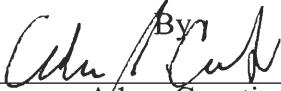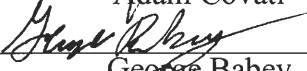# Material Point Method Courseware

An Interactive Qualifying Project
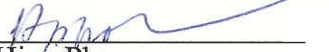
submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE
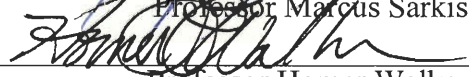
in partial fulfillment of the requirements for the

Degree of Bachelor Science

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3 Abstract

The goal of this project is to create Internet-based courseware for teaching the Material Point Method (MPM). The MPM is a mathematical method for describing collisions and deformations between solids by analyzing the objects on a particle level. Providing novice to advanced levels of textual and graphical mediums, the courseware is a powerful learning tool for all users. By taking advantage of technologies, such as C++ (with OpenGL), PERL (with gd), HTML and JavaScript, this goal has been successfully met.

4 Introduction

Since the realization of the Internet as a tool for the masses, people have been using it to make their lives easier. Online courses are an extension of that movement. They can provide people with all the positive aspects of the classic classroom atmosphere with the added interactivity of the web.

Education on the Internet is a new and evolving area. Because it is still in its infancy its future direction is still not definite. Right now innovative courses are being developed; the success of these courses, however, is still unsure. This online course attempts to break new ground with an innovative teaching methodology that integrates sophisticated Internet technologies and conventional learning styles.

4.1 Courses on the Web

There are many questions surrounding online courses. Some of these are: Why use online courses? Are they as effective as an instructor standing in front of a class? What technology is currently being used for online coursework? These questions will be addressed in the following section about online courses.

One of the great advantages of the Internet is the ability to reach many people with ease and at a very low cost. Online courses allow a person to simply visit a website and follow a structured plan to learn about a topic. This is an exciting new approach to teaching. No longer does a person have to go through the grueling task of searching for a college or institution that offers a course in the material that they want to learn. Nor do they have to physically visit school for each class to follow the instructor's schedule. An

online course allows students to learn at their own pace, in the comfortable environment of their own homes. [Willis 2000]

The integration of text, sound, and video can allow even the most naïve users an easier time with difficult material. An online course can supply multitudes of information such as: syllabi, exercises, literary references, links to other resources on the Internet, as well as references to books and other published mediums. The list of possibilities is endless. Another advantage to online courses is the continuous online dialog between students and instructors; this takes place using several electronics mediums. A continuous dialog between instructor and student can not only help the student understand material better, but the instructor may learn new ways to explain the material to future students.

Online courses can increase the effectiveness of learning considerably in many ways. Materials being available 24 hours a day, 7 days a week cuts down on the need to request materials and allows students to access the material at any time. Different learning styles can be satisfied with different types of media (audio, video, text). Also, the ability for students to openly communicate with each other via bulletin boards, email, video, or voice conferencing allows normally shy students to participate in class discussions. [NEA 2001]

There are many different technologies available today for the Internet that can be used to create an online course. Websites such as Blackboard.com allow an instructor to create a course without any knowledge of HTML. Besides HTML generating programs and websites there is other technology that should not be ignored. Internet browsers (e.g., Internet Explorer) have capabilities to support viewing videos such as MPEG's and

AVI's. Languages such as Macromedia Flash can be used to achieve simple videos to demonstrate basic concepts to students.

Real Audio and Internet Radio are also popular means of communicating information to people. These tools can also be used to broadcast a lecture to students over the Internet in real time, or the instructors can provide the lecture as an audio or video file for students to download and listen to at a later time. These many different technologies, when combined successfully, can create an effective online course that has the ability to surpass an average classroom setting in effectiveness.

4.2 Project Objective

One major goal of this online course, or courseware, project is to create something that anyone can use. There is no assumption that students would have a high level of mathematics education prior to using the online course. Because of this, the chapters for the online course must fully explain all concepts. Not only must this online course provide basic information for beginners, it must also satiate the curiosity of those who have a better understanding of the advanced concepts of the Material Point Method.

This particular online course strives to allow students to see a physical implementation of the theories that they are studying. After learning how the Material Point Method works, they can see the results it produces. Students are also offered the ability to interact with the simulation to see how different values may affect the results. This high level of interaction not only increases understanding; it also encourages students to question how and why certain aspects work as they do. The Material Point Method courseware will help students learn about the concepts behind the Material Point Method while showing them how amazing and powerful it is.

5 Mathematical Overview

5.1 *Mathematical background for MPM*

A goal of the project was to create an online course that users of all backgrounds could benefit from. One area that the online course builds heavily upon is mathematics. To make sure that no users are alienated from using the course, there has to be no assumption about the user's mathematical abilities. Thus, the chapters provided with the tool had to contain explanations that would be understandable, even to those with little or no mathematical experience. Although including these explanations was a challenging task, it was a major goal of the project and of paramount importance.

Although not necessary, knowledge of some areas of mathematics is helpful when learning with the online course. The Material Point Method makes use of some concepts from calculus. Having knowledge of these basic concepts would help to decrease the time that it takes to learn the information provided in the chapters. Familiarity with geometry as well as some advanced topics such as elasticity and linear algebra would also help in the learning process.

Aside from knowledge of mathematics, some competence on physics would be helpful. Concepts such as Hooke's law and Young's Modulus are based in physics principles and would be easier for students to grasp with previous knowledge of these topics. This would also lead to better understanding of ideas that build upon these underlying concepts.

5.2 What MPM is and how it works

The Material Point Method (MPM) is a mathematical method, based on particles and meshes, that simulates elasticity. The MPM examines two or more objects colliding with one another while observing their interaction and deformation. The extent of the deformation depends upon different factors. One factor is the softness of the material, which is described by Young's Modulus. The softer the materials, the more easily deformed they will become. Another factor that affects the deformation is the external force. If one applies a stronger force to the materials, they will deform more than if one applies a weaker force. Furthermore, if one applies too much force, the materials will become permanently deformed. The way in which a material deforms is also described by the Poisson ratio, which states that when a block of material is stretched in one direction, the material is contracted at a right angle to the stretch [Feynman 1970].

The Material Point Method applies complex mathematical calculations based on stiffness and force to each particle. The position of each particle is updated after each time step and the cycle continues [Hobbs 2000, Sulsky 1994]. By applying these transformations to a finite number of particle of an object, instead of relying on different calculations for different types of objects, the Material Point Method can accurately model different types of objects: solids, gasses or liquids [Johnson 1996].

6 Usage and Impact of The MPM Online Course

When developing the online course there were several aspects of online design that were taken into consideration. The course needed to be designed to benefit a specific target group and account for the effects that online courses have on students. It had to be determined who would use the online course to ascertain how the course would be designed. The effects of online courses are important to know so that they can be tested for.

6.1 Target Group

When designing the course, the target group was taken into heavy consideration. This group ranges from an average person who is interested in MPM to a mathematics professor who is quite confident in his/her knowledge of MPM. This range of individuals can be broken into specific groups of people.

First, mathematics majors taking a course on the Material Point Method may be interested in supplementing their coursework by using the online course to better understand MPM. This group would be using the course for learning purposes. Second, persons who are doing research on the MPM would benefit from using the course because it allows them to see a visual representation of how MPM works. Researchers would be using the course more as a simulator than a learning tool in this case. Third are people who are not in a course involving MPM or doing MPM research, but are simply interested in it.

Even though these are the main groups that would benefit from using the MPM online course, there are many other areas in which users can also take advantage of this

exciting tool. For example, the fields of physics, mechanical engineering, and computer science can all use the online course for different purposes. The mathematical concepts coupled with the graphical abilities of the simulation software are extremely inviting for physics and mechanical engineering areas. The area of computer science would not only be interested in these facets of the online course, but also the underlying programming design of the online course, which provides excellent examples on integrating many different technologies.

6.2 Effects on Students

The general effects of online courses on students are both positive and negative. One potential negative effect of online courses is the sociological aspect. By learning via the Internet there is the possibility that the development of social skills will be lost. However, this development is more a result of an individual student's attitude, and can be overcome by the student through other activities such as group work (even via the Internet). Secondly, there is a possibility of the "out of sight, out of mind" effect occurring, in which students become overlooked by the professor. [Kennedy 2000] A professor can use an online course that simply presents the material to the students. Then the only assistance provided is references to external help and tutoring services. This, of course, will reduce the amount of work that the professor has, however, at the expense of the students. To eliminate this effect professors have to understand the learning processes of their students and then provide ways to develop these learning styles. Instead of expending saved time on other projects, professors could put this time into expanding the course or providing more help to students who may need it.

There are several studies that show the positive effects of online courses. These studies have shown that students learn better using online courses. A study was performed at California State University at Northridge with two separate groups of students. One group was taught in a traditional face-face classroom and the other group used an online course. When the course was completed the second group of online course students performed 20% better on average on examinations. Besides performing better on exams, the second group of students reported that there was greater peer-to-peer contact, more time spent on class work, and also a feeling of increased flexibility. [Schutte 1999]

Another study carried out by the New Jersey Institute of Technology over the past decade has provided some very positive results for online courses. They have discovered that the majority of students felt that the use of online courses allowed them to complete more courses in one semester than they would have without the online course. Also, students felt that they had "improved course access, better access to their professors, and the quality of learning was increased." [Hiltz 1998]

The goal of online courses is to utilize technology to improve the effectiveness of learning, and not to simply duplicate the face-to-face classroom situation. To successfully achieve this goal designers of online courses must be aware of the problems that may arise, and they must develop ways to overcome them. If done successfully the positive rewards of online courses will be realized.

6.3 Web Based Learning

An interesting aspect of this online course is that there aren't many online courses such as this one in existence. There are many online courses associated with books; the

purpose of these online courses is for students to download assignments and exams, and complete them, then send them to the professor. The MPM online course is a complete online course. Students read about the topic on the website and use the features of the website to fully understand the subject. This is completely different from previous online courses in that it is entirely self-sufficient and does not require an instructor.

6.4 Projects

The online course can be used not only as a teaching tool; it can also be used to demonstrate the Material Point Method. Anyone doing a project concerning the Material Point Method may wish to have a visual representation (i.e. a movie) to help explain certain concepts.

The simulator also has uses beyond simply demonstrating the MPM in projects. One of these uses is experimentation to see how objects interact. The ability to alter many different values makes the simulator useful for many different fields of study such as mechanical engineering, physics, and civil engineering. An incredible facet of the current simulator is that it can be developed to provide even more advanced uses that cannot be imagined currently since MPM is a new and emerging field of study.

7 Human Computer Interaction

The interface to the system performs the most important job in the eye of the user. To the user there is really no other aspect of the system; it is for this reason that the Graphical User Interface (GUI) must be easy to use, in all ways. There are many different aspects that must be considered when designing a user interface. The layout of the interface determines how well the user can navigate. Within the umbrella of layout there are many different components. The consistency aspect of the online course helps the user feel comfortable when using the interface. Layout also incorporates the organization of the components in the interface and the dimensions of the interface, which are very important for easy navigation.

Another important aspect of an interface are the components chosen to be included so that they assist the user when learning the material and do not take away from the learning experience. Aesthetics involve the visual characteristics of an interface. Specifically the aesthetics of a web page are the color schemes, the font types and sizes, background colors; anything that is visual in the interface. Lastly, interactivity and control are significant parts of an interface. A high level of interactivity and control help to better the user's educational experience. Users understand material better when they are able to control how they are learning. Each of these elements of human-computer interaction is explained in more detail in the following sections.

7.1 Layout

The actual layout of an interface is one of the most important aspects. Interface layout impacts how well users may utilize an interface. With this in mind, there are

several elements of the layout that must be analyzed intensely. These elements include consistency, dimension, component organization, and also internal organization of components. Analysis, implementation, review, and further revisions to these elements create a useful and powerful interface. [The Importance of a Well-Designed Interface 2000]

7.1.1 Consistency

A high level of consistency helps in creating a web page that users will feel comfortable with using. To achieve this, many of the elements of the interface need to be standardized. This consistency allows users to feel comfortable and prevents possible confusion. It is not only important to maintain consistency within the web page, there must be a consistency with the users online and learning experiences as well. [User-Centered Design Principles 2000]

7.1.1.1 Internal Consistency

To better enforce consistency a standard set of colors will be used. This creates a more professional look and feel. This also allows the use of non-standard colors to further emphasize special features or terms. This set of colors should be restricted to approximately 4 colors for standard use. Pastel-based colors have chosen due to their soothing effects. [Schneiderman 1998]

Once these colors are chosen it is important to maintain use of those colors in an intuitive way. This means that colors should be used not only in a way that is not confusing, but also in a way that is consistent with how they have already been used in the interface. One way this is done is by maintaining color consistency from the forms

colors to the colors of the objects in the movies. This use of color helps the users to more easily identify which objects are which, and also does not introduce any extraneous and possibly confusing colors.

The layout of the text and information needs to be consistent as well. This means that the presentation of information and terms should be consistent throughout the teaching process. That consistency must also carry over to the input of data. Maintaining a similar naming scheme for variables (i.e. Poisson Ratio, Velocity) between the chapters and the input forms allows users to easily see the connection between what they learned and how they are using the simulator. [Schneiderman 1998]

The layout of the forms for data input should use logical groupings. This makes the input of data more intuitive. It also helps to reduce error. To further prevent errors, JavaScript can be used to perform error checking as the form is filled out. Error messages can be presented that describe the fault. Explanatory messages are also available to help confused users. [Schneiderman 1998]

7.1.1.2 Web Browsing Consistency

This course is accessed via the Internet, a place in which many users feel comfortable. To take advantage of this, the online course does not veer from the metaphors and conventions that are used in such an environment. These conventions include common navigation links and standard Forward and Backward links. [Web Application Interface 2000]

The form inputs used to gather data from users rely on their familiarity with standard form inputs. Without such familiarity, it might have been difficult to gather data. Standard forms allow data to be gathered without having to explain a new system

of inputs. Smith [March 2001], of IBM, recommends "The best policy is to plagiarize whenever possible (as long as you stay out of jail) and innovate when necessary". He goes on to recommend following corporate or industry standards, such as Forms.

Forms submission also takes advantage of users previous use of forms. Users have learned that clicking on a nearby button, or hitting the *enter* key, will submit a form. Although the button was aptly named "compute", the user's previous knowledge of such conventions allowed this to be performed much more easily than if this were a new concept.
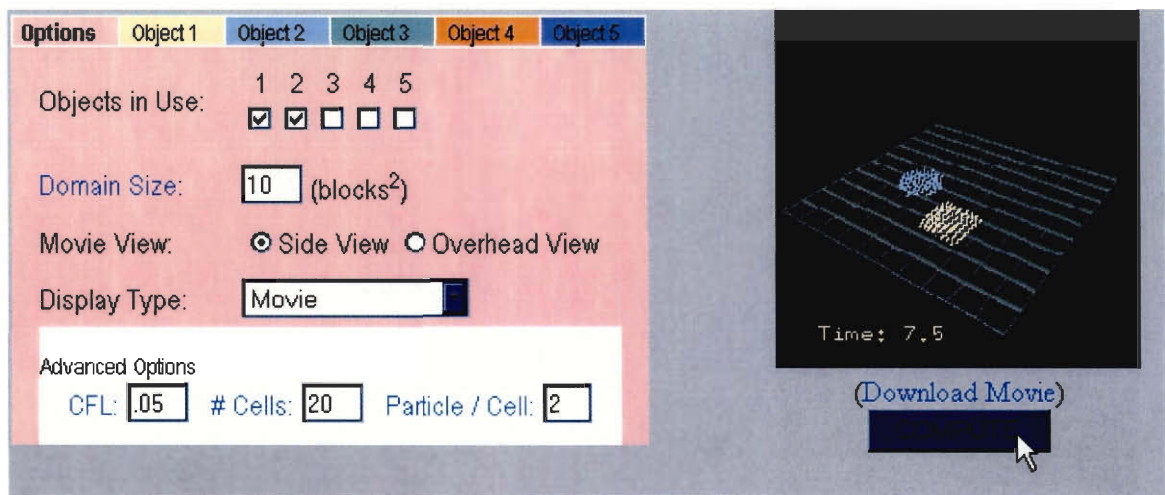
Figure 1 The Forms interface with a user clicking on the Compute Button

One reason to use familiar interfaces is to avoid overwhelming the user with something new. Internet users have been seeing similar interfaces on the Internet for some time now. There have not been any truly innovative interfaces for a while. While it is nice to create an innovative interface, there is a certain loss that comes with such a creation. Users do not feel comfortable, and cannot navigate with as much ease as with familiar interface.

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This is one of the reasons a new technology like Macromedia's Flash was not chosen. Although Flash has become very popular among web designers, it has also received much criticism. One of the reasons for this criticism is that Flash encourages non-standard controls. The current control objects, such as a scrollbar, are well familiar to computer users. For this reason it is best to use a familiar format for a web interface. [Smith 2001, Nielson 2000]

7.1.1.3 Learning Consistency

The Material Point Method courseware is consistent in many ways with classes that users have attended as well as self-learning they have done. This consistency is achieved by emulating both books and lectures within the chapters. The chapters are written in a book form, making use of chapter and page metaphors, but they also take on a lecture-esque style. Straightforward explanations of formulas and concepts attempt to make difficult ideas easier to grasp. Providing both the complex and basic explanations of ideas helps to serve both advanced and beginner users.

Different people learn in different ways; there is no definite understanding of why this is or how it works. Some people are more responsive to hearing information, some prefer to see it in text form, and others prefer to see visualizations. The Material Point Method courseware presents users with many different styles of learning tools to accommodate as many people as possible. Users are provided with textual explanations of the method and its principles. Users may also see visual representations of the method in action. Some people may get a better feel for how the Material Point Method works by changing parameters and running different types of simulations; the Material Point Method courseware supports this style of learning as well. [Winters 2000]

7.1.2 Component Organization

Although the simulator interface and the chapters are next to each other on the page, there is a clear separation between the two. Much as one would keep a calculator on their desk while filing his or her taxes, the simulator interface needs to be separated from the chapters but still readily available for the user to access. The hope is that while reading the chapters, the user can alter the values they just learned to further their understanding of the topic. By combining both the traditional textbook-style learning process with a more hands-on style, the courseware can be useful to users with different learning styles. This required a clear division between the components, while keeping the two easy to switch between; the organization of the components would be crucial.

One decision made was to present the user with all of the components on the screen at the same time. By not using separate pages for the simulator interface and the chapters, this encourages the users to combine the two, using the simulator interface while reading the chapters, and reading while using the simulator interface. Had the two components been separated with two different pages, the user would have been discouraged from using the two at the same time.

It was decided to put the simulator interface at the top of the page to grab a visitor's attention. Similar to everyday tasks, it is expected the user will read top-down, and therefore be more likely to be drawn into the simulator interface (see Default Values for another crucial part in this step), which should captivate the user, appealing to their inquisitive side, and drawing them to investigate further.

Another decision faced in component organization was how to display the results of the simulation. One option was to have the results of the simulation placed where the

parameters had been previously entered. This would have confused the user, due to a change in consistency. Having the movie and the parameters being displayed at the same time allows the user to look back on what parameters they have chosen. With five objects, and each object containing ten or more values, there are at least fifty parameters the user would have to remember, well over the recommended number of objects a person can remember: seven (plus or minus two). The ability to look back at what values were chosen, while viewing the movie, is a great benefit to the user. [Schneiderman 1998]

Presenting the user with a well laid-out page was a major goal and a fundamental part of making a successful online course. By presenting the courseware in a way that would grab the user's attention and still provide a logical separation of the components, the online course is easy to navigate and flows in a logical manner.

7.1.3 Dimension

The size of the interface should also remain consistent. Using a standard size allows users to find what they are looking for in the same place, no matter what section of the site they may currently be in. The size of the interface is approximately 700 pixels by 500 pixels; this size allows for visibility even in some of the more common smaller resolution monitors. This size almost guarantees that all users will not have to scroll to view all data.

A good rule of thumb is to limit the page size to a single maximized window. Usability studies have shown that users have difficulty reading and retaining information in documents that require extensive scrolling, or they may not see content located outside the current view.

[Web-Application Interface 2000]

The site created by the Augustine project does not utilize a fixed, or in any way reduced, page size. The Augustine site has one long page that contains their interactive tool and the description of how it works. This web site is comprised mainly of several long web pages containing many mathematical equations.

An informal study showed that users felt this interface was lengthy and non-intuitive. Almost all of the people in the test group noted that they did not bother to read the information. This was due in part to an overwhelming amount of information presented on each page. The Augustine web site does not present a clear general description, nor does it contain a clear path of navigation for the user. [Leurent 2000, Augustine 2001]

7.2 Interface Components

There are many components that were integrated to create a useful and easily understandable online course. These components range from forms for user input to actual chapters.

There are four main components to the online course, as can be seen in Figure 2. Forms, used for user input, provide the ability to gather information from the user. Chapters, describing how to use the simulator interface and explaining the Material Point Method, are there to provide the user with an educational experience. ToolTips provide subtle inline comments that can give the user a "quick idea" about a specific term. Finally, output, in the form of graphs and movies, gives the user visual representations of what he/she is learning.
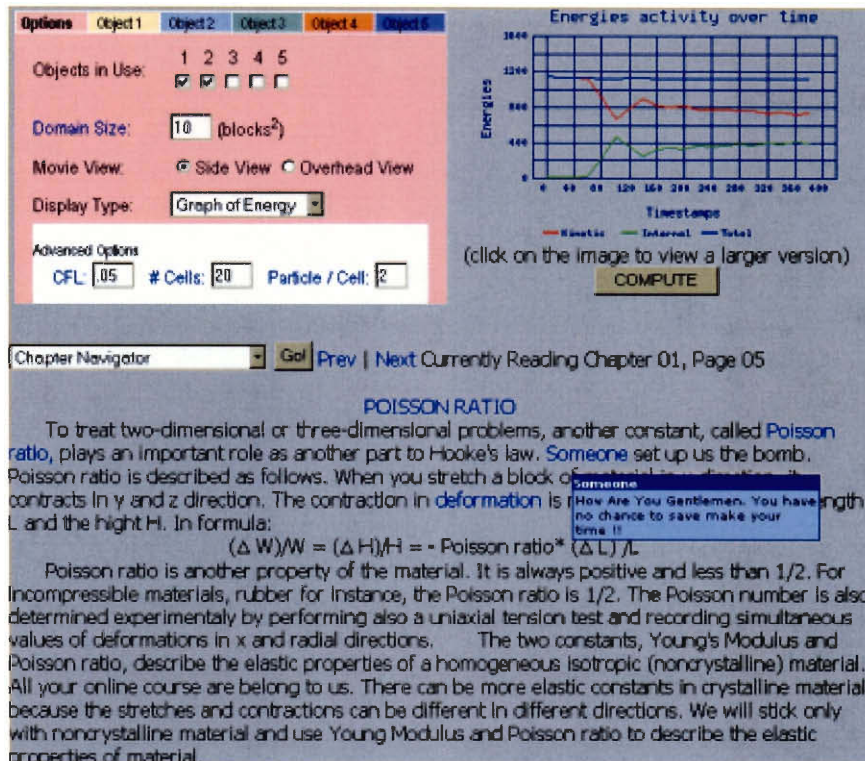
Figure 2 The Material Point Method Online Course Interface

7.2.1 Forms

Forms are an integral part of the online course. By making use of the forms, the user is able to enter an array of different values that are used when generating the movies and graphs.

There are many possible problems that need to be overcome when designing an interface with forms. Some of these problems are: long and complicated forms, unclear purpose for forms, forcing users to answer questions, taking control away from the user, and errors for incomplete or incorrect input. In the online course, however, almost none of these user problems occur.

Each form is short and displays only the values relevant to the MPM method. In other words, values used in the MPM program that the user does not have to set are not

displayed. Also, the purpose of the form is explicitly clear; the user uses the form to enter different values to generate movies and graphs. Most importantly, the forms used in this online course are present solely to give the user control over what the simulator does.

An important aspect of this control is that when a user fills in the values and computes the new values, he/she does not have to wait a long time to see the results. After only a short time of computations the user is returned a movie or graph that he/she created. The forms also initially have values in every field, so the user does not wish to, he/she does not have to enter any values.

The final problem that users have with forms cannot be avoided. The online course has to generate error messages when invalid values are entered. If this functionality was not included then the possibility of errors in the movie and graph creation is greatly increased. [Baker, 2001]

Each of the problems that forms can create are overcome in this interface. The interface was created to give the user the most control possible and not confuse the user with unnecessary information.

7.2.2 Chapters

A notable aspect of the online course is the chapters are designed specifically to assist the user when learning either how to use the simulator interface or to learn about the Material Point Method. The main goal of the chapters is to provide as much information as possible in a small amount of space. To do this the chapters had to explain the important points of MPM as specifically and concisely as possible. It is very important to not flood the user with too much information about MPM. By reducing

complexity of the chapters, the user is more interested and inspired to use the online course. This interest will cause the user to have a stronger desire to learn more about how MPM works.

The main purpose of the "How To" chapters is to assist the user when using the actual simulator interface. They provide information on how to use the forms and what values are available for entry. Also, there is a chapter that tells the user how to download or view the movie or graph depending on what operating system and browser he/she happens to be using. Finally, there are two chapters that provide helpful hints that have been discovered while developing the online course. These tips will help the user immensely. There is also a chapter that describes possible errors the user may run into and solutions to these problems.

An important point is that the chapters are very expandable. As more information is discovered about MPM the chapters should be updated to reflect the newest information. There is also expandability available for the "How To" chapters. Specifically, as new tips and errors are encountered the chapters can be updated to further assist new users of the online courseware. Overall, the goal of the chapters was to help the user better understand MPM and use the simulation interface. This goal, the group believes, has been fulfilled.

7.2.3 ToolTips

The online course seeks to teach people about the Material Point Method within a relatively short period of time. This topic is quite complex and involves many mathematical terms. These terms may be overwhelming for users at times. It is for this reason that ToolTips were added to the MPM web site. ToolTips are tips manifested in

small popup windows, as seen in Figure 3, that help the user in understanding or utilizing certain concepts or devices. As provided in the MPM Online course, ToolTips provide the user with helpful information about a concept without deviating from the current content of the page in any way. [Contextual Help 2000]

ToolTips provide help to users while they are filling in forms to control the behavior of both the MPM simulator and the individual objects that are simulated. [Figure 3]. These ToolTips provide users with an explanation of the input as well as a range for those inputs that require a discrete value. These tips allow the users to use the interface without having to refer back to the help chapters for the simulator interface.
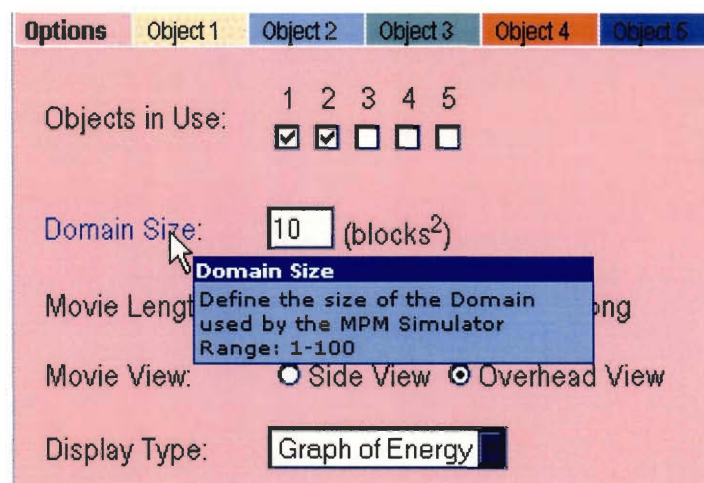
Figure 3 A ToolTip used to help understand MPM Simulator Interface Options Tab

ToolTips also help to refresh the user's memory within the chapters provided in the MPM Tutorial. These ToolTips provide quick definitions that save the user from having to bring up previous chapters if they happen to forget the meaning or significance of a term, as can be seen in Figure 4. Allowing a user to understand a term within the context of the sentence increases productivity as well as reducing potential frustration that may occur from being overwhelmed by new terms and concepts.

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MULTIDEMENSIONAL ELASTICITY (Cont'd)

The displacement of u depends on which point P we start with. U is a function of homogeneous strain in which the strain is constant over the material. For instance, we we stretch it uniformly. We just chan[strain]direction, x-d[A deformation produced by stress.] (x at the origin). The motion U_x of a spot is proportional to position x.

$$U_x / (x - x_0) = (\Delta L) / L \quad (3.2)$$

We will write U_x this way: $x = E_{xx}(x - x_0)$ (3.3) The proportionality E_{xx} is the s

$$E \quad = U / (x - x) \quad (3.4)$$

Figure 4 A ToolTip used within the MPM Tutorial

7.3 Interactivity and Control

Nielson [Jan 24, 1999] points out that the strongest advantage the web has over traditional printed media is the user engagement through non-static elements. The interface should provide users with the feeling that they are in control of the actions that occur. Users must feel that they initiate actions, whether they are actually user-invoked or not. This also means that feedback must be given within a reasonable timeframe to maintain the feeling that the user initiated the action and response. If users are not provided this type of experience then the loss of control can add to confusion and frustration. [User-Centered Design Principles 2000]

One example of user control is the appearance of error messages. Error messages should occur soon after the error has occurred. If the time that the error takes to appear is too long, then the user becomes detached from that action. Thus errors should be shown as soon as possible.

Interactive user interfaces help to attract and maintain interest. If users are unable to interact with the interface they soon feel detached and may become disinterested. This

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is very important to the MPM online course because the user is unable to interact with the site while the page and any movies or graphs are being generated. It was for this reason that great deal of time and effort was put towards reducing the time that the back-end program needed to generate the page.

8   Technical Work

In order to create the Material Point Method (MPM) courseware it was necessary to combine a number of different types of technology. The amalgamation of these different technologies needed to be carefully orchestrated in order to prevent confusion and mistakes. In doing this, a design was prepared to help visualize the web site. This design had to incorporate all of the technologies as well as the means by which they would communicate.

As shown in Figure 5 the entire system is made of several components. The Web Interface is the only section visible to the user; it is used to gather and return information. The Common Gateway Interface (CGI) script, being the central component of the backend, controls the flow of data once the web server has received a request. This script is in charge of calling other programs and passing information between them based on the arguments supplied by the user. The other programs include the MPM program, a graphing program, and the MPEG encoder.

System Flow Diagram
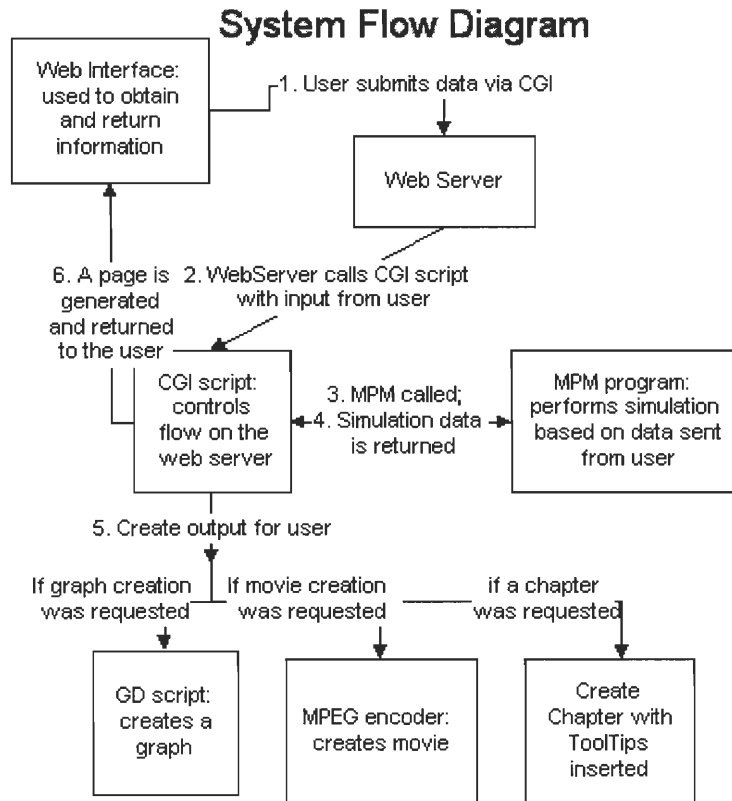
Figure 5 Design of the MPM courseware web site

The MPM program is responsible for generating the dynamic data that drives the web site. This program generates simulation data, in numerical form, from the parameters set by the user. The MPM program uses the simulation data to create image files, via OpenGL, when movie creation is requested. When called, the graphing program makes use of the numerical output of the MPM program to create visualizations of the energy levels. The MPEG encoder uses the image files generated by the MPM program to create an MPEG movie. A more in depth analysis of each of these components, as well as the involved technologies, is necessary to convey a better understanding of how they work.

8.1 The MPM Program: simulation and movies

The Material Point Method project utilized many programming languages, including two traditional languages, C and Fortran. These traditional languages provided the backbone of the Material Point Method program code.

8.1.1 C / C++

It was decided that C would be used with the help of the OpenGL library [8.2.1] to create the pictures that would then be encoded together into a movie. There are many reasons the C language was chosen. The first reason is that C is easy to maintain. Since most computer science students are taught C, oftentimes as an introductory class, there are many students who will be able to update the movie producing code. Second, C was conceived almost 25 years ago; therefore, it is a very stable language and will be continually used by programmers for a long time. Third, many libraries for C exist, such as the OpenGL library that was used for this program. This means that the movie-creation program will be expandable if further updates are needed. Finally, there is a great deal of C resources both in print and online. These resources are advantageous since most of the problems that may be encountered while using C have been found before and are well documented.

8.1.2 MPM Simulation Code

The original Material Point Method simulation code was written in Fortran. Fortran was originally an ideal language since the Fortran compilers are very good at optimizing the code to increase execution speed. Since this code would be run over the

web, where the users are oftentimes impatient, speed was the number one priority and Fortran was a good choice.

Fortran saves time by using static storage allocation, which places data in fixed locations in the computers memory. Unfortunately this means that boundaries would have to be put on such things as the number of particles. Although the speed of Fortran and the fact that the code was already written in this language were appealing, limiting the user was one disadvantage to using Fortran. Static allocation also brings up multi-user problems. Many users using the online course at the same time would use up all of the machines memory in a static memory program, dynamic memory languages, such as C, avoid such issues.

The other disadvantage to Fortran was integrating it with the C code. The Fortran MPM simulation code and the C/OpenGL graphics functions were written in different languages. With both in place, the logical solution was to integrate the two by having either the C code call the MPM Fortran function, or the MPM Fortran code call the graphics functions in C. This turned out to be more complex than previously envisioned. In the interest of conserving time and resources it was decided to convert the Fortran code to C.

In hindsight this turned out to be a good change. Having the code all in one language helps with maintenance and also better organized the flow of the code. The concern that the C code would be too slow became an insignificant detail. This is due to the OpenGL functions taking a majority of the execution time. The MPM code ran quite fast in both languages. Although it was tedious to convert the Fortran code to C, in the end, this was an excellent choice.

8.2 Graphical Technologies: making simulation movies

Once the decision to use a movie to present the user with visual output of the Material Point Method was made, the question of how to create this movie was addressed. The answer was to combine two different technologies, a graphics library for C called OpenGL would create each frame of the movie, and a movie encoder would take these frames, compress them, and combine them into the common movie format, MPEG.

8.2.1 OpenGL

OpenGL is an application programmer's interface (API), or a library of functions, for the C language that gives C programmers the ability to write complex graphic programs without having to manipulate the low-level details..

OpenGL was chosen over other graphics libraries (primarily Microsoft's DirectX) because it is highly portable, running on nearly every operating system. It is included with Microsoft Windows and the newest versions of the Macintosh Operating System. A highly compatible free API called Mesa is also available for Unix and Linux. Although the Material Point Method program only needs to run on one system, a Unix machine (using the Mesa API), the ability to port the code to a different system may prove useful in the future. [Woo et al. 1999]

Utilizing the power of OpenGL, graphics were created in both two dimensions and three dimensions. Although the Material Point Method code does not currently run in three dimensions, extending it to three dimensions is a possibility for future implementations [10.1]. A three-dimensional view was used for the "side view" which shows this flexibility.

OpenGL draws two- and three-dimensional objects into a frame buffer. A frame buffer is a temporary allocation of memory in which a picture is stored before it

presented to the user. Primitives, such as squares in the two-dimensional view and spheres in three, are used to create these pictures.

8.2.2 PPM

Once the frame buffer has been drawn, a function is called which reads each pixel and outputs it in a format known as PPM (Portable PixMap). This format was chosen because of its simplistic nature. Each pixel is written directly to the file without any compression. These PPM files are not stored long; therefore, other still-graphic formats, such as JPEG and GIF, which compress the picture, are not needed. The overhead of compressing the image is unnecessary since the PPM files are deleted a few seconds later, after the movie has been created.

8.2.3 Movies

Once each screenshot is written to a PPM file, a movie encoder takes each frame and builds a compressed movie out of this file. Due to bandwidth limitations, the movie must be delivered in some compressed form.

A codec (short for compressor/decompressor) is an algorithm used to compress a movie file. Since one of the goals is to try to make the project as platform-independent as possible and avoid forcing the user to download many separate programs, many codecs such as Real Video were not an option because they require a separate software download. MPEG-1 is a variant of the MPEG decompression algorithm developed by the Moving Picture Experts Group. This codec was chosen for a couple reasons. First, there is an encoder that is freely available from Berkeley, complete with source code. Second, the standard is widely implemented on various platforms. Windows, Macintosh, and

Unix all come standard with an mpeg player. For these reasons the MPEG-1 codec was chosen. [MPEG-1 2000, MPEG-2 2000]

8.3 Web Technologies

In creating the web interface to the MPM Online course, several evolving Internet technologies were utilized. These technologies include: Hypertext Markup Language, Cascading Style Sheets, Layers, JavaScript, and Common Gateway Interface scripts. Each of these technologies plays an important role in the web page. Without any one of them, the page would not operate. An explanation of each of these technologies is necessary to the understanding of the functions that they perform.

8.3.1 Hypertext Markup Language

The Hypertext Markup Language, known to most as HTML, is the most important of all of these. This is what all web pages are based on. HTML is the language that describes the format and layout of the pages. HTML is comprised of 'tags' that are placed within a normal text document and interpreted by the web browser. Not only does it control layout of pages, it also set fonts and positions of images. For any technology to exist in a web page it must either manipulate or be integrated with HTML. With this in mind it is easy to see that this technology was heavily used in the MPM online course, as it has a web-based interface.

HTML allows programmers to control the layout of the page. This can be done with tags that change the size, font, and color of text. Other tags such as the 'center' tag control the positioning of the text. More complex formatting can be achieved using the

table tag. Complex, even nested, tables can be created to fit the almost any page's needs using this tag. [Hall 1997]

One other very important capability of HTML is the interface it provides via Forms. Forms provide the ability for users to enter information into the page. This information can either be passed to scripts via the Common Gateway Interface or used within the page in some way. In this way the page can be made to interact with the user. [Greenspan 1999]

8.3.2 Cascading Style Sheets

Cascading Style Sheets (CSS) are used to control the formatting of a page from a broad level. Using CSS, rules can be set for all aspects of a page from a single location. This allows for better uniformity within a single page, or among pages in a site.

HTML can often be used to create the same effects as CSS; CSS is used to control several aspects of HTML including: fonts, certain tags' properties, layout, and layers all from one centralized location [8.3.3]. The advantage to using CSS is that it can alter the entire page uniformly and with minimal work. This can help to maintain a more consistent interface much more easily than HTML alone would allow.

Within the MPM online course CSS is used to control the position and size of the Layers. It is also used to make the appearance more uniform and create a visual appearance that is more appealing to the eye than simple HTML formatting would allow. [Hall 1997]

8.3.3 Layers

Layers are an extension of the standard HTML functionality. A web page is like a sheet of paper: words can be written to it, pictures drawn on it, and it can be formatted in many ways. However, objects, such as text, images, or tables, cannot be overlaid on the standard HTML 'sheet of paper'. Layers provide the extra level of functionality that can create the illusion of several sheets, or layers, of paper on a web page [Figure 6]. It is in this way that layers are used in the online course.
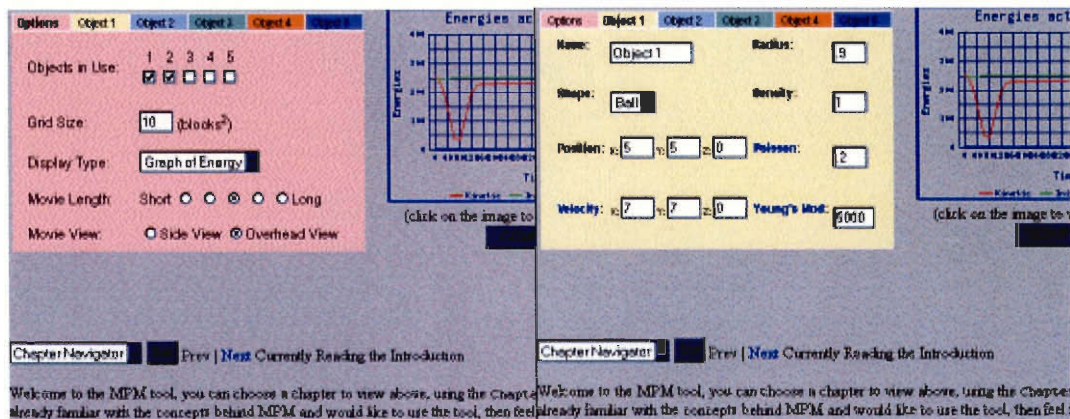
Figure 6 MPM interface showing the Option Layer and Object 1 Layer

Within the page a metaphor is provided that is referred to as 'tabs'. These 'tabs' are similar to cards within a card catalog at a library. Clicking on any one of the 'tabs' brings up the layer that is associated with that 'tab' [Figure 6]. This metaphor is helpful in two ways. Firstly, it provides an intuitive, familiar way of navigating through the forms. Users are not presented with an unnatural or cumbersome interface. It is easy for them to select which form they want, and then easily fill in that form. Secondly, it saves space. This is more important than it sounds. In web page development it is important to maintain a page that is not much larger than the screen that it is viewed in [7.1.3].

Layering the forms over each other allows a large amount of space to be used by other items.

8.3.4 JavaScript

JavaScript, as its name implies, is a scripting language, meaning that the code is not compiled into a binary executable file. Rather, it is read and interpreted by some other program. It is used primarily within web pages to control certain aspects of the page. JavaScript can be used to interact with forms, write text (including HTML, or any other text based language) to the form, and to add a dynamic aspect to a page. A nice aspect of JavaScript is its cross-browser functionality, which is not held by its competitor VBScript. Within the MPM online course JavaScript performs several vital and helpful functions.

In the Netscape version of the page [8.3.6], JavaScript plays a vital role in gathering form data. Netscape is unable to submit forms that are set in separate layers, as they are in the online course. JavaScript is capable of accessing the values in these forms. These values can then be stored in a single form by JavaScript, and that single form can be successfully submitted in Netscape.

JavaScript's ability to retrieve and set values is also taken advantage of in Form checking. The MPM online course's Forms' main purpose is to pass values to the MPM program. If these values are not within a certain range, the MPM program may perform incorrectly. To prevent this, JavaScript functions have been written to check the values that are entered. If these values are not within the correct range, or may in any other way cause problems, then the user is warned and the value is changed to an acceptable value. This allows user interactions to affect the system in real-time, creating a more interactive

feel for the user, which is often lacking with Internet applications. [Hall 1997, Miller Web Interface Design]

8.3.5 PERL - CGI and Scripting

The Common Gateway Interface (CGI) is the machine behind the web interface. CGI is used to add a certain level of dynamics to web pages. Without using CGI, or a similar technology, web pages that users see are static, or non-changing. Every time a user accesses a web page, it is the same. CGI allows programmers to create web pages that are dynamic. These dynamic pages can change based on time, system status, or any number of other things, such as user input. [Hall 1997]

User input is used by the MPM online course to create its dynamic content. When users fill in the Forms on the web page, they are actually setting parameters for the MPM program. When this information is submitted it is sent to a CGI script. This script parses the data that is passed to it and strips out the useful information. This information is then used both to call the MPM program and create the web page that is returned to the browser.

CGI scripts can be written in several different languages. This flexibility is extremely useful. Because of this, programmers may choose to use such languages as C, C++, PERL, Java, and many more. For this project PERL (Practical Extraction and Reporting Language) was chosen due to its strong regular expression parsing abilities and its simple system interface.

8.3.6 Cross-Browser Compatibility

In order for an online course to be useful it must work with all popular web browsers. A browser is a tool used to access and view web pages. The two most popular browsers are Microsoft's Internet Explorer (IE) and Netscape's Navigator, or Composer (Netscape). These two browsers work with the same types of documents, namely HTML files, images, and various other multimedia formats, which are created based on standards. Due to the evolving nature of the Internet, standards are not often created before browsers support such technologies. Even when a standard does exist, support for extra, or sometimes even standard, features varies among browsers. [Veen 1999]

In general, IE's rendering is more flexible than Netscape's in that it will attempt to render a web page even if the HTML, or other code, is not exactly the same as the standards, or that browser, dictate. IE attempts to infer what an author meant to code and render something similar to the desired output, even if it has not been written correctly. This is very important to many people because they are not experts at HTML. This is important to the MPM online course because it also allows IE to support more creative uses of HTML and associated technologies.

One of the most important aspects of the user interface is the layered Form interface. Somewhat different versions had to made for IE and Netscape because both browsers have their own mechanisms for using Layers. While this is a hindrance, it is necessary and cannot be avoided. Several workarounds had to be implemented in order to create a version of the layered Forms that worked on Netscape as it well as it did in IE.

One other difference, and one of the few that create a noticeable difference in the MPM online course, is multimedia support. Due to IE's close ties to the Windows

operating system, it has the built-in ability to play MPEG movies. This makes it possible to embed movies into the web page with little extra work. This same functionality is not present in Netscape, and so, unfortunately the inline movie is not present on the Netscape version of the site. It could be made available using a small application called a plug-in, which is installed into the browser. These small applications must be installed by the user, and are often difficult to install and don't always work. To keep the course as simple and easy to use as possible, this type of technology was not included.

8.3.7 Gd

An important aspect of the online course is giving the user the ability to create graphs on demand. It is necessary to create images on demand to show the energy levels resulting from the interaction of the objects. Creating images on demand is often referred to as 'on the fly' creation.

Creating images on the fly can be made possible via several different technologies. Some possible technologies are PERL, PHP, and C (or C++). There is a readily available package called gd that supports several different languages. This package allows for on the fly creation of JPEGs (Joint Photographic Experts Group; also JFIF) and PNGs (Portable Network Graphics). Gd was ported to PERL from the original gd graphics library written, in C by Thomas Boutell. Creating images on the fly with C/C++ or PHP is similar to PERL due to gd's availability for all of these languages.

PERL was a natural choice considering it is already being used to gather information from the users (via CGI), it makes the most sense to create the images with PERL as well. Also, using PERL for both CGI and image generation allows for a seamless interaction between the two languages. [Stein 1999]

As to which image format to use, currently both Netscape (version 4.04 and later) and Microsoft Internet Explorer support the PNG, JPEG, and GIF formats. JPEG would work as well as PNG in many areas; however, JPEG uses a lossy compression that causes the images to be less clear than a comparable PNG or GIF. GIF could not be used due to the fact that the newest versions of gd package do not support the GIF image format (for copyright reasons). For these reasons PNG will be used as the image format for all graphs. [Guelich 2000]

The gd package has incredible functionality in creating and processing images, and it directly interfaces with the PERL scripting language. There are several primitive functions that can be used to create the base image. These are: Image, Font, and Polygon. The Image primitive holds image data and accepts primitive method calls. Font holds static font information and is used for text rendering. Polygon is used for storing lists or vertices prior to rendering a polygon into an image. Each of these primitives has many functions that can be used to setup data or set many different options for graphing the final image. Gd is able to create images/graphs that contain lines, arcs, text, and multiple colors. Gd also allows the programmer to cut and paste from other images, and to perform flood fills.

The online course makes use of the gd package to generate a graph that charts the changes in kinetic, internal and total energy. The movie is the main part of the online course; it shows the paths and interactions of the objects. However, having a graph of the energies is helpful when attempting to understand what happens to the objects from a mathematical point of view.

9 Survey

To test the effectiveness of the project we presented a group with the online course; they were also asked to fill out a survey after completing the course. This survey was designed to gather information about the course, in terms of the value of the course and effectiveness of the interface.

The group selected for this trial was known to have a reasonable mathematical background. However, no background on the Material Point Method or other directions was provided for these people prior to using the online course. Background and supplemental directions were not provided because this is accomplished via the online course.

9.1 Creating the Survey

It was important to create a survey that was both easy to understand and complete. In order to produce such a survey we iterated through several steps. One of the first and most important steps is to understand the target group. Because the survey was not forced upon the users we wanted to make it simple and easy to complete. By having a more simple survey, which takes little time to fill out, people would be more willing to contribute their opinions. Once we understood our target group the next step was to decide what information would benefit development of the online course.

We specifically wanted to determine how easily people were able to use the course, both in terms of information presented and access to that information. This information is important because it helps to rate the success of the course, while assisting

in further development. After selecting the desired information, also taking into account our target group, we were able to decide which type of question structure should be used.

Of the several types of possible questions, it was decided that close-ended questions with ordered choices would be the easiest method for the respondents. This method is easiest for respondents because it is less demanding of them; they only have to select from labeled options. Other types of questions (Table 1), such as open-ended or partially close-ended questions, involve respondents formulating their own answers. Another type, close-ended with unordered choices, can be confusing for respondents, so it was decided to order the options in a logical way. (Dillman 1994)

Question Structure	Properties	Pros	Cons
Open-ended	Respondents formulate own answers, usually produce many different responses	Take little time to write, useful for topics researchers aren't familiar with, helpful when follows close-ended questions, useful if precise info is needed	Demands a lot from the respondents, does not provide consistent, comparable info, takes lots of time to analyze results
Close-ended w/ ordered choices	A complete range of answer choices are provided	Less demanding for respondent, easier to code and analyze than open-ended	Questions take more time and are harder to write
Close-ended w/ unordered choices	Choices are provided but they don't fall on a continuum	Questions are easier to code and analyze	More difficult to answer than when ordered choices are provided, takes more time to write questions
Partially close-ended	Choices are provided and space is left for respondents to fill in their own answer.	Questions are easier to code and analyze	Questions take more time to write and answers are more difficult to code and analyze than completely close-ended questions.

Table 1 Survey Question Structure [Goodwin 2000]

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As can be seen in Table 1, close-ended questions with ordered answers put little strain on the respondents and are easy to code. Coding is the act of turning survey responses into values that can be used in results analysis. Within the survey positive answers to the questions are equivalent to the value 1, negative answers are equivalent to 5. The only problem with the close-ended questions with ordered answers structure is that questions and responses must be more carefully worded. Extra care is taken to ensure that all biases are eliminated and that a high level of clarity is maintained.

Once the focus of the survey has been decided, the actual questions that would cull such information need to be determined. Once potential questions have been prepared, they must be reviewed thoroughly. Repetitive review is performed to guarantee that the questions are clearly worded and contain no biases. This repetitive analysis coupled with the previous steps culminated in a strong, yet simple, survey. (Dillman 1994)

9.2 Analyzing Survey Results

The results from the survey show a very positive response towards the online course. As can be seen in Figure 7, the average response to each question was no higher than 3, which represents a neutral response. This shows that people did not have negative feeling towards the interface.

Although the results were positive, there are several reasons why they were not as high as expected. Due to time restrictions, the users were only able to use the course for a limited amount of time. This is counter to the flexibility inherent in online courses, and may have had adverse effects on the survey.

Question Key	1 Represents	5 Represents
1. How easy is it to navigate between the chapters?	Very Easy	Very Difficult
2. How do you feel about the speed of the Tool?	Very Fast	Very Slow
3. How appealing are the colors?	Very Appealing	Very Unappealing
4. How easy to understand are the graphs?	Very Easy	Very Difficult
5. How easy to understand are the movies?	Very Easy	Very Difficult
6. How clearly do the Chapters explain the aspects of Material Point Method?	Very Clear	Very Confusing
7. How well did the chapters compliment the Tool?	Very Well	Very Poorly
8. How adequate was the help on how to use the Tool?	Very Helpful	Not Helpful at all
9. What are your general feelings about the entirety of the information presented here?	Very easy to understand	Very difficult to understand
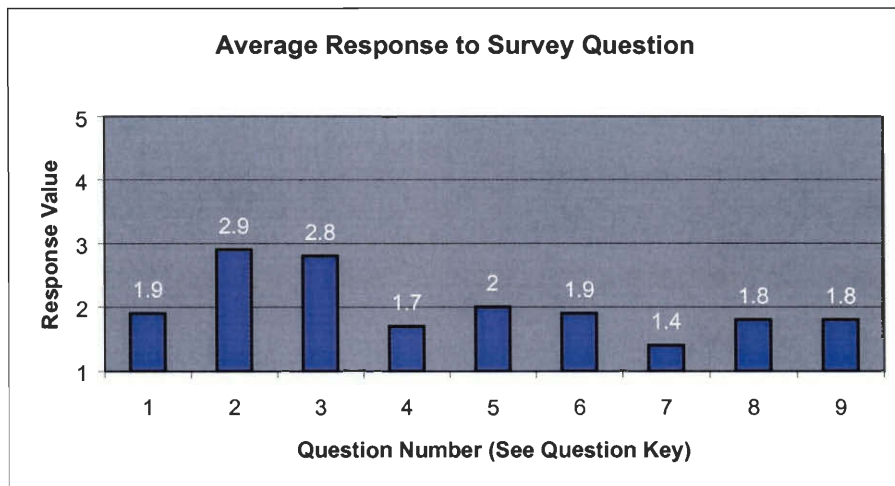
Figure 7 Average Results to Quantitative Survey Questions

A closer review of Figure 7 shows that the speed of the online course received the least favorable responses (question 2). This could be somewhat attributed to the slow speed of the machines that were used for the test group session. Those machines in particular (Unix terminals, using Netscape) are not optimal for viewing the site, and only provide the lowest level of functionality. These machines were used only due to resource limitations. The online course performs better on Windows-based machines using Microsoft Internet Explorer. As seen by the demographic data, this is actually the most popular browser among the test group [DEMO TABLE]. Another reason for the

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decreased speed of the online course may have been high server load. Hosting the site on a dedicated server, rather than on WPI's central web servers, could easily alleviate this.

Similar results were seen on the survey questions referring to the color scheme (question 3) used by the online course. Although this score does not correspond to a negative reaction, it shows that perhaps the respondents would have preferred different color schemes. This could also be attributed to the poor color palette present on the Unix machines that most of the users were on. This perversion of the true color scheme may have been a source of discontent for the users.

Several of the average values seen in the survey results were similar. These questions all received average responses from 1.7 to 2. This shows that the respondents were very happy with these aspects, but that they possibly could use slight improvement. Navigation between chapters (question 1) and comprehension of graphs and movies (questions 4 & 5) received an average response of 1.8. Some of the displeasure with the movies may have been due to the external movie viewing program that was used by the survey respondents. Slight changes could be made to these aspects to improve the user's experience [9.3].

The average response of 1.7 to questions 6, 7, and 8 shows that the chapters are informative and interface well with the online course's simulation tool. This means that other aspects of the online course can be given more attention in further development. This is supported by the last question, question 9, which asks the respondents how they feel about the information provided. The average response of 1.8 shows that the users felt comfortable with the information and the way it was presented.

Along with the quantitative results there was also space provided for respondents to supply comments. One comment that was mentioned by several respondents was that the error message that is returned when the program fails is not descriptive enough. Also other respondents felt that there should be more error checking on the inputs provided to help reduce the number of abnormal results. Several of the respondents had the opportunity to use the online course on a Microsoft Windows based machine. These respondents commented in general that the interface and usability of the online course greatly increased when using Microsoft Internet Explorer in Windows. [9.3]

9.3 Recommendations Based On Results

After a review of both the quantitative and qualitative results several recommendations for future improvements can be suggested. As noted by the survey respondents, the online course's usability decreases when accessed in Unix. To alleviate this problem more time could be devoted to optimizing a version of the online course for the Netscape on the Unix platform. Also, serving the online course from a faster dedicated server would greatly decrease the response time. These two improvements would help to increase overall user satisfaction by improving backend functionality of the online course.

To enhance the interface a new color scheme would be implemented. To determine which color scheme should be used, several schemes would be developed and shown to test groups. Another improvement to the interface would be to present more explicit error messages to the user when the MPM simulation program fails. Currently users are only informed that the MPM simulation failed; no information is available as to why it failed. In the future this standard error could include more information about

specific reasons for failure. Increased error checking before the forms are submitted would also help in preventing failed simulations. Instituting these changes would help to make the online course visibly better for the users.

10 Future Work

Although the online course is at a state were it works and can be used by students, there are still several improvements that could be implemented. Due to time restrictions and resource limitations all the features that were discussed were not included in the final version of the online course. The future improvements are in both the technical and interface realms of the site.

10.1 Technical Improvements

There are several enhancements to the movies that could be implemented. The use of 3 dimensions (3D) in these movies is apparent from the side view movie that can be produced. Although this is a 3D movie, it is actually a 3D representation of a 2 dimensional simulation. To create true 3D movies the MPM simulation code would need to be changed to work with three dimensions.

This would not be a major change to the code, but it would drastically reduce the speed of the program. Tests would have to be performed to ensure that the speed reduction would not adversely affect the time users must wait to receive the generated movie. Minor changes would have to be made to the interface to allow for options, such as Z coordinates. Additional changes would also have to be made to the OpenGL code to support 3-dimensionality, but these are minor and would not require too much work.

The format of the movies could also be changed to the AVI format. This format is inherently supported by Netscape and would allow inline movies to be displayed in Netscape as well. Another option for future movies is MPEG-4, a new version of the currently used standard MPEG. This standard has been developed for use on the Internet

and would serve this online course well. The only disadvantage of this format is that it is very new, as of now it is still in development and will not be widely supported for some time.

One final improvement for the movies would be to provide more textual information within the movie. This would not require too much work technically, but would require extensive testing with users to reveal what types of information would be useful.

Another addition to the online course that was not completed was a graph representing the paths of the objects. This may seem redundant, as the movie provides a similar result. This is useful for Netscape users who must currently download a movie to see a representation of the objects' paths. Providing some inline graphics showing the objects' paths would be useful to the users.

10.2 Interface Improvements

One improvement to the user interface that might provide a large increase in user experience is a more customizable interface. This would involve making the online course more modular, which means breaking it up into pieces. Each piece would be moveable and removable. Allowing users to add or subtract parts based on their needs would be very helpful. One disadvantage of this is that it removes the high level of consistency that the users would otherwise have. Extensive tests would have to be conducted to determine if this would truly be a positive change for the online course.

Another possible change, as mentioned in section 9.3 (Recommendations Based On Results) is different color schemes which would have to be tested on users. A

different color scheme may help better captivate the users. Several schemes would have to be produced and tested.

One final enhancement to the site would be to rewrite the chapters with a mathematically lower-level user in mind. As serving such users is one of the main points of the online course, it would help if the chapters were more understandable to even the most basic of users. This would require reading through the current chapters and providing more in-depth information on some of the more advanced topics.

11 Conclusion

In conclusion, the goals of this project were successfully met. An online course was created which was not only usable by anyone, but also interesting and informative to all as well. It is important to note that this online course was also original in its intent to serve as a self-sufficient course, having no accompanying book or class. This course succeeded in allowing students to learn the Material Point Method through lessons and actual interaction with a simulation of the method.

12 Bibliography

Advocate Online (2001). National Education Association. Retrieved April 10, 2001 from:
http://inte.mwc.edu/blackboard/webcourses_nea.html

Baker, A. (2001). Effective use of forms on websites, Retrieved April 18, 2001 from:
http://www.merges.net/theory/20010301.html

Contextual Help (2000). MSDN Online Library. Retrieved April 8, 2001 from:
http://msdn.microsoft.com/library/default.asp?URL=/library/books/winguide/ch1
3c.htm

Cormier, J., Goodwin, S., Harley, R. (October, 2000). Perceptions of Worcester: A Study
of the Business—College Student Relationship. Worcester Polytechnic Institute,
An Interactive Qualifying Project Report

Dillman, D. A. & Salant, P. (1994). How to conduct your own survey. New York: John
Wiley & Sons.

Feynman, Richard Phillips (1970). Feynman Lectures on Physics. Addison-Wesley
Publishing Co. 1970.

Greenspan, J. (1999, July 23). Good Forms. WebMonkey.com. Retrieved April 2, 2001
from: http://hotwired.lycos.com/webmonkey/99/30/index4a.html?tw=authoring

Guelich, S., Gundavaram, S., Birznieks, G. (2000). CGI Programming with PERL, 2nd
Edition, O'Reilly Publishing [2000, July]

Hall, M. (1997). Core Web Programming. New Jersey: Prentice Hall PTR.

Hobbs, E., Mühlhaus, H-B., Ord, A., Zhang, Y., and Moresi, L. (2000). Fold Growth In
More Exotic Materials, Retrieved April 27, 2001 from:
http://www.virtualexplorer.com.au/VEjournal/Volume2/www/contribs/hobbs/text
/5.html

Johnson, Norman L. (June 1996). The Legacy and Future of CFD at Los Alamos,
Retrieved April 27, 2001 from:
http://gnarly.lanl.gov/History/CFD_paper_6_24_96.pdf

Leurent, T., Prud'homme, C., Rovas, D. V., and Patera, A. T. (2000). Simulations that
Respond: in Context, to Web Queries, Quasi-Instantaneously, with a Certificate of
Fidelity Retrieved April 8, 2001 from: http://augustine.mit.edu/fin.php as well as
http://augustine.mit.edu/description.php

Miller , Richard H. Web Interface Design: Learning from our Past. Retrieved on April 26,
2001 from: http://athos.rutgers.edu/~shklar/www4/rmiller/rhmpapr.html

MPEG-1: General Information (2000) . <u>Codec Central</u>. Retrieved on April 26, 2001 from: http://www.terran.com/CodecCentral/Codecs/MPEG1.html

MPEG-2 FAQ (2000).<u>The Berkely Multimedia Research Center</u>. Retrieved on April 26, 2001 from: http://bmrc.berkeley.edu/frame/research/mpeg/mpeg2faq.html

Nielson, Jacob (October 2000). Flash: 99% Bad. <u>The Alertbox</u>: Current Issues in Web Usability. Retrieved on April 26, 2001 from: http://www.useit.com/alertbox/20001029.html

Schneiderman, B., (1998) <u>Designing the User Interface 3rd Edition</u>, Addison Wesley Longman, Inc., Reading, MA, 1998.

Shaw, Matthew (May 2000). <u>Major Qualifying Project: The Material Point Method</u>. Worcester Polytechnic Institute. May 2000

Smith, Paul (2001, March). Debunking The Myths of UI Design. <u>Developer Works</u>. Retrieved on April 17, 2001 from: http://www-106.ibm.com/developerworks/library/us-myth.html

Stein, Lincoln D. (1999) <u>GD.pm – Interface to gd Graphics Library</u>, Retrieved April 22, 2001 from: http://stein.cshl.org/WWW/software/GD/GD.html

Sulsky, D., Chen, Z., and Schreyer H. "A particle method for history dependent materials." Comput<u>. Methods Appl. Mech. Engrg. 118 (1994) pp. 179-196</u>

The Importance of a Well-Designed Interface (2000). <u>MSDN Online Library</u>. Retrieved April 8, 2001 from: http://msdn.microsoft.com/library/default.asp?URL=/library/books/winguide/ch01c.htm

User-Centered Design Principles (2000). <u>MSDN Online </u>Library. Retrieved on April 8, 2001 from: http://msdn.microsoft.com/library/default.asp?URL=/library/books/winguide/ch02b.htm

Veen, J. (1999, Dec 22). Will Browsers Ever Not Suck? <u>WebMonkey.com.</u> Retrieved April 2, 2001 from: http://hotwired.lycos.com/webmonkey/99/52/index2a.html?tw=authoring

W3C/MIT (1999, June). HTTP 1.1 Protocol. Retrieved April 2, 2001 from: ftp://ftp.isi.edu/in-notes/rfc2616.txt

Web-Application Interface (2000). <u>MSDN Online Library</u>. Retrieved April 8, 2001 from: http://msdn.microsoft.com/library/default.asp?URL=/library/books/winguide/ch10e.htm

Willis, B. (2000). <u>Distance Education At A Glance,</u> Retrieved on April 10, 2001 from:
http://www.uidaho.edu/evo/distglan.html

Winters, Elaine (2000). Seven Styles of Learning. Retrieved on April 17, 2000 from:
http://www.bena.com/ewinters/styles.html

Woo, Mason, Neider, Jackie, Davis, Tom, Shreiner, Dave (1999). <u>OpenGL Programming Guide</u>, Addison Wesley Longman, Inc., Reading, MA, 1999

13 Appendix A

These "HowTo" chapters contain instructions and tips for using the online course.

Introduction
Welcome to the MPM tool, you can choose a chapter to view above, using the `Chapter Navigator`. If you are already familiar with the concepts behind MPM and would like to use the tool, then feel free to go ahead.
Thank you for coming by and checking out the MPM Tutorial/Tool
The MPM team (Adam, John, George, and Hieu).
Once you have read through the chapters and experimented with the tool please fill out our short survey.

HowTo 1
INTERFACE & OPTIONS
The interface to the MPM Tool works in the same way as other web based forms. There are several forms within the interface located in the upper left corner of the web page. To access each individual form, click on the tab (ie. Options, Object 1, Object 2, etc.) for the form you desire. These tabs are located on the form bar at the top-left of the interface.

When you first enter the page the initial form is the "Option Form", which contains system-wide options. These options include the following: which objects you will be using, the domain size (or grid size), the movie view (a top or side view), and display type (either a movie or a graph). There are also several advanced options. These options include: CFL (Courant-Friedrichs-Lewy condition), Number of Cells, and the number of particles per cell. Place your cursor over each of the options (in blue) to obtain more information and help.

HowTo 2
OBJECT OPTIONS
Each of the other tabs contain forms that allow customization of the objects that you are using. The values that you can customize are: name, radius / length, shape, X & Y position, poisson ratio, X & Y velocity, and young's modulus. The chapters explain most of these values because they are essential to understanding the Material Point Method. However, if you place your curser over each of the options more information and help will be displayed

HowTo 3
GENERAL USE FOR MOVIE/GRAPH
Movie:
Internet Explorer
Click on movie to play it again.
Right click on movie to change playback options.
Netscape(Unix or Windows)
Click on the `Download Your Movie` link to download the movie.

The movie should automatically play once it has been downloaded.
Note: If it does not play, right click on the link to save the movie. Then view the movie using the `mpeg_play` command in Unix or, if you are running Windows, your prefered Mpeg player (see links for Mpeg players).

Energy Graph:
Internet Explorer/Netscape
The graph should automatically be displayed on the page after the compute button has been clicked.

HowtTo 4
<div align="center">HELPFUL HINTS</div>

This section contains a list of helpful hints that you may want to refer to. Some of these hints are helpful for generating neat movies and some of the hints are for solving problems that you may encournter with the webpage

- If, when viewing the tool in Netscape you experience problems with where items are placed on the page, you can try changing your font size. Change the font size in the Edit->Preferenes->Font menu.

If a "tool tip" does not appear or if it appears "beneath" another object on the webpage

then you can try clicking the tool tip and it will most likely display correctly.

HowTo 5
<div align="center">POSSIBLE ERRORS</div>

1. There is a possible error caused when the webpage is intially loading. This error only occurs if the user attempts to click on a different form before the page completly loads..
2. Known problems that cause movie creation to fail: If an object moves outside the top, bottom, left, or right boundries then the movie will not be created successfully. Also, the movie creation software is based on an experimental theory. Therefore, it is possible that certain combinations of values will cause the movie creation to fail. If this occurs simply try changing values until you are able to successfully create a movie.

14 Appendix B

These instructional chapters teach the users about the Material Point Method and related concepts.

Elasticity
The following chapters are based on a Major Qualifying Project entitled "The Material Point Method" by Matthew Shaw, May 2, 2000.

ELASTICITY

When a material (usually a solid body) has the ability to recover its size and shape from deformation (caused by a force), the material is said to be elastic. When a force is applied to a material, the material is deformed. How much it gets deformed depends on how strong the force is and how soft the material is. The greater the force, the greater the deformation. The softer the material, the greater the deformation. For example, if we apply a force F to a rectangular box at both ends, the length will be changed by an amount ΔL. In most practical cases, ΔL is only a small fraction of the original length.

Hooke's Law 1

HOOKE'S LAW

We note, however according to many experiments, that a large deformation would cause the object to misshape permanently, and therefore these cases are not considered as an elastic material. For some elastic materials, the relationship between a force and a deformation delta L, for a fixed length L, is directly proportional as:

$$F \,\&\, (\Delta L)$$

Where F is the force, & is directly proportional sign, and L is the length. This formula is known as Hooke's Law.

Hooke's Law 2

HOOKE'S LAW (Cont'd)

If we take two rectangular blocks and attach them end to end and apply an equal force on each block, the deformation ΔL of the two blocks would be twice that of one block. Therefore, the ratio between deformation and total length (i.e. $\Delta L / L$) is constant for a fixed force F. We obtain

$$F \,\&\, (\Delta L) / L$$

Besides the deformation being proportional to the length, deformation is also dependent on the area of a block.

Young's Modulus

YOUNG'S MODULUS, STRESS AND STRAIN

Let's look at another example. If we put two blocks side by side and apply a force F on each block, the total force would be twice that of one block. To add this property to Hooke's Law, we have

$$F = (E * A * \Delta L) / L \quad (1.2)$$

The constant E is called the modulus of elasticity, or Young's Modulus, which is the natural property of the material. A is the cross-sectional area. If we measure force per unit area, we have stress. If we measure stretch per unit length, we have strain. Therefore, Hooke's formula becomes:

$$F/A = (E * \Delta L)/L \quad (1.3)$$

or

Stress = Young's Modulus x Strain.

The Young's Modulus may be determined experimentaly for a given material by performing a uniaxial tension test and recording simultaneous values of stress and strain in the specimen. The modulus of elasticity is therefore equal to the slope of the straight-line portion of the curve drawn by ploting stress as the ordinate and the strain as the

POISSON RATIO

POISSON RATIO

To treat two-dimensional or three-dimensional problems, another constant, called Poisson ratio, plays an important role as another part to Hooke's law. Someone set up us the bomb. Poisson ratio is described as follows. When you stretch a block of material in x direction, it contracts in y and z direction. The contraction in deformation is related to the width W, the length L and the hight H. In formula:

$$(\Delta W)/W = (\Delta H)/H = - \text{Poisson ratio}* (\Delta L)/L$$

Poisson ratio is another property of the material. It is always positive and less than 1/2. For incompressible materials, rubber for instance, the Poisson ratio is 1/2. The Poisson number is also determined experimentaly by performing also a uniaxial tension test and recording simultaneous values of deformations in x and radial directions. The two constants, Young's Modulus and Poisson ratio, describe the elastic properties of a homogeneous isotropic (noncrystalline) material. All your online course are belong to us. There can be more elastic constants in crystalline materials because the stretches and contractions can be different in different directions. We will stick only with noncrystalline material and use Young Modulus and Poisson ratio to describe the elastic properties of material

2D Elasticity 1

TWO DIMENSIONAL ELASTICITY
INTRODUCTION

We would like to be able to describe the conditions of stress and strain inside some big glob of elastic material that is twisted and squashed in some complicated way. To do this, we need to be able to describe the local strain at every point in the body. We can do it by giving the components of a symmetric tensor for each point. Now imagine we start with the material initially unstrained and watch the motion of a single spot in the material when the strain is applied. If we fix the origin of the system to be the corner of the material, the particle that was at the point P located at r(x,y,z) moves to a new position P' at r' = (x',y',z'). The vector displacements from P to P' is called u. u is a function of r.

$$U = r' - r$$

2D Elasticity 2

TWO DIMENSIONAL ELASTICITY

UNIFORM STRAINS

Suppose we have a block of material and we stretch it uniformly. We change its dimensions uniformly in one direction, say in the x direction. The motion u_x of a spot is proportional to the position x. In fact,

$$u_x/x = (\Delta L)/l$$

We will write u_x this way,

$$u_x = e_{xx}x.$$

The proportionality constant e_{xx} is, of course, the same thing as $(\Delta L)/l$. If the strain is not uniform, the relationship between u_x and x will vary from place to place in the material. For the general situation, we define e_{xx} by a kind of local $(\Delta L)/l$, namely by

$$e_{xx} = u_x/x.$$

This number describes the amount of stretching in the x-direction throughout the material. The stretching in the y and z-directions is described by a similar function with those directions instead of the x's.

2D Elasticity 3

TWO DIMENSIONAL ELASTICITY
SHEAR-TYPE STRAIN

We also need to be able to describe the shear-type strains. Suppose we imagine a little cube marked out in the initially undistributed material. When it is pushed out of shape, the cube may get changed into a parallelogram. In this kind of strain, the x-motion is proportional to the y-coordinate and the y-motion to the x-coordinate.

$$u_x = \theta/2\, y, \quad u_y = \theta/2\, x.$$

Where θ is the total shear angle. We can describe such a shear-type strain by writing

$$u_x = e_{xy}y, \quad u_y = e_{yx}x$$

with

$$e_{xy} = e_{yx} = \theta/2.$$

2D Elasticity 4

TWO DIMENSIONAL ELASTICITY
SHEAR-TYPE STRAIN (Cont'd)

It might be thought that when strains are not homogeneous, they can be defined by the quantities e_{xy} and e_{yx} by

$$e_{xy} = u_x/y. \quad e_{yx} = u_y/x.$$

But there is one difficulty. Sometimes there is no strain at all, just a rotation in space. In this case the relative positions of all the atoms are not changed at all. We must therefore make our definitions so that pure rotations are not included in our definitions of a shear strain. The key point is that if u_y/u and u_x/y are equal and opposite, there is no strain. We can solve this dilemma by defining

$$e_{xy} = e_y = 1/2\, (u_y/x + x/y).$$

2D Elasticity 5

TWO DIMENSIONAL ELASTICITY
SHEAR-TYPE STRAIN (Con't)

For a pure rotation they are both zero, but for a pure shear we get e_{xy} is equal to e_{yx}. For the most general distortion we define the state of strain by giving the four combinations

of e $e_{xx},e_{xy},e_{yx},e_{yy}$. These are the terms of a tensor of strain. Because it is a symmetric tensor, there are only three different numbers ($e_{xy} = e_{yx}$). For simplicity in notation, we'll let x1 and x2 stand for x, and y, and u1, u2 stand for u_x, u_y. The general term e_{ij} of the strain tensor can be written as

$$e_{ij} = 1/2 \ (u_j/x_i + u_i/x_j). \ (3.1)$$

Where i j can be 1 or 2. Where we have a homogenous strain, all the e_{ij} are constants and we can write

$$u_x = e_{xx} \ x + e_{xy} \ y.$$

In this case, the strain tensor e_{ij} gives the relationship between two vectors: The coordinate vector r = (x,y) and the displacement vector u = (u_x, u_y).

Material Point Method 1

MATERIAL POINT METHOD ALGORITHM

The purpose of this writing is to give an algorithm of Material Point Method (involving some calculus and basic physics) to calculate the change in particles, using the grid point environment. The first step is to calculate the acceleration. The acceleration can be calculated from the physics formula: F = ma which gives a(t) = f(t)/m(t). The second step is to calculate the velocity using the physics concepts which acceleration is the change in velocity over time. Therefore, from acceleration, we have:

$$a = \{(vtemp)(t + \Delta t) - v(t)\}/(\Delta t)$$

From this equation we can get: vtemp(t + Δt) = v(t) + (Δ t)*a vtemp can represent the change in velocity of a particle. Similar to acceleration is the change in velocity, position is the change in velocity. From the formula vtemp(t + Δ t) = v(t) + (Δt)*a we can get:

$$x(t + \Delta \ t) = x(t) + (\Delta \ t) \ vtemp(t + \Delta \ t)$$

Material Point Method 2

MATERIAL POINT METHOD ALGORITHM (Cont'd)

Now if we want to compute the vtemp or acceleration at the particles, we need to do the interpolation. Let us denote by f a variable that we want to interpolate. The interpolation is based on the following formula:

$$S \ f(x,y) = \{f(A)(x_b - x)(y_c - y)\}/\{(x_b - x_a)(y_c - y_a)\}$$
$$+ \{(f(B)(x - x_a)(y_c - y)\}/\{(x_b - x_a)(y_c - y_a)\}$$
$$+ \{(f(C)(xb - x)(y - ya)\}/\{(xb - xa)(yb - ya)\}$$
$$+ \{(f(D)(x - x_a)(y - y_a)\}/\{(x_b - x_a)(y_b - y_a)\}$$

Material Point Method 3

MATERIAL POINT METHODP ALGORITHM (Cont'd)

For illustration, we can see that if we apply to the formula by simply computing vtemp at point (x_a,y_a) and (x_b,y_b):

$$S(x_a,y_a) = vtemp(A) + 0 + 0 + 0 = vtemp(A)$$
$$S(x_b,y_b) = 0 + B + 0 + 0 = vtemp(B)$$

If we want to calculate the velocity Vtempp of the particle p at the position (X_p,Y_p), we can just take the interpolation of S at vtemp which is:

$$Vtemp_p = S \ vtemp(X_p,Y_p)$$

Material Point Method 4

MATERIAL POINT METHODP ALGORITHM (Cont'd)

For illustration, we can see that if we apply to the formula by simply computing vtemp at point (x_a, y_a) and (x_b, y_b):

$$S(x_a, y_a) = vtemp(A) + 0 + 0 + 0 = vtemp(A)$$
$$S(x_b, y_b) = 0 + B + 0 + 0 = vtemp(B)$$

If we want to calculate the velocity Vtempp of the particle p at the position (X_p, Y_p), we can just take the interpolation of S at vtemp which is:

$$Vtemp_p = S \ vtemp(X_p, Y_p)$$