

0.1 About the Source Code

Commander Keen episodes 1-5 source code is unavailable, as the current owner Zenimax¹ has, at the time of writing, shown no interest in selling the intellectual property. Luckily the ownership of Commander Keen in Keen Dreams was in the hands of Softdisk. In June 2013, developer Super Fighter Team licensed the game from Flat Rock Software, the owners of Softdisk at the time, and released a version for Android devices.

The following September, an Indiegogo crowdfunding campaign was started to attempt to buy the rights from Flat Rock for US\$1500 in order to release the source code to the game and start publishing it on multiple platforms. The campaign did not reach the goal, but it's creator Javier Chavez made up the difference, and the source code was released under GNU GPL-2.0-or-later soon after.

0.2 Getting the Source Code

The source code is available on `github`. It is essential to use the source code from the shareware version 1.13, or you may encounter issues due to incompatible map and graphs headers². To get the correct source code, use the following commands in the console

```
$ git clone https://github.com/keendreams/keen.git
$ cd keen
$ git checkout a7591c4af15c479d8d1c0be5ce1d49940554157c
```

0.3 First Contact

After downloading the repository from `github`, a folder named 'keen' is created, containing all the source files. The `cloc.pl` tool can be used to analyze the folder and generate statistics about the source code. This tool is useful for getting an idea of what to expect.

¹June 24, 2009, it was announced that id Software had been acquired by ZeniMax Media (owner of Bethesda Softworks).

²See issue #7 on <https://github.com/keendreams/keen>.

```
$ cloc keen
```

```
52 text files.
```

```
52 unique files.
```

```
7 files ignored.
```

Language	files	blank	comment	code
C	20	4008	5361	14893
Assembly	5	992	1114	2688
C/C++ Header	19	508	665	1603
Markdown	1	18	0	40
DOS Batch	1	0	0	13
SUM:	46	5526	7140	19237

Approximately 85% of the code is in C, with assembly³ used for bottleneck optimizations and low-level I/O operations such as video and audio handling.

Source lines of code (SLOC) are not particularly meaningful for comparing a single code-base but are helpful for determining the proportion of code in various components. Commander Keen has 19,237 SLOC, which is small compared to most modern software. For instance, `curl` (a command-line tool for downloading URLs) has 154,134 SLOC, Google Chrome has 1,700,000 SLOC, and the Linux kernel consists of 15,000,000 SLOC.

³All the assembly in Keen is done with TASM (a.k.a Turbo Assembler by Borland). It uses Intel notation where the destination is before the source: `instr dest source`.

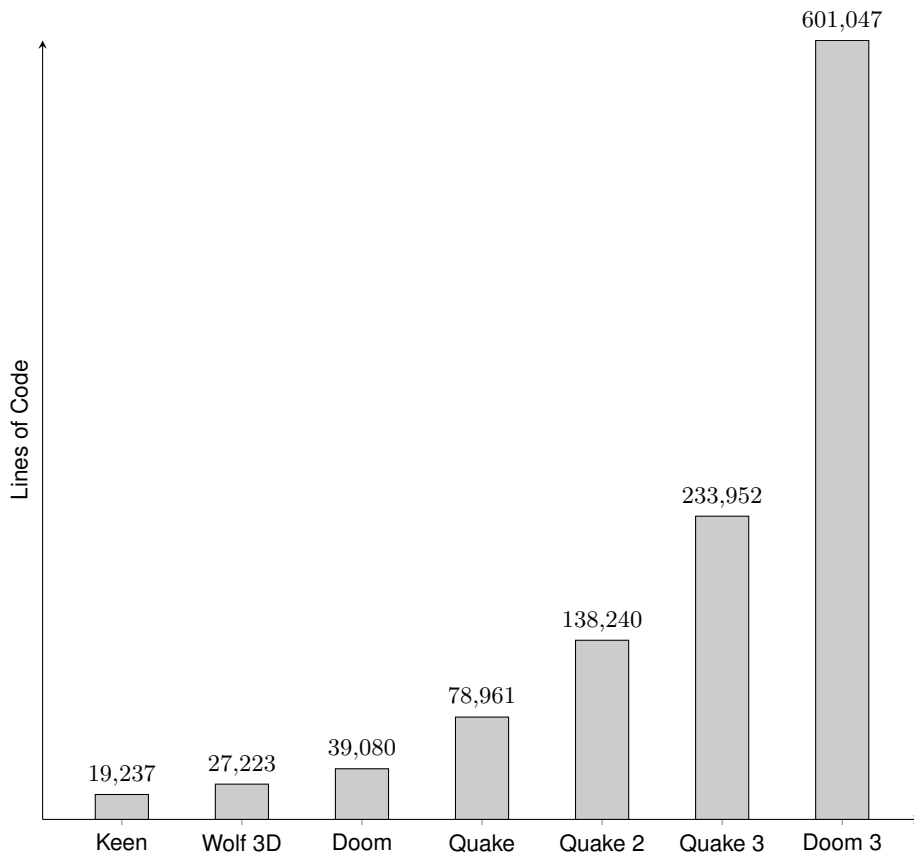


Figure 1: Lines of code from id Software game engines.

The archive contains more than just source code; it also features:

- A `static` folder with static header files for loading assets and maps (as explained in section "??" on page ??).
- An `lscr` folder for loading and decompressing Softdisk text files.
- A `README` file explaining how to build the executable.

0.4 Compile source code

Now let's start to compile the source code. To compile the code like it's 1990 you need the following software:

- Commander Keen source code.
- DosBox.
- The Compiler Borland C++ 3.1.
- Commander Keen: Keen Dreams 1.13 shareware (for the assets).

After setting up DOSBox and installing Borland C++ 3.1⁴, download the source code from [github](#).

Once DOSBox is running and you've navigated to the `keen` folder, create a folder to store your compiled object files.

```
mkdir OBJ
```

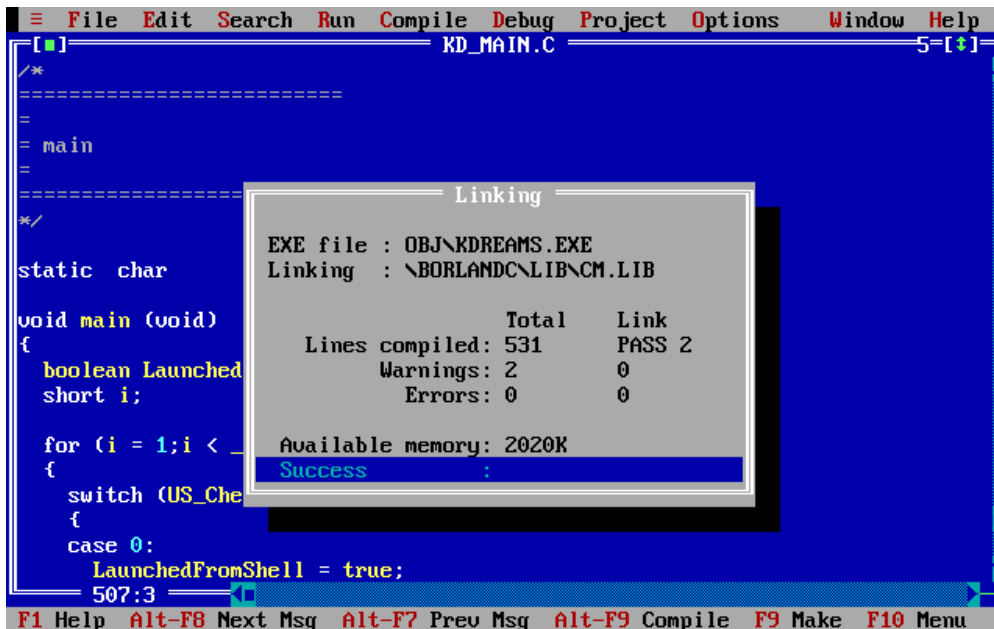
Then, generate the static OBJ header files.

```
chdir STATIC  
make.bat
```

After that, return to the `keen` folder and open Borland C++. Open the `kdreams.prj` project file. Before compiling, adjust the directory settings by selecting Options -> Directories and change the values as shown on the next page.

Now it's time to compile. Go to Compile -> Build All, and voilà! The final step is to copy `kdreams.exe` into the Keen shareware folder. You can now play your compiled version of *Commander Keen*.

⁴you can find a complete tutorial in "Let's compile like it's 1992" on fabiansanglard.net



0.5 Big Picture

The game engine is divided in three blocks:

- Control panel which lets users configure and start the game.
- 2D game renderer where the users spend most of their time.
- Sound system which runs concurrently with either the Menu or 2D renderer.

The three systems communicate via shared memory. The renderer writes sound requests to the RAM (also making sure the assets are ready). These requests are read by the sound "loop". The sound system also writes to the RAM for the renderers since it is in charge of the heartbeat of the whole engine. The renderers update the screen according to the wall-time tracked by `TimeCount` variable.

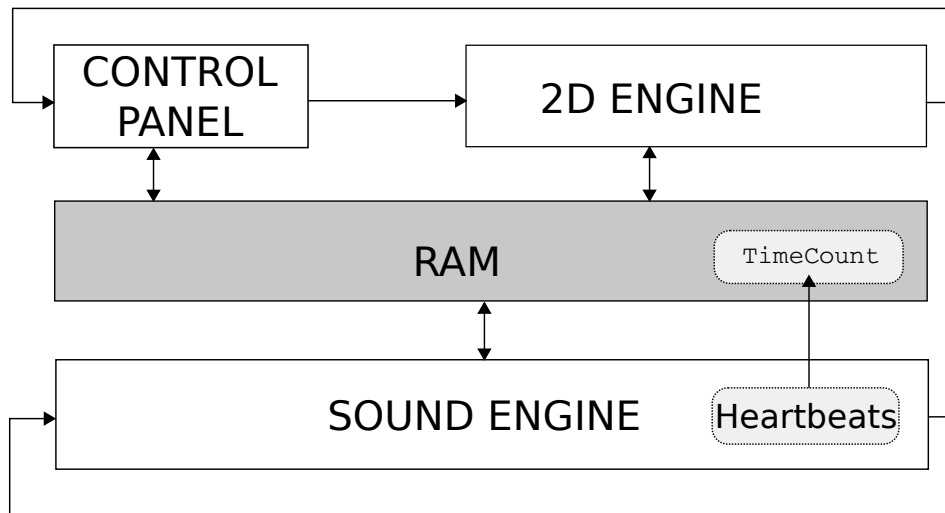


Figure 2: Game engine three main systems.

0.5.1 Unrolled Loop

With the big picture in mind, we can dive into the code and unroll the main loop, starting with `void main()`. The control panel and 2D renderer follow regular loops, but due to limitations discussed later, the sound system is interrupt-driven and therefore operates outside the main loop. In real mode, C types do not behave as expected on a 16-bit architecture.

- `int` and `word` are 16 bits.
- `long` and `dword` are 32 bits.

The first action taken by the program is to set the text color to light grey and the background to black.

```
void main (void)
{
    textcolor(7);
    textbackground(0);

    InitGame();

    DemoLoop();           // DemoLoop calls Quit when
                          // everything is done
    Quit("Demo loop exited???");
}
```

In `InitGame()`, the program checks whether there is enough memory and brings up all the managers.

```
void InitGame (void)
{
    int i;

    MM_Startup ();        // Memory Manager

    US_TextScreen();      // Show intro screen

    VW_Startup ();        // Video Manager
    RF_Startup ();        // Refresh Manager
    IN_Startup ();        // Input Manager
    SD_Startup ();        // Sound Manager
    US_Startup ();        // User Manager

    CA_Startup ();        // Cache Manager
    US_Setup ();

    CA_ClearMarks ();     // Clears out all the marks

    CA_LoadAllSounds ();  // Load all sounds
}
```

Then comes the core loop, where the menu and 2D renderer are called forever.

```
void DemoLoop() {
    US_SetLoadSaveHooks();
    while (1) {
        VW_InitDoubleBuffer ();
        IN_ClearKeysDown ();
        VW_FixRefreshBuffer ();
        US_ControlPanel (); // Menu
        GameLoop ();
        SetupGameLevel ();
        PlayLoop () ; // 2D renderer (action)
    }
    Quit("Demo loop exited???");
}
```

PlayLoop contains the 2D renderer. It is pretty standard with getting inputs, update screen, and render screen approach.

```
void PlayLoop (void)
{
    FixScoreBox (); // draw bomb/flower
    do
    {
        CalcSingleGravity (); // Calculate gravity
        IN_ReadControl(0,&c); // get player input

        // go through state changes and propose movements
        obj = player;
        do
        {
            if (obj->active)
                StateMachine(obj); // Enemies think
            obj = (objtype *)obj->next;
        } while (obj);

        [...] // Handle collisions between objects
        ScrollScreen(); // Scroll if Keen is nearing an edge.
        [...] // React to whatever happened.
        RF_Refresh(); // Update buffer screen and switch
                    // buffer and view screen
        CheckKeys(); // Check special keys
    } while (!loadedgame && !playstate);
}
```


The interrupt system is started via the Sound Manager in `SDL_SetIntsPerSec(rate)`. While there is a famous game development library called Simple DirectMedia Layer (SDL), the prefix `SDL_` has nothing to do with it. It stands for Sound Low level (Simple DirectMedia Layer did not even exist in 1990).

The reason for interrupts is extensively explained in Chapter ?? "??". In short, with an OS supporting neither processes nor threads, it was the only way to have something execute concurrently with the rest of the engine.

0.6 Architecture

The source code is structured in two layers. `KD_*` files are high-level layers relying on low-level `ID_*` sub-systems called Managers interacting with the hardware.

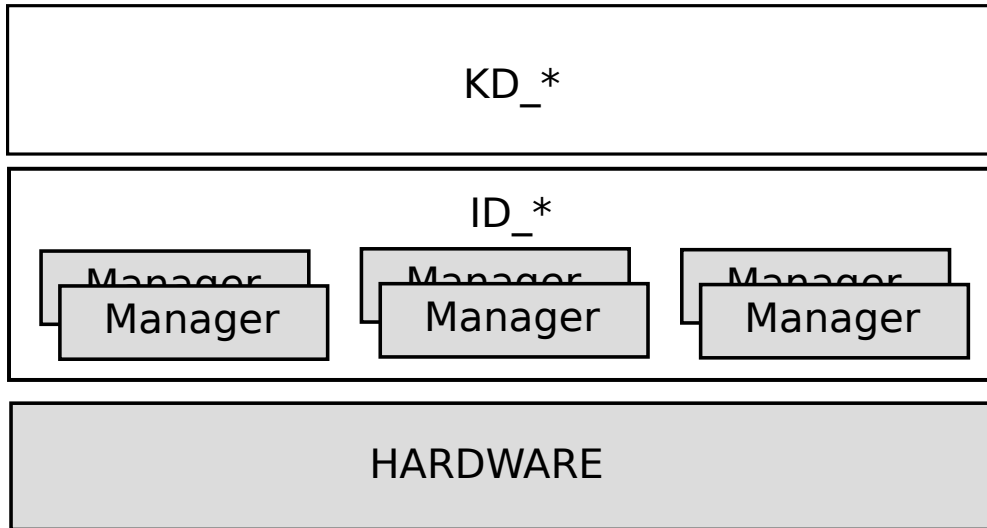


Figure 3: Commander Keen source code layers.

There are six managers in total:

- Memory
- Video
- Cache
- Sound
- User
- Input

The `KD_*` stuff was written specifically for Commander Keen while the `ID_*` managers are generic and later re-used (with improvements) for newer id Software games (*Hovortank One*, *Catacomb 3-D* and *Wolf3D*). Next to the hard drives (HDD) you can see the assets packed as described in section "??" on page ??.

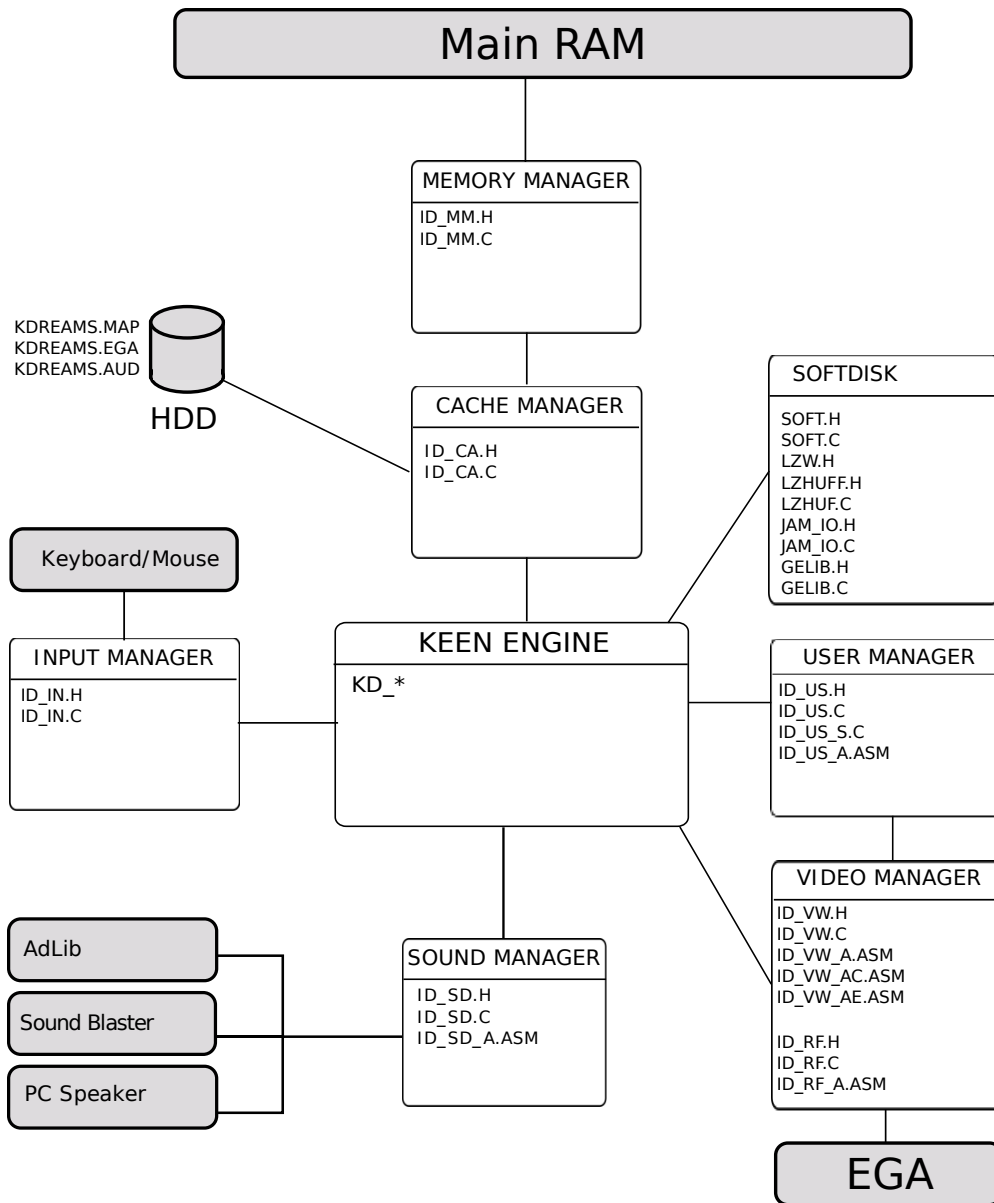


Figure 4: Architecture with engine and sub-systems (in white) connected to I/O (in gray).

0.6.1 Memory Manager (MM)

The engine has its own memory manager, to have more control over memory fragmentation and optimization. The memory manager is made of a linked list of "blocks" keeping track of the RAM. A block points to a starting point in RAM, has a size and can be marked with attributes:

- LOCKBIT : This block of RAM cannot be moved during compaction.
- PURGEBITS : Two levels available, 0= unpurgeable, 3=purge first.

```
typedef struct mmblockstruct
{
    unsigned    start,length;
    unsigned    attributes;
    memptr      *useptr;
    struct mmblockstruct far *next;
} mmblocktype;
```

The memory manager allocates all RAM, starting from 00000h, and assigns segments to the linked list. Since the engine is compiled using the medium memory model, there are two heaps: the near heap between the global variables and stack, and the far heap starting right behind the stack . The total available free memory space for the near heap can be obtained by

```
length=coreleft();
start = (void far *)(nearheap = malloc(length));
```

The memory manager is segment-aligned, meaning it allocates memory blocks in chunks of 16 bytes. Therefore, the start and length of the memory block must be segment aligned.

```
length -= 16-(FP_OFF(start)&15); // round to 16 bytes
seglength = length / 16;        // now in segments
segstart = FP_SEG(start)+(FP_OFF(start)+15)/16;
```

The first block allocated is the unusable memory from segment 0000h to the start of the near heap.

```
GETNEUBLOCK;
mmhead = mmnew; // this will always be the first node
mmnew->start = 0;
mmnew->length = segstart;
mmnew->attributes = LOCKBIT;
```

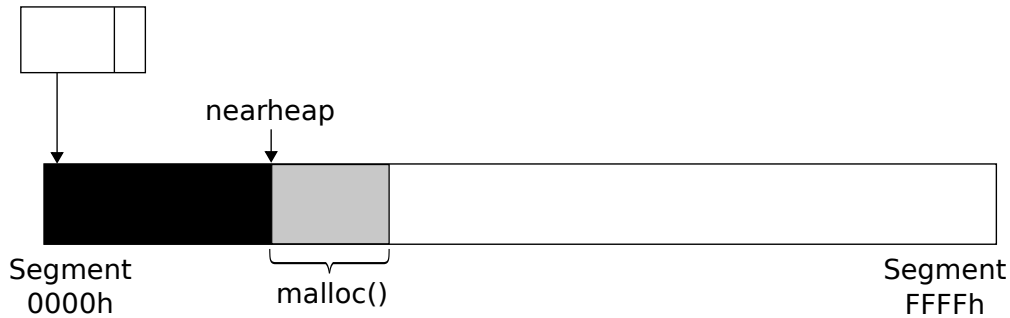


Figure 5: First locked block of unusable memory.

The stack is the next unusable memory block. Since the stack will grow or shrink during game execution, an additional part of the near heap's free memory must be reserved for it.

```
#define SAVENEARHEAP 0x400 //space to leave in data segment
length -= SAVENEARHEAP;    //Reduce length of near heap
```

The next step is allocate the far heap, which can be obtained by

```
length=farcoreleft();
start = farheap = farmalloc(length);
```

The block of unusable memory is between the start of the stack memory (including the reserved block) and the start of the far heap.

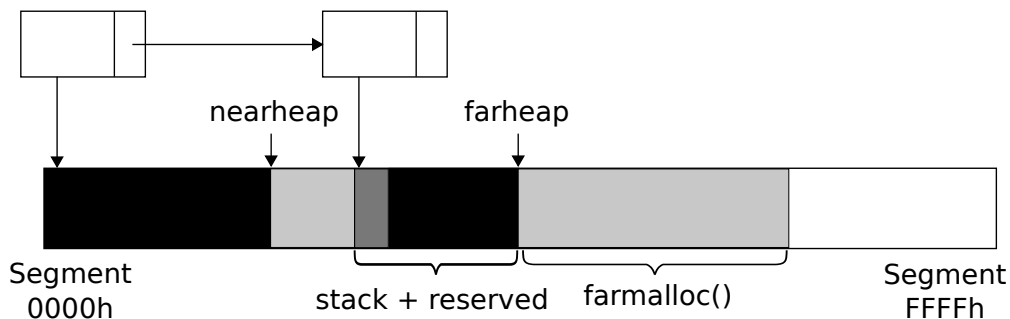


Figure 6: Second locked block: stack.

Finally, the last unusable block of memory lies between the end of the far heap and the end of the 1MiB memory, the area that is typically for VRAM, ROM, etc. Now, the entire

memory space from segment 0000h to FFFFh is allocated, chained together, and fully controlled by the memory manager.

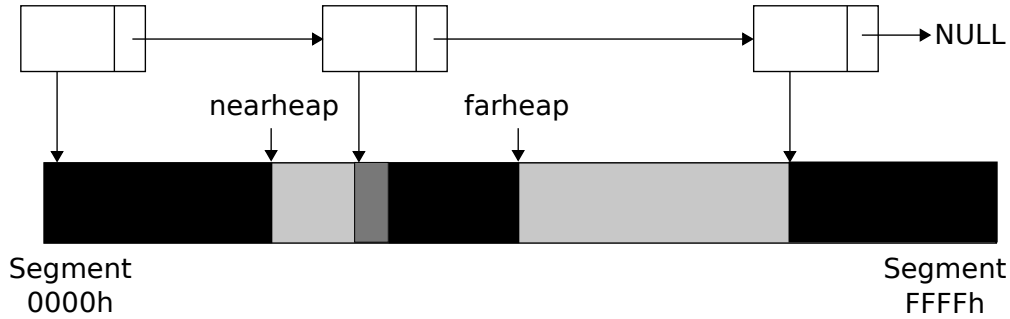


Figure 7: Final initial memory manager state.

The engine interacts with the Memory Manager by requesting RAM (`MM_GetPtr`) and freeing RAM (`MM_FreePtr`). To allocate memory, the manager searches for "holes" between blocks⁵.

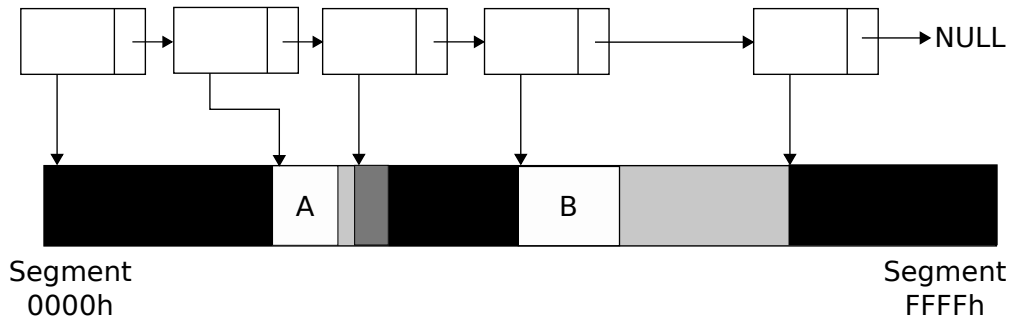


Figure 8: Allocation of memory.

By calling `MM_ShowMemory`, you can inspect the current memory usage during gameplay. Each pixel represents one memory segment of 16 bytes. Red indicates blocked memory, black indicates available memory, blue is unpurgeable memory, and purple is purgeable memory. Small white pixels indicate the start of new memory blocks in the linked list. Notice how small the near heap (the first black line) is compared to the far heap!

⁵See the "Game Engine Black book Wolfenstein 3D" for a detailed description how the memory manager is allocating memory

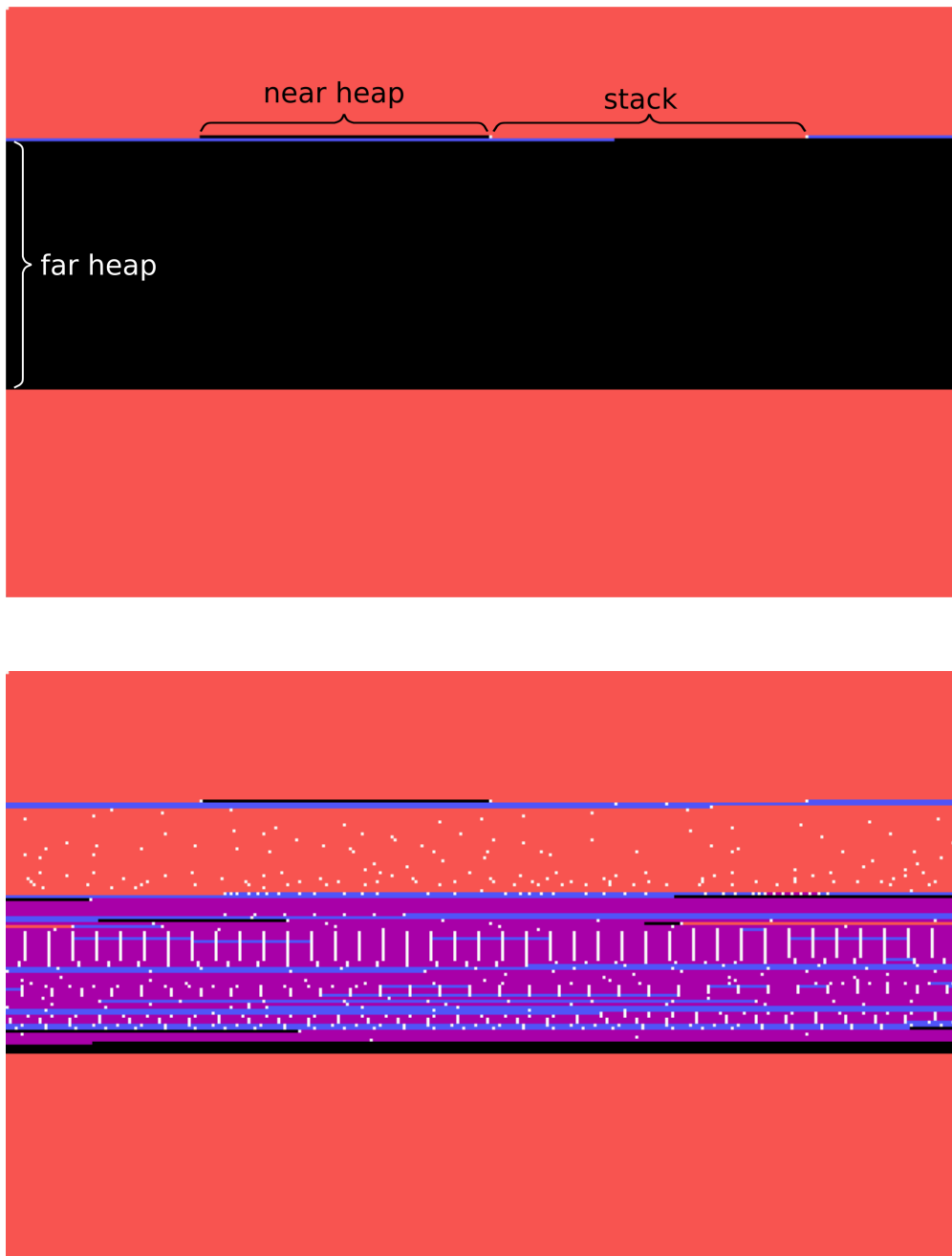


Figure 9: Memory dump after (i) initializing memory manager and (ii) running the game.

0.6.2 Video Manager (VW & RF)

The video manager features two parts:

- The `VW_*` layer is made of both C and ASM, where the C functions abstract away EGA register manipulation via assembly routines.
- The `RF_*` layer is used to refresh the screen, and is also made of both C and ASM code.

The video manager is described extensively in section ?? on page ??.

0.6.3 Cache Manager (CA)

The cache manager is a small but critical component. It loads and decompresses maps, graphics and audio resources stored on the filesystem and makes them available in RAM. Assets are stored into three files:

- A header file containing the offset to allow translation from asset ID to byte offset in the data file.
- A compression dictionary to decompress each asset.
- The data file containing the assets

Details of each asset file are explained in section "??" on page ??. The header and dictionary files are provided in the `static` folder with the `*.KDR` extension. These file types are integrated into the engine code and are required during compilation (converted into an `*.OBJ` file using `makeobj.c`).

“

When I was trying to fit all the data for Keen2 and Keen3 on a 360K floppy and all the files wouldn't fit, I had to convert a bunch of files to `.OBJ` files (using a utility I developed), change the code to forgo the loading process for those files, then I had to link them into the `KEEN EXE` file, then finally I had to `LZEXE` the `EXE` file so it was much smaller

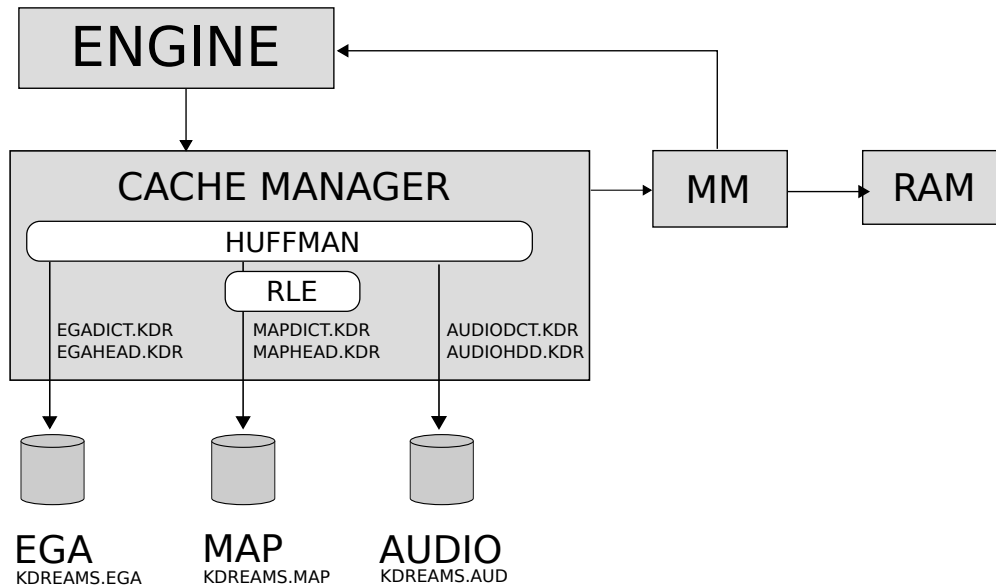
– that was the only way that Keen2 and 3 would fit on a 360K floppy.

John Romero⁶

”

⁶Great article on history of Commander Keen on <https://legacy.3drealms.com/keenhistory>.

The data file containing the assets is not part of the source code and must be obtained by downloading the shareware version. All resources are compressed using Huffman compression, and maps have additional RLE compression. The cache manager is described extensively in the "Asset Caching and Compression" section.



0.6.4 User Manager (US)

The user manager is responsible for the layout of text and control panels, such as loading/saving games, configuring controls, and setting sound devices. Once we start the game, we move the display to EGA graphic mode 0x0D. Here we cannot print characters on the screen using the `printf()` command.

A key function of the user manager is to render text at a specific pixel location. When the engine needs to draw a string, it is passed to `US_Print` which does all measurement (`VW_MeasurePropString`) and then passes this information to `VWB_DrawPropString`, which takes care of drawing the string on screen.

In the graphics asset file, each font character is stored with:

- The width of the character
- The location in memory where each character is stored as a bitmap

Each character is 10 pixels tall, but the width varies, as illustrated in Figure 10.

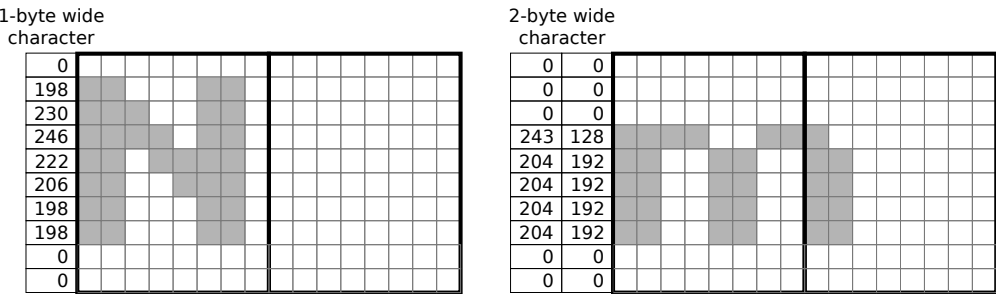


Figure 10: Character bitmaps of 'N' (7 bits wide) and 'm' (11 bits wide)

On the EGA videocard each 8 pixels take up 1 byte of VRAM (as explained in section "??" on page ??). When you need to print characters that aren't perfectly aligned with this 8-pixel grid, how do you manage the alignment? Let's say you want to display the letter 'N' on the screen. If the 'N' starts in the middle of a byte (say at pixel 3 instead of pixel 0), you need a clever way to shift the bits over to ensure it appears correctly on the screen.

Instead of manually shifting every pixel in your character bitmaps, the game engine uses pre-calculated bitshift tables. These tables are essentially lookup guides that help quickly adjust how characters are drawn based on their starting position. Here's how the process works:

1. Start with a base table (called `shiftdata0`) that holds all the possible values for a byte, from 0 to 255, and store this in an integer (16 bits).
2. Next, you generate seven more tables by shifting each value in `shiftdata0` one bit to the right for each table. So for `shiftdata1` the value 198 becomes 99, and for `shiftdata2` it becomes 32817, and so on. This process continues until you have eight tables, each representing a different bitshift.

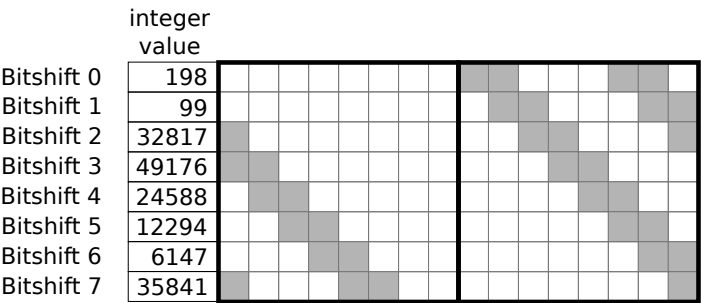


Figure 11: Right bitshift [0-7] for integer 198.

The pre-calculated bitshift tables are stored in `id_vw_a.asm`, below the `bitshift3` table.

```

LABEL shiftdata3 WORD
dw 0, 8192,16384,24576,32768,40960,49152,57344, 1, 8193,16385,24577,32769,40961
dw 49153,57345, 2, 8194,16386,24578,32770,40962,49154,57346, 3, 8195,16387,24579
dw 32771,40963,49155,57347, 4, 8196,16388,24580,32772,40964,49156,57348, 5, 8197
dw 16389,24581,32773,40965,49157,57349, 6, 8198,16390,24582,32774,40966,49158,57350
dw 7, 8199,16391,24583,32775,40967,49159,57351, 8, 8200,16392,24584,32776,40968
dw 49160,57352, 9, 8201,16393,24585,32777,40969,49161,57353, 10, 8202,16394,24586
dw 32778,40970,49162,57354, 11, 8203,16395,24587,32779,40971,49163,57355, 12, 8204
dw 16396,24588,32780,40972,49164,57356, 13, 8205,16397,24589,32781,40973,49165,57357
dw 14, 8206,16398,24590,32782,40974,49166,57358, 15, 8207,16399,24591,32783,40975
dw 49167,57359, 16, 8208,16400,24592,32784,40976,49168,57360, 17, 8209,16401,24593
dw 32785,40977,49169,57361, 18, 8210,16402,24594,32786,40978,49170,57362, 19, 8211
dw 16403,24595,32787,40979,49171,57363, 20, 8212,16404,24596,32788,40980,49172,57364
dw 21, 8213,16405,24597,32789,40981,49173,57365, 22, 8214,16406,24598,32790,40982
dw 49174,57366, 23, 8215,16407,24599,32791,40983,49175,57367, 24, 8216,16408,24600
dw 32792,40984,49176,57368, 25, 8217,16409,24601,32793,40985,49177,57369, 26, 8218
dw 16410,24602,32794,40986,49178,57370, 27, 8219,16411,24603,32795,40987,49179,57371
dw 28, 8220,16412,24604,32796,40988,49180,57372, 29, 8221,16413,24605,32797,40989
dw 49181,57373, 30, 8222,16414,24606,32798,40990,49182,57374, 31, 8223,16415,24607
dw 32799,40991,49183,57375

```

Printing the letter "N" with an offset of 3 pixels involves a simple lookup in `shiftdata3`, resulting in a 3-bit shifted "N" on the screen. By sacrificing a bit of memory, a lot of CPU time is saved.

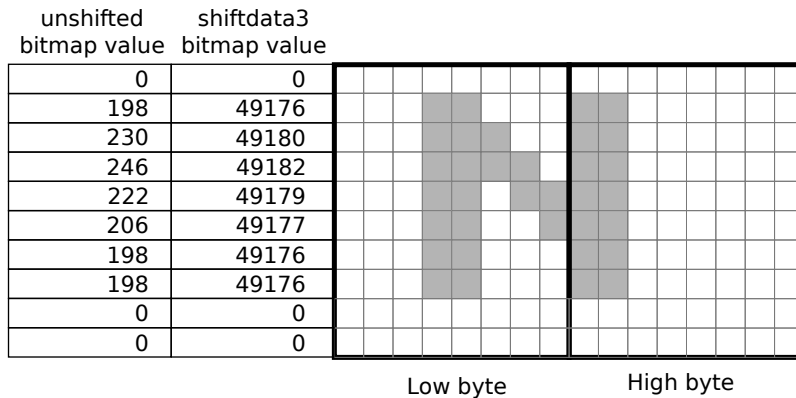


Figure 12: Bitshift 'N' over 3 bits using bit shift tables.

```
charloc    = 2        ;pointers to every character
BUFFWIDTH  = 50        ;buffer width is 50 characters

PROC   ShiftPropChar NEAR

    mov es,[grsegs+STARTFONT*2] ;segment of font to use
    mov bx,[es:charloc+bx]       ;BX holds pointer to
        character data

; look up which shift table to use, based on bufferbit
    mov di,[bufferbit]           ;pixel offset within byte [0-7]
    shl di,1
    mov bp,[shifttabletable+di] ;BP holds pointer to shift
        table

    mov di,OFFSET databuffer
    add di,[bufferbyte]          ;DI holds pointer to buffer
    mov cx,[es:pcharheight]     ;CX contains character height
    mov dx,BUFFWIDTH

; write one byte character
shift1wide:
    dec dx
EVEN
@@loop1:
    SHIFTNOR
    add di,dx                    ; next line in buffer
    loop @@loop1
    ret
ENDP

; Macros to table shift a byte of font
MACRO SHIFTNOR
    mov al,[es:bx]              ; source of font data
    xor ah,ah
    shl ax,1
    mov si,ax
    mov ax,[bp+si]              ; table shift into two bytes
    or [di],al                  ; OR with first byte
    inc di
    mov [di],ah                 ; replace next byte
    inc bx                      ; next source byte
ENDM
```

0.6.5 Sound Manager (SD)

The Sound Manager abstracts interaction with all sound systems supported: PC Speaker, AdLib, and Sound Blaster. It is a beast of its own since it doesn't run inside the engine. Instead it is called via IRQ at a much higher frequency than the engine (the engine runs at a maximum 70Hz, while the sound manager ranges from 140Hz to 700Hz). The sound manager is described extensively in the "??" section.

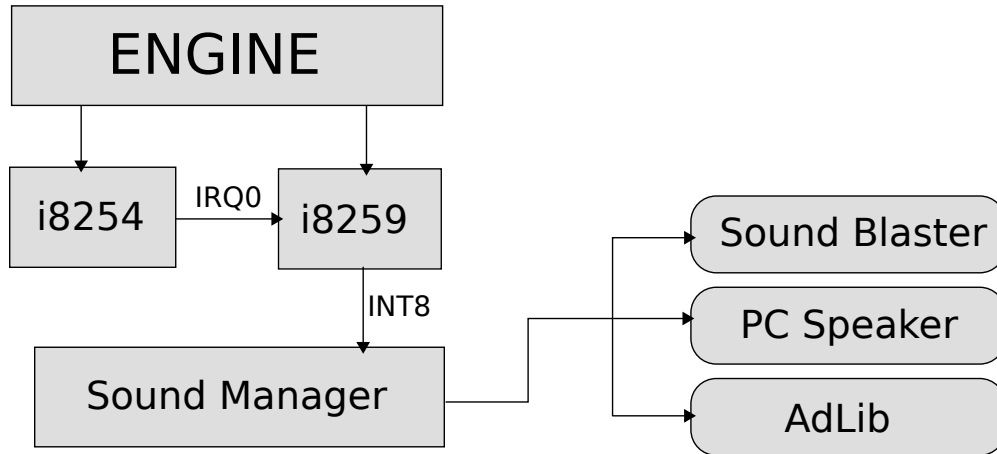


Figure 13: Sound system architecture.

0.6.6 Input Manager (IN)

The input manager abstracts interactions with joystick, keyboard, and mouse. It features the boring boilerplate code to deal with PS/2, Serial, and DA-15 ports, with each using their own I/O addresses.

0.6.7 Softdisk files

The primary function of the Softdisk files is to load and display the intro screen bitmap using the LoadLIBShape function from soft.c. Most of the functions in these files are not used and are therefore not discussed further in this book.

0.7 Startup

When the game engine starts, it first loads the Memory Manager. It then checks if at least 335KiB of RAM is available. If not, a warning is displayed, but the game can still continue. However, the game will likely crash or display an "Out of memory" error soon after.

Once the game has successfully started, the intro image, a Deluxe Paint bitmap image (*.LBM), is displayed. After the user presses any key, the intro image (using 320x200 = 64,000 bytes) is unloaded from RAM to free up memory for runtime, and the control panel is displayed.



Figure 14: Keen Dreams intro screen

