HASSO - PLATTNER - INSTITUT
at the university of Potsdam

OpenCSG: A Library for Image-Based CSG Rendering

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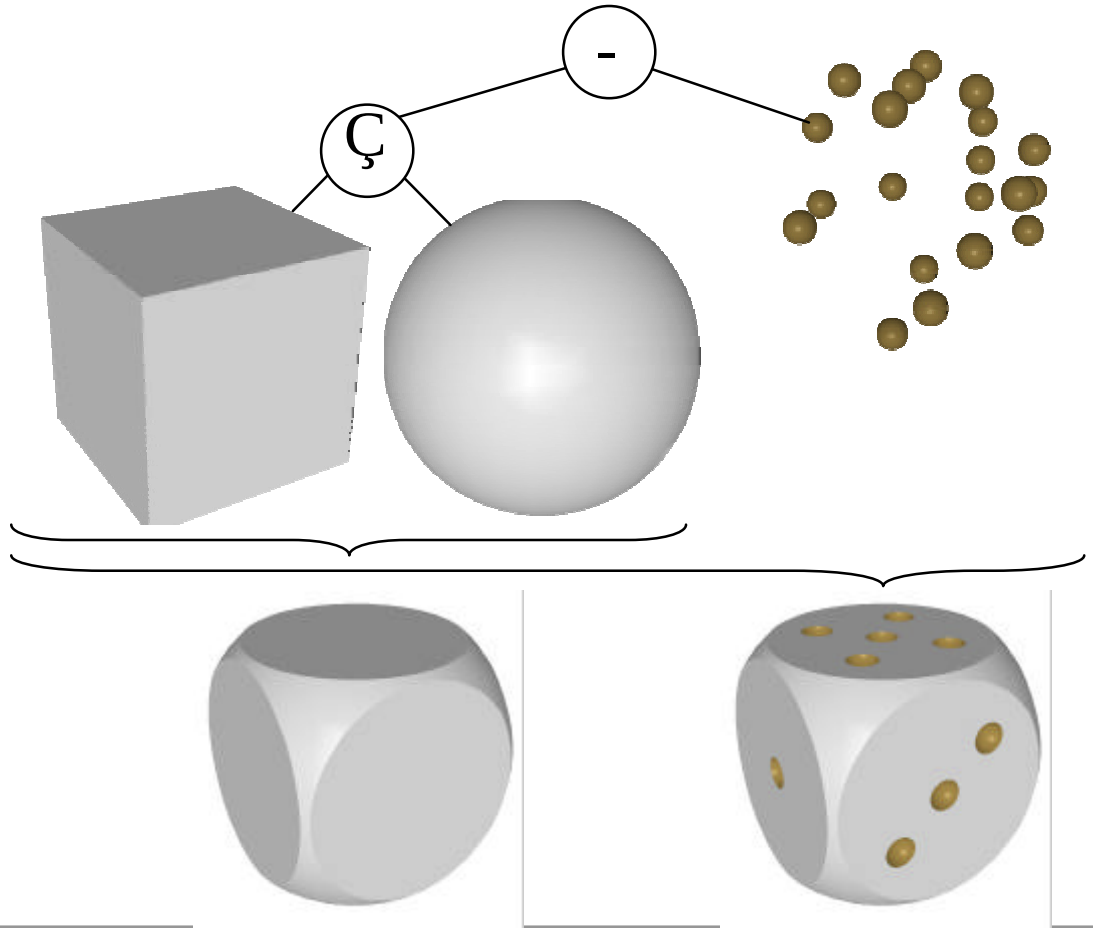
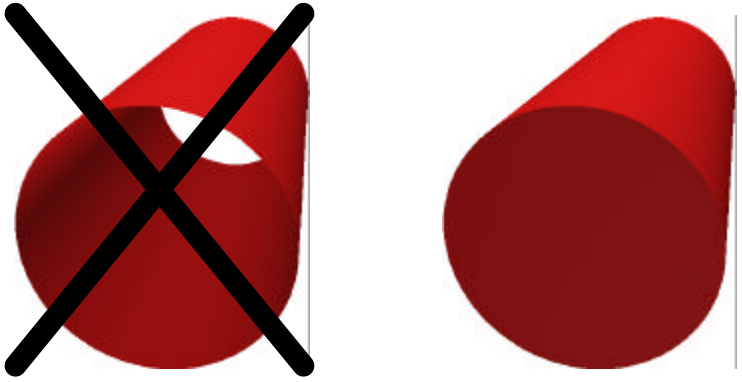
Introduction

- Modeling using CSG (Constructive Solid Geometry)

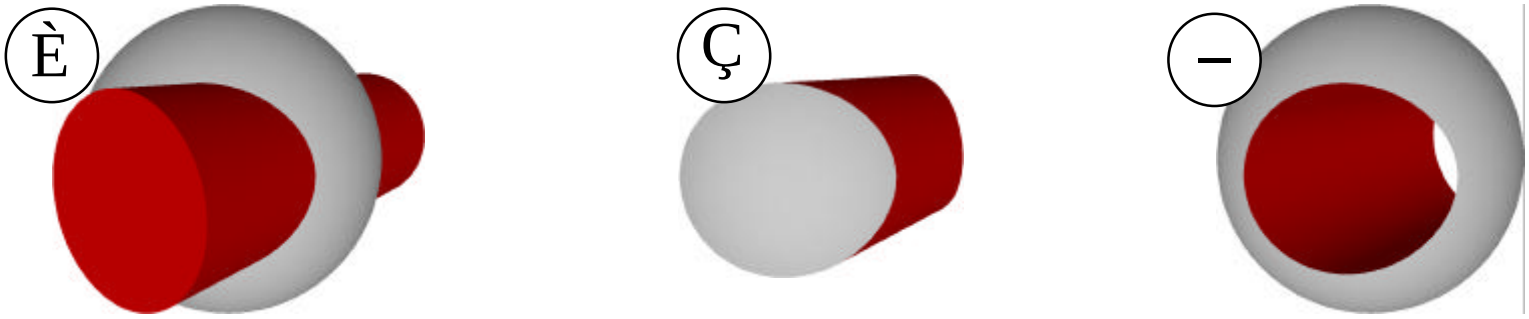


Introduction

- CSG requires: Primitives
  - Leaf nodes of CSG tree
  - Must be closed



- and: Boolean operations
  - Inner nodes of CSG tree
  - Union, Intersection, Subtraction



Introduction

- CSG is available in offline rendering systems
  - RenderMan
  - POV-Ray

Introduction

- CSG cannot be directly rendered with graphics hardware
- How to use CSG in real-time?

1. **Object-based CSG**
   - Calculate boundary of CSG shape mathematically, render mesh
   - Too expensive for dynamically manipulated models
2. **Image-based CSG rendering**
   - Compose final image in frame buffer
   - Suitable for interactive manipulation
   - Advanced use of graphics hardware

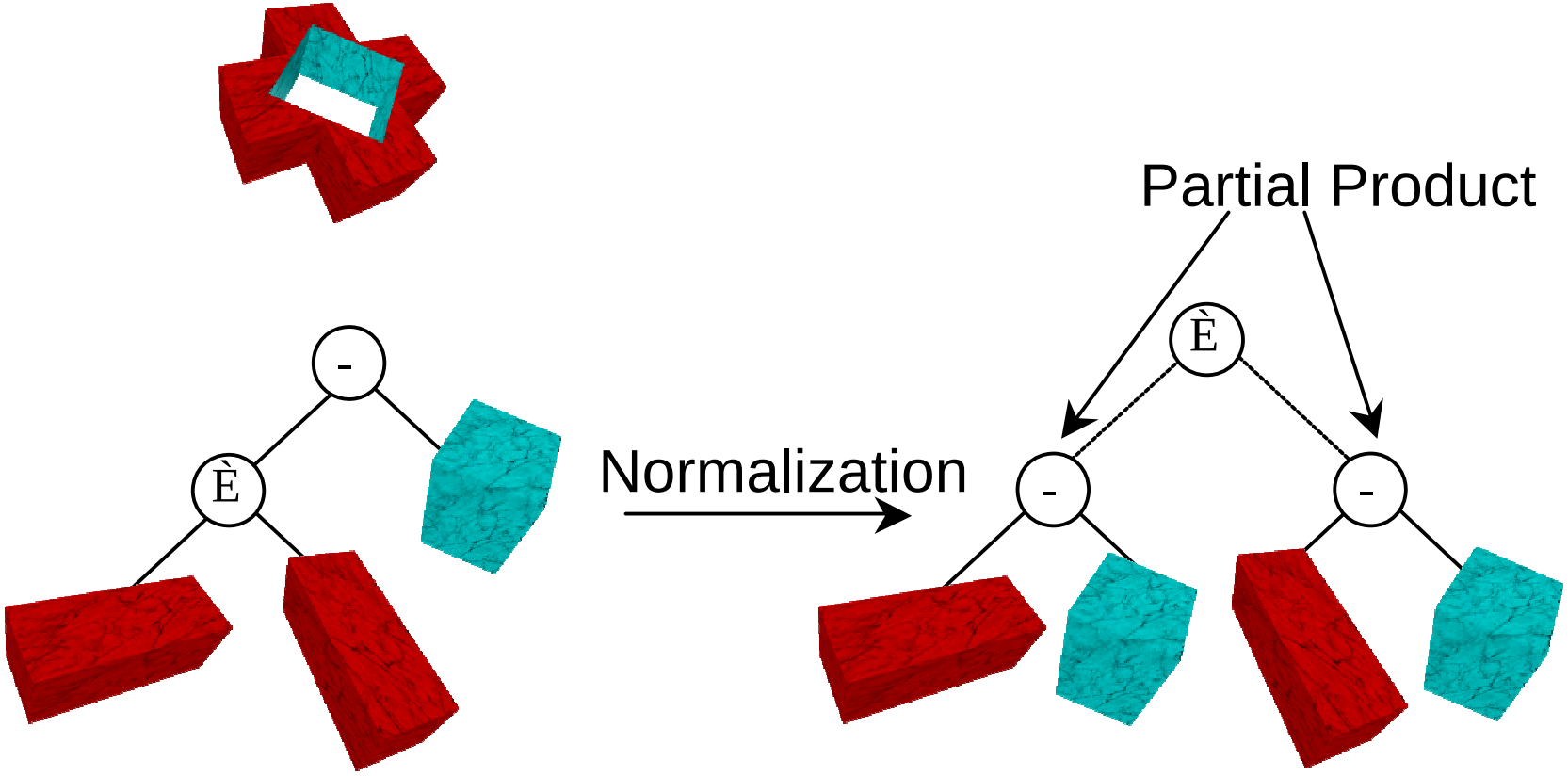
Algorithms

- Two basic algorithms for image-based CSG
- Goldfeather algorithm
- SCS algorithm
- Both require normalization of CSG tree to union of CSG products
- CSG product: $(\ldots((x_1 \otimes x_2) \otimes x_3) \ldots \otimes x_n)$

($\otimes$ is intersection or subtraction)

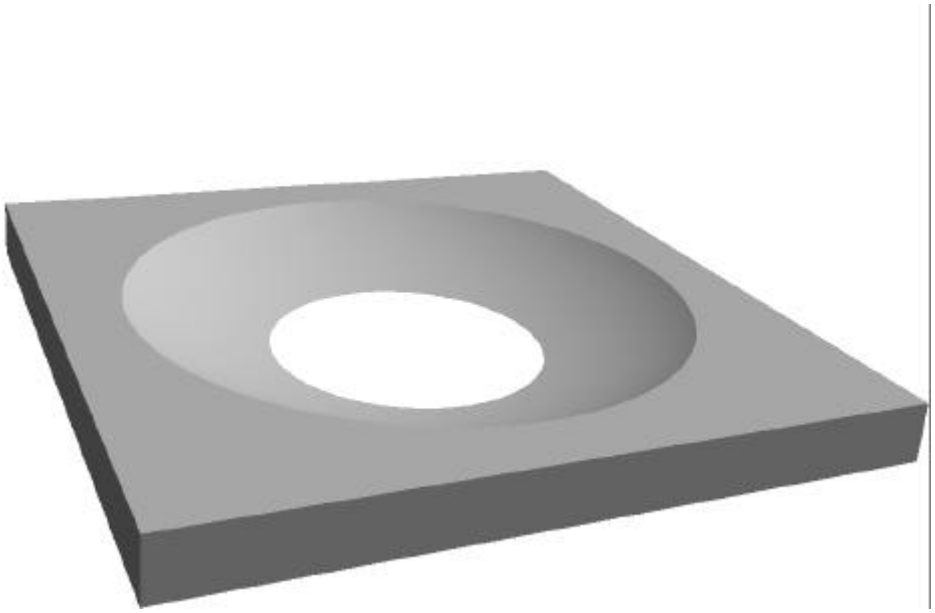
Algorithms

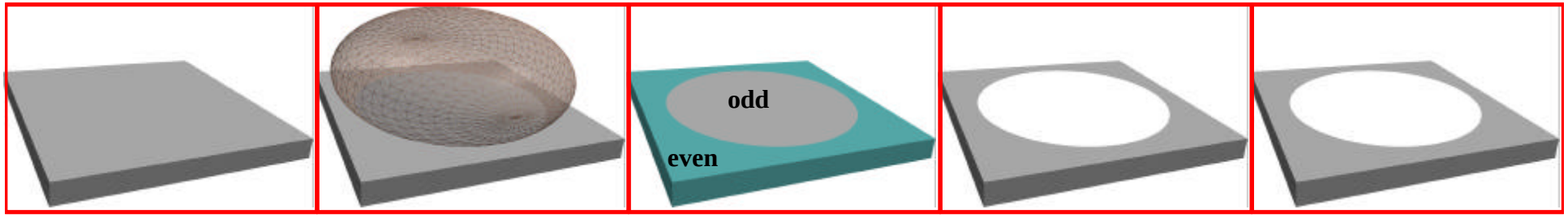
- Normalization of CSG tree to union of CSG products



Algorithms

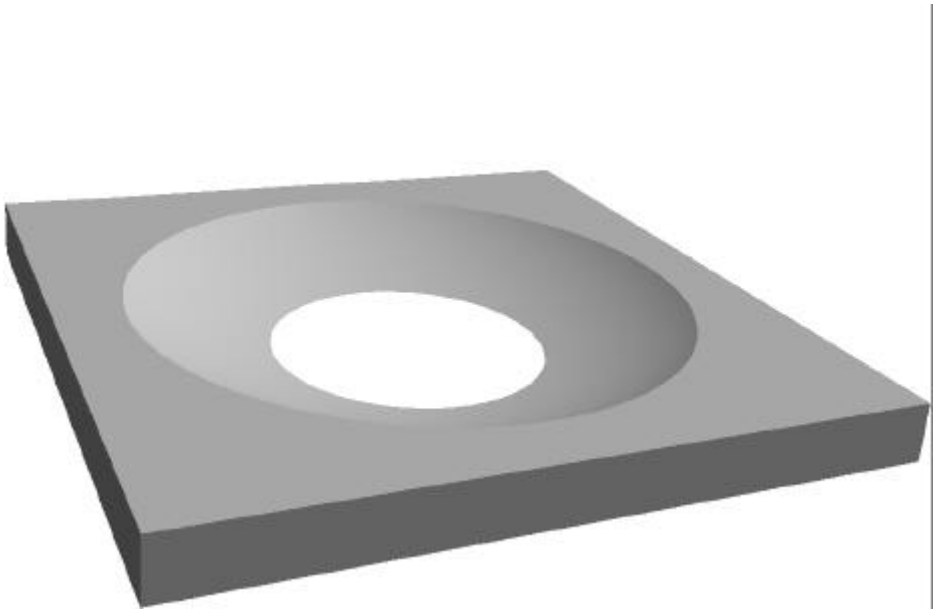
- Goldfeather algorithm: all kinds of primitives
- Handle each primitive separately

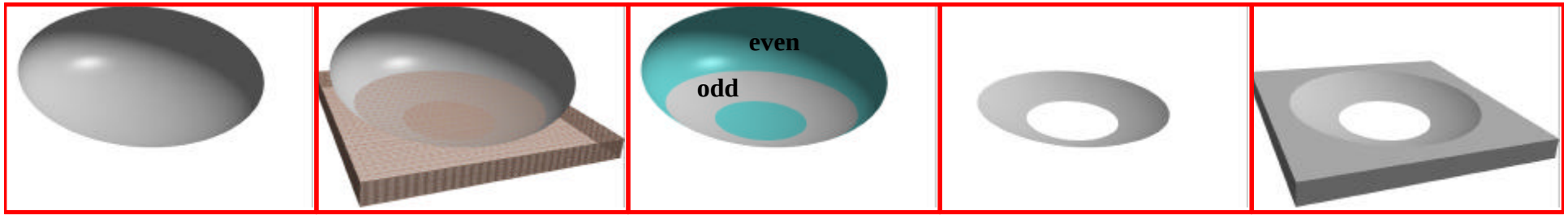




Algorithms

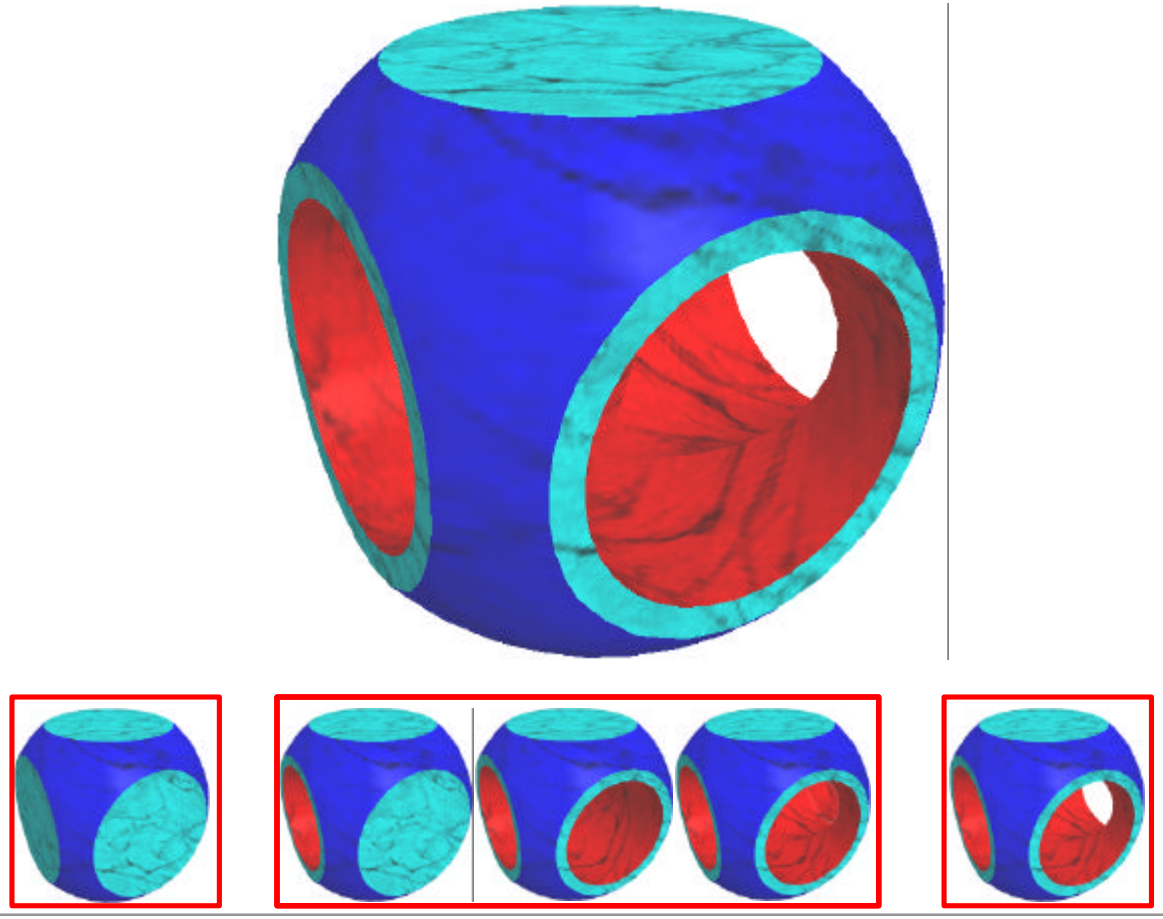
- Goldfeather algorithm
- Different handling of subtracted primitives





Algorithms

- SCS algorithm: only convex primitives



Algorithms

- Problems: Algorithms are complicated
- Seldom used in real applications
- Currently no abstraction layer available

$\rightarrow$ OpenCSG

API: Overview

Design Goals

- Minimal interface
- Only for CSG rendering
- Possibility to use user-defined primitives
- No external dependencies except OpenGL
- ...

API: Overview

```
namespace OpenCSG {
    enum Operation { Intersection, Subtraction };
    class Primitive {
    public:
        Primitive(Operation, unsigned int convexity);
        virtual ~Primitive();
        void setOperation(Operation);
        Operation getOperation() const;
        void setConvexity(unsigned int);
        unsigned int getConvexity() const;
        void setBoundingBox(float  minx, float  miny, float  minz,
                            float  maxx, float  maxy, float  maxz);
        void getBoundingBox(float& minx, float& miny, float& minz,
                            float& maxx, float& maxy, float& maxz) const;
        virtual void render() = 0;
    };
    enum Algorithm {
        Automatic, Goldfeather, SCS
    };
    enum DepthComplexityAlgorithm {
        NoDepthComplexitySampling, OcclusionQuery, DepthComplexitySampling
    };
    void render(const std::vector<Primitive*>& primitives,
                Algorithm = Automatic,
                DepthComplexityAlgorithm = NoDepthComplexitySampling);
}
```

API: Overview

Basic facts

- C++ interface
- Namespace **`OpenCSG`**
- Abstract primitive class
- Render function for CSG rendering

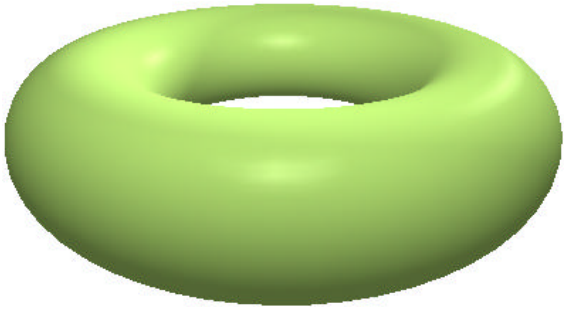
API: Abstract primitive class

- Operation: Whether primitive in CSG product is intersected or subtracted

```
enum Operation { Intersection, Subtraction };
class Primitive {
public:
    Primitive(Operation, unsigned int convexity);
    virtual ~Primitive();
    void setOperation(Operation);
    Operation getOperation() const;
    void setConvexity(unsigned int);
    unsigned int getConvexity() const;
    void setBoundingBox(float  minx, float  miny, float  minz,
                        float  maxx, float  maxy, float  maxz);
    void getBoundingBox(float& minx, float& miny, float& minz,
                        float& maxx, float& maxy, float& maxz) const;
    virtual void render() = 0;
};
```

API: Abstract primitive class

- Convexity



```
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class Primitive {
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    Primitive(Operation, unsigned int convexity);
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    void setOperation(Operation);
    Operation getOperation() const;
    void setConvexity(unsigned int);
    unsigned int getConvexity() const;
    void setBoundingBox(float  minx, float  miny, float  minz,
                        float  maxx, float  maxy, float  maxz);
    void getBoundingBox(float& minx, float& miny, float& minz,
                        float& maxx, float& maxy, float& maxz) const;
    virtual void render() = 0;
};
```

API: Abstract primitive class

- Bounding Box: Maximum extent of primitive in screen space
- Used for rendering optimizations

```
enum Operation { Intersection, Subtraction };
class Primitive {
public:
    Primitive(Operation, unsigned int convexity);
    virtual ~Primitive();
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    void getBoundingBox(float& minx, float& miny, float& minz,
                        float& maxx, float& maxy, float& maxz) const;
    virtual void render() = 0;
};
```

API: Abstract primitive class

- render method: Renders a primitive
- Implemented by subclasses
- Don‘t set colors!

```
enum Operation { Intersection, Subtraction };
class Primitive {
public:
    Primitive(Operation, unsigned int convexity);
    virtual ~Primitive();
    void setOperation(Operation);
    Operation getOperation() const;
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    void setBoundingBox(float  minx, float  miny, float  minz,
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    void getBoundingBox(float& minx, float& miny, float& minz,
                        float& maxx, float& maxy, float& maxz) const;
    virtual void render() = 0;
};
```

API: Render function for CSG rendering

- Render function for CSG rendering
- Initializes Z-Buffer with values of CSG product

```
enum Algorithm {
    Automatic, Goldfeather, SCS
};
enum DepthComplexityAlgorithm {
    NoDepthComplexitySampling, OcclusionQuery, DepthComplexitySampling
};
void render(const std::vector<Primitive*>& primitives,
            Algorithm = Automatic,
            DepthComplexityAlgorithm = NoDepthComplexitySampling);
```

API: Render function for CSG rendering

- Initializes Z-Buffer with values of CSG product
- Arguments:
  - List of primitives

```
enum Algorithm {
    Automatic, Goldfeather, SCS
};
enum DepthComplexityAlgorithm {
    NoDepthComplexitySampling, OcclusionQuery, DepthComplexitySampling
};
void render(const std::vector<Primitive*>& primitives,
            Algorithm = Automatic,
            DepthComplexityAlgorithm = NoDepthComplexitySampling);
```

API: Render function for CSG rendering

- Initializes Z-Buffer with values of CSG product
- Arguments:
  - List of primitives
  - Specifier to choose CSG algorithm

```
enum Algorithm {
    Automatic, Goldfeather, SCS
};
enum DepthComplexityAlgorithm {
    NoDepthComplexitySampling, OcclusionQuery, DepthComplexitySampling
};
void render(const std::vector<Primitive*>& primitives,
            Algorithm = Automatic,
            DepthComplexityAlgorithm = NoDepthComplexitySampling);
```

API: Render function for CSG rendering

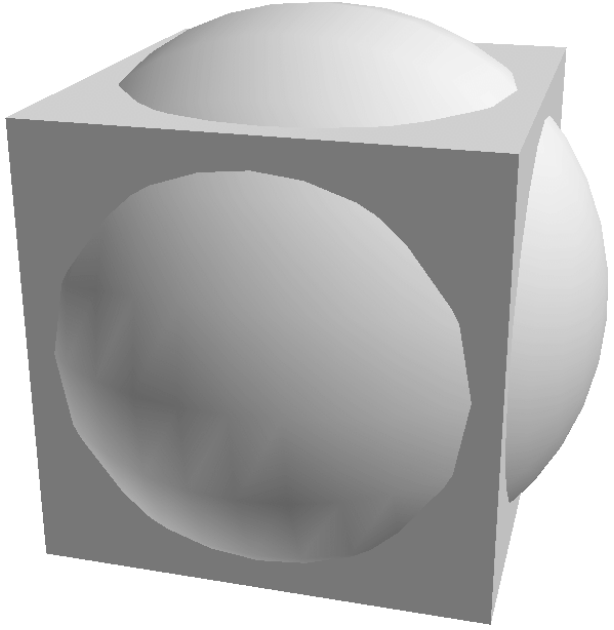
- Initializes Z-Buffer with values of CSG product
- Arguments:
  - List of primitives
  - Specifier to choose CSG algorithm
  - Optimization strategy

```
enum Algorithm {
    Automatic, Goldfeather, SCS
};
enum DepthComplexityAlgorithm {
    NoDepthComplexitySampling, OcclusionQuery, DepthComplexitySampling
};
void render(const std::vector<Primitive*>& primitives,
            Algorithm = Automatic,
            DepthComplexityAlgorithm = NoDepthComplexitySampling);
```

Example

- Basic shapes generated by helper library GLUT
- Stored as OpenGL display lists
- Box and Sphere

```
GLuint id1 = glGenLists(1);
glNewList(id1, GL_COMPILE);
glutSolidCube(1.8);
glEndList();
GLuint id2 = glGenLists(1);
glNewList(id2, GL_COMPILE);
glutSolidSphere(1.2, 20, 20);
glEndList();
```



Example

- Class derived from Primitive class
- Invokes display list in render method
- Create objects for Box and Sphere
- Append to CSG product

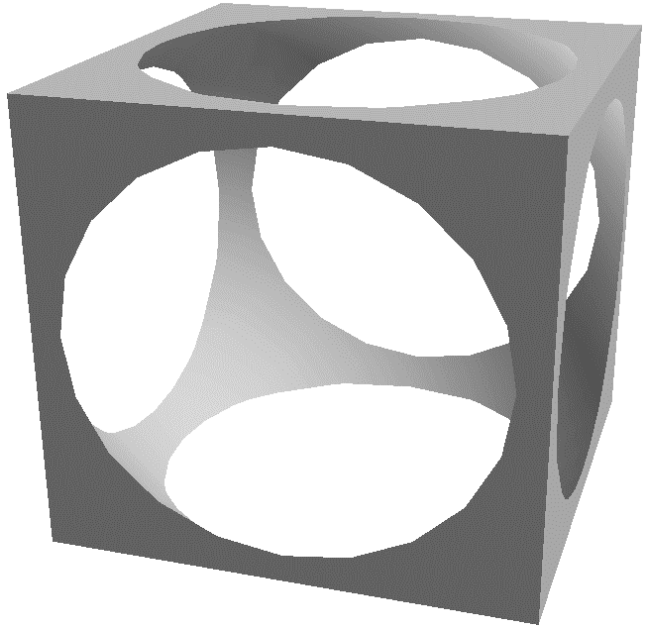
```
class DisplayListPrimimitive : public OpenCSG::Primitive {
    ...
};
namespace OpenCSG;
DisplayListPrimitive* box=new DisplayListPrimitive(id1, Intersection, 1);
DisplayListPrimitive* sphere=new DisplayListPrimitive(id2, Subtraction, 1);
std::vector<Primitive*> primitives;
primitives.push_back(box);
primitives.push_back(sphere);
```

Example

- Call render function
- This initializes Z-Buffer with values of CSG product
- Must shade the primitives now
- Render with z-equal depth test

```
OpenCSG::render(primitives,
                Goldfeather,
                NoDepthComplexitySampling);

glDepthFunc(GL_EQUAL);
// setup lighting and shading
box->render();
sphere->render();
glDepthFunc(GL_LESS);
```



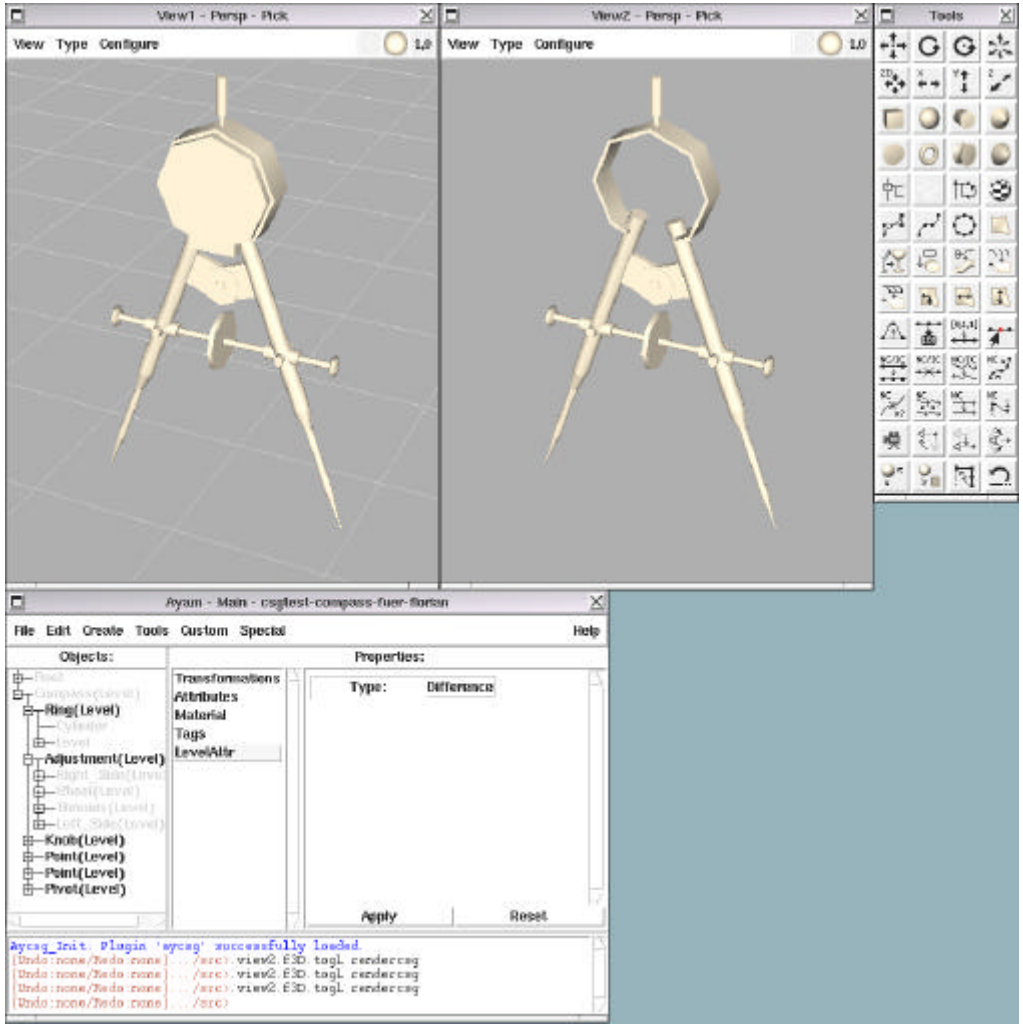
Implementation

- Implementation as described in

Rendering Techniques for
Hardware-Accelerated Image-Based CSG
(WSCG 2004)

Applications

- Modeling applications
- Screenshot: RenderMan modeler **Ayam**



Applications

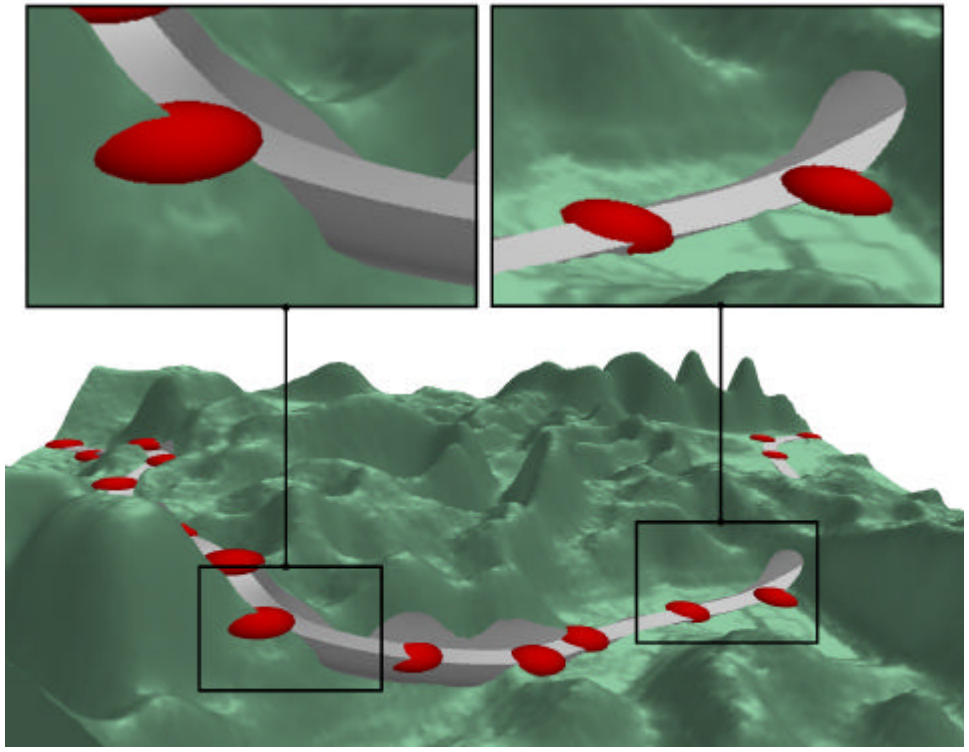
- Beyond traditional uses of CSG

  Gaming

Applications

- Beyond traditional uses of CSG

  Interactive road design

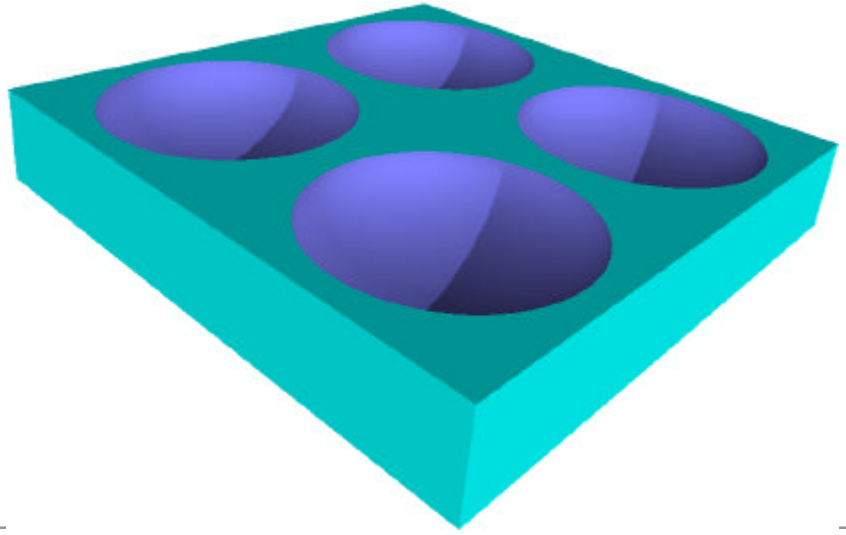


Questions?

OpenCSG: Internals

Size of invisible frame buffer

- Constant, even if used from different windows
- Important for multi-window applications
- And multipass algorithms (e.g., shadow mapping)



OpenCSG: Internals

Further optimizations

- Based on bounding-boxes
- Batching of primitives
- Scissoring