Chapter 15
CG Anatomy

Fig. 15.1 Tori, by Steven Geisler (face), Francisco Cortina (hair and body), and Jake Rowell (body textures)

Anatomy tells us what a character is supposed to look like and how it moves, but it does not tell us exactly how to build it for use in a CG scene. Depending on your project, you may want anything from a highly detailed anatomical model such as the one described in the project for this section, or a very low-resolution polygonal model that uses texture maps to represent all superficial detail, such as muscles. The first fact that you must ascertain, then, is what type of model you desire to make (Figs. 15.1–15.9). The most common varieties are the following (in order of detail, from lowest level to highest):

- Lowest resolution game
  - 750 triangles, 1 texture map, usually about 512 × 512 pixels
- Low-resolution game
  - 2,000 triangles, one 1 k texture map, or multiple maps that in total would fit within a 1,024 1,024 area.

Fig. 15.2 Extremely low-resolution character models. The human has 634 triangles, the dog has 522

- Stand-in film
  - This type of model is used for blocking animation with a complete skeleton. Nurbs surfaces are often used for these, usually of perfect proportions but low detail. Patches will normally have no more than 12 isoparms each. Sometimes they have texture maps, more often if the stand-in is made of polygons.
  - Nurbs
    - Minimum of 6 patches for major limbs, 30 in total including hands and feet. No texture maps.
  - Polys
    - 3,000 triangles, if mapped, it is 1 k
- Medium-resolution game
  - 3,000–5,000 triangles, multiple 1 k maps for color, normals, and specularity
- Low-resolution film
  - Nurbs
    - Very similar to stand-in model, but with textures, sometimes with several layers of information represented by them
    - Polys
    - 5,000–7,500 triangles, multiple 1 k–2 k maps

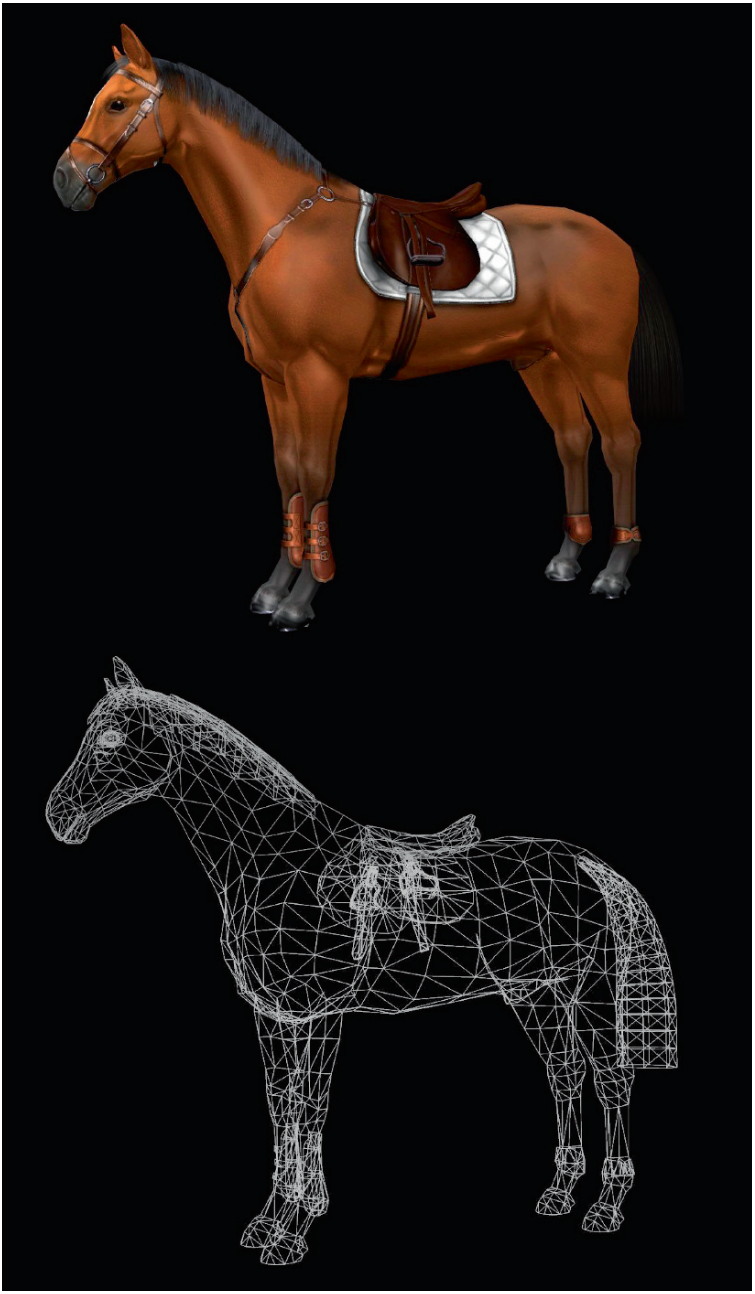

Fig. 15.3 A low-resolution horse and its wireframe (From *My Horse and Me.* Courtesy Wii Games)

Fig. 15.4 One horse becomes many, thanks to a good UV layout and multiple texture maps (From *My Horse and Me.* Courtesy Wii Games)

- High-resolution TV
  - Because of television screen resolution limits, characters rarely need to be of any higher resolution than this, except if the animation requires a long shot and extreme close-up of the same figure. Even then, the poly budget does not need to increase much beyond this level.
  - 7,500 triangles, multiple 1 k maps
- Medium-resolution film
  - Nurbs
    - Axial and appendicular musculature and all digits represented along with full complement of joint articulations, hair, and multiple tex maps between 1 k and 2 k in size. Face is modeled, but might have low-detail teeth and ears as well as simplified anatomical structure. This is the most common resolution for full figure character shots.
  - Polys
    - Same as above, but 7,500–10,000 polygons
- High-resolution game
  - 10,000–15,000 polygons, 3–8 layers of maps, up to 2 k each
- Highest-resolution game
  - 25,000 polygons, 5–10 layers of maps. This resolution is becoming less common because of normal map use as a substitute for high levels of poly gonal detail

Fig. 15.5 This character model has many millions of triangles, but will be reduced to much less after this uber-high-resolution model is converted to normal maps (Copyright © 1998–2008, Epic Games, Inc. All rights reserved)[1]

- High-resolution film
  - Nurbs
    - Up to several hundred complex patches, many layers of maps (3 minimum, to several dozen), up to 4 k in size
  - Polys
    - 50,000 triangles, many layers of maps (3 minimum, to several dozen)
  - Subdivided surfaces
    - May be only one patch, but subdivided for extremely fine detail, including knuckles, fingernails, muscle boundaries, eyelashes, and other small structures. Many maps.
- Medical simulation
  - Nurbs (unusual)
    - Thousands of patches to represent numerous small details, such as circulatory system, bones of inner ear, nervous system, and thickness of arterial walls. Texture maps are unusual, though not unheard of for this type of project.
  - Polys
    - Hundreds of thousands of polys (could be in the low millions), no texture maps.

[1] Epic, Epic Games, Unreal, the "Powered by Unreal Technology" logo, the Circle-U logo, and Gears of War are trademarks or registered Trademarks of Epic Games, Inc. in the United States of America and elsewhere.

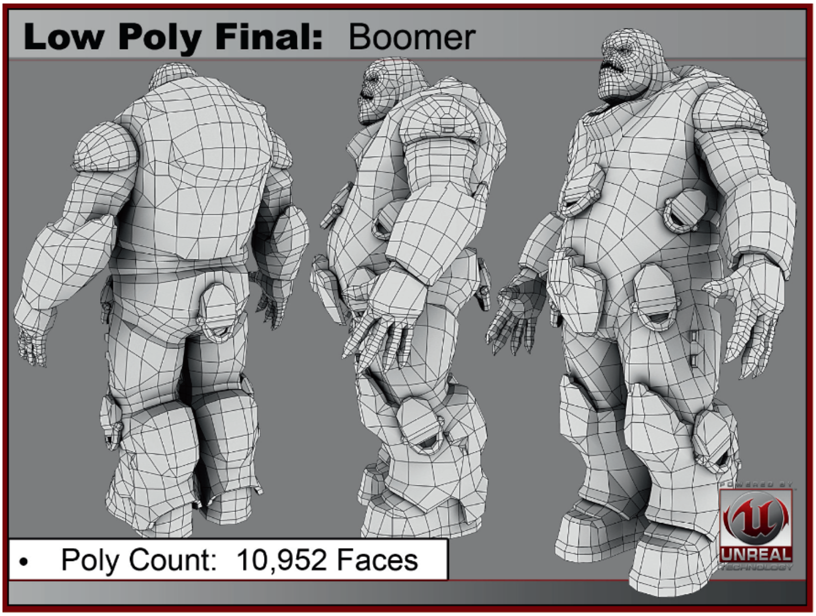

Fig. 15.6 After poly reductions (Copyright © 1998–2008, Epic Games, Inc. All rights reserved)[2]

- Highest-resolution film
  - This level of resolution is reserved for extreme close-ups of large creatures. They are not uncommon in the sense that some movies use models at this resolution, but they are reserved for a small number of shots of major characters only, usually when speaking. This resolution does not apply to most human or simplified character types because the level of detail is not needed to represent them. It is used for creatures that have an extraordinary amount of surface detail built into them, like characters with tentacles or horns.
  - Nurbs
    - A thousand or more patches, many layers of large maps
  - Polys
    - From 100,000 triangles to several hundred thousand. Many layers of complex maps.
- Stand-in normal map detail model, games
  - These models are used as an intermediate object during the modeling process, to generate normal maps only. They can be as high as 20 million polygons, but are more often around one million triangles. No texture maps.

[2] Epic, Epic Games, Unreal, the "Powered by Unreal Technology" logo, the Circle-U logo, and Gears of War are trademarks or registered Trademarks of Epic Games, Inc. in the United States of America and elsewhere.

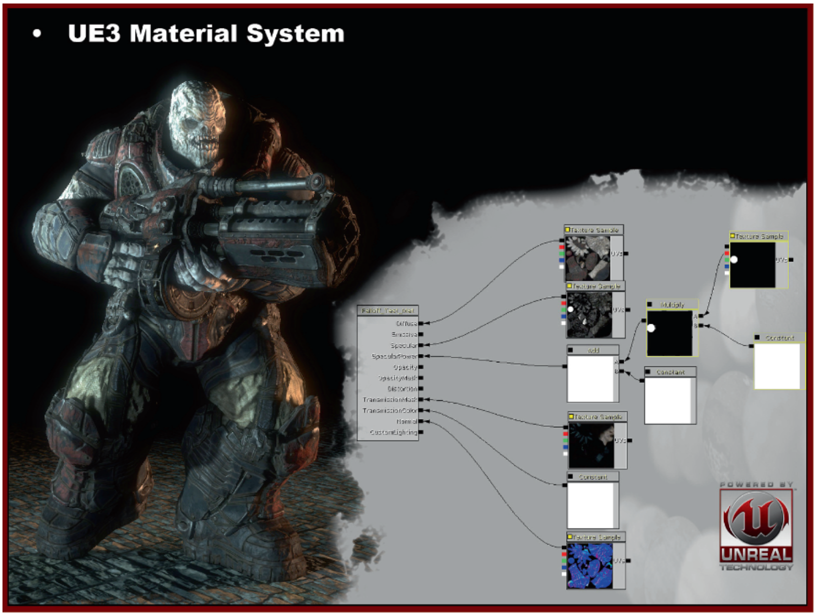

Fig. 15.7 The final character, with many maps applied. The importance of shaders to a character model should never be underestimated. Regardless of the level of detail in the model itself, shaders and maps can enhance it a great deal (Copyright © 1998–2008, Epic Games, Inc. All rights reserved)[3]

When you decide the resolution of your character model, it is a good idea to use the information listed above as a maximum number only, and to try and find a minimum number as well. It is true that, especially at higher polygon counts, additional polygons do not always visibly benefit the model, and they can be quite costly. If you use more polys than necessary in a game, you may have fewer characters or other objects in your environment than you would like, or the frame rate may be unacceptably slow. In a film or other pre-rendered product, render times may be extremely high, and interacting with the model may be extremely slow due to low screen redraw rates.

To arrive at a good budget for a character, you should keep in mind that the polygons primarily accomplish two things: higher curve detail and additional parts. For characters over about 5,000 triangles, additional polygons only add to curve detail, unless the character has extra arms, a complicated costume, or some other type of unusual detail. Here, then, is a list of minimums:

[3] Epic, Epic Games, Unreal, the "Powered by Unreal Technology" logo, the Circle-U logo, and Gears of War are trademarks or registered Trademarks of Epic Games, Inc. in the United States of America and elsewhere.

Fig. 15.8 Half a million triangles for a partial face scan, the starting point for a high-resolution treatment in film

Fig. 15.9 Convincing skin, hair, and other details are crucial to the success of your character model (Image courtesy Francisco A. Cortina – Cortina Digital)

- 2 triangles/1 polygon: A card, mapped with an alpha mapped image of a character, usually animated. Characters in crowd scenes of the film *Space Jam* were built like this. Careful viewing will also show that many of the characters are repeated in the same frame.
- 15 triangles: This is the smallest number of triangles needed to represent independent movement of limbs and hands (not fingers). With this type of geometry, alpha-mapped textures are used to improve the illusion of a three-dimensional character. This type of character can be found in some very old *Doom*-era video games or in the backgrounds of a few later games.
- 250 triangles: Characters built like this do not use alpha maps to enhance resolution of their silhouette, and have the appearance of origami. Curve detail is so low that they are not always convincing, nor do they move in a very credible manner, except at great distances.
- 750 triangles: This is a common triangle budget for a Playstation 1 era video game. These characters have hands simplified by fusing the second through fifth fingers, and reducing the number of joints per hand from 15 to 2. Facial features are painted on, except for the nose, and only rarely do they have an articulated jaw. Animated texture maps are used for eye and mouth movement. Characters built to this budget are not unusual in modern games that have hundreds of characters on screen simultaneously.
- 1,750 triangles: This is a standard budget for representing every major structure of the human body in the round. Therefore, a character with this budget will have every joint of every finger, a mouth that opens, simplified teeth, a nose, simple eyes, sculpted hair, knee joints, extra polys around shoulders and hips for animation, and feet represented with a minimum of three sections (ball, arch, and heel). A character in this budget range will not have a fully articulated spine, but will have at least the three major sections represented: cervical, thoracic, and lumbar. Curve detail remains low here, but skilled artists can disguise this fairly well within this budget.
- 3,500 triangles: A character that has extra appendages, unusual clothing, props, or fairly smooth curve detail may be built within this budget. The silhouette will have a faceted appearance, but only if looked for. Facial detail will include a full mouth, tongue, and teeth. Eyes may be built separate from head model, ears will have good detail, and most facial bones will be evident in geometry. Working at this budget requires some knowledge of anatomy and practice. Less experienced artists will be more comfortable at a higher poly count, but may find that their characters have less structural detail than those made by more skilled counterparts working at this resolution.
- 5,000 triangles: This is a comfortable budget for most artists, regardless of skill, because it is very easy to represent the major structures of a character within it. Skilled artists will be able to sculpt many individual muscles into the figure without any difficulty. Artists with less experience will instead rely on high resolution normal maps to inscribe muscle detail.
- 10,000 triangles: At this level of detail, most visible anatomical detail may be represented with sufficient curve detail that the model does not appear to be faceted except in extreme close-up, or at high resolution, such as on a

movie screen. In a game, to use more polygons than this for any character is only justified when there are numerous small details, such as complicated jewelry, clothing, hair, weapons, or other accoutrements in addition to the anatomy of the character itself.

- 50,000 triangles: This is a sufficient poly count to describe almost any character in fine detail, with smooth enough curve detail that even on a movie screen, no faceting will be evident. Higher poly counts than this is necessary only for shots that include both a long shot of the entire character and close-ups on complex details, such as the blades of individual teeth.
- 100,000 triangles and above: This is strictly for extremely complex characters that have either many more limbs than normal, or the equivalent. The Doctor Octopus character in *Spider-Man 2*, for instance, may have had a poly budget in this range (if he was a poly character) because he had four extra limbs, those limbs had a perfectly round cross-section, and each had dozens of joints.

The most common poly budget in use for games at the time of this writing is between 5,000 and 10,000 tris. Anything within that range is sufficient to accommodate all superficial anatomical details without resort to optimization beyond normal model cleanup. If you are working within that budget range and find that it is difficult to represent the superficial shape of a human body, it may be that you are spending more polygons on curve detail than on finding structural boundaries. This is an important distinction because it defines the difference between artists who prefer curve detail and artists who are able to include a high amount of part detail at the same or lower poly count.

The difference in working method can be apparent almost immediately. A wasteful artist will often start by extending edge loops along the length of every section of the body, without ever modifying the number of vertices around the edge loop to accommodate the amount of structural detail present at that location in the model. Models of this type tend to look as if they have been divided into evenly measured grids around every limb and digit. Sometimes this is done to improve animation by averaging the distance between vertices. This is a legitimate justification, but care should be taken that important structural detail isn't lost to accomplish it. If vertices are present, they should be used to add to the structural definition of the model. When this is not true, the model will suffer from an unnecessarily high poly count without any corresponding improvement in its appearance.

Skin

Depending on age, your character's skin should be either tightly or loosely bound to its muscles (Fig. 15.10). The skin will in most cases reduce definition between muscles at muscle borders by stretching from one muscle to the next at an angle. The end result is very much like a bevel operation performed on every edge. The sharpness

Fig. 15.10 Crouched Woman, by Francisco Cortina – Cortina Digital

of the angle is determined in your subject by the amount of muscle definition, and in the model by the depth of the bevel. If you keep this in mind, you should be able to make a credible character model by simply tracing off the shape of the muscles. Just be careful to keep the skin a constant thickness above the muscles, about half a centimeter, and avoid extremely sharp creases between muscles.

Subdivision Surfaces

Subdivision surfaces are a type of hybrid geometry that allows the user to modify a simple polygonal control mesh to define complex curved surfaces. The geometry type allows for progressive subdivision and multiple branchings, both of which are not allowed with nurbs surfaces. Subdivisions are an excellent geometry class for certain subjects, especially characters, because they can very quickly become complex, smooth, well-articulated forms without having to battle against the limitation of polygons (not smooth) or nurbs (achieving tangency or curvature continuity). In addition to those benefits, subdivision surfaces will convert to either polys or nurbs when you are done, or they can be rigged, textured, and rendered as is.

One defect of subdivision surfaces is that they can result in excessively dense geometry, so when using them, please be aware of this problem in order to avoid it with your model. The reason it happens is that each level of subdivision increases the poly count by four, making each successive level of subdivision much greater than the previous one.

To make a character with subdivision surfaces, you may make a cube and pull it into the basic shape of your character using basic editing tools and then convert the poly object into a subdivision surface. The other way is to make a subdivision surface primitive and model it with basic modeling tools. Some of the options will be different from poly modeling, but most are the same. You may also start with a nurbs object and convert to subdivisions, but this is not an efficient way to work, so it is not recommended.

Neutral Pose

Most character models are built with animation in mind. Exceptions, such as static statues, are not considered "characters" in the sense that they will never be more than a decoration in a scene. A statue that does move is a character. Because of this, modeling characters should always be done with some knowledge of the animator's needs. If not, you are likely to have the model returned for modification.

The first concern of the modeler is that the likeness of the character is good. Secondly, the geometry should be clean. The next most important factor is that the neutral pose of the model should be correct (Figs. 15.11–15.13). Some animators differ on what is the most efficient pose for a character. In the 1990s, the common pose was called the "T-pose," where the character stands erect, with feet spread slightly apart, arms outstretched straight to either side at shoulder height, palms forward, and fingers spread in a fan shape. The purpose of the pose was to aid the animator when attaching it to a skeleton and to provide a neutral start position for all joint animation. If moving parts are too close together, such as if the model were made with the arms at its sides, then the vertices of one half of the torso would become part of the same group of vertices attached to the humerus and lower arm bones and would move with them. Disentangling such errors led to the T-pose, and others like it.

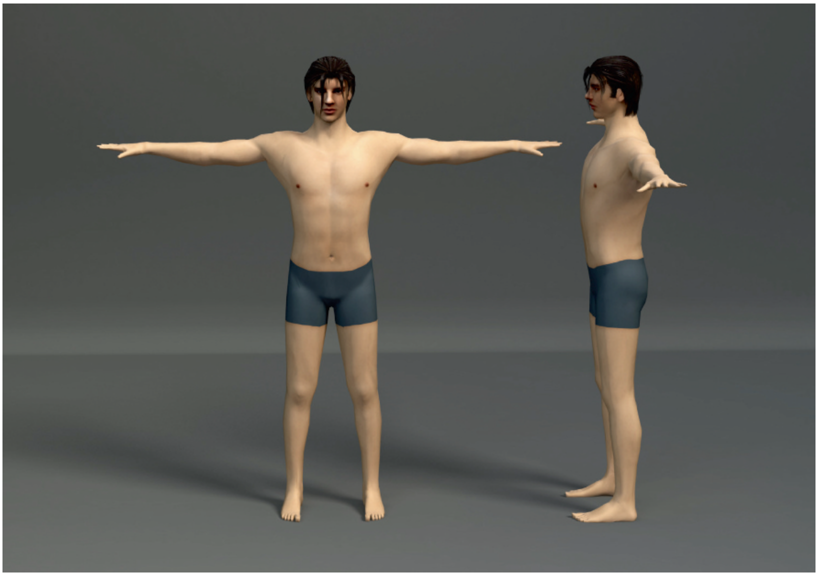

Fig. 15.11 The "T" pose (Courtesy Arno Schmitz)

Fig. 15.12 Neutral, straight-limbed pose (Courtesy Arno Schmitz)

A more popular pose in recent years, used on the film *Spider-Man* and many others afterwards, is the arms and legs akimbo pose. With this pose, the character's spine is erect, but the legs and arms are bent to about the halfway point of their total rotation range, and the legs and arms are rotated slightly outwards from the hip and shoulder joints. The purpose of this pose accomplishes the goal of the T-pose, but adds something extra: because the major joints are rotated to about the midpoint of their range, it reduces the amount of distortion that must be accounted for in the rig because the limb will now only move half as far, in either direction, as it would in a straight-arm and straight-legged pose.

The akimbo pose is a bit more difficult to model because it is unnatural and each limb is rotated out of alignment with the global coordinate system. A solution for this is to build each part separately, and then assemble and stitch them together in the appropriate posture. It is here that knowledge of anatomy becomes very useful, especially if you have a pre-built skeleton to use as reference for positioning the different limbs.

Fig. 15.13 Mid-rotation posture (Courtesy Arno Schmitz)

Once you have the pose set properly, you may need to modify the edge loop pattern at all joints. This is because the surface definition of a character can be done fairly well without reference to how it is supposed to bend during joint rotation. If this is not kept in mind during the modeling process, there is a good chance you will need to modify the model to ensure there are enough vertices at every joint to maintain the shape of surrounding structures during limb rotation. For example, the extensor carpi radialis longus crosses over the elbow joint completely in almost a straight line, with no allowance made for the shape of the elbow. When the arm bends at the elbow, this muscle must also bend, but if does not have vertices aligned with the location of the elbow joint, it will not bend correctly. This same problem is present to differing degrees in many other joints.

The most common solution to joint flexibility issues is to add up to five edge loops at hips and shoulders, and then to have at least three rows at elbows and knees: one row at the top and bottom of the joint and another in the center.

UVs

UVs must be assigned prior to rigging (Fig. 15.4). This must be done because any UV errors may force the animator to throw away any work done up until the point when the UV error was discovered. One way this might occur is if there is an error

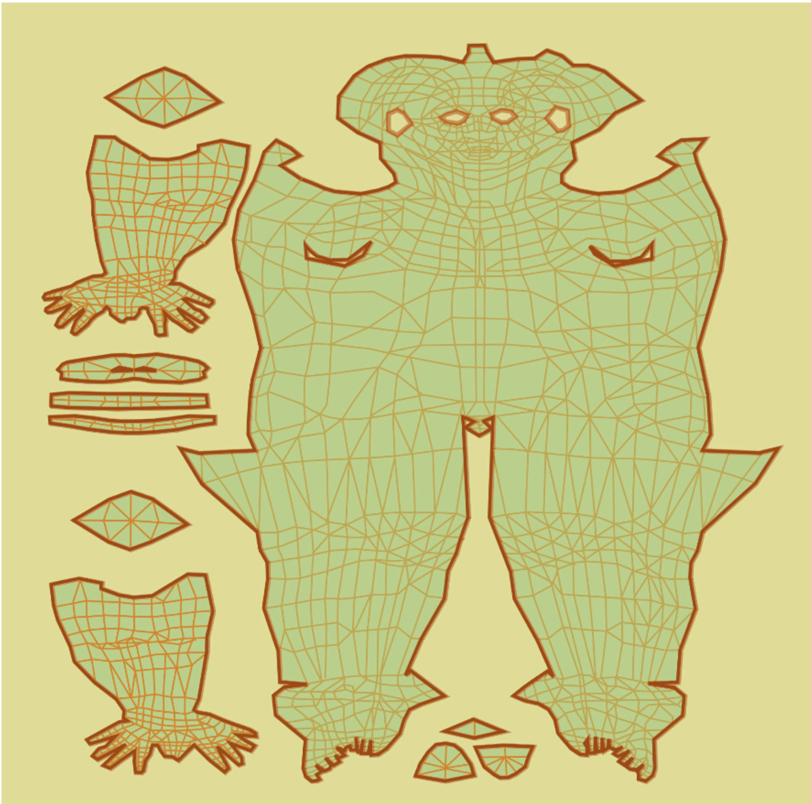

Fig. 15.14 Character UV layout (Based on model by Arno Schmitz)

in a part of the model that is not easily checked, like in the armpit. When the animator moves the arm to test his rig, he may find the mistake and then be forced to send it back to be fixed, and throw away the work he's done so far. One way to help prevent this problem is to use the arms and legs akimbo neutral pose because it is easier to see most faces of a model. You should always carefully triple-check your UVs before delivering the model for rigging (or rigging it yourself) or you risk losing a great deal of work.