The Real-Time Graphics Pipeline

Benjamin Brown

Monday, 26th September 2022

The Key Idea

Basic task in computer graphics is ***render*** 3-dimensional objects:

- given a scene composed of geometric objects in 3d space;
- produce a 2d image showing the objects from a specific viewpoint.

Two methods of rendering:

- ***object-order rendering***: for each object, which pixels are influenced by it?
  - Example: rasterisation.
- ***image-order rendering***: for each pixel, which object is influenced by it?
  - Example: ray-tracing.

Real-Time Rendering

Real-time rendering refers to the process of rendering a scene in less than 1/30$^{\text{th}}$ of a second (i.e., refresh rate $>$ 30 Hz).

- Real-time rendering refers to rendering that is fast enough to allow for the user's ***real-time interaction***.
- As little as 15 ms of temporal delay can slow and interfere with the interactivity.

So speed is essential for interactivity:

- For a 1080p image at 90 Hz, an image-order rendering iteration would need to be performed 186,624,000 times per second.
- Object-order rendering is (usually) faster in this case.

The Graphics Pipeline

The main function of the ***graphics pipeline*** is:

- Given a virtual camera, 3d objects, light sources, etc., render a 2d image;
- Object locations and shapes determined by their geometry, environment, camera placement, etc.;
- Object appearance affected by material, light sources, shading, etc.

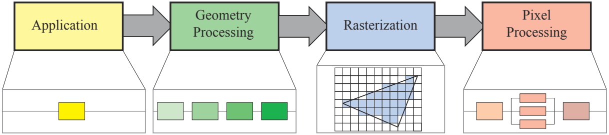
Some key ideas regarding the pipeline are:

- Consists of several states, with each making up part of a larger task;
- The states execute in parallel, with each stage dependent on the result from the previous.

Stages of the Graphics Pipeline

Roughly, the main stages of the pipeline are:

1. ***application***;
2. ***geometry processing***;
3. ***rasterisation***;
4. ***pixel processing***.



The Application Stage

Involves tasks typically implemented by the software running on general-purpose CPUs:

- collision detection;
- animation;
- physics simulation, etc...

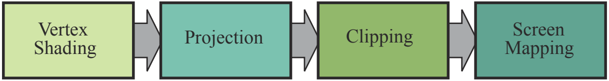
More specifically, the application stage:

- Reads ***primitive*** data and assembles it into primitives for later states.
    - Vertex data (position, normal vectors, colour, etc.),
- Initialises GPU allocated memory buffers.
    - Vertex and index buffers.

The Geometry Processing Stage

Responsible for the per-triangle and per-vertex operations:

- Vertex processing (transforming and shading);
- Projecting;
- Clipping;
- Screen mapping.



The Geometry Processing Stage

Vertex shading deals with:

- Determining the effect of a light on a material (***shading***);
- Projecting from ***world space*** onto ***view space***;
- ***Clipping*** away the view space primitives which do not lie within the view volume;
- Mapping the vertices onto ***screen space***;
-

Rasteristaion

The ***rasterisation*** stage converts vector information (composed of primitives) into a raster image (composed of pixels). It includes:

- Dividing by z for perspective;
- Mapping primitives to a 2D viewport;
- Determining how to invoke the pixel.

-

Tables and Figures

- Use `tabular` for basic tables — see Table 1, for example.
- You can upload a figure (JPEG, PNG or PDF) using the files menu.
- To include it in your document, use the `includegraphics` command (see the comment below in the source code).

Examples

Some examples of commonly used commands and features are included, to help you get started.

Item	Quantity
Widgets	42
Gadgets	13

Table 1: An example table.

Readable Mathematics

Let $X_1, X_2, \ldots, X_n$ be a sequence of independent and identically distributed random variables with $\mathrm{E}[X_i] = \mu$ and $\mathrm{Var}[X_i] = \sigma^2 < \infty$, and let

$$S_n = \frac{X_1 + X_2 + \cdots + X_n}{n} = \frac{1}{n} \sum_{i}^{n} X_i$$

denote their mean. Then as n approaches infinity, the random variables $\sqrt{n}(S_n - \mu)$ converge in distribution to a normal $\mathcal{N}(0, \sigma^2)$.