Thesis Summary

This thesis deals with the so called ‘problem of time’. There are several approaches to tackle this problem from well reputed string theory to a relatively new ‘loop quantum gravity’. In fact, every approach to ‘quantum theory of gravity’ is supposed to tackle this problem. The approach we have followed in this thesis is known as *Shape Dynamics* started by Julian Barbour. Barbour has tried to develop a theory by completely implementing the ideas of Ernst Mach about space and time. Mach believed that the dynamics of Universe should be expressed solely in terms of observable separations, with only relative motions determinable. Time, according to Mach, must be derived from change. Further, Mach believed that the *Inertia* could arise from some causal action of all the masses in the Universe; that is, local physical laws are determined by the large scale structure of the Universe. We would like to mention here that it were Mach’s ideas which guided Einstein formulating his theory of relativity. But, Barbour argues, Einstein could not implement Mach’s ideas completely and it is believed that this is the source of some of problems arising in general relativity, including the problem of time.

We have gone through this radical approach, *The Shape Dynamics,* in some detail. Shape Dynamics is a completely ‘relational’, background independent theory with no absolute structures like Newtonian space and time. The problem of time doesn’t arise here due to this philosophical foundation of the theory. Shape dynamics has some additional qualities: it allows more restrictive solutions than general relativity so that some un-physical solutions like *closed timelike curves*, which allow backward time travel, can be avoided.

The implementation of Mach’s principle requires us to consider not the motion of bodies in space and time, but positions of the Universe in its configuration space. Only the variables that describe the shape of instantaneous particle configurations are dynamical. Shape Dynamics is based on the idea of *best matching,* in which two configurations of a system are brought as close to congruence as possible, then a distance function is defined in terms of their ‘least incongruence’ measure. In terms of this distance function, one can define a *principle of least incongruence* analogous to the principle of least action of Lagrangian Dynamics. Remarkable fact here is that there is no need of absolute space in this process. Further, time is defined in terms of changes in the system as Mach demanded.

We have also discussed Wheeler-DeWitt equation in some detail. This equation arises when we try to quantize gravity and this is the source of so called ‘problem of time’. In this context, we have described the Hamiltonian formulation of general relativity (through ADM approach) to see how WD equation and hence the problem of time actually arises. The

problem with Wheeler-DeWitt equation is that it implies a static Universe which is against our everyday observations.

Further, in chapter 4, we have given an explanation of the *arrow of time*, based on Mach's ideas. Mach asserts that time should be derived from change. The arrow of time appears because we usually do the opposite: starting from a given absolute time, we observe that the physical processes are occurring in a particular order and never in reverse order even though the laws of physics are consistent with both the orders. Once we believe in Machian ideas, arrow of time simply disappears because here time is to be derived from change. A moment of time is nothing but a real number representing a set of simultaneously occurring events in the Universe, next moment is a new set of such events and so on. So, one can see a one-to-one correspondence between the set of simultaneous events (in a given frame of reference) and the points on a number line because every next moment of time is unique by its definition just as we get completely new numbers as we move along number line. In this view, backward motion of time would mean that a given set of simultaneous events has re-occurred which highly improbable seeing the infinite extent of our Universe. If we restrict our life to a cyclic process and define our time using this process, then one can imagine time as being cyclic. For example, consider a hypothetical world in which there is nothing except a rotating earth in front of sun .Time of this hypothetical world will certainly be cyclic because the only change in terms of which it could be defined is cyclic. But, our real world consists of infinitely many independent events which together define a moment of time and their simultaneous re-occurrence is quite unimaginable.

In chapter 5, we have given an interpretation of the famous Wheeler-DeWitt Equation. We have argued, in light of Machian ideas, that to define time, we need some dynamics; for a static system, it loses its existence. If we consider whole Universe as our system, then this system would be static due to conservation laws. A glass of water kept on a table is full of dynamics: water molecules are moving randomly, colliding with each other, changing their momenta and energies etc. But, for an outside observer, the system is completely static. Although the constituents of the system are constantly changing, the system as a whole is static: internal dynamics of the constituents is not capable of changing the system as a whole and this is a consequence of our conservation laws. Same thing happens in case of our Universe as a whole. We can define time in terms of subsystems of our Universe which are dynamical. But the Universe as a whole is completely static like a glass of water kept on the table and for this static system, time becomes meaningless. And if there is no time, there is no question of time evolution of something. This explains the zero on the RHS of WD equation.

Currently, we are following further developments in Shape Dynamics.