## 0.1 About the Source Code

Commander Keen episodes 1-5 source code is not available as the current owner Zenimax[1] has, as of writing this book, no interest in selling intellectual properties. Luckily the ownership of Commander Keen: Keen Dreams was in the hands of Softdisk. In June 2013, developer Super Fighter Team licensed the game from Flat Rock Software, the then-owners of Softdisk, 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 made available via `github.com`. It is important to take the the source code from shareware version 1.13, otherwise you run into issues due to incompatible map headers[2]. To get the correct source code

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

## 0.3 First Contact

Once downloaded via `github` a folder 'keen' is created with all source files inside. `cloc.pl` is a tool which looks at every file in a folder and gathers statistics about source code. It helps for getting an idea of what to expect.

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

[2] See 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
-------------------------------------------------------
```

The code is 85% in C with assembly[3] for bottleneck optimizations and low-level I/O such as video or audio.

Source lines of code (SLOC) is not a meaningful metric against a single codebase but excels when it comes to extracting proportions. Commander Keen with its 19,237 SLOC is very small compared to most software. `curl` (a command-line tool to download url content) is 154,134 SLOC. Google's Chrome browser is 1,700,000 SLOC. Linux kernel is 15,000,000 SLOC.

[3] All 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`.

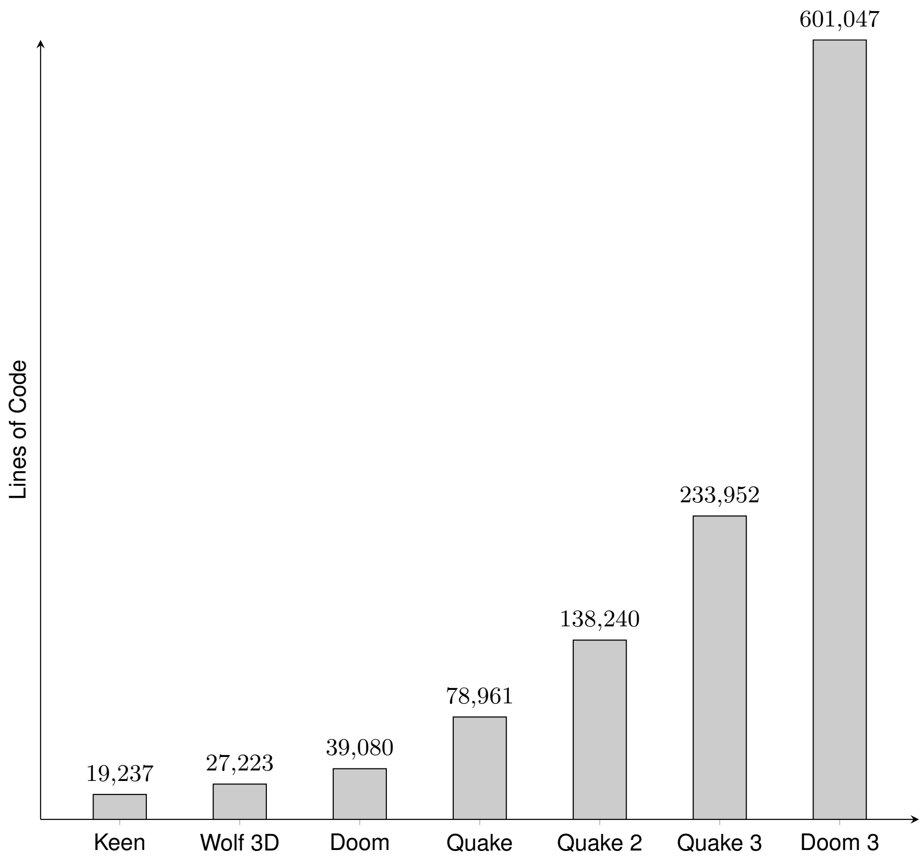



***Figure 1:*** Lines of code from id Software game engines.

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

- `static` folder: Static header files for loading assets (as explained in Section **??**).
- `lscr` folder: Load and decompress Softdisk data files.
- `README:` 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 the DosBox environment, with Borland C++ 3.1 installed (You can find a complete tutorial in "Let's compile like it's 1992" on `fabiensanglard.net`) download the source code via github.

Once you start DosBox and change directory to the `keen` folder, first create the folder where we create our compiled object files.

```
mkdir OBJ
```

Then we need to create the static `OBJ` header files.

```
chdir STATIC
make.bat
```

Once the static object header files are created, move back to the `keen` folder and open Borland C++. Open the `kdreams.prj` project file. Before we can start compiling we need to set the correct directories. Select Options -> Directories and change the values as follow:

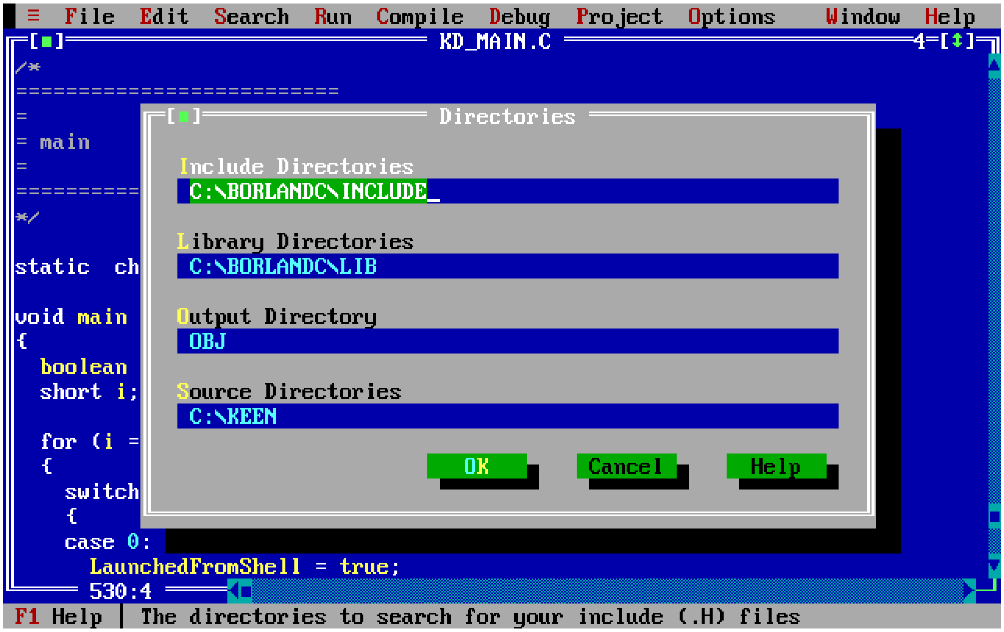



***Figure 2:*** Borland C++ 3.1 directory settings

Now it's time to compile. Go to Compile -> Build all, and voila! The final step is to copy `kdreams.exe` to the Keen shareware folder. Now you can play your compiled version of Commander Keen.

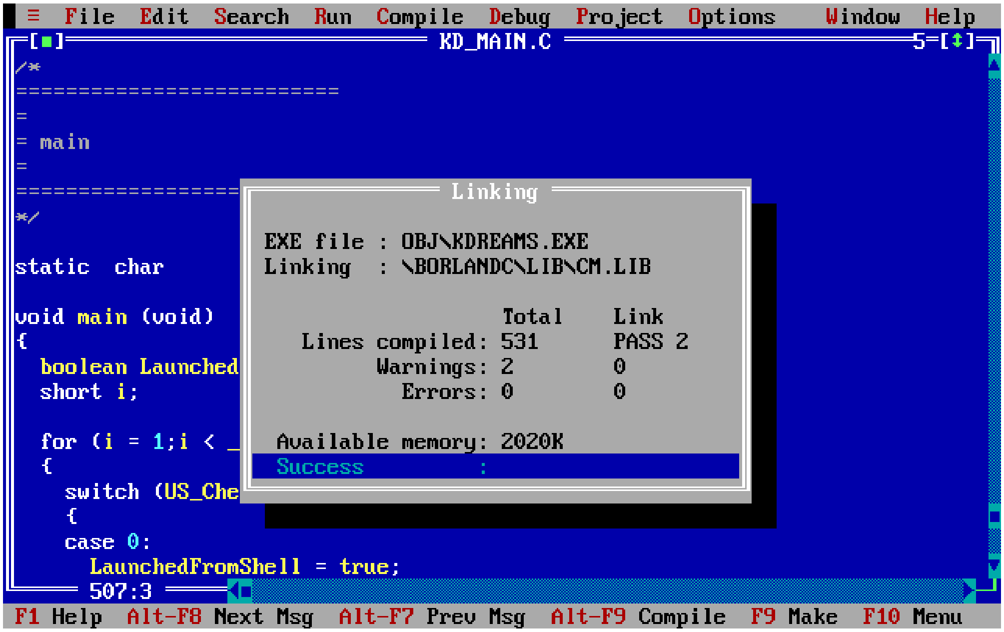



***Figure 3:*** Commander Keen compiling

## 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.

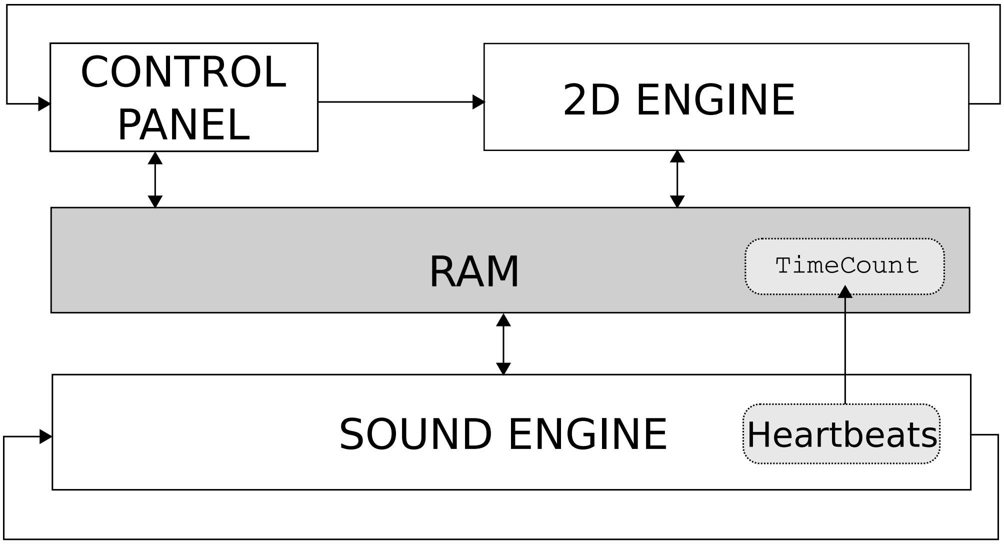



***Figure 4:*** Game engine three main systems.

### 0.5.1 Unrolled Loop

With the big picture in mind, we can dive into the code and unroll the main loop starting in `void main()`. The control panel and 2D renderer are regular loops but due to limitations explained later, the sound system is interrupt-driven and therefore out of `main`. Because of real mode, C types don't mean what people would expect from a 16-bit architecture.

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

The first thing the program does is set the text color to light grey and background color to black.

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

  InitGame();

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

In `InitGame`, a validation is performed to check if sufficient memory is available 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);

    [...]              // Check for and handle collisions
                       // between objects

    ScrollScreen(); // Scroll if Keen is nearing an edge.
                    // Draw new tiles to master screen in
                    // VRAM, and mark them in tile arrays

    [...]              // React to whatever happened, and post
                       // sprites to the refresh manager

    RF_Refresh();      // Copy marked tiles from master to
                       // buffer screen, and update sprites
                       // in buffer screen.
                       // Finally, 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.

An ISR (Interrupt Service Routine) is installed in the Interrupt Vector Table to respond to interrupts triggered by the engine.

```
void SD_Startup(void)
{
  if (SD_Started)
    return;

  t0OldService = getvect(8);  // Get old timer 0 ISR

  SDL_InitDelay();  // SDL_InitDelay() uses t0OldService

  setvect(8,SDL_t0Service);   // Set to my timer 0 ISR

  SD_Started = true;

}
```

## 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.

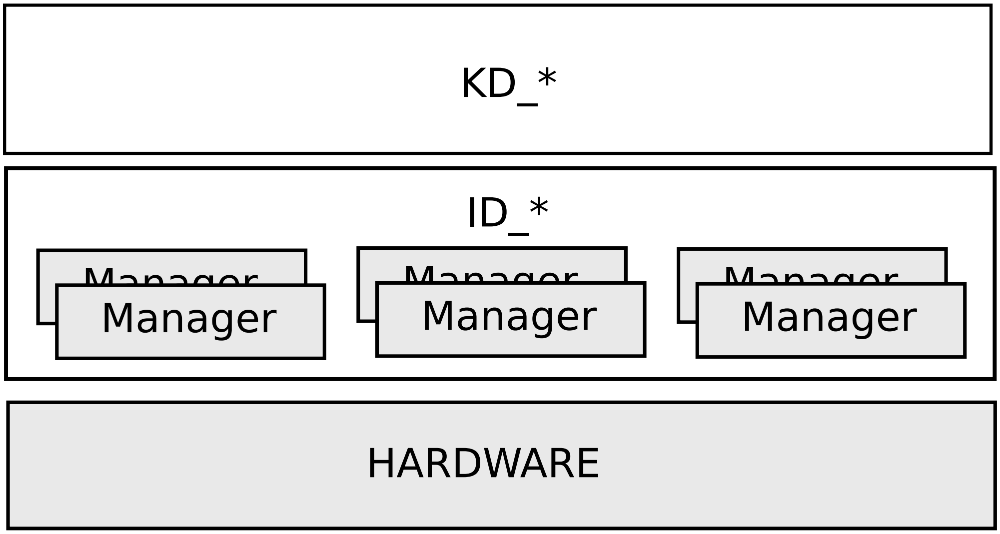



***Figure 5:*** Commander Keen source code layers.

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 games (Hovertank One, Catacomb 3-D and Wolf3D).

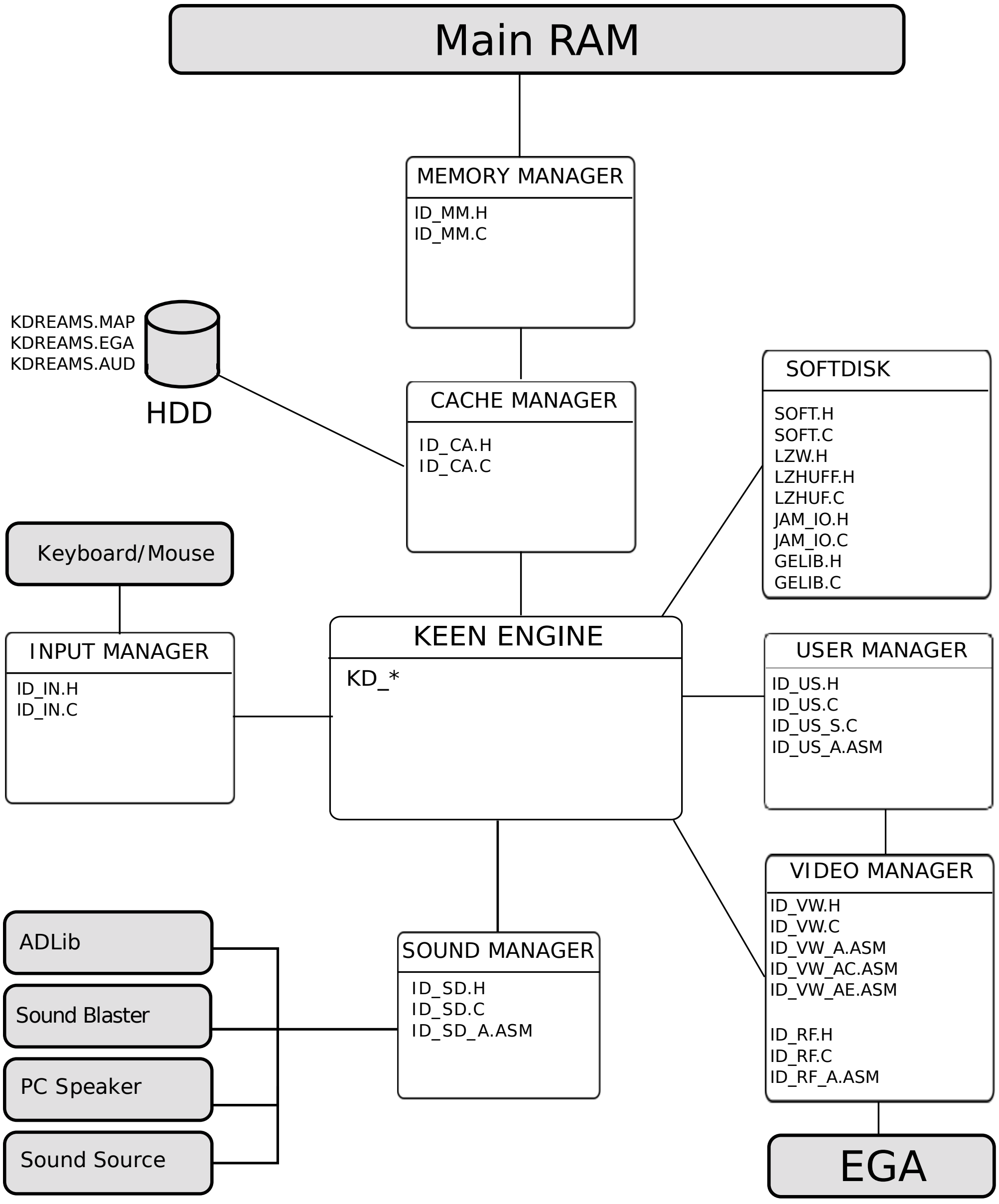



***Figure 6:*** Architecture with engine and sub-systems (in white) connected to I/O (in gray).

Next to the hard drives (HDD) you can see the assets packed as described in Chapter **??**.

### 0.6.1 Memory Manager (MM)

The engine does not rely on `malloc` to manage conventional memory, as this can lead to fragmented memory and no way to compact free space. It has its own memory manager made of a linked list of "blocks" keeping track of the RAM. A block points to a starting point in RAM and has a size.

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

A block can be marked with attributes:

- `LOCKBIT` : This block of RAM cannot be moved during compaction.
- `PURGEBITS` : Four levels available, 0= unpurgeable, 1= purgeable, 2= not used, 3= purge first.

The memory manager starts by allocating all available RAM via `malloc/farmalloc` and creates a `LOCKED` block of size 1KiB at the end. The linked list uses two pointers: `HEAD` and `ROVER` which point to the second to last block.

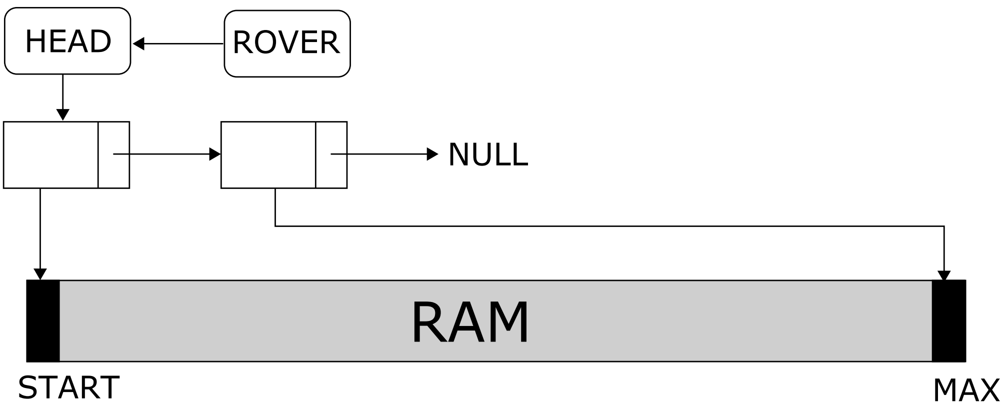



***Figure 7:*** Initial memory manager state.

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 blocks. This can take up to three passes of increasing complexity:

1. After rover.
2. After head.
3. Compacting and then after rover.

The easiest case is when there is enough space after the rover. A new node is simply added to the linked list and the rover moves forward. In the next drawing, three allocation requests have succeeded: `A`, `B` and `C`.

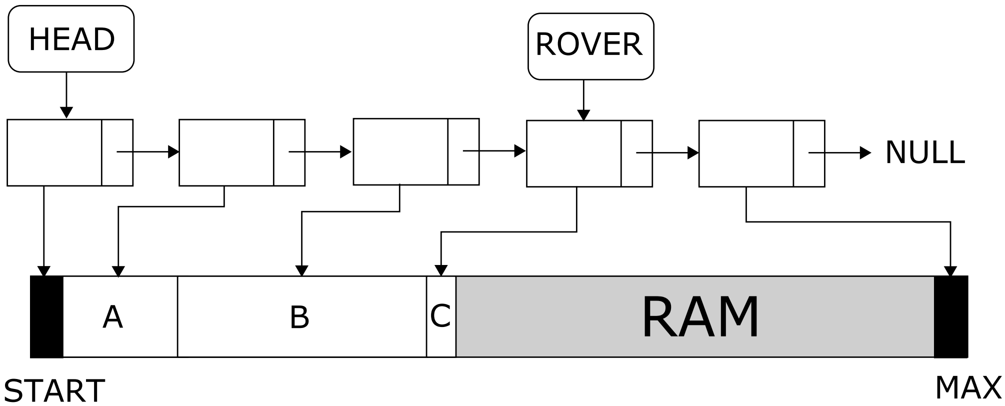



***Figure 8:*** MM internal state after three pass 1 allocations.

Eventually the free RAM will be exhausted and the first pass will fail.

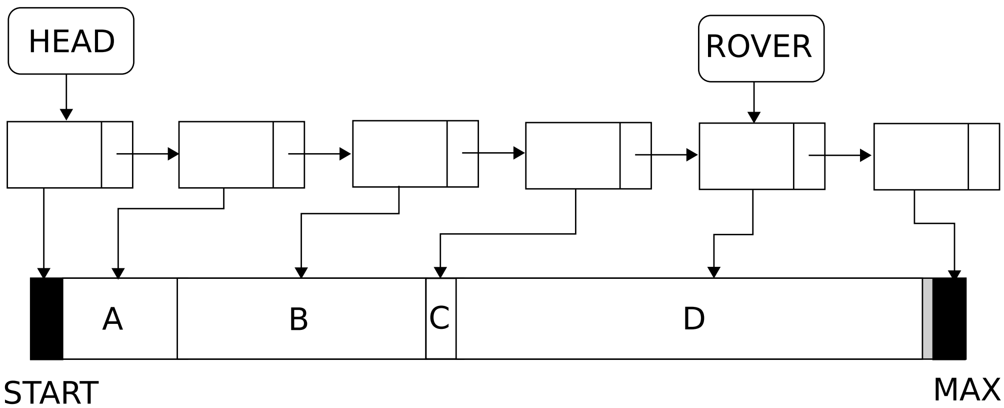



***Figure 9:*** Pass 1 failure: Not enough RAM after the ROVER.

If the first pass fails, the second pass looks for a "hole" between the head and the rover. This pass will also purge unused blocks. If for example block B was marked as `PURGEABLE`, it will be deleted and replaced with the new block E. At this point fragmentation starts to appear (like if `malloc` was used).

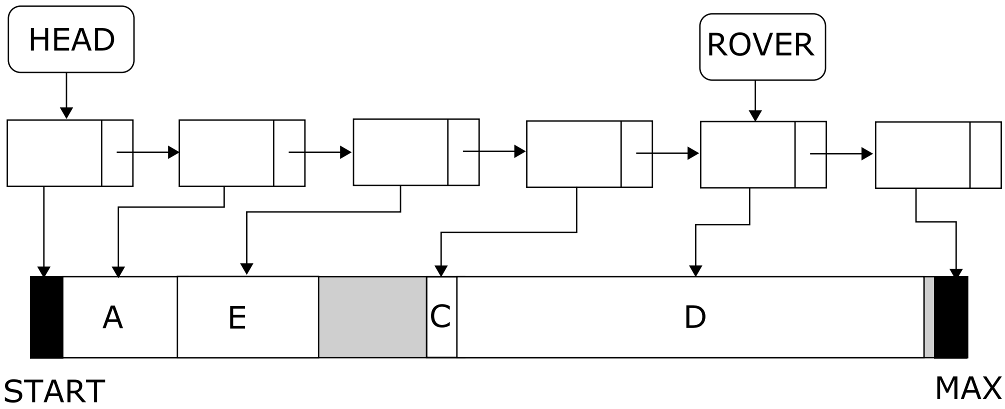



***Figure 10:*** `B` was purged. `E` was allocated in pass 2.

If the first and second pass fail, there is no continuous block of memory large enough to satisfy the request. The manager will then iterate through the entire linked list and do two things: delete blocks marked as purgeable, and compact the RAM by moving blocks.

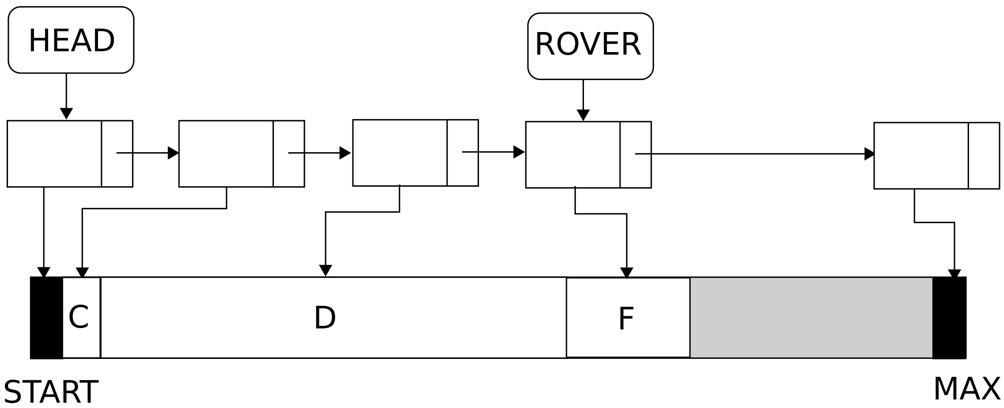



***Figure 11:*** `A` and `E` were purged. `C` and `D` compacted. `F` allocated in pass3.

But if memory is moved around, how do previous allocations still point to what they did before the compaction phase? Notice that a `mmblockstruct` has a `useptr` pointer which points to the owner of a block. When memory is moved, the owner of the block is also updated.

As some blocks are marked as `LOCKED`, compacting can be disturbed. Upon encountering a locked block, compacting stops and the next block will be moved immediately after the locked block, even if there was space available between the last block and the locked block.

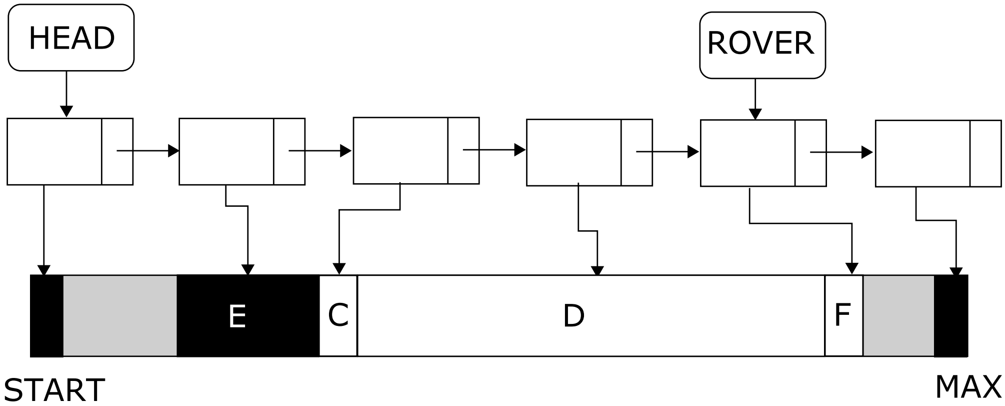



***Figure 12:*** `E` is locked and cannot be compacted.

In the above drawing, C was moved after E, even though it could have been moved before. Avoiding this waste would have made the memory manager more complicated, so the waste was deemed acceptable. Often in designing a component you have to be practical and establish a certain trade off between accuracy and complexity.

### 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.

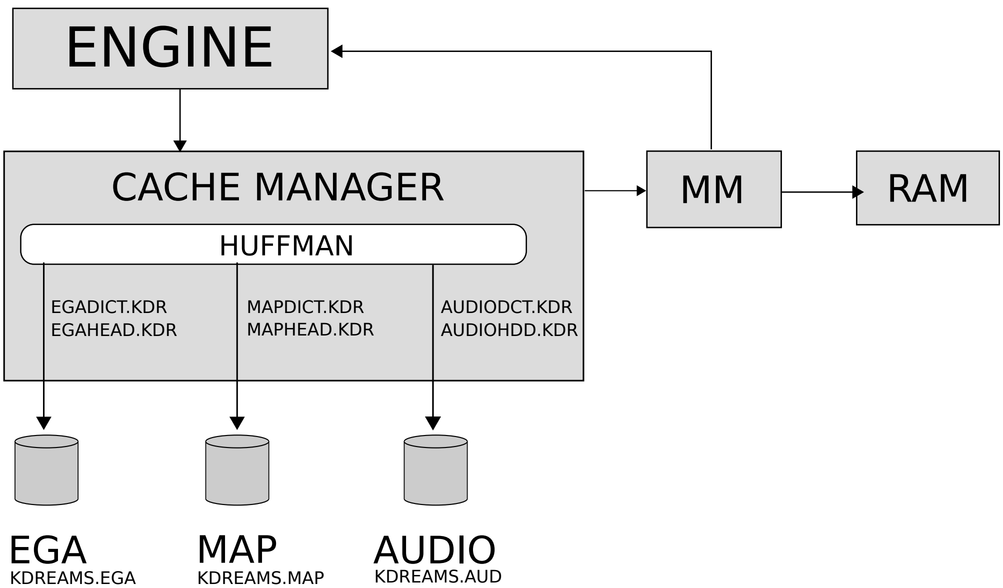
The video manager is described extensively in section **??** on page **??**.

### 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 chapter **??**. The header and dictionary files are provided with the source code in the `static` folder and contain `*.KDR` extension. Both file types are integrated in the engine code and required during compilation (they are converted into an `OBJ` file using `makeobj.c`). The data file containing the assets is not part of the source code and must be acquired via downloading the shareware version. All resources are compressed using a traditional Huffman method for (de-)compression, and the maps have an additional RLEW compression.



### Asset caching

To manage and keep track of the assets to be loaded into memory, an array `gr_needed[]` is maintained to mark if an asset needs to be loaded from disk. The index of this array refers to the graphic asset IDs. By using the eight bits the array can maintain the required assets for different levels. The cache manager starts with an empty `gr_needed[]` array.

| *level bit:* | *8* | *7* | *6* | *5* | *4* | *3* | *2* | *1* |
|---|---|---|---|---|---|---|---|---|
| STARTFONT | | | | | | | | |
| CTL_STARTUPPIC | | | | | | | | |
| CTL_HELPUPPIC | | | | | | | | |
| ... | | | | | | | | |
| KEENSTANDRSPR | | | | | | | | |
| KEENRUNR1SPR | | | | | | | | |
| ... | | | | | | | | |
| SCOREBOXSPR | | | | | | | | |
| ... | | | | | | | | |
| TILE8 | | | | | | | | |
| TILE8M | | | | | | | | |
| TILE16 #1 | | | | | | | | |
| TILE16 #2 | | | | | | | | |
| ... | | | | | | | | |
| TILE16M #1 | | | | | | | | |
| TILE16M #2 | | | | | | | | |
| ... | | | | | | | | |

***Figure 13:*** Initiating `gr_needed[]` array.

When new resources needs to be cached in memory, all required assets are marked by setting the current level bit (bit 1) to 1.

```c
#define CA_MarkGrChunk(chunk) grneeded[chunk]|=ca_levelbit

void InitGame (void)
{
  CA_ClearMarks (); // Clears out all the marks at the current level

  // Mark assets to be cached in memory
  CA_MarkGrChunk(STARTFONT);
  CA_MarkGrChunk(STARTFONTM);
  CA_MarkGrChunk(STARTTILE8);
  CA_MarkGrChunk(STARTTILE8M);
  for (i=KEEN_LUMP_START;i<=KEEN_LUMP_END;i++)
    CA_MarkGrChunk(i);

  CA_CacheMarks (NULL, 0); // Cache marked assets into memory
}
```

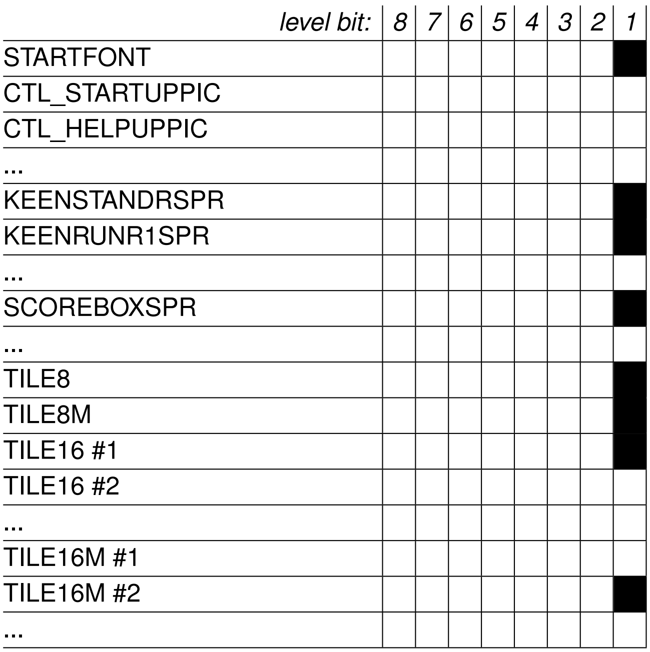



***Figure 14:*** Mark all assets required for the new map in level bit 1.

The function `CA_CacheMarks()` loads and decompress all required graphical assets from disk to memory for the current bit level. If, during playing the game, we open the control panel (e.g. to pause the game), the assets for the control panel needs to be cached. By increasing the bit level we keep the assets for control panel separated from the map.

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

  if (ca_levelnum==7)
    Quit ("CA_UpLevel: Up past level 7!");

  ca_levelbit<<=1;
  ca_levelnum++;
}
```

The `gr_needed[]` array looks as follows

| *level bit:* | *8* | *7* | *6* | *5* | *4* | *3* | *2* | *1* |
|---|---|---|---|---|---|---|---|---|
| STARTFONT | | | | | | | ■ | ■ |
| CTL_STARTUPPIC | | | | | | | ■ | |
| CTL_HELPUPPIC | | | | | | | ■ | |
| ... | | | | | | | | |
| KEENSTANDRSPR | | | | | | | | ■ |
| KEENRUNR1SPR | | | | | | | | ■ |
| ... | | | | | | | | |
| SCOREBOXSPR | | | | | | | | ■ |
| ... | | | | | | | | |
| TILE8 | | | | | | | | ■ |
| TILE8M | | | | | | | | ■ |
| TILE16 #1 | | | | | | | | ■ |
| TILE16 #2 | | | | | | | | |
| ... | | | | | | | | |
| TILE16M #1 | | | | | | | | |
| TILE16M #2 | | | | | | | | ■ |
| ... | | | | | | | | |

***Figure 15:*** Mark all assets required for the control panel in level bit 2.

If the control panel is closed again, it lowers the bit level of `gr_needed[]` to 1, where all required assets for playing the level are memorized. It simply calls the function `CA_CacheMarks()`

to reload any map assets removed from memory.

```
void CA_DownLevel (void)
{
  if (!ca_levelnum)
    Quit ("CA_DownLevel: Down past level 0!");
  ca_levelbit>>=1;
  ca_levelnum--;

  //recaches everyting from the previous level
  CA_CacheMarks(titleptr[ca_levelnum], 1);
}
```

### Asset compression

As the floppy disk is both limited in speed (100-250 kbps[4]) and storage (3½-inch disk size is either 720KB or 1.44MB), it was important to use file compression. This ensures that the game takes up less space and loads faster. id Software used Huffman compression for all asset files and an additional RLE compression to further shrink map files.

| Asset | Uncompressed file[5] | Compressed file |
|---|---|---|
| Graphics (KDREAMS.EGA) | 360KB | 213KB |
| Game maps (KDREAMS.MAP) | 210KB | 66KB |
| Total | 570KB | 279KB |

***Figure 16:*** Compressed versus uncompressed asset files.

Huffman compression involves changing how various characters are stored. Normally, all characters in a given segment of data are equal and take an equal amount of space to store. However, by making more common characters take up less space while allowing less commonly used characters to take up more, the overall size of a segment of data can be reduced.

To illustrate the various aspects of Huffman compression, the following text, where each character is one byte, will be Huffman compressed.

```
Commander Keen in Keen Dreams
```

[4] Kilobit per second is a unit of data transfer rate equal to: 1,000 bits per second or 125 bytes per second.
[5] The uncompressed size is an estimation based on the expanded size of each asset.

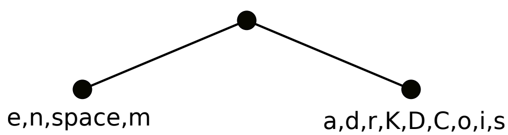
The first step is to make a character frequency table.

| Character | Frequency |
|---|---|
| e | 6 |
| n | 4 |
| space | 4 |
| m | 3 |
| a | 2 |
| r | 2 |
| K | 2 |

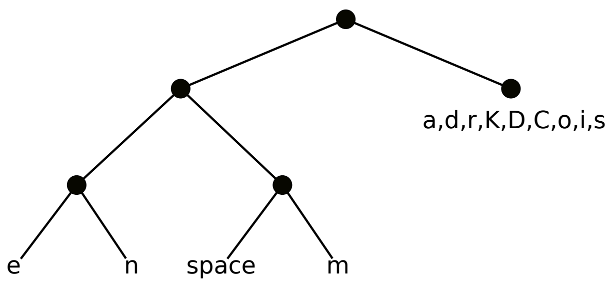
| Character | Frequency |
|---|---|
| d | 1 |
| D | 1 |
| C | 1 |
| o | 1 |
| i | 1 |
| s | 1 |

***Figure 17:*** Character frequency table.

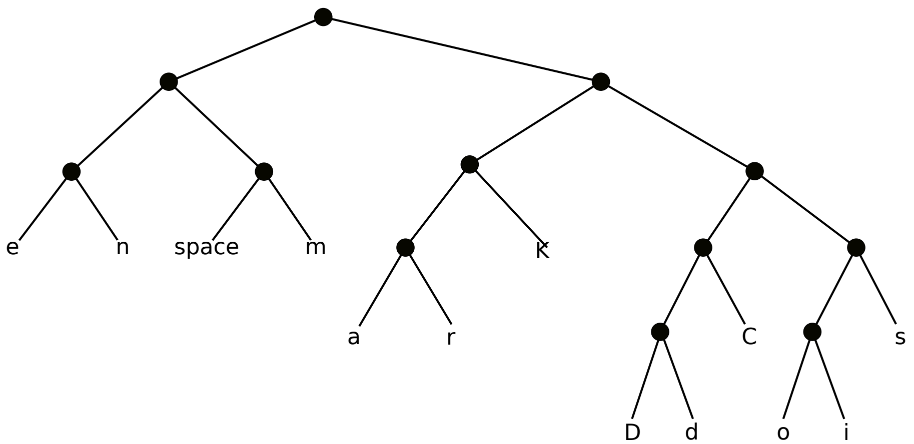
The next step is to create an optimal binary tree, also called a dictionary. This is done by starting with the most common character and checking if it occurs more frequently than all the other characters combined. If not, then the second most common character is added, and so on. In our example, four characters make up more than half of the total number of characters: ’e’, ’n’, space, and ’m’. All of these characters are placed on the left side of the root node, while the remaining characters are placed on the right side.



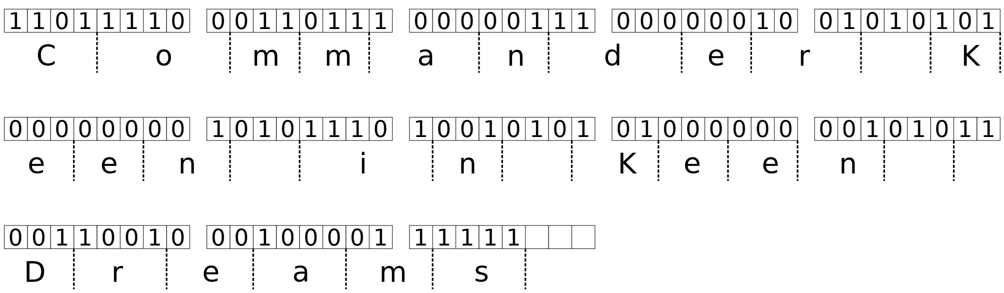

The next step involves creating a new node with left and right branches and repeating the process. The two most common characters in the left node, ’e’ and ’n’, are assigned to the left branch of this new node. A third node is created, and since there are only two options, each is given a branch. The same process applies to the remaining characters of the left node, resulting in:



Then we do the same for the right node, where 'a', 'd', 'r' and 'K' make up more than half of the total number of characters in the right node. After following the same steps, the final binary tree looks as follows




Now we can encode the entire text moving left (bit 0) and right (bit 1) in the tree, starting from the top node. For example, the character 'e' is `000`, 'm' is `011` and 'o' is `11100`. The complete compressed message in bit form is now




This is a total of 13 bytes used for a 31 byte message, more than 50% reduction. In Commander Keen, the dictionary is part of the source code. Therefore, it is important that the asset files from the shareware version correspond with the dictionary files of the source code[6]. Reading the Huffman-compressed asset file is straightforward. You just read bit by bit from the asset file and follow the dictionary starting from the top node until you hit an end-node. Write the byte to memory and start at the top node in the dictionary again for the next bit in the file.

[6] That's why a specific source code version is mention in section xxx).

```
typedef struct
{
  unsigned bit0,bit1; // 0-255 is a character,
                      // >255 is a pointer to a node
} huffnode;
```

The tile map asset files use a second compression, on top of Huffman. Upon closer inspection of a level, you'll notice large chunks of the same tile. For example, consider the first level you enter (Horse Radish Hill), which contains extensive areas of blue sky. Here, RLE compression comes in useful.

The essence of this compression method is to compress data by saving the "run-length" of the encountered values, essentially storing the data as a collection of length/value pairs. To illustrate, the string 'aaaaaaaabbb' could be compressed to '8a3b' (8 bytes of 'a', 3 bytes of 'b'). The trick with RLE is to ensure that the data does not end up becoming larger after processing. For instance, using pure length/value pairs, 'abracadabra' would become '1a1b1r1a1c1a1d1a1b1r1a'.

In Commander Keen this is solved by using a 'flag'. This special value instructs the program to take specific action upon encountering it. Every value is passed through unchanged until an RLE flag value is encountered. When this flag is read, instead of directly outputting it like other values, two further values are read. The first indicates the number of times to repeat, and the second represents the value to be repeated. The algorithm used in Commander Keen is based on 16-bits (word), and therefore is named RLEW, where the 'W' stands for word. The RLE flag is defined as 0xABCD.

```
void CA_RLEWexpand (unsigned huge *source, unsigned huge *
    dest,long length, unsigned rlewtag)
{
  unsigned value,count,i;
  unsigned huge *end;
  unsigned sourceseg,sourceoff,destseg,destoff,endseg,
   endoff;

  end = dest + (length)/2;    // length is COMPRESSED length
  sourceseg = FP_SEG(source);
  sourceoff = FP_OFF(source);
  destseg = FP_SEG(dest);
  destoff = FP_OFF(dest);
  endseg = FP_SEG(end);
  endoff = FP_OFF(end);

  asm mov bx,rlewtag          // RLEW tag: 0xABCD
  asm mov si,sourceoff
  asm mov di,destoff
  asm mov es,destseg
  asm mov ds,sourceseg

  expand:
  asm lodsw
  asm cmp ax,bx               // value is RLEW tag?
  asm je  repeat
  asm stosw
  asm jmp next

  repeat:
  asm lodsw
  asm mov cx,ax               // repeat count
  asm lodsw                   // repeat value
  asm rep stosw

  next:                       // Next word value
  [...]
}
```

### 0.6.4 User Manager (US)

The user manager is responsible for text layout and control panels like loading and saving games, configure controls and setting sound device.

Once we start the game, we move the display to EGA graphic mode `0x0D`. Here we can't directly print characters on the screen anymore. So a key function of the User Manager is to print text on a given pixel location. In the graphic assets file the complete font is stored with the following information for each character:

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

Each character has the same height of 10 pixels, but the character width could vary as illustrated in Figure 18.

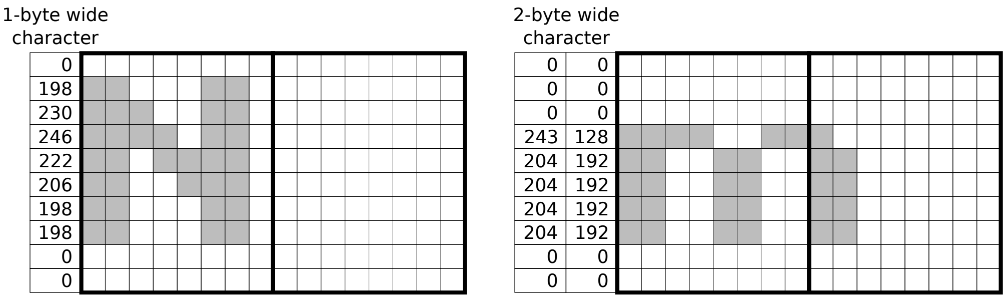



***Figure 18:*** Character bitmaps of 'N' (7 bits wide) and 'm' (11 bits wide)

As explained in section **??** on page **??**, each 8 pixels are represented by 1 byte per memory bank. So how do we print a character which is not perfectly aligned with the memory layout? Here a trick of bitshift tables is being used.

The default table (`shiftdata0`) is defined as integer (16 bits) and contains all values from 0-255. Now, we shift this entire table 1 bit to the right. We can translate the bit shift back into an integer and store these values again in a table (`shiftdata1`). We can do this again when we shift another bit, until we cycled through the 8-bits. So at the end we have created 8 shift tables to fully cycle through 8-bits. In Figure 19 the bitshift for the values '198' is illustrated.

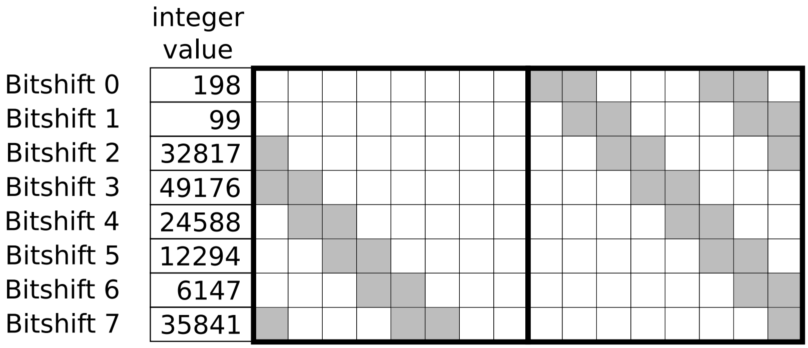



***Figure 19:*** Right bitshift [0-7] for 198.

Each bitshift table is generated in `id_vw_a.asm`, see below bitshift 5.

```
LABEL shiftdata5 WORD
  dw     0, 2048, 4096, 6144, 8192,10240,12288,14336,16384,18432,20480,22528,24576,26624
  dw 28672,30720,32768,34816,36864,38912,40960,43008,45056,47104,49152,51200,53248,55296
  dw 57344,59392,61440,63488,     1, 2049, 4097, 6145, 8193,10241,12289,14337,16385,18433
  dw 20481,22529,24577,26625,28673,30721,32769,34817,36865,38913,40961,43009,45057,47105
  dw 49153,51201,53249,55297,57345,59393,61441,63489,     2, 2050, 4098, 6146, 8194,10242
  dw 12290,14338,16386,18434,20482,22530,24578,26626,28674,30722,32770,34818,36866,38914
  dw 40962,43010,45058,47106,49154,51202,53250,55298,57346,59394,61442,63490,     3, 2051
  dw  4099, 6147, 8195,10243,12291,14339,16387,18435,20483,22531,24579,26627,28675,30723
  dw 32771,34819,36867,38915,40963,43011,45059,47107,49155,51203,53251,55299,57347,59395
  dw 61443,63491,     4, 2052, 4100, 6148, 8196,10244,12292,14340,16388,18436,20484,22532
  dw 24580,26628,28676,30724,32772,34820,36868,38916,40964,43012,45060,47108,49156,51204
  dw 53252,55300,57348,59396,61444,63492,     5, 2053, 4101, 6149, 8197,10245,12293,14341
  dw 16389,18437,20485,22533,24581,26629,28677,30725,32773,34821,36869,38917,40965,43013
  dw 45061,47109,49157,51205,53253,55301,57349,59397,61445,63493,     6, 2054, 4102, 6150
  dw  8198,10246,12294,14342,16390,18438,20486,22534,24582,26630,28678,30726,32774,34822
  dw 36870,38918,40966,43014,45062,47110,49158,51206,53254,55302,57350,59398,61446,63494
  dw     7, 2055, 4103, 6151, 8199,10247,12295,14343,16391,18439,20487,22535,24583,26631
  dw 28679,30727,32775,34823,36871,38919,40967,43015,45063,47111,49159,51207,53255,55303
  dw 57351,59399,61447,63495
```

Now let's take the example of printing 'N', with an offset of 3 pixels. A simple lookup in `shiftdata3` results in the 3-bit shifted 'N'. Note that you first display the low byte and then the high byte value.

| unshifted bitmap value | shiftdata3 bitmap value |
|---|---|
| 0 | 0 |
| 198 | 49176 |
| 230 | 49180 |
| 246 | 49182 |
| 222 | 49179 |
| 206 | 49177 |
| 198 | 49176 |
| 198 | 49176 |
| 0 | 0 |
| 0 | 0 |

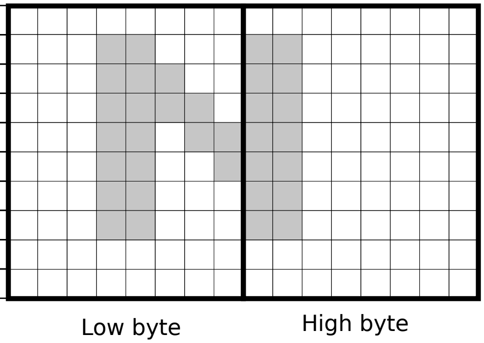



***Figure 20:*** Bitshift 'N' over 3 bits using bit shift tables.

Once both bytes are copied to the data buffer, the buffer pointer is increased with the character width and then the next character is copied. Finally, the data buffer is copied to VRAM, so it gets displayed on the screen.

```
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:
  SHIFTNOXOR
  add di,dx          ; next line in buffer
  loop  @@loop1
  ret
ENDP

; Macros to table shift a byte of font
MACRO SHIFTNOXOR
  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 four sound systems supported: PC Speaker, AdLib, Sound Blaster, and Disney Sound Source. 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). It must run quickly and is therefore written in small and fast routines.

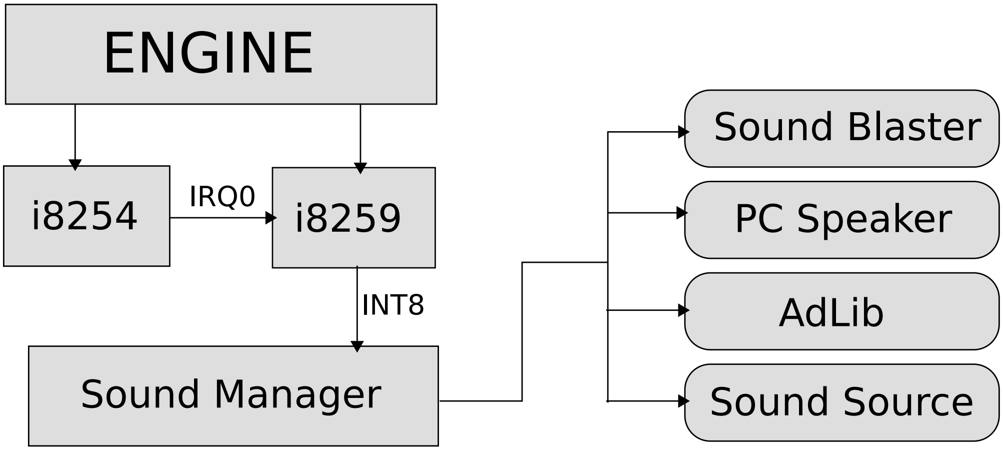



***Figure 21:*** Sound system architecture.

The sound manager is described extensively in the "Sound and Music" section.

### 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 only function for the Softdisk files is to load and show the intro screen bitmap, using `LoadLIBShape` from soft.c. Most of the functions in these files are actually not used and therefor not further discussed in this book.

## 0.7 Startup

As the game engine starts, it will first load the memory manager. Then it will check if there is at least 335KiB of RAM available. If not, it gives a warning, but you can continue with the game. But most likely somewhere soon the game will either crash or receives an "Out of memory" error.

After successfully starting the game the intro image is displayed, which is a Deluxe Paint-Bitmap image (*.LBM). After the user has hit any key, the intro image is unloaded from RAM to make more room for runtime and the control panel is shown.


***Figure 22:*** Keen Dreams intro screen