SIMDop:
SIMD Optimized Bounding Volume Hierarchies for Collision Detection

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Motivation

- Collision computation takes up to 90% in most sampling-based motion planning [Reggiani et al., 2002]
- Physically-based simulation in virtual environment [Damkjær & Erleben, 2009]
Bounding Volume Hierarchies (BVH)
Previous Work

- BVH using various BVs:
  - Sphere [Hubbard, 1996], AABBs [Bergen, 1998] [Zachmann, 2002], k-DOP [Klosowski et al., 1998] [Zachmann, 1998], OBBs [Gottschalk et al., 1996], Convex hull trees [Ehmann & Ming, 2001]
  - In sampling-based motion planning:
    - combination of several BVs (AABB, Sphere, OBB) [Ferguson et al., 2008]
    - AABB-based BVH (Schwesinger et al., 2015)
Bounding Volume Hierarchy Traversal
SIMD Instruction Sets (AVX512)

Scalar

A15 A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 A0

+ + + + + + + + + + + + + +

B15 B14 B13 B12 B11 B10 B9 B8 B7 B6 B5 B4 B3 B2 B1 B0

SIMD

A15 A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 A0

+ + + + + + + + + + + + + +

B15 B14 B13 B12 B11 B10 B9 B8 B7 B6 B5 B4 B3 B2 B1 B0
SIMD Optimization Methods

- Method 1: switch on compiler option `/arch:AVX512`
- Method 2: optimize the BV overlap test manually
- Method 3: redesign of the BVH topology
Our Contributions

1. Novel BVHs with higher branching factor

2. SIMD optimized traversal algorithms
BVH Construction Strategies

• Longest Axis Split
  • Construct the longest axis
    • [Dickerson et al., 2002] prove optimality for kd-tree (binary)
  • Sort polygons based on the axis
  • Partition into desired branching factors

• Extended Longest Axis Split
  • Construct the longest axis
  • Sort polygons based on the axis, split into two
  • Construct longest axis again for both split parts recursively
BVH Construction Strategies

- Batch Neural Gas (BNG) Clustering [Weller et al., 2014]

- Advantages:
  - Very robust behavior with respect to the initial cluster center position
  - Future-proof for further SIMD development
Benchmark

- Use benchmarking suite for collision detection proposed by [Trenkel et al., 2007]
- Use processor with AVX512 capability
Results: BVH Construction Strategies (SISD)

**BVH w/ degree of 4**

- Longest Axis
- Extended Longest Axis
- Batch Neural Gas (BNG)

**BVH w/ degree of 16**

- Longest Axis
- Extended Longest Axis
- Batch Neural Gas (BNG)
Result: BVH Construction Time

![Graph showing BVH construction time for different methods]

- **V-COLLIDE**
- **Traditional k-DOP BVH (Binary)**
- **BNG w/ degree of 4**
- **BNG w/ degree of 16**

The graph plots time in milliseconds against the number of polygons, ranging from 200 to 1800 polygons per 1000.
Simultaneous BVH Traversal Algorithm (4 vs 4)

```c
for ( h = 0; h < degreeBVH; h++)
{
    for ( i = 0; i < degreeBVH; i++)
    {
        for ( j = 0; j < k / 2; j++)
        {
            bool resL = a[j] < b[k / 2 + j];
            bool resH = -a[k / 2 + j] > b[j];
            if (resL || resH)
                return false;
        }
    }
    return true;
}

_mm512 endResult = _mm512_set1_ps( 1.0f );

for ( i = 0; i < k / 2; i++)
{
    _mm512 resL = _mm512_cmp_ps( oriAL, oriBL, _CMP_LT_OS );
    _mm512 resH = _mm512_cmp_ps( oriAH, oriBH, _CMP_GT_OS );
    _mm512 tempRes = _mm512_kor( resL, resH );
    endResult = _mm512_kor( endResult, tempRes );
    if (endResult == 65535)
        break;
}
return endResult;
```

**k-DOP Intersection Test**

*3 x 16 operations / orientation*

**parallel k-DOP Intersection Test**

*5 operations / orientation*
Result: SIMD Implementations

- **Method 1**: Compiler On (/arch:avx512)
- **Method 2**: Optimized BV Test (k-DOP)
- **Method 3**: BVH degree of 16 w/ simultaneous traversal (1x16)
- **Method 3**: BVH degree of 4 w/ simultaneous traversal (4x4)
Results: Comparison with V-COLLIDE

(An experimental comparative analysis has shown that V-COLLIDE outperforms other CD libraries like PQP [Reggiani et al., 2002].)
Conclusions

- Novel BVH with higher branching factors
- Novel heuristic for constructing BVH with arbitrary branching factor (BNG)
- Novel SIMD optimized traversal algorithm
- Our SIMD Optimized BVH outperforms traditional BVHs by an order of magnitude
Future Works

- Explore other BV for SIMD traversal algorithms
- Influence of the number of orientations for k-DOP
- Include magnification control to BNG construction algorithm
Thank You!

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