3D Modeling

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What is a Model?

- It is representation of a person or thing or of a proposed structure, typically on a smaller scale than the original.
  - A real, physical and tangible
- What about a computer model?
- What is a 3D Model?
  - A description or a definition of an object in 3D space
  - Defined in terms of its shape or form

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Types of 3D models and their use

- **Surface modeling** → computer animation, games
- **Solid modeling** → 3D printing, engineering, manufacturing, computer aided design (CAD)
- **Volume modeling** → scientific visualization, medical visualization
- **Particle modeling** → Especial effects such as gases, clouds, smoke, fire

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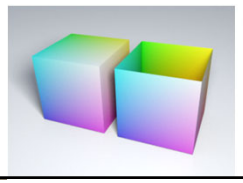
Surface Modeling

- Always has a crisp surface with virtually no thickness.
- Defines shape of an object.
- Can be closed or open.
- Composed of polygons or surface patches.



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Solid Modeling

- An object is defined as a solid mass, often with density, weight and other attributes of a solid.
- Used in 3D printing, engineering, manufacturing, computer aided design (CAD), etc.




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Solid Modeling

- A solid model always has a crisp surface that divides the entire universe into two regions: the inside of the model and the outside of the model.
- A solid model is closed while a surface model can be open or closed.
- The interior of a solid model is homogeneous.

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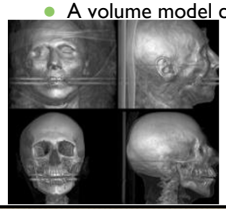
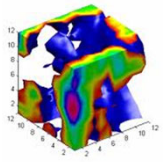
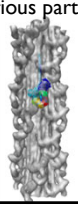
Volume Modeling

- Used in scientific visualization, medical visualization
- Consists of:
  - a data set of a physical characteristic (e.g., density, electric charge and temperature) measured at various locations in the space of interest, or
  - a field defined by mathematical equations.
  - A volume model can represent an egg's various parts - shell, yolk, white, etc.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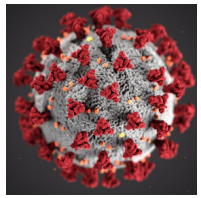
Particle Modeling

- Approach to deal with phenomena such as fire, clouds, smoke and mist which are composed of neither surfaces nor solid volumes which do not have a stable shape.



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Polygonal Modeling

- Basics of Geometry:
  - Point
  - Line
  - Plane
  - Triangle
  - Vertex

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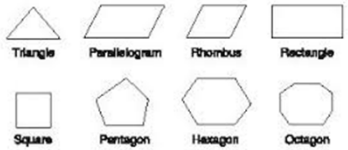
Polygonal Modeling

- Plane figure bounded by three or more straight edges.
- The type of 3D modeling that defines surfaces as consisting of flat polygons is called polygonal modeling.
- Used most frequently in 3D computer animation because they can be rendered faster than surface patches.



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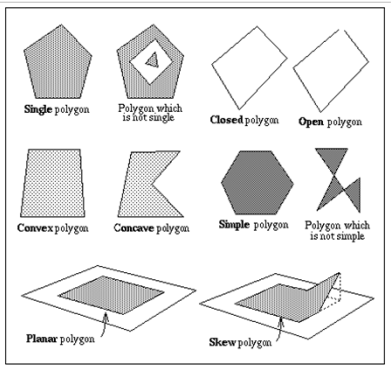
Polygonal Modeling

- Good polygons are:
  - single
  - closed convex
  - simple and
  - planar.



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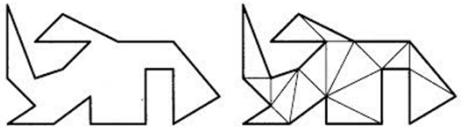
Polygonal Modeling

- Closed single simple planar polygons are almost always rendered correctly but open, non-single, non-simple, or skew polygons often causes rendering problems.
- If concave polygons are rendered incorrectly, triangulate a concave polygon into convex polygons.
- Triangulation eliminates skew (non-planar) polygons.



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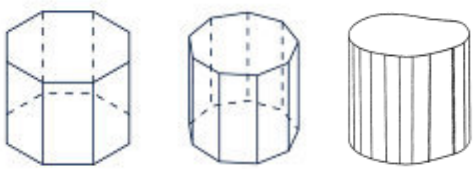
Polygonal Modeling

- Polygonal Approximation



- Can a polygonal approximation produce a truly curved surface?

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Polygonal Modeling

- **Polygon Count**.
  - Polygon count affects the speed with which a computer can process a model
  - Desirable to keep polygon count low. WHY?
  - Low polygon count is important where real-time interaction is needed, such as games.
- Can you **reduce** the polygon count?
- Polygon Reduction - sometimes also called polygon thinning or polygon culling.

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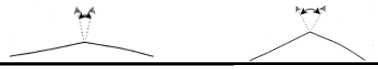
Polygonal Modeling

- Polygon Thinning Techniques:
  - Specify the maximum number of polygon count of a new thinned model.
  - Specify the minimum angle allowed between polygons. If adjacent polygons have nearly the same orientation - reduce to a single polygon without significantly altering the shape of model.
  - The relative orientation of the adjacent polygon is measured by the dihedral angle which is the angle between two intersecting lines or planes, coming perpendicularly off each polygon at the shared vertex.



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SPLINES AND PATCHES

- **Straight line** is a line defined by the shortest distance between two end points.
  - The slope is zero or constant.
- Curved line is a line between two points for which the distance between two points is NOT the shortest.
  - The slope changes but the rate of change may not be constant or uniform
- In real world, curved lines (also called **splines**) and curved surfaces (also called **patches**) are more common than are straight lines and surfaces.
  - For example, leaves, tree branches, hull of a ship, etc.
  - Polygonal modeling can approximate these curves → never represents them with perfect accuracy

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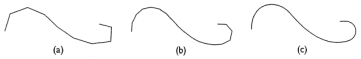
SPLINES AND PATCHES

- In computer graphics (CG), there are several approaches to represent curves.
- One is similar to the technique of **polygonal approximation**
  - a curve is approximated through a series of straight lines and also referred to as polyline technique.
- **Advantages**
  - Conceptually very simple.



- **Disadvantages**
  - Very awkward to edit the shape → too laborious.
  - The number of points required to produce a smooth curve may produce very large quantities of data.
  - Curve is really never a smooth curve.

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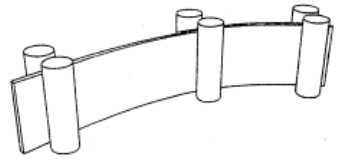
SPLINES AND PATCHES (contd.)

- Most high-end modeling systems provide a different technique that makes use of splines.
  - The word is derived from the era when ships were built of wood. In order to bend a plank of wood to fit the shape of the hull, shipbuilders would force the wooden plank to bend between several fixed posts, called "ducks". The resulting curved plank was called a spline. Placement of the posts determines how much curvature will be given to the plank.



- In CG,
  - the wooden plank → curve
  - ducks → points in space that control the shapes.

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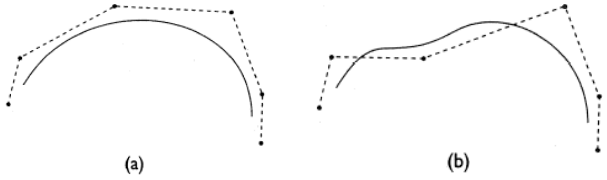
SPLINES AND PATCHES (contd.)

- Consider the curves:



  - The solid curve line is the spline curve itself.
  - The points that lie near the curve are called the control points - CP (also called control vertices - CV) and determine the shape of the curve.
  - The dotted straight line connecting each set of points often is known as the hull for that curve

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SPLINES AND PATCHES (contd.)

- Important to note:
  - Placement of the control points determines shape of the curve.
  - Moving one of the control points changes shape of the curve.
  - The hull of the spline curve doesn't necessarily have to stay on only one side of the curve.
- Answers the three problems of polyline, i.e.,
  - A spline is very easy to reshape.
  - No matter how much you magnify a selection of spline, it remains truly curved.
  - The spline representation of curve is very compact and efficient in terms of amount of data
- Each spline curve can be characterized by way it is controlled by the control point (CP) or control vertices (CV)

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SPLINES AND PATCHES (contd.)

Two broad categories of splines

1. **Interpolating spline**: the spline curve in this type passes directly through each of the control points.
   - **Advantage**: direct relationship between the placement of the control points and the final curve generated.
   - **Disadvantage**: This direct relationship makes it difficult to generate curves having a very smooth and gradual curvature. If you misplace a control point, curve will not be smooth
   - **Cardinal Spline**: in this type, the curve goes directly through all but the first and the last control points (Figure b).

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SPLINES AND PATCHES (contd.)

2. **Approximating Spline:** this type addresses the problem of control point placement by calculating curves such that it goes near but not directly through any of the control points. Advantage: wider margin of error in the placement of control points but still tend to yield a smooth curve.
   - The most common type of approximating spline is called **B-spline.** (the B stands for the word "basis" in mathematics).
   - B-spline curve does not actually touch any of the control points.

   - Like cardinal spline, it does not extend all the way to the far ends of the hull – begins approximately at the second control point and ends at the second-last control point.
   - The most commonly used type of spline employed in 3D computer systems is the NURBS curve (Non-Uniform Rational B-Spline)

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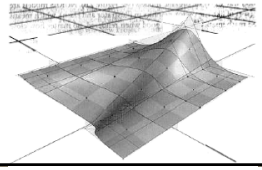
POLYGON, NURBS & SUBDIVISION MODELING

- **NURBS** are good for creating organic squishy objects.
- NURBS tend to produce cleaner models and are generally more precise.
- NURBS models are resolution independent → surfaces look good when rendered, no matter how close the camera gets.
- All renderers must convert all geometry to polygons right as they begin rendering.
- **So why don't you see telltale polygonal facets?**
  - Essentially When the scene is rendered, Maya can use as many facts as necessary to make the surface appear smooth



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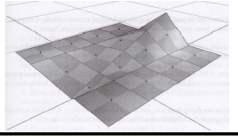
POLYGON, NURBS & SUBDIVISION MODELING (contd.)

- **Polygons** are good for hard-edged, man-made objects.
- Polygonal geometry is made up of facets – called faces.
- Polygonal geometry can be great for creating hard surfaces like building and machines (or if you use enough polygons, organic characters and props).
- Polygonal geometry doesn't adapt its resolution to remain smooth looking in close-ups.
- Polygons can be quicker to render. Therefore, polygons are the primary geometry type used in games and many modelers find the tools more intuitive.
- Polygonal objects can support branching topography (such as fingers or spokes) with which NURBS surfaces have a hard time.



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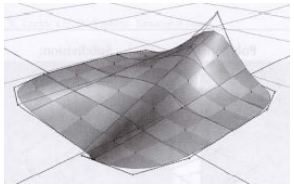
POLYGON, NURBS & SUBDIVISION MODELING (contd.)

- **Subdivision** surfaces are a hybrid of NURBS and polygons → exploit the advantages of both. They produce great results and are good for everything.
- They are resolution independent (like NURBS) but allow arbitrary topology (like polygons).
- With subdivision objects, it is possible to add localized details where you need it and define hard creases and smooth curves in the same model.
- Can be a bit cumbersome with which to work.



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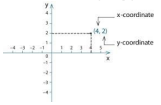
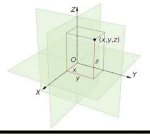
Cartesian coordinate systems

- Also called a **rectangular coordinate system**.
- 2D and 3D Cartesian coordinate systems are commonly used.
- In the 2D Cartesian coordinate system, each location is specified by an ordered set of two distances, an x-coordinate and a y-coordinate, represented as (x, y).



- In the 3D Cartesian coordinate system, each location is specified by an ordered set of three coordinates, an x-coordinate, a y-coordinate, and a z-coordinate, (x, y, z).



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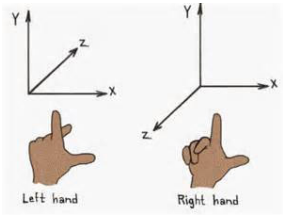
Cartesian coordinate systems (contd.)

- There are two types of 3D Cartesian coordinate systems: Right-handed and Left-handed.
- How to tell if it's a Right-handed or left-handed coordinate system?
- Align your right-hand thumb with the x-axis.
- If you can curl your right-hand fingers from the y-axis to the z-axis to make a fist, that's a right-handed system



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Cartesian coordinate systems (contd.)

- In the right-handed coordinate system, the direction in which your hand closes to make a fist is the direction of a positive rotation around any axis represented by the extended right-hand thumb.

- In the **left-handed coordinate system**, the direction in which your hand closes to make a fist is the direction of a positive rotation around any axis represented by the extended left-hand thumb

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Right-handed coordinate system in 3D applications

- Many 3D animation applications, such as Maya, use right-handed 3D Cartesian coordinate systems.

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Object space and world spaces

- Each object is defined in its **object space** (also called **object coordinate system** or **local coordinate system**.)
- A scene containing a single object or multiple objects is defined in the **world space** (also called **world coordinate system** or **global coordinate system**.)
  - Object space and world space work together.
  - For instance, if the geometric center of an object is at the origin of its object space and if the object is placed at the origin of the world space, it will be centered at origin of the world space.
  - However, if the geometric center of an object is not centered at the origin of its object space, it will be off-centered in the world space even if it's placed at the origin of the world space

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