DEPARTAMENTO DE ENGENHARIA ELÉTRICA

Internal Research Reports

ISSN

Number 41 | October 2015

# Concept Maps and Linear Systems: Beyond Learning Objects

Renan Neumann Duriez Mendes

Ana Maria Beltran Pavani

PUC RIO

**Internal Research Reports**

Number 41 | October 2015

# Concept Maps and Linear Systems: Beyond Learning Objects

Renan Neumann Duriez Mendes

Ana Maria Beltran Pavani

**CREDITS**

**Publisher:**
**MAXWELL / LAMBDA/CCPA/VRAc**
**Sistema Maxwell / Laboratório de Automação de Museus, Bibliotecas Digitais e Arquivos**
**http://www.maxwell.vrac.puc-rio.br/**

**Organizers:**
Alexandre Street de Aguiar
Delberis Araújo Lima

**Cover:**
Ana Cristina Costa Ribeiro

# *Concept Maps and Linear Systems*

## *Beyond Learning Objects*

Renan N D Mendes
Departamento de Engenharia Elétrica
Pontifícia Universidade Católica do Rio de Janeiro
Rio de Janeiro, Brazil
renan_neumann@hotmail.com

Ana M B Pavani, *Member IEEE*
Departamento de Engenharia Elétrica
Pontifícia Universidade Católica do Rio de Janeiro
Rio de Janeiro, Brazil
apavani@puc-rio.br

***Abstract*—This work addresses an extension in the use of Concept Maps related to Linear Time-Invariant Systems in some Engineering curricula. The original work concerned the use of Concept Maps to define the granularity of Learning Objects on this discipline. The objective was to develop reusable and shareable Learning Objects. While the work was under development, the potential of Concept Maps to examine curricula containing courses related to Linear Time-Invariant Systems became obvious. Thus the extension to curricula analysis had two goals – identify potential users of the Learning Objects and map redundancies and holes in the curricula. A by-product was an interesting outcome – the mapping of all courseware related to the topics on Linear Time-Invariant Systems available on the Maxwell System, the university Institutional Repository.**

***Keywords*—Concept Maps; learning objects; courseware; linear time-invariant systems; curricula;***

## I. INTRODUCTION

*Curriculum* is a word whose origin is Latin, meaning a running, course or career, as presented in the Online Etymology Dictionary [1].

The Oxford Dictionary [2] defines the word as:

"The subjects comprising a course of study in a school or college".

The Merriam-Webster Dicitionary [3] has two definitions for the word:

1. "The courses offered by an educational institution".
2. "A set of courses constituting an area of specialization".

This last definition, more specific to the focus of the work under consideration, is used in this article.

In 2012, a project started to develop Learning Objects (LO) as a means to enhance the offer of courseware. The objective was to address the problem of poor student performance in some critical courses of some Engineering curricula at PUC-Rio. It followed an effort of supporting traditional face-to-face courses with ICT – Information and Communication Technology tools that had been going on for many years, well over a decade indeed.

The development of Learning Objects is time and resources consuming. One of their important characteristics is reusability, i.e., the ability they may have to aggregate in different ways to yield lessons, units of courses or even courses. They can be considered "grains" and the way they are defined is referred to as granularity. Another analogous definition was introduced by Wiley [4] in his doctoral dissertation. The terms reusable chuncks of instructional media, reusable instructional components, reusable digital resources, reusable learning object (RLO) were used. Being sharable and reusable digital contents are necessary features [5] of LOs due to the efforts devoted to develop them.

Reusability has been focused under different aspects that are complementary. One is related to the proper use of metadata to describe LOs so that they can be searched and found, thus allowing reuse. Lin, Shih and Kim [6] addressed this aspect. Though with different objectives, Sinclair, Joy, Yau and Hagan [7] were concerned with discoverability, reusability and quality of RLO – Reusable Learning Objects. The work, as expected, also discusses metadata description of RLOs. Garrido and Morales [8] studied the improvement of content personalization and this also included reusability of LOs.

A "chunck" can be associated with a "grain" and the sizes of the smallest "chuncks" with the granularity of the LOs. The definition of the size of the LOs is very mportant because it will allow more flexibility in aggregating them to yield lessons, units of courses or courses as mentioned before.

To address the problem of defining the sizes of the LOs, even after some had already been implemented, Pavani [9], [10] used Concept Maps (CMaps).

Once CMaps had been created to describe concepts and hierarchies associated with LTIS, a second use of the CMaps was thought. It was a consequence of analyzing the potential use of LOs in the courses of different Engineering curricula at PUC-Rio, since reuse was a concern. In order to analyze potential reuse, it was necessary to map how the various topics of LTIS spread in different courses that belong to the Engineering curricula.

This work shows partial results in the mapping of the topics.

Section II presents a light overview of CMaps and section III its extension to Knowledge Maps (KMaps). Section IV addresses the scope of this work. The following two sections, V and VI, are devoted to results – results related to curricula and results related to LTIS, respectively. Finally, comments and next steps are in section VII.

## II. CONCEPT MAPS – A BRIEF OVERVIEW

Joseph D. Novak and his team at Cornell University (http://www.cornell.edu/) created Concept Maps (CMaps) in the 1970s. His original work addressed the following and understanding the changes in children's knowledge of science.

In 2006-2008, Novak and Cañas [11] presented CMaps in detail and showed examples of their use.

Novak and Cañas defined CMaps as ways of organizing and representing knowledge using graphical tools. The elements of the CMaps are boxes (or circles) that contain concepts. Concepts are connected to one another by links (lines) associated with words that express the relationships between two concepts; they are called linking phrases or linking words. CMaps are hierarchical structures with the most inclusive (more general) concepts on the top and the most specific (less general) ones in the lower parts of the graph. CMaps allow the existence of cross-links, i.e., links connecting concepts in different domains (segments) of a CMap. A CMap can have large branches – the domains or segments and this has been extensively used in [9], [10].

Novak and Cañas suggested a focus question be asked before creating a CMap. Its objective is to define the goal to be achieved by drawing a CMap; it yields the context of the knowledge in the map. Currently the authors are with the Florida Institute for Human and Machine Cognition (http://www.ihmc.us/). This institution developed and made available a software product called Cmap Tools (http://cmap.ihmc.us/) to draw CMaps in a very easy way. If this tool is not used, drawing a CMap may be a hard work. It is free and allows the CMaps to be customized in terms of color, styles, etc. It also allows URLs and digital objects, including other CMaps, to be attached to a CMap. This characteristic was of paramount importance for this work since resources of various natures had to be linked to the CMaps boxes.

## III. KNOWLEDGE MAPS – AN EXTENSION OF CMAPS

Castles, Lohani and Kachroo [12] used the term Knowledge Map (KMap) as an extension of a CMap. They made the clear distiction as:

"The distinction between a concept map and a knowledge map is made because these maps not only outline the various concepts and relationships involved in the discipline, but also embed the knowledge of the discipline within the map. The goal of embedding knowledge within the map is achieved by linking each node or vortex in the map to content such as power point slides, pdf files, multimedia content, or websites relevant to the topic at hand. The embedding of such content allows one who is not an expert in the field to be able to view the map of an expert and obtain some knowledge of the discipline."

In this article, though the term CMaps is used, the meaning is that of a KMap. The reason to use a KMap in this work is very different from the one in [12] which was the assessment of students and faculty. In this work the KMaps are necessary because one of the objetives is linking LOs and courseware in general to topics in order to have an inventory of contents.

## IV. STATEMENT OF THE SCOPE OF THIS WORK

### *A. Background*

As mentioned before, CMaps started being used to define LOs. The topic was LTIS – Linear Time-Invariant Systems.

This topic was chosen because the courses where the poor student performance worried faculty were Signals & Systems (S&S) and Electric & Electronic Circuits (E&EC) that have most of their syllabi addressing LTIS. At the same time, other courses' syllabi had LTIS too. One is Controls & Servomechanisms (C&S) that is mandatory in two curricula.

One important aspect of S&S and E&EC is that they are mandatory in the curricula of many careers at PUC-Rio. For this reason, the impact of enhancing students performances in these courses is high.

The LOs are still under development. At the moment there are 28 available in Open Access from the Maxwell System. They can be found at http://www.maxwell.vrac.puc-rio.br/series.php?tipBusca=dados&nrseqser=5. Other seven are under development, though four are not derived from the CMap use. Three fulfill the needs of Electrical Measurements – a support topic for many courses, and the fourth was a suggestion of two students, who are implementing it.

### *B. Current Work*

Once LTIS were mapped by CMaps, the idea was to identify LTIS in other syllabi even of courses that are not taught by the Electrical Engineering faculty.

This was the motivation to keep the work going. This study was originally supposed to have two products. The first was to identify other courses that could use the LOs – this would enhance their usability and shareability. The second was to identify redundancies and holes in the topics of LTIS in the set of courses that address them. These two products are related to Engineering curricula.

A by-product of this work was the mapping of all digital contents (on the Maxwell System) related to each topic in LTIS.

Thus an extended set of CMaps, KMaps, were created to model these relations.

The next sections address the results of this work.

## V. RESULTS RELATED TO CURRICULA

Some decisions were necessary and they were made in different steps.

The first step was to choose the careers that would be examined. The choice was to examine: (1) Electrical Engineering; (2) Mechanical Engineering; and (3) Control & Automation Engineering. Computer Engineering was initially considered but discarded afterwards. The reason was that all courses related to LTIS are taught by the Electrical Engineering Faculty and thus included in the EE CMap.

The second step was to divide the large problem into smaller ones. The problems were: (1) examine all courses in the three curricula to identify the ones that include topics related to LTIS; (2) store the digital files containing the syllabi of these courses; (3) identify in each course the LTIS topics.

The third step was to draw the CMaps. The following subsections present the CMaps that were drawn

### A. *The CMap for LTIS*

The first CMap to be drawn was to model LTIS – the first versions of this CMap were used in [9], [10]. Figure 1 (at the end) is the newest version of the LTIS CMap. It was enhanced by adding information on the courses that address each topic (boxes). The objecitve of this version was to identify possible redundancies.

How is it possible to do it? By checking if the courses addressing the same topics belong to the same curriculum and if they present them in the same way – this indicates a potential case of redundancy. Figure 2 (at the end) shows a CMap with courses in the Electrical Engineering curriculum that address LTIS topics; it will be discussed in the next subsection.

The information on the courses that teach each topic can be found by clicking the icons on the corresponding box of the CMap.

Figure 3 (at the end) shows an example. It is a zoomed image of two boxs of figure 1 with the topics – Shift-Invariance and Superposition Principle; they were aggregated by an external box – a feature of Cmap Tools. By clicking its icon it is possible to see that the topics are addressed in four courses. In the case of this example there is no redundancy because: (1) ENG1710 – Mechannical Vibrations is a course in the Mechanical Engineering curriculum; and (2) ENG1400 – Signals & Systems, ENG1403 – Electric & Electronic Circuits and ENG 1417 – Controls & Servomechanisms are courses in both the Electrical Engineering and the Control & Automation curricula, but the first addresses formal definitions and properties, and the other two use them to study circuits and control systems. ENG1400 is the prerequisite of ENG1403 and ENG1417.

It is important to remark that adding icons with information related to blocks is a feature of Cmap Tools. This information can be of various natures – other CMaps, videos, texts (different formats), executable files, images, texts + images, websites, etc.

### B. *Courses Addressing LTIS in Each Curriculum*

A CMap was drawn for each – Electrical Engineering, Mechanical Engineering and Control & Automation Engineering curricula. Each CMap contains the courses with LTIS topics and the hierarchical relations of prerequisites they have.

Figure 2 shows the CMap for the Electrical Engineering curriculum. This curriculum was chosen as an example because it has the most numbers of courses and hierarchical levels addressing LTIS.

At a first glance, it is clear that the CMap shows the hierarchical relation in figure 4

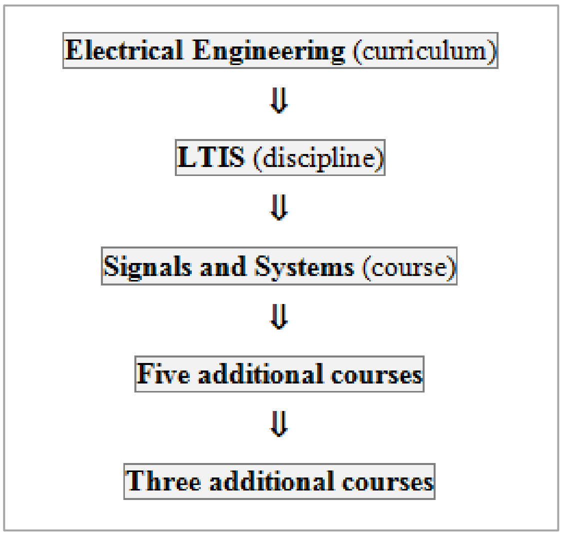


Figure 4 – Hierarchical relation for LTIS in the Electrical Engineering curriculum

One of the courses in the level immediately lower than Signals & Systems is Electric & Electronic Circuits that is the prerequisite to five courses in two hierarchical levels in the Electrical Engineering curriculum (with emphasis in Electronics) and three courses in two hierarchical levels in the Computer Engineering curriculum. This yields the understanding of the importance of LTIS in the Electrical Engineering curriculum – there is a long “chain” of prerequisites. This “chain” is also present in the Computer and the Control & Automation curricula. It impacts many students.

Figure 2 will be discussed later in this work when icons in the different boxes are interpreted – this is the by-product that was mentioned before.

### C. *Current Status of the Analysis*

The interpretation of the results of CMaps of the three curricula are under way. The one related to Electrical Engineering is almost finished. The analysis related to the other curricula must be performed. After the three are individually finished, they will have to be viewed together since at a first glance there seems to exist redundancies among courses in different curricula.

## VI. Results Related to Topics of LTIS

When curricula started being mapped to identify LTIS topics in the courses, the definition of the granularity for Learning Objects was still going on. Learning Objects have been under development since August 2012 and this activity will keep going in the next years.

Cmap Tools is a powerful software product. Among its many features there is one that allows links connecting to resources to be associated to boxes; boxes contain ideas. In the case of the use of CMaps to LTIS, boxes contain topics in the area/discipline.

The links can be associated to different types of information. Figure 3 shows an example of the use of links on the LTIS CMap. On this CMap – the links connect to online resources; they are the syllabi that are available (Open Access) from PUC-Rio's website (http://www.puc-rio.br/). When a link to a resource is added to a box, there is an option of classifying it and this will define the icon to appear on the box. The icon indicates the group to which the resource belongs – there are 14 groups. Some examples of groups are audio, CMap, web address and executable. In the case of figure 3, all resources were web addresses linking to the syllabi.

The possibility of adding resources to CMaps yielded an enhancement to the study of LTIS and LOs. The initial idea was to use CMaps to guide the granularity and the development of LOs. The extension focused on understanding how LOs could be used in different courses.

At the same time, there were two other variables to be considered – the use of blended learning that has been going on for one school year and the fact that PUC-Rio has an Institutional Repository with a large quantity of courseware besides LOs. These two variables are addressed in subsections A and B of this section. Section C presents the results of combining all of them.

### A. *The Institutional Repository – the Maxwell System*

Lynch [13] created the expression Institutional Repository (IR) in 2003 after DSpace was made available in 2002. His definition for an IR is:

"A university-based institutional repository is a set of services that a university offers to the members of its community for the management and dissemination of digital materials created by the institutions and its community members. It is most essentially an organizational commitment to the stewardship of these digital materials, including long-term preservation where appropriate, as well as organization and access or distribution."

This definition implies that not only articles or books can be hosted on an IR, but digital materials in general. It also means that managing and preserving are also part of the services to be provided.

The Maxwell System was created in 1995 as a digital library of courseware. In the almost 20 years it has been in operation, it has added many functionalities and different types of digital contents. It has a LMS – Learning Mangement System module and is compliant to PUC-Rio's administrative data model. Since it has hosted courseware from the very beginning and has widened the scope to all types of digital materials created at PUC-Rio, it offers many items to be used for ICT supported learning through the LMS.

Currently there are over 18 K titles. The main topics that can be classified as courseware are: (1) exercises – almost 900; (2) LOs – over 150; (3) online course modules – over 100; and (4) class notes – over 20. These numbers refer to courseware in general, not only in Electrical Engineering. The Maxwell System serves the whole university.

### B. *Blended Learning*

In the first semester of the school year 2014, two courses switched to the blended learning mode – Signals & Systems and Electric & Electronic Circuits. In the second semester, Control & Servomechanisms switched too. In 2015, three additional courses will use the blended learning mode. So at end of 2015, six courses will be taught in this mode.

This has increased the number of online items and this trend will be maintained.

### C. *The Institutional Repository, Blended Learning and CMaps*

The use of an IR to manage courseware and the introduction of blended learning for three courses that are "heavy users" of LITS became a motivation to extend the use of CMaps to map all courseware suitable for the different topics of this discipline. CMaps allow links to resources, as mentioned in the beginning of this section.

Thus, a by-product of the initial work was possible – to create CMaps with links to resources available for the LTIS courses in the different curricula.

Revisiting figure 2, icons can be seen on the course boxes. There are icons on the curriculum box (top box) as well as on the LTIS box (second level) too. The types of resources represented by the icons are:

- Texts

Some texts are the Electrical Engineering curriculum in text format that can be downloaded; a text with some considerations on LTIS in the curriculum; class notes; sets of assignments (problems); sets of problems for the students to practice; guides to laboratory experiments.

- Text and images

This group was used for the blended learning courses outlines. They are html files that contain the most important definitions and topics, a set of suggested activities for students to practice, links to LOs, class notes, outside resources, videos on the topics specially developed for the courses, images, etc. The students are to follow the outlines to study. The outline gives the overall vision of the course even when they study details.

- CMap

The second box of figure 2 is LTIS, the discipline under consideration. This box has an icon that links to the LTIS CMap, shown in figure 1.

- Web addresses

Web addresses were added to link to the curriculum and the courses syllabi on the university's website.

- Executables

Executables are links to web resources too. But they link to LOs and to the Interactive Books in Electrical Engineering. These two sets of resources are hosted by the Maxwell System and this assures that the links are not and will not br broken.

It was an option not to use external links though there are plenty of excellent resources available from universities worldwide. This was just to make sure the links are not broken. This is a problem that will be solved when DOI – Digital Object Identifiers are used for all digital contents that are in Open Access.

- Videos

A set of videos was developed for the Electric & Electronic Circuits course. They present classes covering all the topics on the syllabus. The icon is used only on the box corresponding to this course. These videos are not embedded in an outline, they can be viewed individually and are in Open Access.

- Unkown

This group was used not because the formats are unknown but because the resource contains both text and executables for MATLAB® (.m). The author developed a text with overviews of the topics in the Signals & System syllabus, a set of problems to be solved and eight executables for the students to use to solve the problems. The is no icon for this combination and this is the reason "unknown" was used.

Figure 5 shows a zoomed view of the Signals & System box of figure 2. I indicates that there are five different groups of resources available for this course. The numbers of resources in each group vary from one to more than 20.

The CMap in figure 2 is a KMap according to Castles, Lohani and Kachroo [12].

The KMap is a very useful tool to guide the devopment of courseware for the blended learning mode. Each course contains links to resources such as its syllabus and all types of digital contents that available on the Maxwell System for student use, even the ones that are not in Open Access.

A challenge to the use of KMaps to manage courseware for all courses in a curriculum is the continuous need to update the KMaps. This happens because new courseware is constantly under development.

## VII. Comments and Next Steps

This work presented the results of using the potential CMaps have to manage and guide courseware development. It is an extension of the previous works [9], [10] that addressed LOs. As mentioned before, there is a need of continuous updating of the CMaps/KMaps to keep up with the new courseware that is made available all the time.

It also created a tool to identify redundancies and holes in curricula. In the case under consideration, redundancies are expected when courses in different curricula are compared. Holes will be found when courses in the same curriculum are examined.

A preliminary examination of the Mechanical Engineering curriculum indicated that Fourier Series and Fourier Transforms are not present – this is an example of a hole. An example of a redundancy is seen in the curriculum of Control and Automation Engineering – state space techniques are addressed in a course taught by the Mechanical Engineering faculty and in another taught by the Electrical Engineering faculty; both are mandatory. When a more accurate analysis is performed, new redundancies and hole will probably be identified.

At the moment only LTIS are under consideration, but there seems to be no limitation to apply this tool to other disciplines in curricula.

When the KMaps were created for the three curricula, it was possible to understand the reason why in [9], [10] it was mentioned that LOs had been developed before CMaps started being used were due to needs of faculty. These LOs were not on general topics of LTIS, but on particular LTIS. This would happen anyhow because syllabi address topics that are specific for each course. An example to illustrate this comment is a set of two LOs – Thévènin Equivalent Circuit and Norton Equivalent Circuit. They are applied to LTI circuits but they are specific of the Electric & Electronic Circuits course. These two topics are not general to LTIS, but apply to specific LTI electric circuits.

The next steps will be devoted to analyze redundancies and holes in detail. CMaps will keep being used to guide the development of courseware in general and LOs in particular.


## Aknowledgement

This work was developed under a PIBIC – Programa Institucional de Bolsas de Iniciação Científica grant awarded to Mr. R N D Mendes who is an undegraduate student of Electrical Engineering at PUC-Rio.

PIBIC is a program of CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil.


## References


[1] Online Etymology Dictionary. Available http://www.etymonline.com/index.php?term=curriculum.

[2] The Oxford Dictionary. Available http://www.etymonline.com/index.php?term=curriculum.

[3] The Merriam-Webster Dictionary. Available http://www.merriam-webster.com/dictionary/curriculum.

[4] D. A. Wiley, II, *Learning Object Design and Sequencing Theory*, PhD Dissertation presented at Brigham Young University, United States, 2000. Available http://opencontent.org/docs/dissertation.pdf.

[5] M. Alsubaie, "Reusable Objects: Learning Object Creation Lifecycle", Proceedings of the Second International Conference on Development of eSystems Engineering", Abu Dhabi, December 2009, pp.301-305, http://dx.doi.org/10.1109/DeSE.2009.63.

[6] F. H. Lin, T. K. Shih and W. Kim, "An Implementation of the CORDRA Architecture Enhanced for Systematic Reuse of Learning Objects", IEEE Transactions on Knowledge and Data Engineering, Vol. 21, No. 6, June 2009, pp. 925-937, http://dx.doi.org/10.1109/TKDE.2008.130.

[7] J. Sinclair, M. Joy, J. Y.-K. Yau and S. hagan, "A Practice-Oriented Review of Learnng Objects", IEEE Transactions on Learning Technologies, Vol. 6. No. 2, April-June 2013, pp.177-192, http://dx.doi.org/10.1109/TLT.2013.6.

[8] A. Garrido and L. Morales, "E-Learning and Intelligent Planning: Improving Content Personalization", IEEE Revista Iberoamericana de Tecnologías del Aprendizage, Vol. 9, No.1, February 2014, pp. 1-7, http://dx.doi.org/10.1109/RITA.2014.2301886.

[9] A. M. B. Pavani, "Concept Maps and Learning Objects – Part 1", Proceedings of the ICEED 2012 – International Congress on Engineering Education, Malaysia, December 2012, pp 105-110, Available http://dx.doi.org/10.1109/ICEED.2012.6779279.

[10] A. M. B. Pavani, "Concept Maps and Learning Objects – Part 2", Proceedings of the CISPEE 2013 – 1st International Conference of the

Portuguese Society for Engineering Education, Portugal, October 2013, pp 1-8, Available http://dx.doi.org/10.1109/CISPEE.2013.6701980.

[11] J. D. Novak and A. J. Cañas, *The Theory Underlying Concept Maps and How to Construct and Use Them*, Technical Report IHMC Cmap Tools 2006-1 Rev 01-2008, Florida Institute for Human and Machine Cognition, United States, 2008. Available http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf.

[12] R. Castles, V. K. Lohani and P. Kachroo, "Knowledge Maps and Their Application to Student and Faculty Assessment", Proceedings of the $38^{th}$ ASEE/IEEE Frontiers in Education Conference, United States, October 2008, pp. S4A-9-15. Available http://dx.doi.org/10.1109/FIE.2008.4720666.

[13] C. Lynch, "Institutional Repositories: essential infrastructure for scholarship in the digital age", ARL Bimonthly Report, 226, 2003, available from http://www.arl.org/resources/pubs/br/br226/.

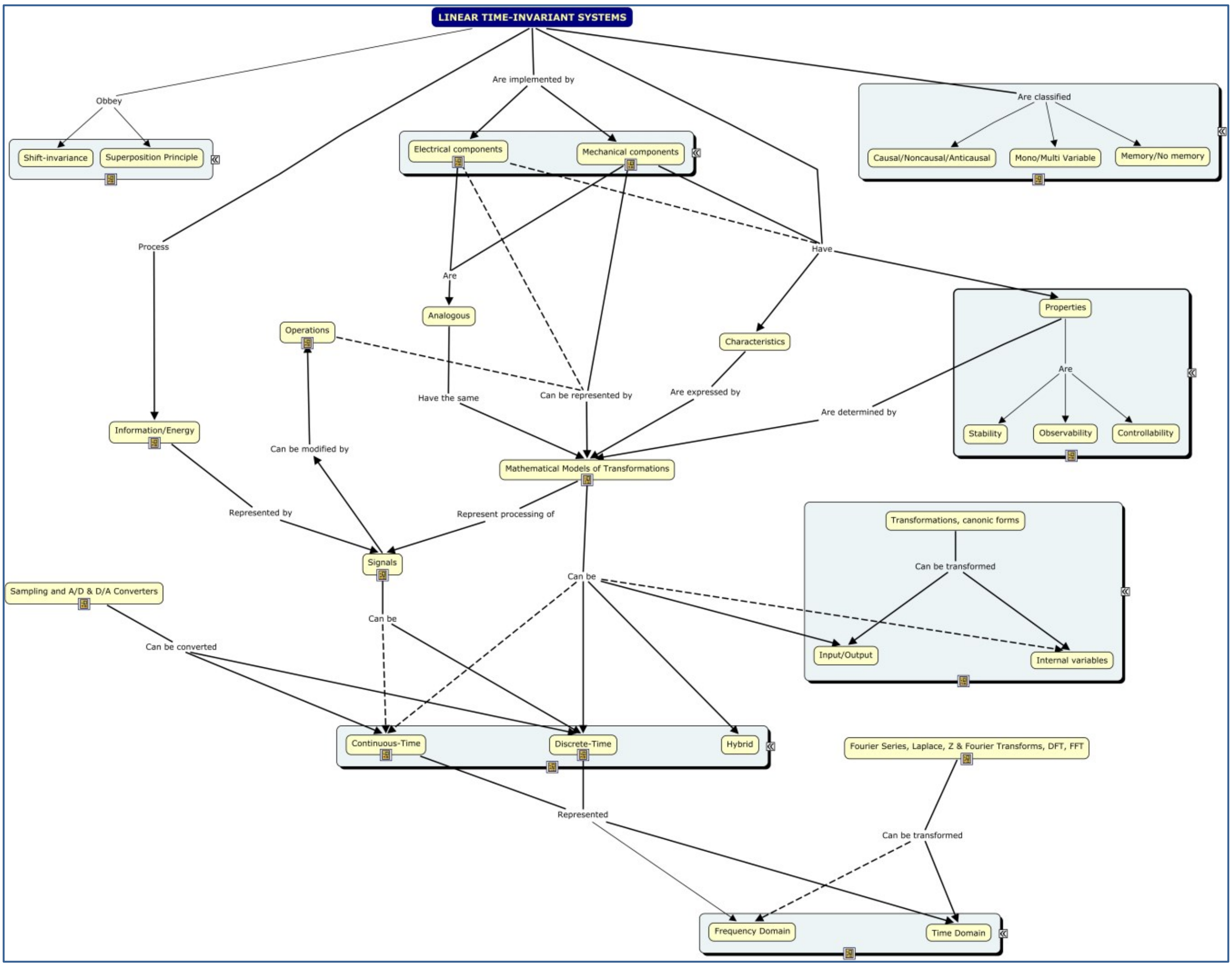


Figure 1 – CMap for LITS with info on courses that address each topic.

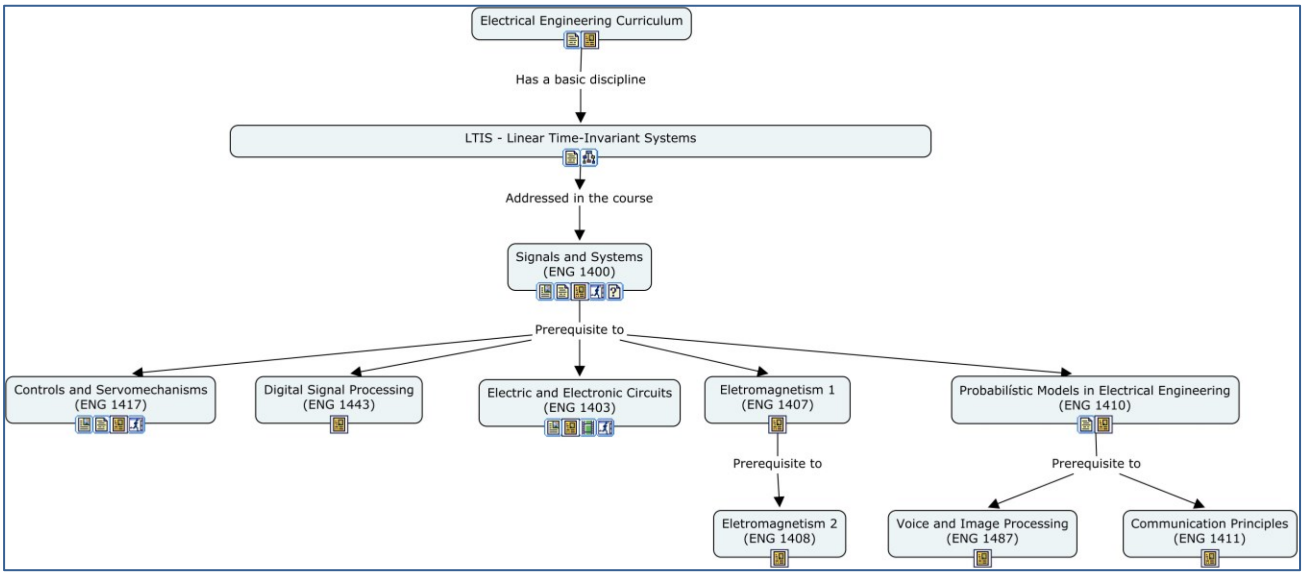


Figure 2 – CMap for the Electrical Engineering curriculum

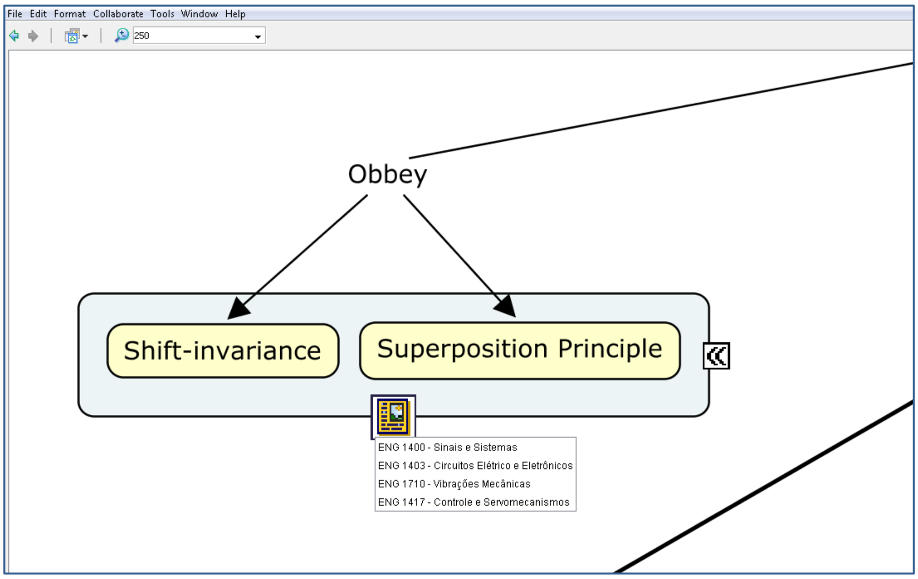


Figure 3 – Zoom of a segment of the CMap in figure 1 showing that four courses address Linearity and Shift-Invariance.

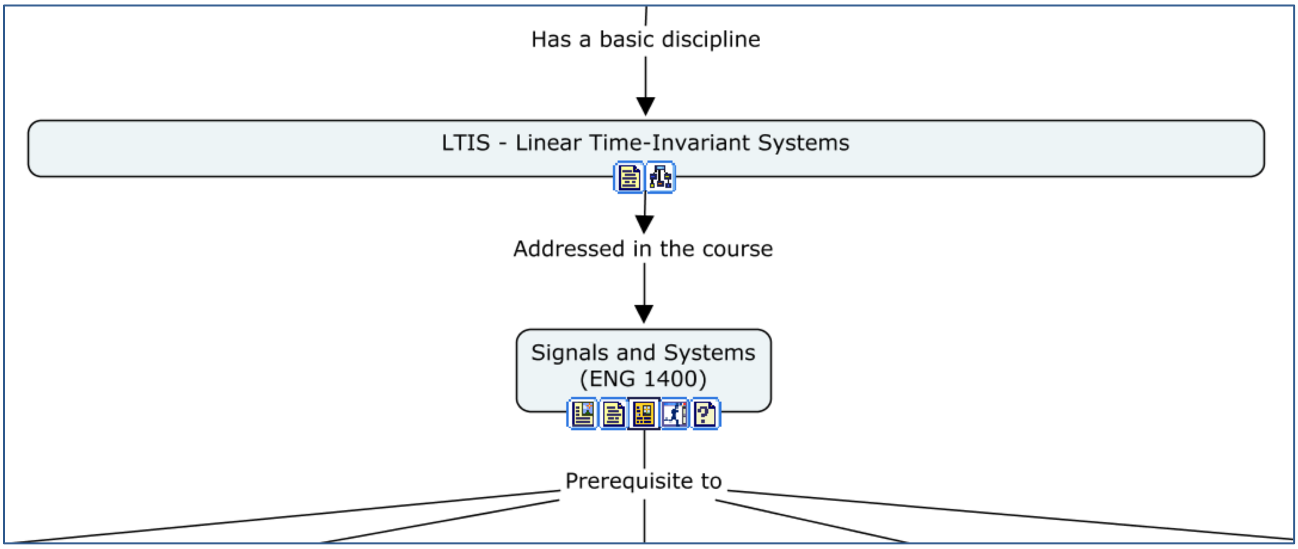


Figure 5 – Zoom of a segment of the CMap in figure 2 showing that the Signals & Systems course has five different groups of resources.