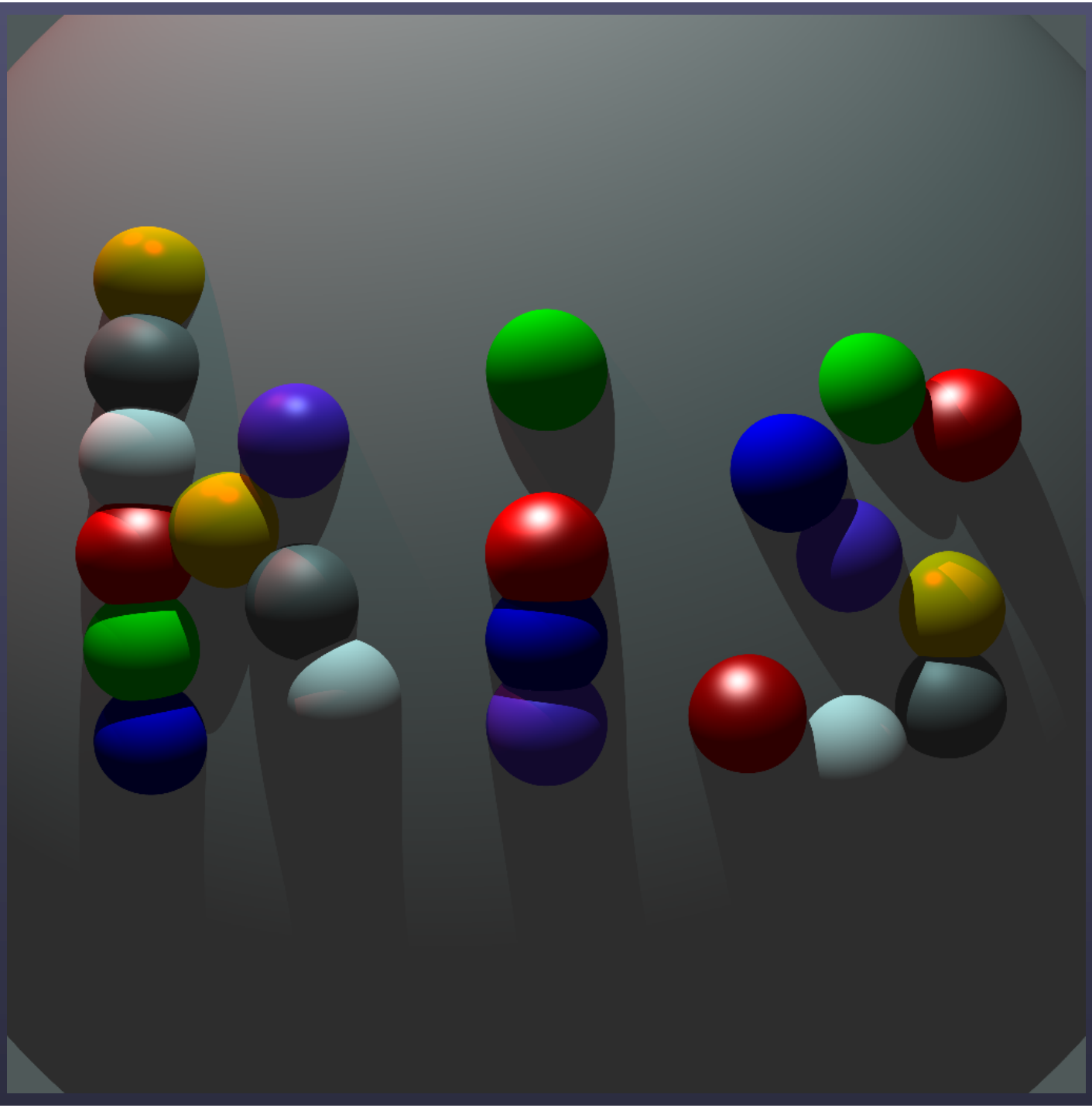
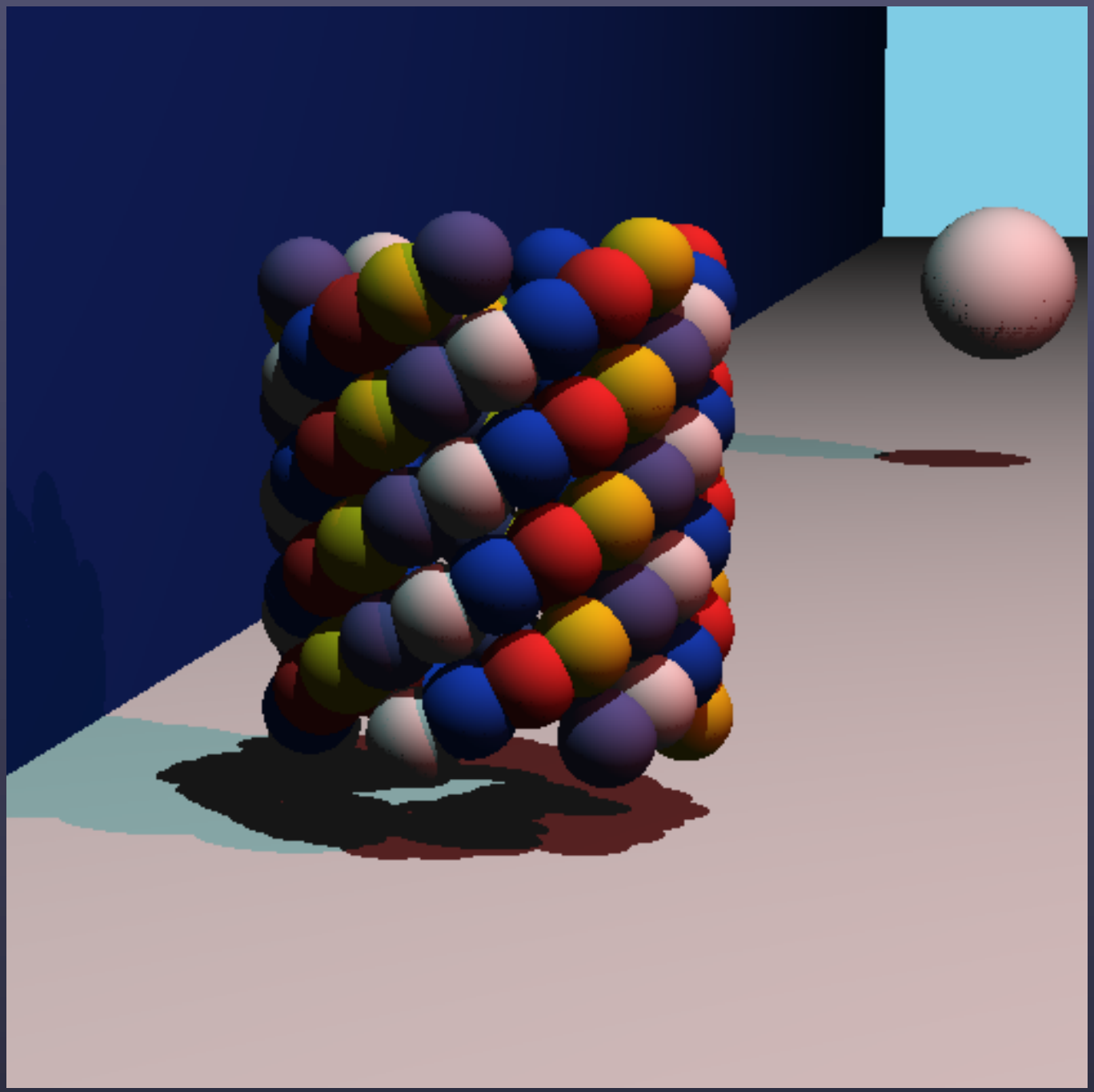
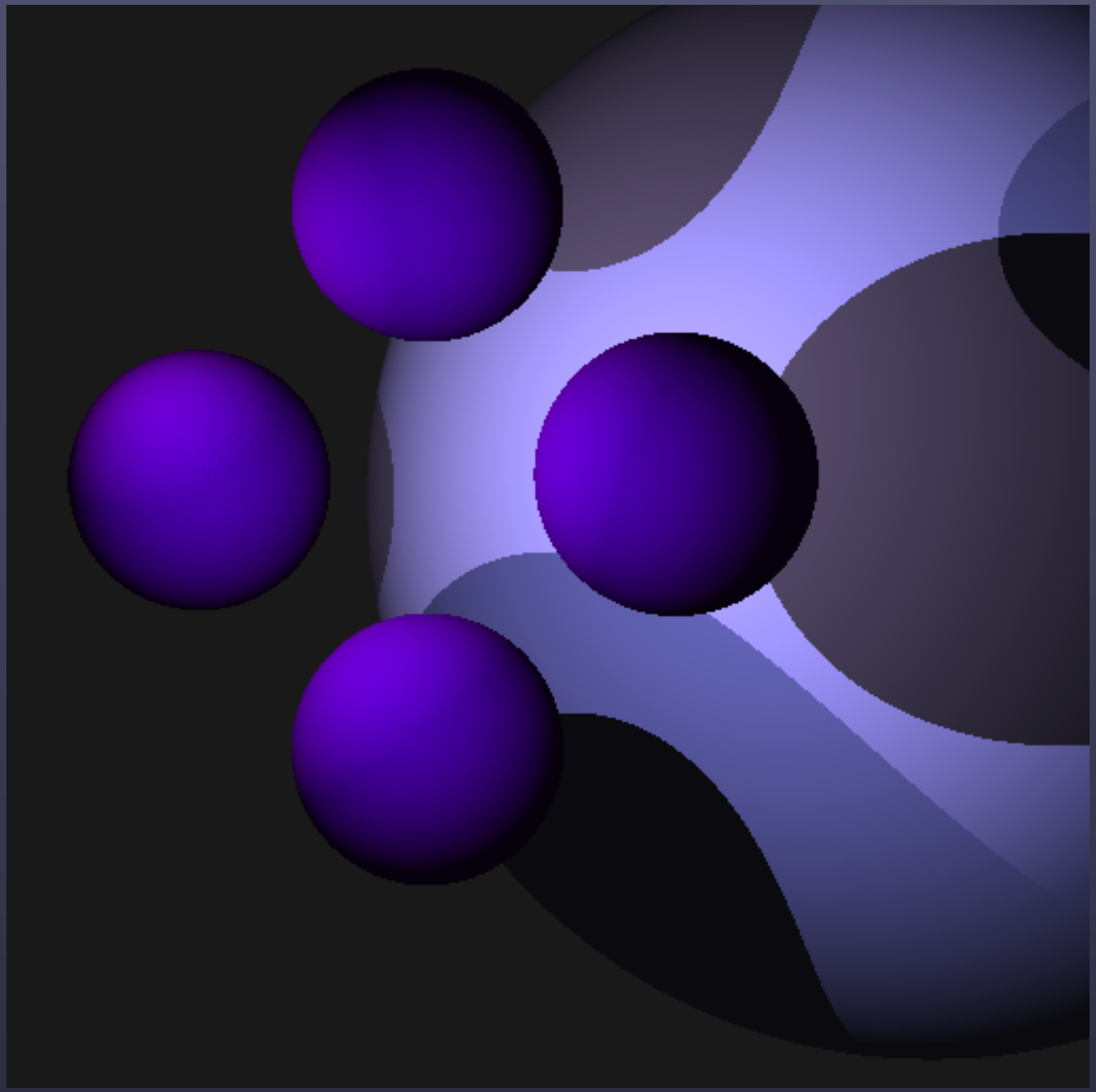
TRaX programming examples

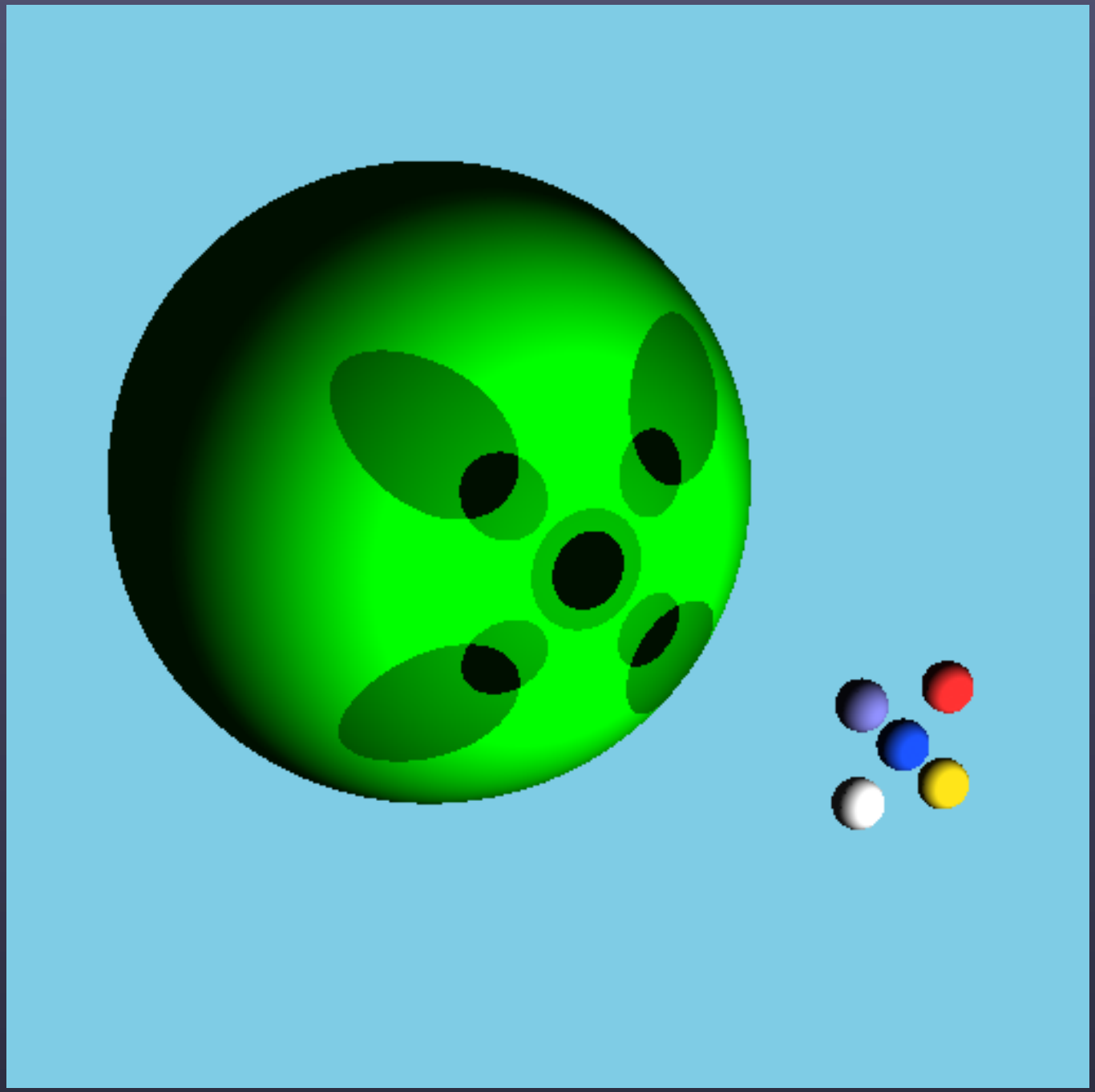
Using global memory

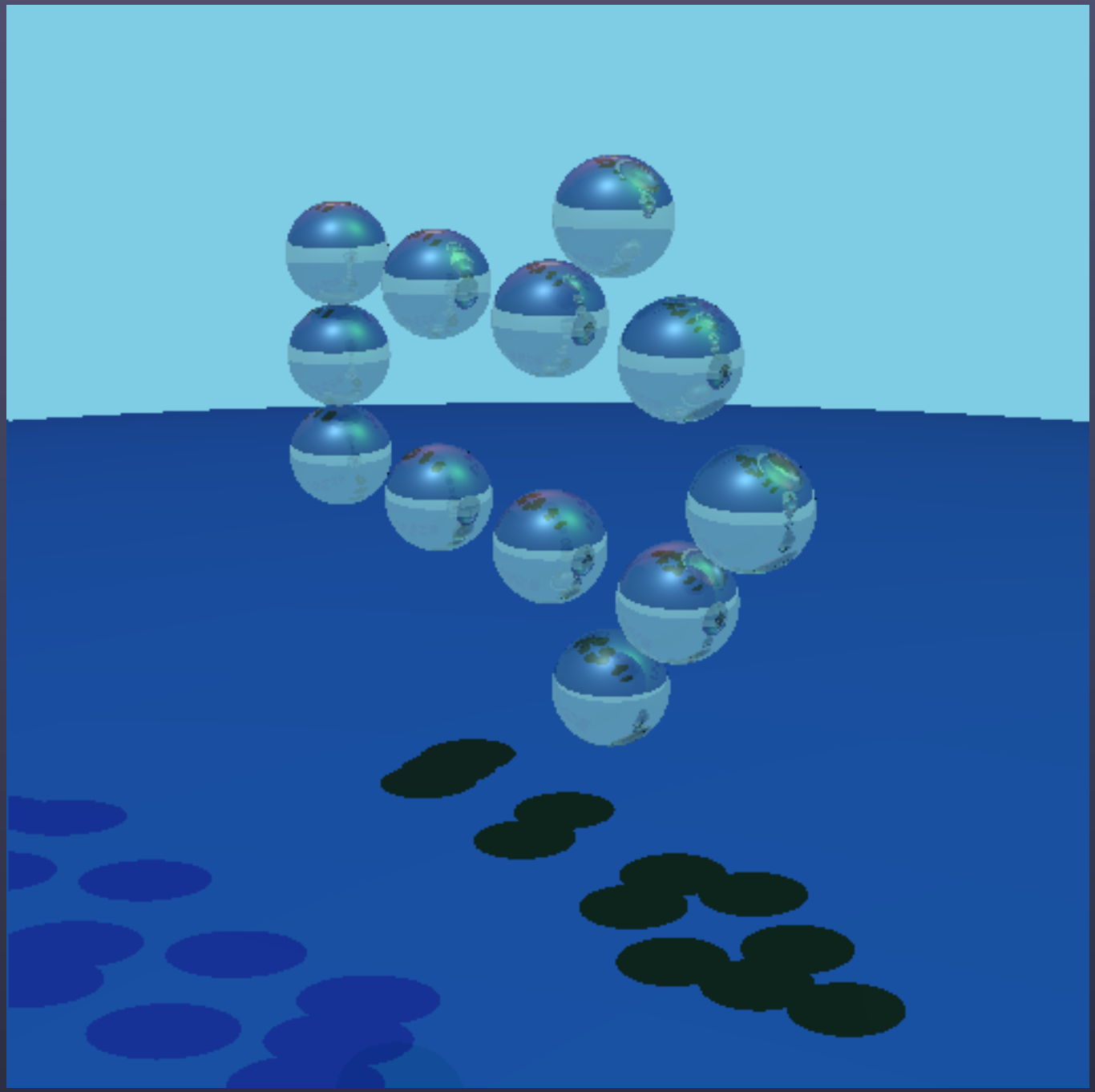
Non-recursive tree traversal

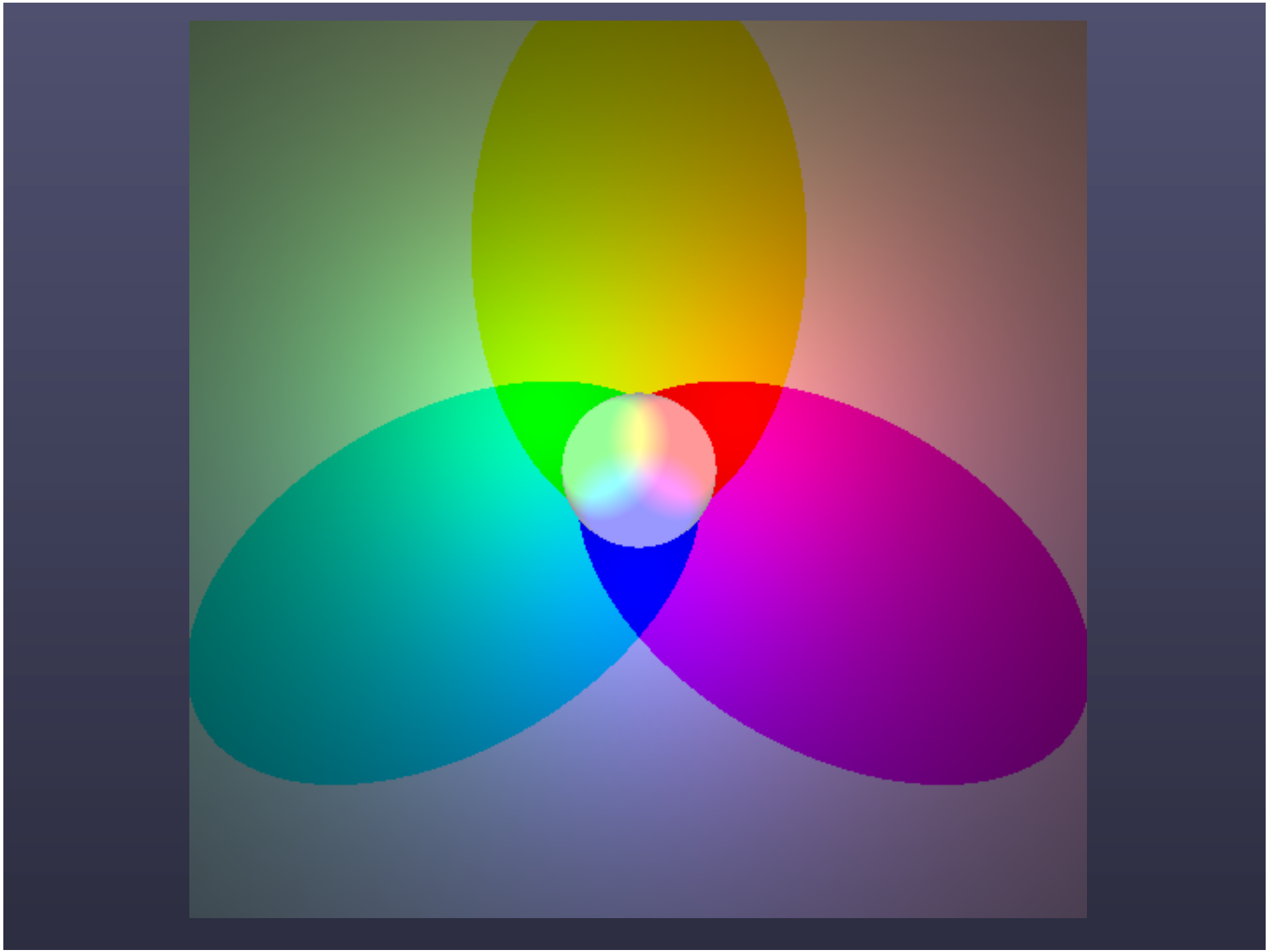












TRaX programming recap

- Local memory (private to every thread)
  - Handled by compiler (stack space)
  - You will never need to explicitly deal with it
- Global memory
  - Pre-loaded by simulator
  - Explicitly accessed
  - loadf, storef, loadi, storei

Global Scene Data

- Light
- Camera
- Model (BVH/grid and triangles)
- Materials

Recap

- First few words of memory hold constants and pointers (LoadMemory.cc):

1: width
2: 1 / width
3: float width
4: height
5: 1 / height
6: float height
7: start_fb
8: start_scene
9: start_matls
10: start_camera
11: background
12: start_light
14: end_memory
15: size - 1
16: ray depth
17: num samples
18: epsilon
28: start_triangles
29: num_triangles

simhwrt arguments

- Many of these values can be set with arguments to the simulator

- --view-file (loads camera data)
- --model (loads the BVH and materials for you)
- --light-file (loads the light position)
- --config-file (configures the TRaX HW)
- --epsilon

- ./simhwrt --help to see all options

simhwrt arguments

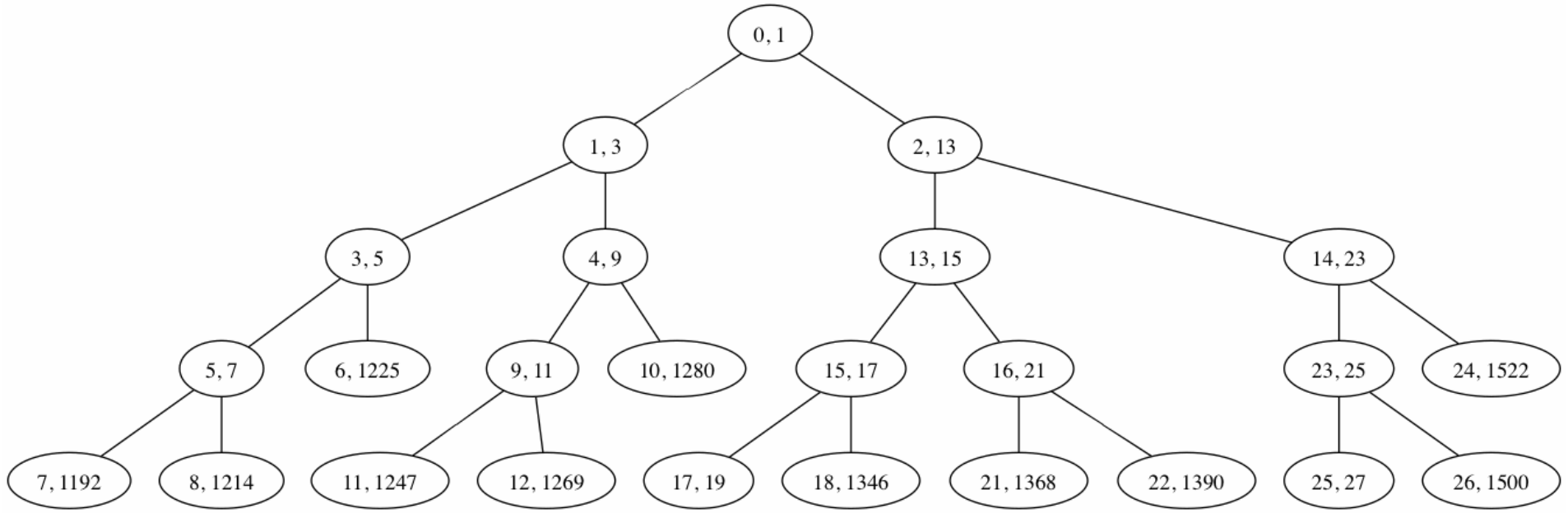
- More useful options:

- --num-thread-procs (number of threads per TM)
- --num-cores (number of TMs)
- --num-l2s (number of TM clusters)
- --no-cpi (don’t print run stats)
- --issue-verbosity (set to 1 for per-cycle details)

--write-dot

- --write-dot <depth>
- Generates “bvh.dot” graph representation of the BVH
- Use the dot tool:
  - dot –Tgif bvh.dot –o bvh.gif
  - Part of the graphviz package
- Can be useful for debugging BVH traversal

--write-dot 4



- Restricted to a depth of 4

Loading the camera

- start_camera = loadi(0, 10)
- eye[x, y, z] is at start_camera + [0..2]
- corner : start_camera + [3..5]
- across: start_camera + [6..8]
- up: start_camera + [9..11]
- gaze: start_camera + [12..14]
- u: start_camera + [15..17]
- v: start_camera + [18..20]

Loading the camera

```
Vector eye( loadf( start_camera, 0 ),
            loadf( start_camera, 1 ),
            loadf( start_camera, 2 ) );

Vector up( loadf( start_camera, 9 ),
           loadf( start_camera, 10 ),
           loadf( start_camera, 11 ) );

Vector gaze( loadf( start_camera, 12 ),
             loadf( start_camera, 13 ),
             loadf( start_camera, 14 ) );
```

Loading the camera

- Recommend a constructor which takes an address

```
PinholeCamera::PinholeCamera(int addr){
  eye = loadVectorFromMemory(addr);
  up = loadVectorFromMemory(addr + 9);
  lookdir = loadVectorFromMemory(addr + 12);
  u = loadVectorFromMemory(addr + 15);
  v = loadVectorFromMemory(addr + 18);
}

PinholeCamera camera(loadi(0, 10));
```

Helper functions

```
inline Vector loadVectorFromMemory(const int
  &address)
{
  float x, y, z;
  x = loadf(address, 0);
  y = loadf(address, 1);
  z = loadf(address, 2);

  return Vector(x, y, z);
}
```

Loading the light

- The light doesn’t specify a color (assume white)

```
inline PointLight loadLightFromMemory(int addr)
{
  return PointLight(loadVectorFromMemory(addr),
  Color(1.f, 1.f, 1.f));
}

PointLight light = loadLightFromMemory(loadi(0,
  12));
```

Triangles

- Triangles are stored as 11 words:
- p1[x, y, z] (address + 0..2)
- p2[x, y, z] (address + 3..5)
- p3[x, y, z] (address + 6..8)
- ID (address + 9)
- material ID (address + 10)

Triangles

```
Vector e1( loadf( addr, 0 ),
           loadf( addr, 1 ),
           loadf(addr, 2 ) );
Vector e2( loadf(addr, 3 ),
            loadf(addr, 4 ),
            loadf(addr, 5 ) );
Vector e3( loadf(addr, 6 ),
            loadf(addr, 7 ),
            loadf(addr, 8 ) );
```

- Encapsulate this in a helper (constructor, etc)
- Don’t call your class “Triangle”!

Triangles

```
inline Vector normal() const
{
  Vector edge1 = p1 - p3;
  Vector edge2 = p2 - p3;
  Vector n = Cross(edge1, edge2);
  n.normalize();
  return n;
}
```

- Don’t compute normals unless you need to shade that triangle

Triangles

- Try to avoid unnecessary memory traffic
- Don’t load material ID every time a triangle is tested for intersection
- Save the address of the closest hit triangle (hitRecord)
- Then only perform load of material ID once during shading

Traversing the scene

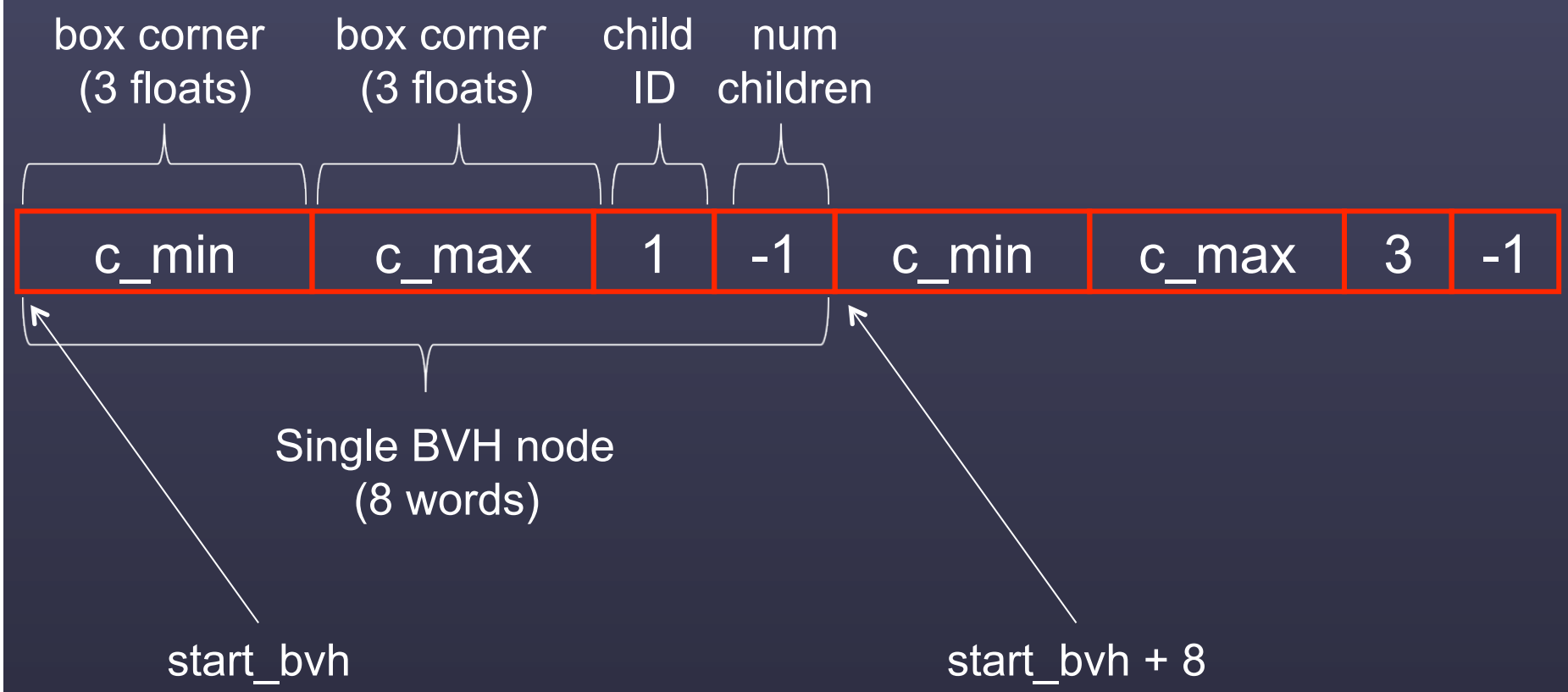
- Before we get in to BVH traversal, a simpler example
- use start_triangles, and num_triangles
- Simply loop through every triangle, loading them from memory

Traversing the scene

```
int start_tris = loadi(0, 28);
int num_tris = loadi(0, 29);
for(int i=0; i < num_tris; i++)
 {
   Tri t =
    loadTriFromMemory(start_tris + (i * 11));
   t.intersect(hitRec, ray);
 }
```

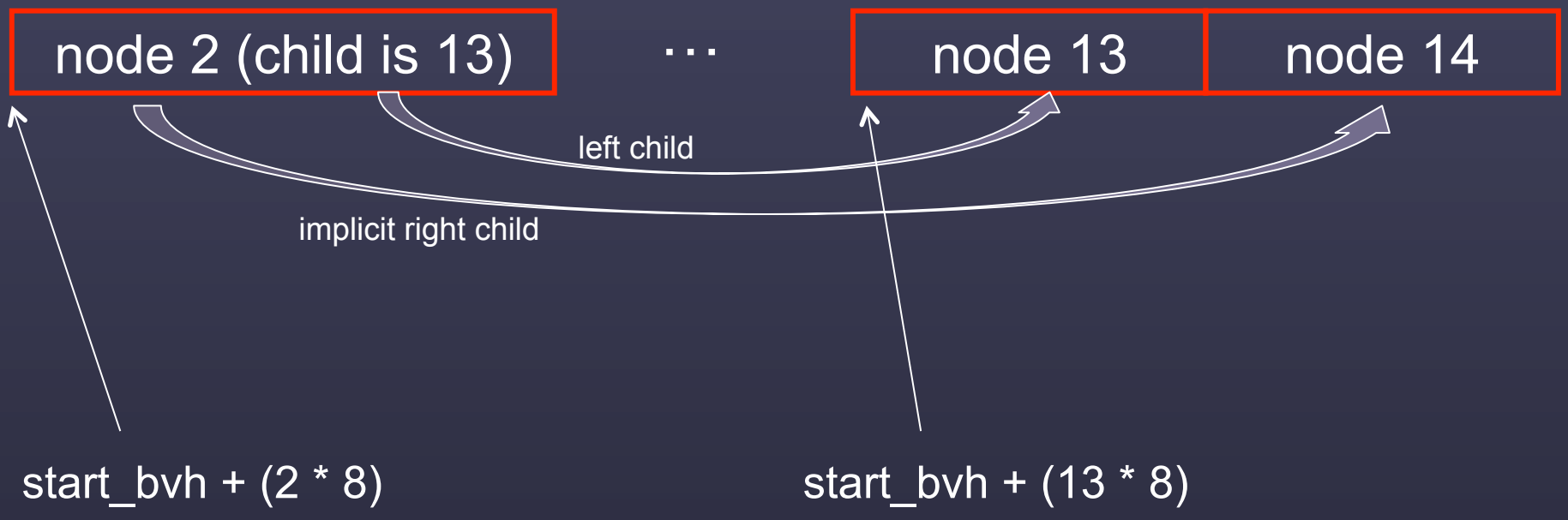
BVH layout

- The BVH is laid out in memory as follows

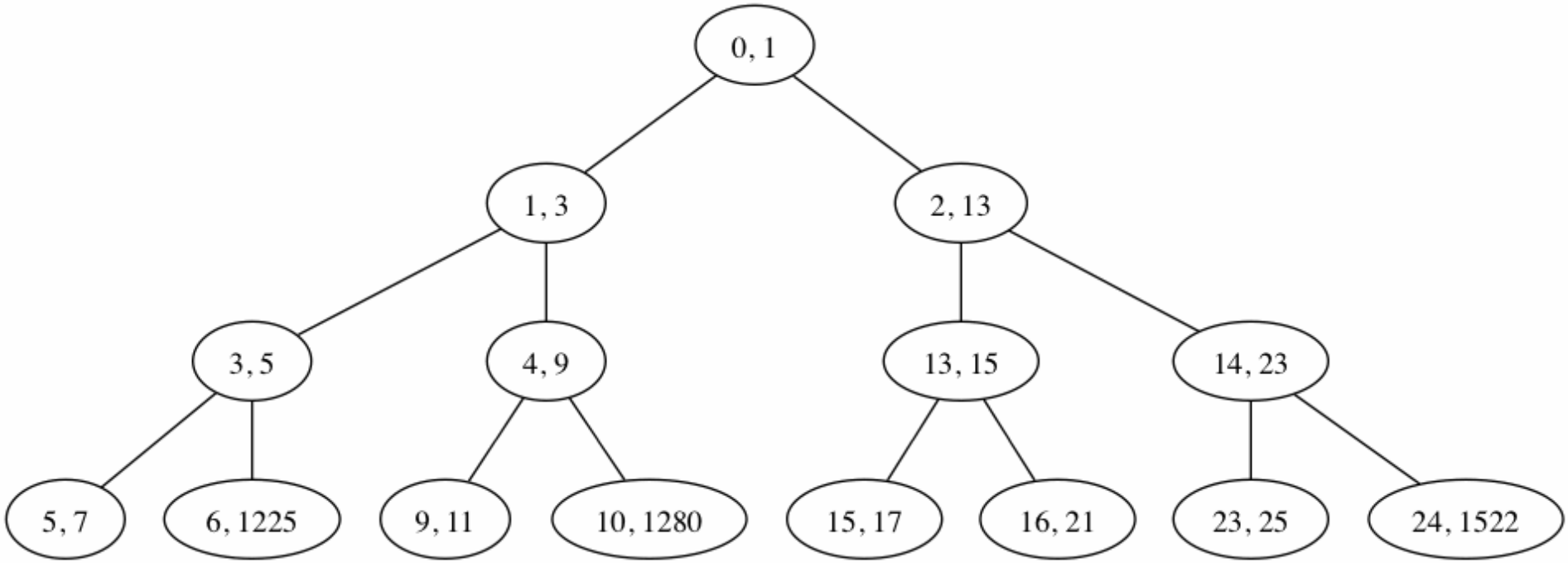


BVH layout

- Sibling nodes are next to each other in memory
- Right child's ID is always left_id + 1



BVH layout


0, 1
1, 3
2, 13
3, 5
4, 9
13, 15
14, 23
5, 7
6, 1225
9, 11
10, 1280
15, 17
16, 21
23, 25
24, 1522

Traversing the BVH

- We don’t want to use recursion
  - Stack frames will quickly outgrow the local memory space
  - Inline function calls are faster
- But we need to traverse a tree (inherently recursive)
- Use a software-managed stack
- `int stack[32]; // holds node IDs`
- `int sp = 0; // stack pointer`

Pseudo code

```
current_node = root
while(true)
   if(ray intersects current node)
     if(interior node)
          push right child
          current = left child
          continue;
     else
          intersect all triangles in leaf
   if(stack is empty)
     break;
   current = pop stack
```

Example

```
inline void intersect(HitRecord& hit,
const Ray& ray) const {
    int stack[32];
    int node_id = 0;
    int sp = 0;
    while(true){
      int node_addr = start_bvh + node_id * 8;
      Box b = loadBoxFromMemory(node_addr);
      HitRecord boxHit;
      b.intersect(boxHit, ray);
      if(boxHit.didHit())
     // and so on...
```

Example (continued)

```
left_id = loadi( node_addr, 7 );
int num_children = loadi( node_addr, 6 );
if ( num_children < 0 )
     {
       stack[ sp++ ] = left_id + 1;
       continue;
     }

tri_addr = left_id;
for ( int i = 0; i < num_children; ++i)
// ...
```

Implementation

```
inline void intersect(HitRecord& hit,
                      const Ray& ray) const
  {
```

- Note that this hit record passed in is for the final hit triangle (or none if background)
- Don’t use the same one for testing against boxes!
- Store the address of the closest triangle in `hit` (used later for shading)

Implementation

```
for each pixel...
 Ray ray;

 camera.makeRay(ray, x, y);

 HitRecord hit;

 bvh.intersect(hit, ray);

 result = shade(hit, ray, bvh, light,
                                start_matls);
```

Important notes

- Remember, the BVH is in global memory
- Don’t try to rebuild it in local memory

- My bvh class contains just a pointer to start_scene

```
BoundingVolumeHierarchy(const int
  &_start_scene)
   {
     start_bvh = _start_scene;
   }
```

- Nodes are loaded 1 at a time as needed

Important notes

- Remember that for leaf nodes, child pointer is an absolute address
- Address of the first triangle

Performance

- Remember, there are some optimizations:
- Traverse down closer child first
- Don’t traverse subtree if closer triangle already found
- The pseudo-code I’ve shown doesn’t do this

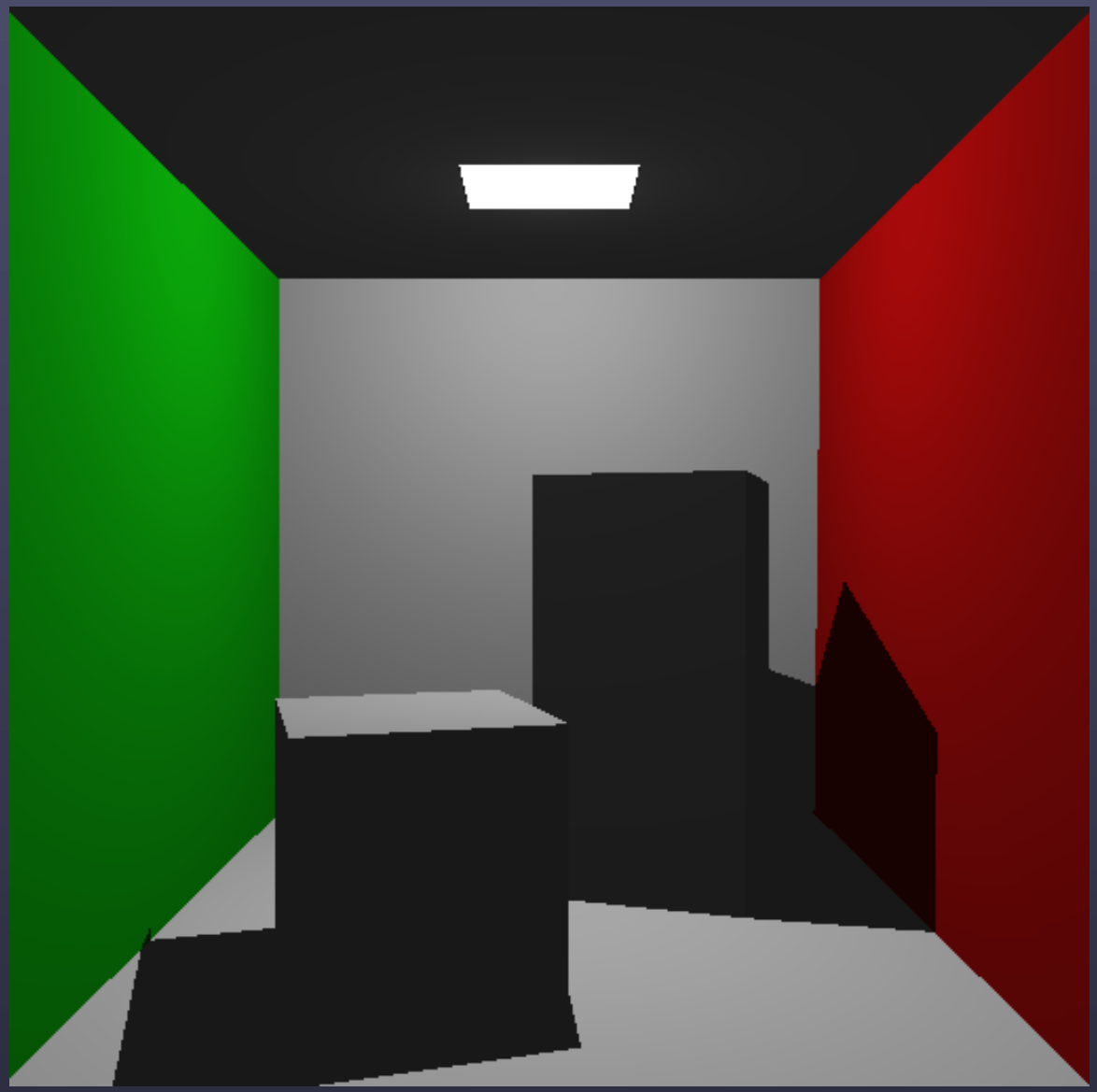
Programs 3, 4

- Both will be available for those who want to skip ahead

- Program 3:
  - Render Cornell scene by looping through triangles
  - Render un-shaded box (for verification of correct ray-box test)

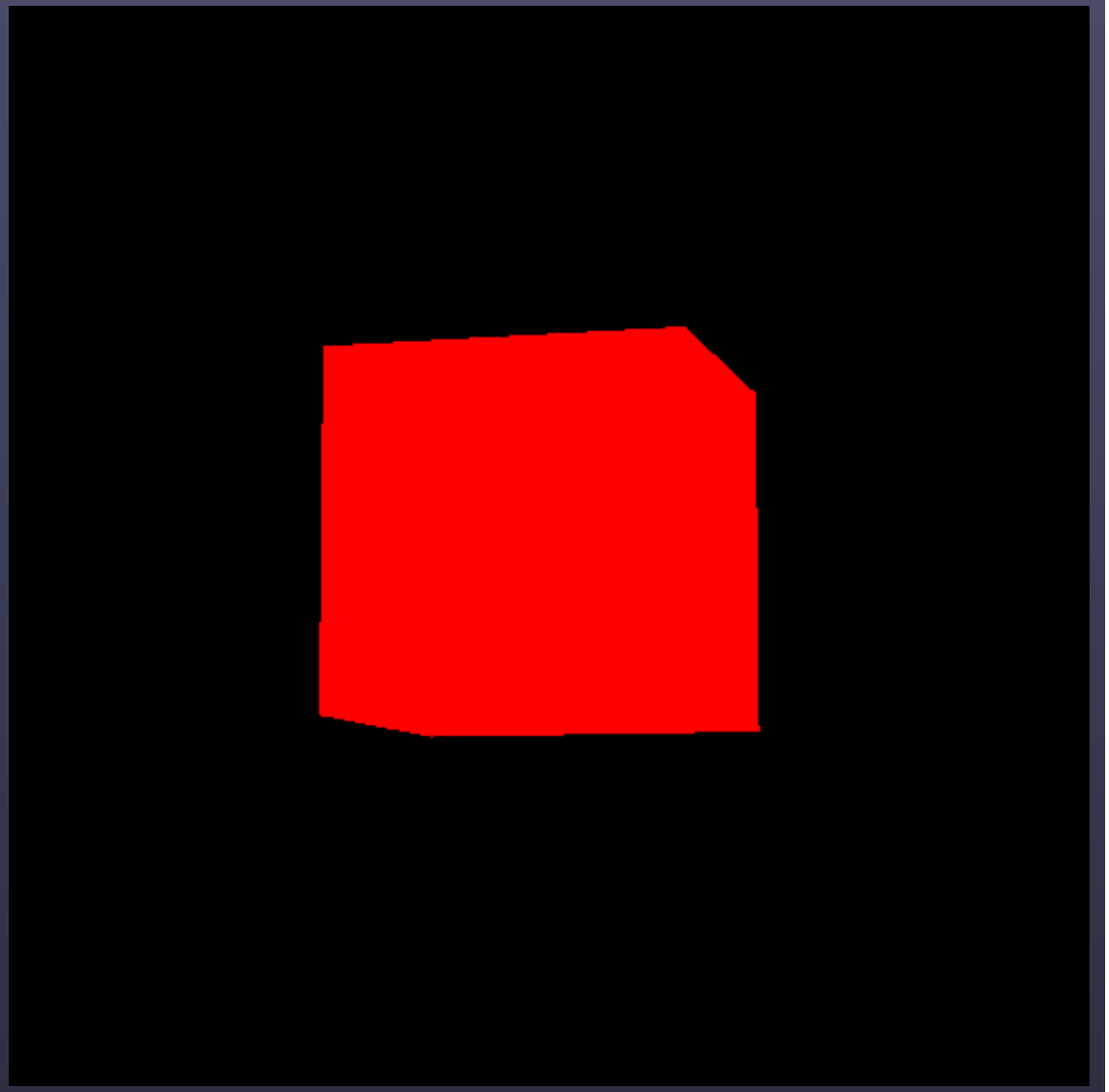
- Program 4:
  - Render Cornell scene using BVH
  - Render conference scene (would never finish without BVH)

Program 3



Program 3

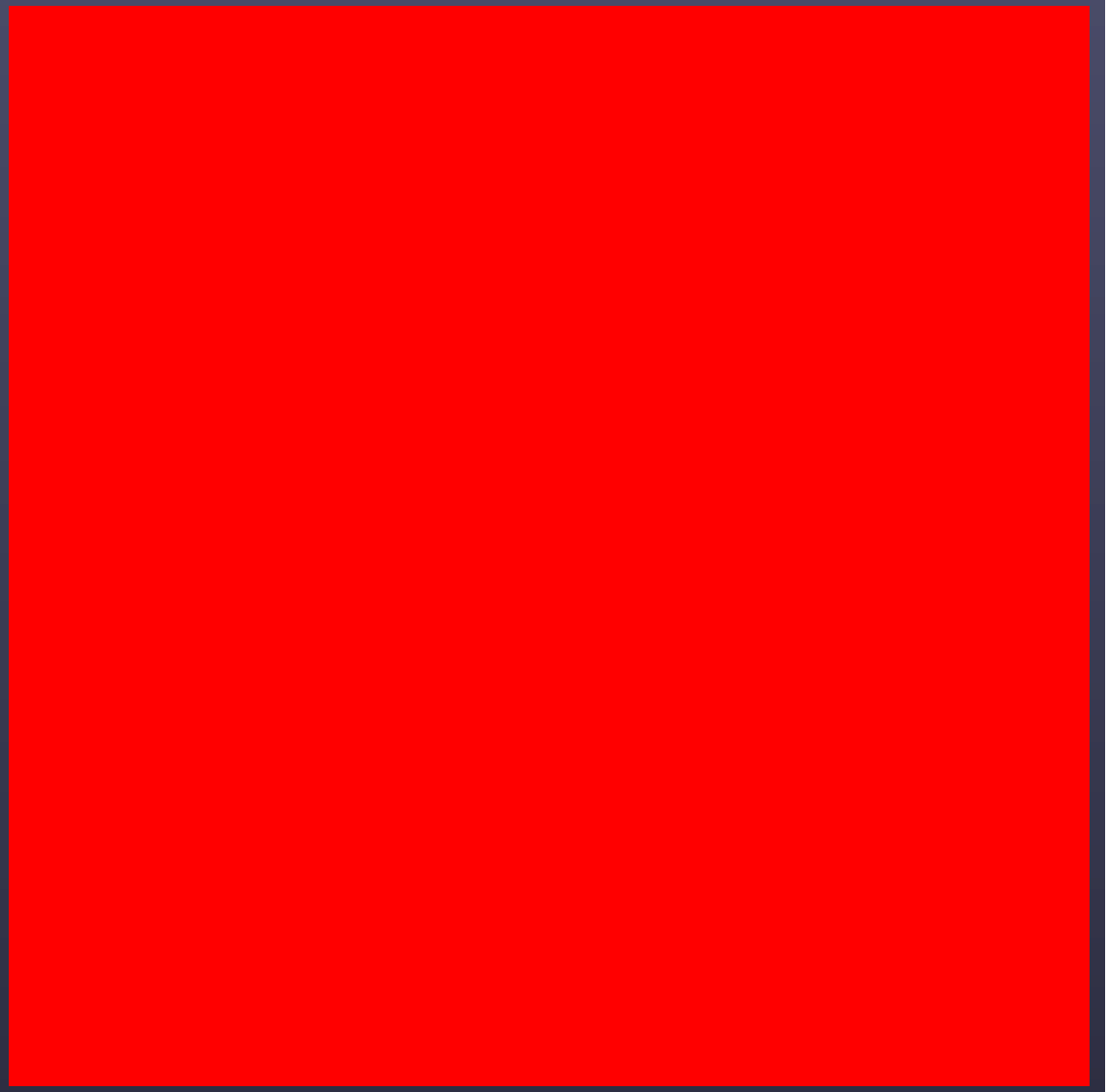
Un-shaded box to verify correct ray-box intersect



Program 3

Rays originating inside the box are often a source of trouble

Most rays will originate inside BVH



Program 4

We will give you plenty of other models to play with as well

Box normals

```
if(Abs(hitpos.x()-c1.x()) < 1.e-6)
   normal = Vector(-1,0,0);
 else if(Abs(hitpos.x()-c2.x()) < 1.e-6)
   normal = Vector(1,0,0);
 else if(Abs(hitpos.y()-c1.y()) < 1.e-6)
   normal = Vector(0,-1,0);
 else if(Abs(hitpos.y()-c2.y()) < 1.e-6)
   normal = Vector(0,1,0);
 else if(Abs(hitpos.z()-c1.z()) < 1.e-6)
   normal = Vector(0,0,-1);
 else
   normal = Vector(0,0,1)
```