Innovation Tool:
Functional Decomposition

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References

- *Associated textbook readings: M&R Chapters 1-3*

Functional Decomposition

- Functional decomposition is of the utmost importance in architecting the system (which maps the functional decomposition to physical form).

- A good functional decomposition becomes increasingly important as complexity increases.

Why Functional Decomposition?

- The transition from customer needs to concrete solutions is seen as more of an art than a science.
- Many design teams tend to seek solutions directly based on the previous experience of the design team members; the links between customer needs and design concepts are, at best, indirect or implicit.
- Over the last twenty years, new methods for engineering design have emerged that focus **first** on mapping customer needs to functional descriptions.
- These descriptions are then used to generate and select concepts that best satisfy underlying functional requirements.
- Can lead to innovative solutions (combining functions of an airbase with the functions of a ship resulted in the aircraft carrier)

Why Functional Decomposition? (Cont.)

- Otto and Wood note some advantages of a functional approach:
  - Focuses on *what* has to be achieved, not *how*; A form independent expression of the design task may be achieved to comprehensively search for solutions.
  - Interactions between the functional elements drive key interfaces which need to be managed.
  - Functions may be derived directly from customer needs.
  - By mapping customer needs first to function then to form, more solutions may be systematically explored. "If one generates one idea it will probably be a poor idea; if one generates twenty ideas, one good idea might exist for further development." *Ullman, 1992.*

Functional Analysis

- Functional analysis as used here is the process of analyzing the functional, rather than the physical, characteristics of a system.
- A function may be stated in the form {verb,noun}.
- It is an action upon something.
- Provide heat, detect crash, and stop vehicle are examples of functions.

Architect’s Role in Understanding Function

- Having determined the functional nature of an object, it becomes the system architect’s job to conceptualize many physical realizations which serve the purpose and choose the realization with the best value.

- In this manner breakthroughs are designed.

Form vs. Function

Function

- What the system needs to do

- The operations and transformations that contribute to performance.

- The action for which a thing exists.

Form vs. Function (Cont.)

Form

- The shape and structure of something.
- The parts, components, or elements which implement the product’s function.
- Where the physical/logical chunks/blocks are.

Function

Function:

- Should be stated in solution neutral form.
- Can be decomposed about one level before a specific concept is required.
- Decomposition even at this level of abstraction is not unique.
- How the decomposition occurs will have a strong influence on architecture.
- Some functions will interact obviously and dramatically, others more subtly, and some not at all.

Function (Cont.)

Function:

- Can show connectivity of function – mass (material), momentum (force), energy, information (signals).

Functions vs Constraints

There are some customer needs that are served not by what a product does, but rather how the product is instantiated in form.

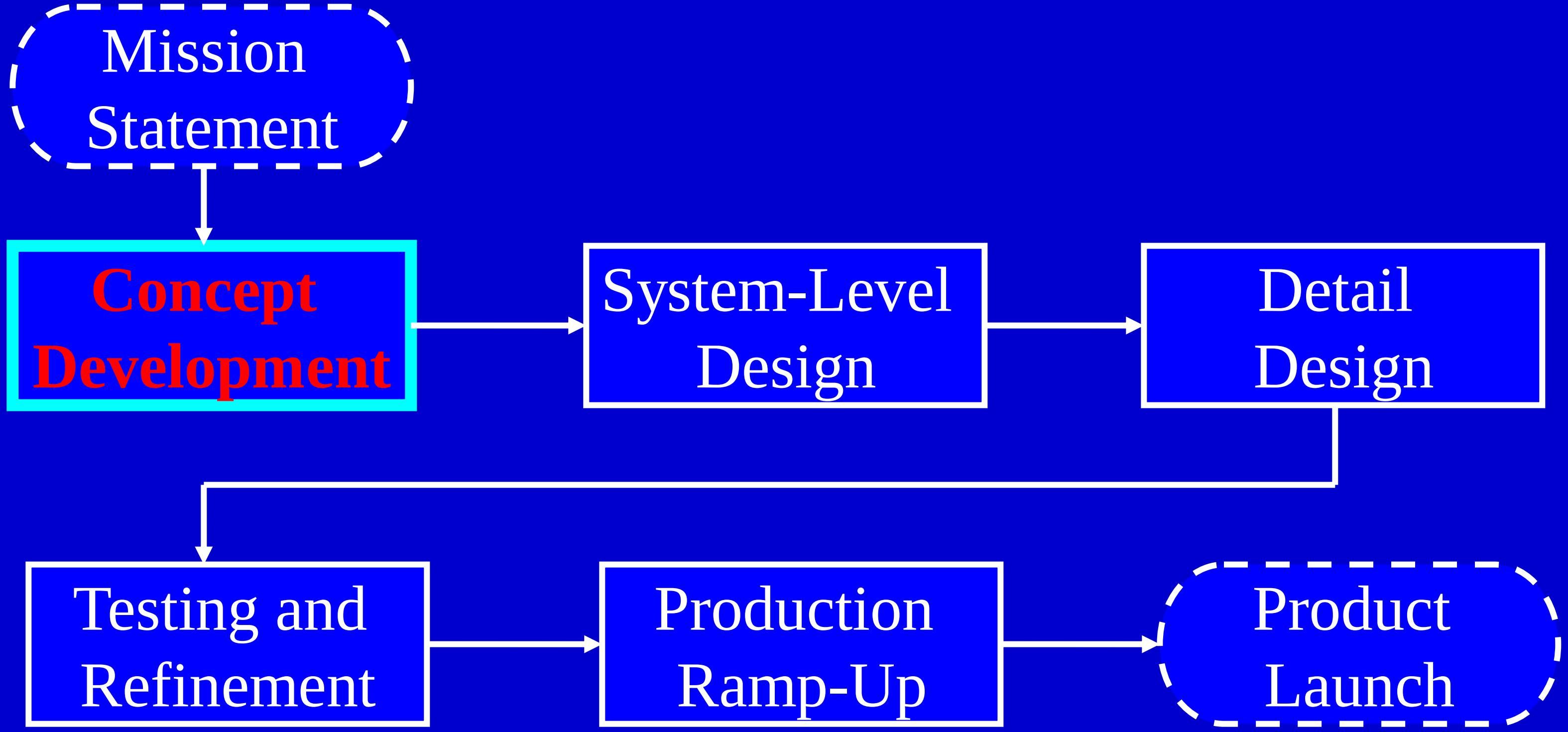
- Example:
  - Airlines have demands on dry airplane weight. The need for lightweight aircraft cannot be represented by a function, since the airplane does not do anything to make lightness. Rather, every component on the airplane contributes to weight.
- A statement of a clear criterion that must be satisfied by a product and requires consideration of the entire product to determine the criterion value.
- Typical examples of constraints include cost, size, mass, and reliability.

Functional Decomposition

- In general, the functional decomposition of the product is carried out at the beginning of the concept generation stage of the product development process.
- Before carrying out the functional decomposition:
  - The needs of the customers/markets must have been obtained, understood and documented.
  - If applicable, competitive benchmarking must have been performed and documented.
  - The target specifications for the product must have been defined and documented.

The Generic Product Development Process

[Ulrich & Eppinger, 1995]



Mission Statement

Concept Development

System-Level Design

Detail Design

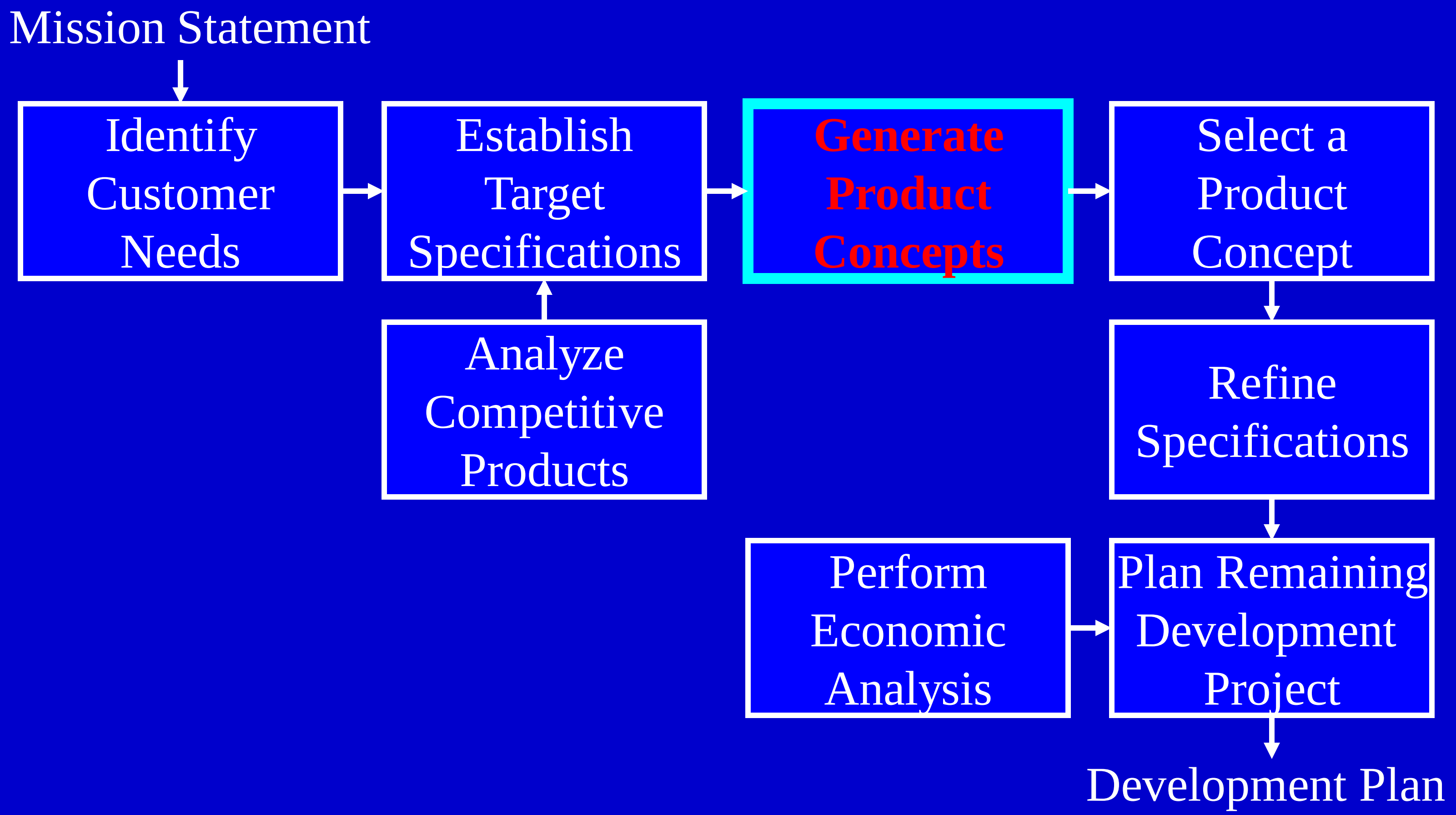
Testing and Refinement

Production Ramp-Up

Product Launch

The Concept Development Phase

[Ulrich & Eppinger, 1995]



Mission Statement

Identify Customer Needs

Establish Target Specifications

Analyze Competitive Products

Generate Product Concepts

Select a Product Concept

Refine Specifications

Perform Economic Analysis

Plan Remaining Development Project

Development Plan

Decomposition Techniques

- An elementary approach to functional decomposition is to decompose the prime function(s) hierarchically into subfunctions; when all subfunctions are satisfied, the prime function is satisfied.
- This can be repeated iteratively down several levels developing a *function tree.”*
- Can be done bottom up (useful in reverse engineering)
- Function trees are fast and easy to construct, but this ease of construction comes at the expense of understanding interactions between subfunctions (links between subfunctions are not considered).

Decomposition Techniques

- A *black box* model is another, more useful way to perform the functional decomposition.
- In this model, the product is modeled abstractly as a black box with inputs and outputs.
- The flow of inputs (material, energy, and information) to outputs are sufficient to describe a technical system or product.
- The inside of the black box is developed by functionally decomposing the prime product function.
- Let’s look at an example done each way.

Hierarchical Functional Decomposition for Asimo

Based on MPD505 work done by Bin Du, Tom White, Will Woodham, MPD Cohort 4

Hierarchical Functional Decomposition for Asimo (Cont.)

- Obey a human master
- Recognize and identify humans
- Receive, recognize, and process valid commands
- Perform household chores
- Move throughout a house as a human would
- Walk over even, uneven, level and sloped surfaces, ascend and descend stairs
- • Stand upright and maintain posture
- • Support its own weight and weight of payload
- • Maintain balance (avoid falling over)
- • Control walking sequence, speed and style
- • Maintain positive traction (avoid slipping)
- Avoid obstacles
- Sense presence and proximity to obstacles
- Maneuver around obstacle
- Recognize and identify household objects

Hierarchical Functional Decomposition for Asimo (Cont.)

- Handle objects and tools as a human would
- Grasp
- Hold
- Carry
- Place
- Push a cart
- Open and close doors
- Determine status of machines and equipment
- Identify out of place objects and return objects to proper location
- Communicate with humans
  - See
  - Hear
  - Speak
  - Gesture
  - Think

Hierarchical Functional Decomposition for Asimo (Cont.)

- Send messages to humans and machines remotely
- Keep track of time
- Receive and store energy
- Avoid injury to household occupants
- Avoid damage to household objects
- Entertain household occupants
- And the list goes on………

Black Box Functional Decomposition Example

[Ulrich & Eppinger, 1995]

- Product:

  Hand-held nailer.

- Some of the assumptions in the mission statement were:

- The nailer will use nails (as opposed to adhesives, etc.)
- The nailer will be compatible with nail magazines on existing tools.
- The nailer will nail into wood.
- The nailer will be hand-held.

Functional Decomposition Example (Cont.)
[Ulrich & Eppinger, 1995]

- The customer needs included the following:
- The nailer inserts nails in rapid succession.
- The nailer fits into tight spaces.
- The nailer is light weight.
- The nailer has no noticeable nailing delay after "tripping" the tool.

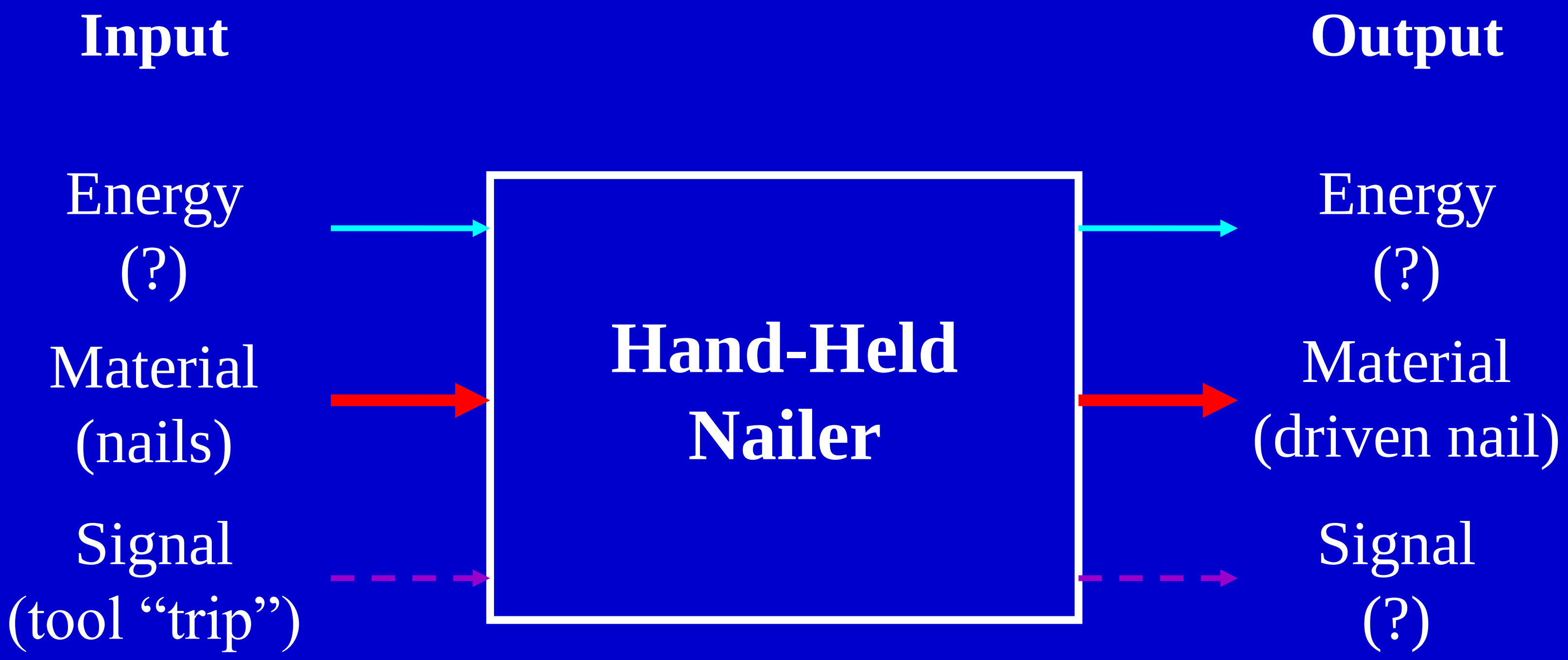
- The target specifications included the following:
- Nail lengths from 50 millimeters to 75 millimeters.

Functional Decomposition Example (Cont.)
[Ulrich & Eppinger, 1995]

- Maximum nailing energy of 80 joules per nail.
- Nailing forces up to 2,000 Newtons.
- Peak nailing rate of 1 nail per second.
- Average nailing rate of 4 nails per minute.
- Ability to insert nails between standard stud/joists (368 millimeter opening).
- Tool mass less than 4 kilograms.
- Maximum trigger delay of 0.25 seconds.

Functional Decomposition Example (Cont.)

[Ulrich & Eppinger, 1995]



Input

Energy
(?)

Material
(nails)

Signal
(tool “trip”)

**Hand-Held
Nailer**

Output

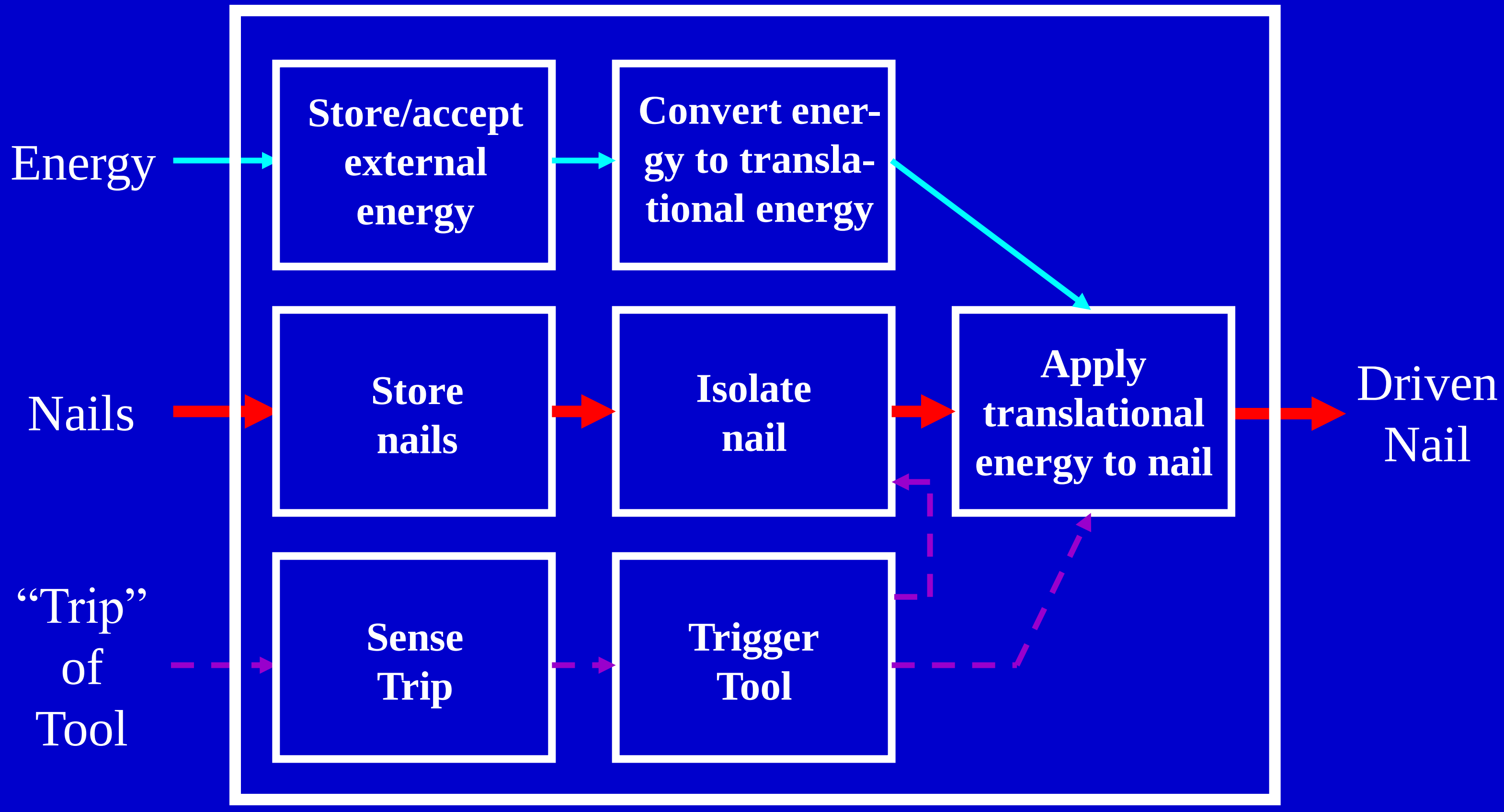
Energy
(?)

Material
(driven nail)

Signal
(?)

Functional Decomposition Example (Cont.)

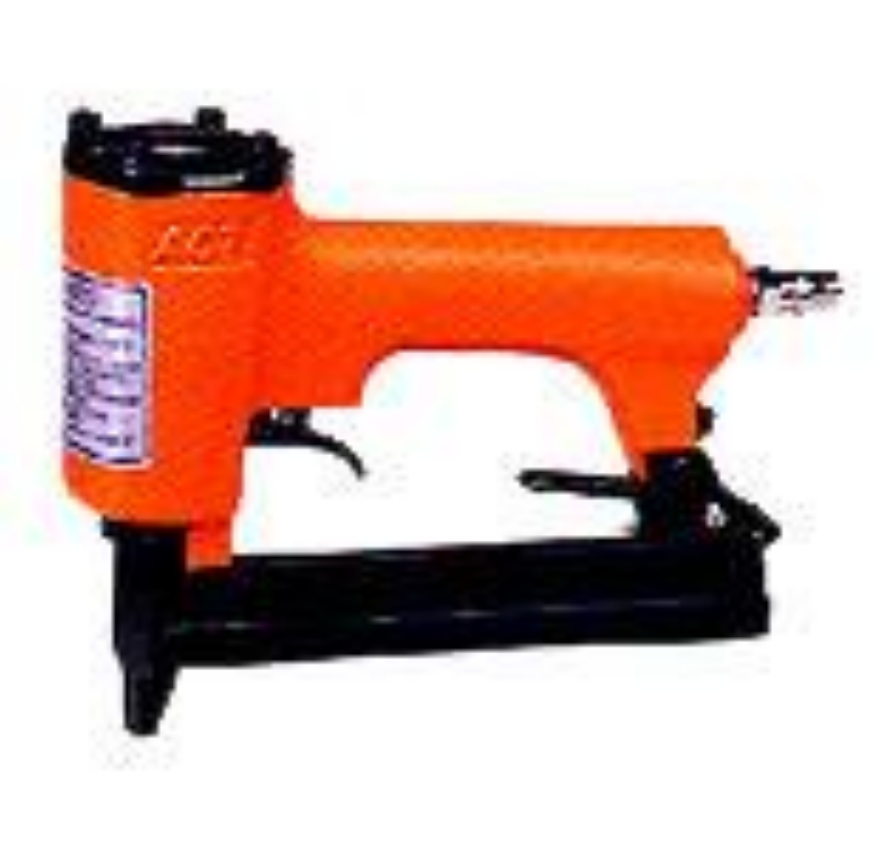
[Ulrich & Eppinger, 1995]



Energy
Store/accept external energy
Convert energy to translational energy
Nails
Store nails
Isolate nail
Apply translational energy to nail
Driven Nail
“Trip” of Tool
Sense Trip
Trigger Tool

Functional Decomposition Example (Cont.)

[Ulrich & Eppinger, 1995]



Form of the Product

Form

Form:

- Unlike function, form *is* in the solution domain.
- There are actual physical/logical chunks/elements.
- It can be partitioned.
- It is related to function by *concept*.
- Connectivity of elements of form are called interfaces.

Form (Cont.)

- Engineering drawings capture form. However, the function associated with each piece of form often resides only in the designers’ head.

- There is generally not a way in which the function which a piece of form is meant to embody is captured in any archival sense.

- This can make re-use difficult.

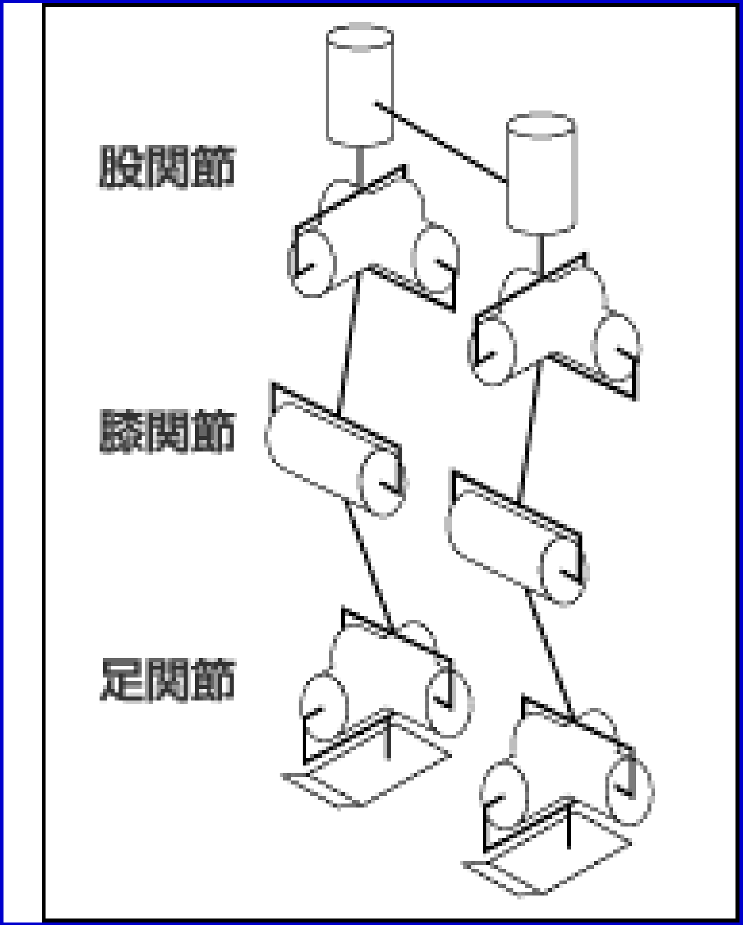
Concept

- A “vision” which:
  - Maps function to form.
  - Must allow for execution of all functions.
  - Embodies “working principles.”
  - Implicitly represents a level of technology.

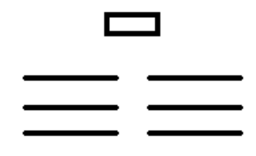
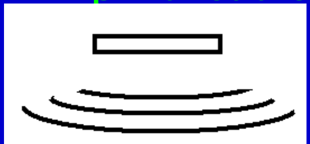
- The *concept* defines the list of variables that get adjusted (during detail design/optimization) to satisfy functional requirements.

Concept (Cont.)

- A concept can be represented by a simple sketch (using symbols and icons). It carries with it all the meaning.
- A sketch is generally the preferred way to document and communicate a concept.



Examples of Function/Concept/Form

Function	Concept	Form
Provide meeting place with visible main speaker and processions	Church (Basilica) 	
Provide meeting place with large main cast	Amphitheatre 	
Provide meeting place with each participant visible to others	Meeting room 	

A Heuristic

- The following heuristic becomes apparent:

  “Form follows function.”

- Do you believe this should be a principle rather than a heuristic? As we’ll see soon, there are cases which violate this heuristic.

It’s Decomposed, Now What?

- The goal of the decomposition techniques is to divide a complex problem into simpler problems that can be tackled in a focused way.
- Once the problem decomposition is complete, the team chooses the sub-problems that are most critical to the success of the product and that are most likely to benefit from novel and creative solutions.
- Teams can usually agree after a few minutes of discussion on which sub-problems should be addressed first and which should be deferred for later consideration.
- Two tools can be useful: *Concept Combination Tables* and *Concept Classification Trees*

Concept Classification Tree

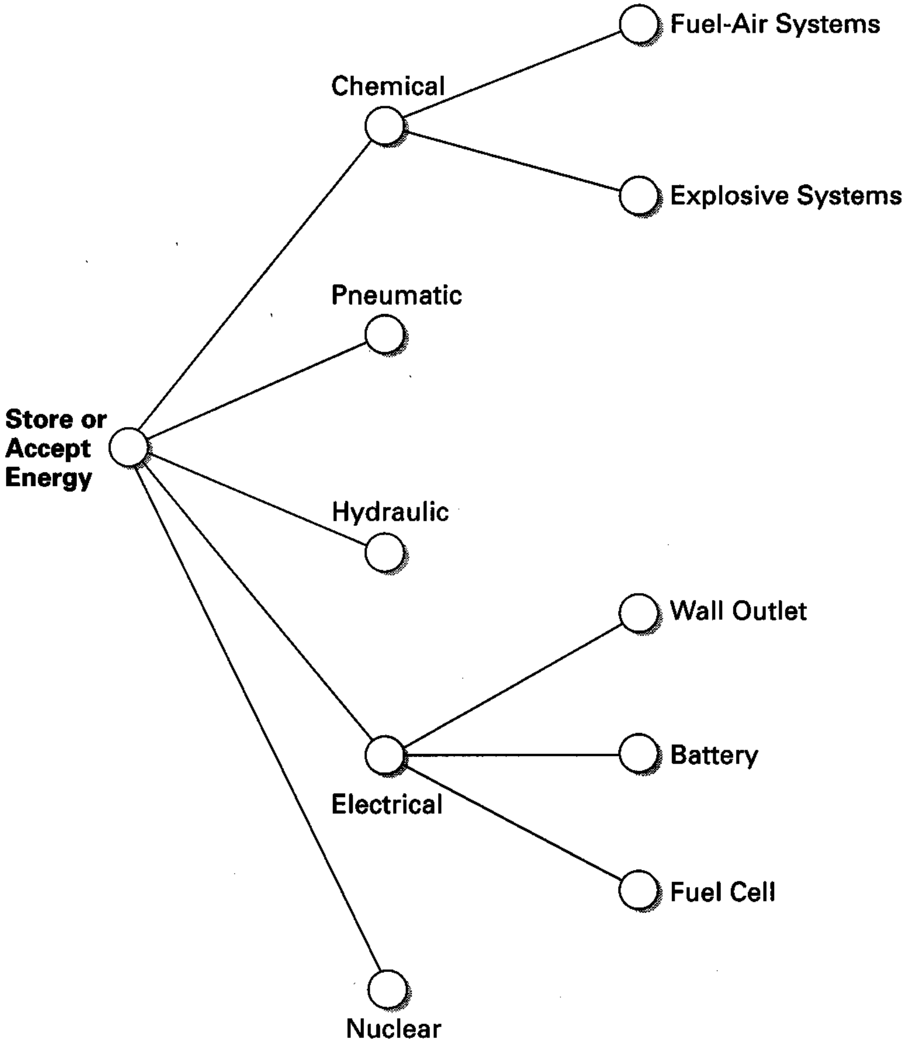
- It is used to divide the entire space of possible solutions for a given sub-problem into several distinct classes.
- It provides at least four important benefits:
  - Pruning of less promising branches.
  - Identification of independent approaches to the problem.
  - Exposure of inappropriate emphasis on certain branches.
  - Refinement of the problem decomposition for a particular branch.

Concept Classification Tree (Cont.)

- In general, a sub-problem whose solution highly constrains the possible solutions to several of the remaining sub-problems is a good candidate for a classification tree.

EXHIBIT 6–7

A classification tree for the nailer energy source concept fragments.



Concept Combination Table

- The concept combination table provides a way to consider combinations of solution fragments systematically.
- The columns in the table correspond to each one of the critical sub-problems that were identified during the first step of the methodology.
- The entries in each column correspond to the solution fragments for each of these sub-problems that were obtained from the external and internal search.
- Potential solution concepts to the overall problem are formed by combining one fragment from each column.

Concept Combination Table (Cont.)

- Choosing a combination of fragments does not lead spontaneously to a solution to the overall problem.
- The combination of fragments must usually be developed and refined before and integrated solution emerges.
- This development may not even be possible or may lead to more than one solution.
- In some ways, the combination table is simply a way to make forced associations among fragments in order to stimulate further creative thinking.

Concept Combination Table (Cont.)

- Two guidelines make the concept combination process easier:
  - If a fragment can be eliminated as being infeasible before combining it with other fragments, then the number of combinations the team needs to consider is reduced.
  - The concept combination table should be concentrated on the sub-problems that are coupled (i.e., the sub-problems whose solution can be evaluated only in combination with the solution to other sub-problems).

Concept Combination Table (Cont.)

- As a practical matter, concept combination tables loose their usefulness when the number of columns exceeds three or four.

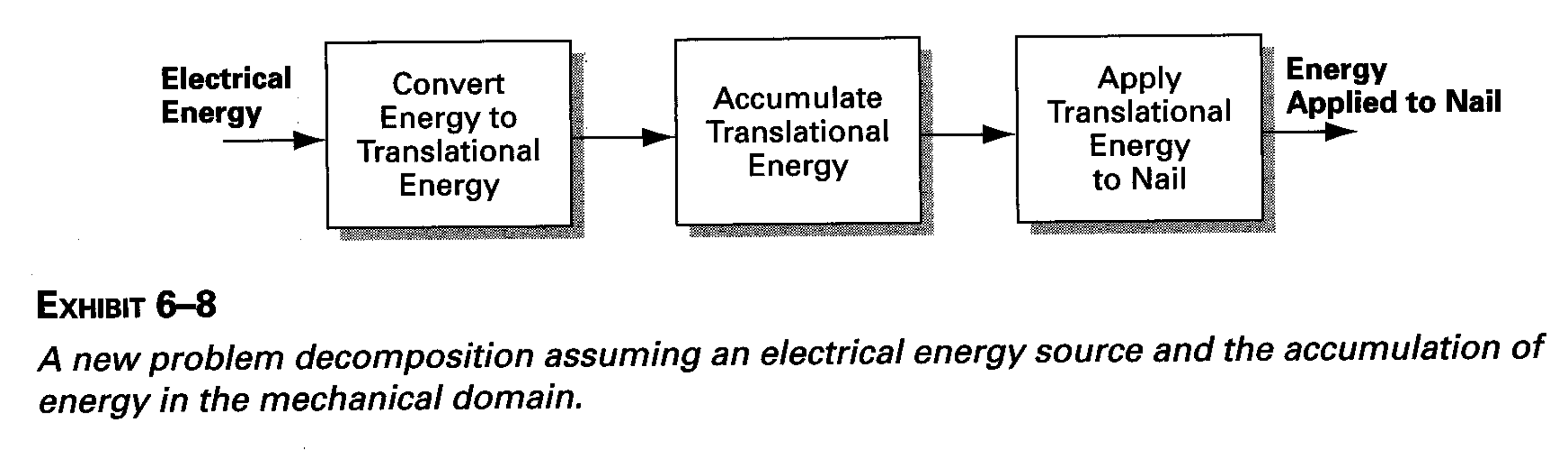
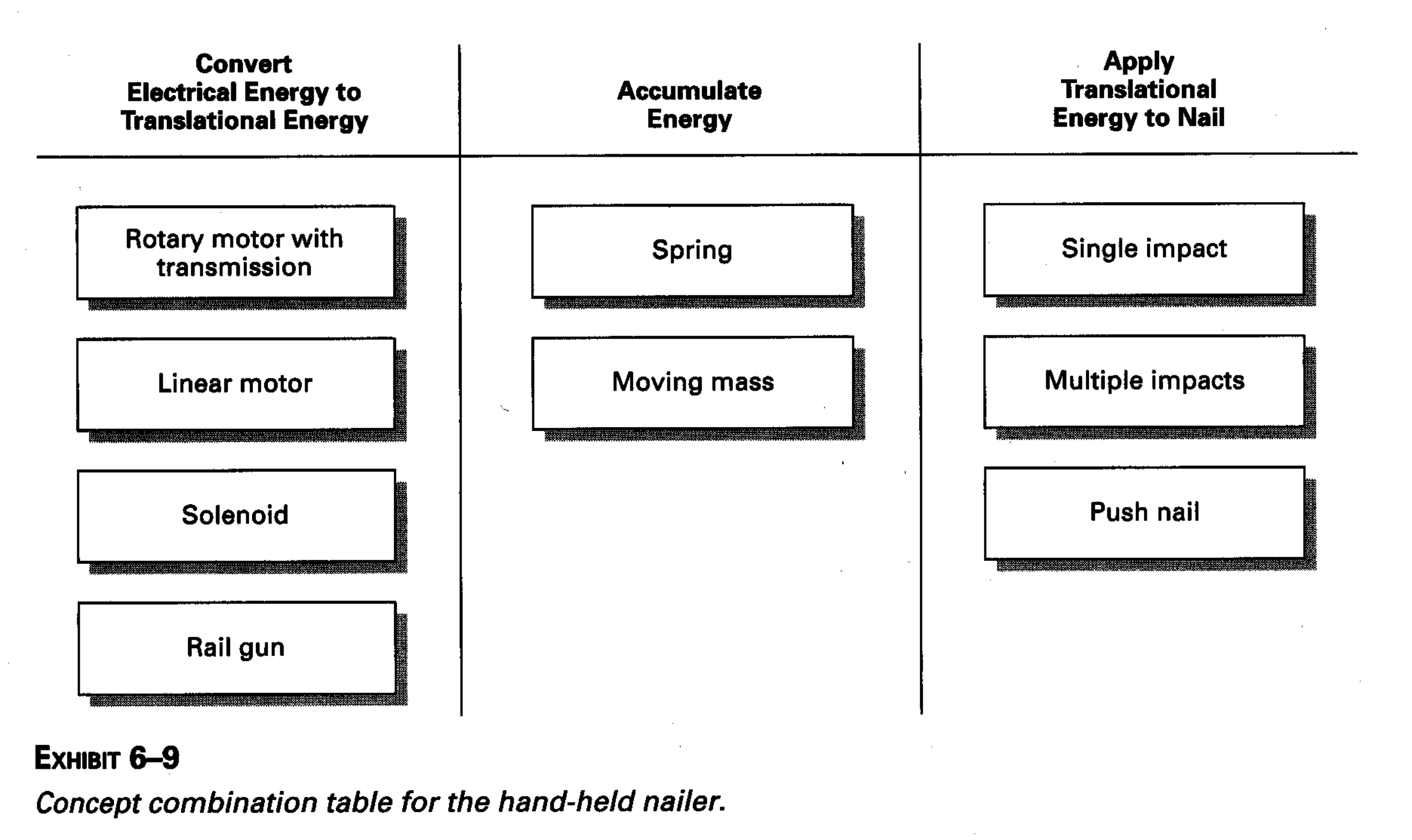

Electrical Energy
Convert Energy to Translational Energy
Accumulate Translational Energy
Apply Translational Energy to Nail
Energy Applied to Nail

EXHIBIT 6–8

A new problem decomposition assuming an electrical energy source and the accumulation of energy in the mechanical domain.

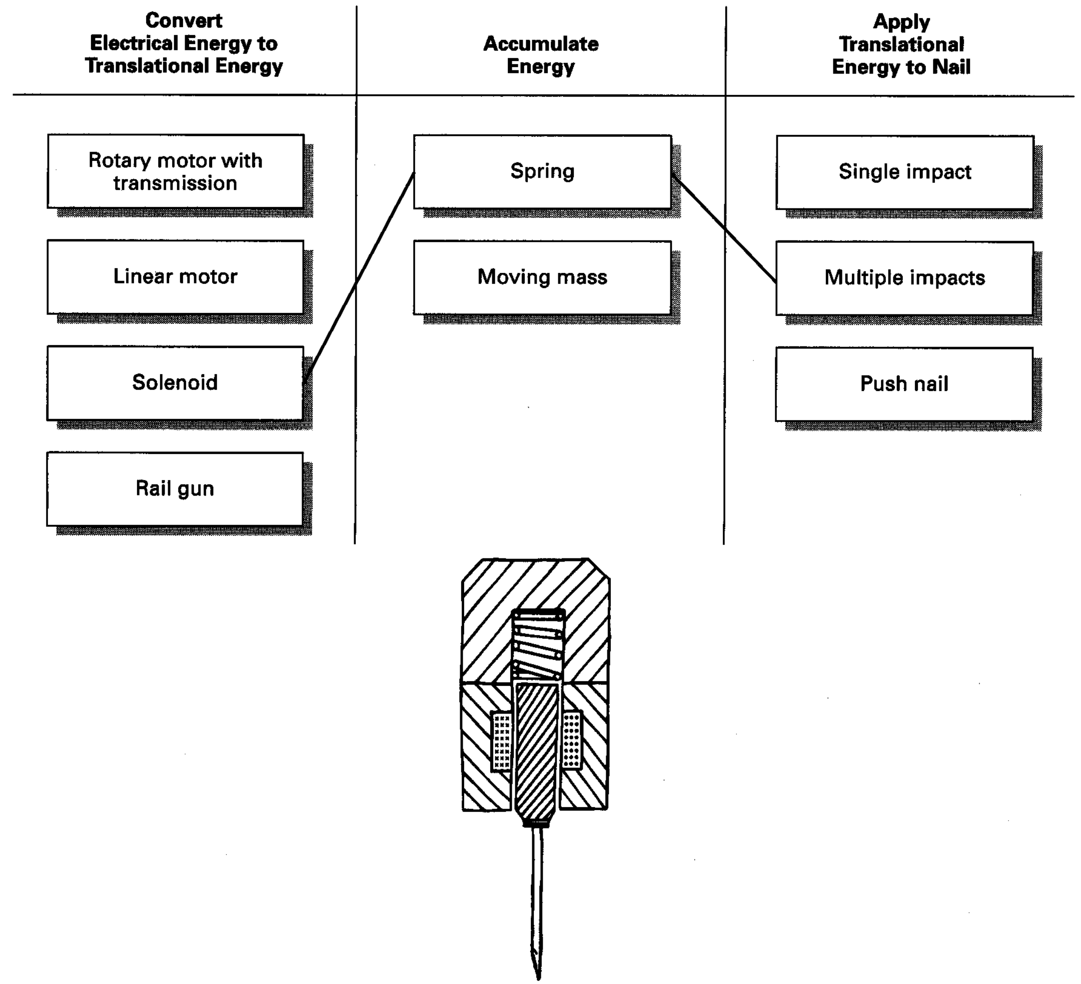


Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		

EXHIBIT 6–9

Concept combination table for the hand-held nailer.

Functional Decomposition



Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		

Exhibit 6–10

In this solution concept, a solenoid compresses a spring and then releases it repeatedly in order to drive the nail with multiple impacts.

Functional Decomposition

Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		

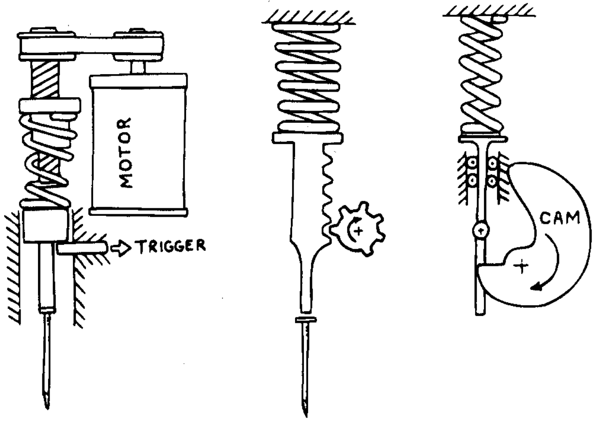


Exhibit 6–11

Multiple solutions arising from the combination of a motor with transmission, a spring, and single impact. The motor winds a spring, accumulating potential energy which is then delivered to the nail in a single blow.

Summary of Key Points

- Function exists in the solution neutral domain.
- Form exists in the physical/logical domain.
- Function reflects upstream processes (requirements, marketing, regulatory, corporate strategy, etc.)
- Form dominates downstream processes (manufacturing, assembly, service, training, etc.)
- Concepts map function to form.
- Function can be decomposed, and neither the nature nor the extent of decomposition is unique.

Summary of Key Points (Cont.)

- The nature and extent of functional decomposition can influence architecture.
- Functional connectivity will influence interfaces in form.
- Form can be partitioned, and the partitions will influence interfaces.
- Function can be mapped to form.
- Form and function often iterate early in the design process (rather than form always follows function).
- Arriving at a good product architecture involves (1) use of synthesis, and (2) having criteria for evaluating goodness of architecture.