or animal. A water balloon builds pressure to its bursting point upon sufficiently fast collision with another object. A submarine can loose pressure and implode when its skin fails and high-pressure water rushes in. A tank of oxygen is susceptible to falling and breaking loose its valve releasing high velocity gas without rupturing the tank. A soap bubble may burst as its liquid skin drains causing it too thin to the point of failure. And a pressure cooker looses pressure when its weighted pressure-release cap is removed without rupturing the cooker. The oxygen tank and the pressure cooker did not rupture catastrophically but in both cases their enclosures were parted.

The images came to mind without conscious reasoning. Their descriptions, on the other hand, were a conscious effort to compose plausible explanations of how they lost pressure. This could be seen as RH serving up concepts for LH to explain, but who knows? Whatever is going on behind the scenes, the result shows how quickly images of an unwanted effect arise.

From these images, and the associated effects found we can expand the diagram of Fig. B.8 and begin to search attribute pairs, as shown in Fig. B.9. Note that the new images followed the conversion of balloon to an ambiguous enclosure. Ambiguity brought to mind specific examples having concrete objects. From these and the initial ambiguous object we can look for new attributes related to an inflated object losing pressure. This again ties attributes to concrete objects but we have gained new thinking space through ambiguity and still have an ambiguous object to use. Let's see what we can deduce of relevance. Since the target is an inflated object loosing pressure, without specifying unwanted effects, some ideas will produce desired effects (they are marked with asterisks in Fig. B.9).

```
                                              Enclosures (Objects)
A                                             dirigible, bomb*,
  \                                           explosive rivet*, puffball*,
   loss of pressure – continuity –            water balloon*, submarine
  /                                           gas tank, soap bubble,
A                                             pressure cooker*
```

Figure B.9 OAU diagram for an unwanted effect, loss of pressure, by example enclosures caused by two undefined attributes. Desired effects are indicated with asterisks.

1. Dirigible: Hydrogen and oxygen react to produce flame;
Flame and skin react decomposing skin and releasing pressure.

Attributes: Heat content of flame and thermal sensitivity of enclosure

Concepts: Inflate with an incombustible gas.
Make skin of incombustible material.

2. Bomb*: Ignition of internal chemicals releases heat and gas.
Internal energy of gas and rate of reaction producing gas increases pressure in the vessel
Gas-pressure builds to the rupture point of enclosure (the desired effect).

Attributes: Heat of gas and pressure of gas

Concepts: Design chemical composition for more rapid combustion.
Design chemical composition to produce more moles of gas per mole of reactants.
Use exothermic reactions releasing more energy.

3. Explosive rivet*: (Similar to bomb)

4. Puffball*: End of growth stage leaves puffball brittle.
Shock ruptures brittle puffball.

Attributes: Brittleness of puffball and momentum of contacting object

Concepts: Design enclosure to change strength upon pressurization.
Shock-mount enclosure.
Make enclosure of high dampening material.

5. Water balloon*: Impact on solid object sends shock waves through its contained fluid spreading the fluid laterally. Threat, suddenness, sound, and resulting mess create the desired feeling of shock.
Elasticity of enclosure yields to momentum of spreading fluid allowing non-uniform expansion of enclosure by the momentum-driven fluid (assuming balloon is filled with a non-compressible liquid).
Expansion of enclosure exceeds yield strength of enclosure before establishing sufficient elastic stress in the enclosure to react and contain the spreading fluid.

Attributes: Dynamic distribution of fluid and yield-strength of enclosure

Concepts: Increase feeling of shock by adding food coloring.
Create foam with a pinch of detergent in balloon contents, to be shaken just before launching balloon.
Design balloon with multiple thin regions to produce accelerated release of water in several directions with more rubber shrapnel (like a hand grenade)

6. Submarine: Weakened skin, under hydrostatic pressure, strains to the point of rupture and fails leading to an implosion.

Attributes: Pressure of water and weakness of enclosure-skin

Concepts: Make skin of a work-hardening material so that strain, in successive emersions, increases its yield point.
Line skin with a supporting lattice to distribute stress away from weaker regions.

7. Gas tank: Jarring a pressurized gas tank unbalances it. As it falls its valve strikes an object and is broken off. Gas is suddenly released sending the tank ricocheting around like a rocket.

Attributes: Weakness of bond and pressure of gas

Concepts: Design a valve-cover that can't be removed until the tank is secured to a post. When the tank needs to be exchanged it cannot be freed from the post until its valve-cover is in place. (Tank exchange may occur with the tank still pressurized.)

8. Soap bubble: Liquid of a soap bubble's skin is in constant motion. It drains to the bottom of the bubble. Draining liquid thins the bubble's skin. Thin skin becomes too weak to balance the stress in the film produced by the air in the bubble and the weight of the film. The bubble bursts with the larger mass of soap at the bottom falling while the upper parts of bursting film send smaller droplets of soap flying more laterally. Surface tension of soap draws the discontinuous film into droplets.

Attributes: Thickness of enclosure and pressure of gas

Concepts: Make bubbles from a liquid that reacts with the air forming a bubble causing a reaction that increases the viscosity of the bubble after it is formed. Thus slowing drainage of film liquid. (Consult expert)

9. Pressure cooker*: A weight covers a port in a vessel causing vapor pressure to build in the vessel until it is able to lift the weight and the vapor escapes, thus limiting pressure build-up in the vessel. During use, the pressure cycles between the maximum release level and a lower level as the release port's weighted cover opens and closes. To fully discharge the pressure, the vessel is cooled and the weighted port cover removed.

Attributes: Pressure of vapor and weight of port-cover

Concept: Design a weighted port cover with an auxiliary pressure-release port. Close the auxiliary port with a differential expansion valve that is closed above minimum operating temperature. Above this point vapor pressure lifts the weighted cover. When auxiliary port valve is closed the weight produces an oscillating pressure in its normal fashion. On cooling the auxiliary valve opens gradually wider as temperature becomes lower allowing faster release of low temperature gas.

Logical explanation of effects builds understanding of cause and effect. Concrete and generic explanations were used above. In three of the examples, bomb (2), water balloon (5) and, pressure cooker (9), a conscious effort was made to use generic wording in the description of the concrete object. This was an effort to seed RH intuition. The pressure cooker description brought to mind an intuitive idea for pin bursting balloon.

A solution concept comes to mind:

Design balloon as a porous shell with each pore having a deflectable flap on the inside of the balloon. Gas pressure within the balloon holds flaps in place. If a pin strikes the balloon, the flap opens releasing gas without rupturing balloon. Inserting a second porous balloon inside of a porous balloon with their pores out of registry can create pseudo-flaps.

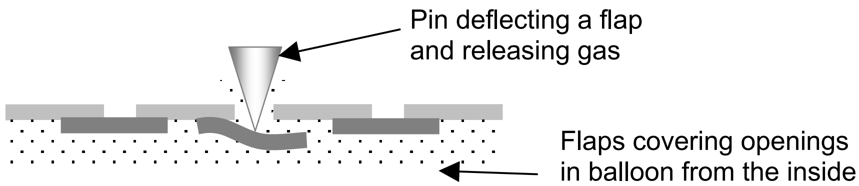


Figure B.10 Porous balloon skin having internal flaps held closed by internal gas pressure. Contact by a pin opens a flap releasing gas without bursting balloon.

Yes, the holes create regions of stress. So the question becomes is there a range of pin radius for which this internal-flap concept is valid? Modeling may determine the answer.

Another argument, independent of pin radius, is that if holes weaken the film, a film without holes is at its strongest. Therefore, simply make the balloon out of the strongest material. But the issue of this concept is the not so logical connection between pressure cooker and a double-lined balloon – a possible RH contribution.

The method just demonstrated for finding attribute pairs is illustrated in Fig. B.11.

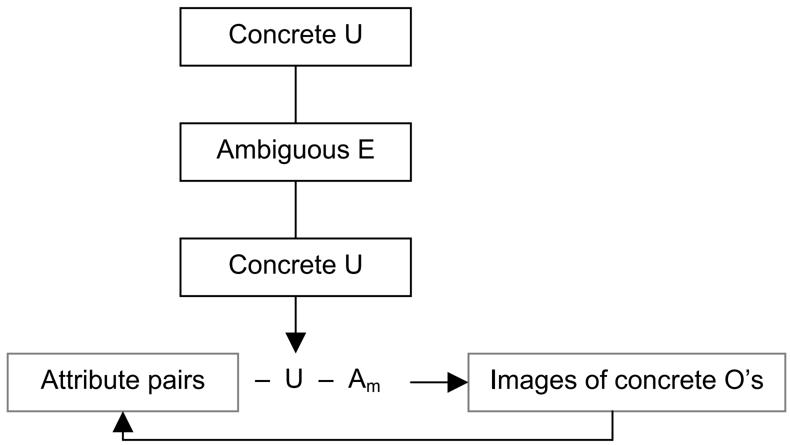


Figure B.11 A concrete effect is generalized and new concrete images found for an effect. These provide new images of objects from which attribute pairs are found.

Solve Exercise E.12.

Thought paths found through attribute triplets

Attribute triplets are the heart of every OAU diagram. In many of the examples of pin and balloon, balloon continuity was a repeated attribute. This automatically causes one to pay less attention to it and focus on the remaining pair. However, an entire triplet can be used as a thought-path. Ignoring objects in an unwanted effect quickly presents three attributes that become a thought-path. A thought-path having three attributes and an effect can be examined in concrete and in generic representations independently of objects.

To create multiple thought-paths having triplet attributes begin by generifying an effect. We can start with an unwanted effect, U, but should generalize it to an effect, E, to bring to mind images of both wanted- and unwanted-effects.

Let's treat "to burst" generically by ignoring specific objects of the original unwanted effect. Here are some images of bursting that come to mind: Opening of a flower blossom (bursting into bloom); something bursting into view; a whale breaching; blowing a smoke ring; christening a ship with a bottle of champagne; hatching an egg; lighting a match; sound of a canon; and a bolt of lightning.

Next we identify attribute triplets for these effects and then solution concepts.

1. Opening of a blossom: Color of blossom and drabness of surroundings burst into view affecting delight.

Attributes: color, drabness, delight

Concept: Populate a garden with different species of flowers selected for different rates of blossom openings. Photograph these with lapse-time photography and set to music for colorful entertainment.

Relevance to pin and balloon: A balloon bearing an artistic image may thwart a would-be ogre bent on destruction by its awe-inspiring beauty.

What ideas come to your mind for the following example?

2. Bursting into view: An unexpected image bursting into view can be unsettling.
Attributes:
Concepts:

As you can see, abstraction (generification) produces ambiguity that invites RH inspiration.

Question: Does butterscotch syrup on vanilla ice cream sound tasty? Or, have you forgotten?

Images in problem solving

On several occasions I have raised the question among friends regarding the degree to which images play a role in their problem solving. Based on my own experience I expected similar responses, namely that images played a pronounced role. To my surprise, a couple of individuals claimed the opposite, that they have little use of images. These are people whom I consider to be expert problem solvers. I have two concerns regarding this difference.

My first concern is that perhaps we have different ideas of what images are, what it means to use mental images in problem solving, and where and how the images originate. My second concern is that readers of this work, who do not use images in problem solving, may have difficulty accepting the claims made here. My only hope for the second concern is that those readers will have sufficient interest to give heuristic innovation a try. For the first concern, I feel that I should explain the role of images in my own problem solving. This section is devoted to that task. You may skip this section if it does not apply to you.

The following is my recollection of how I encountered and solved a real world-problem. I will first explain the problem as it occurred. As you will see, it is not something to brag about. But it will serve the purpose of showing images at work. Then I will attempt a plausible association of specific actions with LH and RH thinking traits.

A real-world problem

Imagine development of the following problem and its solution. Pay attention to the formation of images in your mind as you encounter the language metaphors in the description. Does the language inspire images during this reading?

Attention! I heard my wife's scream of dismay and ran to the laundry room.

Observation: As I stood in the laundry-room doorway I noted that the dryer was running, the washing machine was not running (with its usual loud noise), and there was a puddle of water under the sink next to the washing machine. The room is divided into walking space in the right half and laundry-room equipment in the left half. A storage closet, sink, washing machine, and dryer, stand side by side along the left wall of the room, in that order. Above the dryer, in the end wall of the room, is a window.

Realization: I have a problem! There obviously is a leak. I have to fix it!

Rationalization: But fix what? I don't yet know the source of the leak. I recall replacing a cracked plastic hose connection on the washing machine earlier in the year – for the second time in three years. It caused a rather large leak that drained into the basement. With that recollection I knew immediately the hose connection had cracked again. The parts salesman had said it was a common failure. Since the only things requiring water in the room were the washing machine and the sink, and the sink was empty, I was suspicious of the washing machine and the previous repair.

Plan: I decided first to turn off the auxiliary hot- and cold-water valves behind the sink, the two valves to the washing machine, and the main water valve to the house to stop the leak during repair work (although I hadn't yet determined if the leak was still dripping); second, to clean up the water and look for its source in the process. These actions were deemed to be preemptive solutions to anticipated problems.

Action: Wiping up the water only took about 10 minutes. After waiting a few minutes to let it dry better by evaporation, I ran my hand over the floor and along the baseboard to detect any new water. There was only a small amount right at the baseboard, but I couldn't tell if it was water not wiped up or new water.

Observation: I noted to my surprise while wiping up the water, that the water was not centered near the washing machine but located more under the sink and along the baseboard of the wall. It was a foot away from the washing machine. I found no water on the pump hose of the washing machine.

Rationalization: Since there was no water in the sink or on the pump hose of the washing machine, I abandoned the cracked hose-connection cause and became suspicious of a leak in the inner-wall plumbing bringing water to the laundry room. It came to mind that I might have to cut a hole in the wallboard and look for a leaking solder joint in the copper-pipe plumbing. I could visualize the copper pipes beginning at the sink, passing through the wall board into the inner wall space, turning downward 90^o, reaching the ceiling of the basement, and then running horizontally to the area of the house where the water main enters. I decided that only the plumbing above the floor level of the laundry room was suspicious. (Water doesn't run uphill.)

Action: I prepared to look for a leak in the inner wall plumbing behind the sink. This necessitated removing the sink, which required disconnecting the incoming water hoses. I put a small bucket under the auxiliary shut-off valves to catch any water that might drip when I disconnected their hose connections to the sink. The auxiliary valves were in a tight area between the back of the sink and the wall, and under the backboard of the sink. To reach an auxiliary valve I had to lie on my back and reach into the tight area with a wrench where I had to find the hose-nut by feel. After several tries with intermittent body squirms I managed to get the wrench onto the nut and turn it.

Further action: Gush – suddenly a stream of water hit me in the face!

Realization: Apparently the first turn of the wrench uncoupled the hose connection to the auxiliary shut-off valve releasing the water. The connection must not have been properly tightened at the time of the last repair. The sudden gush of water lasted only long enough to lower the pressure remaining in the pipe between the main shut-off valve and the two auxiliary shut-off valves (which, I had closed earlier).

Solution: I dried my face and tightened the hose connection.

The above problem was a real problem. I encountered the problem and solved it as described.

This simulation of the event recalls, to the best of my ability, how a problem was introduced to me, how information was mentally assembled, how images were formed, how reasoning led to action, and how the problem was resolved (embarrassingly).

Let's look at the way I described the problem. What evidence in the problem description is there for both left- and right-brain activity? Without the services of brain-scanning equipment, we must make plausible associations of word clues with known characteristics of brain-hemisphere activities. The table of brain-hemisphere characteristics is repeated here for that purpose.

Table B.3 Brain-hemisphere traits

	Left Hemisphere		Right Hemisphere	
1	Verbal	Using words to name, describe, define	Nonverbal	Using non-verbal cognition to process perceptions
2	Analytic	Figuring things out step-by-step and part-by-part	Synthetic	Putting things together to form wholes.
3	Symbolic	Using a symbol to stand for something. For example, = for equal and ∑ for sum.	Actual, real	Relating to things as they are, at the present moment.
4	Abstract	Taking out a small bit of information and using it to represent the whole thing.	Analogic	Seeing likenesses among things; understanding metaphoric relationships.
5	Temporal	Keeping track of time, sequencing one thing after another.	Non-temporal	Without a sense of time.
6	Rational	Drawing conclusions based on reason and facts.	Non-rational	Not requiring a basis of reason or facts; willingness to suspend judgment.
7	Digital	Using numbers as in counting.	Spatial	Seeing where things are in relation to other things and how parts go together to form a whole.
8	Logical	Drawing conclusions based on logic: sequences of logical steps or conclusions.	Intuitive	Making leaps of insight, often based on incomplete patterns, hunches, feelings, or visual images.
9	Linear	Thinking in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion.	Holistic	Seeing whole things all at once; perceiving the overall patterns and structures, often leading to divergent conclusions.

Plausible associations between the tabulated brain characteristics and details of the problem description are listed in Table B4. Actions are identified using terminology of the above table.

Table B.4 Plausible LH and RH activities in the laundry-room leak problem.

Problem statement / analysis / solution identified with LH- / RH-activity	
1. Standing in the laundry-room doorway I noted that the dryer was running, the washing machine was not running (with its usual loud noise), and there was a puddle of water under the sink. The room is divided into walking space in the right half and a storage closet, sink, washing machine, and dryer, standing side by side along the left wall of the room, in that order. Above the dryer, in the end wall of the room, is a window.	
LH Language:	Using words to describe and define the continuously changing retinal images. (This applies throughout the remaining description.[7])
RH Nonverbal:	Imagining previous occurrences of leaks and cracked hose connector.
	Assembling images of out-of-sight plumbing, of connectors, and valves as I took mental notes of the changing retinal images.
Synthetic:	Imagining a connection between water puddle, the connector, and the pump hose. Imagining interior parts of washing machine vibrating.
Spatial:	Seeing that the puddle of water was in the vicinity of the two objects that use water, sink and washing machine, and not near the dryer.
Holistic:	Seeing the connectivity of the invisible plumbing and the visible objects.
2. I have a problem! There obviously is a leak. I have to fix it! But fix what? I don't yet know the source of the leak.	
LH Logical:	Inferring a leak as cause of the puddle of water, and that the source of the leak was not obvious.
RH Actual:	Recognizing that water on the floor was not normal.
3. I recall replacing a cracked plastic hose connection on the washing machine earlier in the year (for the second time in three years). It caused a rather large leak that drained into the basement. With that recollection I knew immediately that the hose connection had cracked again. The parts salesman had said it was a common failure.	
LH Logical:	Realization of no customary noise brought to mind images of previous repairs where machine vibration was attributed to connector stress resulting in its failure by cracking.
	Recalling that the parts dealer had mentioned that it was a common failure.
RH Intuitive:	A leap of insight associating image of puddle of water with a leak, of leak with hose, and of hose with previous hose connector failure.
Non-rational:	Immediate conclusion of a cracked hose connection.
4. Since the only things requiring water in the room were the washing machine and the sink, and the sink was empty, I was suspicious of the washing machine and of the previous repair.	

[7] I also use words during problem solving as I mentally describe or analyze what I am doing. But this is done in broken, disjointed phrases, not in complete sentences.

LH Logical: Empty sink was inferred as a clue pointing to washing machine. Apparently LH hasn't caught up logically with RH's intuitive conclusion that the leak was caused by a cracked hose connection. However, RH's intuition began to bias LH's logic leading to incomplete analysis.

RH Holistic: Overview image

5. I decided first to turn off the auxiliary hot- and cold-water valves behind the sink, the two valves to the washing machine, and the main water valve for the house in order to stop the leak during repair work, although I hadn't yet determined if the leak was still dripping; …

LH Rational: Anticipation of a potential problem by associating pressurized plumbing with continuing leak.

Linear: Eliminate supply of water and then find source of leak

RH Holistic: Spatial visualization of plumbing and its connection to the main source of water.

6. … second to clean up the water and look for its source in the process.

LH Linear: Step by step progress.

Logical: Remove standing water to make any new water more easily detected.

RH Real: Seeing standing water as conflicting with visual detection of new water.

7. Both actions were deemed to be preemptive solutions to anticipated problems (if they were not taken).

RH Intuition: Intuitive problem recognition and solution.

8. Wiping up the water only took about 10 minutes. After waiting a few minutes to let it dry better by evaporation, I ran my hand over the floor and along the baseboard to detect any new water. There was only a small amount right at the baseboard, but I couldn't tell if it was water not wiped up or new water.

LH Temporal: Tracking of time.

Rational: Realization that wiping water would leave a film of water needing time to evaporate.

Logical: Deciding that the hand-wipe test was inconclusive.

RH Spatial: Seeing the crack between the floor and the baseboard as still having un-removed water.

Seeing a film of water remaining after wiping and seeing the evaporation process.

9. I noted, to my surprise, that the water was not centered near the washing machine but located more under the sink and along the baseboard of the wall. I found no water on the pump hose.

LH Analytic: Step by step reasoning.

RH Spatial: Noting space relation of water to pump hose.

10. Since there was no water in the sink or on the pump hose of the washing machine, I abandoned the cracked hose-connector cause and became suspicious of a leak in the inner-wall plumbing bringing water to the laundry room.

LH Logic: If no water on visible objects deduce an invisible source.

RH Synthetic: Introducing image of inner wall plumbing.

Holistic: image of room contents and imagined inner wall contents.

11. It came to mind that I might have to cut a hole in the wallboard and look for a leaking solder joint in the copper pipe plumbing. I could visualize the copper pipes beginning at the sink, passing through the wall board into the inner wall space, turning downward 90^{o}, reaching the ceiling of the basement, and then running horizontally to the area of the house where water enters.
RH Intuitive: Thought of need to cut into wall. Synthetic: Introducing image of solder joints. Holistic: View of room, inner wall space, basement, and copper plumbing.
12. I decided that only the plumbing above the floor level of the laundry room was suspicious. (Water doesn't run uphill.)
LH Logic: Water on floor must come from above floor. RH Spatial: Image of invisible plumbing above floor level.
13. I prepared to look for a leak in the inner wall plumbing behind the sink. This necessitated removing the sink, which required disconnecting the incoming water hoses.
LH Analytic: Remove sink to access wall. RH Spatial: Image of the plumbing connections.
14. I put a small bucket under the auxiliary valves to catch any water that might drip when I disconnected their hose connections to the sink.
LH Rational: Need of bucket to catch water. RH Intuitive: Anticipatory image of small amount of water remaining in the tubing at the valve.
15. The auxiliary valves were in a tight area between the back of the sink and the wall, and under the backboard of the sink. To reach an auxiliary valve I had to lie on my back and reach into the tight area with a wrench were I had to find the hose-nut by feel. After several tries with intermittent body squirms I managed to get the wrench onto the nut and turn it.
RH Synthetic: Image of body position needed to reach connector and align wrench. Holistic: Overview image of invisible hand, wrench, and hose nut.
16. Gush! Suddenly a stream of water hit me in the face!
LH Linear: Instant realization that moving wrench caused release of water. RH Nonverbal: Image of water streaming toward face.
17. The leak was coming from the hose connection to the auxiliary valve.
LH Logical: If touching hose connection releases water, valve is the source. RH Synthetic: Image of wrench, hose connector, valve, and gushing water.
18. The sudden gush of water lasted only long enough to lower the pressure remaining in the pipe between the main shut-off valve and the two auxiliary shut-off valves.

LH Temporal:	Observation that water started and stopped.
Rational;	Conclusion that remaining plumbing pressure must have dropped.
19. I dried my face and tightened the hose connection.	
LH Linear:	Water flow had stopped so there was time to dry off before tightening hose connection.
RH Actual:	Wet face needs toweling.

The two columns of one-word adjectives in the table, and their cryptic descriptions, are generalizations of brain hemisphere thinking traits. While they are adequate to summarize the original laboratory studies, they leave some uncertainty in the just completed exercise of associations with a specific problem description. Nonetheless, there is plenty of evidence of two-brain participation occurring. You probably made some of these and other associations.

This example can be summarized in three parts (that did not occur sequentially):

Problem definition: Definition unfolded as information was gathered visually and analyzed. The definition building was iterated with analysis.

Looking back, this written description was completed weeks after the problem occurred and was solved. It is a conscious effort to be comprehensive. The statement was formed almost completely from recall of visual information.

The only testing done was to run my hand along the base of the wall to feel for water.

Problem analysis: Analysis and solution occurred in iterative steps – some analysis followed by actions leading to an eventual solution.

Problem solution: The solution ended the problem but the solution process was extended through iterations of analysis and action before its final conclusion.

[By way of explanation: I don't usually remember problems and their solution processes in detail such as written in the above description. It was just fortuitous that my wife called for help while I happened to be in the process of writing an edition of the USIT Newsletter. As I confronted the laundry room leak problem, it occurred that this might be a useful situation to describe to a USIT class. So I took care to make mental notes of the process while I solved the problem. As you realized on seeing the conclusion, this was not an exemplary performance of a professional problem solver. (My LH blames that on my RH's non-rationalization along with intuitive thinking and acting.)]

The laundry-room leak problem analysis produced four important revelations for me:

- The extent to which images play a role in my thinking processes was greater than expected. They are instantaneous, continuously present, and constantly changing.

- This example of introspection, used to recall the process of solving a problem, was revealing concerning the extensive evidence of iteration. My education in problem solving and my teaching of it has always assumed that problem solving is, or should be, a logical, sequential process of definition, analysis and solution. It isn't! At least not for me. I now see it as an iterative process of building a better statement of a problem, a better understanding of a problem, and a more viable solution through iterative steps. This is logic being applied for organized understanding and rational communication.

- The example also revealed to me how much both of my cognitive hemispheres are involved in problem solving. I had always assumed that I am strongly LH. My first reaction to this revelation is to wonder why I held such an opinion. A quick answer (to be mulled more) is that I took too literally the literature on LH being logical and RH being artistic.

- The real-time execution of the problem's analysis and solution delivered a sobering lesson. When water hit me in the face, I became suddenly aware of how easily biased my problem analysis can be as a result of intuition. Furthermore bias can easily cause a less than thorough problem analysis. (The same can be said of logic.)

From this problem analysis I conclude that a natural process in mental problem solving involves …

- o … iteration through a mixture of problem definition, analysis, and solution with no logical sequencing of these stages;
- o … starting with a comprehensive view of the problem situation;
- o … continuous probing for better understanding; and
- o … bias of intuition interfering with logical reasoning.

This description and analysis of a real problem was very subjective. Such is the wherewithal of introspection. Yet this is the method by which we test, modify, and perfect our problem-solving tools. You may identify with parts of this discussion and not with others. I would encourage your personal attempt to analyze a problem you have solved and assign LH and RH characteristics to your thought processes.

More on cognitive-hemisphere thinking traits

The thinking traits listed in the tables have been expressed in various ways in the literature. None are completely satisfying for purposes of clear identification with recognizable steps of thinking in introspection. Other expressions may aid our understanding. For that purpose the table of thinking traits has been expanded as shown below. (Additions from, “The Question of Cerebral Hemisphere Dominance”, Matthew Bates, www.sci-journal.org)

Table B.5 Thinking traits of our cognitive hemispheres.

	Left Hemisphere		**Right Hemisphere**	
	Each hemisphere is presented the same sensory data simultaneously, but processes it differently.			
	Other expressions of LH behavior: • LH is verbal and analytic. • “The speaking major hemisphere, in contrast, seems to operate in a more logical, analytic, computer-like fashion. Its language is inadequate for the rapid complex syntheses achieved by the minor hemisphere.” • The verbal half of the brain dominates most of the time in individuals with intact brains. • The left hemisphere analyzes over time.		Other expressions of RH behavior: • RH is rapid, complex, whole-pattern, spatial, and perceptual – comparable in complexity to LH’s verbal, analytic mode. • “The data indicate that the mute minor hemisphere is specialized for Gestalt perception, being primarily a synthesist in dealing with information input.“ • The right hemisphere synthesizes over space.	
	• LH and RH tend to interfere with each other. • Both hemispheres use high human-level cognitive modes, though different, they involve thinking, reasoning, and complex mental functioning.			
1	Verbal	Using words to name, describe, define	Nonverbal	Using non-verbal cognition to process perceptions
2	Analytic	Figuring things out step-by-step and part-by-part	Synthetic	Putting things together to form wholes.
3	Symbolic	Using a symbol to stand for something. For example, = for equal and ∑ for sum.	Actual, real	Relating to things as they are, at the present moment.
4	Abstract	Taking out a small bit of information and using it to represent the whole thing.	Analogic	Seeing likenesses among things; understanding metaphoric relationships.
5	Temporal	Keeping track of time, sequencing one thing after another.	Non-temporal	Without a sense of time.
6	Rational	Drawing conclusions based on reason and facts.	Non-rational	Not requiring a basis of reason or facts; willingness to suspend judgment.
7	Digital	Using numbers as in counting.	Spatial	Seeing where things are in relation to other things and how parts go together to form a whole.
8	Logical	Drawing conclusions based on logic: sequences of logical steps or conclusions.	Intuitive	Making leaps of insight, often based on incomplete patterns, hunches, feelings, or visual images.
9	Linear	Thinking in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion.	Holistic	Seeing whole things all at once; perceiving the overall patterns and structures, often leading to divergent conclusions.

Three exercises in introspection follow. Three problems have been broken into steps that I recall using on these problems. One was done in a team setting. You are asked to see if they resonate with your thinking or do you take exception and view the steps differently. Which LH and RH traits do you associate with these steps? (Bulleted lines correspond with numbered rows in Table B.5.)

1. Assembling a jigsaw puzzle whose pieces have been removed from a box having a picture of the finished puzzle on its lid:

- Strategy is mentally verbalized: Sort puzzle pieces first as corners, then edges, then colors, then patterns, and then shapes. Think of options and decide what to do next.
- It is not a continuous verbalization process. Other thoughts are entertained while solving a puzzle. Pieces not immediately placed cause mental verbalization of the needed void shape and boundary colors to accommodate the piece.
- Once work has begun on, say, a pile of yellow pieces, no verbalization occurs unless a piece is not immediately put into place.
- Formation of an initial strategy – corners first, edges second, then inner pieces.
- A mental goal of producing a two-dimensional picture from a pile of parts is thought of.
- No symbolism is used.
- Pieces are accepted and processed as they are picked up.
- No abstraction is evident.
- Seeing likenesses of texture and color on a piece quickly identifies it with the object it represents – green splotches with patches of blue for a tree.
- No sequencing is used.
- A sense of time is easily lost while assembling a jigsaw puzzle.
- Simple conclusions that a piece fits or does not fit are based on whether a specific patch of color has an edge shape that will mesh with an already placed piece.
- Pieces sometimes are placed temporarily and randomly rotated to see if they drop into place.
- Counting is rarely done except to estimate how much work remains.
- This is an extremely spatial exercise.
- A piece is selected from a presorted pile, compared with the picture on the box, then placed in a region of the developing puzzle having the same color or pattern.
- Pieces often are selected intuitively and sometimes fit.
- A large expanse of sky may be done first and then a smaller lake area to get a fast start on the picture.
- A overview initially and throughout the process is heavily used.

Assembling a jigsaw puzzle, for me, is a mixture of LH and RH processing of information, but more heavily weighted toward RH thinking.

2. Computation of the volume of a sphere remaining after removal of a conical section involves:

a. Beginning with a strategy and defining variables.

b. Familiar geometric images come to mind and are sorted (with/without verbalization?).

c. Processing of information begins with a sketch, then a decision made on a system of coordinates, then determination of equations for bounding surfaces, etc.

d. A procedure requiring a variety of symbols for variables and parameters.

e. Models may be used when available.

f. Sets of points, areas, volumes, and functions are all symbolized.

g. Visualization of a sphere from its equation and vice versa are effortless. Likenesses are recognized between a developing equation and its generalized form, which speed the finding of a solution.

h. Temporal sequencing is not used (I can't think of an example.).

i. Solving of mathematical problems, like assembling a jigsaw puzzled, are devoid of time considerations.

j. A process unfolds of establishing facts and drawing conclusions along the way, which become additional facts.

k. The process uses sketches of objects, a coordinate system, and spatial divisions of surfaces and volumes.

l. Logical processing occurs with the beginning and ending of each step.

m. Leaps of insight occur, with oversight of details, that save many tedious steps of algebra.

n. The mathematical steps require "turning the crank".

o. The process begins with an overview that is gradually broken down into pieces to be solved serially. The overview does not solve the problem.

A mathematical computation involving calculus, for me, is both visual and verbal, and uses most of the processing listed in the table of cognitive hemisphere characteristics.

3. **Inventing a specialized electric motor begins with concept creation and involves:**

a. Mental problem definition requiring identification of objects, attributes, and functions.

b. Images formed by metaphors in the problem definition are understood spatially and functionally.

c. Functional components are identified and their spatial relationships sketched.

d. While searching new ideas existing electric motor concepts are recalled.

e. Symbols are used in constructing hierarchical diagrams of functional components. They're also used graphically in simple line drawings.

f. The procedure begins with data collection, problem definition, analysis, and then creation of solution concepts.

g. Supporting components may be represented as labeled boxes in a diagram.

h. Metaphors are created to produce ambiguity for broader scoping metaphors.

i. Little attention is given to time except in scheduled team sessions.

j. Time considerations are secondary in importance.

k. Analysis of unwanted effects is pursued in search of causes and effects.

l. Ideas are not filtered.

m. The spatial scope of attributes is considered.

n. Leaps of insight are common.

o. Objects, attributes, and functions are considered randomly.

p. An overview of the process and its goals is essential.

The process of inventing an electric motor is similar in some ways to solving a mathematical problem but without the mathematics.

What we can expect from RH traits …

- … illogical, random thinking that stumbles onto interesting metaphors from which LH can deduce useful concepts;
- … intuitive access to stored images;
- … intuitive leaps of insight;
- … seeing likenesses between different situations;
- … willingness to suspend judgment;
- … seeing how parts fit together;
- … insights from metaphors;
- … quick holistic view of a problem situation.

With practice we can learn to access these traits.

Heuristics

1. Strategy for Heuristic Innovation Demonstration

Some explanation may help to understand the strategy used in demonstrating heuristic innovation applied to a real-world problem. Heuristic innovation deviates from structured-type problem-solving methodologies. It eliminates organizational structure and encourages the natural thinking traits we use subconsciously. The most important of these is illogical thinking. Yes, illogical thinking – both the inspired and uninspired leaps from a rational path of thinking in acquiescence to our uncontrolled curiosities.

As argued earlier, our subconscious thinking processes (plural for two cognitive engines) are illogical; they are random, uncontrolled, sometimes convergent, and sometimes divergent. On the other hand, our conscious organization of the results our subconscious presents to our conscious is logical. This supports further rationalization as problem solving continues, enables logical communication of these results with others, and checks our path and progress toward solutions.

The strategy of heuristic innovation begins with a comprehensive problem description, at least as comprehensive as initial information allows. From this point on no structure is required. Instead, the maxim of iteration is a constant guide. Everything in a problem statement is available for iteration. Iteration broadens, deepens, and simplifies one's understanding of a problem while inspiring solution concepts. Furthermore, and most importantly, it feeds the subconscious with the maximum variation of thought provoking seeds as one can engender. Challenging or testing every part of a problem statement to find new expression initiates iteration. The resulting path you follow through a problem is determined by the questions you ask yourself, the answers you provide, and the way you react to ideas that come to mind.

Tools are available at every step of the problem-solving process. They are the heuristics one is already familiar with, those newly learned herein, and new ones yet to be found. In structured-problem solving methodologies, such as USIT, there are heuristics for the problem definition phase, the analysis phase, and the solution phase of problem solving. But in heuristic innovation, which minimizes structure, all heuristics are available for use at any time. This makes the process efficient while encouraging our natural tendency to jump rapidly at every new idea that comes to mind and press every question for deeper understanding.

Heuristics we have available include, but are not limited to, the following admonitions:

1. Construct a comprehensive problem statement, verbal (for LH) and graphic (for RH).
2. Iterate every component of a problem statement.
3. Use objects, attributes, and unwanted effects in problem statements.
4. Minimize the number of objects to those containing the unwanted effect – try two.

5. Think in the minimum set of objects (a closed world).
6. Reduce a problem statement to one unwanted effect.
7. Test for convoluted unwanted effects through object minimization.
8. Solve unwanted effects independently of each other.
9. Focus on a point of contact of two objects.
10. Take objects, attributes, and unwanted effects to extremes.
11. Contrarian: Examine the opposite of every position, assumption, or idea pursued.
12. Challenge every explanation used in order to delve deeper into phenomenology for clearer understanding.
13. Utilize an unwanted effect.
14. Nullify an unwanted effect.
15. Eliminate an unwanted effect.
16. Abstract objects, attributes, unwanted effects, and functions into metaphors.
17. Examine attributes in pairs, one from each of two contacting objects.
18. Look for solution concepts at every step.
19. Postpone judgment (filters).
20. Look for patterns. (Contrarian: destroy patterns.)
21. … and many others.

There are innumerable heuristics [Discussed in Part C]. As you practice and pay attention to your use of heuristics you will find ways to combine them for easier recall. For example, the three strategic heuristics, utilize, nullify, and eliminate an unwanted effect, might be recalled with the homonymic mnemonic, “Find unique solutions, or simply uni-solutions.” Where unique begins with the sounds, “u”, and “nee”, for utilize, nullify, and eliminate. Mnemonics are also heuristics.

Heuristics are not quantitative steps of a recipe. They are thought provoking tools to be tested to see what ideas come to mind. You should not be inspired to use a particular heuristic; rather you should use a heuristic to become inspired. As hard as you may try, don’t expect your cognitive engines to follow each heuristic described above to comprehensive conclusion – that would be excessive logic. Rather, expect each heuristic to initiate a thought-provoking journey of insight and discovery. Follow every lead with curiosity.

So intense is our training and experience as technical-problem solvers that we challenge the logic of every idea by trying to shoot it down before giving it any further consideration – the makings of technological curmudgeons. This subverts right hemisphere thinking that discovers curious connections and interesting ideas without the support of language based logic. In heuristic innovation, rational thinking is used as guideposts to be checked occasionally to assure intended progress. It is not used as a critical filter of ideas that surface to our conscious state. We go to some effort to seed our subconscious in hope of discovering unusual ideas. Each idea should be carefully gleaned for its value. This requires a willingness to suspend judgment.

2. Demonstration problem – the loose wire-harness connectors

The following demonstration of heuristic innovation uses an easily understood problem from the automotive industry. [(8)]

Construction of a problem statement
1st IPS (Iteration of problem statement):
During vehicle assembly, bundles of wires called wiring harnesses must be connected quickly and accurately to mating harnesses – a procedure having kin in many industries. An operator manually inserts one connector half into the other and pushes them together to a point where tactile feedback indicates adequate connection. Later in a vehicle's life, a wiring harness may come loose – an unwanted effect. This problem is difficult to simulate and test in the laboratory because root causes have not been confirmed.

Note: a simple solution like a locking tab can be rejected because it requires an extra motion of the installer, for which a company isn't willing to pay. Such are the real-world challenges of problem solvers working for real-world manufactures of real-world products. (This is, of course, a filter.)

But note again: Should a locking tab solution be rejected? Not if we delay judgment. There is the possibility that a clever locking tab idea may arise. If so, it may be worth finding what makes it a clever idea, what attributes it uses, to see if it could be incorporated as an automatic locking tab in the existing connector.

Question: What do we know about a wiring harness?
A wiring harness consists of a bundle of wires terminating in a connector designed to mate with a second connector through which each wire of the bundle connects with a mate and continues its circuit. To prevent a harness from coming loose in use and breaking a circuit, it is designed with a clip-type locking tab that automatically engages during assembly. The clip-type lock allows mechanical release for system servicing.

Various causes have been proposed, but not proven, to explain how a harness becomes disconnected during use. These include …

- Assembly operator not fully mating the two halves of a connector to engage its two locking tabs. This may be caused by …
    - An awkward location of the wiring harnesses.
    - A stiff wiring harness.
    - Operator working too quickly.
    - Operator inattention.
    - Operator deciding proper engagement has been achieved based on tactile feedback while still pushing the parts together (instead of trying to pull them apart).

---

[8] I thank Dr. C. Stephan for suggesting the problem.

- o Misaligned connector halves causing premature tactile feedback (reaction force) an assumption of adequate insertion of parts.
- o Parts not meeting dimensional specifications and thus preventing proper insertion.

- Environmental seals on a connector allow cyclic temperature-induced pressure to build inside the connector, which may help to push the connector halves apart.
- Connector in tight quarters where bumping by other objects causes the locking tabs to loosen.

One hundred percent on-line inspection was tried and still the problem could occur – another unwanted effect.

I'll begin by using the above discussion as our starting problem statement.

Simple sketch
Note: *Since the problem concerns loosening of locking tabs on the two halves of a connector, the internal wire bundles, and their metal-to-metal connections, are not a part of the problem and are not shown.* (Simplification by object minimization)

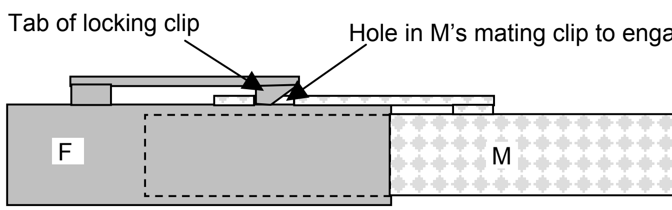


Figure B.12 Two halves of a connector, F and M, are joined by inserting M into F until the tab of the locking clip in F engages the hole in the mating clip of M.

During assembly of two connector halves the locking clip on one connector-half engages the hole (or depression) in the mating connector-half. Once engaged, if force is applied to pull them apart the side of the tab and facing the side of the hole make contact, whence reaction will occur to prevent separation of the connector halves.

Both the locking clip and the mating part are shown in the figure as flexible members mounted on top of their separate connectors (labeled F and M in the figure). It is also possible that only one member is flexible.

An oblique sketch might aid visualization of the locking clip (Fig. B.13).

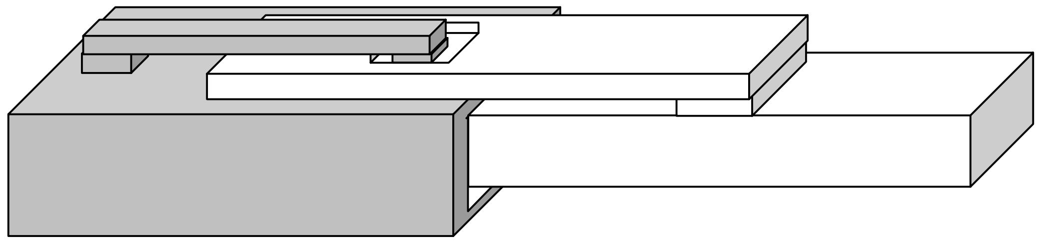


Figure B.13 Oblique drawing of two connector halves and a locking tab in the engaged, but relaxed, position.

The problem exists at the point of contact between the tab and the side of the hole in the mating socket. This contact of two objects can be illustrated in a very simple sketch as shown (Fig. B.14).

Figure B.14 Simple sketch of two connector halves, M and F. The vertical bar of M is the tab and the vertical bar of F is the contacting side of the socket hole. See Fig. B.12 for a cross-section view.

To more easily understand the member, F, in Fig. B.14 view the vertical bar as the side of a depression in F that makes contact with the tab on M (rather than as a hole in F).

Figure B.14 was drawn in elevation view as in Fig. B.12. This is the common configuration in practice. However, while drawing this sketch it came to mind that it could represent either an elevation or a plan view (side or top view). One or both of the engaging members could be mounted on their connectors so as to bend parallel to the connector surface rather than vertical to it as shown. (**SC00**) This leads to the following solution concept:

SC01 Extend long sections (in Figs. B12 – B14) of transversely-mounted connector to allow bumping without separation (Fig. B15).

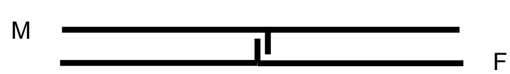


Figure B.15 Extension of the long sections in Fig. B.14 to force them to move without separating if bumped.

This addresses the current problem of a vertically deflecting connector lock coming loose when being pressed or bumped by other objects in tight quarters.

Note that in the following discussion ideas represented by the simplified type of sketch shown in Fig. B.14 can be executed either in vertical or lateral orientations.

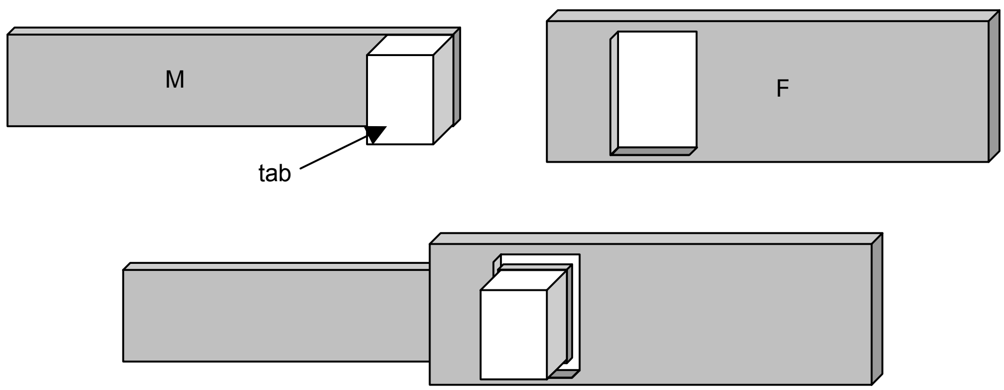


Figure B.16 Upper sketch shows two parts of clip-type lock, M and F. Lower sketch shows the same parts in the engaged position.

Discussion:
An intuitive solution concept that addresses operator-working speed is …

SC02 Reduce operator workload.

This can be done and rather quickly. However, the effect of reduction of operator workload, or any other proposed solution, on unwanted effects found in use may not be detectable for weeks, months, or years, if ever. Consequently, we must identify multiple solution concepts addressing as many of the proposed unwanted effects as possible, treating each unwanted effect independently. Then, a later problem, a strategy for installing, testing, and evaluating solution concepts must be developed and implemented. (Only a sampling of unwanted effects will be demonstrated here.)

The delay in obtaining results of concept tests is a consequence of the time between manufacture and in-use failure, plus the time for a customer or dealer service department to discover and report the failure, plus the time for warranty data to reflect a particular failure (above background noise resulting from binning inaccuracies). If a dealer chooses to replace a part, this can delay its eventual reporting, binning, and subsequent diagnosis.

This first iteration of problem statement was an extensive collection and discussion of information. We now have a considerable amount of information stored in memory. It will speed our progress if next we simplify the problem statement.

Iteration of problem statement

To prepare a second iteration of the problem statement we need to select one unwanted effect. The recommended procedure is to rank the unwanted effects and select one to be analyzed independently of the others. Contrarily, solve them in any order. On completion of this unwanted effect another can be selected for analysis if needed. In fact, since listing of the unwanted effects they are already in our heads. Consequently, solution concepts for one of these, not being focused on at the moment, can come to mind. It happens.

The given unwanted effects are ranked as follows:

1. Connector halves not fully mated
2. Operator inattention.
3. Misaligned connector halves cause premature tactile feedback
4. Stiff wiring harness
5. Bumping of connector in tight quarters loosens tab-lock
6. Parts not meeting dimensional specifications
7. Awkward location of the wiring harnesses
8. On-line inspection failure
9. Environmental seals leak
10. Operator working too quickly

The reasoning for this ranking is not rigorous. Solutions to (3) may solve (1) and (2). The remaining unwanted effects are rather independent and can be taken in any order. However, they lack sufficient information to justify spending time on them. Unwanted effects (1) and (3) can be adequately understood with a simple sketch of the locking-tab system. In fact, (3) can be used as one plausible root cause of (1) and possibly of (2).

2nd IPS:

> *On the assembly line, connector halves are not fully engaged by an operator to insure the locking tab is properly seated because premature tactile feedback resulting from misaligned connector halves is assumed to indicate adequate engagement.*

On reading this version of the problem statement, I think the latter phrase makes a simpler unwanted effect to investigate. The problem can be further simplified.

3rd IPS:

> *Misaligned connector halves cause premature tactile feedback.*

Question: Why does misalignment occur?

Obviously a hand, holding a connector, could easily misalign it. Surely, alignment guides already exist on a connector. A quick check under the hood of my car reveals that wire-harness connectors have various kinds of alignment guides. What are the attributes of alignment guides? *They typically have two, rigid, rail-and-groove-type sliding members of close fit and sufficient length to reduce angular deviation from their mean aligned direction*. They vary from a body sliding into a form-fitting enclosure, or partial enclosure including fingers, to a tongue-and-groove guide of various cross-sectional designs. They also include one or more guide pins in one body fitting into holes in the other body.

Insight: This situation suggests, to me, that in conventional designs alignment and lock engagement are independent functions that may interfere with each other – an unwanted effect.

Contrarian view: If that's the case, let's *try making alignment and lock engagement dependent functions and see if interference can be avoided.* What does this bring to mind?

First, I need a sketch to capture these ideas graphically. The following sketch, Fig. B17, illustrates the two functions – dependent alignment and engagement. The heavy vertical bars in the figure, one on M and one on F, represent each rigid connector, which ties the two functions together making them dependent. These functions are molded into the two connector halves, M and F.

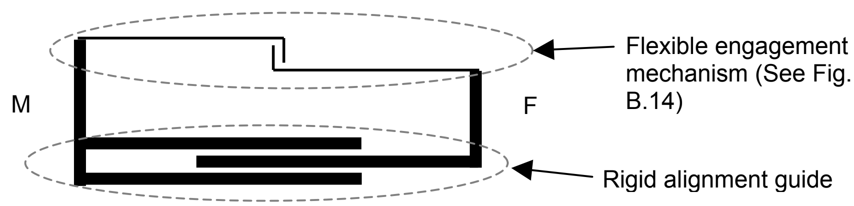


Figure B17 Simple sketch of two connector halves, M and F, having a flexible engagement mechanism and a built-in, rigid, alignment guide. Rigid members are shown as heavy lines. Flexible members have thinner lines. Both features are molded into the same plastic components.

Insight: *It is evident that guides need to be rigid while the two engaging members need to be flexible.* (Questions come to mind.) Why should guides be rigid? What is their function? (Rational answers.) *Guides need to be sufficiently stiff or rigid during insertion to react any tendency to move away from the designed insertion path, either by lateral displacement or twisting. From this observation it becomes plausible that misalignment of rigid, tight-fitting, guide parts is less forgiving than misalignment of the flexible members. The flexible members can adjust to some misalignment, the rigid members cannot. Misalignment of rigid members can cause seizure generating premature tactile feedback.*

Let's exercise a contrarian view. The following ideas comes to mind:

> **SC03**: Use the <u>flexible</u> members as a guide to eliminate at least one rigid guide component and the premature feedback attending a two-component rigid guide. (See Fig. B.18)

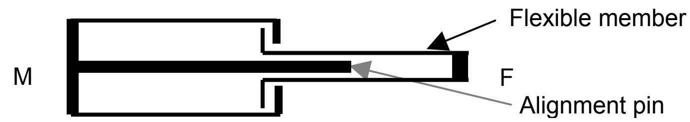


Figure B.18 Simple sketch of two connector halves, M and F, having double locking tabs (and double engagement holes not shown), and an automatic alignment mechanism, a rigid alignment pin, that eliminates rigid guides that could produce premature tactile feedback.

The aligning pin of part M, in Fig. B18, is rigid and on meeting the two flexible members of F, it spreads them to meet and engage the flexible members of M (Fig. B.18).

SC04: It will be advantageous to use tapered ends on either or both engaging members.

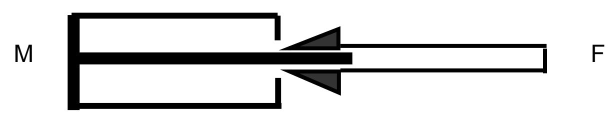


Figure B.19 Locking mechanism of Fig. A.17 shown with tapered ends on member F to deflect the tabs during engagement.

Tapered ends are shown on member F in Fig. B.19. The separations of the two tabs on M and the two engaging hole members of F are *designed so that during insertion of the two parts the guide member is not pinched by the ends of F* (See Fig. B.20). *A thin guide member with a knob, or sharp edges, on its end can reduce friction (by minimizing contact area) during insertion of the connector halves,* See Fig. B.21.

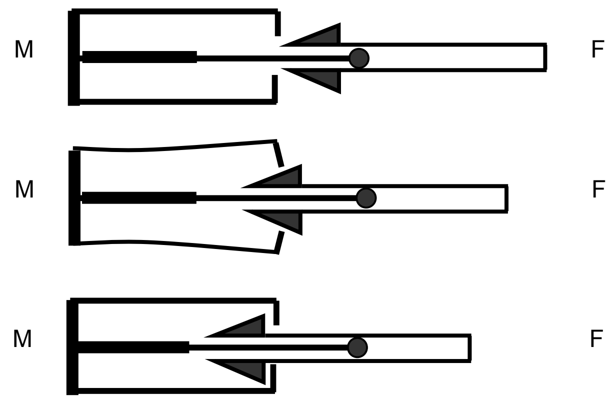


Figure B.20 Locking mechanism of Fig. B.18 shown with a thin guide member having a knob on its end to minimize friction during insertion of parts. The upper sketch shows the connector halves during insertion but before engagement. Center: Insertion showing tapered ends of F deflecting the ends of M. The lower sketch shows the connector halves engaged.

SC05: Two further improvements are *to provide thin edges on the ends of F to allow minimum friction if they should make contact with the aligning pin* and *to provide a solid end of insertion point, a stop, for creating tactile feedback indicating proper insertion depth*.

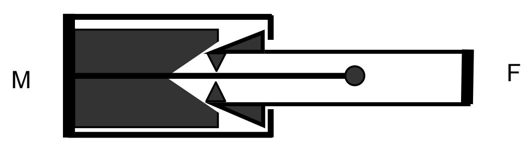


Figure B.21 Thin edges have been added to the flexible members of F and a countersunk stop added to M.

Minimal contact area between the flexible member of F and the guide pin of M is shown in Fig. B.21. A countersunk stop produces tactile feedback when adequate insertion depth has been reached.

Iteration of heuristics

The last few ideas came out of quickly examining a contrarian view toward stiff guides. Other heuristics comes to mind and should be examined – an enormous number are available. Start with your favorites. I'll begin with the strategic heuristics (discussed in Part C).

Utilize an unwanted effect. Convert an unwanted effect into a function; i.e., use an unwanted effect to advantage. What does this bring to mind when thinking of premature tactile feedback that occurs while connecting wiring harnesses?

It makes me think of triggering a visible feedback signal to psychologically override the tactile feedback signal.

> **SC06**: Design the locking process (insertion) to move a flag into view so the assembly-line worker has visible feedback instead of tactile feedback (or in addition to tactile feedback).

This could be done with a hole in the outside housing or guide that moves over a different colored area on the inside housing or guide when the housing reaches proper insertion depth. The new color will appear in the hole. It could also be done with visible flag; a small lever that is moved by the end of the entering connector causing the other end of the lever to appear from an opening in the housing, or in a housing-window.

Eliminate an unwanted effect. Elimination of premature tactile feedback resulting from misaligned guides suggests eliminating the guides. What does this bring to mind?

> **SC07**: Since wiring harnesses enclose bundles of wires and their individual connections, use the designed engagement of the wires ends as alignment guides. This eliminates the need of independent guides molded into the connector halves.

This is an example of how previously eliminated objects in a problem can be remembered and brought into consideration for solution concepts. Eliminating objects during problem simplification does not erase them from memory.

Nullify an unwanted effect. To nullify misalignment seems to suggest making misalignment moot. Making alignment automatic could do this.

> Concept: Taper the end of one connector half and make the end of the mating connector half funnel-shaped so that they slide together from an unaligned orientation automatically into an aligned orientation. (See Fig. B.22.)
>
> As can be seen in the figure, such connectors would require rotation as they slide into alignment. This could cause the pins to be bent or to bind during engagement. To solve this unwanted effect, separate the two functions – alignment and engagement.
>
> **SC08**: Use a spring to pre-position one connector half for alignment during insertion. As insertion continues the aligned connector halves reach the zone of engagement, become locked and remain positively engaged by the compressed spring.

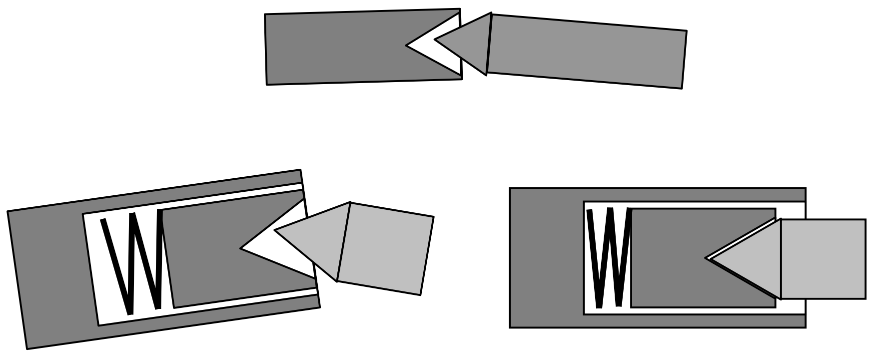


Figure B.22 Upper sketch: Connector halves designed as mating taper and counter sunk shapes for automatic alignment. Lower sketch: Separation of alignment and engagement using a spring to be compressed as alignment is completed and engagement starts.

Challenge assumptions: It was assumed that the locking clips needed to be flexible. What if they were rigid? What ideas come to mind? (None at the moment, so I'll move on.)

Question: What are the active attributes of the clip-type lock having a tab on one connector half and a mating hole on the other?

Active attributes include:

- *Size,* long enough for sufficient deflection of elastic members and continued insertion to a stop.
- *Shape,* to allow engagement of two parts.
- *Tapered end,* taper angle determines the angular range of initial misalignment.
- *Taper,* with small contact area to reduce sliding friction.
- *Elasticity,* to allow deflection without permanent shape change.
- *Yield strength,* to react forces of loosening.
- *Friction,* works against us when causing premature tactile feedback.

Elasticity has already been taken to the extreme of rigidity. Contact area has been taken to the extreme of a point, a spherical knob contacting a plane.

Take objects to extremes: Taking pairs of engaging tabs and mating holes to extremely large numbers brings to mind Velcro ©.

> **SC09**: Mold connector halves so that one slips inside the other. Mold flexible points on the inside of one and holes (or depressions) on the inside of the other. When one is inserted into the other many pins and holes will engage distributing any unwanted forces across many pairs of pins and holes where the forces are reacted through friction.

In previous discussion the connector halves and their clip components were considered to be just two compound objects, in this example the two clip members and their connectors are treated as separate objects.

Let's move on.

4th IPS:

> *Assembled wiring-harness connectors come loose in the field.*

Take attributes to extremes. Taking friction to an extreme suggests to me to glue the connectors together.

> **SC10**: Use a contact cement to glue the ends of the connector ends together when inserted. The cement can be of a type that can be released with tensile force, heat, or a solvent.
>
> **SC11**: Fabricate contacting ends of plastic connectors with surfaces roughened by tiny, molded-in hairs. Warm the connectors during insertion so that some of the hair-hair contacts between the two connector ends partially fuse. They can be pulled apart later when heated.
>
> **SC12**: Imbed magnets in the connector ends to add additional holding force when the connectors are assembled.

5th IPS: *Abstraction*; connectors become blocks and in-field use becomes vibration.

> *Assembled blocks come loose when vibrated.*

An idea comes to mind.

> **SC13**: Mold contacting ends of blocks with multiple ball-and-socket connectors that snap together as balls are forced into snugly fitting sockets. Block material must be sufficiently elastic to allow them to be pushed together and an equivalent force required to separate them. This configuration is immune to loosening by both lateral and longitudinal vibrations. Two or more balls and sockets will restrain any common-plane rotational motion.

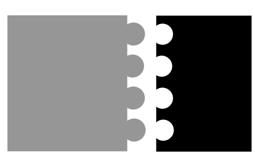


Figure B.23 Blocks molded, with multiple ball and socket connectors over their facing ends, ready to be snapped together.

6th IPS: **Abstraction**; Connectors become guides and the unwanted effect becomes jamming.

Misaligned guides jam.

Jamming suggests that during assembly the operator applies a force at an angle to the desired sliding direction. This produces a normal component of force that can cause adhesion or sticktion in addition to the desired horizontal force for sliding. Delay between the instant of surface contact and the application of the horizontal force can cause sticktion or adhesion. This suggests interrupting the normal force while applying the horizontal force, which could be done using vibration.

> **SC14**: Design a handheld vibrator with which to grasp one connector while inserting the other connector. Transverse vibration of either connector relative to the other will interrupt the normal force allowing sliding to proceed.

7th IPS: Operator omits pulling on the connector to test connector seating because premature tactile feedback is inferred as adequate seating.

Pulling on connector after insertion is omitted.

An intuitive concept comes to mind to eliminate test by pulling. Connector halves separate if inadequately seated.

> **SC15**: Design one or both connector halves with springs in their facing ends. During insertion the springs are compressed. When the operator releases the connected pair the springs will separate them if they are not adequately seated.

This concept offers the additional advantage of continuous positive engagement after proper insertion, which works against vibration as a future cause of separation. (Visualize a spring being compressed between the connector halves shown in Fit. B23.)

8th IPS: *Abstraction*

Tactile information produces an erroneous error message.

Is there a useful pair of attributes to consider? Given connector halves with compatible shapes, the motion of one and the position of the other enable engagement.

```
motion
        \
        to lock – no motion
        /
position
```

Figure B.24 Motion paired with position as active attributes supporting “to lock”.

Motion is detected by feel while position is detected by sight. Motion might be replaced by another attribute that is not sensed by feel. Position is an obvious choice to test.

```
position
        \
        to lock – position
        /
position
```

Figure B.25 Three position attributes supporting "to lock".

This was done in SC06 using a moveable flag to be detected visibly. A contrarian view would suggest doing it without a flag. If there is to be no flag then it seems another form of visible detection is needed. A modification of SC01, using lateral moving clasps, could do this.

SC16: Use moving clasp elements that move laterally on the surface of a connector and have their engaged-position exposed for visual examination. (See Fig. B.26)

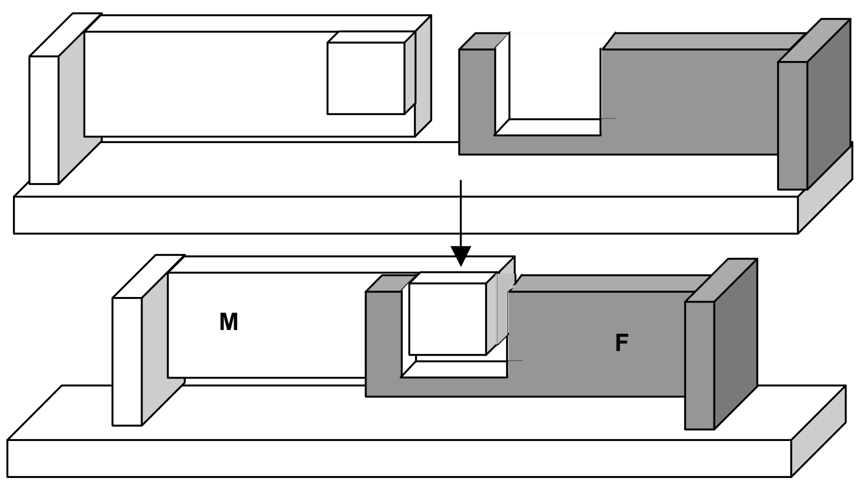


Figure B.26 Laterally flexible clasp elements mounted on the surface of a connector and having their engagement area exposed for visual inspection from above (indicated by arrow). Upper sketch is before engaging, lower sketch is after engagement.

A further improvement is to protect the clasp from lateral contact by neighboring objects. This is illustrated in Fig. B.27 with the addition of protective side walls (heavy lines).

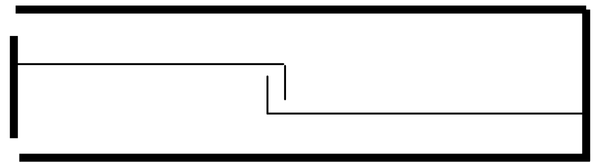


Figure B.27 Schematic of clasp elements shown in Fig. A.14 with protective side walls added. View is from the top.

SC17: Add stiff side walls and a transparent cover to protect laterally displaceable clasp elements.

I have a tendency to worry about assumptions I make during problem solving. Too many times they have come back to bite me. This thought brought to mind the opening assumption I made in this problem: *"Since the problem concerns loosening of locking tabs on the two halves of a connector, the internal wire bundles, and their metal-to-metal connections are not a part of the problem and are not shown."* The assumption led to a useful simplification of the problem. On rereading it, I wondered if any useful attribute of the whole system, connector and bundle of wires, might have been overlooked. One came to mind, "*bundle*".

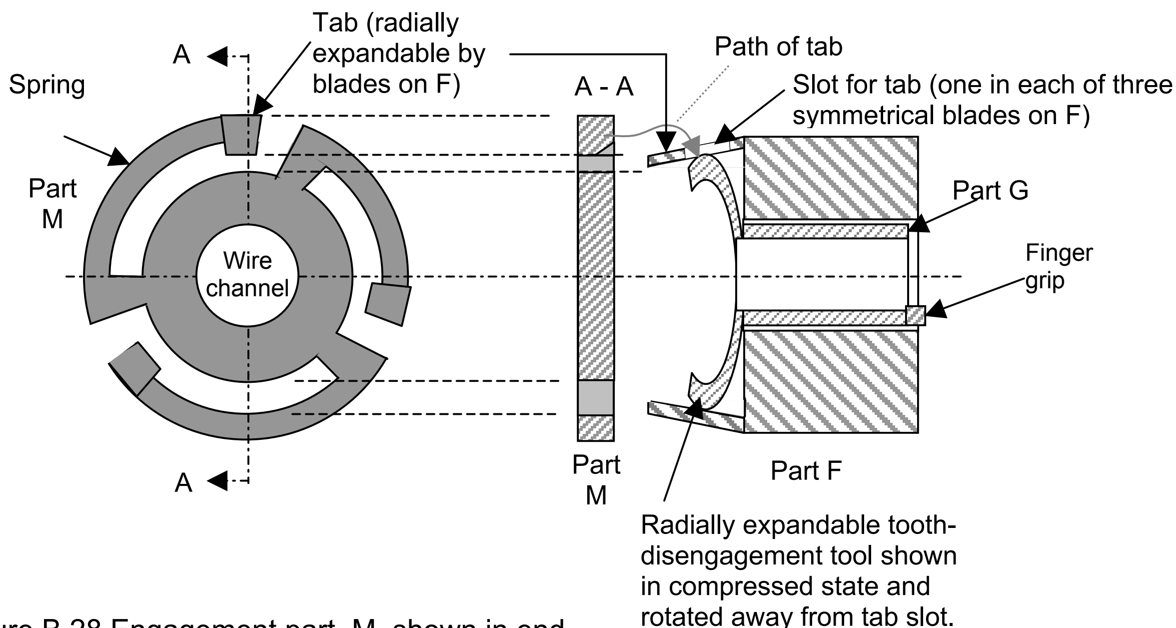
Bundle of wires brought to my mind an image of a cylindrical cable, and that introduced the idea of symmetry. To this point, my view of the system has been that of a cable terminating in a rectangular parallelepiped-shaped connector with the engagement-tab system molded into one side of the connector. Now I wondered, would introduction of cylindrical symmetry, as a new attribute for the connector-engagement function, offer new insight? Two ideas came to mind: a) alignment of telescoping cylinders would be easer than alignment of telescoping rectangular parallelepipeds on the side of a bundle of wires, and b) it would be easy to multiply engagement points symmetrically to counter their tendency to cause lateral forces during engagement (misalignment forces).

SC18: Use cylindrical symmetry in telescoping connector halves to ease their alignment.

In the previous designs, two flexible members slide together and cause lateral forces on each other as their engagement deflects their individual support beams. By adding three symmetrically arranged engagement-tabs around the periphery of a cylindrical connector their lateral forces on the connector would cancel, thus lessening a tendency to cause misalignment of the connectors during engagement.

SC19: Use three or more symmetrically position engagement tabs around the periphery of the connector halves to counter lateral forces during engagement.

Then I wondered about disengagement of three simultaneously engaged tabs. Disengagement is a requirement for future service of the system. This led to the idea of a rotating fan-blade element, having bent blades under compression during engagement, that could be rotated to the positions of the engaged tabs and push them out of their engagement slots. Molded-in-place finger grips could be provided for rotating the disengagement member. These ideas are illustrated in Fig. B.28.



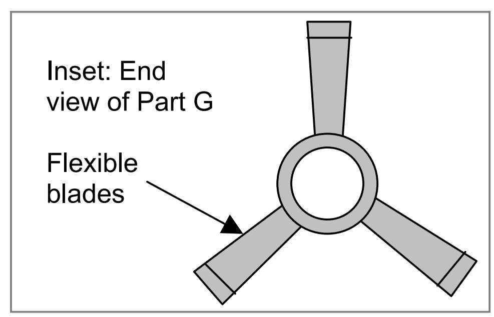


Figure B.28 Engagement part, M, shown in end view in left side of drawing, having 3 expandable tabs. Section AA of part M shown in cross-section in right side of drawing along with cross-section of part F and a disengagement tool, part G. Part G has the same number of blades as tabs on part M.

Part M, shown in the left-hand side of Fig. B.28, is one connector half and Part F, shown in cross-section in the right-hand side of the figure, is the other connector half. Part G is a third part mounted inside of Part F. It has three compressible blades that are initially set at an angle such that their ends do not align with the slots in the three slanted blades of Part F. When needed for system service, Part G is rotated to align its compressed blades with the slots in F and then push the tabs of Part M outwards, thus disengaging them from Part F.

These solution concepts demonstrate how heuristics can induce inspiration. More ideas can be investigated and other concepts can be built from combinations of these.

The Transition from USIT to Heuristic Innovation

The transition from unified structured inventive thinking to unstructured heuristic innovation raises questions regarding suspicion of loss of structured thinking. How does heuristic innovation replace this loss or improve on the original USIT? Another concerns whether anyone is left behind.

This transition was motivated following an analysis of USIT structure to understand its inherent pedagogy and how its structure works. One example is an analysis of the USIT heuristic for identifying plausible root causes. This is a hieratical diagram of links between an unwanted effect and underlying causes that leads to root causes. Let's examine how it works.

The USIT plausible root-cause heuristic

Historically, this heuristic was developed and introduced as a pedagogical tool. Industrial technologists taking USIT courses were found to need help in identifying root causes of an unwanted effect. Even though their industrial training usually includes discussion of the importance of understanding root cause, and statistical methods are taught for finding root cause, the problem still exists.

Reasons for the difficulty students expressed include the following: Some students are taught to find the root cause – a singular cause. This leads to confusion when USIT requests finding multiple root causes. A more critical reason is the lack of a working definition of root causes and an efficient methodology for discovering them. Industrial training typically provides courses in design of experiment (DOE) for this purpose – a tedious, lengthy, and expensive exercise. The USIT plausible root-causes heuristic bypasses DOE, which authenticates root causes, and quickly searches instead for plausible root causes.

Resorting to plausible root causes in lieu of confirmed root causes may seem to be counter intuitive – it appears to ignore the (inferred) truth of confirmation. We are searching, however for *new* insights to problems and innovative solution concepts. "Newness" emphasizes previously unvisited areas of understanding. Plausible root causes, although having no confirmation, are born of our technical knowledge applied in order to understand newly introduced phenomena. They are very appropriate starting points. The resulting concepts can be confirmed later.

The plausible root cause heuristic is a hieratical structure beginning at the top with a single unwanted effect. Next below the unwanted effect is a row of objects containing the unwanted effect. Below each object are one or more branches of cause-effect links springing from the original unwanted effect. The structure with its pedagogical thought process is demonstrated in the following figures. Note that USIT used a row of objects whereas heuristic innovation uses a single pair of objects.

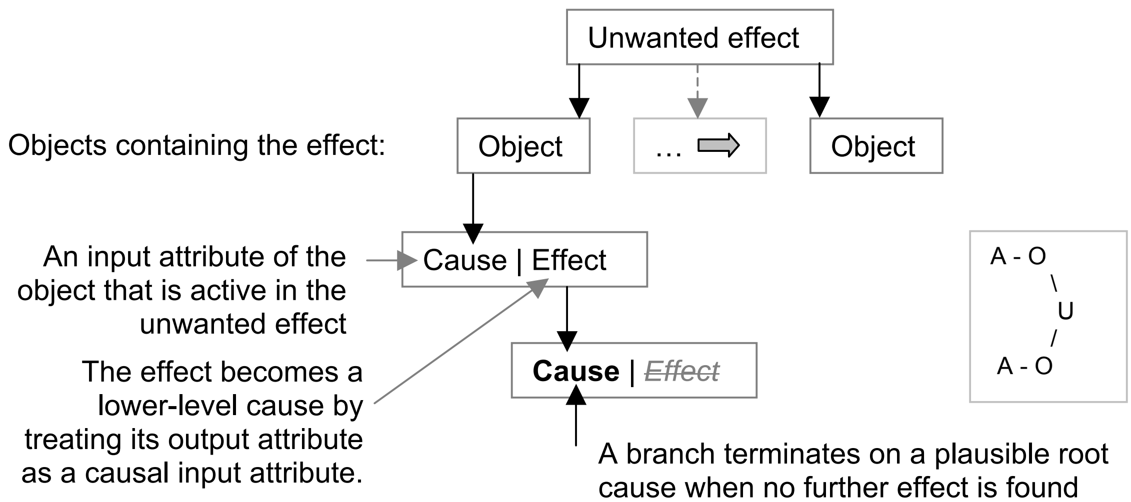


Figure B.29. The USIT plausible root-causes heuristic and its hierarchy of cause-effect links. The inset emphasizes the reversal of A-O connections in USIT versus heuristic innovation.

Figure B.29 defines the plausible root-causes heuristic. Objects containing the single unwanted effect in question are listed below the unwanted effect. Below each object are connected cause-effect pairs. Lower-level causes are identified by finding input attributes of an unwanted effect associated with output attributes of more fundamental causes (unwanted effects). When no new effects can be identified the lowest cause is a plausible root cause. Each branch of the diagram can produce a plausible root cause.

Causes that have not been confirmed by experiment, such as DOE, are termed "plausible root causes". This heuristic is also a useful tool for identifying potential root causes to be confirmed by test.

The efficacy of this heuristic for generating new insights lies in the way one proceeds to develop the hierarchy of cause-effects links to an underlying plausible root cause. A sequence of questions and subsequent searches is initiated designed to stretch the imagination of the problem solver within personal knowledge. A basic element of this question-search sequence is illustrated in Figure B.30. In this figure the A-O linkages of heuristic innovation are used and the roles of objects are subdued. This eliminates some confusion in figuring out to start the first row of causes and effects that students experience.

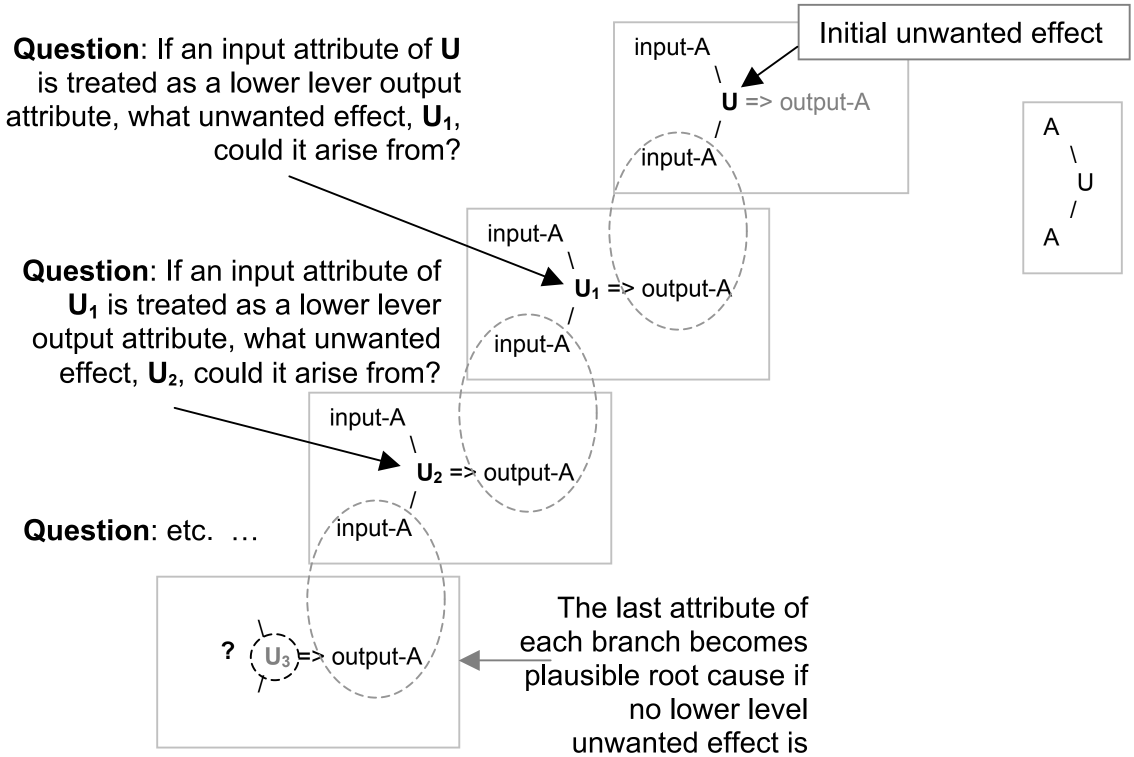


Figure B.30. Cause-effect links in the plausible root-causes diagram arise from the question, “If an input attribute of an upper level unwanted effect is treated as an output attribute of a lower level cause, what is the lower-level cause?”

Note that every unwanted effect has two or more causal attributes (by definition of an unwanted effect). Therefore, to qualify as a root cause, two interacting attributes are needed. However, only one need be countered to void the affect of a pair.

Note also that each attribute can head a new path. This can lead to multiple plausible root causes.

The heuristic-innovation transition

As can be seen in the above analysis the essence of the USIT plausible root-causes heuristic it the process of asking questions to find deeper phenomenological understanding. Specifically, the same question is asked for each deeper level. The transition from USIT to heuristic innovation retains the questioning of this heuristic but shifts emphasis from objects to attributes. This may appear to be a small difference, but it has a profound impact on one’s thinking process.

In heuristic innovation the structure has been removed retaining only the self-induced logical sequence of questions and answers driven by one's innate curiosity.

Whereas in USIT this heuristic was executed in its entirety as a single exercise in the analysis stage of problem solving, it is spread throughout the heuristic innovation process. The iteration procedure of heuristic innovation incorporates this questioning of plausible root causes in each of its iterations. We need only remember to ask the question – "What is a cause of an unwanted effect?" – and that posing the answer as an attribute allows the attribute to become a new effect. An advantage of the iterative process is that you are encouraged to pursue solution concepts at every level of plausible root-cause questioning (Fig. B.31).

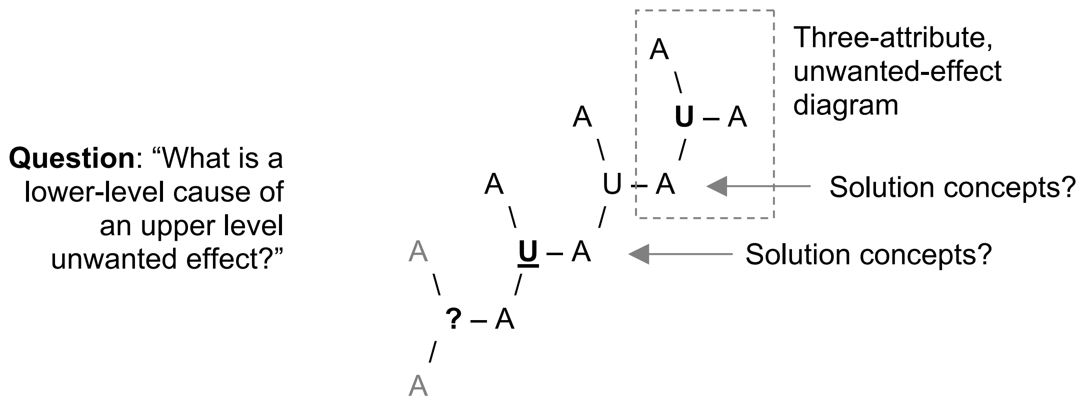


Figure B.31. Three, linked A–U–A diagrams form a chain that illustrates the path to plausible root cause (**U**) through repeated questioning of upper-level cause. Solution concepts are searched at each level during heuristic innovation iteration.

How to invent from an unwanted effect

An example of applying the USIT plausible root-causes heuristic method will help to illustrate how the underlying thought process works. For this purpose we need an unwanted effect. Any problem statement offers an example. Another source is a need to invent. I'll demonstrate the latter.

In heuristic innovation, as in USIT, invention is treated as differing from routine engineering problems only in the filters a solution concept must pass. But filtering of solution concepts is a post concept-generation exercise. Hence, we need only find as many solution concepts as possible and later cull them for uniqueness, surprise, out-of-the-ordinariness, and freshness, whatever filters we wish to apply to define invention.

We begin an invention exercise by constructing an unwanted effect. To do this, we decide on what we want to invent then imagine it as having an unwanted behavior, an unwanted effect. For example, suppose we want to invent a better computer mouse. What unwanted effects might a mouse have? We can list a few and pick one to work on. To do this, simply list the functions it currently has and any new ones that come to mind. Then convert one to an unwanted effect.

Functions of a computer mouse include,

- to be convenient to use,
- to be easily moved,
- to be ergonomically comfortable,
- to operate within a limited space of planar motion,
- to map position within the limited space,
    - to convert rotational motion of a ball into proportional electrical signals relative to a calibrated position,
- to provide accurate position measurement,
- to provide finger-button-signaled position signals,
    - button up/down
        - to signal a sudden relocation,
- to transmit its signals (by wire, radio, light), and
- to provide easy access for cleaning.

No new functions came to mind so the list was terminated. Any of the listed functions can be worded as mal functioning and become an unwanted effect. For lack of any preference, I'll select the first one, to be convenient to use.

The obvious problem statement for this unwanted effect is "a conventional computer mouse is inconvenient to use". Fix it. Here is an opportunity for an invention. First a simple sketch is needed (see Fig. B.32).

Next we need to identify plausible root causes. We begin by identifying objects in the system: mouse, hand, pad, and wire. Each pair of objects provides a two-object point of focus: finger-to-mouse, thumb-to-mouse, palm-to-mouse, mouse-to-pad, and mouse-to-wire.

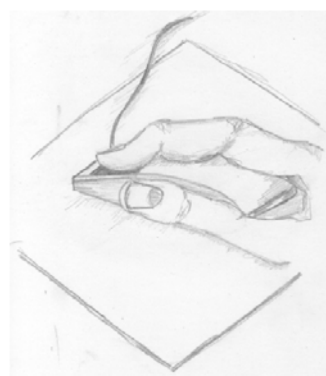


Figure B.32. Sketch of a hand holding and moving a wired-mouse across a pad.

Hand-to-wire is only an occasional contact. Although when it occurs it usually is an issue of inconvenience. This unwanted effect has been addressed with wireless mouse designs.

Instead of drawing the plausible root-causes diagram we need only pick a point of contact and consider what is happening there; i.e., what effects are present – functions or unwanted effects? Let's consider the thumb-to-mouse contact (readers can examine others).

Question: What is the cause of inconvenience of a mouse at the point of contact between thumb and mouse? In order to describe the unwanted effect at the point of contact between the thumb and the mouse we need attribute pairs from these two objects. A simple way to do this is first to list the effects that occur at this point then to select plausible interacting attribute pairs from the two objects. Obvious effects are:

Effects at the thumb-to-mouse point of contact:

- to apply force from thumb to move the mouse,
- to assist in grasping the mouse for lifting and moving,
- to react force of thumb creating tactile feedback for precision control

Potential attributes of thumb are:

stiffness	to react resistance to motion
inertia	to transfer momentum to mouse
agility	to act rapidly
sensitivity	to detect resistance to motion
resolution of motion	to move in small increments
texture	to provide tactile comfort

Potential attributes of mouse are:

- shape
- size
- inertia

To this point, everything I've said about this system is steeped in LH logic. When does RH get a chance? Its chance comes as we combine attributes to see what new ideas come to mind. The logical analysis, to here, is an attempt to be sufficiently thorough that a variety of thought paths will await our investigation. More questions will find them.

Question: What is there about thumb-to-mouse contact that suggests inconvenience? I'll begin with stiffness and shape as active attributes. (No ideas yet, so I'll ask another question.)

Question: If stiffness and shape interact to cause inconvenience what attribute are they affecting? For lack of an obvious answer I'll take the first attribute, stiffness, as the output attribute and ponder that combination.

```
stiffness
         \
          to cause inconvenience – stiffness
         /
    shape
```

Figure B.33. Stiffness and shape shown as input attributes to cause inconvenience.

This causes me to wonder if there is something unnatural about the thumb-to-mouse contact.

Question: That raises the question of what might be more natural? In the realm of moving something in small increments on a planar surface I think of writing, drawing, painting, writing on a PDA (personal data assistant), and doing fine scrimshaw under a magnifying glass. Finally, here are some answers to serve as thought starters.

The way the questions have been posed it seems that, for example, writing is a more natural way of moving something on a planar surface in small increments than is thumb-to-mouse. So let's make mouse in the shape of a pencil. What does this bring to mind? Can that be done? Yes.

Concept: Design mouse as a pencil having micro- or nano-technology sensors to detect, and encode position and motion, and to transmit the information wirelessly to a computer.

Concept: The pencil-mouse could be used as a real pencil at the same time. The computer simply decodes the position information and displays script, numbers, sketches, or whatever the user is doing on a writing surface.

Concept: One could write a column of numbers, using this pencil-mouse, and the computer could display it and keep a running sum, running average, plot a graph, or do other mathematical operations in real time. The computer could be trained to recognize pencil-mouse strokes as characters.

Concept: Using the pencil-mouse, one could print plus, minus, divide, and multiple signs on the paper somewhere and then just touch one with the pencil-mouse to get a desired operation. The position of these symbols will have been recorded when they were first made on the writing surface. Or the computer could recognize mathematical symbols and operators written in-line with numbers.

It appears that these ideas are equivalent to bringing the services of a PDA to one's desk without the PDA. You need not work on the small screen of a PDA but can write on any size pad or sheet of writing material using a real, albeit electronic, pencil. In the process a paper record is also created.

I don't know whether these ideas have been published before, but I wouldn't be surprised to find that they have.

As demonstrated, the procedure for invention in heuristic innovation uses the method of questioning effects in search of deeper understanding in terms of active attributes of a small set of objects. At any level of questioning answers provide thought starters. When no answers come to mind, ask more questions. The method is the same as used in USIT for constructing a plausible root-causes diagram. However, in heuristic innovation these questions are asked throughout the process of iteration. In fact, they motivate iteration.

There remain above a number of possible paths to follow that readers may enjoy trying.

Left behind?

Does the transition from structured problem solving to heuristic innovation leave anyone behind? This question is rooted in the valued pedagogy associated with structure. To instructors, structure provides a neat package, a logical way of explaining methodology. However, to students familiar with structured problem solving it may or may not be an easy transition. It probably depends on their level of confidence with their learned problem-solving skills. To students unfamiliar with structured problem solving, the question may be moot. For them, the concept of a methodology that embraces our natural way of thinking may be readily acceptable. Structure is a hindrance to learning methodologies – less is better.

In the end, it is problem analysis

A pervasive thesis in this book is that the activation of both of our cognitive hemispheres, the relaxation of constraints of problem-solving structure, and the encouragement of our natural thinking capabilities provide us an efficient basis for discovering creative solution concepts to problems. In developing this thesis the case was made for eschewing structure in structured problem solving, at least in minimizing it. Why? What is wrong with structure, especially structure designed to aid us in inventing?

Now’s the time for a sanity check.

This is not an issue of what is right and what is wrong with structure. It is more a pause for some introspection to recognize what we do with the structure we have learned.

After one has taken, for example, a three-day course in structured problem solving methodology, and then returned to his or her workplace, what happens with the newly gained knowledge and tools? Probably nothing happens at first. Typically, problem solving, of the creative design type, is not a daily opportunity for professional technologists. Hence, most likely, one sets aside the new methodology waiting for an opportunity to use it. When an opportunity does arrive one retrieves class notes to refresh memory and to find any worked examples that may be relevant. Then a realization, “I don’t remember how the procedure works!” What happens next can vary among individuals from abandonment of interest to dedicated learning.

At Ford Motor Company in Dearborn, Michigan, this problem was addressed by providing graduates of three-day courses with twice per week, voluntary user-group meetings. To these meetings students brought company problems to be worked by all who attended. In addition to aiding students in developing their skills with the methodology, useful feedback was provided to the instructors.

Here, and in classes at other companies, it was found that the various diagrams that constitute the structure of the USIT methodology were not readily understood. Manipulated by the hands of the instructor the diagrams proved to bring new understanding of the phenomenology of a problem. They were interesting to watch an expert use but were not yet tools the novice could use with confidence. However, the students often had kudos for the way the methodology brought them to new experiences in investigating and understanding a problem.

From the instructor's perspective it was evident that the structure had value in lighting the pathway, so to speak. By following the structure, students seemed to gain some confidence that they were on the right track. However, their approach to executing structure is always one of critical LH rational. It only occasionally produced intuitive solution concepts. This may be due, in part, to the organization of the methodology into three parts: problem definition, problem analysis, and application of solution concepts. Being aware of the fact that the application of solution concepts comes last, students may ignore natural thinking events, such as intuitive ideas, and hold them off until they start the application of solution concepts. In other words, students seem to have a tendency to defer to the structure of the methodology and not to intuitive ideas that appear to be out of place, *al a* the structure.

What about the experts themselves? How do they treat the structure when working problems alone and not teaching the methodology? I can, of course, only speak for my self, but I find that structure is soon ignored as the fundamental features of the structure is assimilated into one's subconscious thinking in problem solving. And what are these fundamental features? They are, first, the guiding principle of constructing a well-defined problem. Second, they are the analytical questions one asks and rationally answers while digging one's way to plausible root causes. With this limited amount of guidance and a pocket full of favorite heuristics, one can produce generous amounts of inspiration and insight. In the end problem analysis is our source of inspiration.

Conclusion

Contemporary structured, problem-solving methodologies consist of a hierarchy of specialized heuristics. They are organized logically to allow progression through a problem from its initial definition, through its analysis, and finishing with application of solution heuristics – three common divisions of problem solving. There are heuristics for each division. One benefit of these methodologies is their acceptance based on their obvious logic. This gives a problem solver initial confidence to invest the effort in applying their methodology. The problem solver's investment soon brings confrontation with new terminology, complex procedures, tedious routine, seemingly arbitrary technique, and an unexpected investment of time to learn the intricacies of a methodology. However, there is plenty of evidence that the method has worked for others and this assurance supports determination to continue. Eventually, the method is sufficiently understood to produce results. Success supports return to the methodology for new problems. However, as experience grows in the use of a methodology, a problem solver soon finds short cuts that eliminate some parts of the methodology and simplify others. Why?

An obvious answer to this question is that the problem solver has found ways to make the methodology more compatible with already engrained ways of thinking about problems. These short cuts have eliminated some un-natural parts of the methodology. If this deduction is correct, what are the un-natural parts of structured problem solving?

It has been demonstrated here that structure and logic appeal to only one cognitive hemisphere, the language-oriented hemisphere. Yet, both hemispheres have highly developed thinking traits. Heuristic innovation was developed to eliminate structure, to throttle vetoing of intuition, and to encourage right-hemisphere involvement in problem solving. To these three reasons for heuristic innovation two more arose.

An often cited claim by experienced problem solvers is, "Show me root cause and I'll show you a solution." I have heard this enough times, and have experienced the same feeling, to realize that there is more than problem understanding to be found in root cause, there are clues to solution concepts. Identification of root causes is a key to successful innovation.

The fifth reason for heuristic innovation is to establish an effective understanding of a problem – depth of understanding is probed through iteration of problem definition.

> Heuristic innovation replaces conventional structure with one focused effort: development of problem statement through iteration. It has heuristics to throttle LH logic and encourage RH intuitive insights. Through iteration of problem statement it pries quickly into more meaningful understanding and varied expression of root causes.

Exercises (See pp. xx –xx for more exercises.)

A. Record your instantaneous mental images to the following incomplete phrases. Record your image before moving to the next phrase. The phrases are printed in reverse to discourage reading ahead.

… seod yhW

… gnirats seod yhW

… nosrep a ta gnirats seod yhW

… esuac nosrep a ta gnirats seod yhW

… nosrep eht esuac nosrep a ta gnirats seod yhW

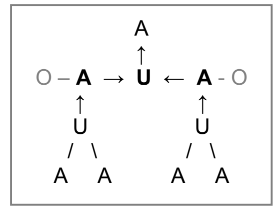
… ?yawa kool ot nosrep eht esuac nosrep a ta gnirats seod yhW

B. Construct a problem statement from your own field of work or interest. It does not have to be an engineering-design type problem Do this before reading the remainder of this exercise.

1. Identify the objects, attributes, effects and metaphors in your problem statement.
2. Does your problem have interacting objects having functions at points of contact?
3. Generify the problem statement.

C. "I dare not put two dozen apples into this box!"
Identify as many causes as you can imagine for this problem situation.

C Theory, Derivation, and Application of Derived Heuristics



Preface

In this part heuristics are derived from a small set of axioms. Derivation is done using the USIT methodology and not heuristic innovation. The reason is that the derivation of heuristics came before heuristic innovation was invented. Work on the derivation of heuristics led to the ideas for heuristic innovation. Since the discovery of how to formulate heuristic innovation it has become the more important subject. Hence, the derivation of heuristics, using USIT, has been placed after the presentation of heuristic innovation.

Heuristics used by technologists 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 axioms are couched in generic terms, independent of a particular field's specialized language, the resulting heuristics are also generic. Hence, a particular derived heuristic can be adapted to a specific field by framing it analogously in terms of objects, attributes, and effects. 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 present a new basis for a problem-solving methodology. They offer problem solvers new perspectives from an attribute-centered methodology in contrast to conventional object-centered methodologies.

Overview

Part B of Heuristic Innovation presented the development of a new problem-solving methodology with heuristics for engaging both left and right cognitive hemispheres of our brains. The methodology is simple and complete as presented and is ready for use.

Part C addresses fundamentals of the new methodology: namely, the theory, derivation, and application of heuristics in general. The discussion is more theoretical than that in Part B. Much of the material in this section was developed before Part B and led to the discovery of the methodology in Part B. It is placed here for easier understanding after reading and trying heuristic innovation.

I. Theory of Heuristics
Section I of Part A covers the background of heuristics, describes examples, demonstrates their use in solving technical problems, and explains how selected heuristics are used in Section II to derive new heuristics. A theoretical basis is laid for derivation of abstract heuristics to follow. Those familiar with heuristics in problem solving and with structured, problem-solving methodologies may wish to skip this section on first reading.

II. Derivation of Heuristics
Section II of Part B 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 renditions. Their application is demonstrated.

III. Demonstration of Derived Heuristics
Section III of Part C demonstrates the application of heuristics derived in Section 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.

I. Theory for Derivation of Heuristics

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 Part C. 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 (Ref. 12):

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.

Although the above twelve heuristics have been identified with solving mathematical problems, each can be applied in solving design-type problems.

Definition of heuristics and intuition

Heuristics are used to seed the 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 (unintentional) intuition to recall a few favorites. 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 C1. 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 C1. 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 [1] 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. (Ref. 13) 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. The two parts are treated as independent activities in structured, problem solving. Heuristics are used in both activities. Focus here 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. [2] 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 heuristics. These methodologies are marketed both in the form of

[1] Source unknown.

[2] 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.

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 one's 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". (Ref. 14) 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 methodology based on a self-consistent set of derived heuristics.

Background

Structured problem-solving methodologies

The methodology called unified structured inventive thinking (USIT, Refs. 1, 5 and 6) is used in this discussion. It is an offshoot of systematic inventive thinking (SIT, now known as advanced systematic inventive thinking, ASIT (Ref. 15)). SIT is an offshoot of the theory of solving inventive problems (TRIZ) originating in Russia in 1947. (Ref. 3) 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. (Ref. 16)

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. (Ref. 17) 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. "Creative" is determined through filters. Finding multiple concepts 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. [3] It is intentionally superficial in order to grasp a few essentials of the process without the detail. The simple model:

[3] 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.

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 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 short-term 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 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 technical drawings, 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 ► technical drawings ► sketches ► labeled box and, even as abstract as an unlabeled box (discussed later). Similar abstraction occurs in verbal and written reports. A 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 quantified and 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 heuristic innovation 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 here will be seen to take advantage of this opportunity.

Objects are burned into our memories with characteristic sizes and shapes. 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 C.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 application.

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. Consideration should be given to non-obvious intuitive associations.

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 conscious 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

Although no algorithms exist for deriving heuristics it will still 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 C.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. One requirement for a well-defined problem is a single unwanted effect. 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. 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 [4]).

Several known heuristics were mentally 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. C.1).

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[4] Image is treated as an object. It can have physical and imagined forms. The forms of an optical image can be analyzed at different stages of its existence: as a mapping of light intensity and color arriving at the retina; as a mapping of electron excitations in retinal molecules that absorb photons; as a mapping of neural activity being created and transmitted to the brain; and as the resulting mental image that the brain creates. Photons, excited electron states and neural activity are physical concepts. The modulation of these concepts across the area of the retina, called mapping, is *information* translated by the brain into a mental image. In USIT, information in any of these forms (images) is treated as an object. Information, as an object, is a convenient generalization that obviates any need to delve into the physical details of the phenomenology of its creation.

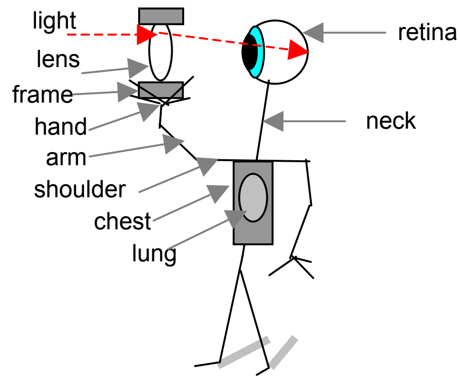


Figure C.1. Simple sketch of hand-held binoculars showing light passing through a lens and forming an image on the retina of an eye. Eye is treated as a single compound object. The binoculars are shown connected to the source of motion, the lungs, through lens frame, hand, arm, shoulder, and chest.

A heuristic that applies to both verbal and graphic statements is

6) 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 (repetition of function). A simplification of the sketch would be to combine these into one object (see Fig. C.2). Another heuristic is to

7) Name objects for their functions (Generification)

rather than use their common or their manufactured names. In this case the unified element in Fig. C.2 is named support.

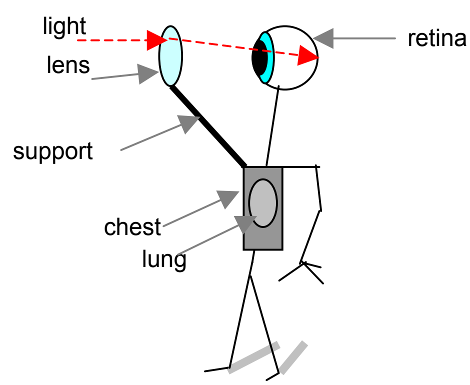


Figure C.2. Simplification of Fig. C.1 that combines components from shoulder to lens as a single object, the support.

Further simplification comes to light on examining the simpler sketch in Fig. C.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. C.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 (Simplification by elimination).

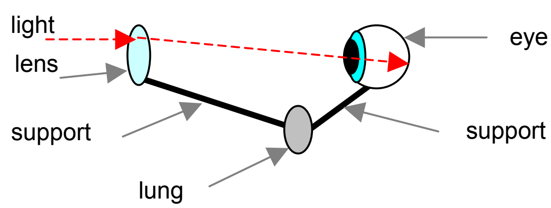


Figure C.3. Simplification of Fig. C.2 by eliminating unnecessary objects without loss of the unwanted effect.

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, *a la* USIT, is to construct an object-function diagram to identify the beneficial functions of each object. A heuristic advises one to construct a hierarchical diagram of objects linked by their single most important functions [5].

The object-function diagram is illustrated in Fig. C.4. [6]

As shown in Fig. C.4, eye, light, and image have been combined as an image-forming system that is inaccessible to the problem solver. [7] 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.

---

[5] This tool is know as the closed-world diagram and is adopted from ASIT.

[6] 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)

[7] 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.

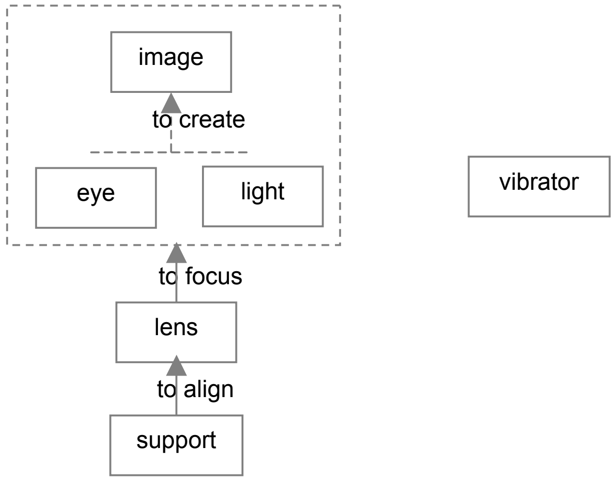


Figure C.4. Object-function diagram illustrating the beneficial relationship of object-object interactions in a hierarchical relationship. Vibrator, the lung, has no beneficial function to any of the objects and is set to the side in the diagram.

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 maintaining alignment of the axes of the two optical elements, lens and image forming system, “eye”. This axis is emphasized in Fig. C.5.

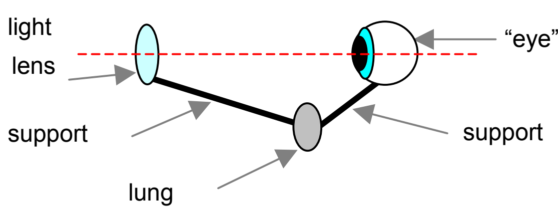


Figure C.5. Simplified version of Fig. C.3 in which the optical axes of lens and “eye” are aligned. The two supports have been further qualified to distinguish them.

The next phase of problem analysis requires

10) Examine interactions between pairs of objects, and

11) identify one attribute from each object and a function they support (Well-defined problem).

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. C.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. C.7. Note in the figure that “coupling to support” refers to “degree” or “strength” of coupling.

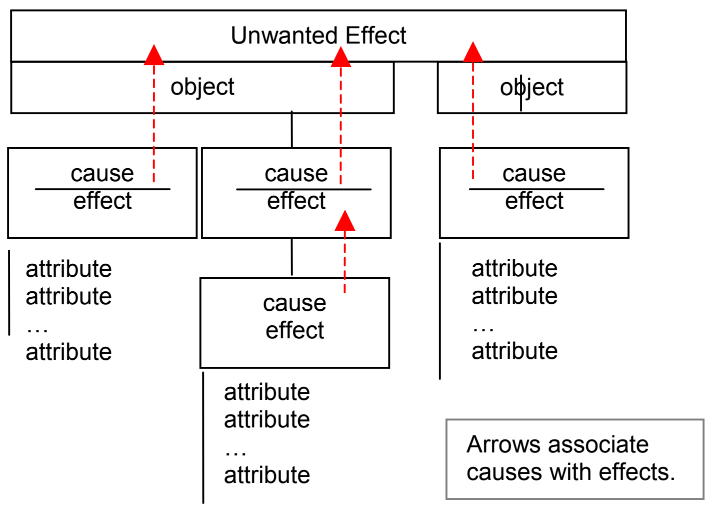


Figure C.6. Proforma diagram for a plausible root causes analysis.

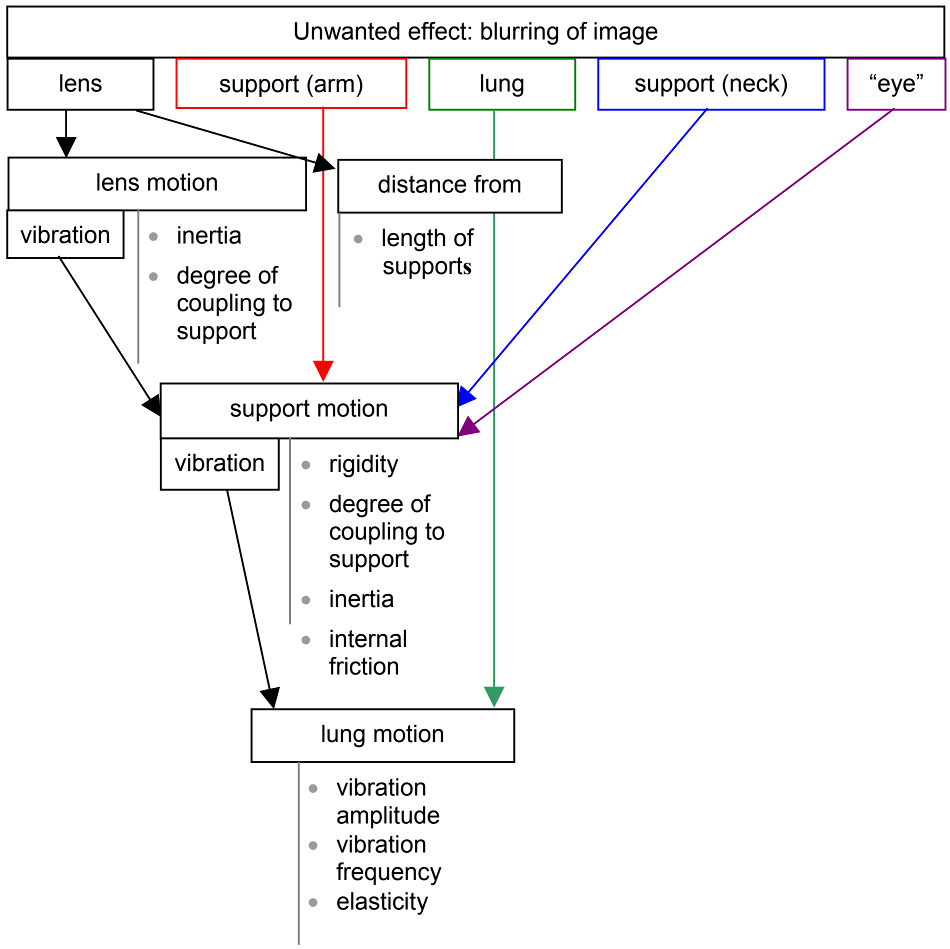


Figure C.7. Plausible root causes diagram for the blurring-of-image problem.

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 (Test extremes).

16) Construct qualitative-change graphs [(8)] for this purpose, as illustrated in Fig. C.8. The objects light and “eye” are not included in Fig. C.8 since their attributes can be considered fixed.

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

[8] From ASIT and USIT

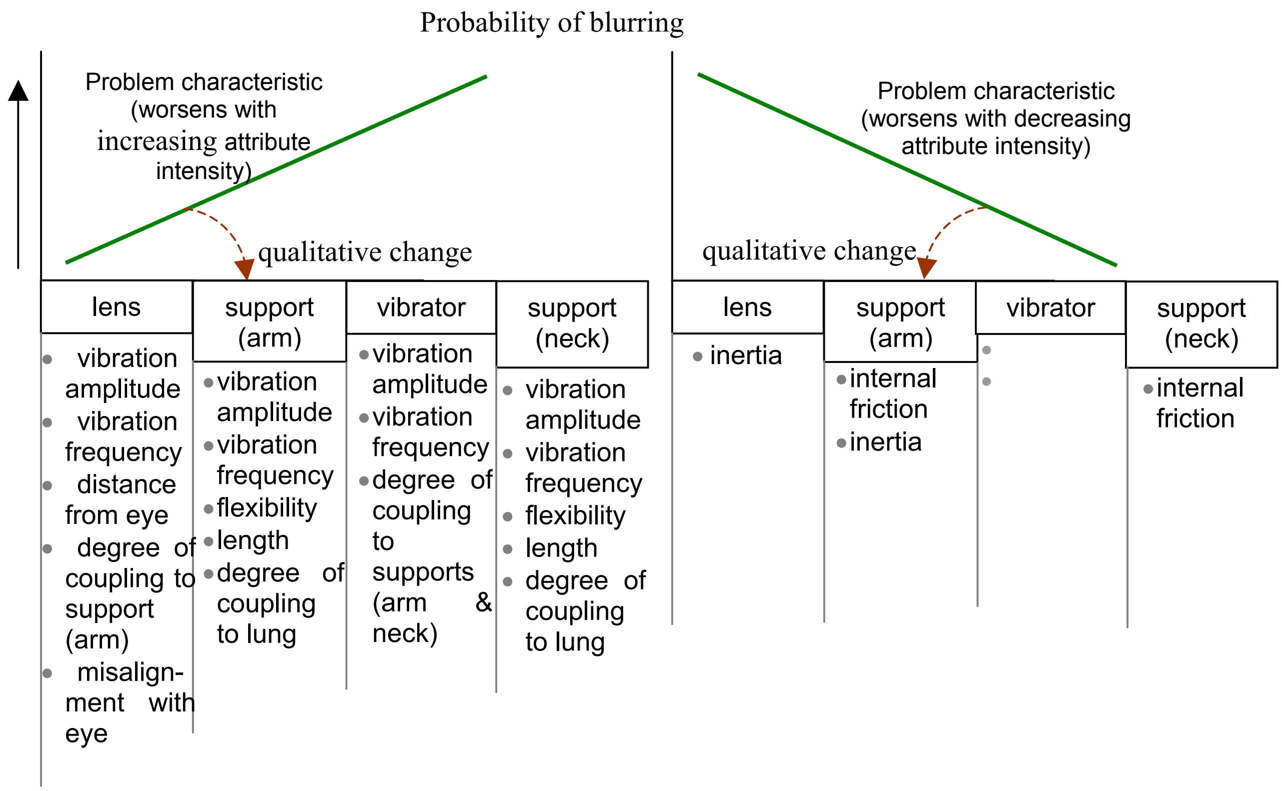


Figure C.8. Qualitative-change graphs for probability of blurring.

From the identified attributes, Fig. C.7, and attribute trends, Fig. C.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.

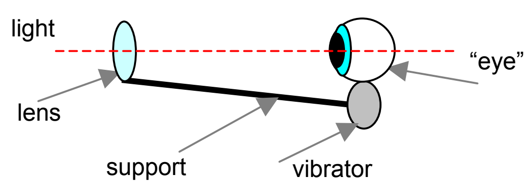


Figure C.9. Simplification of Fig. C.5 by combining supports into one object. Vibrator now moves support relative to "eye". (Vibrator and support could have been placed in reversed positions on the support.)

• 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) Consider a worsening trend as working against us and finding ways to make it work for us (Utilization).

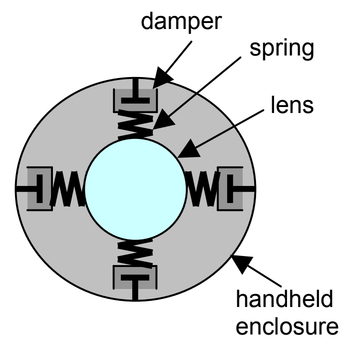
Solution concepts may also be found from the graphs by

18) Consider the implications of making a particular attribute trend have a zero slope [9], i.e., …

19) eliminate an attribute (Test extremes).

Elimination of an attribute means to make an active attribute inactive by discontinuing its use.

●● Five solution techniques from USIT



Five solution techniques (heuristics) from USIT are illustrated: uniqueness, pluralization, distribution, and transduction.

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 inner-ring motion would be damped.

Reduce an attribute's characteristic slope to zero, Fig. C.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. Also known is to simultaneously press one's arms to the body.

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)

Eliminate lens misalignment with 'eye' 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". (Ref. 18)

[9] See ASIT and USIT

Uniqueness

20) Identify unique features of a system and examine them for solution concepts (Uniqueness).

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) Multiply of objects to introduce copies of existing objects and employ them differently (Multiplication).

[S6] Multiplication of supports brings to mind two, hinged supports containing a vibration damper between them. An example is illustrated in Fig. C.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. [10]

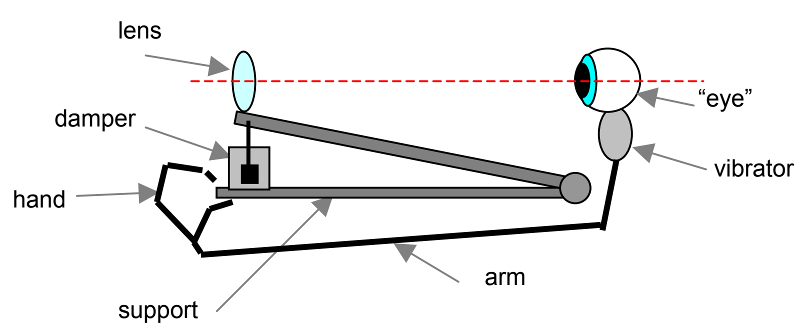


Figure C.10. A hinged support containing a damper on one leg and the lens attached to the other leg is held by hand to align the lens and "eye".

[10] Idea courtesy C. H. Stephan

Division of Objects

22) Divide objects and use the parts differently (Division).

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

Distribution of functions

23) Move functions to different objects (Distribution).

[S8] Could, for example, "support's function to align" be moved to "eye" (Fig. C.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

24) Consider the addition of attribute-function-attribute links to construct a solution concept (Transduction).

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. C.11) (Proforma sketch and well-defined problem).

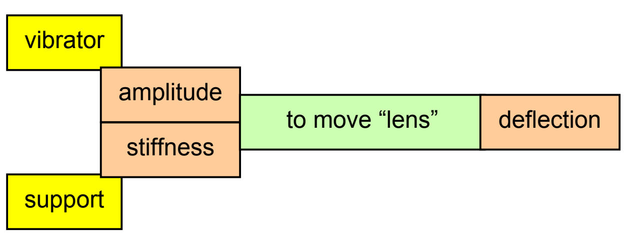


Figure C.11. Amplitude of vibration of vibrator and stiffness of support interact to support the unwanted effect of "lens" motion affecting "lens" position.

An attribute-function-attribute link suggests

26) Use the affected attribute (deflection) as an input attribute to another function that would affect some other attribute of an object in a useful way (A-F-A linkage).

27) Multiple A-F-A links are allowed (Multiplication).

An example is illustrated in Fig. C.12.

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

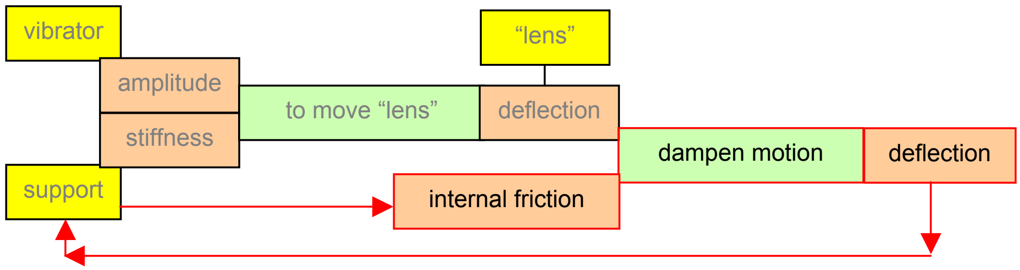


Figure C.12. Addition of an A-F-A link (internal friction – to dampen motion – deflection) to Fig. C.11 to produce dampening of the deflection of the support.

This completes the demonstration of heuristics used in problem solving following the USIT methodology. Heuristics used in this demonstration problem are summarized in Table C.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 C2. 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 C2 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 their being 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 their fields of use.

Of particular interest is that none of the heuristics in Table C.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, 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. 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 – thus defining active attributes. 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 C.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" (Generic proforma sketch),

in Table C.2, is useful for this purpose and is substituted for #5, as shown in Fig. C.13. Although the components are all abstract, their general relationships to one another are clearly illustrated.

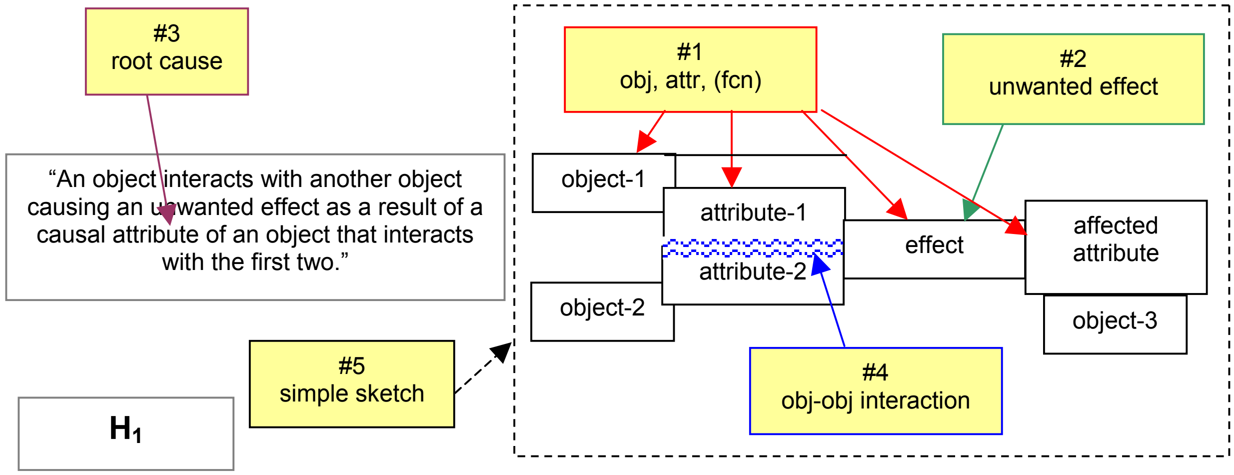


Figure C.13. Problem statement and simple sketch (block diagram) for an abstract problem using heuristics (#1 - 5, 27) of Table C.2 as indicated. Wavy lines indicate the zone of interaction of input attributes A_1 and A_2.

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. C.13 is a graphic heuristic, H_1. (H_x identifies new heuristics by subscript number.)

- **Problem analysis phase**

The only analytical heuristic in Table C.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. C.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 C.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.) [11]

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 Am 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. C.14.

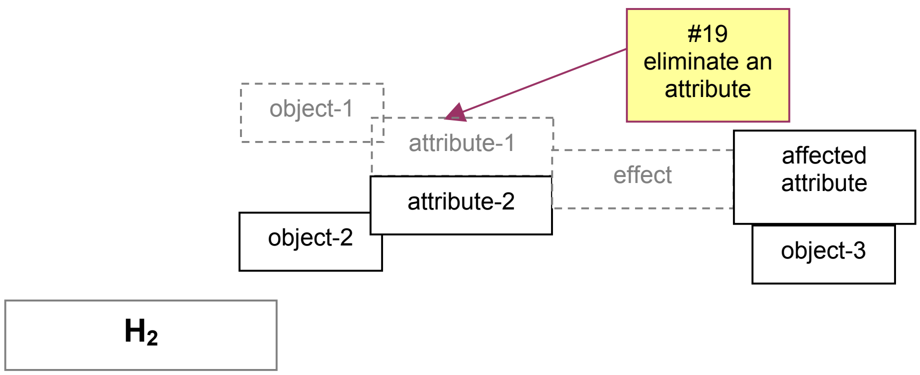


Figure B.14. An unwanted effect can be eliminated by eliminating an input attribute (attribute-1 in the figure).

Figure (B.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 (H_2, H_3, and H_4; the latter two are not shown) represent solutions of the original abstract problem (Fig. C.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. C.13 then Fig. C.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.

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

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 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 [(12)] by activating a new attribute to support a useful function when joined with an existing attribute (see Fig. C.15).

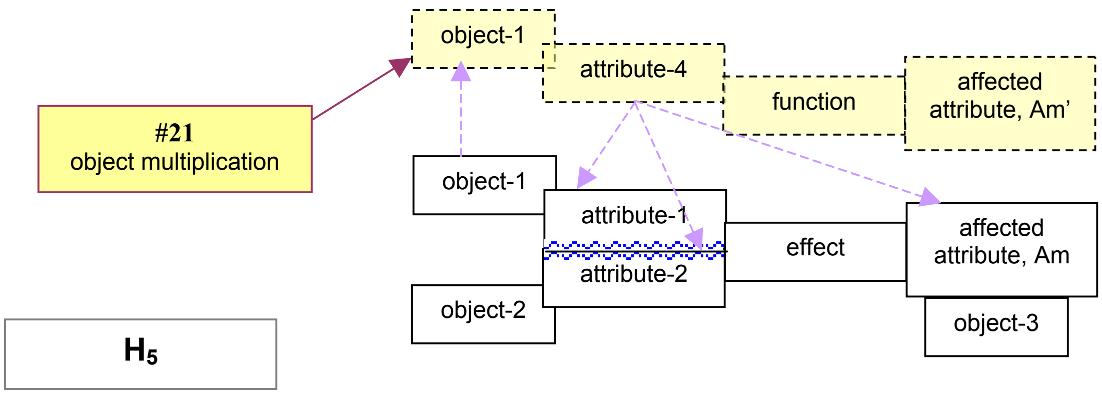


Figure C.15. Object multiplication introduces a copy of an existing object ($O_1 – O_3$) having a new active attribute, A4, which combined with an existing attribute (A_1, A_2, or A_m) supports a function that is useful as a solution to the problem through its affected attribute.

Figure C.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. C.16 where the function that 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 C.3 (heuristics H_5 – H_{16}).

[12] 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.

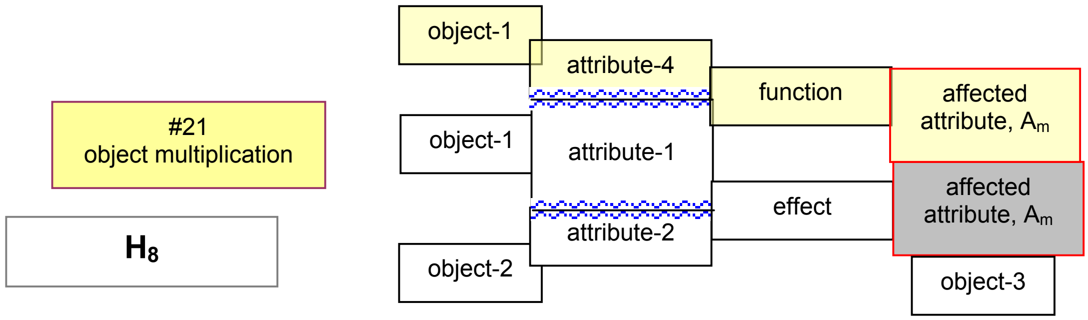


Figure C.16 Attribute A_4 of multiplication object O_1 is allowed to interact with attribute A_1 to support a function that affects the original unwanted-effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

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 ($H_8 - H_{16}$). [13]

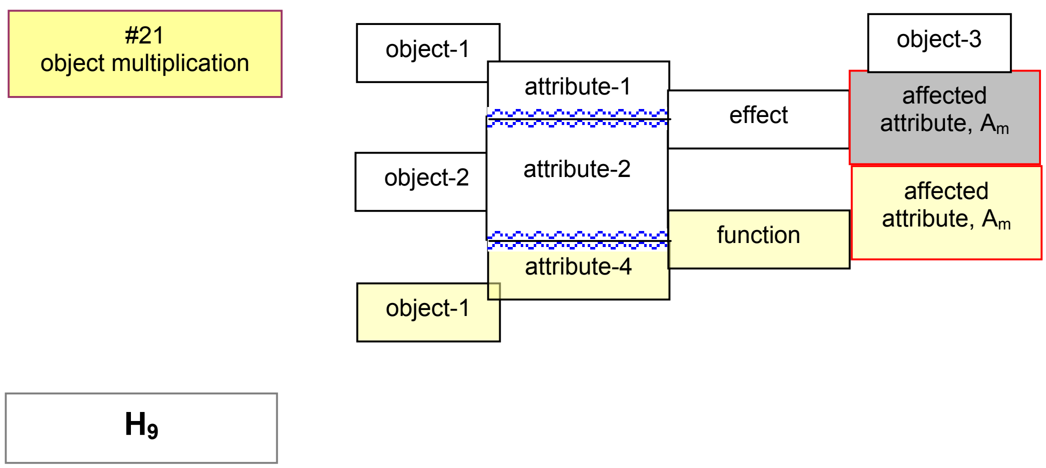


Figure C.17. Attribute A_4 of multiplication object O_1 is allowed to interact with attribute A_2 to support a function that affects the original unwanted effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

[13] 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.

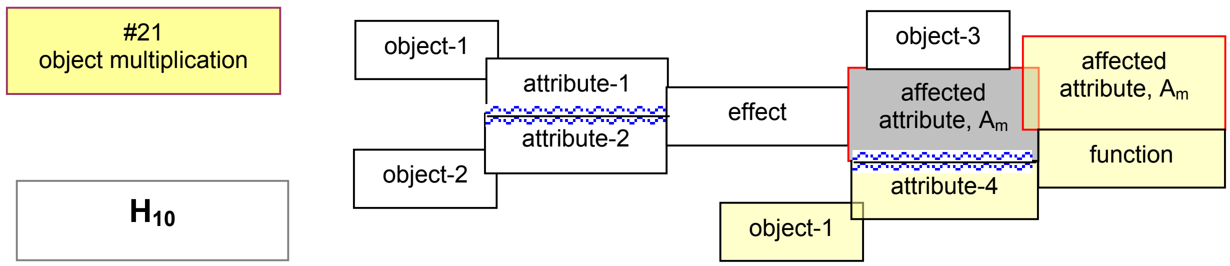


Figure C.18. Attribute A_4 of multiplication object O_1 is allowed to interact with attribute A_m to support a function that affects the original unwanted effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

Figures C.17 and C.18 illustrate multiplication of object O_1 followed by interaction of attribute A_1 with A_2 (Fig. C.17) and A_m (Fig. C.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 effective. Division of O_1 is illustrated in Fig. C.19.

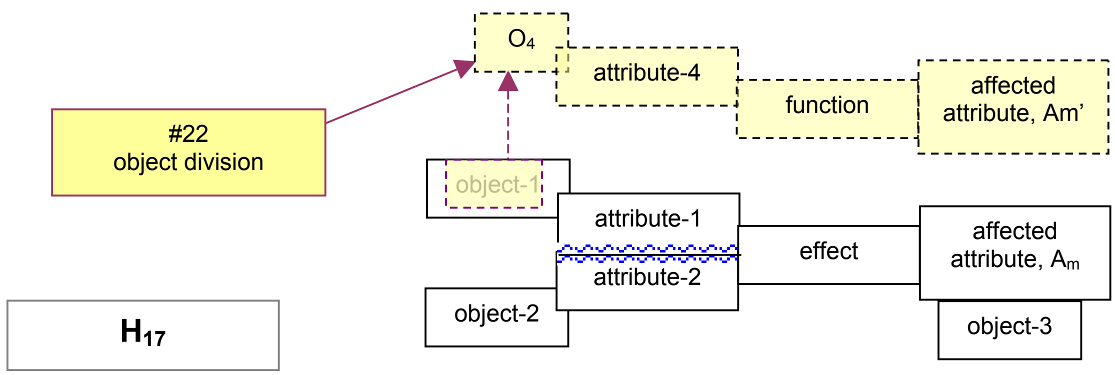


Figure C.19. Object division introduces a part of an existing object (O_1 – O_3) having a new active attribute, A_4, which combined with an existing attribute (A_1, A_2, or A_m) supports a function useful as a solution to the problem through its affected attribute.

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. C.20.

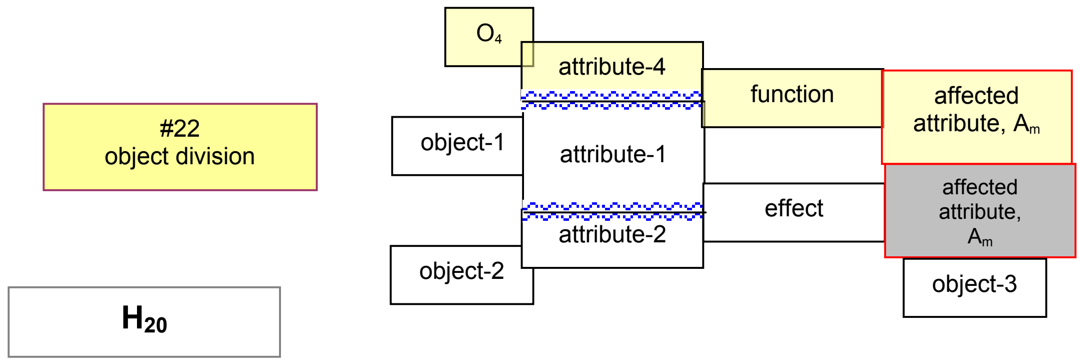


Figure C.20. Attribute A_4 of division object O_1 is allowed to interact with attribute A_1 to support a function that affects the original unwanted-effect attribute, A_m, in a manner to nullify or make useful the unwanted effect.

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. C.21. Adding an A-F-A link allows introduction of a new object and an active attribute from the new object (H29). Multiple links can be used (#26 of Table C.2).

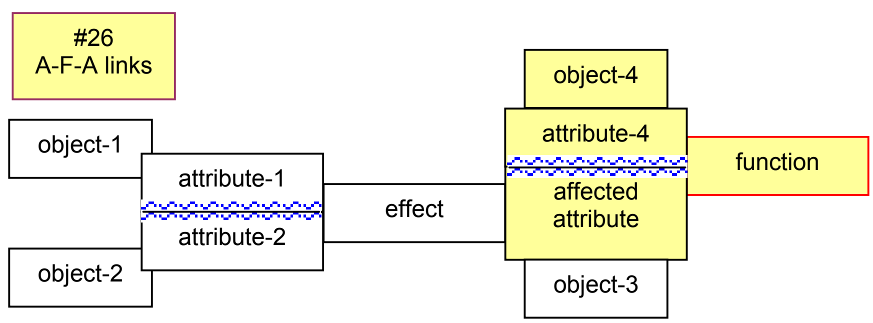


Figure C.21. An A-F-A link has been introduced to the problem diagram through a new object, O_4, and its active attribute, A_4, to support a new function through interaction of A_4 with Am.

The newly found graphic heuristics for solving an abstract problem are summarized in Table C3.

Table C3. Summary of new graphic heuristics for an abstract problem.

	Graphic Heuristic		Object	Attribute
H1	Problem statement			
H2	Attribute elimination (A_x)			A_1
H3	“			A_2
H4	“			A_3
H5	Object multiplication (O_x)		O_1	
H6	“		O_2	
H7	“		O_3	
H8	Multiplication → attribute-attribute interaction	$O_1\rightarrow$	H_5	A_1
H9	“	$O_1\rightarrow$	H_5	A_2
H10	“	$O_1\rightarrow$	H_5	A_3
H11	“	$O_2\rightarrow$	H_6	A_1
H12	“	$O_2\rightarrow$	H_6	A_2
H13	“	$O_2\rightarrow$	H_6	A_3
H14	“	$O_3\rightarrow$	H_7	A_1
H15	“	$O_3\rightarrow$	H_7	A_2
H16	“	$O_3\rightarrow$	H_7	A_3
H17	Object division (O_x)		O_1	
H18	“		O_2	
H19	“		O_3	
H20	Division → attribute-attribute interaction	$O_1\rightarrow$	H_{17}	A_1
H21	“	$O_1\rightarrow$	H_{17}	A_2
H22	“	$O_1\rightarrow$	H_{17}	A_3
H23	“	$O_2\rightarrow$	H_{18}	A_1
H24	“	$O_2\rightarrow$	H_{18}	A_2
H25	“	$O_2\rightarrow$	H_{18}	A_3
H26	“	$O_3\rightarrow$	H_{19}	A_1
H27	“	$O_3\rightarrow$	H_{19}	A_2
H28	“	$O_3\rightarrow$	H_{19}	A_3
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. The image-blurring problem was 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.

Of course, none of these H_x-diagrams needs to be memorized. All are readily deduced from the basic proforma graphic.

This demonstration gives an overview of the procedure to be used in the more thorough Derivation of Heuristics.

Graphic representation of heuristics

Heuristics exist under various names with modifications fitting personal taste and field of use. 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, U, 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, is represented graphically as shown in Fig. C.22.

$O_1 – A_1$

\

$U – A_m – O_m$

/

$O_2 – A_2$

Figure C.22. Graphic representation of a problem consisting of an unwanted effect U, 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. C.23.

$O_1 -$

\

$U - A_m - O_m$

/

$O_2 - A_2$

Figure C.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 later.

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. They may 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 in order to test their viability.
- Generate graphic models of the problems in terms of interacting objects, pairs of attributes, and an unwanted effect as shown herein.
- Reduce commonalities of these graphics to an appropriate proforma model.

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 feature of a well-defined problem in the physical-world is a <u>single</u> unwanted effect described in terms of interacting objects. Identifying a <u>single</u> 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 for the presence 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. C.24. It may be enlightening to examine this model without including objects.

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

Figure C.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, at most, three objects. The use of only two interacting attributes is another degree of simplification. It is a powerful metaphor for points of action. Point of action is itself a powerful metaphor for new perspectives. 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.

Contact may or may not involve physical abutment of two objects. Objects are carriers of attributes. Contact occurs when two objects are in adequate proximity to allow their attributes to interact.

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, if dealing with transducers in control systems when 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 either one.

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 C.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 "turned 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.

Tests of a new prototype problem-solving methodology

After producing a prototype methodology for problem solving, built by analogy as described, there are two important tests to perform.

1. The first test is logic based. It involves reverse engineering of a known problem and solution in the new field using the new methodology. Actually this should be involved in the development process from the beginning to test the logic of new definitions of objects, attributes, and functions.
2. The second test is both a logic- and intuition-based application to an unsolved problem. This will involve testing heuristics and looking for intuitive insights. That requires giving leeway to RH thinking. Presumable, the new field already has solved problems and heuristics used to solve them. Hence, logical methodology already exists in some form, though it may not be organized. The goal of heuristic innovation methodology is to free innovation of criticism and produce new insights.

In using reverse engineering to test a methodology recall that finding a known solution does not validate efficacy of the methodology. Finding new solution concepts is the desired result.

Note on Mathematical Heuristics

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 C4.

Table C4. 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.
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.
7	Divide into cases.	See solution techniques utilization, A-F-A linking, nullification, and elimination.
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.
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.

II. Derivation of Heuristics

Introduction

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). [14] Note that definitions are also heuristics, which often we refer to for clarification of thinking.

Common rules / uncommon language
Heuristics, the tools and techniques used in problem solving, are assembled in varying assortments to compose specific problem-solving methodologies. Different methodologies use many of the same heuristics but in modified wordings.

Heuristic wordings are chosen by the developers of the methodologies to characterize underlying strategy, to emphasize a specific way of applying selected heuristics, to emphasize relationships to other heuristics, to give a methodology's organization a feel of logic, and to invoke a unique identity for each methodology. The wordings often render them unrecognizable from method to method. For example, "Simplify" ➔ "Closed world" ➔ "Point of contact" ➔ "Choose one of multiples" ➔ "Minimize objects" ➔ "Eliminate redundancies" ➔ "Select attributes in pairs" ➔ "Allow only one unwanted effect" ➔ and many more, are all related to Simplify. In all cases, these methodologies are intended for teaching and practicing innovation in solving technical problems.

Differences in wording of heuristics between methodologies cause confusion. Technologists studying one methodology often wonder what is being missed by not also studying a different one, or wonder which one is better, or how can they be compared? As new methodologies are introduced the confusion grows. Lack of a common language exacerbates the confusion.

One can reduce this confusion by learning a generic version of a heuristic and its spin-offs that are employed in particular discipline. Generic heuristics constitute a common language portable to other disciplines. This is the approach used here.

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

Derivation

Definitions [15]

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. [16]

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. [17] Abutting, overlapping, and fused (or mingled) attributes characterize the state of interaction of objects. Desirable 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.

An object without active attributes does not exist!

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.

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[15] Definitions are repeated here for those who skipped Part B.

[16] 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 and ponder active pairs of attributes.

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

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. [18]

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. [19]

An axiomatic model of interaction, constructed of these axioms, is shown in Fig. C.26 with an example in Fig. C.27. [20]

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

Figure C.26. 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, Am, existing in a parent, O_1, O_2, or another object, (O_m).

[18] Dimensions and numerical values are filters used later in culling and scaling concepts.
[19] The mind cannot solve two problems simultaneously.
[20] All illustrations in this writing are graphic heuristics. The axioms are axiomatic heuristics, labeled Ax1 – Ax6.

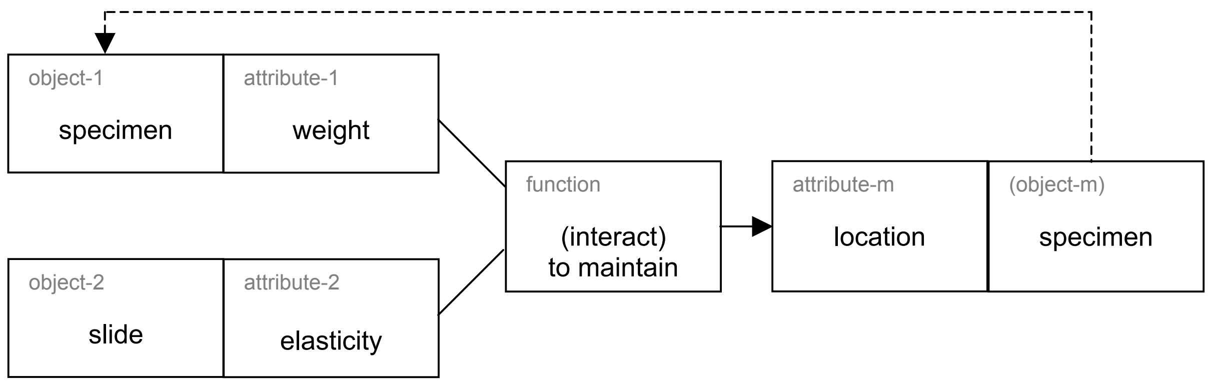


Figure C.27. An axiomatic model having the acted upon object as one of the two interacting objects.

Five specific objects have been cited in the two examples above: specimen, slide, holder, solid, and rod. They likely are recognized and accepted as objects without second thought. Yet, "object" has not been defined (in this section). 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. Thus, the following analysis allows derivation of heuristics at an abstract level (as represented in Fig. C.26), from which they must then be translated to the practical level for application in a specific field (Fig. C.27), with possible rewording in appropriate argot (*"translate abstract 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). [21] *Effective attributes use no metrics* (such as dimensions and numbers) and thus are more conducive to ambiguity for creative thinking (KH). 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

[21] 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.

to *"use known solutions as templates"* (KH) for new concepts – *"analyze known solutions for underlying phenomenology and improve them (KH)"*.

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. [22] Resolution of an unwanted effect uses these definitions and other heuristics to formulate a well-defined problem, analyze its root causes, and discover solution concepts. [23]

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. C.28). 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. A specific example of Fig. C.28 is illustrated in Fig. C.29.

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

[23] Details of a USIT-style well-defined problem may be found in references (1) and (5).

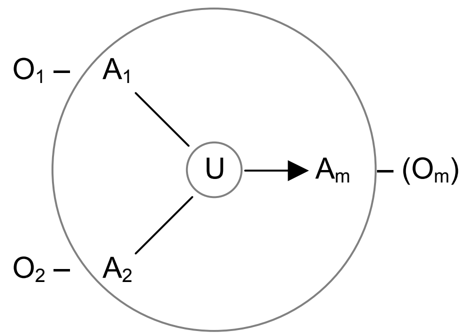


Figure C.28. Schematic of an unwanted effect, U, with input and output attributes, A_1, A_2, and A_m, and their host objects, O_1, O_2, (and possibly O_m) . The unwanted effect is central to a ring of three attributes that is inward to a ring of objects.

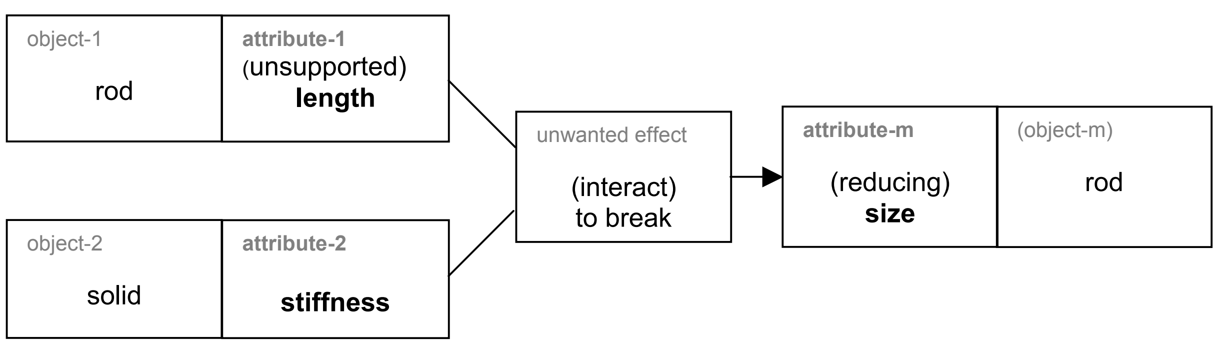


Figure C.29. Schematic of an unwanted effect following the proforma graphic of Fig. C.28.

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. C.28 and C.29. 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. B.28).

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.

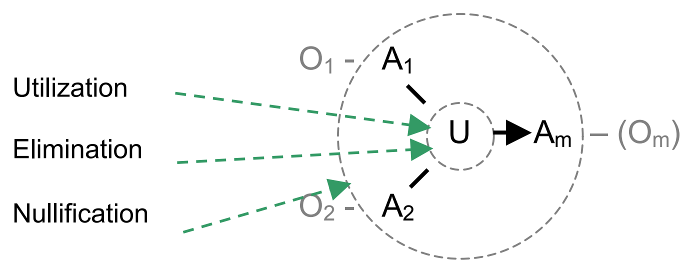


Figure C.30. Utilization and elimination operate directly on the unwanted effect. Nullification attacks the unwanted effect through the attribute it affects.

A problem-state and the three solution states are illustrated in Fig. C.31. 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

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

Solution state

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 C.31. 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. C.31, 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. C.32.

O-A
\
$(\mathit{U} \equiv \textbf{“F”}) \rightarrow \mathbf{A_m}$
/ |
O-A (O_m)

Utilization

O-A
\
$\mathit{U} \rightarrow A_m \leftarrow \mathbf{F}$
/ |
O-A (O_m)

Nullification

O-A
\
(_)
/
O-A

Elimination

Figure C.32. 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. C.33.

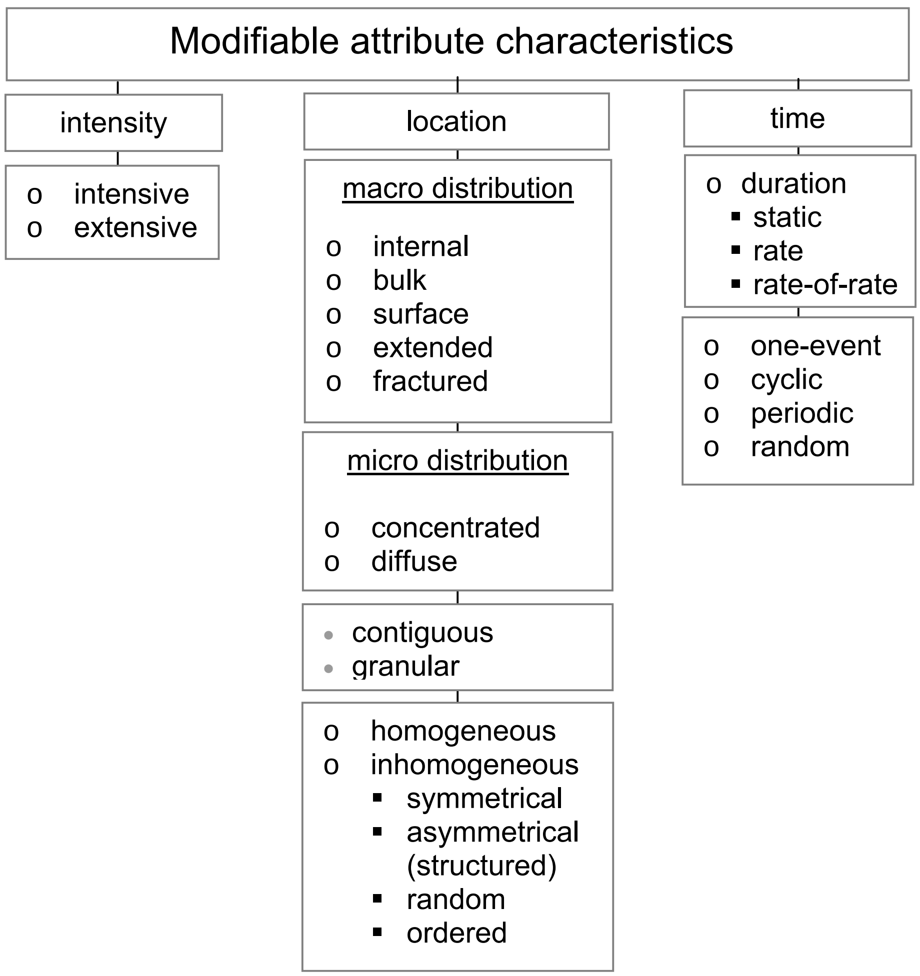


Figure C.33. Hierarchy of modifiable attribute characteristics with physical-world examples.

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 of an object; 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. C.34 for physical-world objects. Thousands of combinations follow from the list in Fig. C.33.

Example attributes of physical objects

- An interior-localized attribute of a car seat is 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 is 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 is 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 C.34. Examples of spatial ranges of attributes in physical objects.

Examples of attribute-attribute interactions of two physical objects are given in Fig. C.35.

Example 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 C.35. 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. C.33 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. C.33, 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. C.33.

Analysis of solution states with examples

In the following analysis of solution-state attributes will provide an 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. C.36, 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 and modify their space-time dependencies.

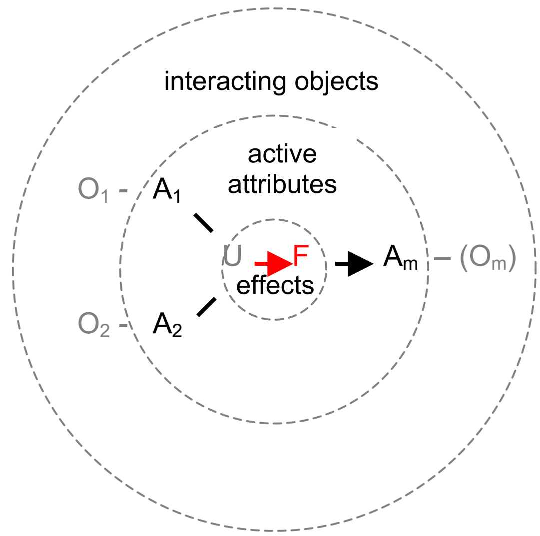


Figure C.36. Interaction zones of objects, attributes, and functions in the utilization scheme of solution concepts. The innermost zone is the effects zone (beneficial and unwanted). Utilization converts the unwanted effect, U, to a useful function, F. Objects are grayed in order to give preferential 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.

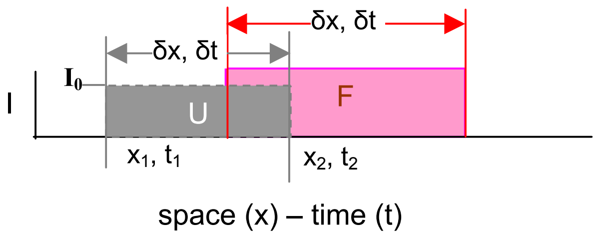


Figure B.37. Available modifications of space and/or time dependence of intensity, I, of an unwanted effect, U, to produce a useful function, F, are illustrated with similar rectangles.

Modifications of the unwanted effect, suggested in Fig. C.37, 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),

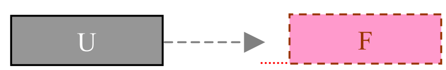
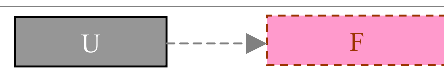
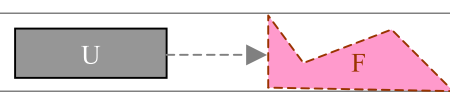
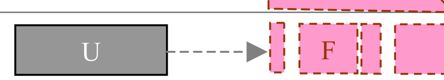
in strength (I_0),

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 C.5. Each active attribute, shown in Fig. C.36 offers a point of application for this attribute-modification strategy.

Table C5. 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	smoothen	

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, for example, 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

$U \equiv F$
$U \rightarrow F$
$U \rightarrow \cancel{F}$
$U \rightarrow F\ F \ldots$
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.

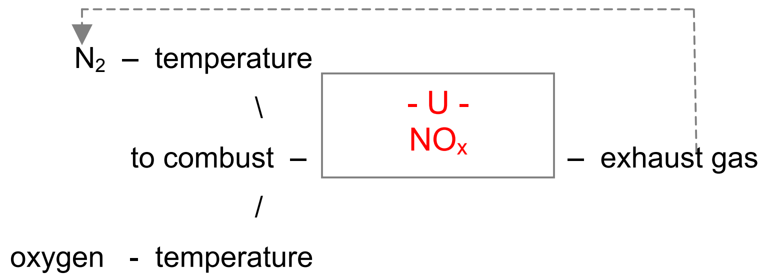


Figure C.38. Example of NO_x in internal combustion engine exhaust as an unwanted effect and its solution by utilization of the exhaust gas.

An approach to reducing NO_x in output exhaust gas of an internal combustion engine is to reduce combustion temperature to favor fuel combustion (more CO_2 and less NO_x). 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. C.38).

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.

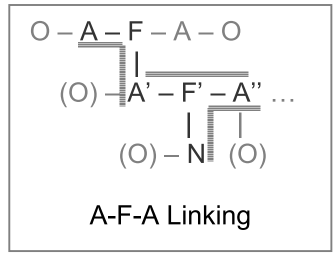
- Multiply it (sequential use): U → F F …

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 …

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 (A-U-A). 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 [24]); see Fig. C.39. 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).

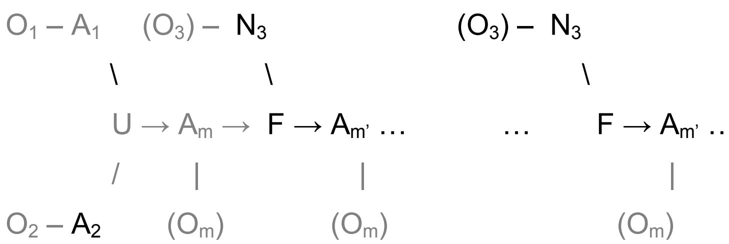


Figure C.39. Illustration of A-F-A Links: Initial links A_1–U–A_m and A_2–U–A_m, solution link A_m–F– $A_{m'}$, and the link it introduces, N_3–F–$A_{m'}$. Note that each added link allows one new function, F, an attribute, N_3, with its optional object, (O_3), and an affected attribute, A_m, with its 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).

[24] The A-F-A link heuristic has been recognized previously in USIT, 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

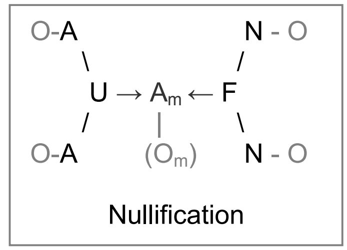
/ N_3

O_3 control unit

Figure C.40. 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, N_3, 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. C.41 with the affected attribute sandwiched between opposing action arrows: one causal, one nullifying. The new function requires supporting attributes (N_3, N_4) that may be accompanied with optional objects (O_3, O_4).

$$
\begin{array}{ccccc}
O_1 - A_1 & & & & N_3 - (O_3) \\
 & \backslash & & / & \\
 & U & \blacktriangleright\ A_m\ \blacktriangleleft & F & \\
 & / & | & \backslash & \\
O_2 - A_2 & & (O_m) & & N_4 - (O_4)
\end{array}
$$

Figure C.41. Schematic showing possible locations of causal attributes, A, nullifying attributes, N, and optional objects, (O), for a nullifying effect (function, F).

Two new attributes (N_3, N_4) can exist in any of five objects, the two or three initial objects and two optional ones (O_3, O_4), but not in the same object (see Ax_3); *“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. C.42). 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

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

Figure C.42. Polymer and strontium carbonate provide a two-object solution state for nullifying birefringence.

two-object embodiment. In this example, $A_1 = N_3$ = birefringence and $A_2 = N_4$ = locale; similar attributes that are scaled differently in their final embodiments. Note that A_1 and A_2 belong to the first object, the polymer, while N_3 and N_4 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 C.43. 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. C.43). (Ref. Design News, 08.18.03)

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

Figure C.44. 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. C.44). 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 C.45. 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. C.45). 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).

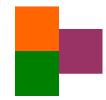
O-A
\\
(_)
/
O-A
Elimination

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. C.46. Modification includes temporal characteristics. In general, "*alter an attribute's intensity, location, and time, to effect elimination* (NH)". (See Fig. C.46 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. (This is a known solution existing in some automotive products.)

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). 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 a target for 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. C.46.

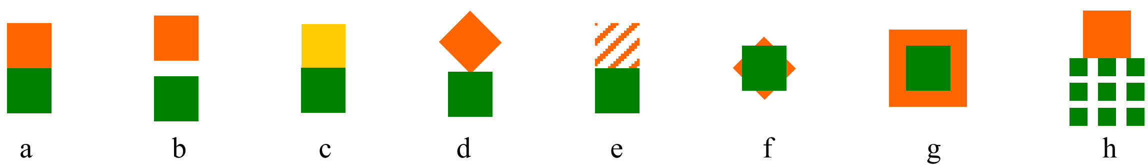


Figure C.46. A small sample of some graphic ways to arrange or modify two attributes represented initially as contacting squares in (a).

The exercise illustrated in Fig. C.46 began with arrangement (C.46a) making the obvious movement of one square with respect to the other (C.46b). Next, (C.46c) by weakening the intensity of one square the strength of its coupling was reduced. Then the interaction was weakened by minimizing area of contact (C.46d). In the remaining graphics (C.46 e –h) a different approach was taken.

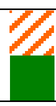
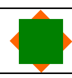
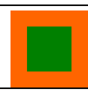
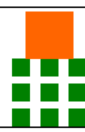
It was noted that an idea of the meaning of decoupling preceded each sketch: (C.46b) separate, (C.46c) weaken intensity, and (C.46d) minimize contact area. Reflecting on this process led to the idea that it was not very creative. The sketches merely served as notations of existing thoughts. Why not create the sketches randomly and see what ideas they produce? [25] 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

[25] This exercise led to the hierarchy of attribute characteristics shown in Fig. C.33.

no reason other than difference from previous arrangements; thus, producing sketches (C.46 e –h).

The exercise turned to examining the random arrangements and deducing plausible associations with attributes. Table C.6. Clearly, the possible modifications and arrangements of two squares is a larger number than shown in the sample in Fig. C.46 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)".

Table C6 Random two-attribute arrangements and their metaphorical implications (From Fig. C.46)

Fig.	**Two-attribute arrangements**	**Metaphorical implications**
C.46e		non-homogeneous weakening of an attribute
C.46f		overlapping, or saturation
C.46g		engulfing or entraining
C.46h		fracturing into parts

Examples of attribute characteristics applied to physical-world objects.
(See Fig. C.33)

- 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. C.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. C.47.

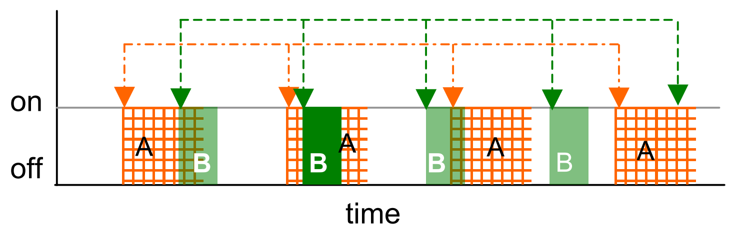


Figure C.47. Two attributes having periodic on-states of two different durations are illustrated: A, shown in patterned shade, has the longer on-time; B, shown in transparent shade has the shorter on-time. Arrows indicate the start of each on-state. The amount of time for attribute interaction varies as the amount of overlap of the attributes during their on-states.

The sketch in Fig. C.47 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. 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. C.47 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. C.46. 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).

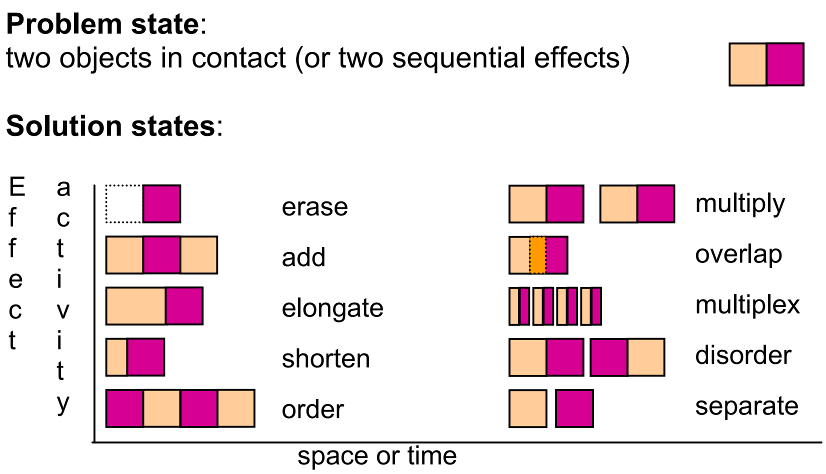


Figure C.48. Activity rectangles represent where or when effects are active in space or time (on or off). Operations are labeled.

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. C.48. 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 C7.

Table C7. 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 [26] – *"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:

- Map 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 diabetic person);
- Map gasoline antiknock onto color of men's trousers → category coding for an automotive contest;
- Map 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: [27]

- 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.

[26] 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.
[27] The five examples are courtesy of Juan Carlos Nishiyama and Carlos Eduardo Requena of UTN FRGP, General Pacheco, Argentina.

- Talking on a public telephone requires protection against the external noise (lull in time) by means of an enclosure (holes in space).
- 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.

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).

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. C.48). These graphs make evident such space | time characteristics as order | periodicity, superposition | simultaneity, size | duration, and other attribute pairs (some are shown in Table C.7). 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. C.48) – a host of heuristics (NHs).

Table C8 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 select 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. Strategies for resolving 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.

$$\begin{array}{llll} \text{O-A} & & & \\ & \backslash & & \\ & & U \rightarrow & A_m \\ & / & & | \\ \text{O-A} & & & (O_m) \end{array}$$

23. Graphic heuristics for solution states

$$\begin{array}{lll} \text{O-A} & & \\ \quad \backslash & & \\ & (U \rightarrow \text{“F”}) \rightarrow A_m & \\ \quad / & \qquad\qquad\qquad | & \\ \text{O-A} & \qquad\qquad\quad (O_m) & \end{array}$$

Utilization

$$\begin{array}{lll} \text{O-A} & & \\ \quad \backslash & & \\ & U \rightarrow A_m \leftarrow F & \\ \quad / & \qquad | & \\ \text{O-A} & \quad (O_m) & \end{array}$$

Nullification

$$\begin{array}{ll} \text{O-A} & \\ \quad \backslash & \\ & (\_) \\ \quad / & \\ \text{O-A} & \end{array}$$

Elimination

24. Examine attributes as adjustable parameters for constructing solution concepts.
25. Intensity, location, and time are three abstract, dependent variables of attributes.
26. A hierarchy of characteristics of a single attribute: begin with intensity, location, and time. See Modifiable Attribute Characteristics for details, Fig. II.33.
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 rectangles 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.

Summary of heuristic strategies for problem solving

Insertion of dependent variables of attributes into an AFA diagram displays the cues of inspiration for problem solving. Broad interpretations of these cues can spark new insights. Dependent variables of attributes are the handles for manipulating functions and creating solution concepts.

$$\begin{array}{ll} A_1(x_1, t_1, I_1) & \\ \qquad\qquad\quad \backslash & \\ & F \rightarrow A_m(x_m, t_m, I_m) \\ \qquad\qquad\quad / & \\ A_2(x_2, t_2, I_2) & \end{array}$$

Figure C.49 An AFA diagram displaying the dependent variables of its attributes. The attributes imply existence of their carrier objects.

Attributes have dependent variables of space (shape, location, and orientation), x, time, t, and intensity, I. Spatial can refer to shape, location, and orientation. A(x) represents the spatial dependence of A for any number of spatial dimensions.

Objects carry attributes. Changing the location, shape or orientation of an object modifies its attributes interaction with another object's attributes and, consequently, modifies the effect they support and its output attribute, $A_m(x_m, t_m, I_m)$.

Solution strategies

Utilization:

a. Ignore U if solving a different problem mitigates its effect.

b. Scale the intensity of U to acceptable values in space and time.

c. Pluralize (multiply or divide) $A_m(x_m, t_m, I_m)$ to make multiple functions available.

d. Link the output attribute, A_m, to become an input of a useful function, F' – AFA linking. A new attribute, N, may be included (Fig. C.50).

$$\begin{array}{lllll} A & & & N & \\ \quad\backslash & & & | & \\ & U \rightarrow & \mathbf{A_m} & \mathbf{- F'} & \mathbf{\rightarrow A'_m} \\ \quad / & & & & \\ A & & & & \end{array}$$

AFA Linking

Figure C.50 AFA diagram of an AFA link. The output attribute of an unwanted effect is used as an input attribute of a new function.

Nullification: Counter the unwanted nature of $A_m(x_m, t_m, I_m)$ with a function. Two new attributes, N, become available through the function.

Elimination: Annihilate U by modifying its input attribute's dependent variables.

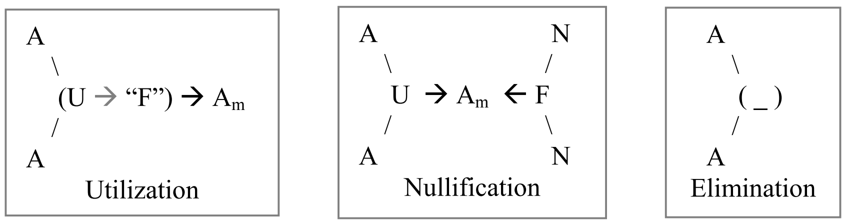


Figure C.51 AFA diagrams for three solution strategies: utilization, nullification, and elimination.

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 appropriately 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 Derivation of Heuristics

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 posited for resolving unwanted effects using attributes; their utilization, nullification, and elimination. Simple graphic models were demonstrated to serve as proforma templates for applying each strategy.

It has been shown 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. 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.

III. Application of Derived Heuristics

Introduction

Applications of the heuristics derived in the last section are demonstrated here.

Derivation of heuristics and application of heuristics in problem solving have different goals requiring different mental processes and expectations. The difference suggests left-hemisphere and right-hemisphere functions. In the process of deriving problem-solving heuristics our attitude is that of critical judgment of logic used 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 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.

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.

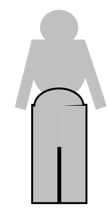
I have selected a problem of the invention-type for a demonstration of using the newly derived heuristics in solving a real-world problem. Although invention is not the usual type of problem most technologists deal with on a daily basis, it is usually the type of general interest in the classroom. By 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 using the newly derived heuristics

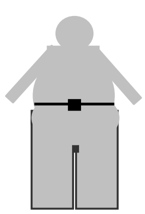
Suppose we are consulting for a manufacturer of men's clothing and are asked to invent a new type of belt for men's trousers. [28] We first define the problem and then turn to the heuristic methodology and use heuristics derived earlier to develop solution concepts. In order to define the problem, let us begin by understanding the intended functions of a belt for trousers.

Deduction of problem definition information

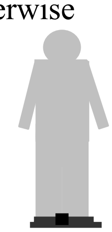


Trousers are usually designed for waist circumferences smaller than hip circumferences so that they do not fall off when buttoned or zipped. Properly sized trousers for "appropriately" shaped torsos do not fall off. Hence, in these cases, belts may be more functional as information creators than as trouser 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

[28] 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 the claims made for USIT

must maintain during the period required to keep trousers suspended. Maintenance of 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 while in use.

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 a different problem that can be addressed separately.) [29]

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 buckle is

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

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. 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 two objects are belt and buckle. The unwanted effect is tendency to loose 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 C.52. 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. C.53. The unwanted effect is tendency to loose a cinched state.

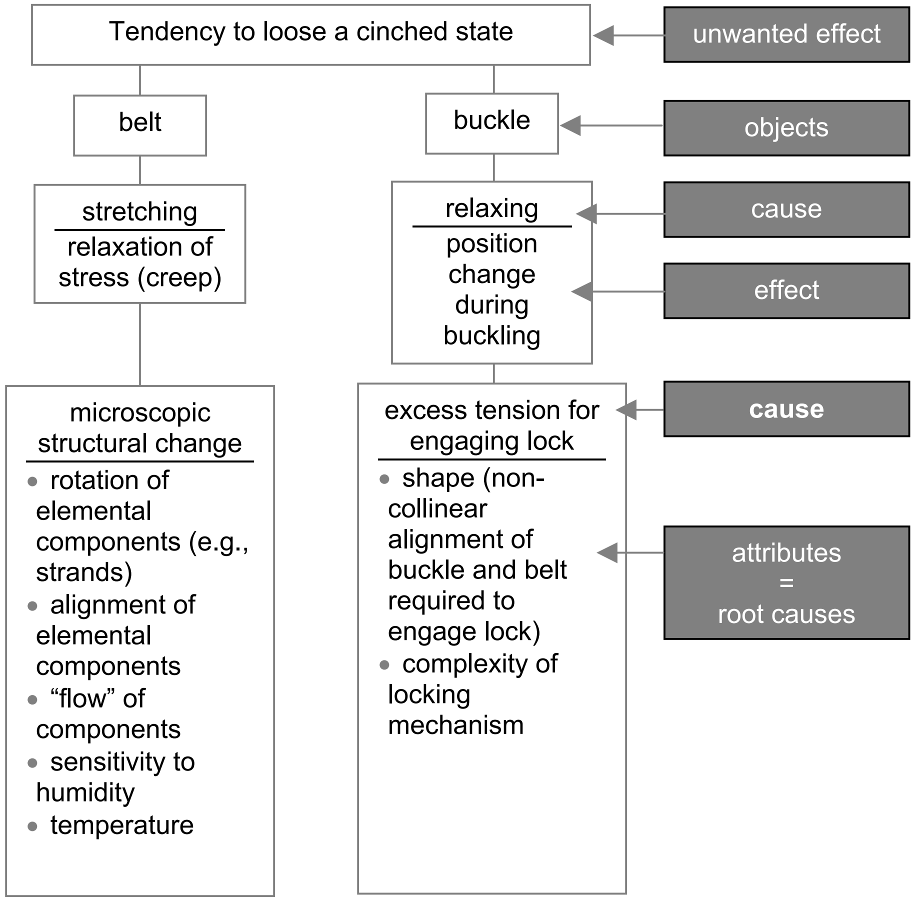


Figure C.53. Plausible root causes diagram for a belt and buckle having a tendency to loose a cinched state of elastic energy.

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. C.54). However, scaling of attributes is permitted to produce solution concepts.

A_1 Causal attributes

belt
- 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

/

A_2 Causal attributes

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

Figure C.54. 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. C.55.

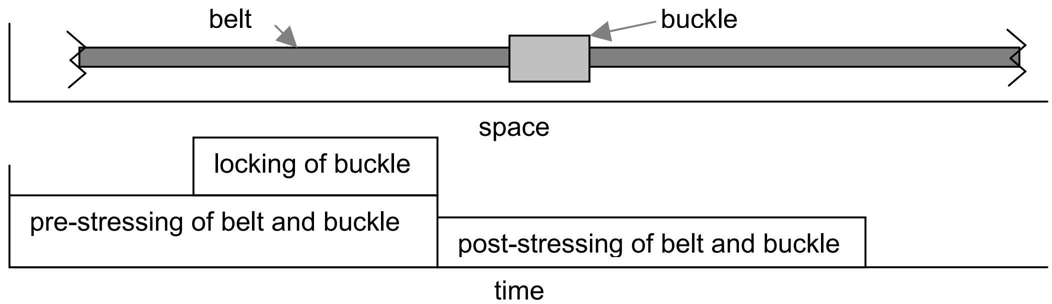


Figure C.55. Spatial and temporal plots of belt buckling process. The unwanted effect occurs during the post-stressing of belt and buckle. Height differences between pre-stressing function and post-stressing function are intended to indicate a decrease in excess stress after locking of buckle.

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. C.56.

A_1 N_3 N_3

\ \ \

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

/

A_2

Figure C.56. 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. C.57. 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 a stress-strain characteristic curve).

stress

\

relaxation → **stress state** → F → Am’ …

/

creep

Figure C.57 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. C.58. 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

Figure C.58. 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 where 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. C.59 without objects. The new function requires supporting attributes (N_3, N_4) that may be accompanied with optional objects.

$$\begin{array}{ccccc} A_1 & & & & N_3 \\ & \backslash & & / & \\ & U \rightarrow & A_m & \leftarrow F & \\ & / & & \backslash & \\ A_2 & & & & N_4 \end{array}$$

Figure C.59. Schematic showing causal attributes, A1 and A2, and nullifying attributes, N3 and N4, 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. C.60.

$$\begin{array}{ccccc} \text{causal attributes} & & & & N_3 \\ & \backslash & & / & \\ & U \rightarrow & \text{state of stress} & \leftarrow \text{reacting stress} & \\ & / & & \backslash & \\ \text{causal attributes} & & & & N_4 \end{array}$$

Figure C.60. 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 (N_3) and lower creep rate (N_4) 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. [30]

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.

[30] No, this is not a “buckle-less belt” concept. Inspiration does not dance to the tune of logic.

Solution by elimination

Elimination of an unwanted effect suggests annihilating it: U → ( ). Elimination of causal attribute interaction is a recommended procedure. Figure C.59 is repeated below (as Fig. C.61) 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)

Figure C.61. 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 Application of Derived Heuristics

The derived heuristics have been demonstrated for application in invention. It is shown that need of 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 used for problem solving, 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.

Appendix 1

Infovores crave information

Biederman and Vessel posed the question, why is *acquiring information* so profoundly gratifying? Their view of this phenomenon is that humans are “infovores” having “a craving that begins with a simple preference for certain types of stimuli, then proceeds to more sophisticated levels of perception and cognition that draw on associations the brain makes with previous experiences.”

The infovores system operates when “there may be no immediate need for the information”. Problem solving, on the other hand, is goal oriented where a solution is needed. This distinction may seem to invalidate my comparison of these two types of hunger for information. Yet successes in defining, analyzing, and solving problems titillate our egos and cause us to hunger for more. I’ll continue the comparison and let you be the judge.

First, let me summarize briefly the physiological facts underlying their thesis (excerpted from their paper):

- The brain is wired for pleasure.
- Opiates stimulate these neural systems.
- Endomorphins, endogenous morphine-like substances, “target mu-opioid receptors localized in parts of the central nervous system implicated in the modulation of pain and reward”.
- Mu-opioid receptors exist along the ventral visual pathway, which is involved in progressively developing visual recognition.
- Receptors are less dense early in the pathway, where contour, color, and texture are recognized, and densest in later stages of the pathway, where visual information engages our memories.
- The pathway of increasing receptor density and image development begins in the V1 area, passes through the V4 area, then through the lateral occipital area and ventral occipitotemporal cortex, and on to the parahippocampal cortex and rhinal cortex.
- These sections of the brain composing the ventral visual pathway are accessible for observation by functional magnetic resonance imaging (fMRI) during a subject’s visual stimulation. Local neural activity is detected by the increased use of blood supplying needed oxygen.

It is the author’s hypothesis that images dense in information should activate increasing numbers of receptors along the visual pathway producing the greatest pleasure in the parahippocampal cortex (the “association area”) where the brain interprets what it is seeing – the more information there is to be interpreted the more neural activity will be required causing an increasing release of endomorphins and greater stimulation of mu-opioid receptors resulting in an increase in pleasant effects. Furthermore, interesting stimuli should produce greater activity in the brain's visual association areas with concurrent and detectable fMRI contrast.

To test this hypothesis the authors first showed a series of images to subjects, not monitored by fMRI, who were asked to rate their relative preferences for the images. The same images were shown to a second group of subjects while undergoing fMRI but not asked to rate their preferences. As predicted, "scenes that were rated highly elicited the most fMRI activity in the parahippocampal cortex".

There is much more to this publication and the above summary does not do it justice. However, it shows that neural chemistry has evolved in humans to reward new visual experience and create a craving for information acquisition. I find these results a plausible explanation for similar chemistry that generates reward for problem solving. Perhaps such findings will be forthcoming in future research of neuroscientists.

Appendix 2

Strategic Partitioning of Problem-Solving Resources

Before assembling a problem-solving team ponder management's strategy and expectations. Consider strategic partitioning of technical problem solving.

Problems for Intuitive innovation
Two specific types of engineering problems are addressed here. Actually they are engineering problems without any engineering. They include routine day-to-day fix-it problems as well as product-development problems. The latter include engineering designs for incremental improvement of a product and invention of new products.

The reason they are devoid of engineering is that they focus on solution concepts – the pre-engineering phase of technical problem solving. Separation of problem solving into finding conceptual solutions, and then engineering selected ones, frees the conceptual phase for rapid generation of multiple solution options. Furthermore, it opens this phase for participation by non-specialists allowing constructive input sharing by various technical disciplines.

No engineering need be performed in the conceptual phase of problem solving. In fact, it is unwelcome. Engineering consists of specialized techniques for scaling concepts into doable, functional, and manufacturable things. Each engineering discipline has its own techniques and rules for scaling.

When engineering is not separated from conception of solutions a technologist is instantly and continuously frustrated with filtering of every concept that comes to mind. Is it doable or not? Is it logical or not? Is it worth the investment or not? Can it be brought to proof-of-concept within the available time or not? Thus, the ability to improve on a tentative concept, or use it to spark new ideas, is prematurely dead. Fewer ideas are produced.

Phenomenology – a common concern
Setting aside engineering specifications in problem solving brings direct focus on understanding phenomenology. The basics of mathematics, physics, chemistry, and general science under gird all technologies. When engineering filters like specifications are relaxed technologists having diverse specialties are able to share experience and creative thinking. For the same reason individuals find encouragement to explore other fields where their ideas are useful; that is, they are less intimidated when faced with problems outside of their specialty.

There are yet more rewards available by dividing technical problem solving into a non-engineering phase followed by specialized engineering scaling. It opens the way to applying generic methodology for defining, analyzing, and solving problems. A generic language becomes available that further deemphasizes engineering filters and enables technologists to share in problem solving at the root-cause level independent of their academic training.

A routine problem

When a power train is returned to a manufacturer for warranty remuneration someone is assigned the task of finding and fixing the problem. But what is the problem? Finding it will likely involve first reproducing the problem in order to identify its symptoms and second disassembly of the power train to find its failure. Perhaps a burned gear is found and suspected to be the cause. This calls for a root-cause analysis.

Establishing root causes can be a major effort. Even identifying attributes to be investigated can be daunting. These issues are simplified and often mitigated through <u>plausible</u> root-causes analysis. Multi-discipline examination of the underlying phenomenology may provide an effective answer, as will be seen.

With or without root cause information, the manufacturer has two paths that need to be investigated quickly and simultaneously. One path is a search for an immediate but temporary fix to stanch the flow of further warranty returns. The second is creation of a new design that can be put in place quickly. The typical approach is to select several specialists, say, in gear design and/or gear manufacturing, and assign them to address these two issues. Emphasis is placed on specialized training and experience – yet root causes may not have been identified nor relevant phenomenology understood.

It is obvious to the technologist, who identified the gear as suspect, that gears are complex. Evidence of burned areas could result from a variety of unwanted effects. But how are these to be identified? “Where do I begin to solve these problems? Do I have the expertise? What performance data are needed? What kind of test stand and instrumentation should be constructed?” Such uncertainty can lead to delayed action while the technologist collects relevant and reassuring information: warranty history, supplier’s opinion, manufacturer’s data-sheets, design manuals, engineering specifications, assembly line procedure, photographs, colleague opinions, textbooks, handbooks, etc. Time passes.

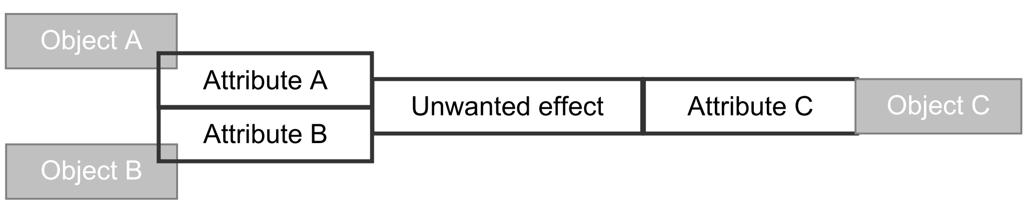
If separation of a problem into concept generation and engineering scale-up is practiced in this company, different and more effective attacks can be made on these two problems. That gears are complex is obvious and a little reflection can suggest effects of concern: parts out of spec, change in the gear material, residue from some chemical reaction, mechanical misalignment in the power train, vibration, overheating, gear-lubricant reaction, insufficient lubrication, impurities in the lubricant, and lubricant breakdown may be suspect. Such suspicions quickly lead to realization that gears are products of several engineering specialties: mathematical design, computer modeling of cog-cog interaction geometries, strength of materials, vibration analysis, noise generation, internal friction (damping), dynamics of torque transfer, wear, fatigue analysis, lubrication dynamics, lubricant wear, heat transfer, surface texture, surface chemistry, and others.

A common language
All of the phenomenological issues can be addressed for plausible root causes before introducing engineering specification issues. This is the place for a team of mixed technical backgrounds, who speak a common language, to be engaged for innovative analysis of plausible root causes and alternative engineering tracks. However, the team must act quickly and then disband for subsequent selection and engineering of their results.

The rewards of this accelerated effort are more than identification of plausible root causes. Root causes generate typical subconscious reactions of intuitive solution concepts! Of course, these concepts lack any engineering scale up, modeling, testing, and prototype evaluation. But they are quick results, inspirational, offer multiple options, and contribute to an effective launch of temporary fix-it solutions and long-term designs. Teams of multi-disciplined technologists speaking a common language can find them. But what is this language? It is structured problem solving. *

Structured problem solving
The typical non-generic language, engineering argot, begins discussion of the gear problem graphically using engineering drawings or photographs of interacting gears. The discussion proceeds doggedly through the information amassed in preparation for solving the problem.

Generic language begins discussion, after an engineering briefing, with graphic tools that emphasize metaphorical representations of gears and their interaction phenomenology.



This graphic illustration is read as two attributes, one from each of two interacting objects, support an unwanted effect that affects an attribute of a third object. Note the psychological ploy of deemphasizing objects in order to focus attention on identification of unwanted effects and their casual attributes. Without specific objects acting as filters, experiences from many fields become valuable resources.

This object-attribute-effect diagram is a simple tool designed to produce unusual viewpoints of a problem for intuitive inspiration. Multiple effects may be present, but each is treated as a (to be identified) pair of interacting attributes. This tool is sufficient to practice the methods discussed here.

Technologists from different disciplines will draw different inferences from this illustration relating to phenomenologies of their own experiences. Thus begins a multi-discipline search for root causes and intuitive solution concepts at the same time.

****

*Structured problem solving is contained, to varying degree and form, in several problem-solving methodologies: examples include unified structured inventive thinking (USIT, see www.u-sit.net), advanced systematic inventive thinking (ASIT, see www/start2think.com), the theory of solving inventive problems (TRIZ, see www.triz-journal.com), and others.

Glossary

```
          A
          ↑
O → A → U ← A ← O
    ↑         ↑
    U         U
   / \       / \
  A   A     A   A
```

artifact — An artifact is a man-made object; i.e., a product of human design.

attribute — An attribute characterizes an object distinguishing it from an otherwise similar object. Attributes are non-quantitative characteristics such as *weight, size, shape, color, conductivity*, etc.

,active — An active attribute is an attribute that supports an effect or is acted upon by an effect.

,removal of an (deactivation, annihilation)
An active attribute is rendered inactive (removed, deactivated, or annihilated) when its use is discontinued.

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 discipline.

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

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

effect — An effect (E) modifies or maintains an attribute (A). E => A
Effects occur within objects or at points of contact between objects – either where proximity permits two attributes to interact or where physical contact occurs and two attributes interact. Effects are usually expressed as infinitives: *to cause* something to change or not change.
An effect has (at least) three active attributes: two input, causal attributes and one output, affected attribute.

A_{input}
\
E => A_{output}
/
A_{input}

Fig. G.1 Proforma graphic of an effect caused by two input attributes.

function: A function modifies or maintains an attribute of an acted-upon object in a desired action.

unwanted effect: A function becomes an undesired effect when its desired action fails.

heuristic Heuristics, as used here, are the non-algorithmic tools, techniques, and tricks that are used in problem definition, analysis, and solution.

information Information is an object. Encoding of information as time or space variations of physical, chemical, biological, or neurological processes or objects can be treated as an object for simplification purposes. When details of the encoding or transmitting process are important they can be treated as interactions of component objects. A sensor or transducer, for example, can be treated as ordinary physical objects. The encoded signals they operate on can be treated as information objects.

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.

iteration: Iteration is a random procedure during which components of a problem statement are incrementally modified. The process gradually reduces a verbose problem statement to a well-defined problem. During iteration statement components are given generic names with a trend toward ambiguity.

metric: Metrics are quantifying measures of intensity, scope, timing, etc. that quantitatively distinguish otherwise similar attributes.

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. (See Information)

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

,well-defined A problem definition based on objects, their active attributes, and a single unwanted effect, accompanied with root causes and a simple sketch showing object interaction.

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

proforma graphic
A standardized form portraying the connectional relationship between two objects (O), attributes (A), and unwanted effects on which all analyses of heuristic innovation are based.

```
              A
              ↑
O → A → U ← A ← O
    ↑           ↑
    U           U
   / \         / \
  A   A       A   A
```

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

root cause Root causes are defined as causal attributes that can be tied directly to an effect. They are the lowest level attributes in attribute-unwanted effect-attribute linkages that are plausible for a problem solver. Each branch of AUA links can end on a root cause, thus allowing multiple root causes occurring at different depths of an analysis.

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

seed A metaphorical representation (verbal or graphic) of an object, attribute, or effect that is used to cue one's subconscious to recall experience.

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.

,problem A problem state supports an unwanted effect.

,solution A solution state supports a desired 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.

Demonstration of

Heuristic Innovation Definitions

Three useful statements that arise from these definitions are:

1. A single attribute will seed the subconscious and bring to mind effects.
2. Two active attributes will seed the subconscious and bring more relevant effects to mind.
3. The two active attributes can be any pair of three co-definitive attributes; i.e., supporting the same effect.

A simple exercise will serve to demonstrate these three statements in the use of attributes as thought starters.

Let's test these ideas.

1) A single attribute will seed the subconscious and bring to mind effects.
This is straightforward to demonstrate. In sixty seconds list as many effects as come to mind when you think of the attribute *sticky*.

I found the following:

to trap an insect,
to patch an inner tube,
to hold a rubbed balloon to a wall, and
to affix a sign to a wall using tape.

The attribute sticky brought to mind first an image of a flytrap. Then came an image of repairing a bicycle inner tube with a pre-glued patch. An image was recalled of the child's trick of rubbing a balloon on a sweater and then touching it to a wall where it clings. And taping a paper sign to a window came to mind. These are un-related effects except that each has a sticky object. Three have mucilage-type stickiness. One produces sticking with an electrostatic charge.

2) Two active attributes will seed the subconscious and bring more relevant effects to mind.

To see this we can start with any attribute and then select a second one that can interact with the first. An example is needed.

Consider the sticky surface of a hanging, coiled ribbon of flypaper – a flytrap. What is a second attribute that could work with stickiness to support the function of a flytrap? The function is to attract and hold flies. Stickiness holds an insect in place. But first it must be attracted to the paper to become trapped. An odor, such as rotting meat, could be used for attracting flies. Thus the pair of attributes, stickiness and odor, constitute an active pair in a flytrap. Let's see what new effects come to mind when thinking of stickiness and odor – in 60 seconds.

You go first.

The first thing I noticed was that ideas took longer to come to mind as a result of the restrictiveness of two specific interacting attributes.

My ideas were …
- to attract customers into a bakery,
- to attract customers to a sidewalk food vendor,
- to attract fish to a baited hook, and
- to snare a wild animal.

In this case, I got off to a slow start until the first idea came to mind. Then my reaction was to lump together stickiness and odor into the idea of a lure. For some unknown reason, changing the word trap to lure seemed to help. Although it was a slower start, once the lure idea occurred other ideas came rapidly. This time the ideas were much more closely related.

3) The two active attributes can be any pair of three co-definitive attributes; i.e., supporting the same effect.

We just finished testing two interacting input-attributes. Let's now try one input attribute and the output attribute of an active triad.

To patch an inner tube should provide a triad. But first, what does a sticky patch do to a leaking inner tube? It doesn't actually repair the hole in the tube. Rather it covers it and provides a path for spreading stress through the tube by providing a non-interrupted path of solid material around the hole, a path that can now support stress without enlarging the hole. The path consists of tube – patch glue – patch – patch glue – tube. Of course, the glue of the patch also stops air leakage by covering the hole.

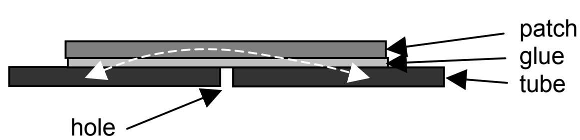


Figure G.2 Path (broken white line) through a tube – glue – patch – patch glue – tube that distributes around a hole in a tube.

Redistributing stress and covering hole are two different functions. This gives us two functions from which to select a triad of active attributes. They can be represented as follows:

Redistribution of stress requires formation of a path of solid around the hole from the tube through the patch. It is evident that solidness of tube and stickiness of glue aid the formation of continuity around the hole.

solidness
\
to form a path of solid material => continuity
/
stickiness

Figure G.3 Solidness of tube and stickiness of glue interact to establish continuity of solid path around hole in tube.

Covering a hole in a tube requires formation of a leak-tight seal around the hole. In this function, stickiness of glue and continuity of glue act to form a seal against air leakage.

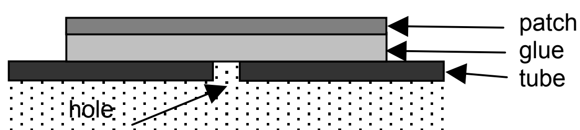


Figure G.46 A patch placed over a hole in a tube forms a seal against air leaking from inside the tube..

A triad of active attributes can be illustrated as follows:

continuity
\
to form a barrier => solidness
/
stickiness

Figure G.5 Continuity of glue and stickiness of glue interact to establish continuity of solid barrier around hole in tube.

From these two examples we have two active input-pairs of attributes supporting two output attributes: solidness and stickiness supporting continuity, and continuity and stickiness supporting solidness.

Obviously, these triads arose not from any physical uniqueness or principles but from the way I happened to analyze their interactions. You will have found different triads. For both of us they provide thought starters for finding further insights into their problem situations.

To continue, I'll select an input-output pair of attributes: say, continuity and solidness. These two attributes relate to a system having a leak. Now I need to test this pair to see what effects, if any, they bring to my mind (sixty seconds).

1. A sheet of notebook paper having a punched hole – the paper's continuity and solidness distribute stress around the hole.
2. A trap-door spider's web-supported lid covers the hole to his lair.
3. A spring-loaded valve of an inner tube distributes stress around the hole in the tube.
4. The pressure-release weight on the exhaust port of a pressure cooker prevents leakage below a nominal pressure.
5. The lips of our mouths divert the path of breathing through our nostrils sealing leakage from our mouths.
6. The cap of fuel tank seals the tank against liquid leakage.

Why? I don't know, but these ideas came to my mind.

This exercise demonstrates ways one can select attribute pairs and use them for inspiration of new insights. It does not demonstrate relevance in a real-world problem-solving situation. That will you have to test for yourself to appreciate the value of the procedure.

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Exercises

The following exercises are intentionally sparse of specific detail. When necessary, you are expected to assume detail you deem necessary and then solve the problem according to your assumptions. For example, a malfunctioning gismo may have one meaning to a particular individual and a different meaning to another person.

E1. A Fix-it Problem

Close your eyes, move your head to a new position, open your eyes, and pick the first object that comes into sight.

1. Name it, as it is commonly understood.
2. Generify its name.
3. List as many functions as you can think of that the object has.
4. Select one function and reword it into a misbehaving function.
5. Construct a first-draft problem statement (not necessarily a well-defined statement at this point).
6. Do a plausible, root-causes analysis to identify causal attributes.
7. Iterate the problem statement to incorporate the newly found causal attributes.
8. Construct a proforma graphic of a well-defined problem.

E2. Reverse Engineering

Reverse engineer the following objects into a well-defined problem with plausible root causes found by analysis.

1. A loaf of bread
2. A bicycle tire
3. A book
4. A wristwatch

E3. Attributes

Name as many attributes as you can (at least ten) for each of the following objects:

1. a brick
2. a computer subroutine
3. a dog
4. the printed character N
5. a computer screen
6. a cirrus cloud

E4. Generification of objects

Generify the following objects:

1. opener
2. wheel
3. propeller
4. cup
5. pot

6. fertilizer
7. statute

E5. Points of contact

Imagine a cup of hot steaming tea is resting on a saucer being held by a person's hand.

Make a simple sketch of this image (a stick-figure sketch will suffice).

1. Identify as many two-object points of contact as you can in this system of objects.
2. Name as many functions as you can for this system.
3. Name as many active-attribute pairs as you can for this system.

E6. Invention

1. Name as many functions as you can for a kite.
2. Invent a better kite.

E7. Well-defined problems

I. Form well-defined problems for the following objects:

1. Bicycle wheel
2. Lunch box
3. Rocking chair
4. Railroad car
5. Tape recorder

II. Name as many know solutions as you can for each problem in I.

III. Solve the problems.

E8. Functions

1. A wooden pencil is painted with yellow enamel and has a rubber eraser mounted at one end. What functions might the enamel have? Invent a new one.

2. A bucket has a handle that swings freely in two end pivots. What functions might the handle have? Invent a new one.

3. Pick a system of four objects. Identify points of contact and the functions supported at each.

E9. Object minimization

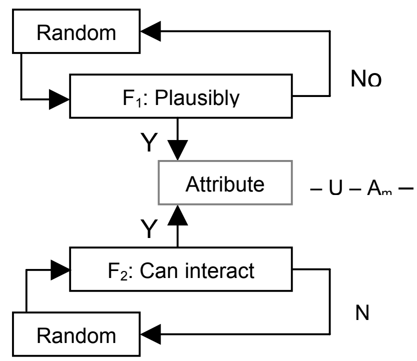
Divide a lawnmower into at least 10 components. Make a simple sketch. Consider the following unwanted effects and find the minimum number of its components needed to contain each effect.

1. The mower makes a curved train instead of a straight one.
2. The mower cuts grass unevenly – shorter on one side of the trail than the other.
3. The mower is too noisy.
4. The mower is too difficult to push.

E10. Solution strategies

Solve each of the unwanted effects in E9 using each of the three strategies: utilization, nullification, and elimination.

E11. Attribute pairing from lists of randomly selected attributes



1. List all attributes of the following objects that you can imagine (no functions are implied).

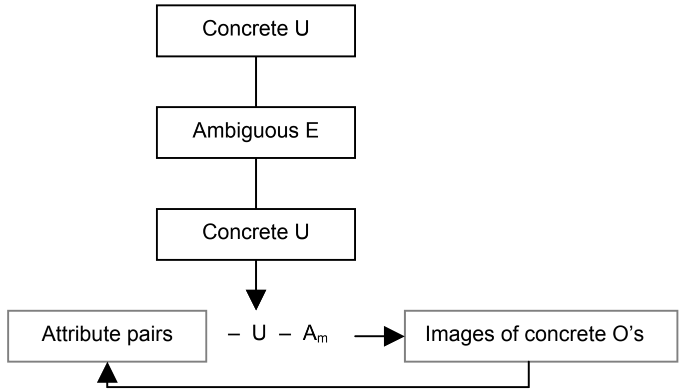
   Bucket of water; Knife; Apple; Newspaper; Can of paint; Stepladder; Loaf of bread, Cat.

2. Pick two of these objects that you have seen in contact with each other or can imagine a plausible situation in which they are in intentional contact.

3. Create an unwanted effect for their point of contact.

4. From the lists of attributes in (1) make two lists, one for each of your selected two objects in contact, of those attributes that could plausibly interact and be causal of the unwanted effect.
5. Construct A-U-A diagrams for each causal pair and their unwanted effect.
6. List any intuitive solution concepts that may have come to mind in this process.
7. Examine carefully the implied phenomenology of each A-U-A diagram and note whether any additional intuitive solution concepts come to mind.

E.12 Attribute pairing in ambiguous effects



1. Generalize the wording of the unwanted effect used in E.11 to form an ambiguous effect. Recall inflated balloon becoming a pressurized enclosure.
2. List as many concrete examples with plausible root causes as come to mind from your generalized unwanted effect.
3. For each plausible root cause list interacting, causal attributes.
4. For each pair of interacting, causal attributes identify solution concepts.

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The author is indebted to Dr. Craig Stephan, formerly Senior Technical Specialist of the Physical and Environmental Sciences Department, Research Laboratory, Ford Motor Company (now retired) for years of jointly 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. Our work at Ford in teaching, user-group sessions (Dr. Stephan's project), and USIT-team work provided a very dynamic and effective laboratory for further developing the structured problem-solving methodology.

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feedback that has impacted further development of the methodology. Thanks to those efforts USIT is now known and practiced in a number of Japanese companies. It also was well represented by papers published in the Second TRIZ Symposium Japan (Osaka, 2006). The Japanese USIT work can be followed at Professor Nakagawa's web site: http://www.osaka-gu.ac.jp/php/nakagawa/TRIZ/eTRIZ/indexGeneral.html

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

Academic background: Ph.D. in physics from the University of Virginia: Visiting Lecturer in Physics, Sweet Briar College; Associate Professor of Physics, University of Denver; transmission electron microscopy studies at the Cavendish Laboratory of Cambridge University, Cambridge England. Consulted on development of surface science research at the New Universitidad de Autonoma de Madrid, Spain and at the University of Campinas, Brazil. Lecture touring in Brazil, China, Japan, Mexico, and Spain. Honorary Professional Degree from the University of Missouri – Rolla.

Industrial background: Assembly-line automotive welder; 135 mm ordnance inspector; aircraft riveter; laboratory studies of air bearings and molecular pumps; design and modeling of miniature sensors and actuators. Named Inventor on 13 US patents.

Industrial positions: Senior staff scientist; manager; corporate technical specialist (Ford Motor Company); and president of Ntelleck, LLC (currently). Served on the Industrial Board of the Sensors and Actuators Center of the University of California – Berkeley.

Basic research: Internal friction of metals; growth morphologies of layered structure crystals; microcalorimetry of single-crystal whiskers; mechanical and electrical properties of single-crystal whiskers; electron scattering from surfaces of atomically clean metals; secondary-electron spectroscopy, low-energy electron diffraction, Auger electron spectroscopy, Auger line-shape analysis, and energy-loss spectra.

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USIT: Introduced structured inventive thinking program into the Ford Motor Company through monthly, three-day courses and weekly user-group meetings; developed unified structured inventive thinking (USIT), which he now teaches in on-site classes for industrial corporations; USIT workshops given in Australia, England, Germany, Sicily, South Korea and the US.

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