Scaling a mobile tutoring project: strategic interventions in C³TO

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Abstract

Scalability is a critical characteristic for successful software solutions – especially networked software and social software. Scalability can be defined as how well the software solution works when the size of the problem increases. Dr Math was a software platform which provided help to primary and secondary school pupils with their mathematics homework. Tutors used traditional workstations and pupils used Mxit on their cell phones. The original implementation of Dr Math was designed for no more than approximately fifty pupils. When Dr Math unexpectedly started receiving queries from hundreds and then thousands of pupils, it was found that the original implementation did not scale. It did not work well when the size of the problem increased. C³TO (Chatter Call Centre/Tutoring Online) is a scalable platform for online, mobile tutoring which solves the problems encountered with the original Dr Math implementation. The need for scalability underpinned the design of C³TO. The features implemented in C³TO which specifically address scalability can be divided into three different groups: technical features, tactical features, and strategic features. This paper specifically addresses the strategic interventions found in C³TO.

Keywords: C³TO, Mxit, math, cell phones, scalability.

1. Introduction

The *scalability* of a software solution can be defined as how well the software solution works when the size of the problem increases (Macri 2004). The concept of scalability is not limited to software. Different industries have different issues in scalability.

Consider the differences between increasing the number of users of cell phone service vs increasing the number of users of a landline telephony service. In the first case (the cell phone service), a client purchases a cell phone and is often immediately able to use the service. In the second case (a landline telephone service), telephone poles may have to be erected, cables may have to be strung, etc, before the client can use the service. It is much easier to add clients to the cell phone service than to add clients to the landline telephone service. The cell service is easier to scale.

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Consider the differences between increasing the number of pupils at primary school vs increasing the number of students taking a correspondence course (or distance learning course). In the first case (a new pupil at a primary school), the new pupil needs a desk, a locker, and depending on the school budget, may receive books, notebooks, paper, and pencils. The pupil will need access to water, ablutions, the canteen, and possibly even hostel facilities. In the second case (a new student on a correspondence course), the new student merely needs to be mailed a parcel of documentation. It is much easier to add a student to a correspondence course than to enrol a pupil in a physical school. The correspondence course is easier to scale.

In the case of software, especially networked based software and social networking software, the total number of users will continually increase (Laitinen, Fayad & Ward 2000). When providing software services, scalability involves various considerations. If a new "user" is added to a system, he or she will require resources such as storage space, bandwidth, processor power, and administrator time. Depending on the software application involved, the storage space required may be minimal (a place to store a name and address) or substantial (as in storage of videos and images). Bandwidth also varies depending on the software application (compare Wikipedia which is predominately text based to YouTube which is predominately video based). And processing requirements varies per application (compare an email server vs a gaming server).

It is therefore critical that when considering scalability that one considers capacity planning. Problems in capacity planning manifest themselves through non-availability symptoms (i.e. slow response times).

This was also the case with Dr Math. Dr Math is a mobile, online tutoring environment where primary and secondary school pupils can use Mxit on their cell phones and get help from university students (who are using full sized computer workstations connected to the internet) in order to get help with their mathematics homework (Butgereit 2007a).

2. Brief history of dr Math

Dr Math was started in January, 2007. It was a research project aimed to answer the question "Will pupils use their own personal cell phones, at their own personal costs, with their own personal airtime in order to get assistance with mathematics homework?" At that point in time, the researchers considered the possibility that the pupils (especially teenagers) might think that mathematics would "contaminate" their cell phones. A cell phone is such a personal possession (almost akin to a toothbrush) that perhaps young people would not want educational material on their cell phones at all.

During the early days of the Dr Math project, researchers expected no more than 20, 30 or maybe 50 pupils to take part in the project. Within a few months, however, there were hundreds of pupils asking Dr Math for help with mathematics homework. Within a few subsequent months, more than a thousand pupils were using Dr Math. The early days of Dr Math are well documented (Butgereit 2007b, Butgereit 2008b, Butgereit 2008c).

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As more and more pupils started using Dr Math, however, it became obvious that the software could not handle the increased load. As the numbers reached a few thousand pupils, response time degraded. In retrospect, this should be expected of a solution which was initially designed for approximately 50 users and now had 4000 users. In a specific educational pilot using Dr Math, Butcher (2009) found delays occurring on the platform and some pupils were waiting un unacceptable amount of time for responses from tutors.

It was necessary to redesign the platform with specific focus on scalability issues.

3. How C³TO tackles scalability issues

C³TO, Chatter Call Centre/Tutoring Online, tackles scalability issues on three levels:

1. Technical level
2. Tactical level
3. Strategic level

The technical level is concerned primarily with "what" was used to implement C³TO. Technical level features included items such as Linux, Jboss, Mobicents, Seam, Postgresql, and JSF (Java Server Faces). The tactical level is concerned primarily with configurability concerns and security concerns. Being able to completely configure C³TO over the internet is a tactical level feature. Security features which ensure that the Internet access is safe are tactical level features. The various features and components at the technical and tactical level have been well documented (Butgereit & Botha 2010).

The strategic level is concerned primarily with trying to answer the pupils' questions before linking them up to a tutor. The human tutors are the scarce resource in C³TO and their time is extremely valuable. The strategic level facilities attempted to give the pupils answers to their questions without taking up valuable human tutor time.

Managing the capacity of C³TO can be seen as a balancing act between three opposing forces arrayed in a triangle. At one point on the triangle, we have the objectives of the project – better mathematics skills. At a second point in the triangle, we have the pupils desperate for help in mathematics. And at a third point in the triangle, we have the scarce resources of the tutors.

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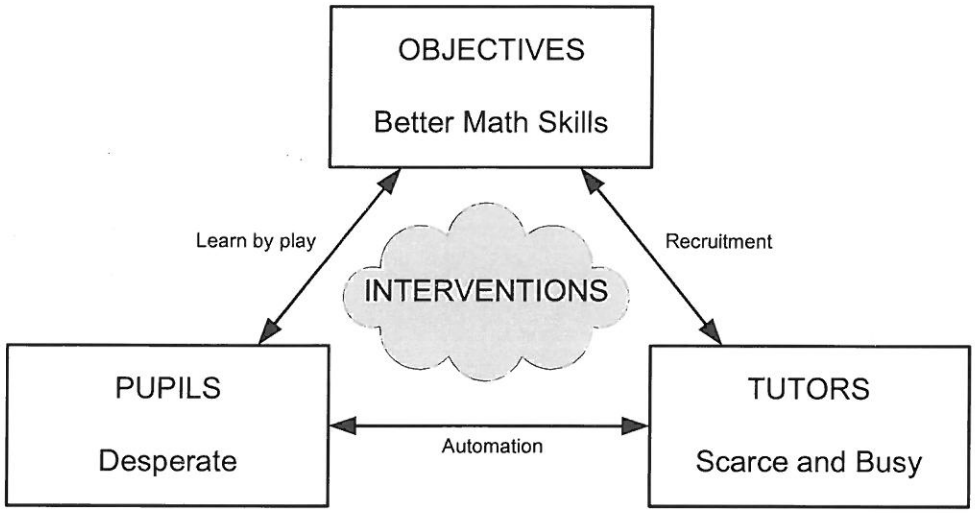

The features that help keep these forces in balance are the various technical, tactical, and strategic level features of the C^{3}TO architecture. For example, the ease in which tutors can volunteer, register and be managed by a system administrator on C^{3}TO is a tactical feature (or configuration-type feature).

The remaining portion of this paper deals primarily with the various strategic interventions in scaling a mobile, online tutoring environment.

4. Strategic level features

Strategic Level features attempt to protect scarce human tutor resources by providing answers for pupils without requiring human tutor intervention. This is done by the implementation of various "bots" or automated replies. These "bots" can be grouped into two broad categories: work and play.

The "bots" in the "work" category attempt to provide information to the pupils in order to answer the pupils' questions without requiring access to a tutor. These "bots" include:

1. Scientific calculator
2. Lookups of static data
3. Web Scrapes.

The work "bots" provide traditional information about mathematics similar to what a pupil would find in a textbook or at the school library.

The "bots" in the "play" category attempt to provide the pupils with fun and enjoyable activities in which they will learn and practice mathematics while they are having fun. These "bots" include:

1. Arithmetic/algebraic skills competitions
2. Multiple choice quiz competitions

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3. Single user text adventure games
4. Multi-user text adventure games
5. Leader board.

The play "bots" also provide activities to pupils who are bored and who would otherwise just want to chat with a tutor about non-mathematical topics.

Both of these types of "bots" or automated replies give the mobile pupils information without interfering with human tutors. Besides protecting scarce resources, these strategic level features are available all the time providing information to pupils when tutors are not actually logged in and available.

5. Work bots

The "bots" which can be classified as "work bots" provide traditional information about mathematics and other school topics.

5.1 Scientific calculator

During the early days of Dr Math, tutors were surprised at the number of mobile pupils who asked tutors to do calculations. When queried, it became apparent that numerous pupils did not have access to a calculator – scientific or otherwise. In addition, many pupils who did have cell phones capable of running scientific calculator programs did not want to leave Mxit in order to use the calculator program.

In order to protect tutors from wasting time doing calculations, a scientific calculator "bot" was implemented using JFEP – Java Fast Expression Parser. This is Java library released under the Apache License, Version 2.0. It supports all the traditional arithmetic calculations (addition, subtraction, multiplication, and division) and also includes modulus and power.

In addition, all of the trigonometric functions (sin, cos, tan, asin, acos, atan) are provided including more advanced hyperbolic functions (sinh, cosh, tanh, asinh, acosh, atanh). Logarithmic functions (including the natural logarithm) in base 10 and base 2 are also supported.

Unfortunately, the trigonometric functions operated in radians. Since few high school pupils are familiar with radians, C³TO added an additional set of simple trigonometric functions which specifically operated in degrees (dsin, dcos, dtan, adsin, adcos, adtan).

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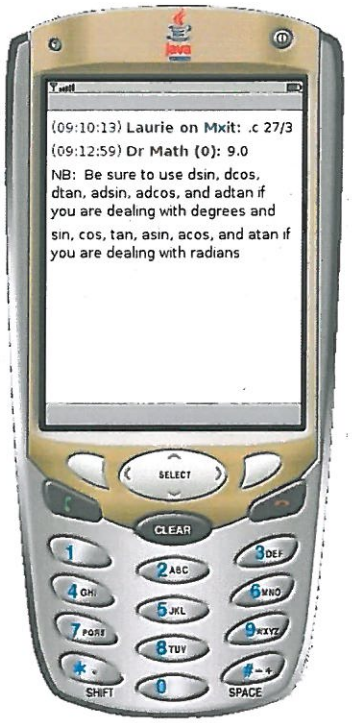

5.2 Lookups of static data

C³TO supports an unlimited number of administrator (or expert) defined collections of static information. In the case of Dr Math, these collections include lists of common mathematics definitions (such as "equilateral" and "isosceles") and common mathematics formulae (such as "area of a circle" and "Pythagorus").

It is easy for a C³TO administrator (or expert) to create these collections of static information using a web interface. Mobile pupils can easily find this static information via Mxit on their cell phones. Tutors can also refer mobile pupils to these static lookups if the tutors are extremely busy.

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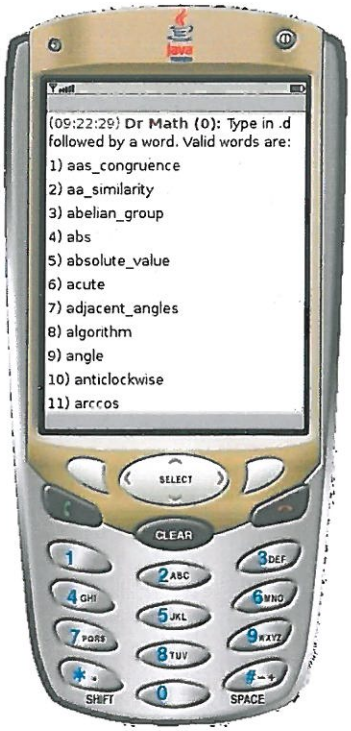

5.3 Web scrapes

Although the static data is used often by the mobile pupils, the pupils still ask the tutors for information which is unrelated to mathematics for projects in other classes. For example, pupils would ask about planets, countries, famous people, etc.

The web scrape facility allows a C³TO administrator to configure a scrape of an encyclopaedic website. The first implementation of this facility was to access Wikipedia. Wikipedia is a free content, multilingual encyclopaedia which is collaboratively written by authors all over the world (Denoyer & Gallinari 2006). Mobile pupils would send a request to the Wikipedia "bot" implemented in C³TO and that "bot" would forward it onto Wikipedia. The resulting introduction and table of contents would be returned to the mobile user. The mobile user could then easily navigate through the table of contents to find information.

From reviewing the log files, teenagers send numerous requests with terms about sexuality and celebrities (such as pop stars, actors, singers, etc.). Wikipedia cannot be considered to be pornographic in any way and eventually the pupils start searching for good information in various courses.

Common search terms indicate that pupils are looking up information in science classes (physics, biology, and health especially). A quick look through the log files of C³TO reveal searches for terms such as cyclones, chromosomes, Newton, genetic disorders, pollution, hydrogen, momentum, Kyoto Protocol, ionic bonding, and Mars.

In addition, pupils are also using the web scrape to look up information for literature classes. By reviewing the log files, it is clear that high school pupils are still studying *Lord of the Flies* and are still studying works by Sylvia Plath. Other common search terms which indicate that pupils are looking for information for literature classes include mockingbird, English novel, and Oxford dictionary.

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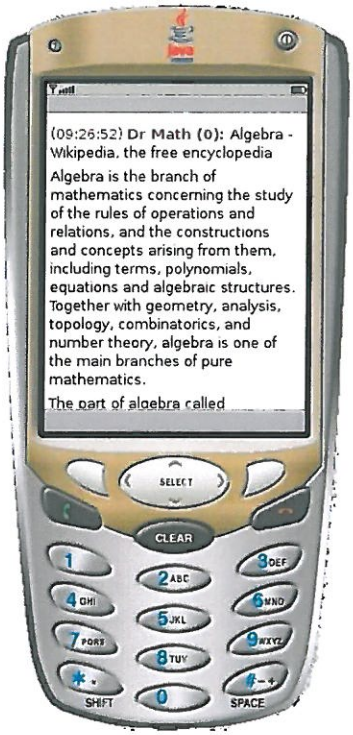
Pupils are also using the web scrape to look up information for social science classes. This is evidenced by searches for Nelson Mandela, Sir Seretse Khama, Barack Obama, Zulu royal family, and South African culture.

The log files also show that pupils are concerned about their further education and career choices. Common searches which indicate this include meteorologist, mining engineer, chartered accountant, university of Cape Town, MTech, BTech, and bursary letter.

The Wikipedia web scrape provides important information to the mobile pupils 24 hours a day regardless of whether tutors are available or not. When tutors are available, they often refer mobile pupils to the Wikipedia facility when the questions are not specifically on topic and when tutors are rushed for time.



6. Play bots

The "bots" which can be considered to be Play Bots provide games and competitions where pupils can practice their mathematics skills in an entertaining and enjoyable environment. They also provide a place where bored teenagers can be entertained without interfering with tutors.

6.1 Arithmetic/Algebraic skills competitions

During the early implementations of Dr Math, prior to C³TO being implemented, younger mobile pupils often asked the tutors to "Test me on my 5 times tables" or "give me an addition sum". Tutors often spent valuable time merely generating calculations for pupils to do.

The arithmetic/algebraic skills competitions are "bots" which generate calculations and check to see if the mobile pupils' response is correct. This is done in a competitive manner with "top scores" being maintained.

This facility was actually originally implemented during the previous implementation of Dr Math.

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The educational aspects of these skills a competition has been documented previously (Butgereit 2008a). The competitions have proven to be so popular with mobile pupils that they have been ported and expanded on C³TO. A brief summary of the competitions is repeated here with emphasis on how it relates to scalability.

Competitions exist in the following arithmetic/algebraic skills:

1. Addition – addition of two positive integers from 1+1 up through 14+14
2. Subtraction – subtraction of two positive integers where the difference is a positive integer from 2-1 up through 28-14
3. Multiplication – multiplication of two positive integers from 2x2 up through 14x14
4. Division – division of two positive integers where the quotient remains an integer from 2/2 up through 196/14
5. BODMAS – order of operations with positive integers where the result is a positive integer using mixed operations and parenthesis such as 4 + 10 / 2
6. Times tables – specific multiplication competitions where one number is constant. For example the 5 times tables or the 7 times tables
7. Addition and subtraction of positive and negative integers – addition and subtraction of positive and negative integers ranging from -14 to +14
8. Multiplication and division of positive and negative integers – multiplication and division of positive and negative integers where any quotient is also an integer.
9. Simultaneous linear equations – two equations in the form y=mx+b where the intersection point has integer coordinates between -14 and +14
10. Prime factors of a number – finding the prime factors of a number
11. Simple Interest – calculation of simple interest finding either the interest rate, original principal, resulting value, term, or interest accrued where all values are integers or multiples of R100.00
12. X-intercept – finding the x-intercept or the root of a straight line given in the form y=mx+b where the root is an integer between -14 and +14 and all coefficients are integers
13. Roots of a 2^{nd} degree polynomial – finding the roots of a 2^{nd} degree polynomial given in the form $ax^2+bx+c=0$ where the roots are integers between -14 and +14 and all coefficients are integers
14. Factors of a 2^{nd} degree polynomial – find the factors of a 2^{nd} degree polynomial given in the form ax^2+bx+c where the roots are integers between -14 and +14 and all coefficients are integers

The rules of all the competitions are the same:

1. The pupil is given the current alias of the current "top score" and the current score (such as 90%)
2. The pupil is given 10 calculations and is given his score after each calculation
3. If the new pupils ties or betters the previous "top score", then this new pupil becomes the "top score"
4. The previous "top score" is sent a message telling him or her that he or she has been displaced as the "top score" and invites him or her to return to reclaim the title
5. If the current competitor is the "top score" and is doing more than 10 calculations and begins to make mistakes, his or her score can drop.

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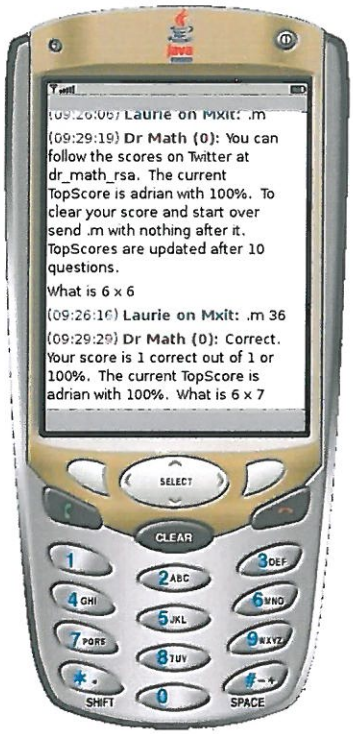
From analysis of the log files, these competitions are embarrassingly popular. Pupils will often play on and off over a 20 hour period to remain the "top score".

In addition to being popular and helping pupils practice skills, the tutor can also refer pupils to the competitions once the tutor is sure that the pupil understands the theory behind some type of calculation. This frees up the tutor to assist other pupils.



6.2 Multiple choice quiz competitions

The Multiple Choice Quiz competition was an attempt to duplicate the success of the arithmetic/algebraic competitions but for topics which were not necessarily mathematical. Administrators or experts could create multiple choice questions such as "What is an isosceles triangle?" The administrator or expert would then provide 3 or 4 alternative answers:

1. A triangle with 2 equal sides
2. A triangle with 3 equal sides
3. A triangle with 4 equal sides.

The administrator or expert would indicate which answer was the correct answer.

This facility has the potential to be as popular as the arithmetic/algebraic competitions but it has not yet achieved its potential. The drawback is the amount of work required of the administrator or expert. In order to have a good random collection of 10 questions, at least 100 questions (and ideally 200 questions) need to be entered into the database.

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Each of these questions needs to have 3 or 4 answers. That is a lot of work for the administrator or expert.

In the case of the Dr Math implementation on C³TO, one such multiple choice quiz competition was created for common geometry definitions and terms.

6.3 Single user text adventures games

Single user text adventure games were some of the first types of computer games available. These text adventure games allow a player to interact with a map or " dungeon" of rooms. Simple movement commands such as "Go north" allow the player to navigate. A simple action command such as "Open the window" allows the player to interact with the environment (Lebling, Blank & Anderson 1979).

Prior implementations of Dr Math supported simple text adventure games (Butgereit 2009). This facility has been ported and expanded in C³TO in order to keep mobile pupils discussing and thinking about mathematics and science without impacting on the human tutors.

The single user text adventure game "Dr Math's Missing Laptop" invites the player to wander through an office block searching for Dr Math's missing laptop computer. The office block is populated with doors and safes which have digital keypads. Formulae for the secret codes are written on walls in the virtual world. For example, if the player types in the message "inspect whiteboard", the reply would be "the pin for the door is 81/9" (where the formula listed is created by a random number generator ensuring that the quotient remains an integer).

In addition, various objects are placed around the virtual office block such as a cell phone (which needs a pin code), a calculator (to assist the player if the calculations are too difficult) and a math textbook (when more detailed information is needed).

6.4 Multi user text adventure games

Multi-User Text Adventure Games (also known as MUDs for Multi-User Dungeons) were also implemented in C³TO to further attract teenagers to mathematics and science.

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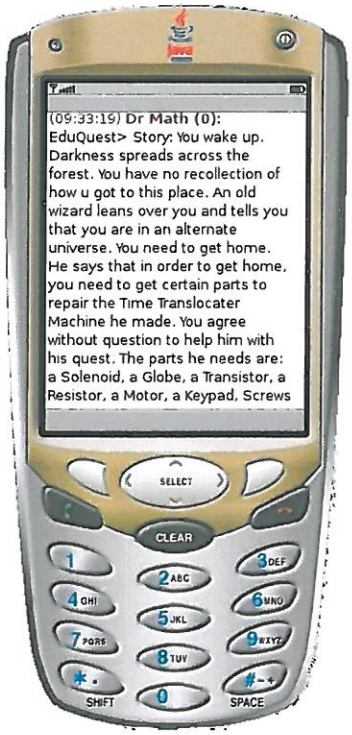

This addition to C³TO was done in conjunction with students from the University of Pretoria (Butgereit et al. 2010). These multi-user games were similar to the single-user games with the added feature that players could interact with each other inside the various rooms in the virtual world. Due to the nature of the relationship with University of Pretoria, it is hoped that one or two new multi-user games can be added to C³TO each academic year.

6.5 Leader board

As mentioned above, all of the competitions keep track of the "top score" and encourage competition and repetitive attempts to remain the "top score" thereby increasing the number of calculations a pupil will do.

From analysis of the log files, however, it was clear that once a pupil began to compete, he or she very quickly started scoring 100% on the simpler competitions such as addition and multiplication. From a psychological point of view, this gave the pupil good, positive, successful feelings about mathematics. Some pupils did hundreds of calculations in order to remain the "top score". C³TO needed another mechanism for rewarding these pupils.

A pupil needs to obtain 100% in order to be placed on the leader board. The leader board keeps track of the number of times a pupil obtained 100% in a competition. That means that if a pupil has the score 50 on the leader board, that indicates that the pupil has obtained 100% on 50 competitions of 10 calculations each. Doing the math, that means that the pupil has done 500 calculations perfectly.

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From analysing the log files, it is clear that there are times where two or more pupils are competing with each other for placement at the top of the leader board not just merely competing to be the "top score".

At the time of writing this paper, a number of the competitions have leader board scores in the low hundreds indicating that pupils have done more than one thousand correct calculations.

7. Conclusion

Scaling a small software research project where a small number of users are expected up to a large production project can be challenging. This was especially true in the case of Dr Math where pupils could get help with their mathematics homework by using Mxit on their cell phones. A new platform, C³TO was developed to host Dr Math and to specifically address the issue of scalability.

C³TO tackles the problem of scalability on three different levels: the technical level, the tactical level, and the strategic level. The technical level addresses the components which are used to build C³TO. The tactical level addresses how these components are configured. The strategic level attempts to answer questions from pupils without referring pupils to scarce resources.

This paper specifically covers the strategic level resources or facilities which were implemented in C³TO.

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