Collaborative Concept Mapping at an Interactive Tabletop

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This thesis is submitted in partial fulfillment of the requirements for the degree of Bachelor of Computer Science and Technology (Honours)

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1 November 2010
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Abstract

Concept mapping is a proven educational technique, developed in the 1970’s by Joseph D Novak [Novak 1998]. It involves the process of defining ideas (concepts) and linking phrases (propositions) to represent an individual’s knowledge of a particular topic.

Concept mapping exists primarily as a paper-based task, with some PC equivalents such as CMap-Tools (Cañas et al. 2004) and VCM (Cimolino and Kay 2002). While these effectively support the process of continuous revision that Novak emphasises is so important, they are not perfect and there is still much room for innovation.

PC-based concept mapping is, by nature of the hardware, only capable of handling input from a single user at a time. While this is sufficient for single user tasks, in collaborative ones this presents a significant drawback.

Interactive tabletops are an emerging technology in the field of natural user interfaces. Their horizontal orientation along with their touch based interaction naturally encourages collaboration while their multi-touch technology allows for simultaneous interaction from multiple users. Here lies an opportunity to enhance existing tasks, such as concept mapping, by introducing co-located collaboration in an exercise that was traditionally performed individually.

In working together toward a common goal, individuals have an opportunity to learn from each other. Tabletop technology invites this type of activity and hopefully provides a more engaging experience.

This thesis presents the design, and implementation, of a collaborative concept mapping application (TouchMapper) for the multitouch interactive tabletop and compares it to its PC based equivalent, CMapTools.
Acknowledgements

I would like to first thank my supervisor, Professor Judy Kay, for her invaluable motivation, insight, guidance, patience and dedication throughout this project.

Additionally, to all the people with whom I had impromptu discussions about interface designs and challenges, particularly Roberto Martinez, thank you.

Significant thanks goes to the headmaster and staff of St Pius X College, Chatswood for helping me plan and successfully execute my usability testing with the year 6 students, who were incredibly enthusiastic and provided valuable feedback for this study.

Finally, thank you to everyone who tested my various prototypes and identified all the bugs that I had no idea existed, in particular my parents and brother.
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Chapter 1

Introduction

This thesis explores the adaptation of the educational technique of concept mapping from a primarily paper or computer based task, to one performed at an interactive tabletop. Additionally, it will adapt concept mapping from being an individual activity, to a collaborative one. We will present a novel approach to address challenges imposed by tabletop displays and simultaneous multi-user multitouch interaction, and present an evaluation of this approach to measure its effectiveness.

1.1 Definitions

**Concept Map** a diagram showing the relationships between related ideas or objects (concepts). A graphical tool for organising and representing knowledge of a particular domain.

**Interactive Tabletop** a touch screen of some type, horizontally oriented, embedded in a table shaped enclosure. An example of surface computing.

**Single Display Groupware** describes devices where multiple users simultaneously and collaboratively interact with a single display.

**Surface Computing** is a research area focusing on computer human interaction facilitated by an interactive surface.
1.2 Motivation

Interactive tabletops show great potential for supporting collaboration with digital information, as multiple people can sit face-to-face and interact with a shared workspace simultaneously. Tabletop hardware is appearing quickly (e.g. the Microsoft Surface), but software that effectively leverages its potential is slower to emerge.

This research is focused on taking the educational technique of concept mapping, as proposed by Joseph Novak [Novak 1998], and applying it to a multitouch tabletop context. The aim is to promote collaborative learning, in a task which would traditionally be performed individually. Multitouch technologies shall be leveraged to facilitate intuitive interaction which may occur simultaneously between any number of co-located users.

![Figure 1.1: Traditional concept map example](image)
1.3 Context

Concept mapping is a task that aims to represent a participant’s knowledge of a topic as a series of words (concepts) and connecting phrases generally positioned in a hierarchical layout, though not necessarily. Traditionally, it has been a task performed individually, and on paper, in recent times this activity has been moved to the desktop PC, allowing for continuous and immediate revision.

Simultaneous and co-located collaborative concept mapping, however, has not been attempted in any known research to date. Given that desktop PC’s were only designed for interaction by a single user at a time, we cannot assume that this hardware, or associated interface paradigms will be adequate for multi-user collaboration at an interactive tabletop (where there is typically no keyboard or mouse present). This study is particularly significant as it is the first known study of collaborative concept mapping at an interactive tabletop.

Tabletop hardware is an area of constant development and there are a number of manufacturers in the market. While the products they sell all achieve the same purpose, their methods vary greatly. Some use vision-based touch recognition, others use capacitative touch and in our case, an infrared based overlay. The most well-known tabletop is probably the Microsoft Surface, followed closely by the DiamondTouch, SMART Table and then various generic and homebrew setups. Each implementation has its own strengths and weaknesses, for example capacitative screens will only detect fingers and not other objects. Infrared based systems generally provide highly accurate touches with low latency, though usually have a limit on number of touches. Vision based systems provide the largest number of simultaneous touches, though tend to falsely register somewhat frequently and require significant calibration.

1.4 Challenges

Though concept mapping has already been achieved digitally with CMapTools, there is little that can actually be reused in terms of interface design. Surface computers represent a completely different interaction paradigm compared to the traditional WIMP (Window, Icon, Menu, Pointing device) approach and as such, the same guidelines cannot be applied to this new context.

Design challenges related to this project include:
1.4. Challenges

Chapter 1. Introduction

Easily learned and intuitive gestures

Choosing gestures and their mappings is an important part of the design process in tabletop applications since this is the primary means of interaction. For this reason, it is important to choose gestures and mappings which either seem natural to the user, or are easily learned. This will vary from user to user and so requires significant thought and user testing.

Accurate touch gesture detection

When developing touch based systems, one must consider how to model the various gestures programmatically. It is important that gestures be clearly defined and as dissimilar as possible in the interest of correct detection (since heuristics are involved), otherwise users become quickly frustrated. An additional concern in regards to gesture detection is the accuracy and ‘quirks’ of particular hardware such as inconsistent and false touches in vision based systems.

Text orientation

Text orientation presents a significant challenge in tabletop interfaces since unlike traditional vertically oriented displays, users are not all positioned in a single (general) direction. On a tabletop, users may be interacting from almost any possible angle often with two users facing each other, this clearly presents a problem as text is generally unreadable upside-down. As such, much thought must be put into interface design to provide appropriate orientation of text in as many scenarios as possible.

Concept map orientation

In addition to text orientation, concept map orientation is also an issue. It is important that all participants in a collaborative concept mapping exercise are able to view the map as a whole to keep their actions in context. This is obviously a significant challenge with shared workspaces due to the aforementioned text orientation issues.

Text input

Text input is a problem that was solved long ago for the desktop PC, however, in tabletop design it is still a significant challenge. Tabletop hardware does not usually include any input device other than the touch screen and as such, text entry is usually by means of an onscreen virtual keyboard. This is far
from optimal as it provides little to no tactile response to the user and as a result text input is usually very slow.

An alternative is to use multiple wireless keyboards and provide space around the touch screen to rest them on, though this requires operating system and software support for multiple keyboards which is not necessarily feasible.

**Simultaneous input**

Mouse interaction is relatively predictable, it is constrained to a single point within a two-dimensional plane and it always has an onscreen position. It has fixed states of up and down, where an ‘up’ must always follow a ‘down’ and to get from point A to point B, it must pass through the area in between.

Multitouch, however, presents a very different form of input. While still constrained to a two-dimensional plane, touches appear and disappear at will, the number of touches at any time could be one, or one hundred. Though it has the same states of up and down, due to quirks in hardware, a “TOUCH_UP” event doesn’t necessarily fire after a corresponding “TOUCH_DOWN” (e.g. placing a whole hand on the table and then spreading out the fingers to individual points). Additionally, new touches have no inherent history associated with them unlike a mouse which must follow a trajectory to arrive at a location.

For these reasons, multitouch design requires much deeper analysis of the input gestures to arrive at a result that will work well (usually based on detection heuristics and visual feedback to the user). Additionally, existing interaction primitives which exploit a sense of global state (such as a colour picker in a paint program) are no longer appropriate in a shared space such as a tabletop since there is no way to track that finger once it has left the table. For example, in between moving from the colour picker and then over to the desired area, another user will likely touch elsewhere unaware of the colour change.

**Individual identification within a group**

One feature which would solve many of the issues of shared workspaces, is identification of individual users. Where one can match touch points to individuals, then one can make assumptions about desired actions. Examples such as the multi-user paint program mentioned above could be implemented to simply change the colour for touches originating from that individual, therefore preventing any disruption to other users.
Linking of touch points to individuals is actually possible today through the use of technology present in MERL’s (Mitsubishi Electric Research Laboratories) DiamondTouch hardware, though since most available hardware does not support this functionality it will not be considered in our design.

**Appropriate configuration/calibration**

Natural user interfaces, such as table tops, aim to be intuitive to new users with only minimal explanation. Unfortunately, the implementation of ‘intuitive’ is highly subjective and varies between individuals. What is obvious to a child, may seem completely illogical to an adult. As a result, it is important to do user testing throughout the design and development process and attempt to reach an effective compromise in which the majority of your user base is accounted for.

Specific instances requiring careful calibration include delays, timeouts and sensitivity. While one individual’s ‘hold’ gesture may be perfectly still, another may have a shaky hand and require a small threshold of reasonable movement. Timeouts are often required to prevent clutter in tabletops, however, what one person considers to be adequate time for a task is not enough time for another person. For this reason it should be obvious how to prevent timeouts from kicking in (by say, leaving a finger held down over the element) and how to remove elements prematurely (e.g. cancelling out of a selection list).

**Tabletop clutter**

Though tabletop displays are usually large compared to desktop monitors, considering other requirements such as large text and large touch points, they still become cluttered very quickly. As a result, tradeoffs must be made against usability to prevent clutter, for example having timeouts on menus and making objects as small as is reasonably possible.

**Large concept maps**

Regarding concept mapping, it would seem valuable to be able to navigate large maps potentially of infinite size. This, however, is not a requirement of the project as concept maps are generally kept relatively small to prevent large cognitive demands on the users.
## 1.5 Thesis Goals

The primary goal of this thesis is to explore ways of moving concept mapping from an individual to a co-located, collaborative task. This consists of:

1. Creating an application that supports and encourages collaboration
2. Bringing a predominantly paper-based task to the interactive tabletop
3. Exploring and implementing alternative methods of display and construction of concept maps and optionally:
4. Designing a method for verification of concept maps against expert ones
5. Providing feedback both to students and to teachers regarding concept mapping performance
6. Providing an intuitive interface that requires minimal instruction to learn
7. Providing compatibility with existing software for desktop concept mapping

### 1.6 Contributions

This thesis presents a novel approach to collaborative concept map construction at the tabletop, the specific contributions include:

- A detailed analysis of existing research in areas of concept mapping, tabletop interaction,
- Exploration of multiple approaches to designing the interface, based on prototyping and heuristic evaluation.
- Design and implementation of a novel tabletop user interface that supports collaborative concept mapping through simultaneous interaction by multiple group members.
- A detailed qualitative evaluation that compares the implemented collaborative concept mapper with an existing solution for concept mapping.
- A detailed analysis of evaluation results to determine the effectiveness of the designed application at promoting collaboration.
1.7 Thesis Structure

Chapter 1 provides an introduction to the topic of this thesis. It describes the motivation, context, goals and challenges of this research.

Chapter 2 discusses a broad range of existing work relevant to this project. It intends to provide a background to this thesis’s topic, justifying its contribution and providing a foundation to build upon.

Chapter 3 covers the design process associated with this research. It includes prototype designs and associated evaluations along with the final design for the TouchMapper application.

Chapter 4 describes the implementation details of the TouchMapper system from both a high-level overview and from a technical implementation standpoint.

Chapter 5 outlines the design and experimental procedure of a qualitative user evaluation used to assess the approach taken in this research. The chapter begins by defining the evaluation goals, and provides a full explanation of the experiment design and procedure.

Chapter 6 presents the results obtained during the evaluation, followed by a detailed analysis. The results are reported based on observations and feedback obtained from participants. An analysis is presented to address each of the original evaluation goals.

Chapter 7 outlines potential areas for future work, both in academic research and in real-world implementation.

Chapter 8 expresses the final conclusions drawn from this study and responds to the original thesis goals.
Chapter 2

Background

This thesis explores a new way to conduct collaborative concept mapping tasks, on an interactive tabletop. This chapter provides an overview of the previous work on concept mapping, collaboration and tabletop design in the context of this study.

2.1 Tabletop Design

Interaction

Concept Map Visualisation

Visualization techniques for circular tabletop interfaces (Vernier, Lesh, and Shen, 2002)
- specifically the PDH
- uses a radial hierarchy
- elements expand when selected to form a branching structure
- comparable to a hyperbolic tree
- Hierarchical visualisation, interacting with a tree (click, lasso, drag-drop, contextual menu)

Gestural Interaction

A gestural interaction design model for multi-touch displays (Lao, Heng, Zhang, Ling, and Wang, 2009)
- Explores mapping of motivations to actions.
- Many to many associations between gestures and motivation.
- Different people represent the same motivation differently.
Different contexts invite different mappings.

*Multi-Finger and Whole Hand Gestural Interaction Techniques for Multi-User Tabletop Displays* (Wu and Balakrishnan, 2003)
- take advantage of this increased input bandwidth provided by whole-hand gestures
- both multi-finger and whole hand
- explore gestural input, interaction and visualisation
- RoomPlanner
- content sensitive pies

*System Guidelines for Co-located, Collaborative Work on a Tabletop Display* (Scott, Grant, and Mandryk, 2003)
- attempts to define guidelines, though highly biased toward their experience
- e.g. (5) the use of physical objects

**Input Types**

*Putting the Physical into the Digital: Issues in Designing Hybrid Interactive Surfaces* (Kirk, Sellen, Taylor, Villar, and Izadi, 2009)
- Explores the modelling of real-world interaction
- Use of tangible objects vs simulated.
- Many drawbacks observed with use of tangibles.
- ReacTable able to recognise fiducials

*Bringing Tabletop Technologies to Kindergarten Children* (Marco, Cerezo, Baldassarri, Mazzone, and Read, 2009)
- details differences of developing an interface for young children
- manipulative learning

*Children Designing Together on a Multi-Touch Tabletop: An Analysis of Spatial Orientation and User Interactions* (Rick, Harris, Marshall, Fleck, Yuill, and Rogers, 2009)
- generally interacted directly in front of them
- multitouch increased touch events by 50% (despite there being 3 participants)
Tabletop Collaboration

The cueTable: Cooperative and Competitive Multi-Touch Interaction on a Tabletop (Gross, Fetter, and Liebsch, 2008)
- explores a combination of coop and competitive interaction

Equal Opportunities: Do Shareable Interfaces Promote More Group Participation Than Single User Displays? (?)
- mouse tends to stay with one person throughout the activity
- the physical±digital condition, that is, the one designed with the most tangible and accessible entry points, invited the most equitable participation in terms of verbal contributions.
- tabletop shown to have most equitable participation
- those who spoke least were found to interact the most
Beyond logging of fingertip actions
- explores data mining approaches to tabletop data

Tabletop Collaborative Learning

Tabletop displays for small group study: affordances of paper and digital materials (Piper and Hollan, 2009)
- Direct simulation of paper based method in a digital context
- Participants were seen to appreciate the ability to easily change their choices.
- Participants also elected to repeat the exercise once completed due to the ease of resetting the work area

Learning at the Tabletop

Learning Through Reflection at the Tabletop: A Case Study with Digital Mysteries (Kharrufa, Olivier, and Leat, 2010)
- tabletop promotes reflection rather than serial action

Multi-touch Display Technology and Collaborative Learning Tasks (Butler, McGivern, Artmann, and Morgan, 2010)
- breaks up tasks and assigns tasks
- makes use of personal spaces, with no common work area
2.2 Concept Mapping

Theoretical Basis


Discusses the psychology of learning and the importance of effective learners.

Presents concept mapping as an effective tool in the formation of meaningful understanding as opposed to rote knowledge.

Learning from Texts


- Analysed the relations between cognitive processes during concept mapping
- Two types of ineffective learners were identified: ‘non-labelling mappers’ and ‘non-planning mappers’
- Effective learners, showed much effort in planning their mapping process and constructing a coherent concept map.
- Suggestions for a direct training approach and an indirect training approach were developed


- Examined the influence of concept mapping on learning from texts

An Investigation of Student Thinking from Concept Mapping of Reading Material (Oliver 2007)

Concept Mapping Tools


- Discusses the technique and implementation of verified concept mapping.
- A tool was developed both for expert task creation and student assessment and learning.
Chapter 2. Background 2.2. Concept Mapping

- the verification process involves the user confirming their map as an accurate representation of their understanding of the domain.

- identifies misconceptions and provides detailed feedback to the teacher.

CmapTools A knowledge modeling and sharing environment (Cañas, Hill, Carff, Suri, Lott, Eskridge, Gómez, Arroyo, and Carvajal 2004)

Collaborative Concept Mapping

Learning with collaborative concept maps A Meta-Analysis (Adesope and Nesbit 2009)

A Review of Studies on Collaborative Concept Mapping What Have We Learned About the Technique and What Is Next (Gao, Shen, Losh, and Turner 2007)

A Qualitative Review of Research on Learning with Collaborative Concept Maps (Adesope 2008)

From theory to practice the foundations for training students to make collaborative concept maps

The Comparative Effect of Individually-generated vs. Collaboratively-generated Concept maps on Science Concept Learning (Kwon and Cifuentes 2005)

Computer Supported Concept Mapping

Individual versus collaborative computer-supported concept mapping A study with adult learners (Coutinho 2009)

Comparing Hand Drawn and Computer Generated Concept Mapping (Royer and Royer 2004)

Collaborative Concept Mapping Processes Mediated by Computer (Chiu, Wu, and Huang 2000)

Layout adjustment and the mental map (Misue, Eades, Lai, and Sugiyama 1995)

Preserving the mental map in interactive graph interfaces (Freire and Rodríguez 2006)

A Comparison of User-Generated and Automatic Graph Layouts (Dwyer, Lee, Fisher, Quinn, Isenberg, Robertson, North, and Inkpen 2009)

A Focus+Context Technique Based on Hyperbolic Geometry for Visualizing Large Hierarchies (Lamping, Rao, and Pirolli 1995)

Some algorithms for graph drawing Algorithms for drawing graphs an annotated bibliography A simple algorithm for drawing large graphs on small screens Accelerated force computation for physics-based information visualization

2.2. Concept Mapping

on an expressive collaborative learning task. (pp. 149-158). British Computer Society. (Adesope and Nesbit 2009)

- No significant advantage was observed in the testing conducted.
- Possibly due to limitations of physical objects involved.
- Supports case for fully digital interface.
Chapter 3

Interface Design

This chapter describes the prototyping approach taken to design TouchMapper’s user interface. While concept mapping has been effectively implemented on desktop computers, to our knowledge it had not yet been attempted on interactive tabletop. This new context is challenging since there are little to no existing design paradigms for this type of software.

During the research stage, it was apparent that tabletop application design is full of tradeoffs. While it may seem simple to design a tabletop concept mapper in theory, in practice there are so many competing priorities that it seems impossible to satisfy them all. It was decided that rather than working towards a perfect solution, it would be more productive to build prototypes of the best ideas and then compare and refine these designs.

After much research and discussion, two ideas proved most practical, one top-down and another circular. Since these designs varied significantly, and the decision of software development framework had not yet been made, it was decided to use this opportunity to evaluate not only the design but the implementation approach.
3.1 Circular Prototype

The circular design is shown represented in figure 3.1. This was a drawing mid-way through the design process and depicts the use of concentric rings, outward facing text and a circular approach to layout concept maps for collaboration. It demonstrated all the core ideas behind this design before any implementation work had been completed.

Figure 3.2 shows a screenshot of the circular prototype at the final stage of prototype evaluation. It is not complete, however, it implemented enough functionality to be an accurate assessment of the prototype’s potential.

**Design Rationale**

This design presents a circular approach to the shared workspace problem. Ideally it would be implemented on a circular tabletop, though it works well enough on a rectangular one assuming a smaller number of users.

The reasoning for the circular layout is largely to do with creating a sense of equality and allowing any number of people to participate. It could be reasonably expected that anywhere between 2 and 6
people could effectively collaborate around a large enough circular table of this design. There are no user spaces defined which leaves users free to position themselves as they wish and are not constrained to their original position.

The concept map, which would normally be oriented top-down, in this case is spread outward from the centre. Assuming a somewhat balanced approximation of a tree with a small amount of cross-linking this reorientation works perfectly. Of course, these need not be assumptions, they are merely an implied result of concept maps created using this interface.

**Presentation**

The interface consists of four main features; concepts, link names, links and rings. The main benefit to this approach, aside from an implied equality between participants is the fact that some amount of text is perfectly readable from any angle, and that text is on the objects closest to the user.

Concepts are oriented outward from the centre and are divided by rings which imply each step between the general concept in the middle to the many specific and specialised concepts on the outer rim. These rings help imply a hierarchical flow and are intended to prevent sub-maps from developing
which are mostly detached from the main one. Link names are oriented perpendicular to the link to which they are attached.

In the implemented prototype, a metaphor of a corkboard has been used in an attempt to keep interaction intuitive. Post-it notes represent concepts and the smaller (blue) labels represent link names.

**Interaction**

Interaction for this design was kept as simple as possible, the only gesture used is "tap-drag". Concepts may be created by dragging Post-it notes off the pad and dropping them on the work area and the same for link names. It is then simply a matter of connecting them all up with the aforementioned tap-drag gesture. Concepts may also be created by double tapping the corkboard background.

A single tap would theoretically allow you to edit the text of a concept or link name with a virtual keyboard, or by choosing from a pre-assembled quick choice list. It is also worth noting that the entire work area rotates by dragging the background of the (corkboard) and that concepts and link names may be moved with a simple drag gesture which results in real-time rotation of the concept relative to the centre (not shown in prototype).
Chapter 3. Interface Design

3.1. Circular Prototype

**Evaluation**

When evaluating this design it is important to consider both the actual implementation and the concept drawing it was based on, neither contains all the functionality intended. The main piece of functionality, the outward orientation of text was unfortunately not implemented in time for this evaluation, however it is demonstrated well enough in the concept drawing to make an evaluation.

Though there is not the facility to manually rotate elements, this is seen as a positive aspect since it leaves users able to focus on the actual act of mapping rather than spending time rearranging labels. It has been shown that people can still read text up to 90 degrees rotated from them (on a horizontal surface) with reasonable accuracy and if we assume this, then each user is constantly able to view 50% of the map’s content even as the number of users scales up.

After testing on an actual tabletop it was found that while the tap-drag gesture was easy to simulate with a mouse, on the tabletop it was not intuitive at all. Additionally it was noticed that there was no capacity to delete objects or to remove links.

The concentric rings do not appear on this prototype not only due to time constraints, but also since it was difficult to find a method of interaction which allowed them to stay out of the users way and yet still be adjustable. Two approaches were considered, one static and another dynamic. The static one involved either stationary rings, or rings which align themselves automatically and cannot be changed directly by the user. The other involved rings which were either explicitly added by the user, or appeared with each new concept, these would allow "snapping" of concepts on and off the ring and manual adjustment of ring distances. Both approaches demonstrated potential to aid the user in constructing a largely hierarchical map though it was not clear at this stage whether they would pose more of a hindrance than a help.

Finally with regards to the software framework Flash, it was definitely appropriate for this type of work. It took only a couple of days to develop a mostly working prototype using mouse input events rather than touch (though physically testing on a touch screen). This was largely due to experience with the framework, but that aside, it provided exactly the tools needed to achieve the desired result. It was expected to be a simple matter to change these mouse inputs to multitouch ones.
3.2 Top-down Prototype

The top-down design is shown represented in figure 3.4. This was a drawing mid-way through the design process and depicts the use of a single large shared space along with optional private spaces. It demonstrated all the core ideas behind this design before any implementation work had been completed.

Figure 3.5 shows a screenshot of the top-down prototype at the final stage of prototype evaluation. It is not complete, however, it implemented enough functionality to be an accurate assessment of the prototype’s potential.

Design Rationale

This design presents a more top-down approach to collaboration involving the use of a single shared workspace encompassing the entire table, along with personal "screens" for each individual which may be turned on and off as desired. It is expected that users would interact with the main workspace during discussions and then return to their personal screens for individual editing.

This approach provides a totally synchronous interaction, uninhibited by the actions of others and
yet perfectly able to work cooperatively. Personal screens means that every participant can read all text simultaneously and yet still get an accurate view of the entire map.

Though this approach allows a traditional top-down map to be formed easily, this does not necessarily mean that the users will follow this layout. This design is believed to cater for approximately 2-6 people where table size is scaled proportionally to the point where reach becomes an issue.

**Presentation**

This interface is intended to provide rich feedback to users of other participants’ actions while within their personal screens. Dotted boxes are used to indicate the viewable area in a particular user’s personal screen, and any actions taken will be tagged with that user’s colour for a short time.

The interface provides a large common area to work with which may be zoomed and rotated, and personal viewing panels which support the same actions. Concept and link names are all displayed towards the “bottom” of the map by default, but may be rotated at will.
Interaction

The main work area and individual screens all take the same input gestures. A multi-finger (or multi-hand) zoom gesture will react as expected, as will a pinch gesture (zoom out). Concepts may be created by holding a finger on a blank area for a moment and links may be created with the "tap-drag" gesture mentioned previously.

Personal screens scroll, rotate and zoom independently of the main workspace and any action in a personal screen will reflect in the main workspace in real time. Virtual keyboards are used to add new concepts and link names.

Evaluation

This approach was seen to have a lot of potential, however, its inherent complexity made it a risky choice. It was not clear which features could be skipped over if implementation took longer than was expected.

The ability to manually rotate labels is potentially a drawback since it creates confusion in the main map, users can still see it oriented correctly in their personal map but this forgoes the advantage of being able to view the map as a whole in the shared workspace. The multitouch gestures such as zoom, pinch and rotate are well known and should be easy for users to pick up.

The PyMT framework was used to develop this prototype and was found to be highly effective for a few common tasks such as photo-sharing but not so appropriate when one wishes to extend the implemented functionality. It is still in an alpha stage and as a result, documentation is sparse and often far out of date.
3.3 Final Design

After analysis of both designs and their potential for full implementation, it was decided to pursue the circular approach. The design evolved with the implementation and as a result of informal user testing. It is worthy of note that the final implementation is missing the concentric rings that were originally an important part of the design. Even as usability studies approached it was expected that they would be implemented, though in the end due to time constraints and some instability in the software this was never achieved (basic ring implementation caused high CPU utilisation due to an inefficient design).

Aside from the rings, key differences include orientation of link names, use of context menus, use of word lists, the method for linking concepts and the use of virtual keyboards.

Link Names

In the original design, link names were oriented perpendicular to the link they were attached to. This was changed for two reasons, firstly because support for branching propositions was added and secondly since cross linking (links between two concepts at a similar distance from the centre) resulted in text that was needlessly offset by 90°. The branching propositions meant that there was now no longer an
inherent direction associated with a proposition as before. Link names are now oriented in the same way as concepts, outward from the centre of the work area.

![Figure 3.7: Context menu associated with TouchMapper elements](image)

**Context Menu**

To solve the issue of having to learn a large number of gestures for different purposes, a context menu was added. Both concepts and link names have context menus which may be activated with a ‘hold’ gesture. These were then able to contain a number of options, all accessed via a single gesture. Ultimately it was decided for the sake of consistency to provide the same options on both element types (‘Link’, ‘Change’, ‘Delete’), though they could very well have been different. The ‘change’ and ‘delete’ functions acted as a quick means of fixing accidental or incorrect additions while ‘Link’ allows directional connections to be made between concepts and link names.

**Linker**

Upon choosing the ‘link’ option in the context menu for some object, you will be presented with a transparent circle attached to that object by a directional link. You must then drag and drop this circle onto the object you wish to link to. If you attach a concept to another concept, a list will appear to choose a link name, while when linking a concept to an existing link name, it simply adds a connection (creating a branching link). Connecting any object to itself, or a link name to another link name has no
Figure 3.8: List box used to select new concept or link names

**List Box**

When adding a new concept or link name, one is presented with a list box. This contains a list of suggested concepts or link names which are set ahead of time by a teacher or domain expert. The user may scroll the list up and down by touching and dragging up or down and then choose by tapping on the appropriate item. If the user wishes to add an item not contained within the provided list, they may use the add button at the bottom to activate a virtual keyboard.

**Virtual Keyboards**

Virtual keyboards are activated as needed and are positioned one per user, a thin line links them to their target label. On a circular table they would appear below the item they are editing.
3.3. Final Design

Chapter 3. Interface Design

Figure 3.9: "Create Concept" selection list

Figure 3.10: "Create Link" selection list
Table 3.1: Comparison of prototype features

<table>
<thead>
<tr>
<th></th>
<th>Circular</th>
<th>Top-Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of users</td>
<td>2-6</td>
<td>2-6</td>
</tr>
<tr>
<td>Shared workspace</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Entire map readable</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Entire map viewable</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Use of personal spaces</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Synchronous interaction</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Useable from any angle</td>
<td>yes</td>
<td>somewhat</td>
</tr>
<tr>
<td>Employs simple gestures</td>
<td>yes</td>
<td>somewhat</td>
</tr>
<tr>
<td>Needs to be taught</td>
<td>somewhat</td>
<td>somewhat</td>
</tr>
<tr>
<td>Allows manual text rotation</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Implies a hierarchical structure</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Elegantly handled large maps</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Framework difficulty</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Implementation difficulty</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Existing MT UI components</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Easy to track other users’ actions</td>
<td>somewhat</td>
<td>yes</td>
</tr>
</tbody>
</table>
Chapter 4

System Implementation

This chapter describes the high-level architecture and technical implementation details of TouchMapper.

4.1 High-level Architecture

TouchMapper is designed to work both as a standalone application, and as a complementary tool for use alongside CMapTools or other concept mapping software. It provides an effective environment for groups to create concept maps, edit existing ones, or simply as a viewer for completed concept maps.

Figure 4.1: Demonstration of two way compatibility with TouchMapper and CMapTools.

4.2 Technical Overview

TouchMapper was developed in Actionscript 3 with the Flash CS5 development environment. It exploits a combination of Flash Player 10.1 native multitouch and TUIO for multitouch support.
4.2 Technical Overview

Figure 4.2: Demonstration of the Interactive Tabletop used in this project

Tabletop Hardware

The tabletop used in this thesis is a combination of a PQLabs G3 46” touch overlay and a 46” LCD screen with a 180° viewing angle in both x and y axes and designed to lie flat rather than upright. The touch panel theoretically supports up to 32 touch points, though in practice approximately 20 may be recognised accurately. The specifications of the LCD panel were required since unlike vertically mounted displays which are generally viewed from a specific angle, tabletops may be viewed from any side, at a range of distances.

This hardware represents a leap forward from the Mimio pens and the “homebrew” vision-based table used previously. The pens required users to take turns and relied on a projector mounted to the ceiling projecting downward. The vision-based FTIR (Frustrated Total Internal Reflection) tabletop was fully multitouch, however, vision processing was imprecise and as a result many false touches were registered, confusing both the software and the user.

Though the PQLabs overlay is much more precise compared to the Mimio pens, there are some tradeoffs. With pen based input a user may be uniquely identifiable by the specific pen they hold whereas this is not possible with infrared touch systems. This presents a challenge for interface design in that it must either employ clearly defined ‘user spaces’ or be designed not to rely on user identification. Additionally, since touch points are determined by interrupting a beam of infrared light (shone just above the screen), any opaque object may register as a touch, including ties, sleeves and jewellery. This presents a minor issue which is easily solved through user instruction.
Chapter 4. System Implementation 4.2. Technical Overview

**Touch Drivers**

The PQLabs G³ comes with Windows, Mac and Linux drivers, though for the sake of this study we will be using Microsoft Windows 7. The Windows driver contains a few configurable elements, including both TUIO and native multitouch support. Native multitouch is a new feature in Windows 7, allowing applications to receive touch events as a system event rather than through a proxy such as a TUIO client (socket connection).

We aim to implement both native and TUIO support to keep TouchMapper both platform and hardware agnostic.

**Flash/Flex/AIR Platform**

As a result of much past experience with the Adobe Flash stack, it was decided to develop TouchMapper on top of this platform instead of the Cruiser framework, a product of the CHAI research group. Flash, Flex and AIR are all libraries for the Actionscript 3 scripting language and provide various benefits for rapid prototyping while also being a mature enough platform for a final product. Additionally Flash programs will run on Windows, Mac, Linux, as either a desktop application or inside a browser so it was seen to fit with the goals of the Cruiser framework to be both platform and hardware agnostic. Mobile deployment is also possible both to native iPhone and AIR Android apps as well as to Flash Lite applications for low-power mobile phones.

**Actionscript 3 Native Multitouch**

As of June 2010, Flash Player 10.1 (and AIR 2.0) support native multitouch both on desktop computers (Mac, Windows) and mobile devices (Android, iPhone). This is supported in two modes, gesture-based and simple touch point based. The gesture based system, in its current form however, does not support more than one gesture at a time and so is not appropriate for this project.

Native multitouch support was developed first due to its simplicity, it is entirely plug-and-play with drivers obtained by Windows Update. TUIO, often requires complex configurations sometimes involving multiple computers.
4.2. Technical Overview  Chapter 4. System Implementation

**TUIO Support**

It was originally intended for TouchMapper to support both TUIO and Native Multitouch events automatically, depending on which was available at runtime. Unfortunately, due to time constraints this was never achieved. What was achieved, however, was to use both simultaneously for different components of the system.

As a result of Flash’s security sandbox, it requires a separate application (outside the sandbox) to proxy the TUIO requests to it (when not compiled as a desktop application), conveniently the PQLabs driver has this behaviour implemented natively and so no extra configuration was required.

**TouchLib Integration**

Since Flash native multitouch did not exist when this thesis was started, there were no libraries in existence to streamline the development process. There were, however, various Flash examples utilising TUIO present in the TouchLib source tree. TouchLib is a C++ framework for vision-based multitouch systems, however, it includes a number of Flash-based examples and an associated library of community-contributed components of varying quality.

When it came to implementing virtual keyboards, the native Windows multitouch keyboard was the obvious choice, however this could not be rotated as was required by TouchMapper. As such, the options were to either implement one from scratch or to attempt to use a TUIO component.

We went with the TUIO option after it was found that the hardware was already sending FlashTUIO signals and that they could easily be made to work side-by-side with the native touch events. This saved a lot of time, though increased the application’s dependencies significantly, had there been more time we would have rewritten the component to work with native events.

**CMapTools (CXL) Parser**

CXL is an XML based format which is the default export type of CMapTools.

TouchMapper is able to read CMapTools CXL files for the purposes of both loading complete or incomplete maps, and for obtaining words lists for new concepts and links. Actionscript’s E4X (ECMAScript for XML) support was utilised to do so easily with inline XML filters.
Chapter 4. System Implementation

4.2. Technical Overview

TouchMapper File Format

Though originally intended, a separate file format for TouchMapper files was not required. All required data could be contained within the CMapTools CXL format.

Concept and link names intended to appear in the list, but not instantiated, are simply added within <concept> or <linking-phrase> tags with no linked <connection>, <concept-appearance>, or <linking-phrase-appearance> tags (as per instantiated ones).

Additionally, had there been any extra information required to be saved, this could have easily been injected into extra attributes of existing tags, or by adding extra tags. Through testing it was found that CMapTools will ignore anything outside (or contained within) its defined XML structure which is not expected. It also gracefully handles missing tags which it would normally expect by simply rendering everything which does make sense.

Gesture Recognition

We were unable to find any appropriate multitouch gesture libraries for Flash during the development process and as such, all gesture recognition is done manually in the TouchMapper codebase. Gestures were found to vary significantly between user and as such, a configuration was determined that would provide a high success rate with the most number of people through much informal testing with volunteers. The drawback of trying to make a "one size fits all" configuration is that everything is a tradeoff and so by improving the interaction for one person, you may create effects to the detriment of another.

Configuration and Calibration

Since this software aims to be both platform and hardware agnostic, it must be highly configurable to account for the differences between devices. TouchMapper is mostly configured for the hardware on which it was developed, the current configuration would not be expected to accurately recognise the difference between some gestures on different hardware (such as a vision based system) however it should be easy to configure.

Configuration options include those shown below.

Due to the design of our tabletop, an issue arises regarding perspective. Since the touch panel is positioned above the display's surface (about 0.5cm or so) parallax error occurs. Since they can only
4.2. Technical Overview

Table 4.1: Configuration options for TouchMapper

<table>
<thead>
<tr>
<th>Options</th>
<th>Units</th>
<th>Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multitouch</td>
<td>true/false</td>
<td>true</td>
</tr>
<tr>
<td>Rings</td>
<td>true/false</td>
<td>false</td>
</tr>
<tr>
<td>Virtual keyboards</td>
<td>true/false</td>
<td>true</td>
</tr>
<tr>
<td>Debug mode</td>
<td>true/false</td>
<td>false</td>
</tr>
<tr>
<td>Work area radius</td>
<td>pixels</td>
<td>550</td>
</tr>
<tr>
<td>Fraction of work area grabbable for rotation</td>
<td>-</td>
<td>1/5</td>
</tr>
<tr>
<td>Padding around concept text</td>
<td>pixels</td>
<td>30</td>
</tr>
<tr>
<td>Concept &amp; link name font size</td>
<td>pt</td>
<td>16</td>
</tr>
<tr>
<td>Hold delay</td>
<td>milliseconds</td>
<td>600</td>
</tr>
<tr>
<td>Hold movement threshold</td>
<td>pixels</td>
<td>30</td>
</tr>
<tr>
<td>Context menu timeout</td>
<td>milliseconds</td>
<td>3000</td>
</tr>
<tr>
<td>List view timeout</td>
<td>milliseconds</td>
<td>3000</td>
</tr>
<tr>
<td>Interact timeout</td>
<td>milliseconds</td>
<td>500</td>
</tr>
<tr>
<td>Minimum list proximity</td>
<td>pixels</td>
<td>200</td>
</tr>
<tr>
<td>Momentum</td>
<td>true/false</td>
<td>false</td>
</tr>
<tr>
<td>Momentum sampling size</td>
<td>frames</td>
<td>5</td>
</tr>
<tr>
<td>Momentum multiplier</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Momentum upper bound</td>
<td>pixels per frame</td>
<td>30</td>
</tr>
</tbody>
</table>

touch the glass above, and not the image itself, one will touch at a different position depending on their perspective (the point at which the glass intersects their line of sight to the intended location).

In an attempt to mitigate this problem, we calibrate the touch input using two people sitting opposite each other at the centre of the table (at the maximum reasonable angle of distortion). Each time a calibration point appears, the closest person touches it, being careful only to turn their head and not to move closer to it. This achieves a calibration that is technically incorrect for both users, but on average a much more accurate representation and a more user-friendly experience. This is done in combination with designing applications to have large touch areas so that inaccuracy of touches is not so much of an issue.

Caveats

Unfortunately, the current version of TouchMapper cannot save completed concept maps, nor log user interaction. These features, however, would not be difficult to implement. Also, its recognition of the hold gesture is a little too sensitive (yet, in some situations, not sensitive enough) and probably requires
a rework.

It is important to note that although you may technically move concept maps in both directions, a top-down map developed in CMapTools will not necessarily map elegantly to TouchMapper’s circular interface, particularly if it contains a large amount of cross-linking. To resolve this, we would provide an import wizard that helps in rearranging the map to suit the tabletop, this could potentially use a force-directed or other algorithm to generate a theoretically good map and have the user decide.

**PyMT**

The top-down prototype was written in python, using the PyMT framework. It is currently at version 0.5.1 and is very much experimental software. It was found to be very good at the simple tasks it was intended for, however, once more complex functionality was required it was very difficult to work with.

PyMY is an open source library for multitouch development, it is cross platform and comes with native support for both TUIO devices and Windows 7 native multitouch. It provides a mashup of a few popular frameworks along with a set of user interface components designed specifically for multitouch.
Chapter 5

Evaluation Design

The goal of this thesis is to explore concept mapping as a collaborative learning activity on interactive tabletops. The TouchMapper system is designed to allow simultaneous interaction from multiple participants working towards a common goal, it intends to provide an interface that more effectively facilitates collaboration than existing solutions.

5.1 Evaluation Goals

The primary goal of this evaluation is to determine the effectiveness of TouchMapper as a tool for co-located collaboration in concept mapping tasks. This is assessed through a comparison with CMapTools, an established digital concept mapping tool.

The performance of each system will be measured by the following factors:

- Ease of Use
- Accuracy of Maps
- Level of Collaboration
- Repeated Revisions of Maps

Ease of Use

Ease of use was a key design goal in this project, we aimed to create an interface that is both intuitive and consistent. It should not be difficult to learn and only require a short demonstration to master. Ease
of use will be measured from participant feedback.

**Accuracy of Maps**

Assuming that one interface is substantially more effective than the other in this collaborative context, it would follow that this would produce more correct maps. Since all group members should be cooperating effectively, the resultant map should be a representation of their combined understanding (which should be greater than any one individual’s).

**Level of Collaboration**

Though very subjective, the level of collaboration may be measured through analysis of the experiment recordings and computer logs. Since the primary goal of this project is to promote collaboration, it is only logical to measure this in some way.

**Repeated Revisions of Map**

Joseph Novak’s many papers on concept mapping emphasise the importance of concept mapping being an iterative process. The mapper should go through a constant process of repeated revision on the way to a final, accepted representation. This should be even more prevalent in a collaborative context, as participants will not share the same understanding of the material and as such, errors may be corrected by other team members.

5.2 **Experimental Design**

In order to evaluate TouchMapper’s approach in terms of the above goals, a basis of comparison is required. We have chosen to use IHMC’s CMapTools concept mapping application as it is the de-facto standard for computerised concept mapping and was developed in close communication with Joseph Novak.

This implementation provides an effective tool for concept map construction, though a strictly single user one. As such, any co-located collaboration is facilitated by swapping control of the keyboard and mouse, or through leaving one person in control who enacts the intent of others.

CMapTools uses a traditional WIMP interface to enable concept map creation. Rounded squares with text represent concepts, and borderless text fields with arrows represent propositions. New concepts
may be created by double-clicking in an empty area then typing, and propositions may be created by
dragging from a marked hotspot above the concept to the corresponding component and then typing.
This process is simple enough that participants are not expected to have any trouble understanding it.

The experiment was designed to consist of the following stages:

• background questionnaire

• demonstration of both interfaces

• reading of text 1

• construction of concept map with interface A

• reading of text 2

• construction of concept map with interface B

• post-experiment questionnaire

Experiment Participants

Participants for this experiment are to be chosen from two year 6 classes of St Pius X College, Chatswood.
All students within those years will be given equal opportunity to participate, though the study is limited
to 32 places. Being an all boys school, and considering the year group selection all participants will be
male and within the age range of 10 to 12.

Considering the school has most primary classrooms fitted with interactive whiteboards, it should be
noted that the students studied may be more familiar with touch interfaces than other children of their age.

The evaluation is to be conducted in pairs and due to the collaborative nature of the tasks, partici-
pants are allowed to choose their partner. This is important to ensure that participants feel comfortable
interacting with each other during both tests. There will be no preference placed on candidates based
on any factors other than the order in which students return their consent forms (in the case of more
applications than places).
5.3. Experiment Procedure

Tasks

Two tasks are to be performed by participants (aside from the background and post-experiment questionnaires). Both are concept mapping exercises, one being performed at an interactive tabletop, and the other at a computer. They are designed to emulate a classroom style exercise in which students are provided with new information to absorb since this hardware/software combination is intended as an educational tool for use in such a scenario.

Each task will involve the same process:

1. Participants individually read through a provided passage (under one page in length).

2. Participants come together as pairs at their allocated device. They proceed to construct a concept map together as they see fit, representing the content contained within the text (which they still have for reference).

3. Once complete, they signal the researcher that they are complete and move to the next stage of testing.

This is done twice, once for each interface. The concept mapping task will be using the TouchMapper software developed for this thesis, and the computer-based one will be performed on the CMapTools application. In each, the participants are provided with the required concepts and propositions and are merely required to place and link them appropriately.

5.3 Experiment Procedure

Background Questionnaire

The background questionnaire is designed to gather basic information about the participants in regards to their relevant experience. This covers age, amount of computer use, prior use of interactive whiteboards/tabletops, prior use of concept maps and ability to work in a group. This data is required in order to perform a meaningful analysis of the result obtained. A full list of background questions asked can be found in the appendix.
Demonstration of Both Interfaces

Participants are first given an explanation of concept mapping, how to construct one and what its purpose is. Next they are shown the individual actions in each interface (add concept, add link, change, delete), tabletop first and PC second.

**TouchMapper Demonstration**

- Press and hold to bring up list box
- Scroll to appropriate item and tap to select
- Repeat the process two more times on the second instead choosing "add concept"
- Use the virtual keyboard to enter a concept name (you should now have three concepts)
- Press and hold on one concept to trigger the context menu
- Choose the ‘change’ option with a tap gesture
- Select a new item from the list to replace the existing one
- Trigger the context menu again and this time choose ‘link’
- Drag the linker circle over to an appropriate concept and release
- Choose an appropriate link name from the resultant list
- Trigger the linker again but this time drop it on the chosen link name to demonstrate a branching proposition
- Drag workspace rim to rotate concept map
- Open context menu on a random concept and choose delete

**CMapTools Demonstration**

- Double click to create a new concept
- Type in name of concept
5.3. Experiment Procedure

- Repeat twice more resulting in three concepts
- Click on a concept to select it
- Rename the concept using the keyboard
- Create a link between this concept and another by dragging and dropping the link icon
- Type the name of the new proposition
- Link again but this time demonstrate a branching proposition by connecting some other concept to the existing link name

Read Text 1

Participants are then given a passage of text regarding ‘The Water Cycle’ (see below) and instructed to highlight ten important concepts and optionally any significant propositions. This is done individually.

TouchMapper Procedure

Participants are instructed to use the techniques demonstrated to create their own map, choosing from the provided lists if they contain the desired label or otherwise typing concepts and propositions in with the virtual keyboards.

Read Text 2

After completing task 1 participants are given their second passage to read and highlight individually. This passage is on ‘The Butterfly Life Cycle’.

CMapTools Procedure

Participants are instructed to use the techniques demonstrated to create their own map, typing each concept and proposition in manually.

Post Experiment Questionnaire

The post experiment questionnaire is designed to gather qualitative feedback about the participants experience during the study. The post-experiment questionnaire is shown below.
Chapter 6

Evaluation Results & Analysis

User testing was completed over the course of two days with 24 year 6 students of St Pius X College. Unfortunately I did not have anyone to assist in managing children, saving out log files, taking screenshots, settings up recordings, resetting video cameras, etc. and as a result some data was lost. Additionally technical issues with the tabletop hardware, software caused significant delays.

6.1 TouchMapper Results

Significantly sized maps, lots of links, exactly the same as CMapTools outcome.

6.2 CMapTools Results

Significantly sized maps, lots of links, exactly the same as TouchMapper outcome.

6.3 Background Questionnaire Results

All participants had used an interactive whiteboard before, one claimed to have used a tabletop and one had created a concept map before.

6.4 Post Experiment Questionnaire Results

Users preferred TouchMapper over CMapTools, though this was most likely due to the novelty of a multitouch tabletop. They found both easy to use and were able to understand how they worked.
Participant Code: ______

**Background Questionnaire**

Please complete the following questions about your background:

Age: ______

1. How many hours do you typically use a computer each week? (please tick one)
   - [ ] None
   - [ ] 1 to 10
   - [ ] 11 to 20
   - [ ] 21 to 30
   - [ ] 31 to 40
   - [ ] 41 or more

2. Have you ever used an interactive whiteboard?
   - [ ] No
   - [ ] Yes

3. Have you ever used an interactive tabletop?
   - [ ] No
   - [ ] Yes

4. Have you ever created a concept map?
   - [ ] No
   - [ ] Yes

5. How would you rate your ability to work in a group? (please tick one)
   - [ ] 1 (Low)
   - [ ] 2
   - [ ] 3
   - [ ] 4
   - [ ] 5 (High)

Please tell the experimenter when you have finished completing the questionnaire.

Thank you for your participation in this study.
Participant Code: __________

Post-Experiment Questionnaire

Please complete the following questions. For each of the questions, put a cross in the box that corresponds to your answer.

1) It was easy to use the top-down interface:

   | strongly disagree | disagree | somewhat disagree | neutral | somewhat agree | agree | strongly agree |
   |                  |         |                   |        |               |      |               |
   | [ ]              | [ ]     | [ ]               | [ ]    | [ ]           | [ ]  | [ ]           |

2) It was easy to use the circular interface:

   | strongly disagree | disagree | somewhat disagree | neutral | somewhat agree | agree | strongly agree |
   |                  |         |                   |        |               |      |               |
   | [ ]              | [ ]     | [ ]               | [ ]    | [ ]           | [ ]  | [ ]           |

3) In the top-down task your group worked together well:

   | strongly disagree | disagree | somewhat disagree | neutral | somewhat agree | agree | strongly agree |
   |                  |         |                   |        |               |      |               |
   | [ ]              | [ ]     | [ ]               | [ ]    | [ ]           | [ ]  | [ ]           |

4) In the circular task your group worked together well:

   | strongly disagree | disagree | somewhat disagree | neutral | somewhat agree | agree | strongly agree |
   |                  |         |                   |        |               |      |               |
   | [ ]              | [ ]     | [ ]               | [ ]    | [ ]           | [ ]  | [ ]           |

5) Which interface did you prefer?

   | circular | top-down |
   |         |          |
   | [ ]     | [ ]      |

8) Overall, I was able to understand how the circular and top-down interfaces worked:

   | strongly disagree | disagree | somewhat disagree | neutral | somewhat agree | agree | strongly agree |
   |                  |         |                   |        |               |      |               |
   | [ ]              | [ ]     | [ ]               | [ ]    | [ ]           | [ ]  | [ ]           |
9) Which parts of the interface (circular and/or top-down) did you like?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

10) Which parts of the interface (circular and/or top-down) did you dislike?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

13) Do you have any other general comments regarding either interface?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Please tell the experimenter when you have finished completing the questionnaire.

Thank you for your participation in this study.
**Water Cycle Stages**

Here are the four steps of the water cycle:

**Stage #1 Evaporation:** In this stage, the Sun starts to evaporate the water in the water bodies, like oceans, seas, lakes, ponds, and rivers. This water is in the liquid stage in the water bodies, but change in weather and heating due to Sun converts it into gaseous form. Slowly, these vapours of water start to rise up to the sky. Transpiration, which is water escaping from plants due to Sun's heat, also contributes to some extent, to the process of evaporation.

**Stage #2 Condensation:** It is in this stage that cloud formation occurs. The water in the form of the vapours rising, cools down at a certain height and condenses to form clouds.

**Stage #3 Precipitation:** The water keeps condensing to form clouds, but when there is too much accumulation or collection of water in these clouds, the clouds become heavy. This means the air can no longer hold this much amount of water, and the water starts to fall back, mostly in the form of rain. Sometimes this collected water, comes down to the Earth's surface in the form of snow, hail, partially melted snow which is called sleet. Rarely, acid rain can be observed due to the effects of environmental pollution.

**Stage #4 Collection:** This water falling down in the form of rain or snow, gets collected in different water bodies. When it falls on the ground, it gets stored under the ground, and is called ground water. Then, again evaporation starts due to the Sun's heat and the cycle reoccurs.
Every butterfly or moth goes through four stages in its life. Each stage is very different from the others. The cycle of stages is called **metamorphosis**.

**Egg**

The egg is the first stage in the butterfly and moth life cycle. Butterfly and moth eggs are very small and round, oval or **cylindrical**. Many have **ribs** or other tiny features. Females lay their eggs on or near the plants that will later become caterpillar food.

**Larva**

The larva hatches from the egg. Butterfly and moth larvae are usually called caterpillars. Caterpillars spend most of their time eating. Butterflies and moths do all of their growing when they’re caterpillars, and food gives them the energy and body-building materials they need. A caterpillar’s **exoskeleton** can’t stretch or grow, so the caterpillar sheds its skin, or molts, several times as it grows.

**Pupa**

When a **caterpillar** has finished growing, it forms a pupa. From the outside, the pupa looks as if it’s resting. But inside, every part of the caterpillar is changing. Most of its organs and other body parts dissolve and re-form into the organs, tissues, limbs and wings of the adult. Butterfly pupae are called chrysalises. Many moth **caterpillars** spin ** cocoons** and form pupae inside them.

**Adult**

When the **pupa** has finished **changing**, it molts one last time and emerges as an adult butterfly or moth. The adult **emerges** with its wings folded up against its body. The butterfly or moth pumps blood into the wings to expand them. The adult is the stage when butterflies and moths mate and reproduce. Females lay their eggs on plants or other surfaces, and the cycle starts all over again.
Task 1 with TouchMapper

(Water Cycle Exercise)
Task 1 with CMapTools

(Water Cycle Exercise)
Task 2 with TouchMapper

(Butterfly Stages Exercise)
Task 2 with CMapTools

Technical Issues

(Butterfly Stages Exercise)
Group 6 – Participants 12 and 13

Concepts: 16, Links: 15

Group 7 – Participants 14 and 15

Concepts: 14, Links: 10
Group 8 – Participants 16 and 17

Concepts: 9, Links: 9

Group 9 – Participants 18 and 19

Concepts: 11, Links: 13

Concepts: 9, Links: 8

Concepts: 7, Links: 7
Group 10 – Participants 20 and 21

Concepts: 11, Links: 14

Group 11 – Participants 22 and 24

Concepts: 13, Links: 4

Concepts: 13, Links: 5
6.5 Questionnaire Results

6.6 Overall Results

Overall, the results largely showed equivalent results for both interfaces. Both from looking at the data and from viewing the participants interact, it was obvious that TouchMapper was just as effective as CMapTools for a co-located collaborative task. This is a significant achievement since CMapTools is a mature product developed over many years and in widespread use worldwide (both in industry and education).

6.7 Errors in User Interaction

The list below contains all the issues that users had with the system during the course of their interactions.

- missing menu button (touching next to)
- tried tapping ‘link’ and then the concept they wanted to link to
- did not realise they could drag the linker off the edge to delete
- one user kept putting his arm over the side of the table causing false touches and other touch recognition issues
- lag was experienced by some groups as a result of background screen capturing
- unable to delete individual links, only concepts or link names
- snapping was too sensitive with the linker
- virtual keyboard input was slow
- some groups didn’t talk much
- some groups developed individual maps and only considered joining them at the end
- keyboard had a bug where it would not disconnect from a concept
• some users tried to create a link when there was only one concept on the map (and therefore nothing to connect to)

• some users expected the ‘link’ to be draggable instead of waiting for the linker to appear

•
###背景调查

<table>
<thead>
<tr>
<th>参与者代码</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>参与者ID</td>
<td>PC* 1.1</td>
<td>PC* 1.2</td>
<td>PC* 2.1</td>
<td>PC* 2.2</td>
<td>PC* 3.1</td>
<td>PC* 3.2</td>
<td>PTC 4.1</td>
<td>PTC 5.1</td>
<td>PTC 5.2</td>
<td>PTC 4.2</td>
<td>*</td>
<td>PTC 6.1</td>
</tr>
</tbody>
</table>

####背景调查

- 年龄: 11 12 12 12 11 12 12 12 11 12 12 12
- 每周使用电脑的小时数: 11-20 1-10 21-30 1-10 1-10 11-20 1-10 11-20 11-20 41+
- 你是否曾经使用过交互式白板? 是 是 是 是 是 是 是 是 是 是 是
- 你是否曾经使用过交互式桌面? 否 是 否 否 否 否 否 否 否 否 否
- 你是否曾经创建过概念图? 否 是 否 否 否 否 否 否 否 否 否
- 你如何评价你的团队合作能力? 4 4 4 4 4 4 4 5 4 5

####实验后调查

- 在顶部向下界面中，很容易使用: 5 5 6 6 6 6 7
- 在圆形界面中，很容易使用: 7 7 4 4 6 6 5 6 3
- 在顶部向下任务中，团队合作良好: 7 7 7 7 7 7 7 6
- 在圆形任务中，团队合作良好: 7 7 6 7 7 7 7 5
- 你更喜欢哪个界面? T T T T C C C C
- 总体上，我能够理解圆形和顶部向下界面的工作: 7 7 6 6 7 5 6 7 6

* 前期测试组，未按照其他人的方式完成任务
* 由于技术问题，未使用顶部向下界面
* 数量未分配
- 学生提前离开

###图6.1: 背景和实验后问卷调查结果
### Background Survey

<table>
<thead>
<tr>
<th>Age</th>
<th>12</th>
<th>12</th>
<th>11</th>
<th>12</th>
<th>12</th>
<th>11</th>
<th>11</th>
<th>12</th>
<th>11</th>
<th>11</th>
<th>12</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many hours do you typically use a computer each week?</td>
<td>41+</td>
<td>11-20</td>
<td>11-20</td>
<td>11-20</td>
<td>11-20</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
<td>1-10</td>
<td>11-20</td>
<td>11-20</td>
</tr>
<tr>
<td>Have you ever used an interactive whiteboard?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever used an interactive tabletop?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Have you ever created a concept map?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>How would you rate your ability to work in a group?</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Post-Experiment Survey

| It was easy to use the top-down interface | 5 | 7 | 5 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 7 |
| It was easy to use the circular interface | 4 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 6 | 6 | 6 |
| In the top-down task your group worked together well | 6 | 7 | 6 | 5 | 4 | 7 | 6 | 6 | 2 | 5 |
| In the circular task your group worked together well | 5 | 7 | 7 | 4 | 4 | 7 | 7 | 5 | 5 | 2 | 7 |
| Which interface did you prefer? | C | C | T | C | C | T | C | T | C | C |
| Overall, I was able to understand how to the circular and top-down interfaces worked | 6 | 7 | 7 | 7 | 7 | 6 | 7 | 7 | 6 | 7 |

+ Preliminary testing group, did not perform task in the same manner as others
* Did not use top-down interface due to technical issues
^ Number unassigned
- Student left early

Figure 6.2: Background and post-experiment questionnaire results continued
### Figure 6.3: Long responses from post-experiment questionnaire

<table>
<thead>
<tr>
<th>Code</th>
<th>Which parts of the interfaces did you like?</th>
<th>Which parts of the interfaces did you dislike?</th>
<th>Do you have any other general comments?</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC*2.1</td>
<td>I liked the way you could have more than one person touching at a time, and the way you could link something to another.</td>
<td>Nothing, it was great!</td>
<td>It was fun to do and I hope we can get them in the class room.</td>
</tr>
<tr>
<td>PC*2.2</td>
<td>I liked the way it was so easy to pick up as in understand.</td>
<td>Nothing except the way the link would go straight to the nearest link.</td>
<td>It was really cool and fun and I would like to have one in the classroom and I would like to go to school if there was one in the classroom.</td>
</tr>
<tr>
<td>PC*3.1</td>
<td>I liked how you can use multiple fingers and it was a fun way to learn, it was a smart system and worked well.</td>
<td>You have to hold instead of double touch mechanism.</td>
<td>The touch system could have been more precise but otherwise I thought it was very good, 9/10.</td>
</tr>
<tr>
<td>PC*3.2</td>
<td>I liked how you can use multiple fingers at the same time.</td>
<td>I disliked how it would to the change, link, delete on a word when you want to move. I also disliked how the word shook when you dragged it.</td>
<td></td>
</tr>
<tr>
<td>PTC4.1</td>
<td>I like the part when it was touch screen and it is very fun using that piece of technology and moving it around.</td>
<td>I disliked when it sometimes does not read our fingerprints and it freezes.</td>
<td>No.</td>
</tr>
<tr>
<td>PTC4.2</td>
<td>Interactive, keeps you occupied.</td>
<td>Lagged a bit.</td>
<td>No.</td>
</tr>
<tr>
<td>PCT5.1</td>
<td>I like the circular interface because more than one thing can touch the board.</td>
<td>I didn't really like interface circular because it keep on lagging.</td>
<td>No.</td>
</tr>
<tr>
<td>PCT5.2</td>
<td>I liked the circular interface because it was more interactive but you had more control with the top-down interface.</td>
<td>I didn't like one part of the circular interface and that was it.</td>
<td></td>
</tr>
<tr>
<td>PTC6.1</td>
<td>I liked the touch screen because it is multitouch unlike smartboards.</td>
<td>I disliked the top-down because it's very complicated. The circular was not what I thought it was. It was also very slow.</td>
<td>No. I hope they go on the market but the price should go down. I hope you can fix the bugs in the system!</td>
</tr>
<tr>
<td>PTC6.2</td>
<td>(Circular) I loved the touch screen and the multitouch feature. (top-down) It was good because it was easy to manipulate.</td>
<td>(circular) hard to manipulate the features and a bit out of whack and it was slow.</td>
<td>They're fun.</td>
</tr>
<tr>
<td>Code</td>
<td>Which parts of the interfaces did you like?</td>
<td>Which parts of the interfaces did you dislike?</td>
<td>Do you have any other general comments?</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>PCT7.1</td>
<td>Of the top-down I liked the convenience of the program. Of the circular the multi touches.</td>
<td>The quality of the program for circular.</td>
<td>The market of this product will be booming!</td>
</tr>
<tr>
<td>PCT7.2</td>
<td>The touch sensor on the circular and it was easy to move our work around.</td>
<td>The circular sometimes didn't pick up our touch.</td>
<td>No, but I enjoyed using it.</td>
</tr>
<tr>
<td>PTC8.1</td>
<td>The dragging and quick word menus.</td>
<td>The typing was really hard and when you wanted to write something new the thing you wrote last time shows up and you have to delete it.</td>
<td></td>
</tr>
<tr>
<td>PTC8.2</td>
<td>I liked the fact that you could touch the table.</td>
<td>I disliked the bugs in the system.</td>
<td>NO.</td>
</tr>
<tr>
<td>PTC9.1</td>
<td>I liked how you can do 32 touches at once on the circular. They were both easy to control.</td>
<td>It was a bit too sensitive and sometimes it is hard to control.</td>
<td></td>
</tr>
<tr>
<td>PTC9.2</td>
<td>How you can use 32 touches at once. They were both easy to use.</td>
<td>It was a bit too sensitive and sometimes it is hard to control.</td>
<td></td>
</tr>
<tr>
<td>PTC10.1</td>
<td>I like circular you could just type things in and easily make the concept map.</td>
<td>On the circular sometimes it froze and it went out of control and lagged somewhat sometimes.</td>
<td>The circular interface is actually a very smart interface and it was a good experience to use it.</td>
</tr>
<tr>
<td>PTC10.2</td>
<td>I liked to have the ability to be doing many things at once.</td>
<td>It was some times the circular interface lagged, and it was somewhat hard to control moving the bubbles.</td>
<td></td>
</tr>
<tr>
<td>PCT11.1</td>
<td>I liked the touch screen and awesomeness of the circular.</td>
<td>They were both very fiddly.</td>
<td>Yes, ITS AWESOME</td>
</tr>
<tr>
<td>PCT11.2</td>
<td></td>
<td>How sometimes is didn't work.</td>
<td>NO!!!!!!!!!!!!</td>
</tr>
</tbody>
</table>

Figure 6.4: Long responses from post-experiment questionnaire continued
Chapter 7

Conclusions

7.1 Thesis Goals

The primary goal of this thesis was to explore ways of moving concept mapping from an individual to a co-located, collaborative task. This consisted of:

1. Creating an application that supports and encourages collaboration
2. Bringing a predominantly paper-based task to the interactive tabletop
3. Exploring and implementing alternative methods of display and construction of concept maps and optionally:
4. Designing a method for verification of concept maps against expert ones
5. Providing feedback both to students and to teachers regarding concept mapping performance
6. Providing an intuitive interface that requires minimal instruction to learn
7. Providing compatibility with existing software for desktop concept mapping

All of the initial thesis goals were achieved except the optional ones 4 and 5.

7.2 Contributions

This thesis presented a novel approach to collaborative concept map construction at the tabletop, the specific contributions include:
7.3 Future Work

- A detailed analysis of existing research in areas of concept mapping, tabletop interaction,

- Exploration of multiple approaches to designing the interface, based on prototyping and heuristic evaluation.

- Design and implementation of a novel tabletop user interface that supports collaborative concept mapping through simultaneous interaction by multiple group members.

- A detailed qualitative evaluation that compares the implemented collaborative concept mapper with an existing solution for concept mapping.

- A detailed analysis of evaluation results to determine the effectiveness of the designed application at promoting collaboration.

All contributions have been completed.

7.3 Future Work

- Resolving user interface issues
  - Incorrect alignment of arrows to edges of concepts/link names
  - Incorrect handling of bidirectional arrows
  - Bug where keyboard use permanently locks out rotation
  - Lack of scrollbar on list component (to see where you are in the list)
  - Lack of momentum on work area, concepts and link names
  - Overzealous snapping of linker object
  - False triggering of hold gesture (context-menu, list) during a drag action

- Saving concept maps (complete and incomplete)
  - Output to CXL files (CMapTools export format)
  - Output to database

- Data logging
  - Logging of touch events
– Logging of interface actions
  – To an external database and local log file

• Automated feedback
  – Based on an expert/teacher map
  – Based on already marked maps
  – Based on heuristics such as crossed lines, number of concepts, amount of linkage, detached sub-maps, etc.
  – On both complete and incomplete maps

• TouchMapper server
  – Create user profiles (login to the tabletop)
  – Associate all created concept maps to that account
  – Teacher can set tasks for individuals
  – Teacher can assess maps through a web interface
  – Teacher can view aggregate information of a class’s knowledge, misconceptions, etc.
  – System builds user models over time
  – Students may work remotely through a web interface

• Printable output of concept maps

• Circular tabletop hardware to allow for an arbitrary number of users (16:9 results in too much whitespace/reach issues)

• TUIO and Native multitouch support (currently using a hybrid approach)

• Cruiser integration (allow launching of arbitrary programs not written in cruiser with multitouch support)

• Capacity for multiple users to bring together individual maps for comparison/discussion/merging

• Educational data mining

• Implement top-down approach with PyMT
Bibliography


L. Cimolino and J. Kay. Verified concept mapping for eliciting conceptual understanding. In *ICCE ’02:*


M. Wu and R. Balakrishnan. Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In UIST ’03: Proceedings of the 16th annual ACM symposium on User interface
Appendix A

CXL File Format

From http://cmap.ihmc.us/xml/CXL.html

```xml
<cmap xmlns="http://cmap.ihmc.us/xml/cmap/
   xmlns:dc="http://purl.org/dc/elements/1.1/
   xmlns:dcterms="http://purl.org/dc/terms/
   xmlns:vcard="http://www.w3.org/2001/vcard-rdf/3.0#">
  <res-met>
    <dc:contributor>!— Last user that modified the resource —>
      <vcard:FN>Full name (First [Middle|Initial] Last)</vcard:FN>
      <vcard:EMAIL>Email address</vcard:EMAIL>
      <vcard:ORG>
        <vcard:OrgName>Organization name</vcard:OrgName>
      </vcard:ORG>
    </dc:contributor>
    <dc:creator>!— Original author —>
      <vcard:FN>Full name (First [Middle|Initial] Last)</vcard:FN>
      <vcard:EMAIL>Email address</vcard:EMAIL>
      <vcard:ORG>
        <vcard:OrgName>Organization name</vcard:OrgName>
      </vcard:ORG>
    </dc:creator>
    <dc:description>Focus question of the Cmap</dc:description>
    <dc:format>x-cmap/text-xml</dc:format>
    <dc:identifier>HTTP URL with resource id (e.g. http://cmap.ihmc.us/rid=10002929_292992_19)</dc:identifier>
</cmap>
```
Appendix A. CXL File Format

```
<dc:language>Language code (RFC1766) (e.g. en_US)</dc:language>
<dc:publisher>IHMC CmapTools v. 4.X</dc:publisher>
<dc:relation>HTTP URL, location based (e.g. http://cmap.ihmc.us/plants.cxl)</dc:relation>
<dc:source>cmap:
  <server-id>
  :
  <folder-id>
  :
  <resource-id>
</dc:source>
<dc:subject>Keyword list, comma delimited</dc:subject>
<dc:title>Name of the Cmap</dc:title>
< dcterms:created>Date when the Cmap was created (ISO Date yyyy-MM-dd'T'
    HH:mm:ss'Z' GMT Time Zone)</dcterms:created>
< dcterms:extent>size (integer [space] units)</dcterms:extent>
< dcterms:modified>Date of last modification (ISO Date yyyy-MM-dd'T'HH:mm:ss'Z
    ' GMT Time Zone)</dcterms:modified>
< dcterms:rightsHolder> <!-- Cmap owner -->
  <vcard:FN>Full name (First [Middle | Initial] Last)</vcard:FN>
  <vcard:EMAIL>Email address</vcard:EMAIL>
  <vcard:ORG>
    <vcard:OrgName>Organization name</vcard:OrgName>
  </vcard:ORG>
</dcterms:rightsHolder>
</res-meta>
<map>
  <concept-list>
    <concept/>
    ...
  </concept-list>
  <linking-phrase-list>
    <linking-phrase/>
    ...
  </linking-phrase-list>
  <connection-list>
    <connection/>
    ...
```

Appendix A. CXL File Format

```xml
</connection-list>
<resource-group-list>
    <resource-group>
        <resource/>
        ...
        </resource-group>
        ...
    </resource-group-list>
    <proposition-list>
        <proposition>
            <prop-conn/>
            ...
            </proposition>
            ...
        </proposition-list>
        <not-a-proposition-list>
            <proposition>
                <prop-conn/>
                ...
                </proposition>
                ...
            </not-a-proposition-list>
            <concept-appearance-list>
                <concept-appearance>
                    <localized-style/>
                    ...
                    </concept-appearance>
                    ...
                </concept-appearance-list>
                <linking-phrase-appearance-list>
                    <linking-phrase-appearance>
                        <localized-style/>
                        ...
                        </linking-phrase-appearance>
                        ...
                    </linking-phrase-appearance-list>
                    <connection-appearance-list>
                        <connection-appearance>
```
Appendix A. CXL File Format

```xml
  <control-point/>
  ...
  </connection-appearance>
  ...
  </connection-appearance-list>
  <resource-appearance-list>
    <resource-appearance/>
    ...
    </resource-appearance-list>
  <style-sheet-list>
    <style-sheet>
      <map-style/>
      <concept-style/>
      <linking-phrase-style/>
      <connection-style/>
      <resource-style/>
      </style-sheet>
    ...
    </style-sheet-list>
  <extra-properties-list>
    <properties-list>
      <property/>
      ...
      </properties-list>
    ...
    </extra-properties-list>
  <extra-graphical-properties-list>
    <properties-list>
      <property/>
      ...
      </properties-list>
    ...
    </extra-graphical-properties-list>
  <image-list>
    <image/>
    ...
    </image-list>
  </map>
</cmap>
```