GPU-Accelerated Route Planning

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The Challenge

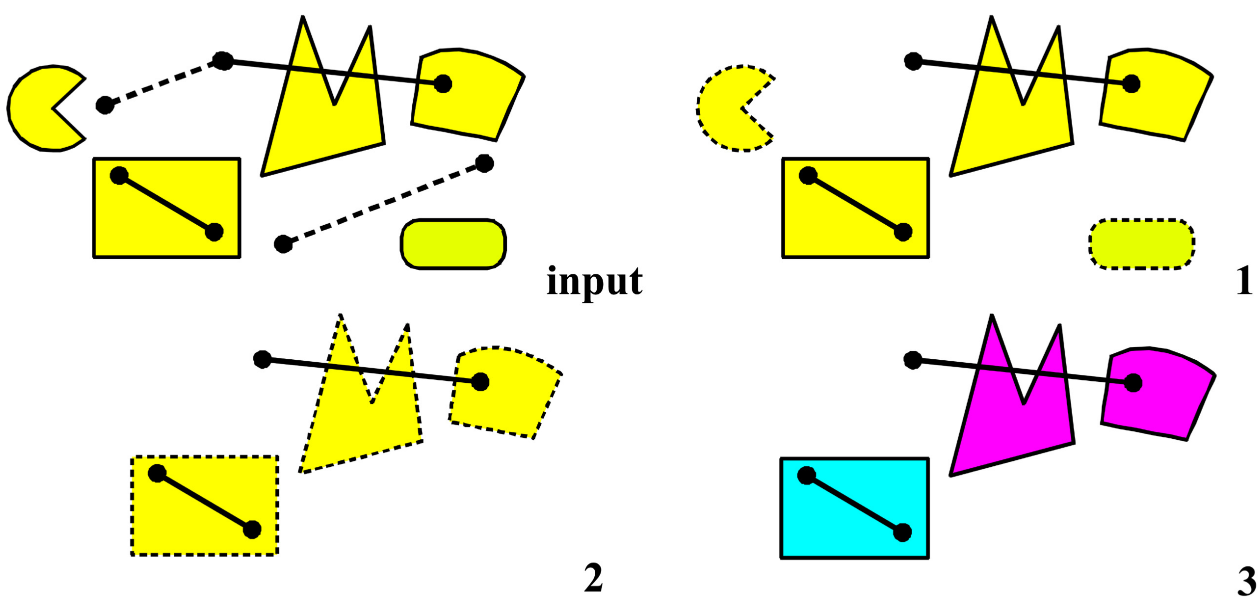
The problem of route planning over a complex terrain has been studied for many years. The topic has received considerable attention largely due to the high computational complexity associated with it. Good solutions to route planning have applications in many areas, including autonomous navigation or planning among collaborating agents. We present a method for accelerating route planning for computer generated forces (CGF) that utilizes graphics processing units (GPUs). GPUs have become an integral part of many commodity PC systems and gaming consoles. Additionally, GPU performance has been increasing at a faster rate than that of their CPU counterparts. For non-graphics-intensive applications such as route planning, the GPU represents a computational resource in addition to the CPU.

We present an algorithm that tackles the feature intersection problem, a bottleneck in route planning systems. The algorithm exploits the parallel computing capability of GPUs along with their ability to perform visibility culling.

We then combine the GPU accelerated computations with exact intersection tests on the CPU. This approach supports dynamic terrains as well as planning multiple routes in parallel. The method is able to perform feature intersection tests in a few microseconds on a commodity PC.

Highlights

- **Rapid feature intersection checks for potential route segments against terrains**
- **Multiple simultaneous feature overlap tests performed in parallel using GPUs**
- **Conservative reduction of the number of feature intersection tests**
- **Significant speed-up over the CPU-based sequential algorithm**
- **System integrated with OneSAF**
- **Demonstrated 30-50x speedup in feature analysis computation for route planning using GPU-based algorithms**
- **Demonstrated 10x speedup in route planning and overall simulation in OneSAF on a single CPU/GPU machine**
- **GPU route planning code transitioning into Block D Build 24 of OneSAF**
- **Will be distributed to every battalion in the Army (650 sites), every laboratory, and simulation center**



Our GPU-based culling algorithm proceeds in three phases. First, non-intersecting segments are pruned. Second, non-intersecting features are pruned. Third, potentially intersecting features are paired with segments.

The Approach

In a CGF application, quick and accurate route planning is critical for accurate and effective unit movement. However, a planning task for a single unit or group can be very expensive. When large numbers of units require route planning, the task becomes too daunting to be performed in a reasonable amount of time. In the OneSAF system, the bottleneck (taking over 50% of CPU time) is feature analysis computation. In order to improve the performance of planning in the OneSAF system, we need to improve this task.

Each feature analysis task can be generalized to determining the exact set of features that a single portion of the route intersects. Our GPU-accelerated algorithm performs a quick and conservative culling of both non-overlapping route segments and terrain features. This step produces a near minimal set of segments and features which require CPU-based exact intersection tests.

GPU-based culling proceeds in three phases:

- The number of segments is reduced by culling them against the full feature set
- The number of features is reduced by culling them against the reduced set of segments
- The reduced feature set is culled against each individual segment in the reduced segment set

Culling is performed using the GPU's occlusion query capability, a hardware based visibility test. These queries can quickly determine whether two objects are overlapping when rendered from a particular viewpoint. Thus, overlaps between segments and features can be determined simply by rendering them in succession.

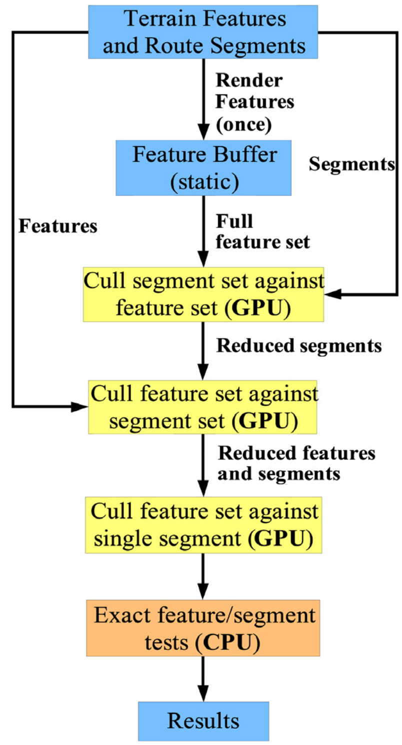
The algorithm proceeds by first rendering all the features. This step typically only has to be done once, but also must be repeated anytime the features or terrain changes. We then perform occlusion queries of each individual segment against these features. This quickly removes segments which intersect no features. The next step, culling features against segments, is similar except that occlusion queries are performed for the features. Finally, the remaining segments and features are paired together if they potentially overlap.

Each successive step reduces the number of segments and features that are tested in subsequent steps. After all three phases, almost all non-intersecting segment/feature pairs have been culled away. The number of resulting pairs that require CPU-based exact tests is very small, and each pair is tested only once.

The terrain features being tested for intersection can be very complex. This may result in small details of the features being smaller than one pixel after rendering. Due to this inaccuracy, an image-based technique may miss intersections. In order to ensure that all potential intersections are found, we conservatively expand the size of the features and segments as in [Govindaraju et al 2004].

Results

Compared to a solely CPU-based algorithm, this method has many advantages. While the OneSAF system finds routes by proceeding one segment at a time, our GPU-based



We use three forms of GPU culling before performing exact intersection tests between features and segments.

algorithm has the ability to test multiple route segments in parallel. Our algorithm performs intersection queries on all potential segments simultaneously, in a small fraction of the time required to test them individually on the CPU. Parallel queries allow us to realize a more efficient search of the large planning space, while also enabling the planning of routes for multiple units in parallel.

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Selected Publications

Govindaraju, N., S. Redon, M. Lin, and D. Manocha. "CULLIDE: Interactive collision detection in large environments using graphics hardware," *Proc. of ACM SIGGRAPH/ Eurographics Workshop on Graphics Hardware*, 2003, 25-32.

Govindaraju, N., M. Lin, and D. Manocha. "Fast and Reliable Collision Culling using Graphics Processors," *Proc. of ACM VRST*, 2004.