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# Concept Maps and Learning Objects

Part 2

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***Abstract*—This paper addresses the use of Concept Maps (CMaps) to model topics that make up the area known as Linear Time-Invariant Systems (LTI Systems) as taught in engineering curricula. The CMaps are used to define the granularity of Learning Objects (LOs) in this area. The results of this work allow future extensions in terms of examining the syllabi of the undergradutae courses that teach LTI Systems. Results are presented and future developments are also considered.**

*Keywords— **Concept Maps; Learning Objects; Linear Time-Invariant Systems; Signals & Systems; Electric Circuits; Electrical Engineering***

## I. Introduction

The identification of high attrition rates among students of two undergraduate courses that are core to engineering curricula led to different actions by the faculty who teach the courses. One was the development of Learning Objects (LOs) in an attempt to enhance the learning process. At first, the decision on which objects to create was based on the experience of the faculty members who are involved with the actions.

LOs must be shared and reused so that the resources necessary for their development yield the most benefit. For this reason, the definition of the scope of a LO, its granularity, can be made based on a more "scientific" way. This does not mean that faculty experience and intuition are to be neglected; they may be used to check and to "polish" results.

The author decided to use Concept Maps (CMaps) as the tool to define the granularity of LOs. Granularity is of paramount importance in the reuse of LOs. If the "grains" are too big, topics may be added that are not necessary, if the are to small, too many "grains" must be used and more managing work is required.

CMaps were created by Joseph D. Novak and his team at Cornell University (http://www.cornell.edu/) in the 1970s. A current work that presents CMaps in detail and also indicates examples of use [1] was taken as a reference to the work. In [1] there are two points worth mentioning.

The first is their definition. CMaps are ways of organizing and representing knowledge using graphical tools. They are composed of boxes (or sometimes circles or ellipses) that contain concepts. Concepts are linked to one another by lines associated with words – linking phrases or linking words – that express the relationships between two concepts. CMaps are hierarchical with the most inclusive (more general) concepts on the top and the most specific (less general) ones in the lower parts of the graph. There can also exist cross-links, i..e, links connecting concepts in different domains (segments) of a CMap. A CMap can have large branches – the domains or segments.

The second important point is that the authors suggest that before a CMap is created, it must clearly be defined the objective of the organization of knwoledge or why a Cmap is being created. They call it the focus question to be answered; it yields the context of the knowledge in the map.

The use of CMaps by the author of this work started with Linear Time-Invariant Systems (LTI Systems) that are the main focus of the two courses with high attrition rates – Signals & Systems and Electric & Electronic Circuits. At the same time, there is a third course that is based on this subject; it is Controls & Servomechanisms. This is the first course in control systems and deals with LTI Systems. The focus question was the granularity of the LOs to be developed.

The first set of results of the use of CMaps to define LOs on LTI Systems was presented in [2]. It was a preliminary study that is to have follow-ons not only in the design to LOs but also in: (1) the design of the structure of online courseware to fulfill the needs of courses or part of them – this can be done by creating the "story boards" that link the LOs; (2) the analysis of LTI Systems subject in Electrical and Controls & Automation Engineering curricula at PUC-Rio and, as consequence; (3) the definition of the corresponding courses syllabi. The curriculum of Mechanical Engineering must be examined too since it has courses on Control Systems that address LTI Systems.

These extensions of the work came as consequences of the potential use of organizing the topics on LTI Systems that are taught in engineering curricula.

In order to be able to address the three possible follow-ons, it was necessary to enhance the CMapping of LTI Systems. Additional work on this topic identified and two errors that were corrected. The first was the absence of the Time-Invariance property that is part of the characterization of LTI Systems – it was missing and had to be added in the same hierarchy of Linearity & the Superposition Principle. The second was the lack of physical models for the usual LTI Systems used in the courses – linear circuits (R, L, C and sources) and linear mechanical systems (spring, mass, damper and external forces). This has already been done.

When CMaps are used to address curricula problems, some works may be cited. A very interesting use of CMaps related to curricula was addressed by Morsi, Ibrahim and Williams [3]. The authors used CMaps to help students understand the overall picture of each curriculum and the relations of its different elements. At the same time, they reasured that CMaps are not to substitute for flowcharts that are important tools for planning and scheduling. Another work that deserves attention was presented by Cornwell [4]. He used CMaps to analyze a Mechanical Engineering curriculum starting with the entire curriculum and getting down to the CMaps of two specific courses.

In both works, it seems that the authors take for granted that the definition of the scopes of the courses is to be preserved. This is probably so because in both cases the analyses focused on individual curricula, not considering overlappings among curricula.

This work addresses the results of the second stage of a project that focuses on the use of Concept Maps (CMaps) to identify the granularity of Learning Object (LOs). Stage 1 was presented in [1] where the motivation for the development of LOs was addressed. Stage 2 has the same motivation, but goes further in order to consider the "regions" in the CMaps that allow the definition of the "story boards".

Follow-ons (2) and (3) will be subject to additional study since curricula analysis is required. The planned next steps are presented in the end of this paper.

Section II is devoted to the changes in the original CMap that yielded the new CMap for LTI Systems. Section III addresses the identification of "regions". Section IV relates LOs and digital libraries, a suitable type of system to manage them. Section V presents some comments and the next steps to be followed.

## II. The Original CMap Revisited

As mentioned in section I, the continuation of the work allowed the identification of 2 errors in the original CMap – called version 1 (v1), shown in figure 1. The 2 errors are discussed in this section, as well as the change in development actions that resulted from the creation of v1 and the correction of errors.

### *A. Time-Invariance (Shift-Invariance) Property*

Figure 1 shows, that though the box on the top contains the concept "Linear Time-Invariant Systems", to its left, related by the link "Obbey", only the "Superposition Principle" was specified in a box. There was no "Obbey" relation to "Shift Invariance".

This was a serious error since Time-Invariance or Shift-Invariance is part of the definition of LTI Systems. Figure 2 shows v2 of the LTI Systems CMap with a second "Obbey" link connecting to a "Shift-Invariance" box.

### *B. Physical Linear Time-Invariant Electrical and Mechanical Elements*

Students in Computer, Control & Automation and Electrical Engineering must take Electric & Electronic Circuits as a mandatory course. About 75% of its syllabus is devoted to linear circuits. This means that modelling physical LTI Systems is part of these engineering curricula. When the Controls & Servomechanisms course is considered, linear-time-invariant mechanical systems are modelled; their parallel with electric systems is considered too.

At the same time, the study of Control Systems requires new concepts related to systems models (input-output versus internal variable models), canonical representations, relation between input-output models and internal variable models, etc.

For these reasons, the CMap had to be modified to include physical implementations of at least the systems addressed in the curricula as well as the concepts and links related to Control Systems. These changes are also shown in figure 2.

It is important to observe that system properties (stability, controlability and observability) have been included but not fully represented. Concerning physical implementations, the study of Linear Circuits requires that the CMap be expanded; the same happens with systems properties.

At the moment there is not a clear decision on how to deal with these two problems (Linear Circuits and systems properties). Two options are under consideration and will be examined in the near future.

### *C. Change of Order in Development of LOs*

Two faculty members who teach Signals & Systems, Electric & Electronic Circuits and Control & Servomechanisms started developing LOs. The first four LOs were made available in August and early September 2012 and the choice of topics was intuitive – topics that are important in the courses. They were:

- Half-wave Rectifier – a Non Linear System
- Thévènin Equivalent Circuit
- Full-wave Rectifier – a Non Linear System
- Norton Equivalent Circuit

It quite obvious that the LOs contained topics of Electric & Electronic Circuits, though two of them were deeply related to system classification (the two rectifiers are non linear systems); they can be used in a Signals & Systems course.

The next four objects were:

- Linearity
- The Mass, Spring and Damper System
- The RLC Series Circuit
- The Discrete-time Convolution

If the eight LOs are considered, only the one on Linearity can be used in the three courses. The others can be used in two or only one. At the same time, this set can not fulfill a teaching topic in any of the courses.

For this reason, the results of the CMap (v 2) started being taken into consideration to guide the new developments. The LOs currently under development or to be developed in the near future are:

- Time-Invariance
- Signals and Energy
- Signals and Their Operations
- Sampling and A/D & D/A Converters

When the last four are completed, there will a set of 12 LOs. Some LOs in this set allow for a "region" of the CMap to be identified. This is discussed in the next section.

## III. Identification of "Regions"

The word "region" was chosen to mean an area of the CMap that contains concepts and links corresponding to LOs that can be grouped to generate a module of a course. If such a module were to be supported by ICT – Information and Communication Technology – it would require a "story board" (a script) to link the LOs and specify the relations they hold. In a traditional face-to-face situation, the instructor would link the LOs or the topics they contain, but in an ICT supported situation, this must be accomplished through a digital content with the specific function.

Figure 3 shows a region in the CMap that holds the main characteristics of signals – the concept boxes are painted light blue in the map. The LOs to be included in this module would be: (1) Signals and Their Operations; (2) Signals and Energy; (3) Discrete-time Convolution; and (4) Sampling and A/D & D/A Converters.

Another example is in figure 4. It shows a region in the CMap that holds time domain / frequency domain transformations; the boxes are painted green. This region could be a module in a Signals & Sytems course as well as in Principles of Communications course, for example. It could also be split into two others in case either continous or discrete time signals were considered separately.

Concepts (boxes) may be part of many regions. This means the granularity of LOs must be such that they can combine in different sets to fulfill the needs of the various modules/courses. Sets of regions may yield a complete course.

This view of CMaps and LOs seems to be suitable to increase the reuse and sharing of course contents in digital formats.

For LOs to be found and used, it is necessary that they are properly described and stored. This requires that repository managers follow standards and best practices in the mangament of the digital collection.

Sharing LOs does not depend only of technical/technological aspects. The "owners" of the LOs must be willing to let their products to be combined for different purposes. The use of Creative Commons Licenses (http://www.creativecommons.org/) may solve this problem. This introduces another challenge to faculty and courseware developers – the will to cooperate requiring the establishment of best practices to be followed by those involved in the effort.

Once owners are willing to share, this may be accomplished using digital libraries to support LO management.

## IV. LOs, CMaps and Digital Libraries

Digital Libraries have been quite useful in managing shareable digital contents in general and courseware in particular [5, 6]. They allow digital contents to have "independent life", i.e., they can be searched, retrieved and used even when the user is not a student in the course. This happens if the authors yield access to other persons besides their students. At the same time, since they have "independent life", they are not limited to only a course / class – many curses / classes can share them without replication, making it easier to update when necessary.

CMaps have been used to automatically navigate contents on a digital repository. An example of such use is a project developed at Georgia Tech for a course on DSP – Digital Signal Processing [7, 8]. This project focuses in naviganting in a repository that already has contents on a certain subject.

The present work is concerned in defining a strategy to create LOs based on CMaps. Existing and future LOs are and will be managed by a Digital Library, but the objective is the opposite of [7, 8] – it is to populate the repository with LOs that are defined using CMaps.

The repository / digital lbrary that hosts the LOs has many other digital contents (class notes, interactive books, lists of problems, etc) in the same areas of the LOs. For this reason, the work developed at Georgia Tech will be considered as a possible extension of this one.

## V. Comments and Next Steps

The use of CMaps to define LOs in LTI Systems seems to be yielding good results. The development strategy has been modified and when the 4 new LOs are available, it will be possible to create a module on the characteristics of signals.

Other LOs will be identified from the CMap as well as other "regions" will be defined to create new modules. The modules will be implemented.

The problem of dealing with physical models, electrical and mechanical, must be addressed. The same happens with the properties; stability is a very important and long topic.

At the moment there seem to be two options. The first is to create related CMaps for each of these topics. This solution was used by Morse, Ibrahim and Williams [3] to analyse curricula. A second approach is to expand the current CMap as far as necessary, making it very broad in terms of coverage of LTI Systems with Electrical and Mechanical implementations. It will also be very complex. To deal with the complexity, views of "regions" could be created, as if subsets were focused with the remaining CMap ketp in background. It is important to remark that in the second solution, it is necessary to have boxes and links connecting all parts in the same “region”.

Most probably both options will be tested and compared.

In the future two follow-ons will be addressed – the analysis of the structure of the courses on LTI Systems in the Control & Automation and the Electrical Engineering curricula, and the extension of this analysis to include the Mechanical Engineering curriculum.

The LOs are organized in a series that can be found at http://www.maxwell.lambda.ele.puc-rio.br/series.php?tipBusca=dados&nrseqser=5. Alternatively, one can access the Maxwell System (http://www.maxwell.lambda.ele.puc-rio.br/), choose *Séries* in the left hand side menu and then click Objetos Educacionais em Engenharia Elétrica in the Portuguese interface. If the English interface is used, the choice will be Series in the left hand side menu.

## ACKNOWLEDGMENT

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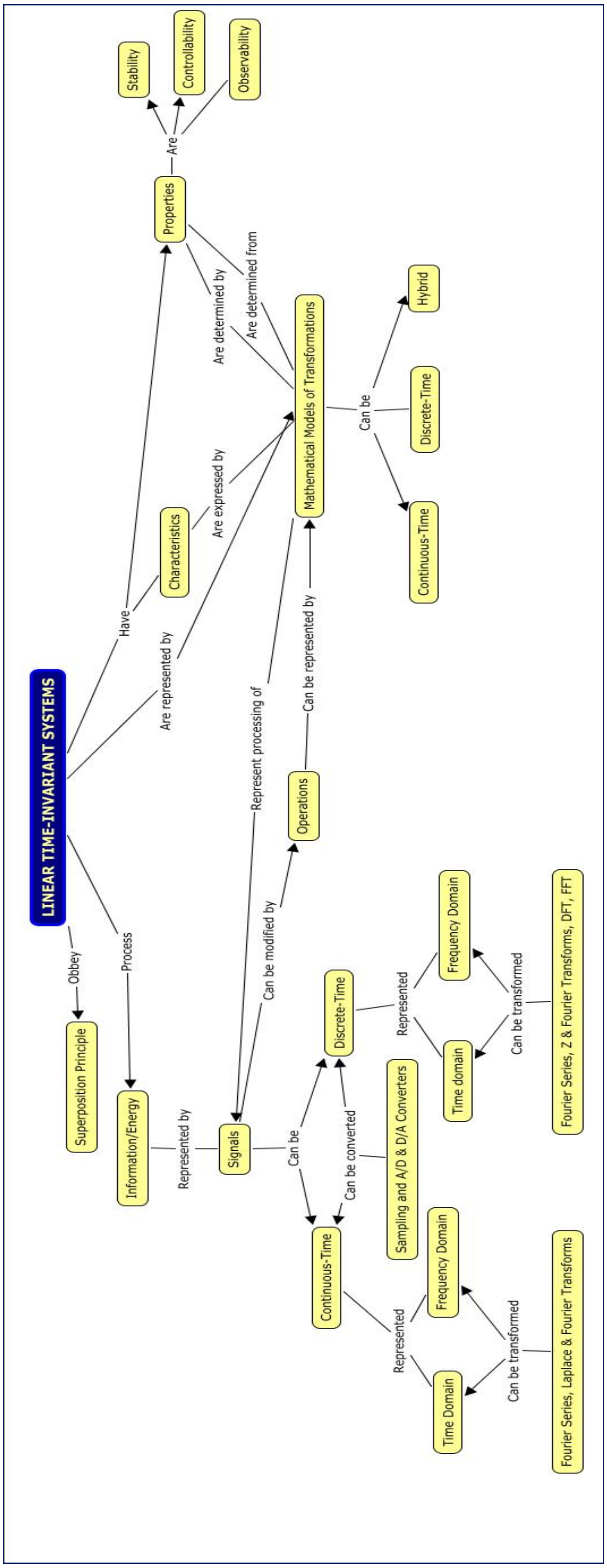


Fig. 1 – CMap (v1) for Linear Time-Invariant Systems

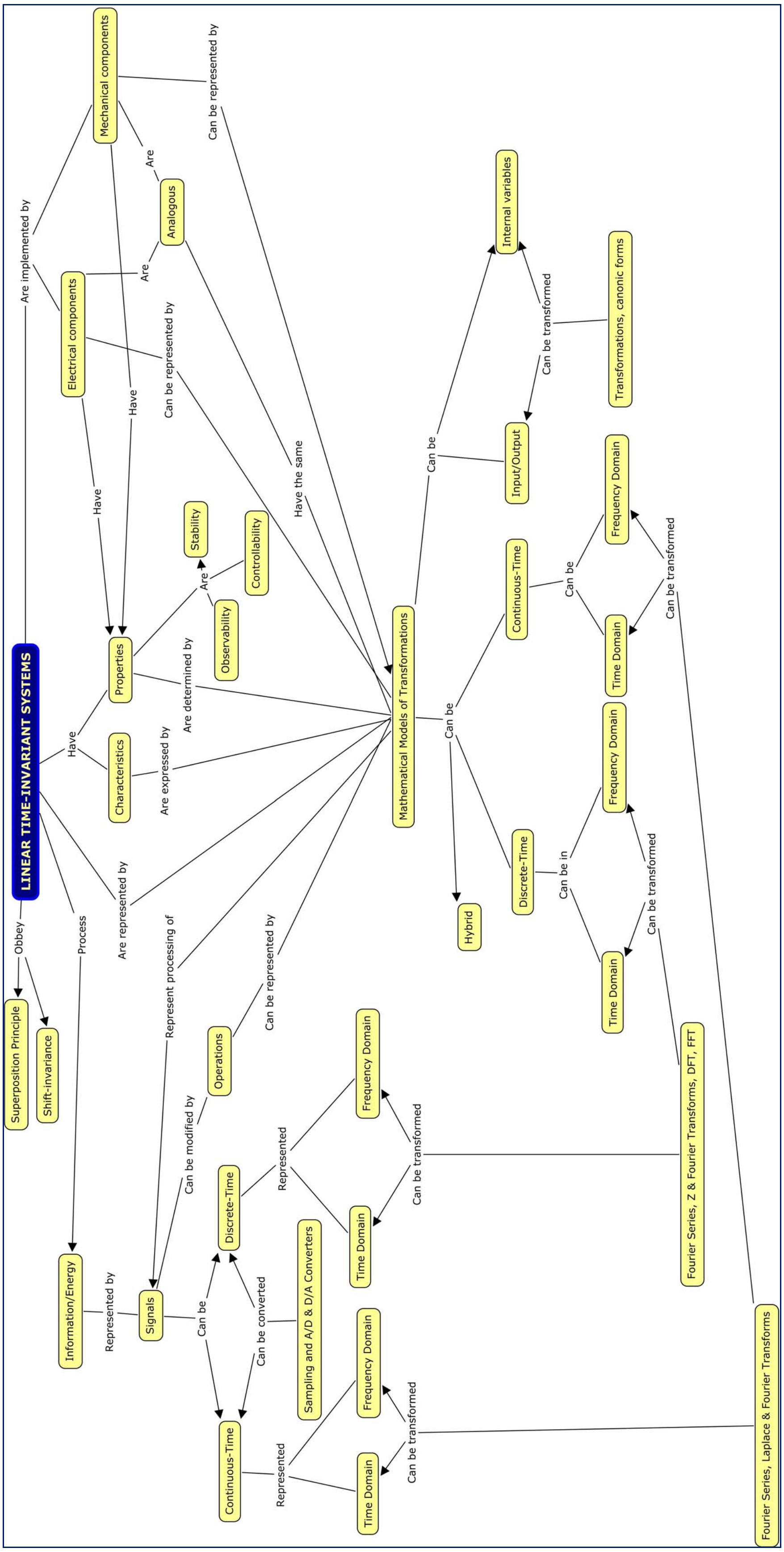


Fig. 2 – CMap (v2) for Linear Time-Invariant Systems

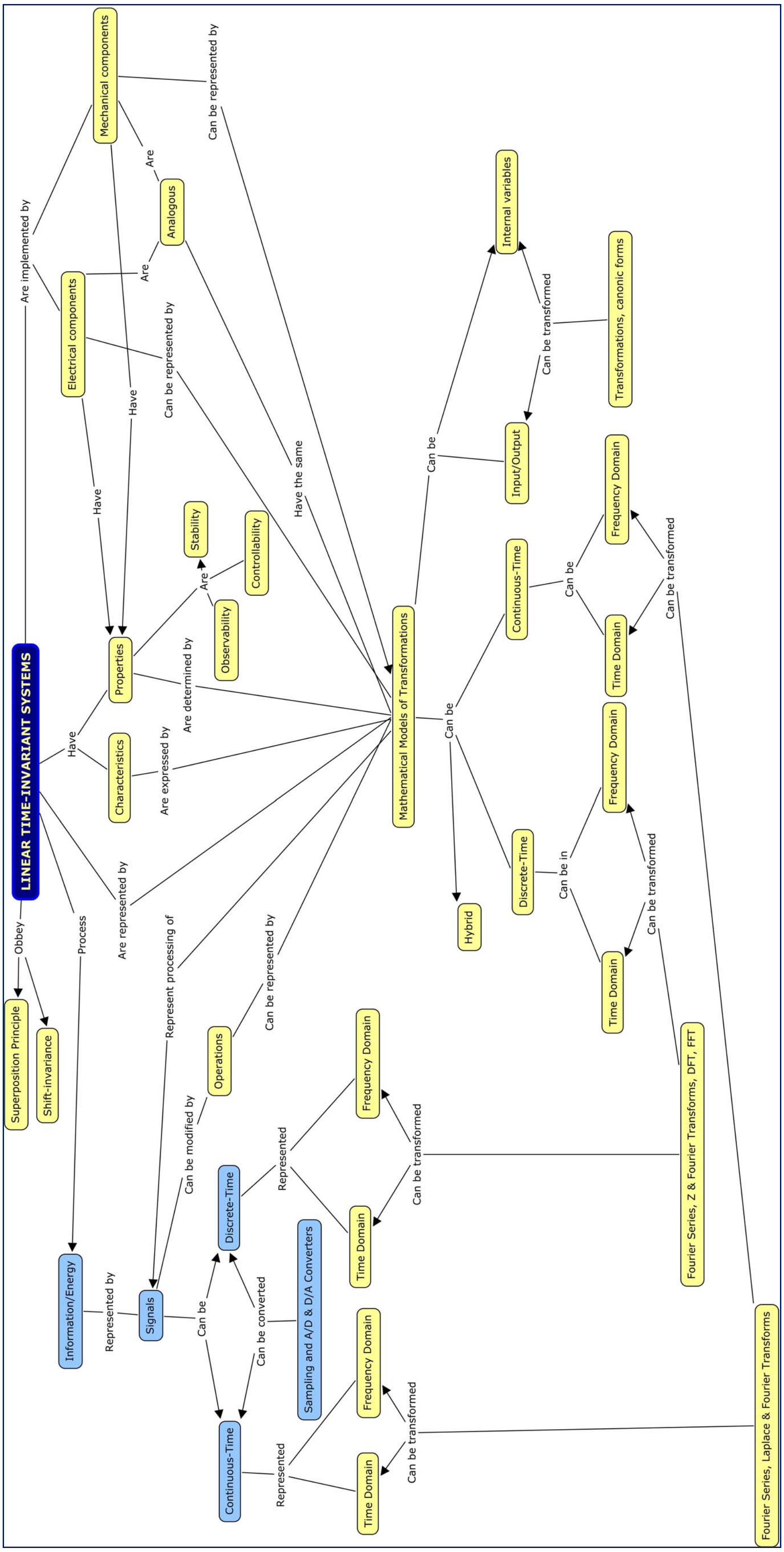


Fig. 3 – Region 1 of CMap (v2) for Linear Time-Invariant Systems – Main Characteristics of Signals

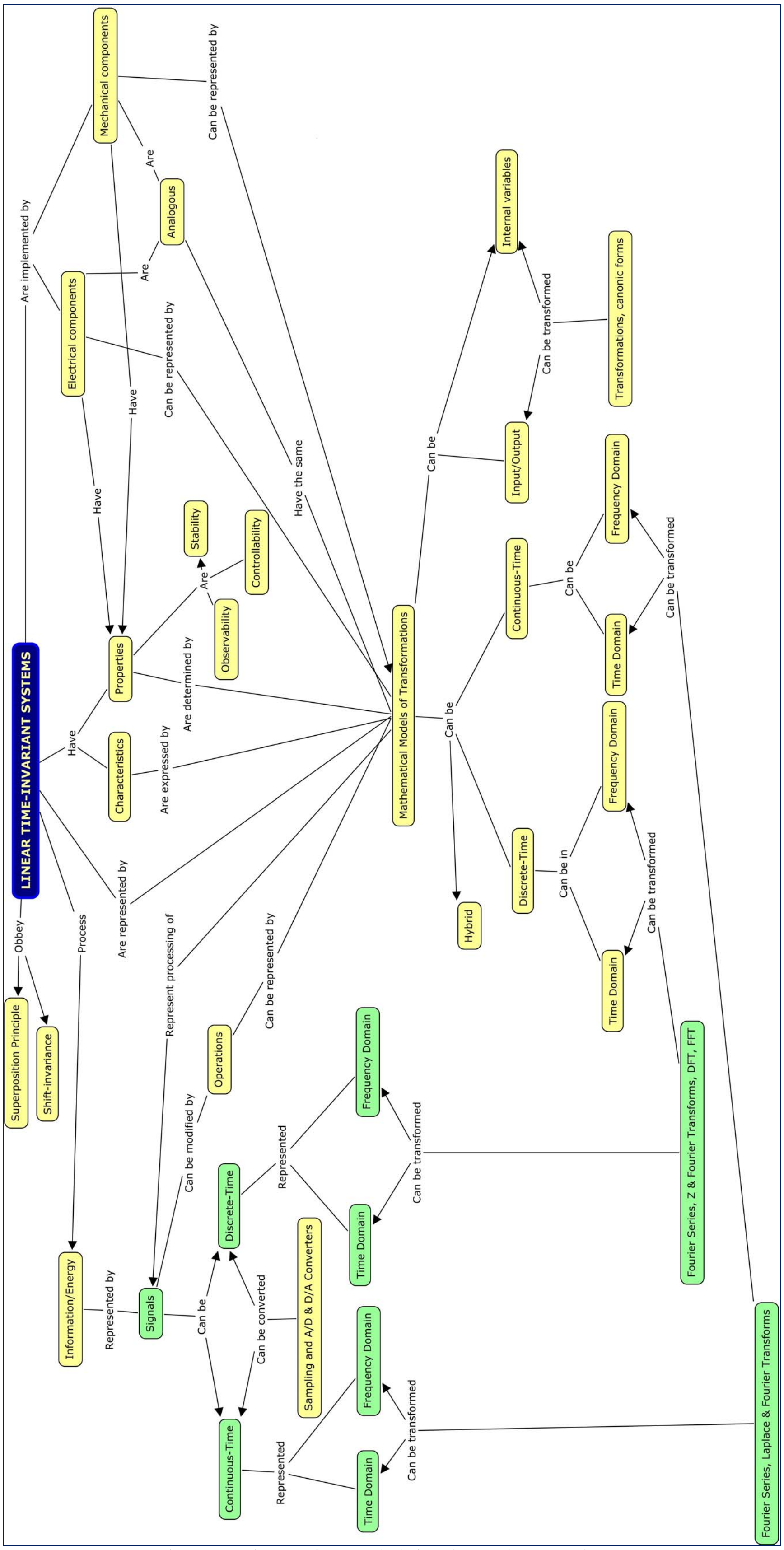


Fig. 4 – Region 2 of CMap (v2) for Linear Time-Invariant Systems – Time Domais / Frequency Domain Transformations