on the fundamentally Newtonian 'bang-bang' hypothesis by Braitenberg.[1,2,3,4] The space-timing was pictured as shooting one cannon to initiate a motion and then stopping it by firing, at a precisely timed moment, an opposing cannon.[4] Braitenberg called this scheme a "chronometric control of movement" and the timepiece necessary for this was placed in the cerebellum which was to be a "clock in the millisecond range".[2] Braitenberg's concept is regarded as a brilliant pioneering effort[34] that evolved through almost a decade.[2,3] It started with a space-time concept not inconsistent with our approach.[3] However, his hypothesis did later adopt the classical mechanical point of view, since in its final form it related the cellular morphology of the cerebellar cortex to an assumed 'clock-function'.[2] It is noteworthy that up to now his scheme has been the only cerebellar model to consider the problem of space-timing, although this is a key element of the function of cerebellum: motor coordination.

The assertion of a clock-function received a measure of support experimentally by the finding that following peripheral stimulation, due to the conduction time along the parallel fibers, Purkinje cells in the cerebellar cortex demonstrated precise time delays as they were sequentially activated.[5] Nevertheless, the clock-work view of cerebellar function, has difficulties even if it were conceptually sound. This is so because (i) mossy fiber afferent inputs are not synchronous; (ii) the fibers have different conduction velocities, signals being spread over 10–20 ms;[16] (iii) a given volley can activate different sets of parallel fibers all reaching the same Purkinje cell with quite different latencies. All the above would contribute to a significant blurring in the time coordinate axis. However, while these facts seriously complicate models based on Braitenberg's hypothesis,[6] the most profound limitation of his approach is the inapplicability of a separable space and time frame.

The fundamental problem is that the signal propagation speed along the axons of nerve cells is not several orders of magnitude faster than the speed of the 'timed' movement, but in fact, has the very same order of magnitude. This is in contrast to cases in which the concept of simultaneity can be applied, where there is a practically instantaneous synchronizing signal (that is fast enough to arrive at the clock from all 'simultaneous' event points within the resolution of the central clock). The case of the CNS is comparable to taking a picture of a moving object, not with an instantaneous flash, but replacing the light with a set of axons (each having a different conduction time). Creating an internal 'picture' of the external reality in the CNS in such a manner, through differently delayed neuronal signals, simultaneous external events will not be represented in the CNS as simultaneous. Conversely, simultaneous onset of firings of a group of neurons with different conduction times will not produce a set of simultaneous external events either. 'Simultaneous occurrence' can be detected by a clock only in the case where an instantaneous (or otherwise synchronous) access is available to it from the 'timed' events. Since in the case of CNS the difference between the speed of controlled events (e.g. movements) and that of the controller signals (slowly propagating neuronal firings) is not great enough to allow for instantaneous and synchronous access to a clock through the axons, simultaneity cannot be established; therefore this concept is not applicable to the internal functioning of neuronal systems. To give a vivid example for the problem of space-timing by a central clock, consider an attempt of coordinating the position of speeding battle tanks from the headquarters, not with instantaneous radio signals but by cavalry messengers.

It is clear that if no superfast command signal is available, then an alternative mode of space-timing must be found that does not rely on the concept of simultaneity. In the same vein, since within the CNS simultaneity of external events could not be established by the use of any 'brain clock' even if such a device were to exist, therefore, the brain must be using an alternative mode of space-timing.

Conceptual alternatives of space-time representation

The establishing of space-time coincidences is a basic biological skill; the survival of animals often depends on their ability to generate rapid, goal-directed movements such as in feeding or escaping. The capture of a target by an interceptor, however, can also be described in a more abstract manner that leads directly to a new conceptual model of unified space-time representation in the brain.

A capture is a *coincidence of events* in which both the target and interceptor merge into a single event-point. This is an invariant, known in physical sciences as a four-dimensional Minkowski-point or a world-point.[14,26,28,31,37] The understanding of space-time events as invariants is fundamental in both physical and biological sciences, since interactions usually require that events coincide.

From this point of view, the question of space-time coincidences is reduced to the problem of the *representation* of an event-point (in the external world or in the CNS). This is a fundamental question of abstract geometry; how can coordinates be assigned to an entity which is, by its nature, invariant to coordinate systems.

The problem is well expressed from contemporary physics, which holds the separation of space and time to be arbitrary. According to this view, the four space-time coordinates of an event need not be separated into two groups, one for 'space' and another for 'time': "...space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."[14] In the rest of this paper, we elaborate the view that although neuroscience has hitherto adhered to a classical mechanical point of view it really ought to adopt the modern physical concept.