Chapter 53

Raw Speed and More

Chapter 53

The Naked Truth About Speed in 3-D Animation

Years ago, this friend of mine—let's call him Bert—went to Hawaii with three other fellows to celebrate their graduation from high school. This was an unchaperoned trip, and they behaved pretty much as responsibly as you'd expect four teenagers to behave, which is to say, not; there's a story about a rental car that, to this day, Bert can't bring himself to tell. They had a good time, though, save for one thing: no girls.

By and by, they met a group of girls by the pool, but the boys couldn't get past the hi-howya-doin stage, so they retired to their hotel room to plot a better approach. This being the early '70s, and them being slightly tipsy teenagers with raging hormones and the effective combined IQ of four eggplants, it took them no time at all to come up with a brilliant plan: streaking. The girls had mentioned their room number, so the boys piled into the elevator, pushed the button for the girls' floor, shucked their clothes as fast as they could, and sprinted to the girls' door. They knocked on the door and ran on down the hall. As the girls opened their door, Bert and his crew raced past, toward the elevator, laughing hysterically.

Bert was by far the fastest of them all. He whisked between the elevator doors just as they started to close; by the time his friends got there, it was too late, and the doors slid shut in their faces. As the elevator began to move, Bert could hear the frantic pounding of six fists thudding on the closed doors. As Bert stood among the clothes littering the elevator floor, the thought of his friends stuck in the hall, naked as jaybirds, was just too much, and he doubled over with helpless laughter, tears streaming down his face. The universe had blessed him with one of those exceedingly rare moments of perfect timing and execution.

The universe wasn't done with Bert quite yet, though. He was still contorted with laughter—and still quite thoroughly undressed—when the elevator doors opened again. On the lobby.

And with that, we come to this chapter's topics: raw speed and hidden surfaces.

Raw Speed, Part 1: Assembly Language

I would like to state, here and for the record, that I am not an assembly language fanatic. Frankly, I prefer programming in C; assembly language is hard work, and I can get a whole lot more done with fewer hassles in C. However, I *am* a performance fanatic, performance being defined as having programs be as nimble as possible in those areas where the user wants fast response. And, in the course of pursuing performance, there are times when a little assembly language goes a long way.

We're now four chapters into development of the X-Sharp 3-D animation package. In realtime animation, performance is *sine qua non* (Latin for "Make it fast or find another line of work"), so some judiciously applied assembly language is in order. In the previous chapter, we got up to a serviceable performance level by switching to fixed-point math, then implementing the fixed-point multiplication and division functions in assembly in order to take advantage of the 386's 32-bit capabilities. There's another area of the program that fairly cries out for assembly language: matrix math. The function to multiply a matrix by a vector (**XformVec()**) and the function to concatenate matrices (**ConcatXforms()**) both loop heavily around calls to **FixedMul();** a lot of calling and looping can be eliminated by converting these functions to pure assembly language.

Listing 53.1 is the module FIXED.ASM from this chapter's iteration of X-Sharp, with **XformVec()** and **ConcatXforms()** implemented in assembly language. The code is heavily optimized, to the extent of completely unrolling the loops via macros so that looping is eliminated altogether. FIXED.ASM is highly effective; the time taken for matrix math is now down to the point where it's a fairly minor component of execution time, representing less than ten percent of the total. It's time to turn our optimization sights elsewhere.

LISTING 53.1 FIXED.ASM

```
; 386-specific fixed point routines.
; Tested with TASM
ROUNDING_ON     equ  1          ;1 for rounding, 0 for no rounding
                                ;no rounding is faster, rounding is
                                ; more accurate
ALIGNMENT       equ  2
      .model    small
      .386
      .code
```

```
;-----------------------------------------------------------------------
; Multiplies two fixed-point values together.
; C near-callable as:
;     Fixedpoint FixedMul(Fixedpoint M1, Fixedpoint M2);
;     Fixedpoint FixedDiv(Fixedpoint Dividend, Fixedpoint Divisor);
FMparms struc
           dw      2 dup(?)      ;return address & pushed BP
M1         dd      ?
M2         dd      ?
FMparms    ends
           align   ALIGNMENT
           public  _FixedMul
_FixedMul       proc    near
        push    bp
        mov     bp,sp
        mov     eax,[bp+M1]
        imul    dword ptr [bp+M2]       ;multiply
if ROUNDING_ON
        add     eax,8000h               ;round by adding 2^(-17)
        adc     edx,0                   ;whole part of result is in DX
endif ;ROUNDING_ON
        shr     eax,16                  ;put the fractional part in AX
        pop     bp
        ret
_FixedMul       endp
;-----------------------------------------------------------------------
; Divides one fixed-point value by another.
; C near-callable as:
;     Fixedpoint FixedDiv(Fixedpoint Dividend, Fixedpoint Divisor);
FDparms struc
           dw   2 dup(?)                ;return address & pushed BP
Dividend   dd   ?
Divisor    dd   ?
FDparms    ends
      align ALIGNMENT
      public      _FixedDiv
_FixedDiv       proc    near
        push    bp
        mov     bp,sp

if ROUNDING_ON
        sub     cx,cx                   ;assume positive result
        mov     eax,[bp+Dividend]
        and     eax,eax                 ;positive dividend?
        jns     FDP1                    ;yes
        inc     cx                      ;mark it's a negative dividend
        neg     eax                     ;make the dividend positive
FDP1:   sub     edx,edx                 ;make it a 64-bit dividend, then shift
                                        ; left 16 bits so that result will be
                                        ; in EAX
        rol     eax,16                  ;put fractional part of dividend in
                                        ; high word of EAX
        mov     dx,ax                   ;put whole part of dividend in DX
        sub     ax,ax                   ;clear low word of EAX
        mov     ebx,dword ptr [bp+Divisor]
        and     ebx,ebx                 ;positive divisor?
        jns     FDP2                    ;yes
        dec     cx                      ;mark it's a negative divisor
        neg     ebx                     ;make divisor positive
```

```
FDP2:   div     ebx                         ;divide
        shr     ebx,1                       ;divisor/2, minus 1 if the divisor is
        adc     ebx,0                       ; even
        dec     ebx
        cmp     ebx,edx                     ;set Carry if remainder is at least
        adc     eax,0                       ; half as large as the divisor, then
                                            ; use that to round up if necessary
        and     cx,cx                       ;should the result be made negative?
        jz      FDP3                        ;no
        neg     eax                         ;yes, negate it
FDP3:
else ;  !ROUNDING_ON
        mov     edx,[bp+Dividend]
        sub      eax,eax
        shrd     eax,edx,16                       ;position so that result ends up
        sar      edx,16                           ; in EAX
        idiv     dword ptr [bp+Divisor]
endif                                             ;ROUNDING_ON
        shld     edx,eax,16                       ;whole part of result in DX;
                                                  ; fractional part is already in AX
        pop      bp
        ret
_FixedDiv       endp
;-----------------------------------------------------------------------
; Returns the sine and cosine of an angle.
; C near-callable as:
;     void CosSin(TAngle Angle, Fixedpoint *Cos, Fixedpoint *);

      align ALIGNMENT
CosTable label dword
      include costable.inc

SCparms struc
           dw    2 dup(?)                   ;return address & pushed BP
Angle      dw    ?                          ;angle to calculate sine & cosine for
Cos        dw    ?                          ;pointer to cos destination
Sin        dw    ?                          ;pointer to sin destination
SCparms    ends

      align ALIGNMENT
      public _CosSin
_CosSin    proc  near
      push  bp                              ;preserve stack frame
      mov   bp,sp                           ;set up local stack frame

      mov   bx,[bp].Angle
      and   bx,bx                           ;make sure angle's between 0 and 2*pi
      jns   CheckInRange
MakePos:                                    ;less than 0, so make it positive
      add   bx,360*10
      js    MakePos
      jmp   short CheckInRange

      align ALIGNMENT
MakeInRange:                                ;make sure angle is no more than 2*pi
      sub   bx,360*10
CheckInRange:
      cmp   bx,360*10
      jg    MakeInRange
```

```
        cmp     bx,180*10                   ;figure out which quadrant
        ja      BottomHalf                  ;quadrant 2 or 3
        cmp     bx,90*10                    ;quadrant 0 or 1
        ja      Quadrant1
                                            ;quadrant 0
        shl     bx,2
        mov     eax,CosTable[bx]            ;look up sine
        neg     bx                          ;sin(Angle) = cos(90-Angle)
        mov     edx,CosTable[bx+90*10*4]    ;look up cosine
        jmp     short CSDone

        align   ALIGNMENT
Quadrant1:
        neg     bx
        add     bx,180*10                   ;convert to angle between 0 and 90
        shl     bx,2
        mov     eax,CosTable[bx]            ;look up cosine
        neg     eax                         ;negative in this quadrant
        neg     bx                          ;sin(Angle) = cos(90-Angle)
        mov     edx,CosTable[bx+90*10*4]    ;look up cosine
        jmp     short CSDone

        align   ALIGNMENT
BottomHalf:                                 ;quadrant 2 or 3
        neg     bx
        add     bx,360*10                   ;convert to angle between 0 and 180
        cmp     bx,90*10                    ;quadrant 2 or 3
        ja      Quadrant2
                                            ;quadrant 3
        shl     bx,2
        mov     eax,CosTable[bx]            ;look up cosine
        neg     bx                          ;sin(Angle) = cos(90-Angle)
        mov     edx,CosTable[90*10*4+bx]    ;look up sine
        neg     edx                         ;negative in this quadrant
        jmp     short CSDone

        align   ALIGNMENT
Quadrant2:
        neg     bx
        add     bx,180*10                   ;convert to angle between 0 and 90
        shl     bx,2
        mov     eax,CosTable[bx]            ;look up cosine
        neg     eax                         ;negative in this quadrant
        neg     bx                          ;sin(Angle) = cos(90-Angle)
        mov     edx,CosTable[90*10*4+bx]    ;look up sine
        neg     edx                         ;negative in this quadrant
CSDone:
        mov     bx,[bp].Cos
        mov     [bx],eax
        mov     bx,[bp].Sin
        mov     [bx],edx

        pop     bp                          ;restore stack frame
        ret
_CosSin         endp
;------------------------------------------------------------------------
; Matrix multiplies Xform by SourceVec, and stores the result in
; DestVec. Multiplies a 4x4 matrix times a 4x1 matrix; the result
; is a 4x1 matrix. Cheats by assuming the W coord is 1 and the
; bottom row of the matrix is 0 0 0 1, and doesn't bother to set
; the W coordinate of the destination.
; C near-callable as:
;     void XformVec(Xform WorkingXform, Fixedpoint *SourceVec,
;           Fixedpoint *DestVec);
;
; This assembly code is equivalent to this C code:
;   int i;
;
;   for (i=0; i<3; i++)
;      DestVec[i] = FixedMul(WorkingXform[i][0], SourceVec[0]) +
;          FixedMul(WorkingXform[i][1], SourceVec[1]) +
;          FixedMul(WorkingXform[i][2], SourceVec[2]) +
;          WorkingXform[i][3];   /* no need to multiply by W = 1 */

XVparms struc
                 dw    2 dup(?)         ;return address & pushed BP
WorkingXform     dw    ?                ;pointer to transform matrix
SourceVec        dw    ?                ;pointer to source vector
DestVec          dw    ?                ;pointer to destination vector
XVparms          ends

      align ALIGNMENT
      public _XformVec
_XformVec   proc  near
      push  bp                          ;preserve stack frame
      mov   bp,sp                       ;set up local stack frame
      push  si                          ;preserve register variables
      push  di

      mov   si,[bp].WorkingXform        ;SI points to xform matrix
      mov   bx,[bp].SourceVec           ;BX points to source vector
      mov   di,[bp].DestVec             ;DI points to dest vector

soff=0
doff=0
      REPT 3                            ;do once each for dest X, Y, and Z
      mov   eax,[si+soff]               ;column 0 entry on this row
      imul  dword ptr [bx]              ;xform entry times source X entry
if ROUNDING_ON
      add   eax,8000h                   ;round by adding 2^(-17)
      adc   edx,0                       ;whole part of result is in DX
endif ;ROUNDING_ON
      shrd  eax,edx,16                  ;shift the result back to 16.16 form
      mov   ecx,eax                     ;set running total

      mov   eax,[si+soff+4]             ;column 1 entry on this row
      imul  dword ptr [bx+4]            ;xform entry times source Y entry
if ROUNDING_ON
      add   eax,8000h                   ;round by adding 2^(-17)
      adc   edx,0                       ;whole part of result is in DX
endif ;ROUNDING_ON
      shrd  eax,edx,16                  ;shift the result back to 16.16 form
      add   ecx,eax                     ;running total for this row

      mov   eax,[si+soff+8]             ;column 2 entry on this row
      imul  dword ptr [bx+8]            ;xform entry times source Z entry
if ROUNDING_ON
      add   eax,8000h                   ;round by adding 2^(-17)
      adc   edx,0                       ;whole part of result is in DX
```

```
endif ;ROUNDING_ON
      shrd  eax,edx,16                    ;shift the result back to 16.16 form
      add   ecx,eax                       ;running total for this row

      add   ecx,[si+soff+12]              ;add in translation
      mov   [di+doff],ecx                 ;save the result in the dest vector
soff=soff+16
doff=doff+4
      ENDM

      pop   di                            ;restore register variables
      pop   si
      pop   bp                            ;restore stack frame
      ret
_XformVec   endp
;-----------------------------------------------------------------------
; Matrix multiplies SourceXform1 by SourceXform2 and stores the
; result in DestXform. Multiplies a 4x4 matrix times a 4x4 matrix;
; the result is a 4x4 matrix. Cheats by assuming the bottom row of
; each matrix is 0 0 0 1, and doesn't bother to set the bottom row
; of the destination.
; C near-callable as:
;       void ConcatXforms(Xform SourceXform1, Xform SourceXform2,
;               Xform DestXform)
;
; This assembly code is equivalent to this C code:
;   int i, j;
;
;   for (i=0; i<3; i++) {
;      for (j=0; j<3; j++)
;         DestXform[i][j] =
;               FixedMul(SourceXform1[i][0], SourceXform2[0][j]) +
;               FixedMul(SourceXform1[i][1], SourceXform2[1][j]) +
;               FixedMul(SourceXform1[i][2], SourceXform2[2][j]);
;      DestXform[i][3] =
;            FixedMul(SourceXform1[i][0], SourceXform2[0][3]) +
;            FixedMul(SourceXform1[i][1], SourceXform2[1][3]) +
;            FixedMul(SourceXform1[i][2], SourceXform2[2][3]) +
;            SourceXform1[i][3];
;   }

CXparms struc
                 dw    2 dup(?)          ;return address & pushed BP
SourceXform1     dw    ?                 ;pointer to first source xform matrix
SourceXform2     dw    ?                 ;pointer to second source xform matrix
DestXform        dw    ?                 ;pointer to destination xform matrix
CXparms          ends

      align ALIGNMENT
      public _ConcatXforms
_ConcatXforms    proc  near
      push  bp                           ;preserve stack frame
      mov   bp,sp                        ;set up local stack frame
      push  si                           ;preserve register variables
      push  di

      mov   bx,[bp].SourceXform2         ;BX points to xform2 matrix
      mov   si,[bp].SourceXform1         ;SI points to xform1 matrix
      mov   di,[bp].DestXform            ;DI points to dest xform matrix
```

```
roff=0                                  ;row offset
     REPT 3                             ;once for each row
coff=0                                  ;column offset
     REPT 3                             ;once for each of the first 3 columns,
                                        ; assuming 0 as the bottom entry (no
                                        ; translation)
     mov   eax,[si+roff]                ;column 0 entry on this row
     imul  dword ptr [bx+coff]          ;times row 0 entry in column
if ROUNDING_ON
     add   eax,8000h                    ;round by adding 2^(-17)
     adc   edx,0                        ;whole part of result is in DX
endif ;ROUNDING_ON
     shrd  eax,edx,16                   ;shift the result back to 16.16 form
     mov   ecx,eax                      ;set running total

     mov   eax,[si+roff+4]              ;column 1 entry on this row
     imul  dword ptr [bx+coff+16]       ;times row 1 entry in col
if ROUNDING_ON
     add   eax,8000h                    ;round by adding 2^(-17)
     adc   edx,0                        ;whole part of result is in DX
endif ;ROUNDING_ON
     shrd  eax,edx,16                   ;shift the result back to 16.16 form
     add   ecx,eax                      ;running total

     mov   eax,[si+roff+8]              ;column 2 entry on this row
     imul  dword ptr [bx+coff+32]       ;times row 2 entry in col
if ROUNDING_ON
     add   eax,8000h                    ;round by adding 2^(-17)
     adc   edx,0                        ;whole part of result is in DX
endif ;ROUNDING_ON
     shrd  eax,edx,16                   ;shift the result back to 16.16 form
     add   ecx,eax                      ;running total

     mov   [di+coff+roff],ecx           ;save the result in dest matrix
coff=coff+4                             ;point to next col in xform2 & dest
     ENDM

                                        ;now do the fourth column, assuming
                                        ; 1 as the bottom entry, causing
                                        ; translation to be performed
     mov   eax,[si+roff]                ;column 0 entry on this row
     imul  dword ptr [bx+coff]          ;times row 0 entry in column
if ROUNDING_ON
     add   eax,8000h                    ;round by adding 2^(-17)
     adc   edx,0                        ;whole part of result is in DX
endif ;ROUNDING_ON
     shrd  eax,edx,16                   ;shift the result back to 16.16 form
     mov   ecx,eax                      ;set running total

     mov   eax,[si+roff+4]              ;column 1 entry on this row
     imul  dword ptr [bx+coff+16]       ;times row 1 entry in col
if ROUNDING_ON
     add   eax,8000h                    ;round by adding 2^(-17)
     adc   edx,0                        ;whole part of result is in DX
endif ;ROUNDING_ON
     shrd  eax,edx,16                   ;shift the result back to 16.16 form
     add   ecx,eax                      ;running total

     mov   eax,[si+roff+8]              ;column 2 entry on this row
     imul  dword ptr [bx+coff+32]       ;times row 2 entry in col
```

```
if ROUNDING_ON
     add   eax,8000h                    ;round by adding 2^(-17)
     adc   edx,0                        ;whole part of result is in DX
endif ;ROUNDING_ON
     shrd  eax,edx,16                   ;shift the result back to 16.16 form
     add   ecx,eax                      ;running total

     add   ecx,[si+roff+12]             ;add in translation

     mov   [di+coff+roff],ecx           ;save the result in dest matrix
coff=coff+4                             ;point to next col in xform2 & dest

roff=roff+16                            ;point to next col in xform2 & dest
     ENDM

     pop   di                           ;restore register variables
     pop   si
     pop   bp                           ;restore stack frame
     ret
_ConcatXforms    endp
     end
```

Raw Speed, Part II: Look it Up

It's a funny thing about Turbo Profiler: Time spent in the Borland C++ 80×87 emulator doesn't show up directly anywhere that I can see in the timing results. The only way to detect it is by way of the line that reports what percent of total time is represented by all the areas that were profiled; if you're profiling all areas, whatever's not explicitly accounted for seems to be the floating-point emulator time. This quirk fooled me for a while, leading me to think sine and cosine weren't major drags on performance, because the **sin()** and **cos()** functions spend most of their time in the emulator, and that time doesn't show up in Turbo Profiler's statistics on those functions. Once I figured out what was going on, it turned out that not only were **sin()** and **cos()** major drags, they were taking up over half the total execution time by themselves.

The solution is a lookup table. Listing 53.1 contains a function called **CosSin()** that calculates both the sine and cosine of an angle, via a lookup table. The function accepts angles in tenths of degrees; I decided to use tenths of degrees rather than radians because that way it's always possible to look up the sine and cosine of the exact angle requested, rather than approximating, as would be required with radians. Tenths of degrees should be fine enough control for most purposes; if not, it's easy to alter **CosSin()** for finer gradations yet. GENCOS.C, the program used to generate the lookup table (COSTABLE.INC), included in Listing 53.1, can be found in the XSHARP22 subdirectory on the listings diskette. GENCOS.C can generate a cosine table with any integral number of steps per degree.

FIXED.ASM (Listing 53.1) speeds X-Sharp up quite a bit, and it changes the performance balance a great deal. When we started out with 3-D animation, calculation time was the dragon we faced; more than 90 percent of the total time was spent doing matrix and projection math. Additional optimizations in the area of math could still be made (using 32-bit multiplies in the backface-removal code, for example), but fixed-point math, the sine and cosine lookup, and selective assembly optimizations have done a pretty good job already. The bulk of the time taken by X-Sharp is now spent drawing polygons, drawing rectangles (to erase objects), and waiting for the page to flip. In other words, we've slain the dragon of 3-D math, or at least wounded it grievously; now we're back to the dragon of polygon filling. We'll address faster polygon filling soon, but for the moment, we have more than enough horsepower to have some fun with. First, though, we need one more feature: hidden surfaces.

Hidden Surfaces

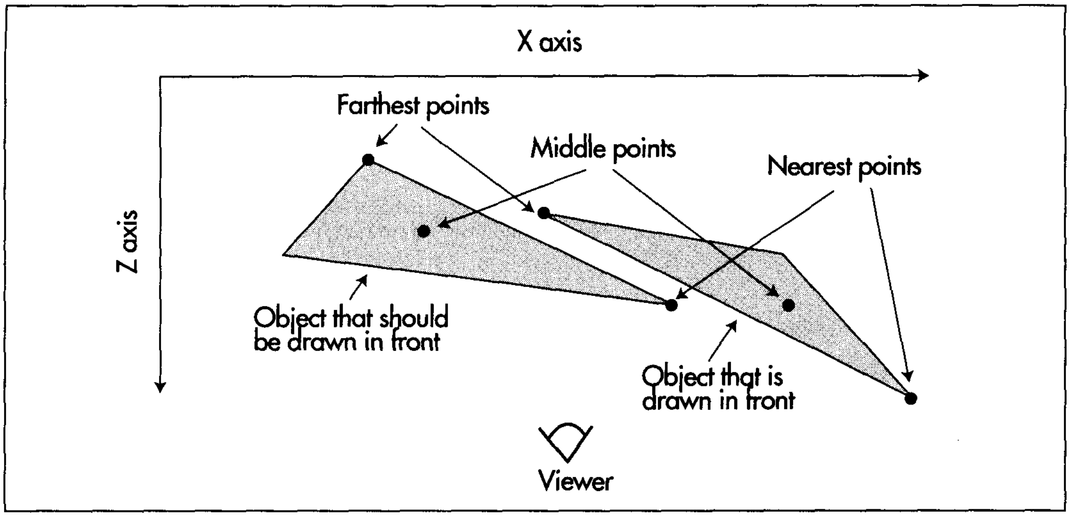
So far, we've made a number of simplifying assumptions in order to get the animation to look good; for example, all objects must currently be convex polyhedrons. What's more, right now, objects can never pass behind or in front of each other. What that means is that it's time to have a look at hidden surfaces.

There are a passel of ways to do hidden surfaces. Way off at one end (the slow end) of the spectrum is Z-buffering, whereby each pixel of each polygon is checked as it's drawn to see whether it's the frontmost version of the pixel at those coordinates. At the other end is the technique of simply drawing the objects in back-to-front order, so that nearer objects are drawn on top of farther objects. The latter approach, depth sorting, is the one we'll take today. (Actually, true depth sorting involves detecting and resolving possible ambiguities when objects overlap in Z; in this chapter, we'll simply sort the objects on Z and leave it at that.)

This limited version of depth sorting is fast but less than perfect. For one thing, it doesn't address the issue of nonconvex objects, so we'll have to stick with convex polyhedrons. For another, there's the question of what part of each object to use as the sorting key; the nearest point, the center, and the farthest point are all possibilities—and, whichever point is used, depth sorting doesn't handle some overlap cases properly. Figure 53.1 illustrates one case in which back-to-front sorting doesn't work, regardless of what point is used as the sorting key.

For photo-realistic rendering, these are serious problems. For fast PC-based animation, however, they're manageable. Choose objects that aren't too elongated; arrange their paths of travel so they don't intersect in problematic ways; and, if they do overlap incorrectly, trust that the glitch will be lost in the speed of the animation and the complexity of the screen.

Listing 53.2 shows X-Sharp file OLIST.C, which includes the key routines for depth sorting. Objects are now stored in a linked list. The initial, empty list, created by **InitializeObjectList()**, consists of a sentinel entry at either end, one at the farthest possible z coordinate, and one at the nearest. New entries are inserted by **AddObject()** in z-sorted order. Each time the objects are moved, before they're drawn at their new locations, **SortObjects()** is called to Z-sort the object list, so that drawing will proceed from back to front. The Z-sorting is done on the basis of the objects' center points; a


X axis
Z axis
Farthest points
Middle points
Nearest points
Object that should be drawn in front
Object that is drawn in front
Viewer

Why back-to-front sorting doesn't always work properly.
Figure 53.1

center-point field has been added to the object structure to support this, and the center point for each object is now transformed along with the vertices. That's really all there is to depth sorting—and now we can have objects that overlap in X and Y.

LISTING 53.2 OLIST.C

```
/* Object list-related functions. */
#include <stdio.h>
#include "polygon.h"

/* Set up the empty object list, with sentinels at both ends to
  terminate searches */
void InitializeObjectList()
{
   ObjectListStart.NextObject = &ObjectListEnd;
   ObjectListStart.PreviousObject = NULL;
   ObjectListStart.CenterInView.Z = INT_TO_FIXED(-32768);
   ObjectListEnd.NextObject = NULL;
   ObjectListEnd.PreviousObject = &ObjectListStart;
   ObjectListEnd.CenterInView.Z = 0x7FFFFFFFL;
   NumObjects = 0;
}

/* Adds an object to the object list, sorted by center Z coord. */
void AddObject(Object *ObjectPtr)
{
   Object *ObjectListPtr = ObjectListStart.NextObject;

   /* Find the insertion point. Guaranteed to terminate because of
      the end sentinel */
   while (ObjectPtr->CenterInView.Z > ObjectListPtr->CenterInView.Z) {
      ObjectListPtr = ObjectListPtr->NextObject;
   }
   /* Link in the new object */
   ObjectListPtr->PreviousObject->NextObject = ObjectPtr;
   ObjectPtr->NextObject = ObjectListPtr;
   ObjectPtr->PreviousObject = ObjectListPtr->PreviousObject;
   ObjectListPtr->PreviousObject = ObjectPtr;
   NumObjects++;
}

/* Resorts the objects in order of ascending center Z coordinate in view space,
   by moving each object in turn to the correct position in the object list. */
void SortObjects()
{
   int i;
   Object *ObjectPtr, *ObjectCmpPtr, *NextObjectPtr;

   /* Start checking with the second object */
   ObjectCmpPtr = ObjectListStart.NextObject;
   ObjectPtr = ObjectCmpPtr->NextObject;
   for (i=1; i<NumObjects; i++) {
      /* See if we need to move backward through the list */
      if (ObjectPtr->CenterInView.Z < ObjectCmpPtr->CenterInView.Z) {
         /* Remember where to resume sorting with the next object */
         NextObjectPtr = ObjectPtr->NextObject;
         /* Yes, move backward until we find the proper insertion
            point. Termination guaranteed because of start sentinel */
         do {
            ObjectCmpPtr = ObjectCmpPtr->PreviousObject;
         } while (ObjectPtr->CenterInView.Z <
               ObjectCmpPtr->CenterInView.Z);

         /* Now move the object to its new location */
         /* Unlink the object at the old location */
         ObjectPtr->PreviousObject->NextObject =
               ObjectPtr->NextObject;
         ObjectPtr->NextObject->PreviousObject =
               ObjectPtr->PreviousObject;

         /* Link in the object at the new location */
         ObjectCmpPtr->NextObject->PreviousObject = ObjectPtr;
         ObjectPtr->PreviousObject = ObjectCmpPtr;
         ObjectPtr->NextObject = ObjectCmpPtr->NextObject;
         ObjectCmpPtr->NextObject = ObjectPtr;

         /* Advance to the next object to sort */
         ObjectCmpPtr = NextObjectPtr->PreviousObject;
         ObjectPtr = NextObjectPtr;
      } else {
         /* Advance to the next object to sort */
         ObjectCmpPtr = ObjectPtr;
         ObjectPtr = ObjectPtr->NextObject;
      }
   }
}
```

Rounding

FIXED.ASM contains the equate **ROUNDING_ON**. When this equate is 1, the results of multiplications and divisions are rounded to the nearest fixed-point values; when it's 0, the results are truncated. The difference between the results produced by the two approaches is, at most, 2^{-16}; you wouldn't think that would make much difference, now, would you? But it does. When the animation is run with rounding disabled, the cubes start to distort visibly after a few minutes, and after a few minutes more they look like they've been run over. In contrast, I've never seen any significant distortion with rounding on, even after a half-hour or so. I think the difference with rounding is not that it's so much more accurate, but rather that the errors are evenly distributed; with truncation, the errors are biased, and biased errors become very visible when they're applied to right-angle objects. Even with rounding, though, the errors will eventually creep in, and reorthogonalization will become necessary at some point.

The performance cost of rounding is small, and the benefits are highly visible. Still, truncation errors become significant only when they accumulate over time, as, for example, when rotation matrices are repeatedly concatenated over the course of many transformations. Some time could be saved by rounding only in such cases. For example, division is performed only in the course of projection, and the results do not accumulate over time, so it would be reasonable to disable rounding for division.

Having a Ball

So far in our exploration of 3-D animation, we've had nothing to look at but triangles and cubes. It's time for something a little more visually appealing, so the demonstration program now features a 72-sided ball. What's particularly interesting about this ball is that it's created by the GENBALL.C program in the BALL subdirectory of X-Sharp, and both the size of the ball and the number of bands of faces are programmable. GENBALL.C spits out to a file all the arrays of vertices and faces needed to create the ball, ready for inclusion in INITBALL.C. True, if you change the number of bands, you must change the **Colors** array in INITBALL.C to match, but that's a tiny detail; by and large, the process of generating a ball-shaped object is now automated. In fact, we're not limited to ball-shaped objects; substitute a different vertex and face generation program for GENBALL.C, and you can make whatever convex polyhedron you want; again, all you have to do is change the **Colors** array correspondingly. You can easily create multiple versions of the base object, too; INITCUBE.C is an example of this, creating 11 different cubes.

What we have here is the first glimmer of an object-editing system. GENBALL.C is the prototype for object definition, and INITBALL.C is the prototype for general-purpose object instantiation. Certainly, it would be nice to someday have an interactive 3-D object editing tool and resource management setup. We have our hands full with the drawing end of things at the moment, though, and for now it's enough to be able to create objects in a semiautomated way.