Concept Mapping as a Communications Tool in Systems Engineering

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Abstract: In any "deep learning" situation, and in communicating in particular, understanding will be enhanced by using techniques that more closely fit the nonlinear structure of our thinking processes. This idea is particularly relevant to systems engineering, which deals with so many interrelated concepts—concepts whose parts are often handled by separate organizations with different "languages" and foci, presenting additional barriers and confusions in understanding. In the figures in this paper, we have tried to show a variety of patterns that concept mapping can be cast in, for flexibility and interest. Our experience in Boeing is that such an approach simplifies, deepens, and clarifies communications, while providing the opportunity to find ways to develop more complete and better integrated concepts.

INTRODUCTION

Systems engineering suffers traditional communications problems across domains, industries, companies, and disciplines. The same general problems plague military, commercial, government, industrial, and service applications. These problems have been cited in companies such as Boeing, TRW, Lockheed, and Westinghouse. Some solution approaches include structured project documentation (military), procedural modeling (process engineering), and object-oriented modeling (computer-based systems). (Oliver 1997)

In part, these breakdowns in communication are chronic across systems engineering applications because they are based in the mismatch between our linear language and our holographic, hierarchic thought processes, which are rich with unacknowledged linkages between concepts. Since linearly-constructed language alone cannot adequately portray the rich interweaving of concepts, other ways must be found.

Various techniques are being developed to allow people to make explicit the nonlinear relationships between concepts, and to cast them in a visual medium. Visual media are more suitable for noting patterns and for processing large amounts of information simultaneously. One such visual technique is "context mapping," developed by Joseph D. Novak. (Novak 1984) Although deceptively simple, context mapping is a powerful tool in exploring and communicating relationships.

CONCEPT MAPPING - WHAT IS IT? WHO USES IT?[1]

A concept map is constructed with circles containing labels for objects or events. The circles are arranged in a hierarchical manner from most general to most specific, and then are linked by lines to show which concepts are related. Each line has an associated description of the relationship between the contents of the circles it connects. Figure 1 shows an example of the form. Reading the labels of the two circles and linking line implies a sentence such as "*Dogs perform work*" *or* "*Dogs (were) domesticated from wolves*" or "*(Dogs) work as herders*."

Concept mapping was originally designed as a tool to enhance deep learning in school children. This type of learning (in contrast to rote learning) involves taking in a new concept and linking it to previously learned concepts. The concept mapping technique was developed specifically to reflect our internal cognitive structure, which is holographic, hierarchical, and implicit, and to permit that structure to be viewed externally and explicitly. In contrast, written and spoken messages are, by their nature, linear sequences of concepts.

The applications of concept mapping have expanded beyond the original intent. The uses include:

[1] See also http://www.graphic.org/concpet.html This web site contains a good overview of the technique, as well as references to books and other web sites.

- developing an understanding of a *body* of knowledge
- gathering and exploring new knowledge and information, and determining how it fits in with prior knowledge
- accessing prior knowledge, perhaps from diverse sources
- sharing knowledge and information generated
- designing structures or processes such as written documents, web sites, building organizations
- exploring problem solving options

Novak believes that "achievement in nearly every area of human endeavor would probably be enhanced if the relevant concepts and how they function were understood and used to interpret events or objects."

Specifically in the area of communications, concept mapping can be used:

- to help us to understand where each person is starting from—what concepts they know and how they link them together. The most important single factor influencing learning is what the learner already knows; what we know affects what we take in and how we perceive it. In communicating meanings, ascertain what the other person knows, and communicate accordingly.
- as a tool for negotiating meaning, by focusing attention on the task, and not on the people. Concept mapping tends to "democratize" the situation, to promote conferring and cooperation.
- to provide a format to exchange views on why a particular linkage is good or faulty, or to recognize missing linkages.
- to present a complex subject in smaller chunks by going in stages from the few most general concepts to a large number of more specific ones. This allows the view to focus on one area without losing its relationship to other concepts.
- to identify misconceptions. Misconceptions usually involve either a linkage between two concepts that leads to a clearly false proposition or a linkage that misses the key idea relating two or more concepts.

HOW TO USE CONCEPT MAPPING CONCEPTS.

"The making and remaking of concept maps and sharing them with others can be seen as a team effort in the sport of thinking."[2] The first step in concept mapping is to create a rough draft showing the objects and events in circles. Because meaningful learning proceeds most easily when new concepts are subsumed under broader concepts, the objects and events are placed on the page in a hierarchy with the most general material at the top and the most specific (specific instances, for example) at the bottom. Then lines and arrows are drawn between related concepts. Lines imply a relationship which can be read in either direction, whereas arrows denote a one-way relationship.

It is important to attach descriptions to as many of the connecting lines as possible, and to avoid assuming that whoever reads a map can fill in satisfactory linking words. Novak's experience has shown that few people, other than experts in the subject being mapped, are able to do this automatically. In addition, the labeling process itself is a rich experience. Different ways of linking two concepts may be equally valid, but each way will have a different connotations. Concept maps are powerful tools for observing the nuances of meaning, and can be remarkably revealing of cognitive organization.

It is important to redraw the map at least once. A second map usually shows key relationships more explicitly. Ideas that are very different from the ones we already hold, or which have far-reaching implications for the ones we already hold, are difficult to integrate. There may be a lot of internal changes associated with the new concepts, which require time and internal work, reforming the internal system of

TWO CONCEPT MAPPING APPLICATIONS AT BOEING

FIRST APPLICATION: WORKING WITHIN A GROUP TO DEVELOP ALIGNMENT

Boeing's Systems Engineering group used concept mapping in a project to develop and communicate a vision for "airplane-level engineering." A team had previously produced a preliminary—a sixty page document describing the

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[2] See also http://www.uwp.edu/academic/biology/100/concpt.mapping.faq.html This is a web site propared in 1997 by paul D. Boyer, Ph.D., University of Wisconsin—Parkside, paul.boyer@uwp.edu. If you don't have access to J. D. Novak's books, this is a good on-line reference for how to do concept mapping.

current situation, the vision, the concepts involved, and the processes and products supported in those concepts. The larger group was offered an opportunity to review and change the document, even to scrap it entirely and start over. Only 15% of the group responded, and, of those who did, many found the document overwhelming. The team decided to replace the document with a series of concept maps on a web site.

The first thing that the team noticed was how much simpler it was to display the material. The basic ideas can be conveyed in just a few linked maps with words hyperlinked to deeper discussions of the various concepts and their relationships. This format allows the users to select how deeply they want to explore. Of course, this is also a quality of web site hyperlinks, but the hierarchical structure of concept maps lends itself to presenting layers of conceptual abstraction while maintaining an overall sense of the relationships between the concepts.

In refining the maps, it became clear that there were concepts which had been placed in inappropriate relationship to each other. This discovery provoked a set of interesting discussions while tending to pull the focus toward the concept map itself, and on getting it "right," and away from individuals and their positions. As we added processes and products to support our proposed systems engineering concepts, it was easy to see what additional processes and products would be needed to support the project, as well as easy to show what parts of a comprehensive plan are currently being supported, and what parts are missing. This illumination of missing elements in the program makes the maps a useful tool for communicating the group's needs, ideas, and concerns with higher management.

Figure 2 shows the top level chart, which maps the relationships between organizations to show how airplane-level engineering fits in. In this case, we chose to represent the hierarchical structure by nesting the circles. The arrows coming down the page show one set of relationships—the relationship of the more general organization to the more specific organization. The arrows going up the page show another kind of relationship: how the more specific organization supports the more general organization. This page sets the context for airplane-level engineering activities. "Airplane-Level Engineering" links to the next level of concept mapping, which shows the relationship between the definition of airplane-level engineering, its vision, its strategy, its implementation plan, and the execution of the plan. (Figure 3.) This map is not hierarchical because the nature of the subject is that each element feeds into the next to form a circle. Originally, one might start with "definition," but over time, the definition will change. The "A-LE Vision" circle links to the next layer of abstraction, showing the relationships between all of the concepts, processes, and products. It was at this level that we began to see the holes in our vision.

The main benefits of using concept mapping in this project were:

- a visual, compact, non-linear way to present complex, non-linear concepts
- in-depth discussions, and, during disagreements, focus on the task instead of on individuals
- illumination of faulty connections between concepts
- discovery of missing concepts

Because we had found concept mapping so useful in the above project, we are using it again. In this second project, we have a 60-page legal contract concerning a consortium of suppliers. From throughout the document, we pulled out the critical information concerning the purpose, organizational structure, funding structure, and proposed activities of the consortium, and described them in five concept maps. These maps have made it quick and easy to introduce the consortium to new people, while greatly simplifying management's task in evaluating how they need or want to support the activity.

SECOND APPLICATION: WORKING WITH DIVESE GROUPS TO DEVELOP PREFERRED PROCESSES

A team developing preferred processes for the Electrical/Electronic Enterprise Group worked with people from diverse organizations, from engineers in the Design organization to shop mechanics in the Build organization. The team used concept mapping, and had software written to facilitate the mapping process.

Concept mapping turned out to be helpful in the following kinds of ways:

- The process brought out the fact that different "languages" in different organizations were leading to confusion
- Participants were forced to think out succinct descriptive sentences
- The process required a new level of detail and rigor in thinking about tasks and relationships
- The process helped participants organize thoughts on things they really knew about

- Great debates developed over subtle differences over what people thought they understood
- "Odd" and erroneous relationships were exposed
- The mapping forced anomalies to the surface
- The process allowed people from different domains (design and shop) to appreciate what was important to the other
- Participants were able to start to write valid rules, to identify key features
- Mapping took debate out of the emotional level, taking it from blame to "Oh, I understand"

From the point of view of the participants, the most important aspect of using concept mapping was the process of people working together to develop the maps, and not the final maps themselves. The team members had a very diverse group to communicate amongst and to communicate out to. The technique allowed them to have a rich experience of diversity, rather than a frustrating one.

To show another style, Figure 4, from this team's final document, maps a process, showing the resources and people involved, and the form of the process.

SUMMARY

In any "deep learning" situation, and in communicating in particular, understanding will be enhanced by using techniques that more closely fit the nonlinear structure of our thinking processes. This idea is particularly relevant to systems engineering, which deals with so many interrelated concepts—concepts whose parts are often handled by separate organizations with different "languages" and foci, presenting additional barriers and confusions in understanding. In the figures in this paper, we have tried to show a variety of patterns that concept mapping can be cast in, for flexibility and interest. Our experience in Boeing is that such an approach simplifies, deepens, and clarifies communications, while providing the opportunity to find ways to develop more complete and better integrated concepts.

REFERENCES

Novak, Joseph D., and D. Bob Gowin, *Learning How to Learn*. Cambridge University Press, New York, 1984

Oliver, David W., Timothy P. Kelliber, and James G. Keegan, Jr., *Engineering Complex Systems*. McGraw-Hill, New York, 1997

BIOGRAPHIES

Morgan McCartor is a systems engineer for Boeing Commercial. She has a BS in Mechanical/Environmental Engineering from UC Santa Barbara, a BA in Psychology from UC Berkeley, and is working on a Master's in Whole Systems Design from Antioch University. Her interests include cross-cultural learning and communication, thinking modes for working with complexity, and the epistemology of subjective experience.

Joseph J. Simpson is a systems engineer for Boeing Commercial Airplanes. His primary interests involve complex system identification, description, analysis, and characteristic communication. He was a charter member in the Tri-Cities chapter and is current president of the Seattle Metropolitan Chapter of INCOSE. He studied systems engineering and environmental engineering and graduated with bachelor's and master's degrees from the University of Washington. He then worked for the Department of the Army, Westinghouse Hanford Company, and Boeing.

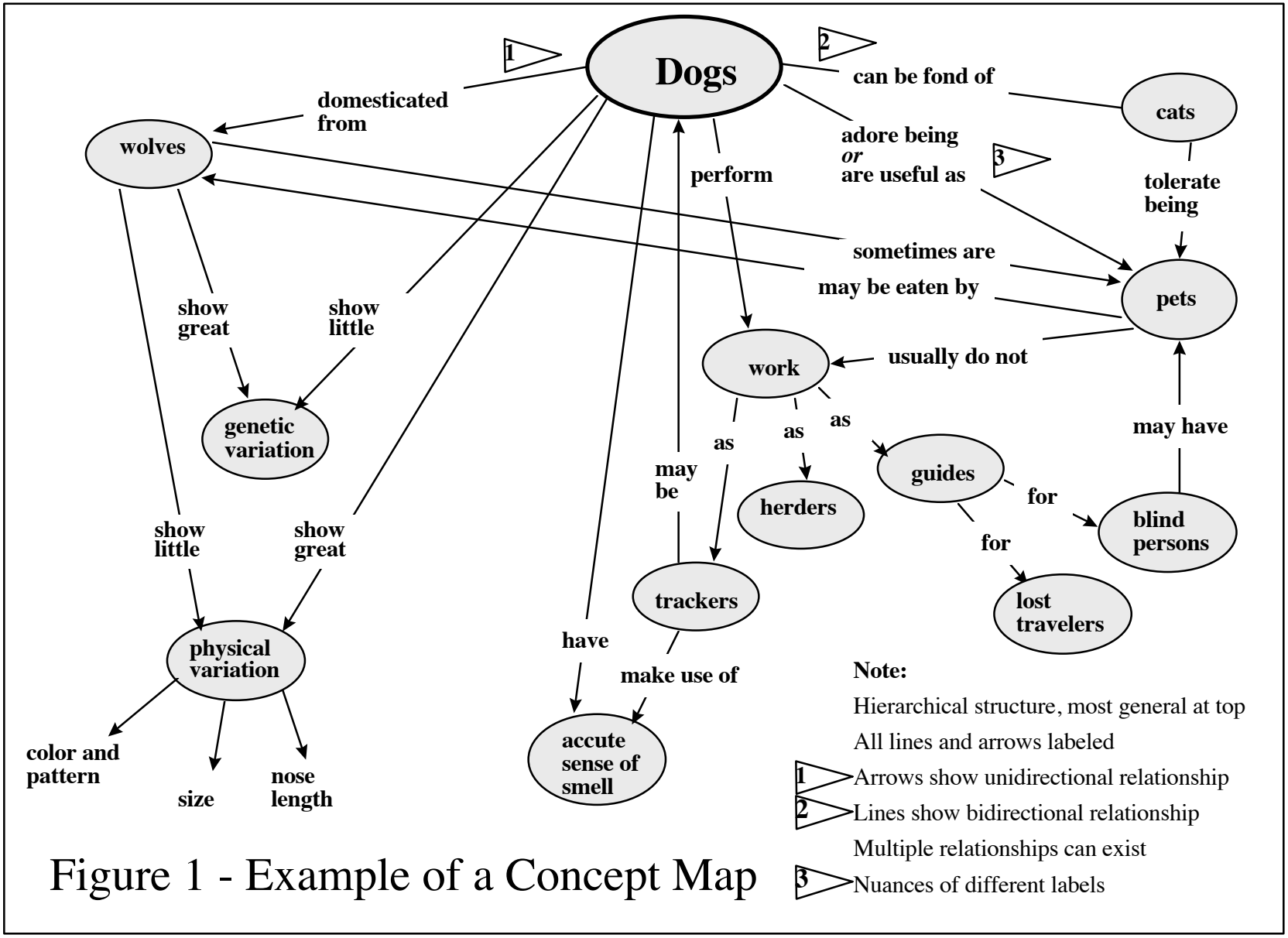
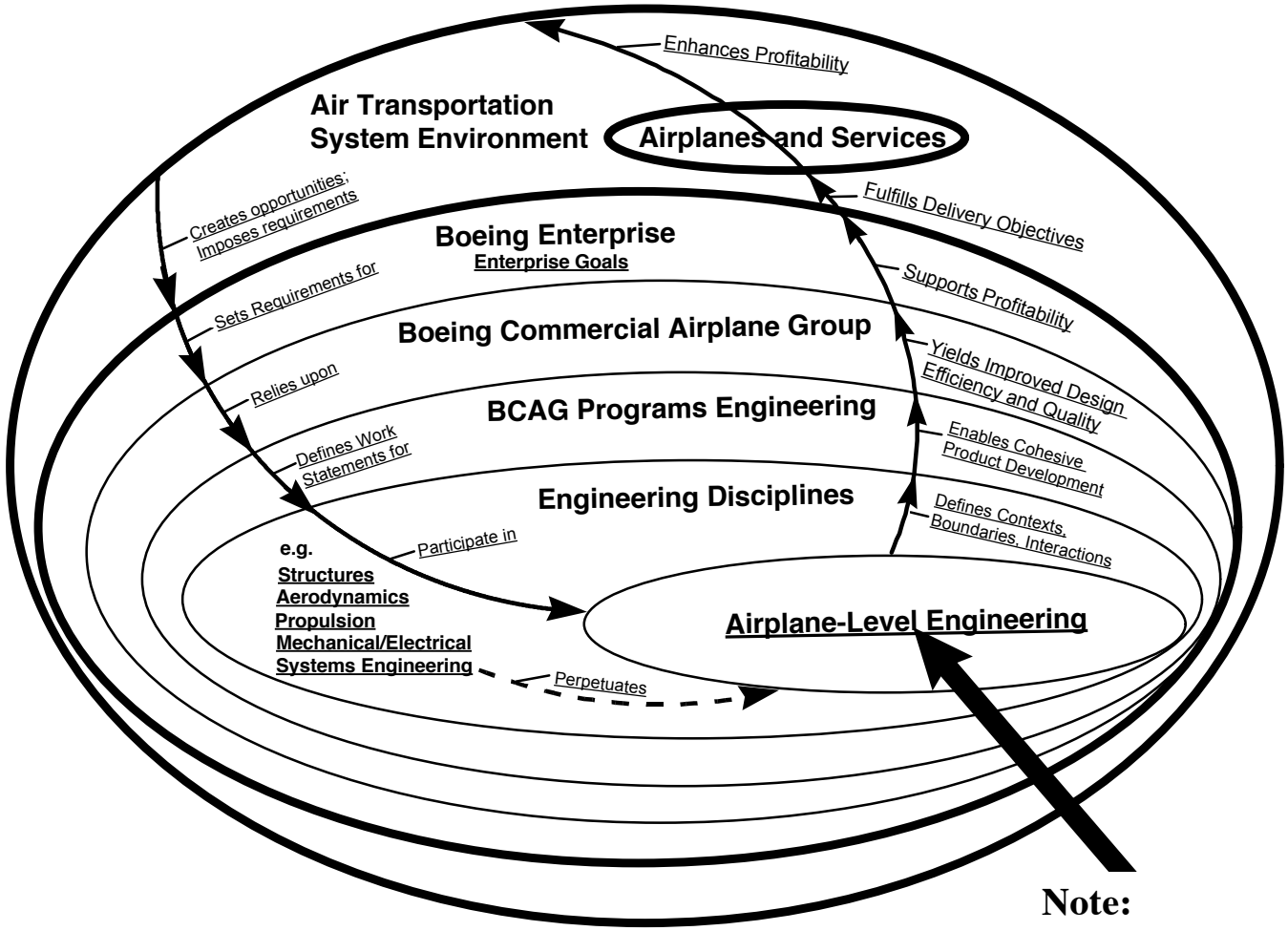


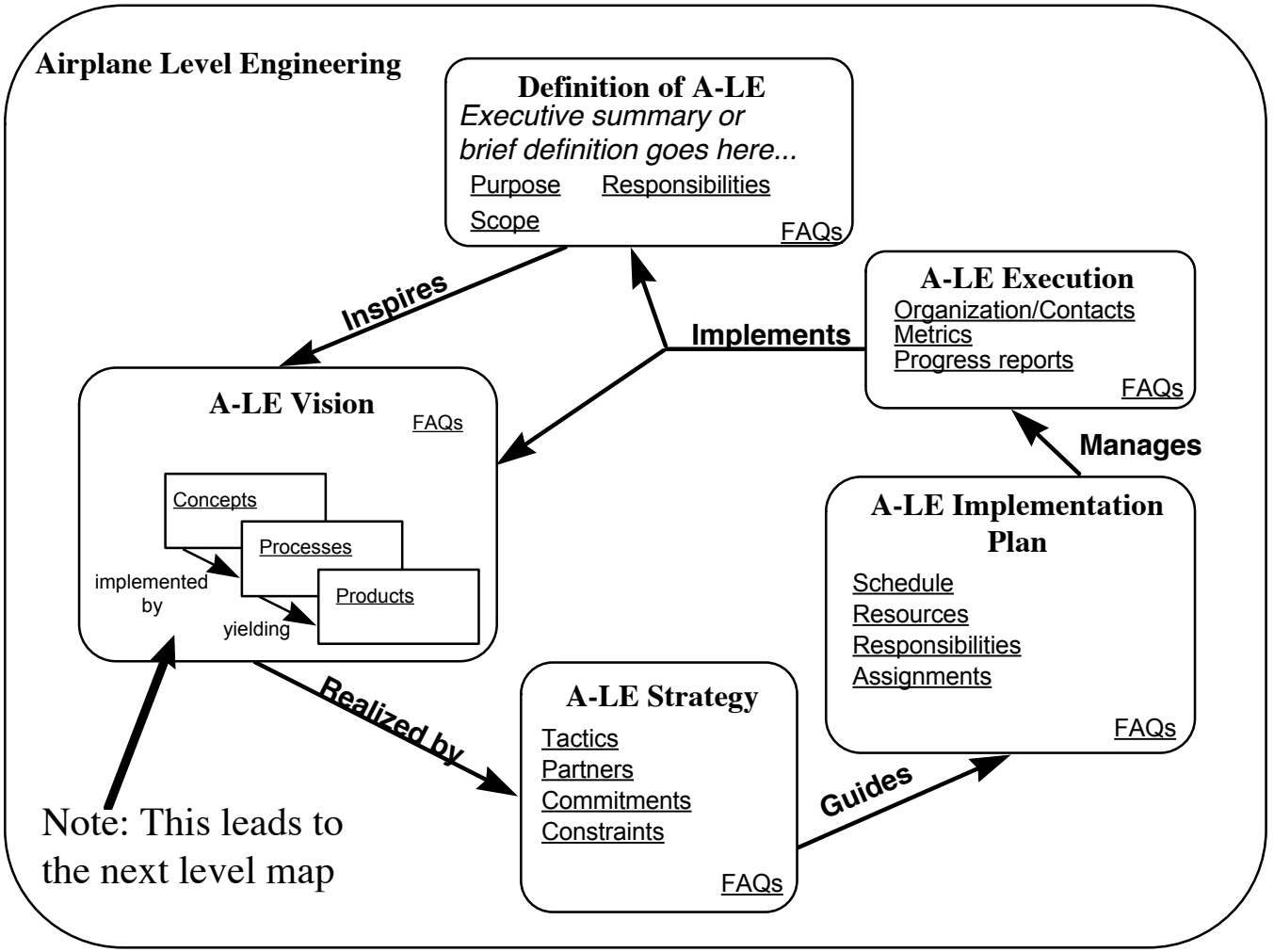
Figure 1 - Example of a Concept Map



Note:
Hierarchical structure, but in a nested format
Two sets of relational elements

Note:
This leads to the
next level map

Figure 2 - Top Level Map for the Web Site



Note:
Map can't be hierarchical because of circular feedback

Figure 3 - Second Level Map for the Web Site

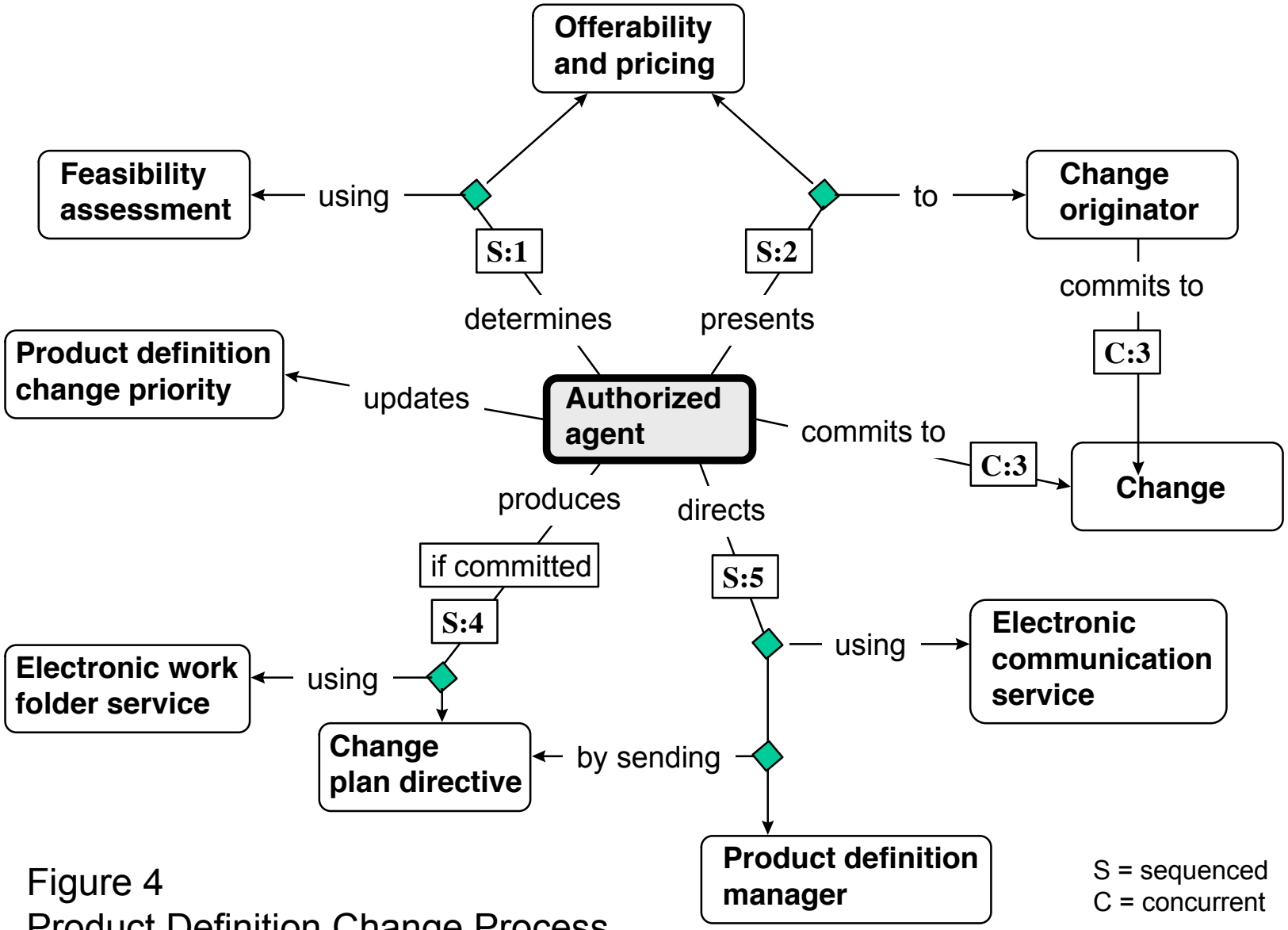


Figure 4
Product Definition Change Process