造　型

计算机图形学——原理、方法及应用（第4版），潘云鹤、童若锋、耿卫东、唐敏、童欣，高等教育出版社，2022。

网格

曲面造型

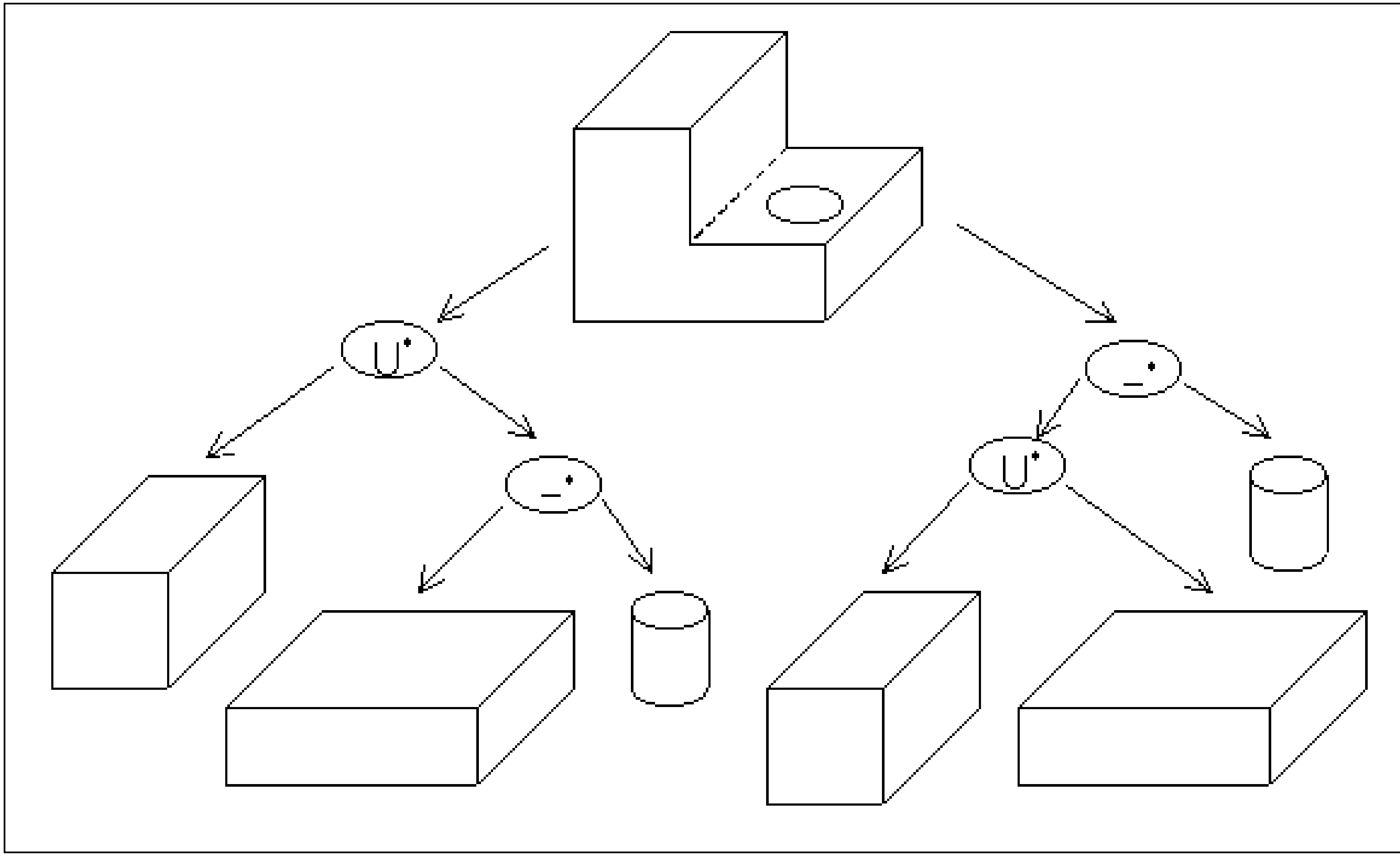
实体造型

其它方法

物体表达的基本方法

- **CSG树 Constructive Solid Geometry**
- 分解表达 Decomposition
- 边界表达 Boundary representations

- **CSG树**



CSG 表达

- 通过布尔运算组合长方体、柱体等简单体元.
- 以树的形式存储：叶节点为基本体元，中间节点为布尔运算或变换.
- 基本体元可以是长方体、柱体、球、锥体等.
- 表达不唯一，但紧凑.
- 数据结构简单.
- 全局操作简单：树的合并、子树删除.
- 可以转化为BREP.
- 局部操作困难.
- 显示困难.

物体表达的基本方法

- CSG树 Constructive Solid Geometry
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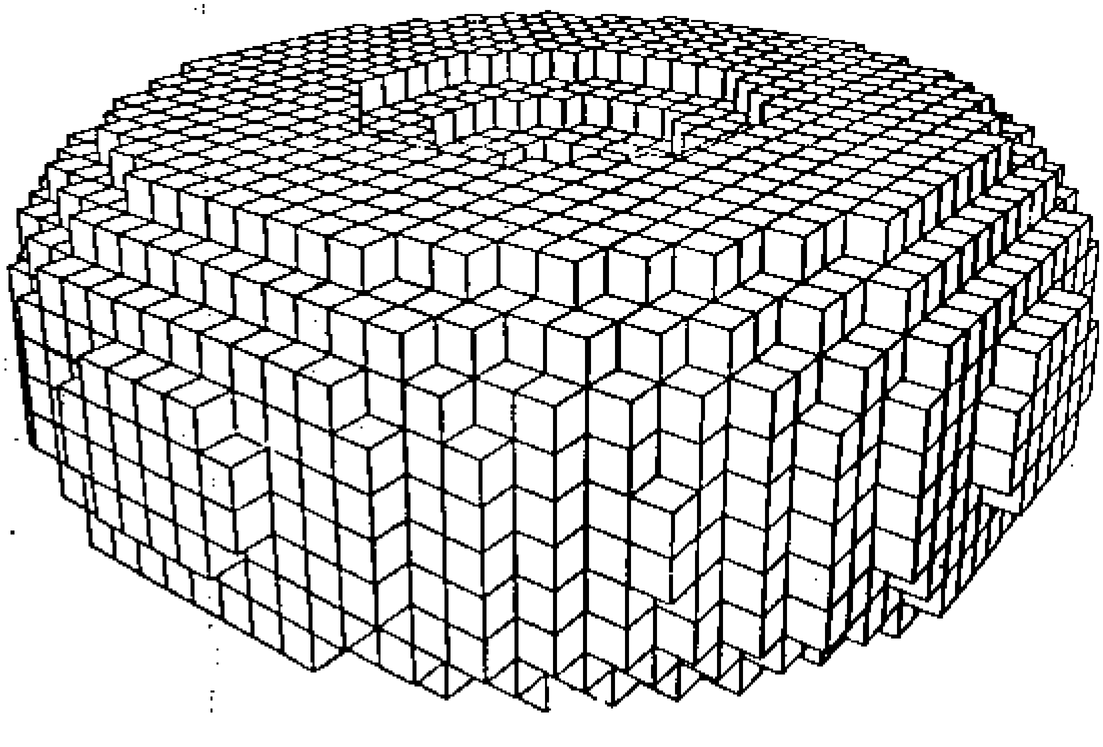
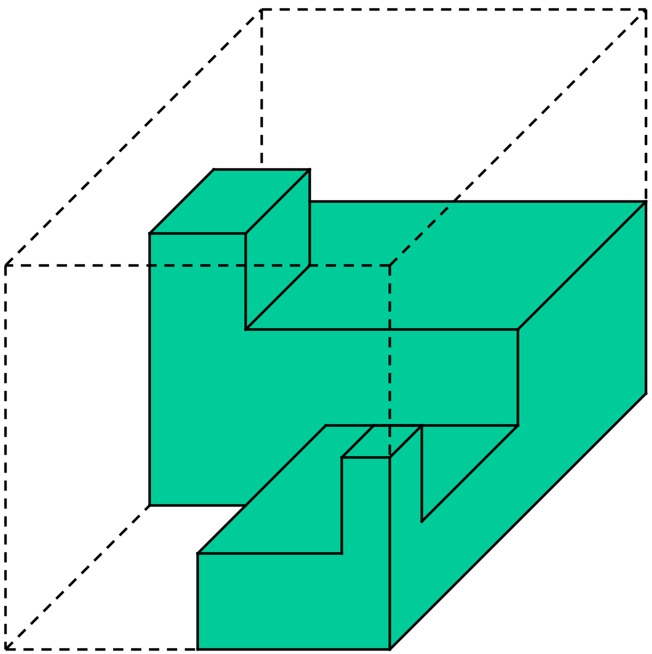
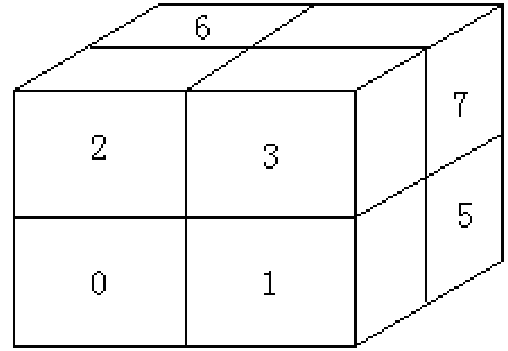
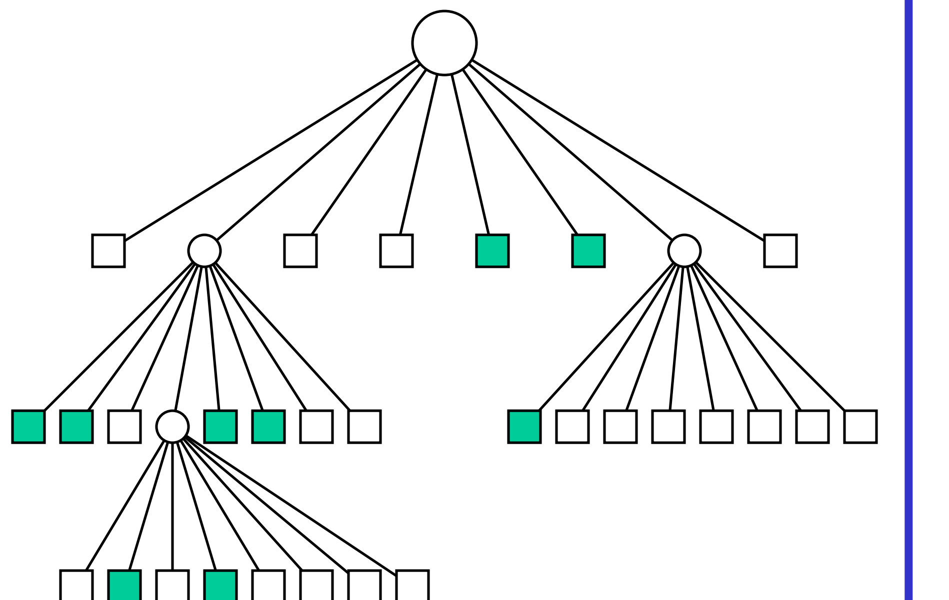


用体素表示物体，类似像素表示二值图像

八叉树表达







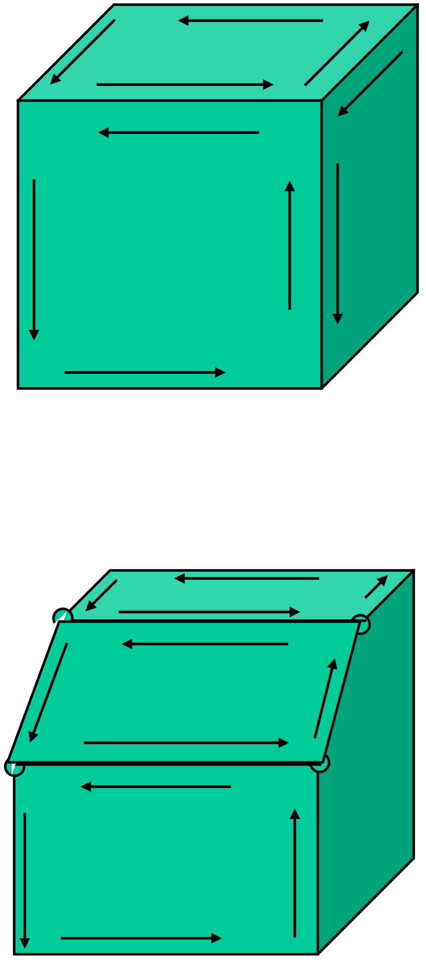
物体表达的基本方法

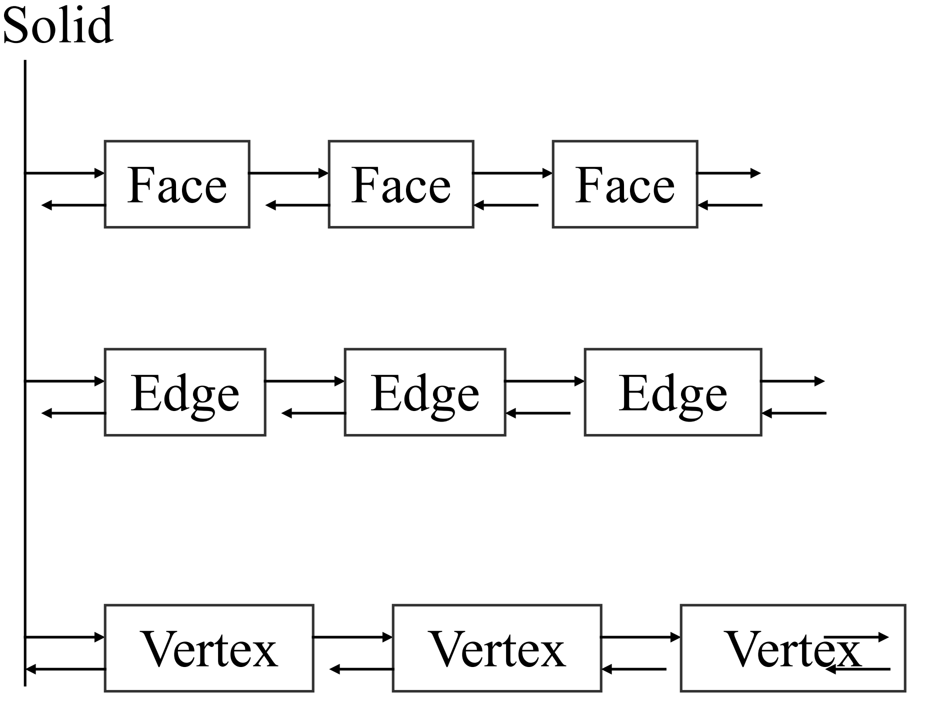
- CSG树 Constructive Solid Geometry
- 分解表达 Decomposition
- **边界表达 Boundary representations**

Brep: 边界表示 Boundary Representation

- 由物体的边界（面、边、顶点）来表示物体。
- 以一定方式存储面、边、顶点间的相邻关系，称为拓扑关系。
- 易于实现局部操作。
- 布尔运算由于求交计算中误差的因素可能导致不可预知的结果。

Brep: 边界表示

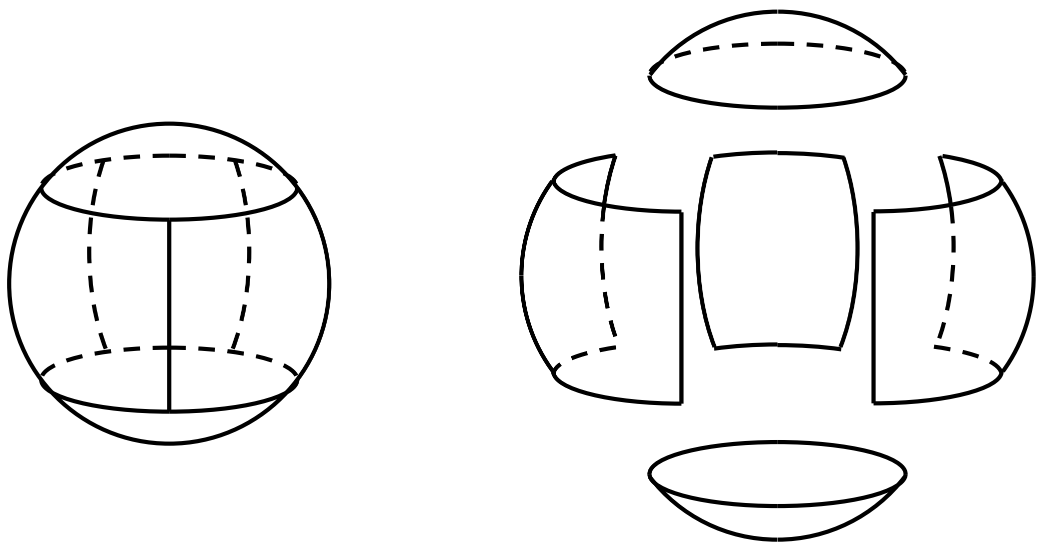




一个物体要存储两类信息

- 几何数据
- 拓扑数据

几何数据由基本形状的参数构成，如NURBS曲面的控制顶点、节点等。而拓扑数据则包含几何元素间的连接关系。



一个合法的多面体：
无悬挂面、边。一条边只能是两个面的交线。

欧拉公式：

亏格为零的多面体的欧拉公式

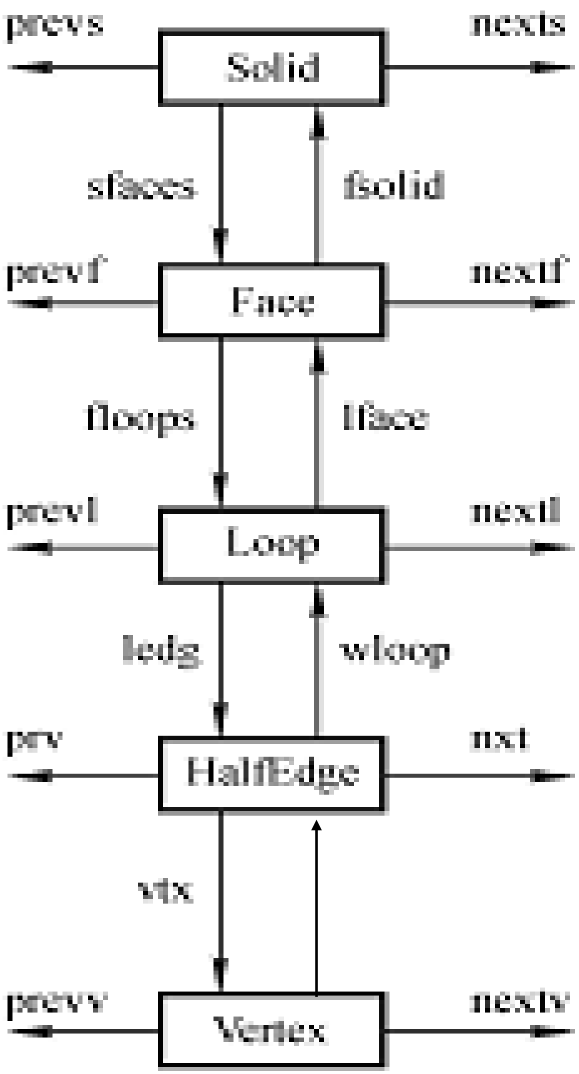
$$V - E + F = 2$$

广义多面体的欧拉公式

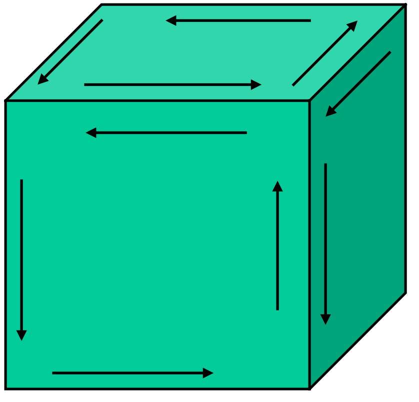
$$V - E + F - L = 2 (S - G)$$

半边数据结构

半边结构中的的5个类型：Solid、Face、Loop、HalfEdge、Vertex：

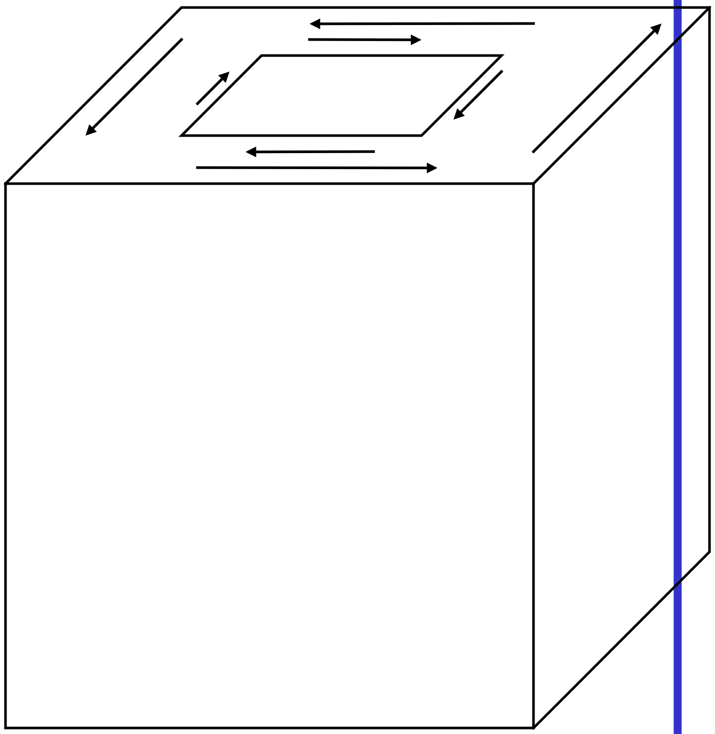


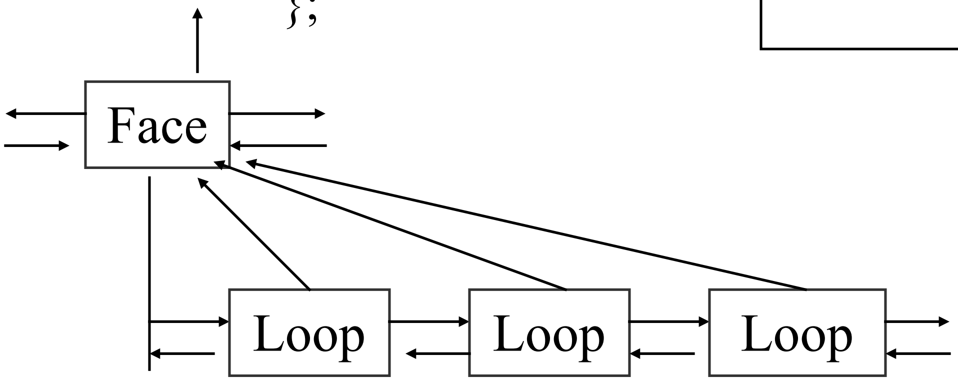
typedef struct solid　Solid;
typedef struct face　Face;
typedef struct loop　Loop;
typedef struct halfedge HalfEdge;
typedef struct vertex　Vertex;
typedef struct edge　Edge;
typedef union nodes　Node;



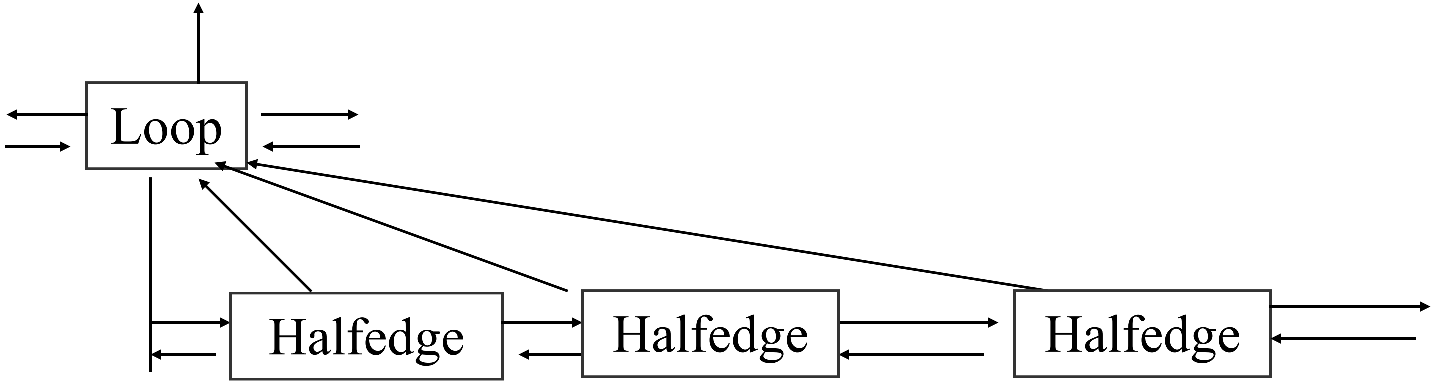
```
struct solid
{
    Id       Solidno;  /*solid identifier*/
    Face     *sfaces;  /*pointer to list faces*/
    Edge     *sedges;  /*pointer to list of vertices*/
    Vertex   *sverts;  /*pointer to list of solid*/
    Solid    *nexts;  /*pointer to next solid*/
    Solid    *prevs;  /*pointer to previous solid*/
};
```

```
struct face
{
Id  faceno;  /*face identifier*/
Solid *fsolid;  /*back pointer to solid*/
Loop *flout;  /*pointer to outer loop*/
Loop *floops; /*pointer to list of
                              loops*/
vector  feq;  /*face equation*/
SURFACE *fgeom ;
Face *nextf;  /*pointer to next face*/
Face *prevf;  /*pointer to previous
                              face*/
};
```

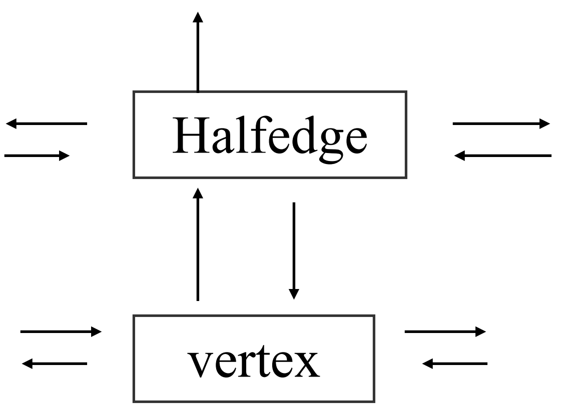




```
struct loop
{
    HalfEdge *lege;  /*pointer to ring of halfedges*/
    Face *lface;  /*back pointer to face*/
    Loop *nextl;  /*pointer to next loop*/
    Loop *prevl;  /*pointer to previous face*/
};
```

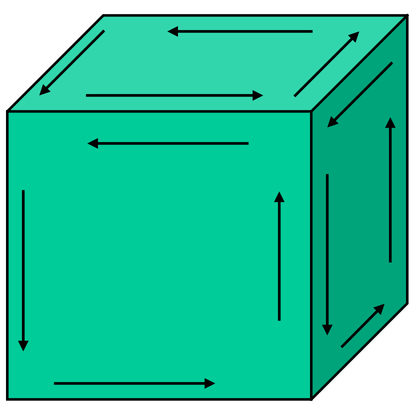


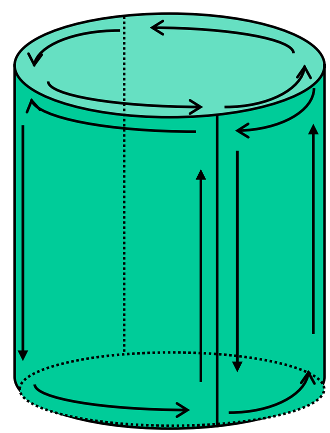
```
struct halfedge
{
Edge *edg;  /*pointer to parent edge*/
Vertex *vex;  /*pointer to starting vertex*/
Loop *wloop;  /*back pointer to loop*/
HalfEdge *nxt;  /*pointer to next halfedge*/
HalfEdge *prv;  /*pointer to previous
                              halfedge*/
};
```

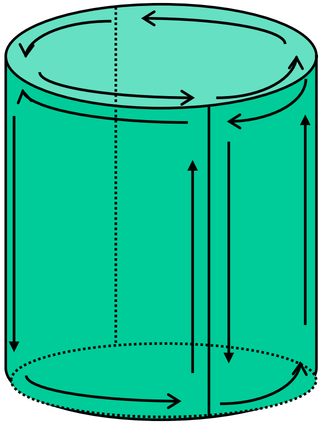


```
struct vertex
{
    Id 1 vertexno;          /*vertex identifier*/
    HalfEdge *vedge;        /*pointer to a halfedge*/
    vector vcoord;          /*vertex coordinates*/
    Vertex *nextv;          /*pointer to next vertex*/
    Vertex *prevv;          /*pointer to previous
                                      vertex*/
};
```

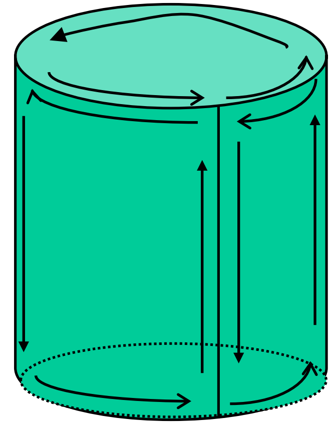
```
struct edge
{
    HalfEdge *he1;  /*pointer to right
                                halfedge*/
    HalfEdge *he2;  /*pointer to left halfedge*/
    Edge *nexte;  /*pointer to next edge*/
    Edge *preve;  /*pointer to previous edge*/
    Curve *cgeom ;
};
```





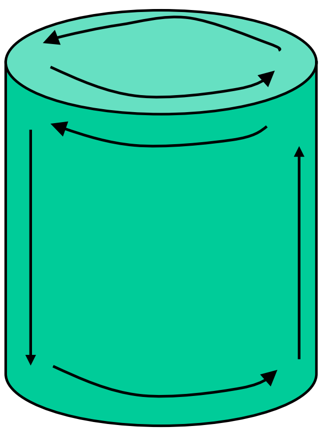


$8v - 12e + 6f = 2$

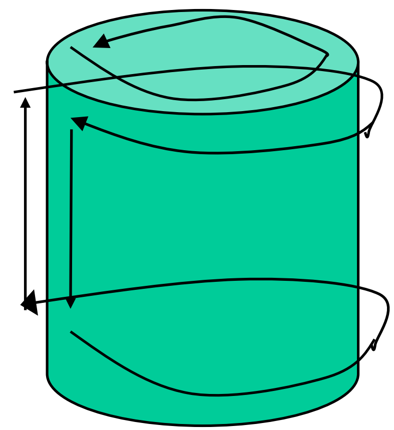


$6v - 9e + 5f = 2$

$v - e + f = 2$



$4v - 6e + 4f = 2$



$2v - 3e + 3f = 2$

欧拉操作Euler’s Operators

编辑三维模型时对半边结构的操作是非常繁琐及易错的，为此将对半边结构的基本操作封装为欧拉操作，对模型半边结构的所有修改都通过调用欧拉操作实现。

欧拉操作必须符合欧拉公式

$$v-e+f=2(s-h)+r$$

欧拉操作的命名规则：

M(make) K(kill) V(vertex) E(edge)F(face) S(solid) H(hole)R(ring)

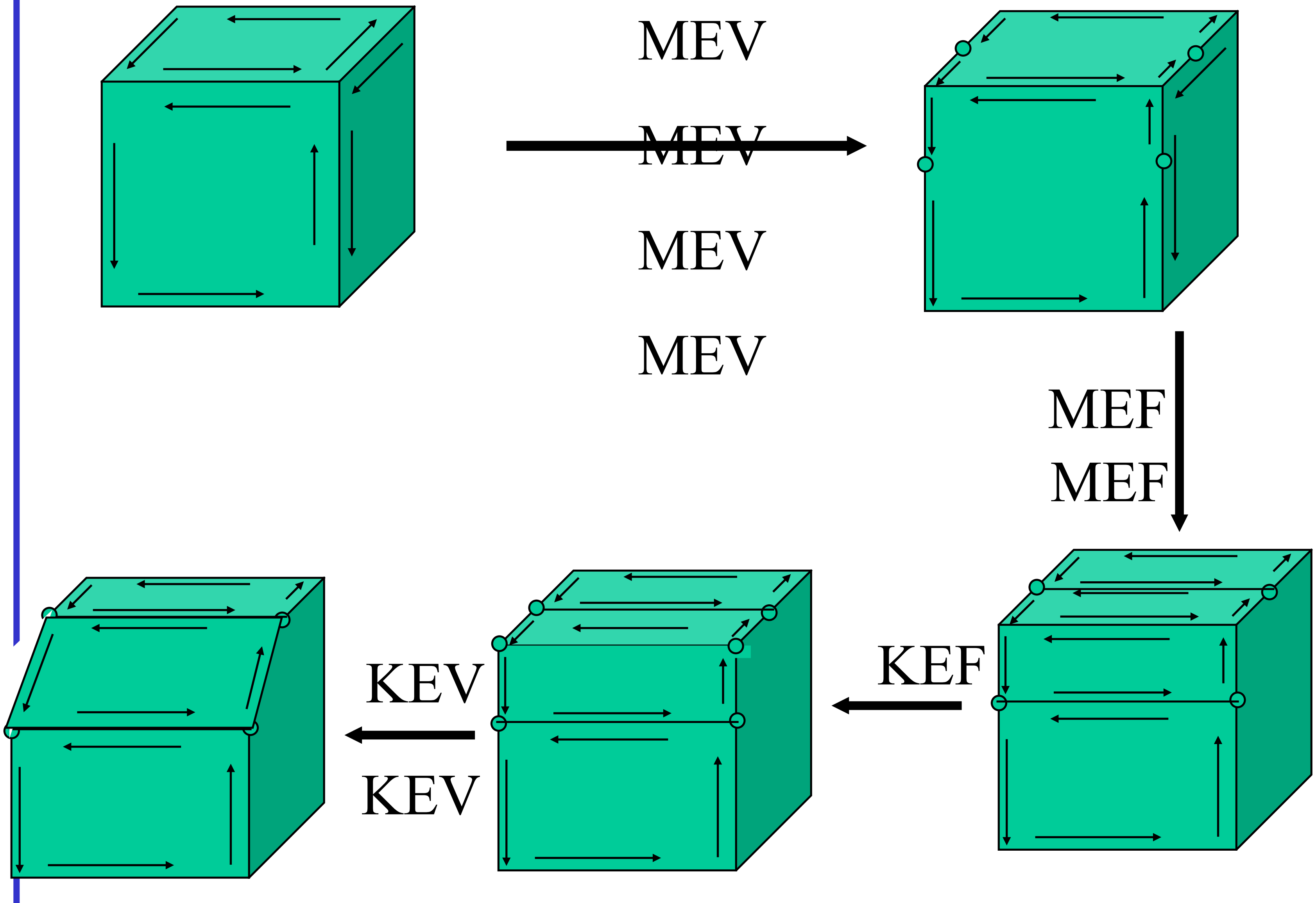
基本欧拉操作

- 增加一条边一个顶点 (MEV)
- 增加一个面一条边 (MEF)
- 生成一个体一个面和一个顶点 (MFVS)
- 增加一个通孔和一个环、减少一个面 (KFMRH)
- 增加一条边、减少一个环(MEKR)

上述所有欧拉操作都有相应的逆操作。

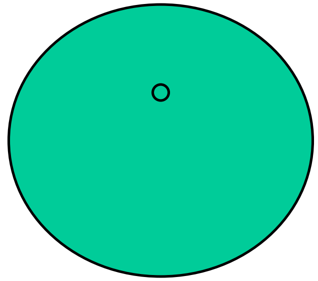
M(make) K(kill) V(vertex) E(edge) F(face) S(solid) H(hole) R(ring)

局部操作实例



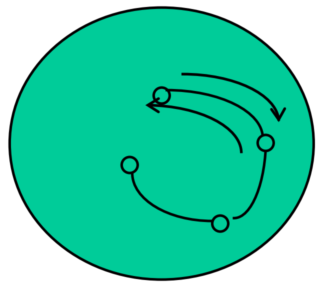
立方体的生成

1. MVFS



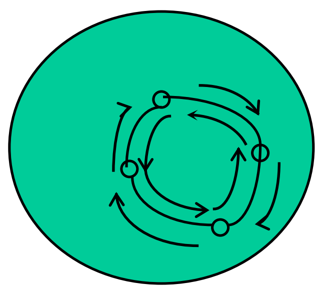
1 solid， 1 face ， 1 vertex

2. MEV
MEV
MEV

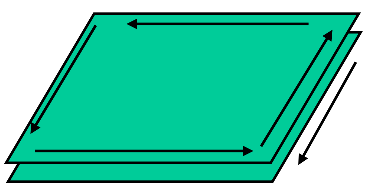


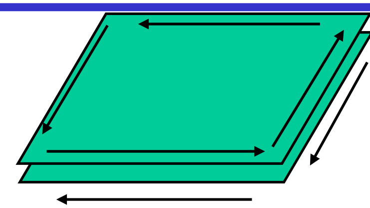
1solid， 1 face， 3 edges，
4 vertexes

3. MEF



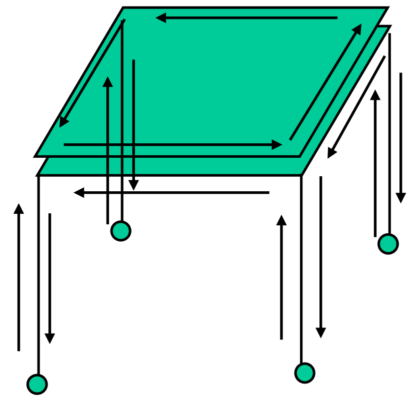
1solid， 2 faces， 4 edges
，
4 vertexes





4. MEV

MEV
MEV
MEV

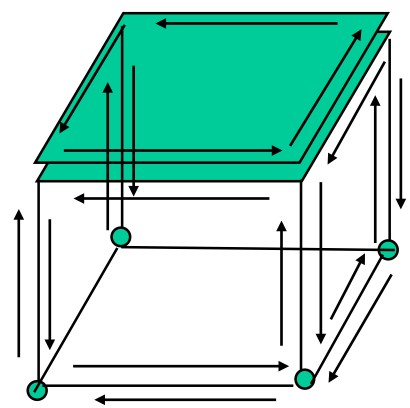


5. MEF

MEF

MEF

MEF



不同表达方式的对比

- 精确度: 空间分解表达、多面体的 BREP是物体的近似表示； CSG、含曲面的BREP精确表达.
- 表达能力: CSG表达能力有限；空间分解表达、BREP表达能力强.
- 唯一性: 空间分解法在确定范围和精度下有唯一性； CSG、BREP无唯一性，但唯一性并不重要.

谢 谢