Scalability for Virtual Worlds

Virtual worlds attract millions of users and these popular applications --supported by gigantic data centers with myriads of processors-- are routinely accessed. However, surprisingly, virtual worlds are still unable to host simultaneously more than a few hundred users in the same contiguous space. The main contribution of the thesis is Kiwano, a distributed system enabling an unlimited number of avatars to simultaneously evolve and interact in a contiguous virtual space. In Kiwano we employ the Delaunay triangulation to provide each avatar with a constant number of neighbors independently of their density or distribution. The avatar-to-avatar interactions and related computations are then bounded, allowing the system to scale. The load is constantly balanced among Kiwano's nodes which adapt and take in charge sets of avatars according to their geographic proximity. The optimal number of avatars per CPU and the performances of our system have been evaluated simulating tens of thousands of avatars connecting to a Kiwano instance running across several data centers, with results well beyond the current state-of-the-art. We also propose Kwery, a distributed spatial index capable to scale dynamic objects of virtual worlds. Kwery performs efficient reverse geolocation queries on large numbers of moving objects updating their position at arbitrary high frequencies. We use a distributed spatial index on top of a self-adaptive tree structure. Each node of the system hosts and answers queries on a group of objects in a zone, which is the minimal axis-aligned rectangle. They are chosen based on their proximity and the load of the node. Spatial queries are then answered only by the nodes with meaningful zones, that is, where the node's zone intersects the query zone. Kiwano has been successfully implemented for HybridEarth, a mixed reality world, Manycraft, our scalable multiplayer Minecraft map, and discussed for OneSim, a distributed Second Life architecture. By handling avatars separately, we show interoperability between these virtual worlds. With Kiwano and Kwery we provide the first massively distributed and self-adaptive solutions for virtual worlds suitable to run in the cloud. The results, in terms of number of avatars per CPU, exceed by orders of magnitude the performances of current state-of-the-art implementations. This indicates Kiwano to be a cost effective solution for the industry. The open API for our first implementation is available at \url{http://kiwano.li}. 