APPENDIX A

STATISTICS FOR SAMPLE DATASETS

This appendix describes and gives statistics for several test databases that are used throughout the dissertation. Each of these database is composed of polygons (though in one case, the polygons are generated by tiling spheres). Various lighting and shading models are used.

These datasets were intended to be representative of datasets that might be displayed on a high-performance image-composition system. An effort was made to choose datasets that have varying characteristics, such as numbers, shapes, sizes, and distributions of primitives. The datasets were chosen to fulfill four requirements: 1) cover a wide spectrum of applications, including types and distributions of primitives, 2) contain large numbers of primitives—approximately the size of databases that would be real-time or interactive in the prototype system, 3) used in real applications, and 4) readily available to the author.

We wanted to include datasets representing the range of applications we could imagine for the architecture, including:

- Architectural walkthrough with radiosity.
- Flight simulation.
- Medical imaging.
- Molecular graphics.
- Computer-aided design.

Each sample database has its own section (Sections A.1 through A.6). A photograph of the dataset is presented, followed by a description, credit information, and a variety of primitive and rendering statistics. The statistics include the following information:

- **Visible triangles.** The number of triangles that could not be trivially rejected during clipping and were passed to the rasterization phase of the renderer. Note that these can be slightly different for high- and low-resolution images because the antialiasing kernel extends the screen boundaries slightly. The effect is more pronounced for low-resolution images.
- **Active pixels.** The percentage of non-background pixels.
- **Complex pixels.** The percentage of pixels where two or more surfaces (including background) were visible.
- **Triangle area.** The number of screen pixels covered by a visible triangle (after clipping to screen boundaries). The mean, standard deviation, and maximum values over all visible triangles are given.
- **Depth complexity.** The total number of triangles that completely or partially cover a pixel (whether they are visible or not). The mean, standard deviation, and maximum values over all pixels are given.

The following two statistics are mainly relevant for A-buffer rendering:

- **Visible triangles per pixel (maximum).** The total number of triangles that are visible at a pixel at any time during rasterization. The number of partially-visible triangles at a pixel can increase or decrease as partially covering or completely covering fragments are added. This statistic gives an indication of the maximum bandwidth that must be supported anywhere in the image-composition network in an A-buffer system. Again, mean, standard deviation, and maximum values over all pixels are given.

- **Visible triangles per pixel (final).** The total number of triangles that are visible at a pixel after all triangles have been rendered. This gives an indication of the bandwidth required at the root of the image-composition network in an A-buffer system. Again, mean, standard deviation, and maximum values over all pixels are given.

Each of these statistics is calculated under four conditions: for the full dataset rendered at low-resolution (640x512 pixels) and high-resolution (1280x1024 pixels) and for one partition of the dataset (we assume there are 36 renderers so one partition contains 1/36 of the primitives) at the same two screen resolutions. The statistics for a single partition give an idea of the rendering performance and bandwidth required at each renderer and at the renderer input of each compositor.

The last set of statistics applies to systems such as PixelFlow, which subdivide the screen into regions. The static load-balance ratio is a measure of the effectiveness of the database distribution method. It is the ratio of the number of on-screen primitives on the busiest renderer to the average number of on-screen primitives on any renderer. The dynamic load-balance ratio is a measure of the unevenness of the screen distribution of primitives on different renderers and is described in Section 5.4.3.

- **Static load-balance ratio (scattered).** The static load-balance ratio resulting from a scattered distribution of primitives over the 36 renderers.
- **Static load-balance ratio (clustered).** The static load-balance ratio resulting from a clustered distribution of primitives over the 36 renderers.
- **Dynamic load-balance ratio (scattered).** The dynamic load-balance ratio resulting from a scattered distribution of primitives over the 36 renderers.
- **Dynamic load-balance ratio (clustered).** The dynamic load-balance ratio resulting from a clustered distribution of primitives over the 36 renderers.
- **Bin replication factor.** The average number of times each triangle needs to be processed (caused by falling into more than one screen region). Small primitives generally fall into a single region. Large primitives or primitives that cross region boundaries fall into several regions and must be processed several times.

A.1 SPACE STATION AND SHUTTLE

Figure A.1: Image of Space Station and Shuttle database (1280x1024 resolution).

Description: Space shuttle docking with proposed NASA space station. Database contains 3,784 phong-shaded polygons (quadrilaterals and triangles).

Credits: Dataset courtesy of Don E. Eyles of the Charles Stark Draper Laboratories, Cambridge, MA.

Rendering statistics:

Parameter	Entire scene		1 partition (out of 36)	
	640x512	**1280x1024**	**640x512**	**1280x1024**
Visible triangles	6,566	6,549	187	187
Active pixels (percent)	46.1	44.7	3.2	2.8
Complex pixels (percent)	14.8	9.3	1.8	1.1
Triangle area (in pixels)				
mean	80.01	264.08	66.33	214.11
standard deviation	355.27	1,369.33	196.79	734.12
max	12,392	48,790	1,739	6,607
Depth complexity				
mean	2.60	2.32	1.04	1.03
standard deviation	2.45	1.97	0.22	0.19
max	27	23	5	5
Visible triangles per pixel (maximum)				
mean	1.34	1.18	1.02	1.01
standard deviation	0.85	0.55	0.17	0.12
max	18	14	5	5
Visible triangles per pixel (final)				
mean	1.26	1.13	1.02	1.01
standard deviation	0.76	0.48	0.17	0.12
max	18	14	5	5
Region statistics (160x128 regions)				
Static load-balance ratio (scattered)	1.09	1.10	–	–
Static load-balance ratio (clustered)	1.56	1.81	–	–
Dynamic load-balance ratio (scattered)	1.32	1.78	–	–
Dynamic load-balance ratio (clustered)	8.24	13.07	–	–
Bin replication factor	1.24	1.53	1.28	1.51

A.2 POLIOVIRUS

Figure A.2: Image of Poliovirus database (1280x1024 resolution).

Description: 3D space-filling model of the poliovirus molecule. Database contains 46,200 Phong-shaded spheres, rendered as 16-(triangular)-sided polyhedra.

Credits: Dataset courtesy of James Hogle, Marie Chow, and David Filman, Research Institute of Scripps Clinic.

Rendering statistics:

Parameter	Entire scene 640x512	Entire scene 1280x1024	1 partition (out of 36) 640x512	1 partition (out of 36) 1280x1024
Visible triangles	370,158	369,819	10,288	10,281
Active pixels (percent)	76.6	76.2	22.0	18.9
Complex pixels (percent)	64.6	44.6	19.6	12.3
Triangle area (in pixels)				
mean	15.38	42.07	15.35	41.99
standard deviation	7.88	25.25	7.89	25.13
max	57	184	53	173
Depth complexity				
mean	18.38	12.86	1.48	1.33
standard deviation	14.25	9.93	1.08	0.79
max	85	66	14	12
Visible triangles per pixel (maximum)				
mean	3.41	2.35	1.34	1.17
standard deviation	1.94	1.31	0.79	0.50
max	14	12	10	8
Visible triangles per pixel (final)				
mean	2.37	1.67	1.33	1.16
standard deviation	1.48	0.94	0.78	0.49
max	14	10	10	8
Region statistics (160x128 regions)				
Static load-balance ratio (scattered)	1.01	1.02	–	–
Static load-balance ratio (clustered)	1.24	1.20	–	–
Dynamic load-balance ratio (scattered)	1.07	1.19	–	–
Dynamic load-balance ratio (clustered)	9.76	13.61	–	–
Bin replication factor	1.11	1.17	1.12	1.17

A.3 RADIOSITY LOBBY

Figure A.3: Image of Radiosity Lobby database (1280x1024 resolution).

Description: Radiosity-shaded model of Sitterson Hall lobby, home of the UNC Computer Science Department. The lobby database contains 3,954 color-interpolated polygons (mostly quadrilaterals).

Credits: Dataset courtesy of the UNC Building Walkthrough project, F. P. Brooks, Principal Investigator.

Rendering statistics:

Parameter	Entire scene 640x512	Entire scene 1280x1024	1 partition (out of 36) 640x512	1 partition (out of 36) 1280x1024
Visible triangles	4,786	4,786	146	146
Active pixels (percent)	96.7	96.5	6.4	5.6
Complex pixels (percent)	19.8	11.7	3.5	2.0
Triangle area (in pixels)				
mean	313.67	1,117.23	181.63	591.60
standard deviation	1,491.23	5,892.04	298.13	1,090.32
max	52,247	208,381	1,804	6,690
Depth complexity				
mean	5.58	5.08	1.08	1.07
standard deviation	4.09	3.38	0.33	0.29
max	39	32	6	6
Visible triangles per pixel (maximum)				
mean	1.43	1.23	1.04	1.02
standard deviation	0.85	0.57	0.25	0.17
max	14	13	5	5
Visible triangles per pixel (final)				
mean	1.30	1.15	1.04	1.02
standard deviation	0.72	0.47	0.25	0.17
max	10	9	5	5
Region statistics (160x128 regions)				
Static load-balance ratio (scattered)	1.26	1.47	–	–
Static load-balance ratio (clustered)	1.73	2.80	–	–
Dynamic load-balance ratio (scattered)	1.50	2.12	–	–
Dynamic load-balance ratio (clustered)	8.19	11.22	–	–
Bin replication factor	1.51	2.21	1.51	2.18

A.4 HOUSE INTERIOR

Figure A.4: Image of House Interior database (1280x1024 resolution).

Description: Radiosity-shaded model of Professor F. P. Brooks' home. The house model contains 64,796 color-interpolated polygons, many of which were textured in the original model.

Credits: Dataset courtesy of the UNC Building Walkthrough project, F. P. Brooks, Principal Investigator. Special thanks to Amitabh Varshney for converting the model into PPHIGS archive format.

Rendering statistics:

Parameter	Entire scene		1 partition (out of 36)	
	640x512	**1280x1024**	**640x512**	**1280x1024**
Visible triangles	51,937	51,922	1,443	1,442
Active pixels (percent)	100	100	16.4	14.4
Complex pixels (percent)	21.8	12.5	8.4	4.8
Triangle area (in pixels)				
mean	44.03	146.26	45.40	151.23
standard deviation	166.57	636.24	153.87	581.92
max	10,274	40,472	2,739	10,578
Depth complexity				
mean	7.98	2.11	1.20	1.17
standard deviation	9.04	4.61	0.50	0.44
max	122	93	8	7
Visible triangles per pixel (maximum)				
mean	1.54	1.29	1.10	1.05
standard deviation	1.00	0.66	0.35	0.24
max	15	15	6	6
Visible triangles per pixel (final)				
mean	1.30	1.15	1.10	1.05
standard deviation	0.70	0.45	0.34	0.24
max	12	15	6	6
Region statistics (160x128 regions)				
Static load-balance ratio (scattered)	1.01	1.02	–	–
Static load-balance ratio (clustered)	1.56	1.48	–	–
Dynamic load-balance ratio (scattered)	1.08	1.16	–	–
Dynamic load-balance ratio (clustered)	4.95	8.09	–	–
Bin replication factor	1.19	1.25	1.18	1.25

A.5 EARTH

Figure A.5: Image of Earth database (1280x1024 resolution).

Description: Topographic database of the Earth sampled at 1-degree resolution and broken into vertex-colored triangles. Vertex colors correspond to elevation. The model consists of 4,654 triangle strips, containing 133,534 triangles.

Credits: Dataset courtesy of Jonathan Leech, University of North Carolina at Chapel Hill.

Rendering statistics:

Parameter	Entire scene		1 partition (out of 36)	
	640x512	**1280x1024**	**640x512**	**1280x1024**
Visible triangles	128,880	128,880	3,640	3,640
Active pixels (percent)	49.4	49.2	4.4	3.6
Complex pixels (percent)	33.7	20.6	3.9	2.6
Triangle area (in pixels)				
mean	8.92	22.94	8.83	22.69
standard deviation	8.29	26.10	8.06	25.32
max	107	351	73	234
Depth complexity				
mean	4.51	3.26	1.10	1.06
standard deviation	4.32	2.80	0.55	0.38
max	74	67	20	18
Visible triangles per pixel (maximum)				
mean	1.85	1.44	1.08	1.04
standard deviation	1.50	0.94	0.47	0.28
max	19	22	17	16
Visible triangles per pixel (final)				
mean	1.54	1.27	1.08	1.04
standard deviation	1.02	0.64	0.46	0.28
max	14	12	17	16
Region statistics (160x128 regions)				
Static load-balance ratio (scattered)	1.03	1.04	–	–
Static load-balance ratio (clustered)	1.48	1.22	–	–
Dynamic load-balance ratio (scattered)	1.15	1.33	–	–
Dynamic load-balance ratio (clustered)	4.50	7.18	–	–
Bin replication factor	1.11	1.14	1.12	1.13

A.6 PIPES

Figure A.6: Image of Pipes database (1280x1024 resolution).

Description: Procedurally generated database containing numerous pipes and fittings. Model consists of 139,032 discrete, Phong-shaded triangles.

Credits: Database courtesy of Lee Westover, Sun Microsystems Inc.

Rendering statistics:

Parameter	Entire scene		1 partition (out of 36)	
	640x512	**1280x1024**	**640x512**	**1280x1024**
Visible triangles	137,905	137,747	3,832	3,827
Active pixels (percent)	52.7	51.4	12.6	8.4
Complex pixels (percent)	51.5	39.9	12.6	7.8
Triangle area (in pixels)				
mean	13.48	34.28	13.04	32.68
standard deviation	21.48	57.15	20.26	52.70
max	292	766	251	704
Depth complexity				
mean	6.66	4.59	1.15	1.10
standard deviation	7.54	4.83	0.44	0.33
max	78	52	6	7
Visible triangles per pixel (maximum)				
mean	2.88	2.06	1.15	1.09
standard deviation	2.23	1.44	0.42	0.31
max	20	20	6	6
Visible triangles per pixel (final)				
mean	2.35	1.68	1.15	1.09
standard deviation	1.71	1.06	0.42	0.31
max	19	20	6	6
Region statistics (160x128 regions)				
Static load-balance ratio (scattered)	1.01	1.01	–	–
Static load-balance ratio (clustered)	1.14	1.14	–	–
Dynamic load-balance ratio (scattered)	1.06	1.12	–	–
Dynamic load-balance ratio (clustered)	11.80	22.32	–	–
Bin replication factor	1.09	1.15	1.09	1.15

APPENDIX B

COST ESTIMATES FOR THE PROTOTYPE SYSTEM

The following sections contain cost estimates for the various components of the prototype system. Most prices are based on actual costs for similar items used in Pixel-Planes 5 (prices paid in 1990–1991). Except where noted, assembly, integration, and testing costs are omitted in these cost estimates. If the machine were produced in production quantities, component costs would decrease by perhaps a factor of two, due to higher volume and cost-driven design changes. A rule of thumb described by [BISH91] is that a niche computer product's selling price is approximately 3–5 times its component cost. This means that the approximate retail cost for a commercial prototype system might range from $435,000 to $730,000 for a one card-cage system and $822,000 to $1,370,000 for a two card-cage system.

B.1 CARD-CAGE COMPONENTS

Part type	**Quantity**	**Unit Cost**	**Cost**
1500W switching Power Supplies	2	$3,500.00	$7,000.00
19" Relay rack	1	$3,000.00	$3,000.00
19" Custom Card Cage	1	$3,500.00	$3,500.00
AC power controller/distr	1	$1,000.00	$1,000.00
Cabling, connectors, etc	1	$500.00	$500.00
		Total:	**$15,000.00**

B.2 RENDERER/SHADER COMPONENTS

Part type	Quantity	Unit Cost	Cost
9u 10-layer PC Board	1	$1,500.00	$1,500.00
PC Board assembly	1	$500.00	$500.00
Custom 4-rank connector	1	$100.00	$100.00
Bypass cap's	300	$0.16	$48.00
Terminators	100	$0.40	$40.00
Misc conn's, sockets, etc.	1	$100.00	$100.00
i860XR 40 MHz	1	$600.00	$600.00
1Mb VRAM	64	$20.00	$1,280.00
22V10-7 PLD (ring network)	8	$25.00	$200.00
72225 Fifo	2	$110.00	$220.00
Misc PAL's	30	$10.00	$300.00
Misc SSI/TTL	40	$5.00	$200.00
Clock Gen components	1	$100.00	$100.00
EMC[1]	80	$50.00	$4,000.00
IGC[2]	1	$1,600.00	$1,600.00
22VP10-7 PLD (compositor)	80	$25.00	$2,000.00
		Total:	**$12,788.00**

B.3 HOST INTERFACE COMPONENTS

Part type	Quantity	Unit Cost	Cost
9u 10-layer PC Board	1	$1,500.00	$1,500.00
PC Board assembly	1	$500.00	$500.00
Custom 4-rank connector	1	$100.00	$100.00
Bypass cap's	150	$0.16	$24.00
Terminators	50	$0.40	$20.00
Misc conn's, sockets, etc.	1	$100.00	$100.00
1Mb VRAM	80	$20.00	$1,600.00
22V10-7 PLD (ring network)	8	$25.00	$200.00
72225 Fifo	2	$110.00	$220.00
Misc PAL's	10	$10.00	$100.00
Misc SSI/TTL	30	$5.00	$150.00
Clock Gen components	1	$100.00	$100.00
Corner-Turner PGAs	10	$300.00	$3,000.00
22V10-7 PLD (compositor)	54	$25.00	$1,350.00
		Total:	**$8,964.00**

[1]Price quotation from Hewlett-Packard based on 2000 working PixelFlow EMCs, packaged in 100-pin quad flat-pack, 0.5M transistors, CMOS 34 process (includes mask charges). Unit price is $41.60 for 3000 working parts.

[2]Estimate based on cost of Pixel-Planes 5 IGC reimplemented in HP CMOS 34 technology.

B.4 FRAME BUFFER COMPONENTS

Part type	Quantity	Unit Cost	Cost
9u 10-layer PC Board	1	$1,500.00	$1,500.00
PC Board assembly	1	$500.00	$500.00
Custom 4-rank connector	1	$100.00	$100.00
Bypass cap's	150	$0.16	$24.00
Terminators	50	$0.40	$20.00
Misc conn's, sockets, etc.	1	$100.00	$100.00
i860XR	1	$600.00	$600.00
1Mb DRAM	64	$6.00	$384.00
1Mb 3-port DRAM's	80	$45.00	$3,600.00
22V10-7 PLD (ring network)	8	$25.00	$200.00
72225 Fifo	2	$110.00	$220.00
Misc PAL's	30	$10.00	$300.00
Misc SSI/TTL	50	$5.00	$250.00
Clock Gen components	1	$100.00	$100.00
Corner-Turner PGAs	10	$300.00	$3,000.00
22VP10-7 PLD (compositor)	54	$25.00	$1,350.00
200MHz RAMDAC's	3	$205.00	$615.00
		Total:	**$12,863.00**

B.5 TOTAL SYSTEM COST

B.5.1 One Card-Cage Configuration[1]

Component	Quantity	Unit Cost	Cost
Renderers	18	$12,788.00	$230,184.00
Shaders	2	$12,788.00	$25,576.00
Host Interface	1	$8,964.00	$8,964.00
Frame Buffers	1	$12,863.00	$12,863.00
Card cage, etc	1	$15,000.00	$15,000.00
		Total:	**$292,587.00**

B.5.2 Two Card-Cage Configuration[2]

Component	Quantity	Unit Cost	Cost
Renderers	36	$12,788.00	$460,368.00
Shaders	4	$12,788.00	$51,152.00
Host Interface	1	$8,964.00	$8,964.00
Frame Buffers	1	$12,863.00	$12,863.00
Card cage, etc	1	$15,000.00	$15,000.00
		Total:	**$548,347.00**

[1] Sufficient for Gouraud shading only. Impacts composition network performance because of burp transfers.

[2] Sufficient for Gouraud or Phong shading.

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