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# Investigation of Sheet Bending, using Mass-Spring Systems within a Virtual Environment


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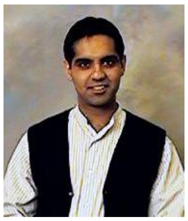
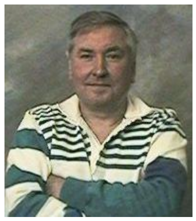
|  |  |  |


## Research Hypothesis

*"It is possible to create a computationally inexpensive environment for visibly accurate simulations of deformable sheet materials within a real-time system, through the employment of novel approaches".*

## Research Overview

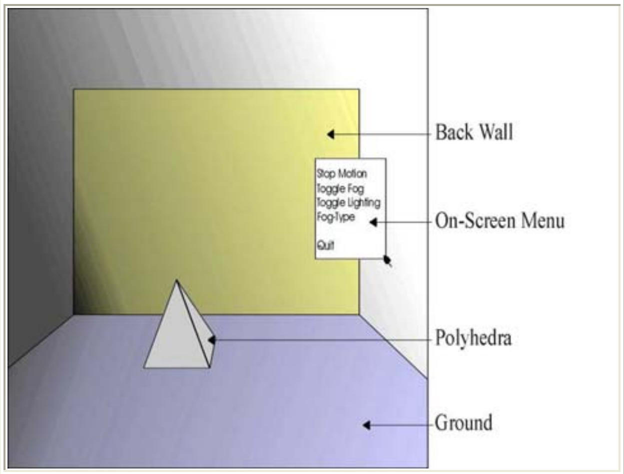
The aim of the study is to build an application for studying a model that (utilising Object Oriented technology) simulates the complex mechanical behaviour found within thermoplastic sheet materials. The work is within existing research, currently being carried out in the fields of computer graphics, specifically computer based animation and virtual reality.

The benefits of Object Oriented development have allowed the system to be constructed in a systematic and modular approach, with the foundations of the environment being based upon the ***'Mass'*** and ***'Spring'*** classes.

To produce an open system that is both portable across a diversity of platforms and which takes advantage of the latest breakthroughs in computer graphics based libraries and toolkits, the system utilises the OpenGL environment, along with its defacto development system, the GLUT toolkit.

The final application aims to produce an aesthetically accurate real-time simulation of thermo-sensitive sheet behaviour being subjected to heat transfer. Our approach differs from conventional finite element based systems which, although producing highly accurate results, involve high levels of computation that are awkward to implement in real time. Mass-Spring based systems have already been shown to work effectively within graphics based animation and simulation, portraying fast and aesthetically accurate behaviour of cloth and other sheet materials. Our system consists of a number of different sheet models (see 'Sheet Structures') that are inserted into the ‘virtual’ world containing several environmental parameters. These include sheet elasticity and plasticity, variable sheet moment stiffnesses, differing levels of gravity and simulated heat transfer.

**Figure 1 - The WoW Environment**




The polyhedral objects are used to demonstrate the behaviour of the sheet when in collision with external objects. These objects are 'inserted' into the environment (see figure 1) to demonstrate the effects of collisions with external bodies. A secondary form of interaction, using a mouse (initiated by the user) to manipulate the sheet in 3D space is currently under development.

The use of a World on Window (WoW) non-immersive based approach is made in order to remain within the parameters of the hypothesis, i.e. to produce a *computationally inexpensive* simulation.

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## Mass-Spring Systems

A ***Mass*** instance consists of several properies that are used to describe its current behaviour within free space at any one time. These parameters (see Figure 2) which are mapped using vectors, consist of the current displacement (or location within free space), the (vector of any) forces being applied to the ***mass***, its current velocity and acceleration.
Naturally, a value for representing the actual mass of the ***Mass*** instance
is also maintained. The ***Masses*** are interconnected through a network of spring systems (see Figure 3) that also contain a number of different properties.

| **Figure 2 Mass-Object Properties** | **Figure 3 - Simple 2D Mass-Spring System** |
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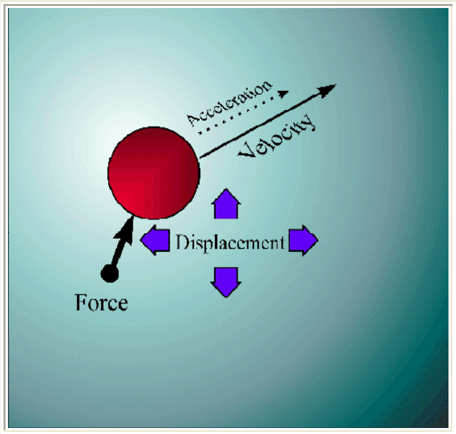
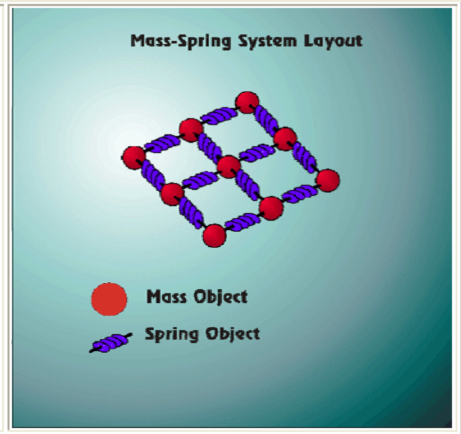
***Spring*** data includes information about its position with the sheet model through the use of pointers to its interconnected ***Masses*** spring stiffness and the undisplaced length of the

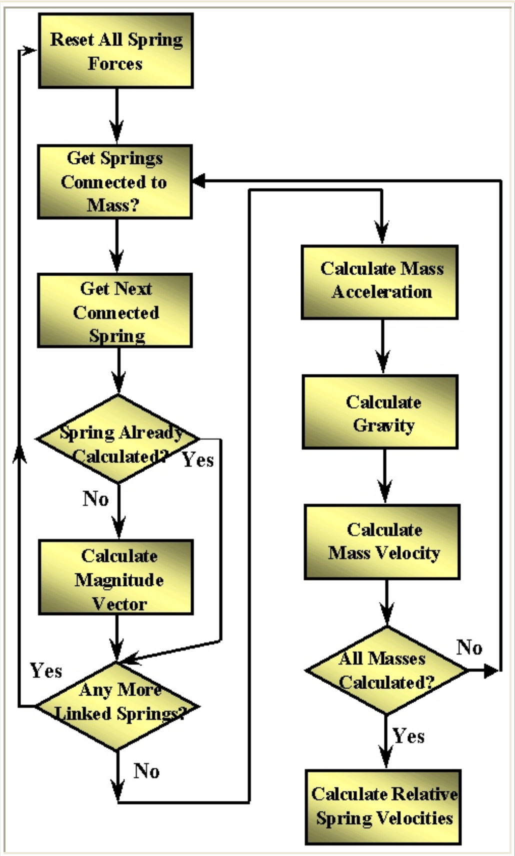



spring. These are used to model the behaviour of the overall object by depicting whether the manipulation of one ***Mass*** will have an effect upon its surrounding ***Masses***.

## Dynamics Model

**Figure 4 - Dymanics Flowchart**




The dynamics mass-spring engine was designed and created using a modular structure in order that the application may in future be extended to cater for a diversity of other shape simulations such as solid object deformation modelling.
Additional complexity required for modelling sheet behaviour such as bending moments is catered for in the structures employed to build the sheet models. Using a third (depth) dimension allows a greater level of flexibility, since the inter-layer cross springs can be easily modified to cater for different levels of modular stiffness.
This is a breakaway from traditional mass-spring research which has tended to employ 2D structures with complex rotational stiffness calculations to simulate sheet bending moment.
Instead our approach in essence has opted to use a simpler piece of code to calculate sheet behaviour which is reused many times, rather than use a complex algorithm which is called a few times a frame. This way, through careful optimisation of the system, it is hoped that significant improvements in sheet simulation may be achieved.

## Damping Model

Figure 5 - Simple Damping Model

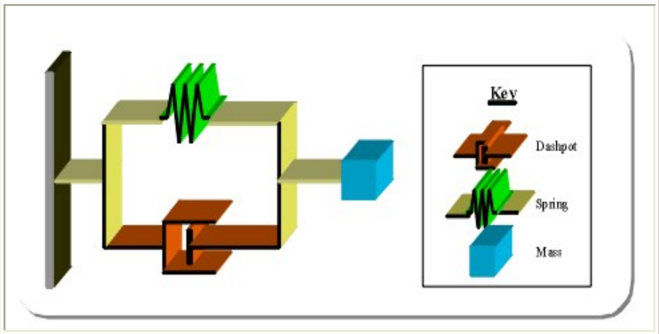
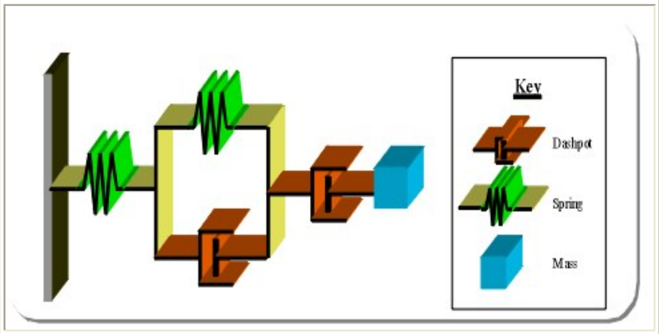



Figure 6 - Complex Damping Model




At this moment, a simple generalised single-degree of freedom model is used to represent frictional forces acting upon the sheet within the environment (see figure 5). However, to produce a more realistic simulation of viscoelastic sheet behaviour, a more complex model (see figure 6) is presently being developed and adopted into the model. The new model is an extension to the Voigt-Kelvin element spring and dashpot model which has been combined with a Maxwell element system. It is hoped that this new damping structure will prove beneficial once the heat simulation components of the system are employed to allow the sheet to reproduce viscoelastic behaviour.

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## Sheet Structures

In total, four sheet sheet structures have been devised and tested, although the first structure (see figure 3) due to its two dimensional nature i.e. its lack of depth perception (resulting in no accounting of bending moment) make it an impractical choice for further investigation.

The square model structure, known as SaMM (see figure 7) is based upon the standard square-matrix sheet structure (see figure 3) with the addition of a third (depth) dimension which is provided through the addition of a second (or evenmultiple) layers of square matrices. Each ***mass*** placed in higher layers of the sheet is positioned in the centre of the square formed by the ***masses*** in the layer below.

Each mass in the upper layer is then interconnected to the layer below through four ***springs*** which link it together with the four ***masses*** that form the square in the lower level.

The square-latice model structure, know as SLaMM (see figure 8) is identical to the SaMM layout with the addition of a diagonal cross-member spring that interconnects the near-side left ***mass*** with its relative far-side right ***mass***.

The triangular model, known as TRiMM (see figure 9) represents a radical change from the earlier structures. A triangular mesh forms the base of structure with succesive layers being positioned in an over-lapping manner (in a simlar manner to theSaMM and SLaMM structures).

Once again, each ***mass*** in the upper layer is connected (through a series of ***springs***) to the lower layer via the 3 ***masses*** that form the triangle directly below which the ***mass*** is positioned.

**Figure 7 - Square Sheet Structure**

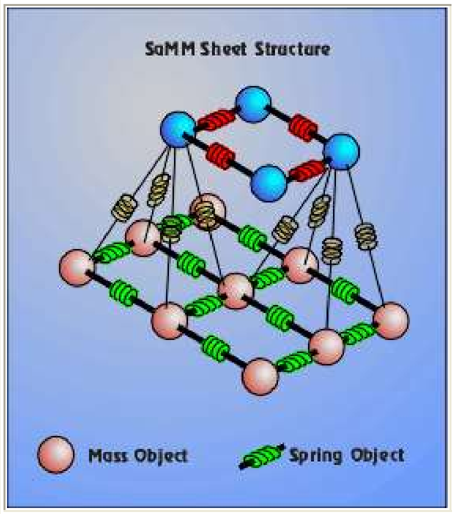



**Figure 8 - Square-Latice Sheet Structure**

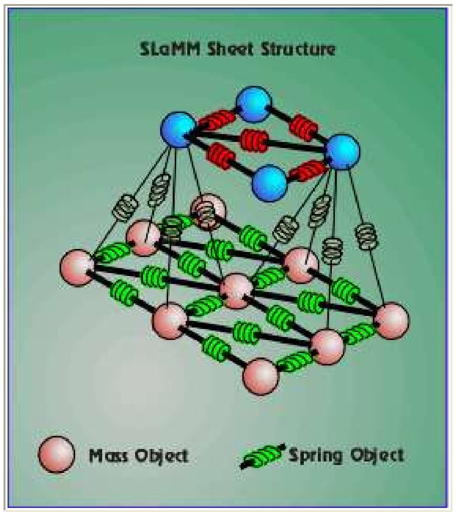
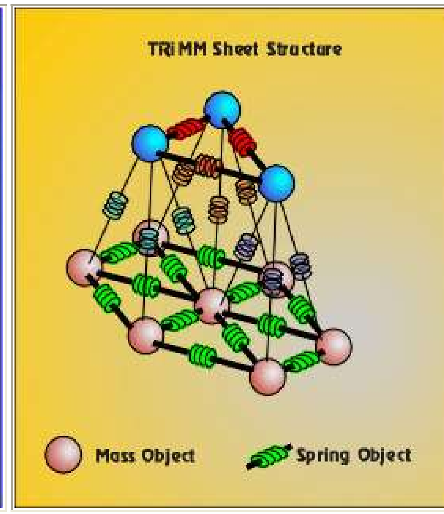



**Figure 9 - Triangular Sheet Structure**

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