Rube Goldberg Project Analysis:
A CS296 Group 16 Report.

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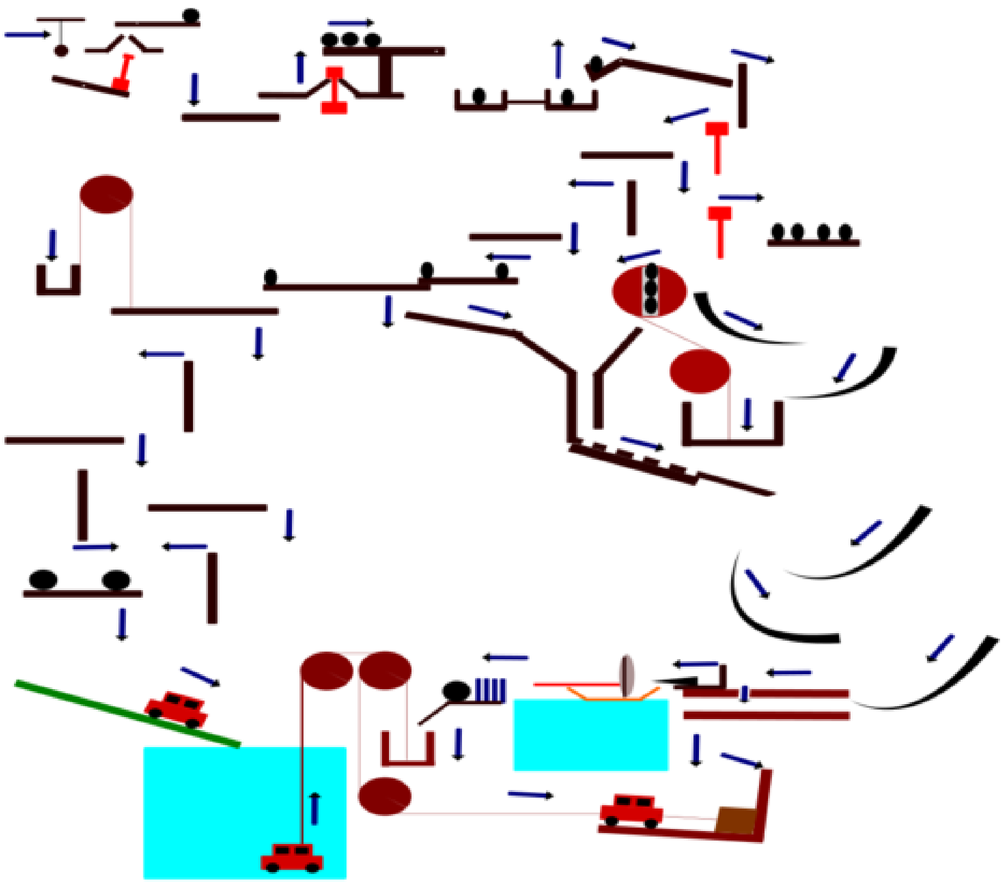
1 Introduction

The pupose of this report is to analyse various aspects of the Rube Goldberg Machine simulation. We describe the initial design that was proposed, the changes made to the design, analysis of the time taken for different parts of the program and an overview of optimizations involved.

2 Initial and Final Designs

The purpose of our Rube Goldberg machine is to lift a box that has fallen in a pit. (Which was originally planned to be a car that fell into a pond).

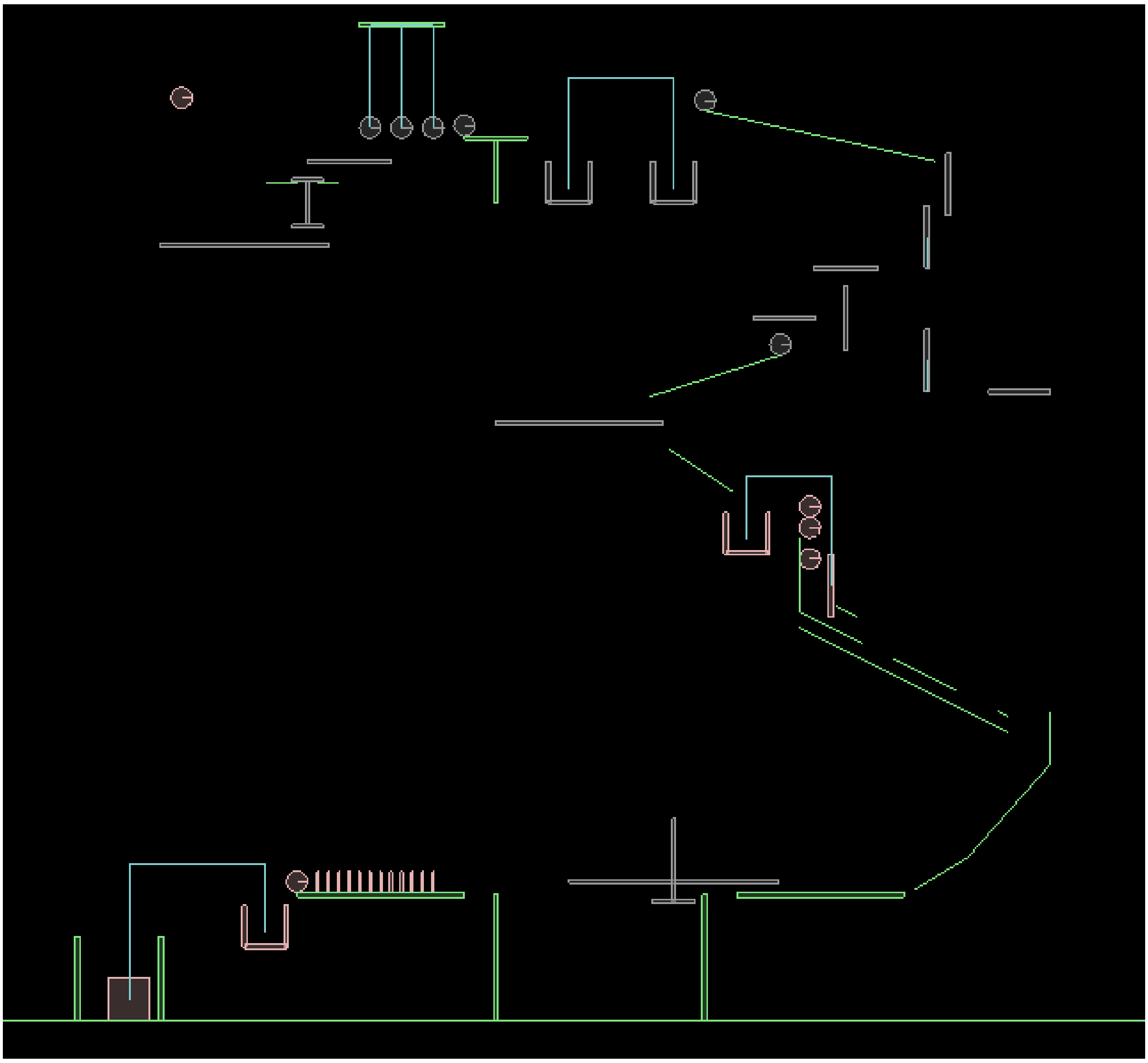
This was the design first proposed by our group -



We made the following changes to the original design (for primarily two reasons - either the unavailability of a feature in Box2D, or to avoid the simulation becoming unnecessarily repetetive and cumbersome) -

- **Fewer curves and planks in the ball's path:** Originally, there were a large number of curves and planks (to bring the ball down from a height) which didn't actually affect the complexity of the design itself. So we removed the un-necessary parts wherever we felt that a single curve or plank would suffice - leaving the design as complicated as it was before, while making it less cumbersome.
- **Removal of two or three features:** One of the features included in the initial design - a pulley which contained three balls in its centre - can apparently not be made in Box2D. Besides, we made one grave mistake in the original design - we unnecessarily included an apparatus for pushing the car in the water. We decided it made more sense to omit this part in the final.
- **Changed the starting apparatus of the simulation:** The original starting appratus involved, among other things, a plank that had to be balanced with a weight on one side. This, as far as we could find out, cannot be done reliably in Box2D. So we had to change the entire starting appratus - though we tried to retain as much superficial similarity as possible.
- **Change in appearance of a few objects:** There was no way to render a car or a boat in Box2D. So what looks like a car in the initial design becomes a box in the final, and what looks like a boat becomes a simple structure made up of three rods.

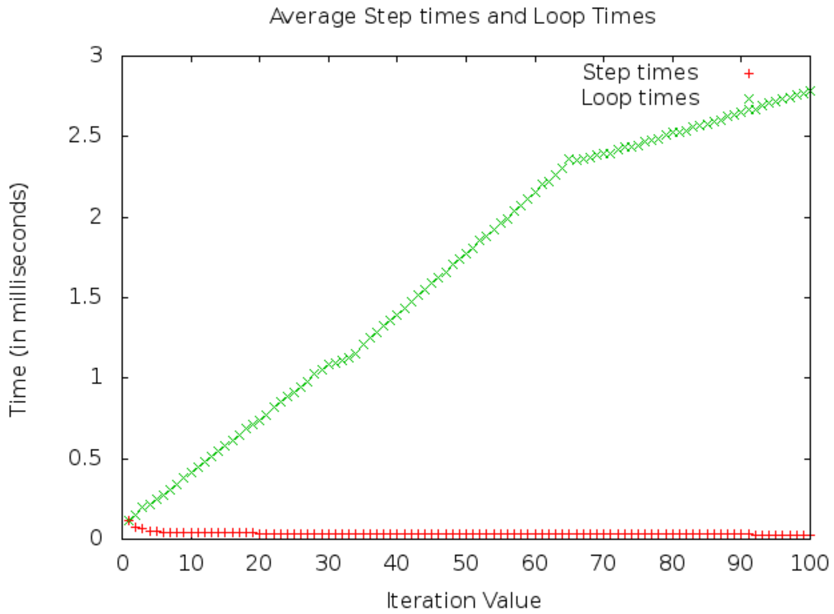
In the end, this was the design actually prepared -



3 Time Analysis

Several processes involved in the simulation have been timed over various number of iterations, the program being run many number of times for each iteration, to obtain a large sample. Also, the program has been run under different loads on the CPU, and in different versions.
The following conclusions can be drawn from the five plots:

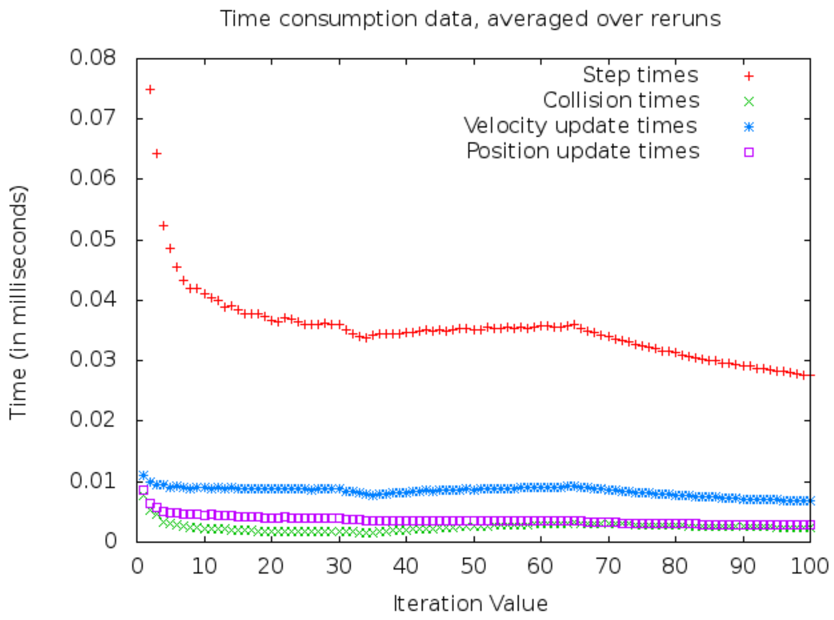
3.1 Total Loop Time



As can be seen, the total loop times are roughly in one straight line from the 1^{st} to the 65^{th} iteration, and in another straight line from 65^{th} iteration onwards. To understand this, we checked out the executable, which explains this behaviour simply -

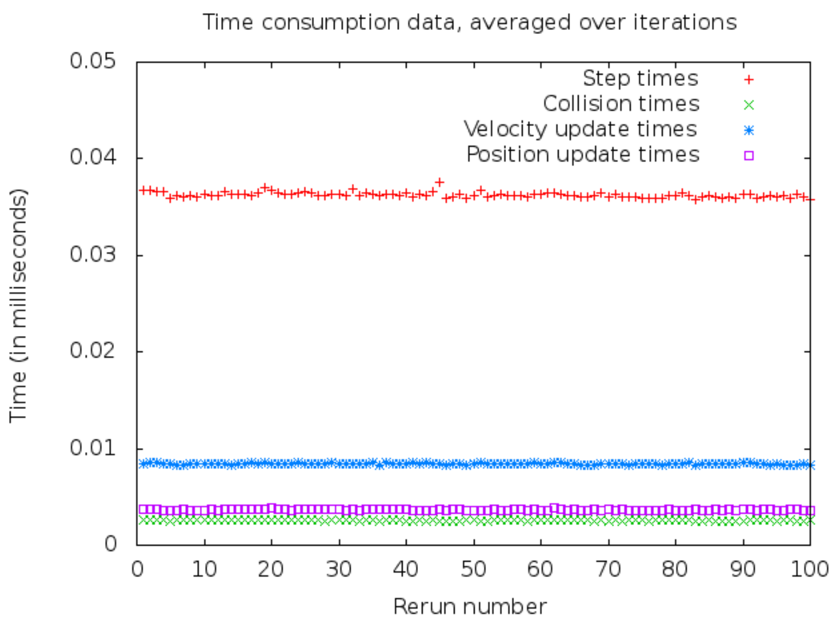
- Till the 30^{th} step, no object had settled. So in every loop the program considered the possibility of collision of every single object, and hence had to update positions and velocities of each one.
- In the 30^{th} step, all the planks and some containers "settled down". However, all these were the objects which were not colliding before anyway. So, the overall velocity update time did not change (since these were not contributing to it), but the position update time reduced (since they were moving slightly).
- However, as seen from the next graph, velocity update time for all iterations is almost thrice as large as position update time. So, despite the position update time being halved, total time for each step did not change much at all.
- In the 65^{th} step, the dominoes settled down. These, unlike the planks, were indeed colliding (with the floor). So, the total velocity update time dropped drastically, reducing the total step time considerably.
- No further 'activation/deactivation' of any object occurred after the 65^{th} step. So, the time required for each individual step again became a constant, leading to a straight line behaviour of the total time required upto the n^{th} step, for $n > 65$.

3.2 Average times over steps



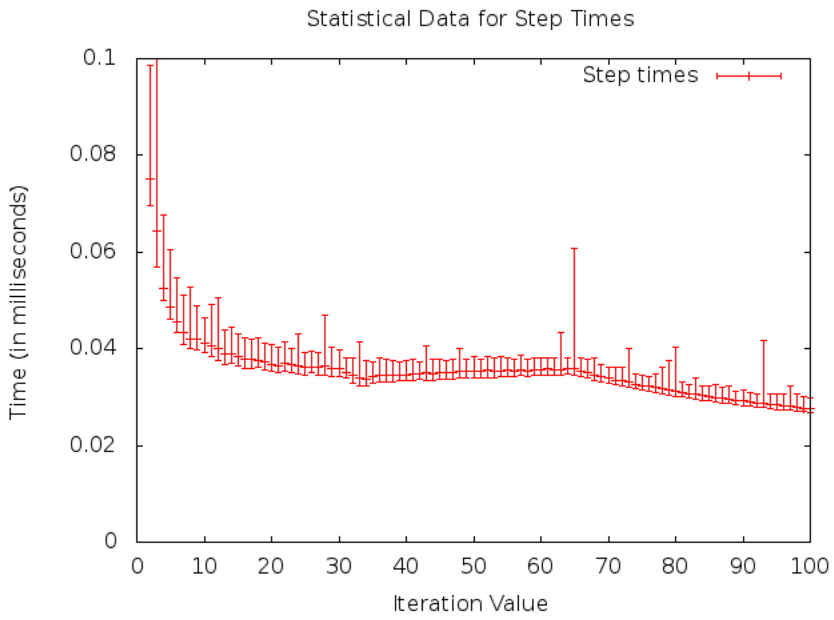
The variation in these average times can be understood directly using the previous graph. Time required for the first step is naturally higher than the other steps, since the program has to call various constructors and load positions and velocities as opposed to incrementally updating them. Then for the next few steps, due to the nearly constant time required for each step, the total loop time takes the form $ax + b$, with a small b (Since b is the extra time required for the first step). So the average times are of the form $a + \frac{b}{x}$. The small value of b implies that the graph appears to fall for some time and then becomes constant. After 30 steps, due to the reduction in slope of total time, the graph takes the form $cx + d$, with a relatively large d. So, the graph appears roughly hyperbolic.

3.3 Variations over reruns



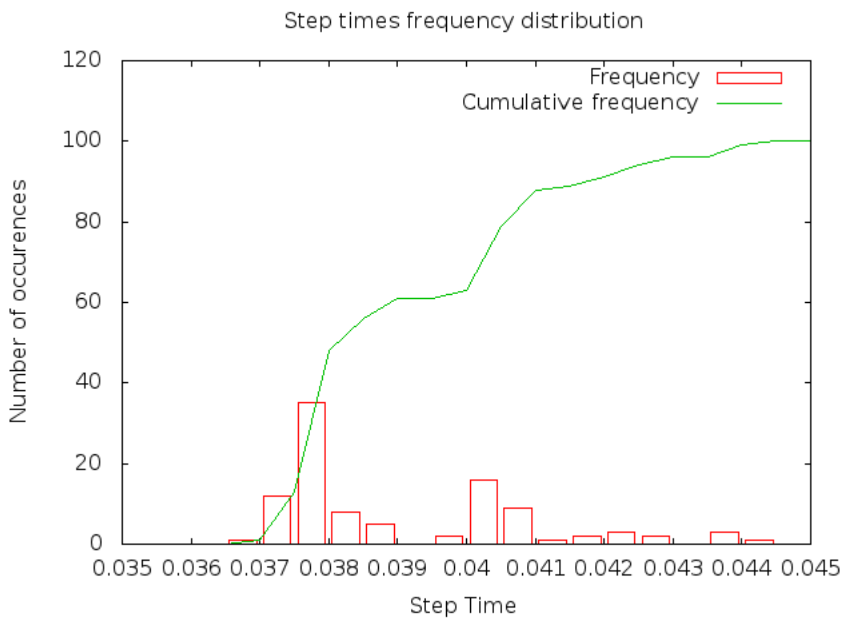
Hardly anything surprising here. However, if we run the simulation when the CPU is under considerable load, one interesting difference arises. The average time becomes about twice as much. Also, the graph often goes below the average level, but seldom above. The most reasonable guess we could make is that the modal level occurs when the CPU (which is dual core) is able to devote one core to the program. Reductions in time taken represent those relatively rare instances when both the cores are free.

3.4 Error bars for step times



The most noticeable aspect of this plot is the reduction in the sizes of the error bars. Well, there's obviously the reason that the values themselves decrease, so even at the same relative error, the error bars would have got smaller. But that's not *exactly* the case - here, even the relative error is decreasing. This too, however, is expected. As we can see from the previous graph, the CPU is mostly at one particular speed. For natural numbers $0 < a < b < 100$, the average speed for any a iterations would naturally show more relative variation than the average speed for b iterations. So, we would have a higher chance of observing a significantly different time for the first a iterations than for the first b.

3.5 Frequency of step times



Most of the values here are concentrated in a small range (0.036 to 0.042). This would be because the data for this graph is the time for the same iteration (number 14) over different reruns. As seen in graph #3, that does not vary considerably.

4 Optimization

We have not done any optimization in the code itself, since the inbuilt optimizations provided by compilers have done quite a good job of reducing running time. Box2D has been installed in the Release mode, and the source code has been compiled with the O3 flag. Besides elementary optimizations, this flag copies the code for most functions into the code of the caller, which results in expansion of the code but reduces the time taken (as function calls are avoided). Since there are no recursive functions anywhere in our project, this means the function calls have been removed altogether in the executable, leading to an extremely fast and low-memory program.