Chapter 14

Animation

14.1 Introduction

In this chapter, "animation" will be used as a shorthand for "a sequence of computer-generated images, rapidly displayed so as to create the illusion of continuous motion, as in a movie".

Unfortunately, the technology to both generate the image-sequence in the computer, and to output it to screen, videotape, CD-ROM, DVD or film, and the software tools and file formats to do so, are rapidly evolving. Nevertheless, because an animation is often the only way to display time-dependent reality through a time-dependent visualization, animation is becoming increasingly important

14.2 Animation versus Stills

A single frame from a film, or a single image used as a substitute or supplement to an animation, is called a "still". The first theme about animation is that it should be used sparingly: animation is expensive both in computer resources (rendering time, hard disk storage) and in reader time (because the viewer must concentrate intensely for the whole duration of the animation, and process a large number of images).

The best advice is: dynamic phenomena are best presented dynamically (that is, as animations) whereas static phenomena are best visualized as stills. However, there are some subtleties.

I once had a Ph. D. student who proudly (but inappropriately) created an animation of the developing wave in a linearized hydrodynamic stability calculation. The animation was rather useless because the approximations inherent in the "linearization" meant that the wave never changed its SHAPE as it evolved, but only grew in amplitude at a steady, exponential rate. The contour lines flickered during the animation because the contouring subroutine had to adjust the contour levels as the wave amplified, but the shapes depicted by the isolines — that is, the location of the highs, lows, zero-lines, etc. — never changed. A single still conveyed exactly the same information as the entire animation.

So, the notion of "static" (and animation-inappropriate) has to be generalized to include not only behavior which is truly independent of time, but also time-dependence that is TRIVIAL and SHAPE-INVARIANT. Spatially-uniform growth is one example; steady, shape-invariant wave propagation is another.

The notion of "dynamic" needs to be narrowed, too, because what animation does best is to display MOTION. When the shape changes, it sometimes does so only to shift from one quasi-steady state to another ("snap-through dynamics".) In such a case, it may be far more useful to display a set of stills of the quasi-steady states, preferably combined into a single figure, rather than an animation of the entire time-dependent evolution. Animation is not justified merely because the flow evolves with time; the evolution must be so dramatic that it is difficult to follow all the shape changes through a collection of four to six pictures in a single figure.

A multi-panel graph has the advantage that the reader can linger over each frame as long as desired, drinking in the details. In contrast, an animation shifts continuously so that is possible to linger over nothing. Most of us have had the feeling, when watching a theatrical movie, that an interesting scene flashed by too fast — to fast to comprehend the intricate plot details, too fast to enjoy the beauty of the backdrop (or the leading actor/actress).

A partial remedy for this is to hybridize the panel-of-stills with the animation. Computer animation formats such as Quicktime display a slider underneath the "movie screen" so that one can display the animation one frame at a time, or move forwards or backwards one frame at a time at a user-controlled rate. Alternatively, one can click a button to play the motion at full speed, either forward or backward. While freeze-frame, slow motion, and reverse are options with ordinary celluoid movies, these options are much easier on a computer, where a touch of a key suffices, than with celluloid movies, where a mechanical projector has to physically slow, stop, or reverse gears.

The late Tetsuya "Ted" Fujita, the world's leading authority on tornadoes, was a master of visual presentation. In 1974, an Indiana TV cameraman filmed the first movie of a multi-vortex tornado. The short film clip (about ten seconds) was made widely available to the scientific community, and several authors showed it at the 1975 SESAME conference in Boulder. One group began with an apology; to identify features in the fast-moving whirl of subvortices, they had rerun the film so often that their copy had become heavily scratched and degraded. It was hard to see much of anything as the four subsidiary vortices danced around their common center while simultaneously their center rapidly translated parallel to the ground.

In contrast, Fujita had duplicated the clip and reshot it. His two-minute film showed the ten-second clip twice at normal speed, then twice in slow-motion, then once in slow reverse motion, then paused to freeze-frame several key moments. (The freeze-frame images were reproduced by filming the same frame of the original fifty times to make two seconds of the Fujita film.) There were no pauses to slow down or stop the projector, which ran at full speed throughout Fujita's presentation. Fujita's clever reprocessing had overcome most of the limitations of movie film.

Nevertheless, the viewer has much more control over a Quicktime animation, and Fujita, who retired in the mid-90s when computer video editing had just arrived, doubtless wished it had been available when he was analyzing and editing the multi-vortex tornado. When movie film or video is captured into a computer, editing and viewing is enormously simplified; a computer is the ultimate freeze-frame/slowmo/reverse movie projector.

Nevertheless, even Fujita's cleverness and/or the replacement of projector gears by silicon and on-screen controls cannot entirely compensate for limits of animation. A multi-panel graph can be printed; an animation can't. A multi-panel graph allows graph-to-graph movement controlled only by the eyes; an animation can be shifted only with a mouse. A multi-panel graphs allows easy comparison of different states; an animation shows one frame at a time.

So the first great issue in animation is: Do I need a movie? Would stills be better?

Quicktime movies or other rapidly-played sequences of images are a powerful tool for depicting many phenomenon. However, there are plenty of situations where animation is not appropriate, but is "chartjunk" and/or a "graphical duck" instead.

To summarize, situations that should NOT be animated include, but are not limited, to the following:

1. Steady-state phenomenon
2. Steadily-growing solution without shape change
3. Steadily-translating wave
4. Snap-through dynamics: rapid changes from one quasi-steady-state to another with uninteresting brief periods of transience.

Actually, it may be helpful to animate a steadily-propagating wave for K-12 education, but college students can mentally translate a shape without needing to be shown it.

14.3 Films versus Video versus Quicktime

14.3.1 Film

Celluloid film is now rare in scientific visualization. First, cheap movie cameras have been largely replaced by videocameras; movie equipment is relatively rare and therefore expensive, aimed more at Hollywood than daddy-filming-his-little-girl in a suburban backyard. Second, export from the computer requires special equipment and is relatively expensive; Industrial Light and Magic has the necessary equipment, but it is increasingly rare for a non-professional to do so. Third, movie projectors are becoming rarer, older and less reliable.

The great advantage that film has over other media is long-shelf life. Paper has been a very successful archival medium: the linen-rich, acid-free paper and carbon-based inks of Gutenberg have degraded but little in the half-millenium since he printed his Bible in the 1450s. Film is not so long-lived — indeed, the celluloid stock of early twentieth century movies is chemically unstable, and some early silent films have quite literally exploded in the vault — but is likely to be much more durable than other computer-based formats.

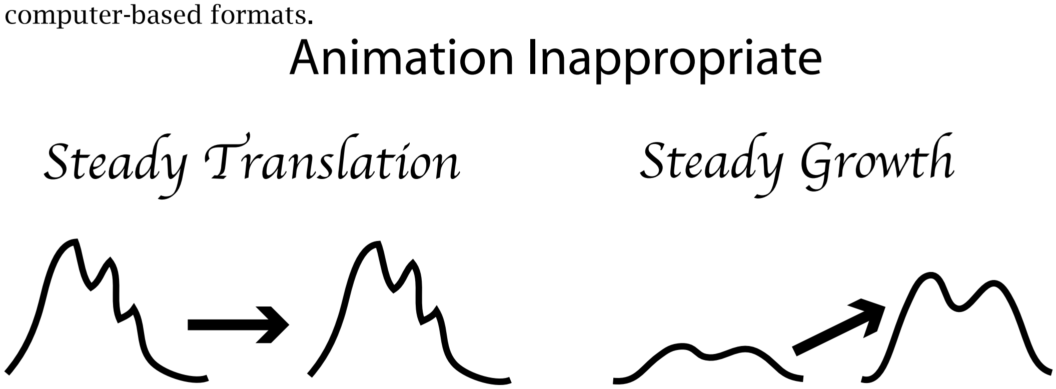

Figure 14.1: Schematic of time-dependence that too is simple for animation: If the shape doesn't change, it doesn't need to be animated.

14.3.2 Archiving

Archival survival is based on three factors:

1. Durability of the medium
2. Availability of readers/projectors
3. Interest and ability to preserve through duplication.

Acid-free paper can last many centuries; ordinary wood-pulp paper will last a few decades; modern black-and-white film stock can probably last fifty to one hundred years; analog (VHS) videotapes may last five to twenty years; CD-ROMS and DVDs will last a couple of decades or more, but no one is entirely sure.

Paper is the champion in the "projector" category; the only "reader" needed is the viewer's eyes, the only complication would be a switch to a simplified spelling system. Of course, paper is useless for stills. In contrast, analog (VHS/SVHS/Betamax/VHS-C) video is likely to disappear in the next decade, replaced by digital video. Thus, an animation-on-video in 2002 will be very hard to view in 2012 even though the magnetic oxide coating on the tape is still okay. Similarly, CD-ROM drives will likely be gone in ten years also; however, the present generation of DVD readers can also read CD-ROMS, so this format is likely to more long-lived than analog video. Computer formats are hard to predict; theoretically, there is a lot of backward compatibility and it seems likely that it will be possible with effort to read animation files of twenty years earlier. However, most workstations will have only the latest standards, and these may or may play current-day Quicktime and AVI formats.

Animations in old formats can be preserved by copying to new formats, such as analog video to DVD. However, this takes time, money, and enthusiasm. Undoubtably many films and computer videos of today will never be converted to DVD (or whatever), and will simply disappear like the hoop skirt and Nehru jacket.

14.3.3 Video

The charm of video is that the tapes are inexpensive, and can be played on hobby-level equipment. All conferences and academic departments and many private homes have video players. A computer is not necessary for replay. Further, video always includes audio whereas including or even playing an audio track on film usually requires professional-grade equipment.

Creating video from computer animations is fairly straightforward. Some solutions require buying a card which does the conversion in hardware and contains a video connector that projects out through the back of the computer. The new generation of Macintoshes (even though the bottom-of-the-apple iMac Powerbook) all have built-in hardware and software to input and output video; it is not possible to buy a new Macintosh that DOESN'T have video input/output capabilities.

One downside of video is that are several incompatible formats including VHS, SVHS, 3/4" tapes, Betamax, Digital 8-mm, etc. VHS is an analog format which is very widely used; there are tens of millions of VHS players in the world. The bad news is that VHS is a low resolution format.

In the early days of PCs when color computer monitors were hideously expensive, it was common to use a TV as a monitor for color graphics. Even in the early 80s, though, monochrome computer monitors with much higher numbers of pixels were available. My first PC was a dual monitor setup. Letters were visible on the TV only when displayed in twice the size of what was clear and legible on the 720 x 540 monochrome display.

Thus, animations that will be transferred to VHS must be designed to use BIG LETTERS. The other features of the graph must similarly be OVERSIZE. Flow vector arrows that may look fine on the computer screen may well be washed-out, visible only as directionless, blurry black sticks, on VHS.

Analog video records a record of the intensity of the camera signal without digitization. Although it works, it is hard to tune; an engineers' joke is that the acronym NTSC for standard video means "Never Twice the Same Color". Analog video is not a good format for computers because the workstation must perform an analog-to-digital conversion and back before doing anything useful with the signal.

Because an analog signal degrades a little each time is copied, a heavily edited VHS tape looks awful. To compensate, professionals use 3/4" tape for editing. The format is the same as standard VHS except that the signal is recorded at lower density on the wider tape, which greatly reduces editing degradation. In contrast, digital video never degrades because of copying.

For these reasons, analog TV (and video) are being phased out. It may be another decade before the number of digital home TVs exceeds the number of analog boxes, despite the government's present timetable to cease analog broadcasts at an earlier data. Digital cameras are growing in popularity much faster than digital TVs because

1. They're much less expensive than digital TVs (though more costly than analog cameras).

2. Digital video is much easier to edit.

3. Digital camcorders have always have a digital-to-analog converter so that they can be played on an analog TV through a cable.

Apple's integrated software/hardware video capability is therefore focused entirely on digital video. The iMovie software not only edits, but also sends stop/start commands to most digital camcorders. (In contrast, analog camcorders are only rarely configured so that they can be controlled by software.) This is yet another reason why digital camcorders are rapidly pushing analog aside, especially as a camcorder/computer combination.

It is unfortunate that video in an unstable analog-to-digital transition. For conference presentation, a VHS tape is the best because analog players are more widely available than digital (though this is changing). However, the VHS tape will be obsolete in a few years. So, unless the tape has only one-time value, it is desirable to make a digital video, too, where possible. This is easy if the editing is done on a digital camcorder; the VHS copy or "dub" can be made by rewinding the tape, connecting the digital camcorder to the input of a VHS player or "deck", and hitting the play button on the digital machine and "record" on the analog tape.

14.4 Movie Jargon

ANALOG (VIDEO): Videotapes (and TV) in which the record or displayed signal is simply the strength of the signal detected by the camera. This is opposed to DIGITAL VIDEO, in which the camera signal is converted to numbers.

CLIP: Movie jargon for a short section of an animation, typically containing one scene or a portion of a scene; a clip is a portion of the film bounded by two "cuts" where the viewpoint shifts to a different camera, viewing angle, etc.

CODEC: A protocol for compressing and then decompressing video files. Codecs are extremely important because all but the shortest video files require so much storage in uncompressed form as to be unmanageable; in addition, uncompressed files require too much processing to permit real-time display on older workstations. Video editors support several protocols each, which may be implemented either in software or on special hardware video cards inserted into the computer.

DIGITAL (VIDEO): TV/video in which the input from the camera is converted immediately to numbers so that numbers, rather than undigitized pixel intensities, are recorded onto tape.

DUB: Movie jargon for "copy". When an audio track is added in the studio to a video track which has been photographed on location, the audio track is said to be "dubbed" into the movie. When a computer animation is copied onto a VHS videotape, the result is a "VHS dub".

KEYFRAME: In animation, a frame that is drawn or compressed very accurately; frames between keyframes are drawn by interpolating or "tweening" between the keyframes. (Used both in animation/drawing and also in video compression/decompression.)

ROTOSCOPING: Drawing directly on invididual frames of film. Adobe Photoshop can import video in filmstrip format as a single file from Adobe Premiere, draw on individual frames, and then export the filmstrip back to Premiere for video rendering or export.

SPRITE: Graphic objects which are stored once in a movie file, and then duplicated or moved as needed. Early personal computer sprites were bitmaps were moved, without making big demands on the CPU, by blitting the sprite to the frame buffer. Modern sprites may either bitmap, vector, or 3D.

STILL: A single image, often taken from an animation, as opposed to the ANIMATION itself, which is composed of many frames.

STORYBOARD: A collection of sketches which narrate the plot, settings and characters of a movie.

TRACK: Different components of a movie or animation, playing simultaneously, are "tracks". Most movies have both a video track and an audio track, but with the use of transparency masks, it is possible to layer a larger number of tracks in a single animation. Different species of images which are played at different times may also be identified as distinct tracks, such as a video track which is followed a still-image track that freezes a single picture on the screen for a couple of seconds.

TWEENING: In old-fashioned celluloid animation, a small subset of the cells were sketched by the animators; most of the drawings were produced by less-skilled artists called "tweeners", who interpolated between the KEYFRAMES created by the animators. Computer animation programs, notably Flash, use similar strategies to reduce the workload on animators.

14.5 Computer Animation Formats

The major animation format on the Macintosh is Quicktime, which was developed by Apple itself. Apple freely distributes its Quicktime Player on both Macintosh and all makes of Windows platforms. Its simple video editor, Quicktime Player Pro, may be purchased for $30 as a download for either Macintosh or Windows. The format is rich enough to support various compression options, still images, audio; Quicktime Player can directly open Animated GIF, AVI, DV, FLC/FLI, MPEG-1 (only on Mac), MPEG-2 (only on Mac) video files, AIFF, Audio CD, MIDI, KAR (Karaoke) and Sound Designer audio files, 3DMF three-dimensional graphics files, and BMP, GIF, JPEG/JFIF, MacPaint, QuickDraw GX, Photoshop, PNG, SGI, Targa, and TIFF image files, among others. The format allows a large number of different video and audio tracks including sprites, three-dimensional object tracks, hinting tracks to assist Internet streaming and so on.

The AVI format was once Microsoft's answer to Quicktime, but AVI allows only video and audio tracks. It is so limited compared to Quicktime that Microsoft actually adopted its rival's Quicktime for some of Microsoft's own products such as the Encarta CD-ROM encyclopedia. Microsoft attempted to replace AVI with something called ActiveMovie, but this was never fully released, and was instead replaced by Direct Show. In practice, the FLI/FLC format has been the standard Windows animation protocol.

The DV format is the standard cross-platform protocol for digital video. As digital camcorders rapidly chase analog camcorders from the field, DV is rapidly growing in importance. It seems unlikely to entirely replace Quicktime because DV is strictly a video/audio TV format, and was not designed to accomodate Internet streaming, sprites or other kinds of technology that are important in computer graphics. It will almost certainly handle 99% of the camcorder/computer data transfers by 2005.

Apple has embraced digital video so enthusiastically that it is no longer possible to buy an Apple that is NOT equipped to import, export and edit DV. The hardware side is a fast cable/interface technology that Apple developed and calls "Firewire". Apple put this into the public domain and allowed it to be standardized by a committee of the Institute of Electrical and Electronic Engineers (IEEE). Other computer manufacturers usually refer to Firewire as the IEEE 1394 interface. Even the lowliest iMac Powerbook has one Firewire port; desktop models have two. It is becoming increasingly common for PCs to have Firewire (IEEE 1394) ports.

Using a program called iMovie which is supplied free with all new Apples, one can plug a Firewire cable to the corresponding port on a digital camcorder, and import, edit, and export digital video with the software controlling the play, record, and rewind functions of the camcorder. (Almost all digital camcorders are Firewire/Apple compatible, but there are a few exceptions, so one should check the documentation of the camcorder.)

Windows PCs are made by a huge variety of vendors, so there is not as much standardization in the Windows world. However, most PC companies sell hardware/software combinations that will do digital video editing right out of the box.

If one wants to show an animation at a conference which lacks a DV player, , it is fairly easy to make a "VHS dub" of a digital tape by connecting the video-out of the digital camcorder to the input of a VCR. (Because digital video must almost always be played on a standard, VHS TV, digital camcorders always have a VHS video-out port.)

MPEG, which comes in several flavors, is a public domain standard that is very widely used for Internet movies. Free players are available for almost all types of platforms. MPEG movies are usually somewhat grainier than Quicktime animations, but this will probably change as more advanced flavors of MPEG become more common. The long-term future of MPEG is a little confusing because there is no vendor with a strong, vested interest to continue rapid development of this format.

Flash is a widely used format for vector animation which is aimed specifically at the Web. It was developed in conjunction with the animation program, Macromedia Flash, but the format and Web player-plugins have been placed in the public domain. Flash is very good at allowing Web site designers to create simple animations that will jazz up a Web site. However, it has been used very little for scientific and engineering visualization. Flash assumes that the animation will be DRAWN by the animator from simple shapes combined with “morphing” or “tweening”, which is described more below.

Table 14.1: (Selected) Animation Formats

Acronym	Preferred Platform	Remarks
QuickTime	Mac (Windows, too)	
AVI	Windows (Mac, too)	Once dominant for Windows, now becoming obsolete
FLI/FLC	Windows	New official Windows animation format, replacing AVI
DV	All	New digital video standard
MPEG	All	Several flavors: MPEG-1, MPEG-2, etc. Popular, still evolving. Hardware MPEG codec available.
Flash	All	Vector-based animation, primarily for the Web

14.6 Video Players with Quicktime as an Example

The Quicktime Player, in common with other video players, has a control panel which imitates a VCR. The main button is for normal playblack; just to its right is a Pause buttom, marked by two vertical bars. These controls are always visible. By clicking on an icon with four dots, one can make a tray of additonal controls appear below. Included are buttons to jump to the beginning and end (right pair), play one frame at a time forward or one frame at a time backwards (middle pair; triangles plus a vertical bar) and fast forward/fast rewind (left pair; each icon is a pair of triangles). If there is an audio track, a little speaker icon is always visible next to a volume dial (extreme left of the player) which can be dragged up or down to change the volume. When the control tray is visible, there are additional treble/balance controls for the sound at the extreme bottom of the player.

There are some additional features, not available in a VCR, in Quicktime Player and other computer video software. First, there is always a time slider which can be dragged to jump to any point in the movie: videotape is SEQUENTIAL access (meaning one has to wait while the mechanical process of spinning tape proceeds) but computer animations are always RANDOM access, meaning one can jump instantly to any point in the film, independent of the speed of a mechanical tape-winder.

Some Quicktime movies have “chapter” or “cue points”. If a Quicktime animation has such, then just to the right of the time slider will appear a pair of up and down arrows. Clicking these allows one to jump to the beginnings of the segments (“chapters”) constructed by the movie’s creator.

Quicktime has a “Present as Movie” option which eliminates the control frame, and shows just the movie itself against a black background. This is very helpful when (i) showing the movie at a conference and (ii) copying (“dubbing”) the movie to videotape.

“Present as Movie” has a slideshow option in which the movie is displayed, frame-free, one image at a time. Clicking on the image, or pushing the forward and reverse arrow keys, allows one to navigate through the slide shown.

14.7 Audio

Though silent movies have obsolete in commercial theaters for over 70 years, most scientific animations have no audio. The first reason is that when a video is played at a conference, the speaker usually provides the commentary live. The second reason is that computer animations tend to last only a few seconds. If the time-dependence is so complex that it requires even a couple of minutes to display it, it is unlikely that the viewer will be able to absorb and the entire sequence. Further, a couple of minutes of video is, even a compressed form, a very large fil.

For Web distribution, an audio track is theoretically useful. However, 100 MB animations take a prohibitively long time to download, even with a cable modem or other fast connection. Web animations therefore must be rather short. This means that it is difficult to convey useful information while an animation of say, twenty seconds duration, unfolds.

In a theatrical film, the audio and video of a scene are closely integrated: the sound of a battleship blowing is accompanied by fire and smoke and ship fragments flying out of view. Narrating computational parameters while a flow field simulation is playing is a distraction, however, because this sort of important background information is divorced from the vortices and fronts that appear. Narration of features, such as “The primary vortex divides into two smaller vortices, which then rotate around one another”, is audio that *is* integrated closely with the video — but also a bit insulting. The viewer can see the big vortex split into two, etc. It is difficult to devise narration which is simultaneously (i) well-integrated with the pictures and (ii) not merely a description of what the viewer can see for herself. In presentations of scientific animations, it is common for the speaker to make a number of prefatory remarks before starting the film, and then remaining silent while it is playing.

Consequently, we shall not discuss audio further. However, all standard animation formats and editors support audio tracks, which can be added separately after the video has been created.

14.8 Functions of Videotape Editors

1. Assemble an image sequence into an animation.
2. Delete sections of boring or redundant video or computer animations.
3. Assemble multiple clips or cases into a single film
4. Mix disparate visual tracks, such as videotape clips and Quicktime or FLI/FLC or MPEG computer-generated clips, into a single movie.
5. Add full page text blocks, such as movie or chapter titles
6. Add text underneath the image to run in parallel with it for edit-chosen durations.
7. Add documentation blocks of text to make the film self-documenting [in the spirit of comment statements that make computer programs self-documenting].
8. Add audio or music tracks.
9. Add transitions between chapters or cases so as to avoid abrupt jumps from scene to scene.

Table 14.2: Quicktime Track types

Track Types	Remarks
Video	Standard Quicktime visual track, but not the only visual track
Sound	Standard audio track
Music	Musical score, analogous to MIDI very low storage compared to standard sound track
Text	Used to caption movie (if enabled) Used for chapters (jumppoints) and searchable index (usually disabled)
3D	holds geometric definitions of objects, texture and lighting operates in conjunction with "tween" track, which describes motion
tween	describes motion of 3D objects in the 3D track
hint	Must be one for each Web-streamable track: tells browser how to break up the hinted track into packets
streaming	All streamable-tracks are flattened into a single streaming track for viewing while streaming

14.9 Tracks

A movie can hold a large number of disparate tracks, at least in a rich format like Quicktime. Each track can be manipulated, turned off, turned off, and deleted independently of the others, and the tracks need not run parallel through the entire animation. A video might have three music tracks, for example: one for the music of the first part, a second for the sound of the middle frames of the animation, and a third piece of music on its own track for the conclusion.

14.10 Text: Captioning and Documenting

A text track can be used to provide information about the video in three ways:

1. Separate, detailed documentation pages.
2. Silent film captions: blocks of large-type text that are displayed for a couple of seconds between clips of animation.
3. Under-the-image captions.

In an ideal world, movie formats would support a special type of text track that is invisible when the animation is played at the normal rate, but accessible through a "documentation" button or something. Alas, no format provides this. We shall describe workarounds for this limitation in a later section.

Silent films put the dialogue onto frames of text which were displayed for several seconds at a time, long enough for the audience to read them, between clips of action. All computer animation formats support audio, so there is no absolute necessity for silent film text captions. However, when the action clips are rather short, and also when the movie creator has a strong accent, it may be difficult to present all the necessary information by voice while the pictures are being displayed. Silent film captions are a useful option. These text blocks allow one to present necessary background information and documentation without distracting the viewer from the movie frames themselves.

Quicktime and some other formats allow one to play a text track and a video track simultaneously. The text will display in a small rectangular box underneath the video frames, thus providing a running caption.

In scientific visualization, the best way to caption is using the program that generated the video. Matlab, for example, can create running titles, labels, and text blocks that can be updated (using the **num2str** and **int2str** functions) as the animation evolves. Use these features to the max because then both image and text are being controlled by a single program, and one can see at once if there are any problems, such as text obscuring key features of the pictures.

However, sometimes key information can only be added later after the animation has been analyzed. Then, adding a text track with this late-discovered information can improve an animation.

14.10.1 Example: Quicktime Procedures

Non-text track method: How to add text to a movie as silent film caption.

1. Select current frame in the movie; text will be pasted BEFORE current frame

   When the current frame is the result of a paste to the end of a movie, it may be necessary to back up a couple of frames and then go forward to paste text in the middle, or else the text may be tacked on at the very end of the movie.

2. Create the text block in a word-processing program (use large font size, such as 24 point) and then paste. The text will appear as white letters on a black background.

To add small amounts of text as under-the-image-running caption, do the following:

1. Create a text file with the blocks of text in the desired font and size. Copy a block.
2. Move diamond in time slider to point where this block should first appear.
3. If this isn't the first block, then Edit > Select None
4. Move the right triangle — before movement, the two triangles form a single triangle just below the current location diamond. When right triangle is at the correct stopping point, let go. The grey area between the diamond and right triangle is where the text block will appear in the movie.
5. Hold down Shift and Option-Alt keys simultaneously
6. Edit > Add Scaled
7. Repeat

The text will appear in a thin black box, as white letters, just below video track, providing an after-the-fact caption.

There are more sophisticated text track creation schemes which are useful when one wants to add a lot of text, but these procedures will give a flavor of how video editors add text.

14.11 Resolution and Font Sizes

Analog videotape lacks the resolution of a full computer screen. (The maximum is about 640 x 480 pixels whereas a typical computer screen is about 1024 x 768 and an 8.5” x 11” printed page on a 300 dpi printer has a resolution of 2250 x 3000, making allowance for nonprinting margins.) Just as in labeling graphs which will be reduced for journal publication, it follows that it is highly advisable to use

Table 14.3: Frame Rates

Rate (Frames/second)	Format
30	some video formats
29.97	NTSC video (analog standard in U. S. and Japan)
25	PAL & SECAM video (usual analog standards outside North America)
24	Theatrical movies
12	Hanna-Barbara cartoons
2-10	Streaming Web video

1. Large font sizes

2. Sans serif fonts

One must exercise similar care with other graphical elements. The arrows of quiver plots are easily blurred by video. It is therefore better to use a few large arrows rather than a lot of shorter arrows. (Note that to avoid overlapping arrows, the maximum length of an arrow must be inversely proportional to the spacing of the grid on which the arrows are displayed.) It is usually necessary to "downsample the quiver grid". This means that if the flow field is computed on a grid of 100 x 100 poins (say), the arrows will be legible on video only if displayed on a 10 x 10 or 20 x 20 grid. Fortunately, it is a trivial exercise to "downsample" to a coarser grid as long as the grid spacing of the coarse grid is an integer multiple of that of the fine grid.

14.12 Frame Rate

Broadcast video and theatrical films use a rather high frame rate. Hanna-Barbara, founders of the cartoon animation firm that still bears their names, discovered that a frame rate of 12/second did not produce unduly jerky images, and adopted this for their cartoons. Streaming video is even slower because typical Internet connections rarely can support anything close to 30 frames/second even with optimum codecs.

In making scientific visualizations, a frame rate of 10-12/second is probably adequate to avoid jerkiness, and at the same time keep the file size manageable.

14.13 Tweening

A ten-minute animated cartoon requires about 12000 drawings at the usual cinema rate of 24 frames/second. It is quite impossible for a small team of highly skilled animators to create so many drawings. Therefore, the usual production method was to have the folks with the job title of "animator" draw only a small subset of the total, the "key frames". All the rest was drawn by less skilled draftsman called "tweeners".

The "tweeners" were doing a kind of manual linear interpolation between the key frames. Since computers are very good at linear interpolation of numbers, one might suppose that "tweening" would be important in scientific visualization.

Actually, tweening is rare in scientific applications for two reasons. The first is that if the animation is the result of a numerical simulation, the computer can generate all the intermediate frames simply by saving more images to the hard disk as the simulation is being calculated. Direct calculation is far more accurate (and simpler, since it requires no additional programming) than interpolation.

The second reason is that tweening is actually very difficult except for VECTOR graphics. For example, suppose the keyframes show the same shape in two different positions. If the shape is a trapezoid, then in vector graphics, this shape is defined by the locations of the four vertices (together with the subsidiary information that each vertex is connected by straight lines). When the trapezoid is moved, the subsidiary information is unchanged, so it is trivial to interpolate. If the vertices are interpolated between the initial and final positions of each vertex, then the "tween" frames will correctly show the exact shape (trapezoids) at smoothly-varying intermediate positions. Success!

Suppose that the same trapezoid is approximated by a block of white pixels against a black background, and suppose further that the trapezoid moves by more than its own width between keyframes. Interpolating the colors of the pixels in the keyframes means averaging black-with-white for each pixel covered by the trapezoid in either of the keyframes. It follows that the tween frames will not show a trapezoid of white, but instead both the initial and final shapes will appear in the tweens as shades of gray. As we move from the initial keyframe towards the second keyframe, the trapezoid at the initial position will fade to black whereas the pixels of the final position will brighten from black to white. Interpolation will create a fadein/fadeout transition instead of movement.

If the keyframes are closer in time so that the initial and final shapes overlap, then such pixel interpolation may create a limited sense of movement. But it is not surprising that programs that do "tweening" well, such as Flash, are VECTOR-BASED formats.

14.14 Rotoscoping

"Rotoscoping" is a cinematic term for drawing on individual frames of film. This was first done back in the silent film era.

The video editor Adobe Premiere has an export option, "filmstrip", which is helpful in rotoscoping. The filmstrip file can be imported into Adobe Photoshop as a single file. The filmstrip appears in Photoshop as a single picture in which the individual frames appear as if one were looking at a celluloid filmstrip with the images one above the other, separated by thin grey borders which are automatically supplied.

If the filmstrip will be eventually played as a normal animation, then the overdrawings in neighboring frames must be very similar, like the frames of a Bugs Bunny cartoon, or the eye will not be able to detect the overdrawing (except as a blur) when the frames are played at 24 frames-per-second (or whatever). It follows that the easiest way to make the drawing for frame fifty-six is by copying the image from frame fifty-five, and then making slight adjustments in position or graphical elements. Copy-and-modify is very efficient when successive overdrawings are only slightly different from one another.

Because the filmstrip images are in a single file, it is easy to rotoscope by copy-and-modify. When the overdrawing for the first frame is copied to the second, it is all done in one file and one window — no need to switch between files and/or windows.

When the rotoscoping is completed, the filmstrip can be exported back to Premiere, which can then export the animation either direct to video or as a standard computer animation format.

Rotoscoping is potentially quite useful in scientific and engineering graphics. If the animation is a sequence of satellite photographs of clouds, for example, one can rotoscope the the warm and cold fronts, the land masses underneath the clouds, add letters "H" and "L" to mark the location of the pressure high and low, etc. Photoshop rotoscoping is rather labor intensive because the additions are made manually, but the labor may be worth it if the animation is important.

Rotoscoping can also be done in Matlab. For example, Matlab could important a sequence of matrices storing pressure data and calculat the location of the high and low for each time. Matlab could then important a sequence of consecutively numbered images in TIFF format — just a **for** loop — and write the letters “H” and “L” at the appropriate point on each TIFF image, and then rexported each annotated frame as a TIFF file, consecutively numbered, with a new name. A video editor can then import the whole sequence of TIFF files as a single animation.

14.15 Annotations and Documentation

An animation by itself is of little scientific interest. The flow fields may be very pretty, but what was the Reynolds number? The initial condition? The boundary conditions?

It is very important to DOCUMENT the animation by providing these answers.

In a better world, animation formats would provide a lot of flexibility for self-documentation. It would be very nice, for example, if one can read the creator-written documentation for a Quicktime movie by merely clicking a button in the Quicktime player. Unfortunately, the format-developers have not shown that much foresight.

Quicktime has a very limited capacity to support what Apple causes “annotations”. Unfortunately, these are limited to three phrases which are further restricted to topics as Name of Creator, Copyright Notice, and so on. However, the range of annotations may expand in future releases of Quicktime and of other editors.

In the absence of internal documentation, it is necessary to provide external publication. On Web sites, one can embed the animation in a text page that provides the necessary information. The user can then download both movie and text page. It is annoying, however, to have to carry two files in different formats for each movie.

It is also possible to document within a movie by adding pages which are pure text. Even Quicktime Pro, which is the cheapest video editor on the planet, allows this option. If one wants the viewer to actually read the text while the movie is playing, one can specify that the text page will display for say, five seconds, or typically 120 frames.

Alternatively, however,one can specify a very short frame rate of 1/30 second. The viewer will not see the documentation when the movie is played at the normal rate, but will be able to peruse the text at leisure by using the step-one-frame-at-a-time controls that most video players (and all flavors of Quicktime) possess.

14.16 Exporting Stills

Video editing programs almost always have the ability to extract individual frames of an animation and export them as still images. Premiere, for example, can export TIFF, Targa, PICT, Quicktime, GIF, and Animated GIF formats.

One popular nonscientific use is to stick a still at the end, and use it as the background while the movie credits roll.

Stills can be scientifically useful by illustrating key stages or states in the time-dependent evolution. These can be published in the print documentation that accompanies or explains an animation, or supplement the animation on a Web page.

If one exports a sequence of consecutively numbered image frames, these can be imported by a different video editor, thus providing a method to transfer animations from one video editor to another.

The export-a-still function is often irrelevant in scientific visualization, but the underlying philosophy is not. The reason is that if one is performing, say, a time-dependent simulation of fluid flow in Matlab, a good way to make the movie is to Matlab output a numbered sequence of still images in the TIFF format and then ask Quicktime Pro or another editor to assemble these images into a movie. Since one already has still images of every frame of the animation, it is silly to export frames from the movie.

However, it may be very useful to move and rename selected stills from the movie to preserve key moments in the time evolution. We cannot emphasize too strongly that movies and stills are complementary. One of the best things about computer video players is that they provide easy, blur-free freeze-frame so that one can linger over key frames. However, to supplement an animation with print publication or notes, it is essential to have the crucial frames in separate, paper-printable form.

14.17 Publishing

Paper, alas, is unable to display movies, so it is impossible to publish animations in a conventional journal. There are three alternatives:

1. Publication-by-conference presentation

2. E-journals

3. Personal Web site

Presenting an animation at a conference is becoming easier and easier; an analog VHS player is almost universal at conference venues. Projectors that can take input from a laptop computer are becoming more and more common. The disadvantage of conference presentation (of any kind) is ephemerality: the animation cannot be archived or preserved for the future even if the conference publishes proceedings on paper. The most lasting result of a conference are the new friends that you make.

Electronic, on-line journals or "E-journals" distribute articles exclusively over the Web, and thus can include animations as easily as stills and text. Most professional societies have created E-journals, but these experiments are far from flourishing.

One problem is that it is much easier to publish in a print journal since most scienists already have learned how to write a conventional paper. Working animations into a paper is alien and unfamiliar. Furthermore, E-journals usually impose some restrictions on graphic formats, file size, and so that the influx of e-manuscripts does not overwhelm their Web servers and editorial staff, who are learning as they go along.

A second problem is archiving. The reason journal articles have bibliographies is that one can find and consult the articles upon which the present paper has been built. Print publications are achived simply by keeping the volumes on a library shelf. E-journal archiving requires that

1. The journal continues to exist

2. The older e-publications are preserved on the Web site

3. Obsolete file formats are replaced by translating animations to new file formats

A third problem is subscriptions. E-journals are rather inexpensive in theory because the text and figure preparation is done entirely by the author, and there are no costs for typesetting, printing or mailing. In theory, a single PC-server and a part-time clerical assistant should be able to keep the journal going indefinitely. Unfortunately, creating and maintaining the Web site is rather costly. An editor must not only be scientifically-literate, but also rigidly enforce file format standards and such that the animations will display on all platforms. In reality, subscribers are likely to have varying degrees of difficulty in reading animations and e-publications, in part because of obsolescent browser or other software on the Web site. An e-journal must therefore hire expensive computer staff to fix such incompatibilities and hold the hands of novice users.

The American Meteorological Society and the American Geophysical Union teamed up to create a journal called *Earth Interactions*. After several years of not-much-happening, the journal was completely revamped. It remains to see whether *Earth Interactions* will succeed, but the fact that it was not abandoned is a sign that the professional societies and other journal publishers feel strongly that they *must* experiment with e-publication. Unfortunately, we are still very young in this experiment. Consequently, e-journal publishers have charged rather hefty subscription fees. Already groaning under the weight of subscriptions to thousands of print journals, most university libraries are reluctant to substract to e-journals or indeed to any new journal of an kind. Thus, e-journals often reach a very small audience compared to conventional print publications.

Thus, e-publication is not attractive at the moment because of the large technical difficulties and the small readership. However, this will surel change.

A personal Web site is good because one has complete control, and catchy animations can make the Web site into a powerful advertisement for the merits of one's scientific achievements. The disadvantage is that the user must know HTML and must manually build every feature of the Web sight. In addition, the creator's close friends will come and visit his Web sight, but who else will come? A print journal is automatically send to thousands of subscribers, and its printed table of contents is perused two thousand times a day. Thus, Web site publication may also be unattractive.

14.18 Video Editing, Transitions and All That

Scientific videotapes, CD-ROMS, etc., often contain multiple simulations. If the video is shown all the way through, the viewer will experience some rather disconcerting jumps from one simulation to another. Professional and home video editors usually try to minimize these jumps (so that the viewer can focus on the clips themselves, and not what happens in between).

Video editing software offers a rather bewildering variety of transitions. Most of these are designed to be "arty" and visually-striking, thereby distracting the viewer from the content, and therefore are irrelevant to scientific visualization. However, simple transitions may be useful.

The Cross-Dissolve, for example, fades out one scene while slowing bringing the second on top of it. A variation is to Fade to Black at the end of one segment, and then slowly increase the brightness of the title of the next segment. Since even these simple transitions are rare in scientific animations, we will not discuss them further. A simple transition can be helpful, though, if a scientific visualization has distracting scene jumps without a transition.

The most common scientific transition, however, is a frame of text that is inserted between two animations to introduce and explain the second animation.