CSC209: Computer Graphics

Unit 6 – Solid Modeling

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Solids and Solid Modeling

- A solid is a state of matter characterized by particles arranged such that their shape and volume are relatively stable.
- Solid modeling is the representation of the solid parts of the object on our computer. It is the most advanced method of geometric modeling in three dimensions. It is a complete geometric data representation of an object that enables points in space to be classified relative to the object, if it is inside, outside or on the object.

Solids and Solid Modeling

- Solid modeling is the foundation of 3D computer aided design (CAD) and in general support the creation, exchange, visualization, animation, etc.
- The solid modeling CAD software helps the designer to see the designed object as if it were the real manufactured product. This helps the designer to be sure that the object looks exactly as they wanted it to be.

Solids and Solid Modeling

- To make the solid models we must first make the wireframe model of the object and convert it into 3D view. After that, surfaces are added to the 3D wire model to convert it into 3D solid model.
- For creating the solid models, we need to have special CAD software that can create solid models. One of the most popular CAD software for solid modeling is SolidWorks. Solid modeling software are being used in engineering, medical industry, entertainment industry ,etc.

Solid Modeling

- Solid modeling (or modelling) is a consistent set of principles for mathematical and computer modeling of three-dimensional solids.
- A mathematical technique for representing solid objects.
- An object with following specification is called solid:
  - **Vertices (nodes), edges, surfaces, weight, and volume**

Solid Modeling

- There are three types of 3D model:
  1. **Wireframe**
  2. **Surface**
  3. **Solid**
- Solid model of an object is a more complete representation than its surface (wireframe) model. It provides more topological information in addition to the geometrical information.

Methods for Solid Modeling

- **Boundary Representation**
- **Sweep Representation**
- **Primitive Instancing**
- **Constructive Solid Geometry (CSG)**
- **Octree Representation**
- **Binary Space Partitioning**

Constructive Solid Geometry (CSG)

- A CSG model is based on the topological notion that a physical object can be divided into a set of primitives (basic elements or shapes) that can be combined in a certain order following a set of rules (Boolean operations) to form the object. Each primitive is bounded by a set of surfaces; usually closed and orientable.
- It is based on the idea of providing a set of predefined object types such as cubes, cone, sphere etc.
- A solid model is created by retrieving primitive solids and performing Boolean operations

Constructive Solid Geometry (CSG)

- Three types of Boolean operations:
  - **Union (join)**: the operation combines two volumes included in the different solids into a single solid.
  - **Subtract (cut)**: the operation subtracts the volume of one solid from the other solid object.
  - **Intersection**: the operation keeps only the volume common to both solids.

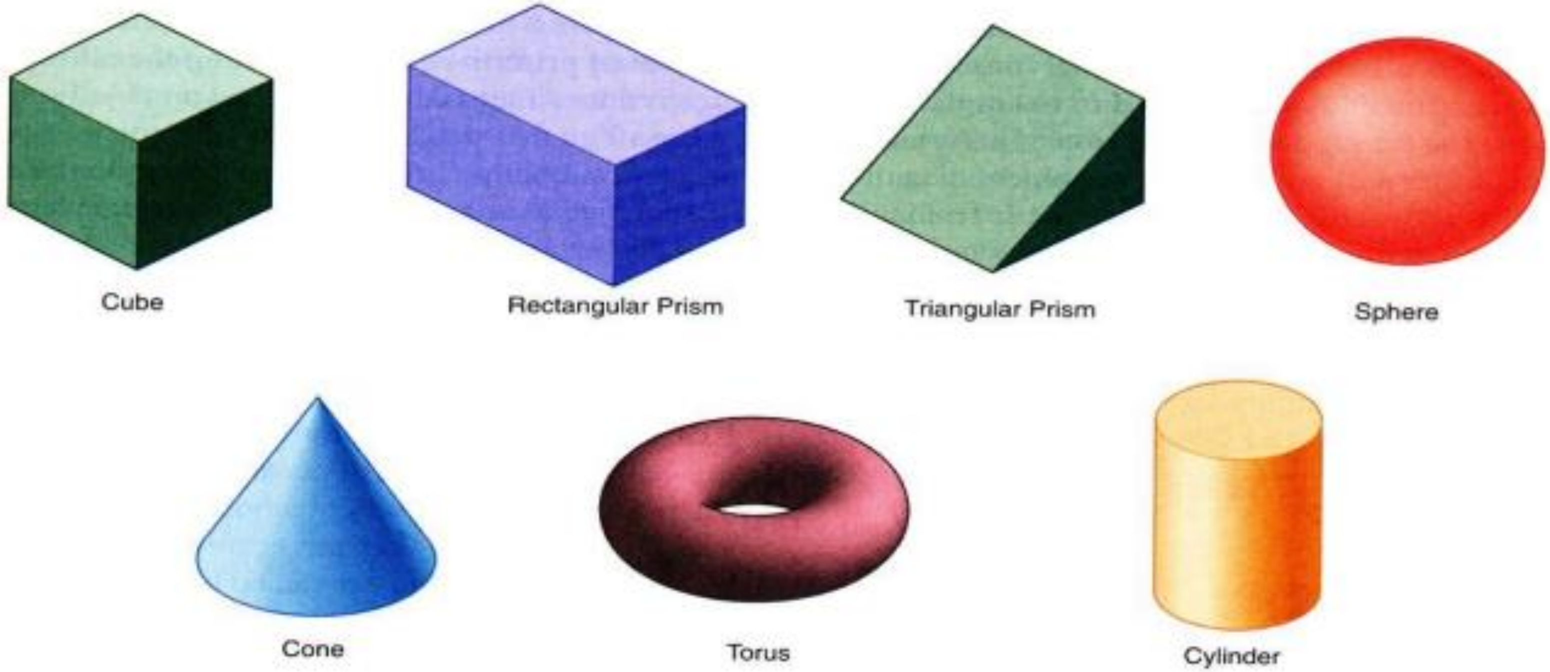
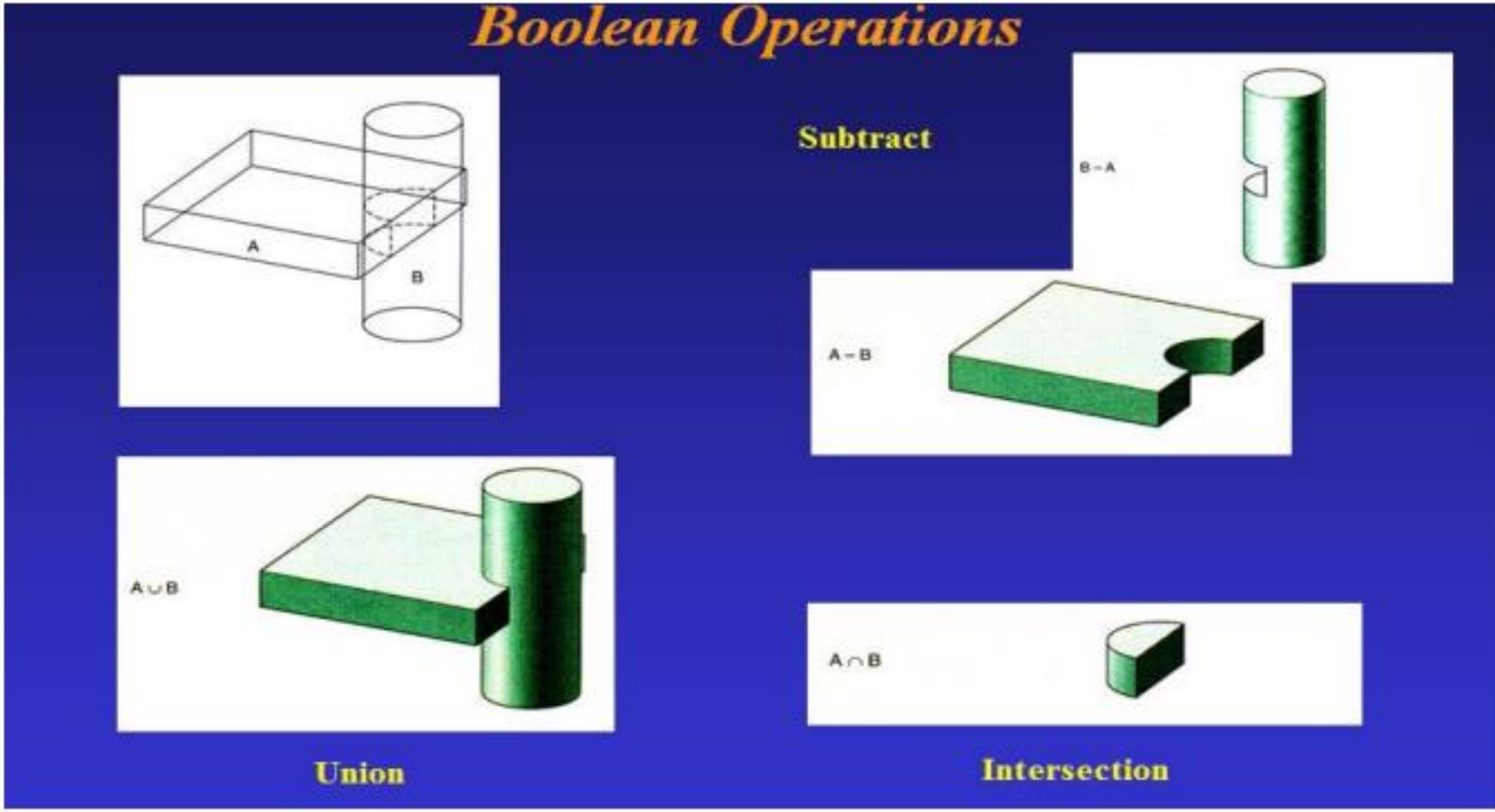


Fig: the basic primitive solid


Boolean Operations
A
B
Subtract
B − A
A − B
A ∪ B
A ∩ B
Union
Intersection

Sweep Representation

- Sweep representations create solid by moving a 2D shape (triangle, rectangle, polygon etc.) according to predefined rule (translating, rotating).
- Sweep representations are used to construct 3D object from 2D shape that have symmetry.
  - For example, a prism can be generated using a translational sweep and rotational sweeps can be used to create curved surfaces like an ellipsoid or a torus.
- There are two types of sweep representation:
  - Translational Sweep
  - Rotational Sweep

Translational Sweep

- A 2D shape is translated by a predefined translation vector.
    - Example: following figure shows a translational sweep of a rectangle.

Steps

- Define a shape as a polygon vertex table as shown in figure (a).
- Define a sweep path as a sequence of translation vectors figure (b).
- Translate the shape; continue building a vertex table figure (c).
- Define a surface table figure (d).

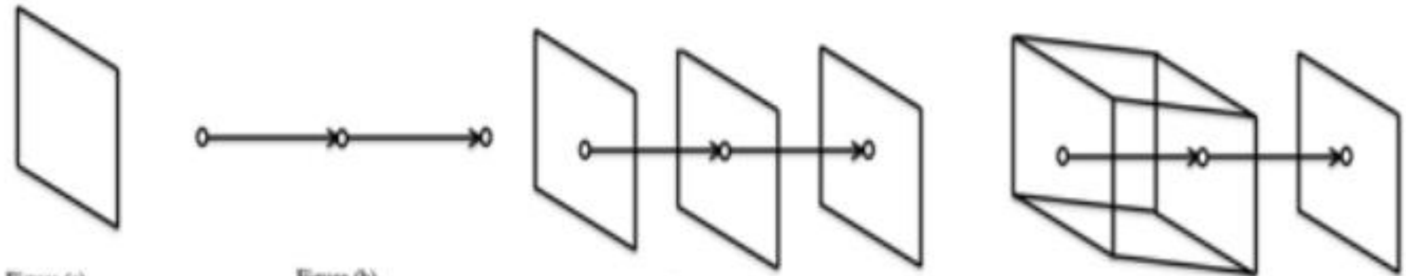


Figure (a) Figure (b) Figure (c) Figure (d)

(a) (b)

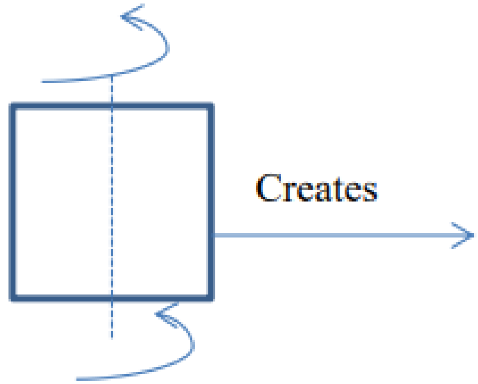
Constructing a solid with a translational sweep. Translating the control points of the periodic spline curve in (a) generates the solid shown in (b), whose surface can be described with point function $\mathbf{P}(u,v)$.

Rotational Sweep

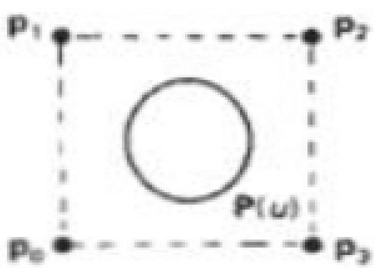
- A 2D shape is rotated by a predefined rotational vector.
  - Example: following figure shows a rotational sweep.

Steps

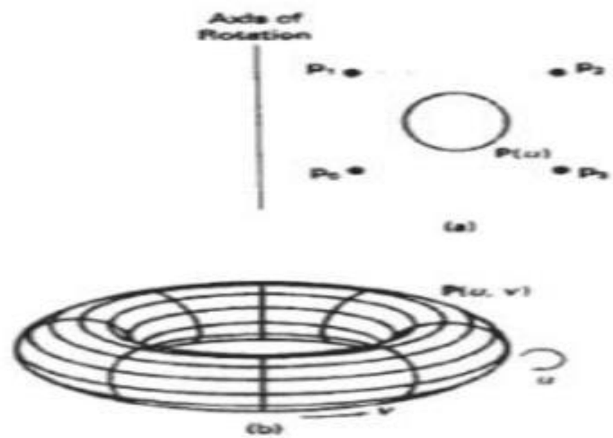
- Define a shape as a polygon vertex table as shown in figure (a).
- Define a sweep path as a sequence of rotations.
- Rotate the shape; continue building a vertex table as shown in figure (b).
- Define a surface table as shown in figure (c).



sweep (rotate)



(a)



Constructing a solid with a rotational sweep. Rotating the control points of the periodic spline curve in (a) about the given rotation axis generates the solid shown in (b), whose surface can be described with point function P(u,v).

Boundary Representation (B-rep)

- Boundary representations (B-reps) describe a three-dimensional object as a set of surfaces that separate the object interior from the environment. Objects are represented as a collection of surfaces.
- A boundary representation (R-rep) of an object is a geometric and topological description of its boundary. The object boundary is segmented into a finite number of bounded subsets, called faces.
- A face is represented in a B-rep by its bounding edges and vertices. Thus, a B-rep consists of three primitive topological entities: faces (2D entities), edges (1D entities) and vertices (0D entities). Geometric information consist of the shape and location in space of each of the primitive topological entities.

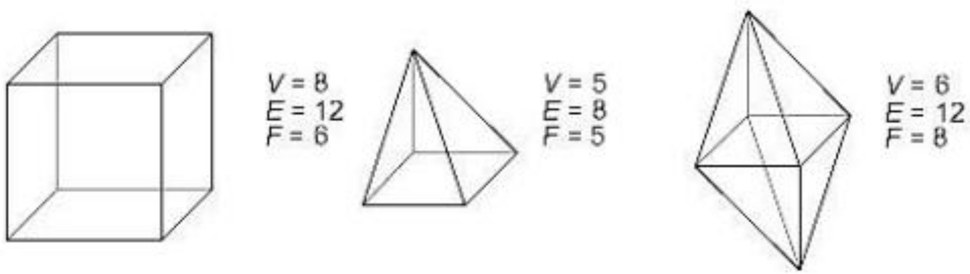
Advantages and Disadvantages of B-rep

- The main advantage of B-rep is that it is very appropriate to construct solid models of unusual shapes that are difficult to build using primitives. [Useful to model the objects or unusual shape which are difficult to be modeled by CSG approach]
- It is relatively simple to convert a B-rep model into a wireframe model.
- The disadvantage of the boundary model is that it requires large amounts of storage. The model is defined by its faces, edges and vertices which tend to grow fast for complex models.

Polyhedron

- Solid delimited by a set of polygons whose edges belonging to two polygons.
- Boundary representation for single polyhedron satisfy Euler's formula.

$$V - E + F = 2$$



Spatial-Partitioning Representation

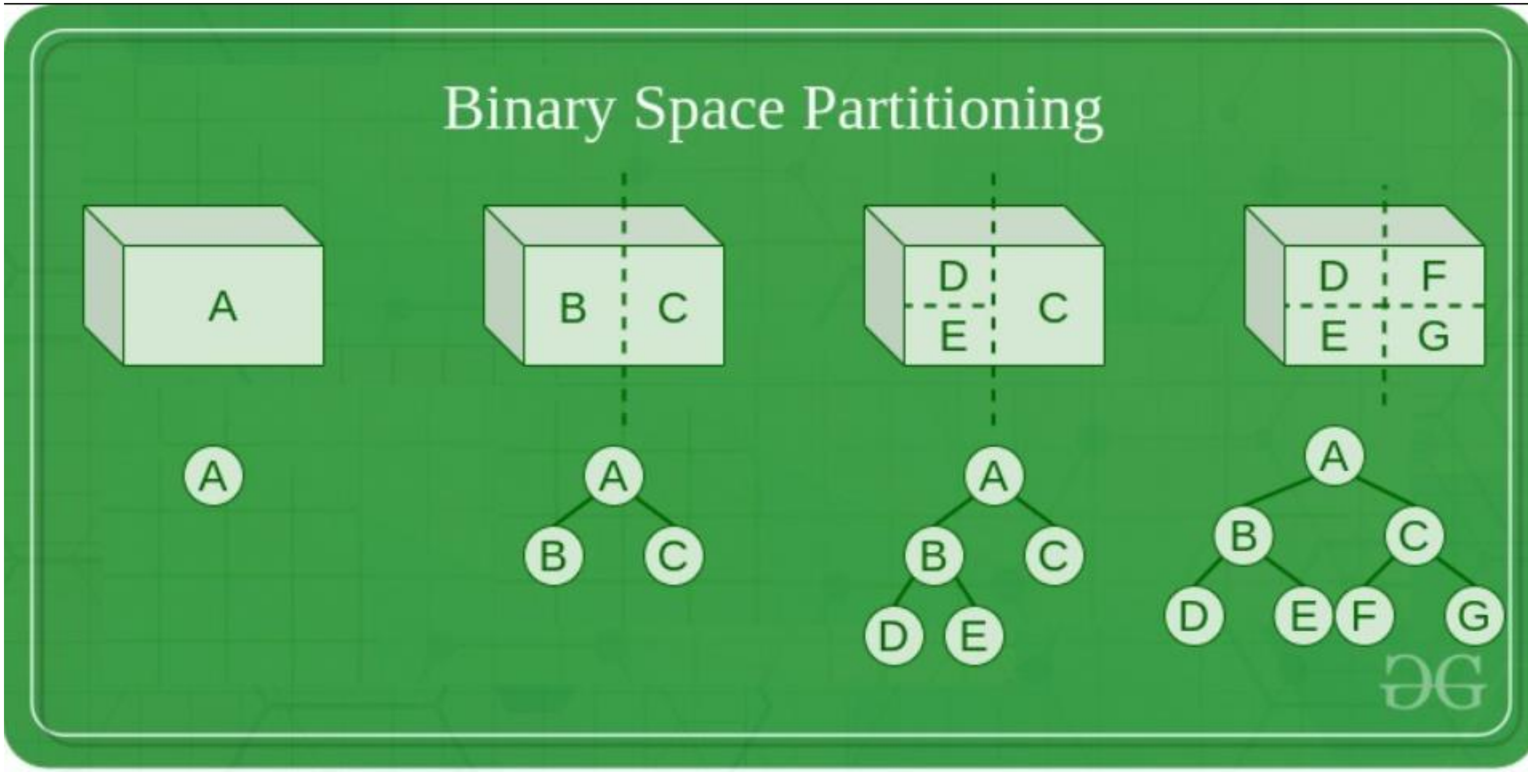
- Spatial-partitioning representations are used to describe interior properties, by partitioning the spatial region containing an object into a set of small, non-overlapping, contiguous solids (usually cubes). A common space-partitioning description for a three-dimensional object is an octree representation.
- Example: Quadtree, Octree representations.

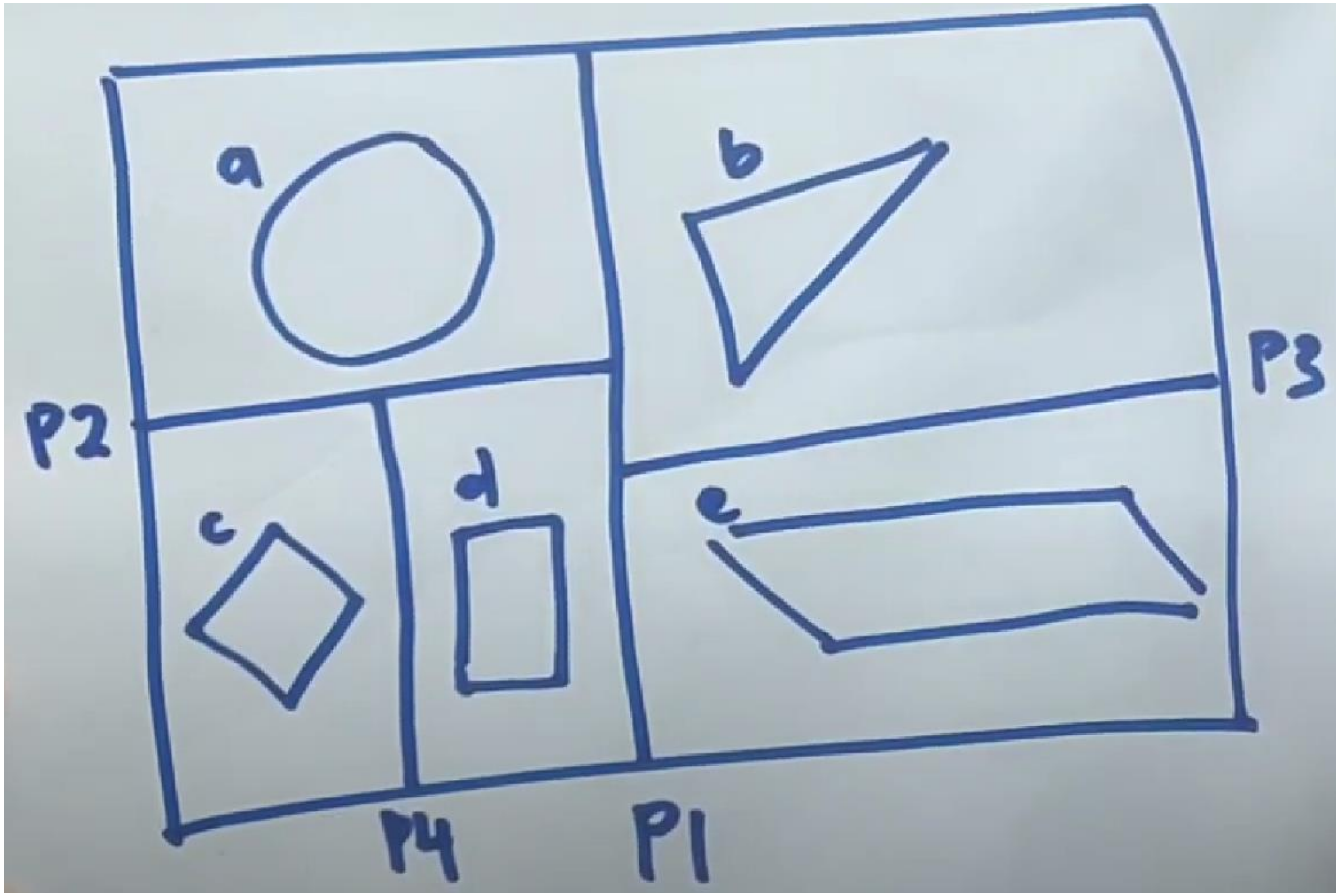
Spatial-Partitioning Representation

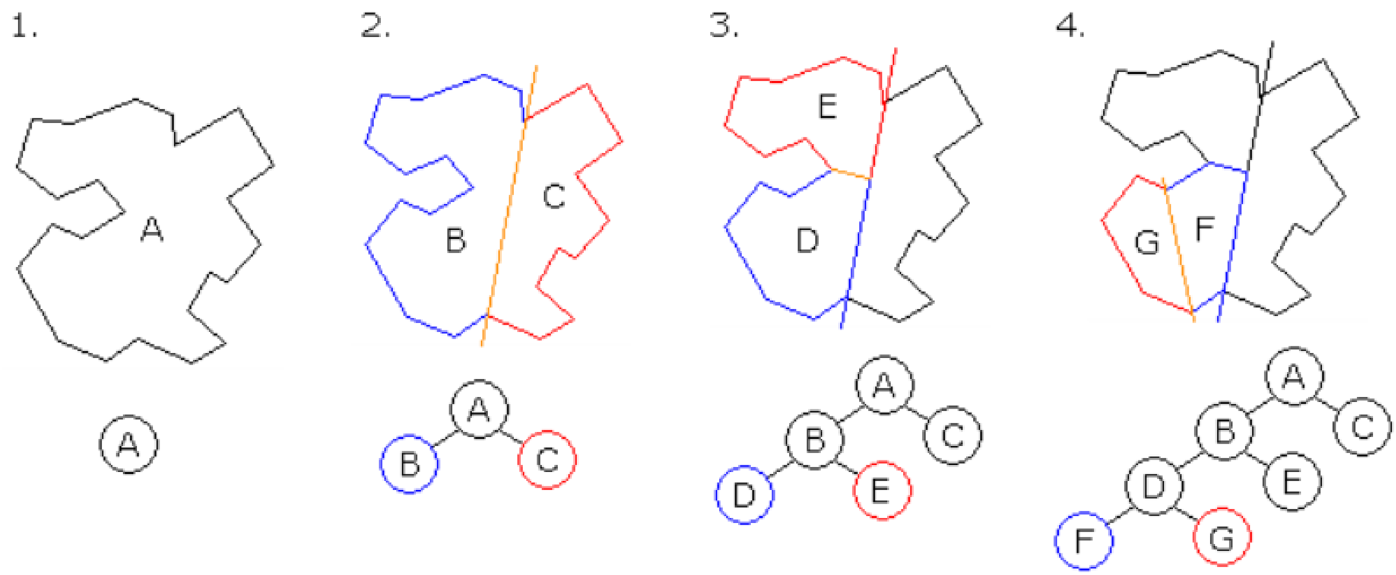
- It describes the objects as collections of adjoining non-intersecting solids.
- It creates collections of solids that may or may not be the same type of the original object.
- It creates collection of solids that are like building blocks and can vary in type, size, position and orientation.
- Recursively partitioning space using planes produces a BSP tree, which is one of the most common form of space partitioning.

Binary Space Partition Trees (BSP)

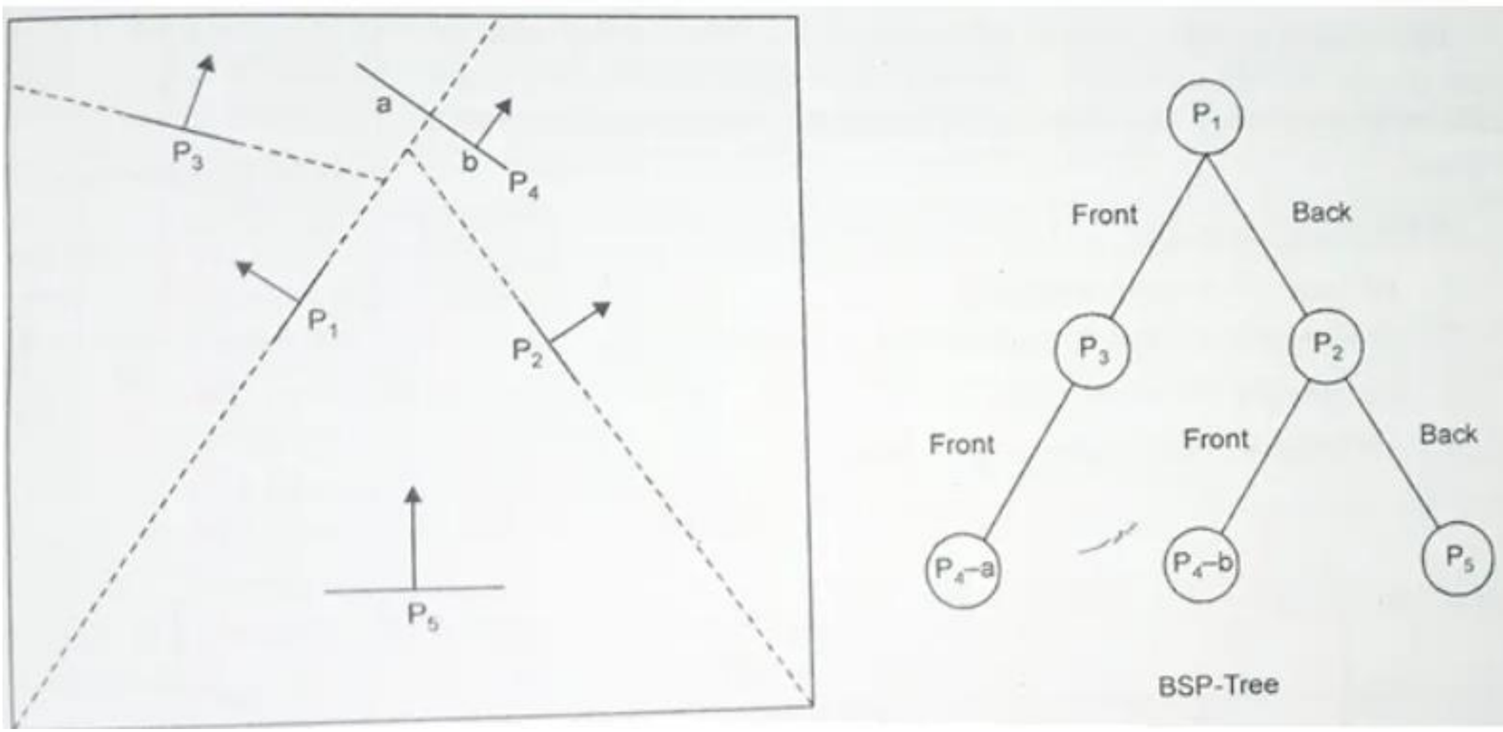
- Binary space partitioning is a generic process of recursively dividing a scene into two until the partitioning satisfies one or more requirements. It is a way of grouping data so it can be processed faster.
- Many 3D modeling and rendering programs utilize a Binary space partition tree (BSP tree) to make rendering go faster.
- BSP trees provide more efficient partitioning since we can position and orient the cutting planes to suit the spatial distribution of objects. This reduces the depth of the tree representation for a scene compared to octree and thus reduce the time to search the tree.
- BSP trees are useful for identifying visible surfaces and for space partitioning in ray-tracing algorithms.


Binary Space Partitioning
A
A
B
C
A
B
C
D
E
C
A
B
C
D
E
D
F
E
G
A
B
C
D
E
F
G


a
b
P3
P2
d
c
e
P4
P1



1.
A
A
2.
B
C
A
B
C
3.
E
D
A
B
C
D
E
4.
G
F
A
B
C
D
E
F
G


a
b
P_3
P_4
P_1
P_2
P_5
P_1
Front
Back
P_3
P_2
Front
Front
Back
P_4–a
P_4–b
P_5
BSP-Tree

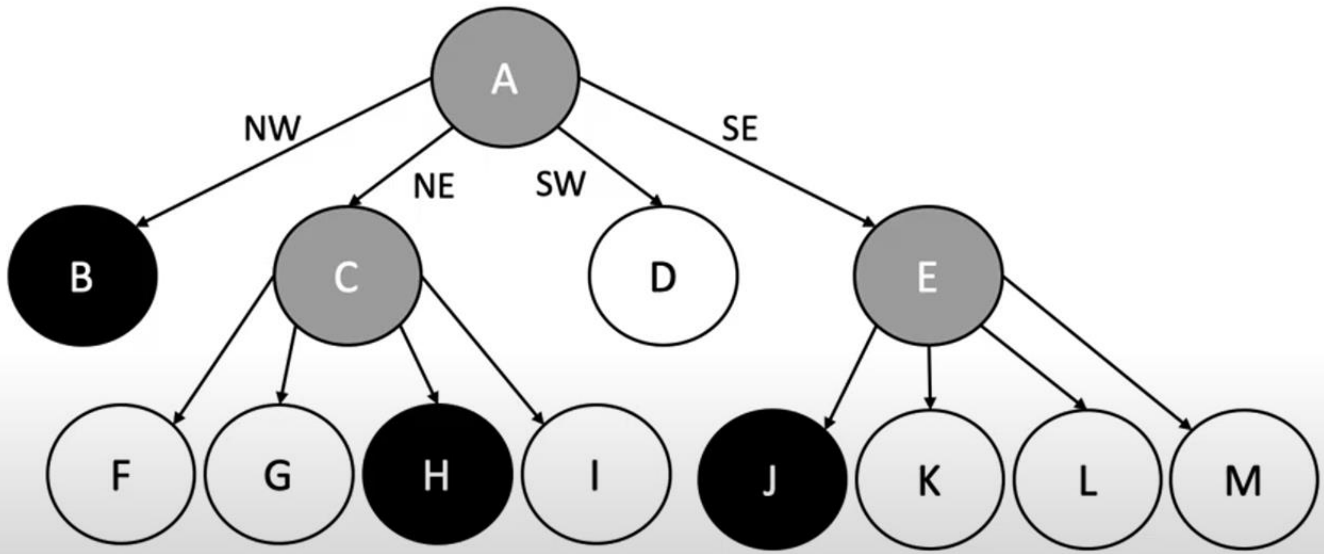
Octree Representation

- This is the space-partitioning method for 3D solid object representation. Octrees are hierarchical tree structure that describes each region space as nodes. They are used to represent solid objects in some graphics system.
- Octrees are used to partition a 3D space by recursively subdividing it into eight octants. Octant subdivisions continue until the region of space contains only homogeneous octants.
- Octants are often used in 3D graphics and 3D game engines.

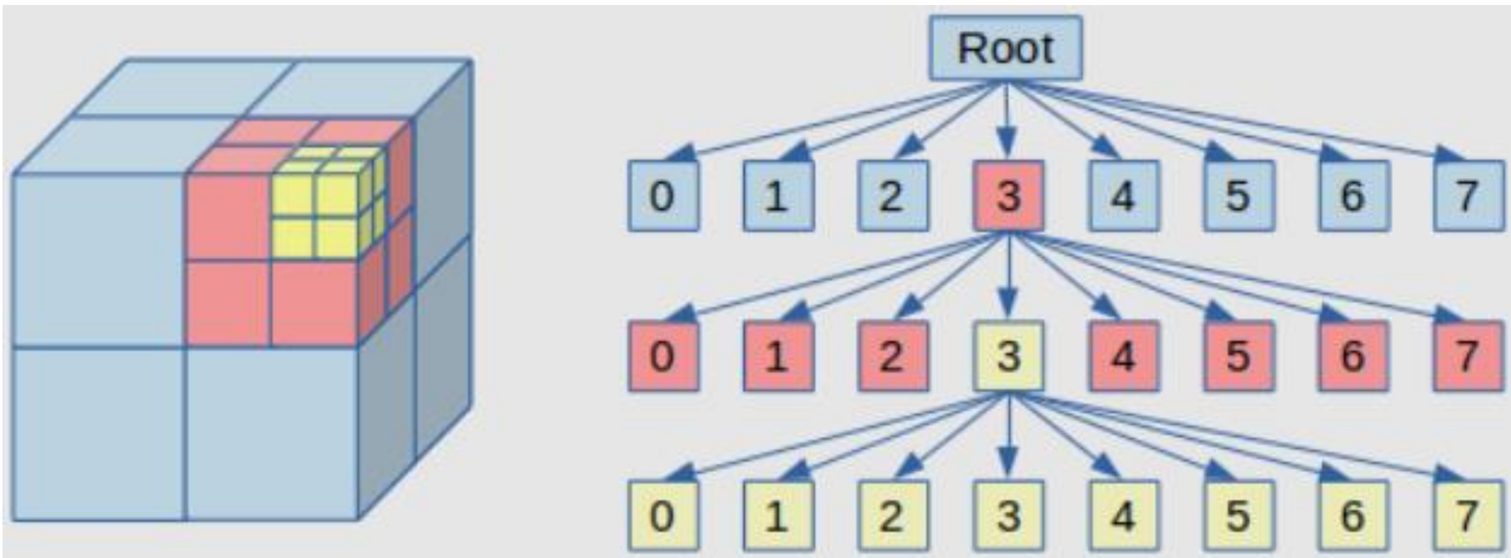
Region Quadtree Example

1	1	0	0
1	1	1	0
0	0	1	0
0	0	0	0

<table>
<tr><td rowspan="2" colspan="2">B</td><td>F</td><td>G</td></tr>
<tr><td>H</td><td>I</td></tr>
<tr><td rowspan="2" colspan="2">D</td><td>J</td><td>K</td></tr>
<tr><td>L</td><td>M</td></tr>
</table>



http://devmag.org.za/2011/02/23/quadtrees-implementation/


Root
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7