0.1 Action Phase: Adaptive Tile Refreshment

After the player is done setting up the game, it is time for the scrolling engine to shine. On bitmapped displays without hardware scrolling like the EGA card, the entire screen have to be erased and redrawn in the slightly shifted position whenever the player moved in any direction. This would kill the CPU as you need to update all pixels of all four planes on the EGA card (remember the planar mapping of section **??**?).

So here John Carmack came with a smart solution. The scrolling engine is based on a simple yet powerful technology called Adaptive Tile Refreshment. The core idea is to refresh only those areas on the screen that needed to change.

The visible screen is divided into tiles of 16x16 pixels. On a screen with 320x200 pixels, it means a grid of 20x13 tiles (actually it is 12.5 tiles high, but we need to round to integer). Let's look at *Commander Keen 1: Marooned on Mars* in Figure 1. This is the first level of Marooned, immediately to the right of the crashed Bean-with-Bacon Megarocket. The first figure is the start of the level, the second figure is after Keen has moved one tile (16 pixels) to the right through the world. They look almost identical to the naked eye, don't they?

Now, if we perform a difference on both images you see which tiles needs to be changed upon screen refresh. The trick behind the scrolling in the first Commander Keen games was to only redraw tiles that actually changed after panning 16 pixels (one tile), since most maps had large swathes of constant background. In case of Figure 1 only 69 tiles of the total 260 tiles need to be refreshed, which is 27% of the screen!

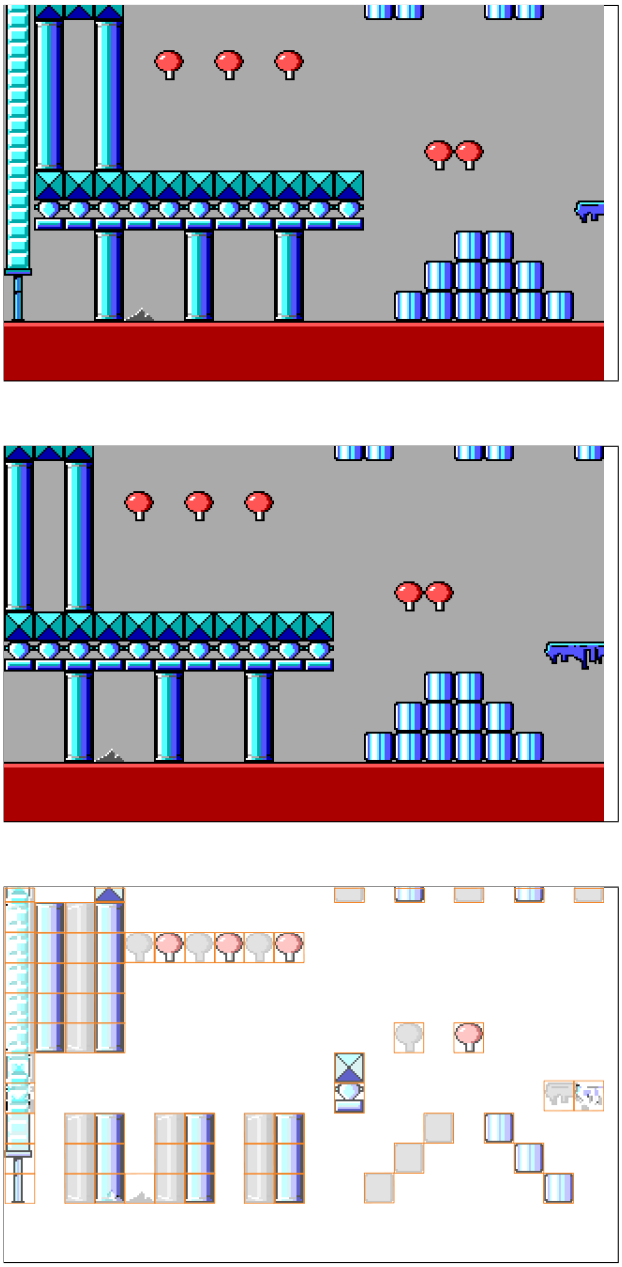


Figure 1: Start of the world, moved one tile to the right and difference.

So now we know how to scroll the screen in steps of 16 pixels, which is still pretty 'choppy'. For smooth scrolling we need to dive deeper into the EGA card, which is explained in the next section.

0.1.1 EGA Virtual Screen

The EGA adds a powerful twist to linear addressing: the logical width of the virtual screen in VRAM memory need not to be the same as the physical width of the screen display. The programmer is free to define a logical screen width of up to 4096 pixels and then use the physical screen as a window onto any part of the virtual screen. What's more, a virtual screen can have any logical height up to the capacity of the VRAM memory. The logical width of the virtual screen is expressed in the number of words of display memory considered to make up one scan line. So 20 words of display memory is setting a scan line of 320 pixels. The code below illustrates how to change the logical width.

```
CRTC_INDEX  = 03D4h
CRTC_OFFSET = 19

;==============
;
; set wide virtual screen
;
;==============

mov dx,CRTC_INDEX
mov al,CRTC_OFFSET
mov ah,[BYTE PTR width]  ;screen width in bytes
shr ah,1                 ;register expresses width
                         ;in word instead of byte
out dx,ax
```

The area of the virtual screen displayed at any given time is selected by setting the display memory address at which to begin fetching video data. This is set by way of the Start Address register. The default address is A000:0000h, but the offset can be changed to any other number. In EGA's planar graphics modes, the eight bits in each byte of video RAM correspond to eight consecutive pixels on-screen. Panning down a scan line requires only that the start address is increased by the logical width in bytes. Horizontal panning is possible by increasing the start address by one byte, although in this case only relative coarse of 8 pixels (1 byte) adjustments are supported. See the code below how to set the Start Address register.

```
CRTC_INDEX   = 03D4h
CRTC_STARTHIGH   = 12

;==============
;
; VW_SetScreen
;
;==============

  cli                       ;disable interrupts

  mov   cx,[crtc]           ;[crtc] is start address
  mov   dx,CRTC_INDEX       ;set CRTR register
  mov   al,CRTC_STARTHIGH   ;start address high register
  out   dx,al
  inc   dx                  ;port 03D5h
  mov   al,ch
  out   dx,al               ;set address high
  dec   dx                  ;set CRTR register
  mov   al,0dh              ;start address low register
  out   dx,al
  mov   al,cl
  inc   dx                  ;port 03D5h
  out   dx,al               ;set address high

  sti                       ;enable interrupts

  ret
```

0.1.2 Horizontal Pel Panning

Smooth pixel scrolling of the screen is provided by the Horizontal Pel Panning register in the Attribute Controller (ATC). Up to 7 pixels' worth of single pixel panning of the displayed image to the left is performed by increasing the register from 0 to 7. This exhaust the range of motion possible via the Horizontal Pel Panning register. The next pixel's worth of smooth panning is accomplished by incrementing the Start Address register by one byte and resetting the Horizontal Pel Panning register to 0.

Horizontal PEL Panning Registers will resolve the final 8 pixels 'jolt'. By setting the first 4 bits of the register we select the number of pixels to shift the entire screen up to 8 pixels horizontally to the left. As long as Keen is within the 16 pixels of a tile, scrolling is supported by EGA hardware and the game doesn't need to use any CPU time to scroll the

screen.

There is one annoying quirk about programming the Attribute Controller: when the ATC Index register is set, only the lower five bits (bits 0-4) are used as the internal index. The next most significant bit, bit 5, controls the source of the video data send to the monitor by the EGA card. When bit 5 is set to 1, the ouput of the palette RAM controls the displayed pixels; this is normal operation. When bit 5 is 0, video data doesn't come from the palette RAM, and the screen becomes a solid color. To ensure the ATC index register is restored to normal video, we must set bit 5 to 1 by writing `20h` to the register.

```
ATR_INDEX = 03C0h
ATR_PELPAN  = 19

;==============
;
; set horizontal panning
;
;==============

  mov dx,ATR_INDEX
  mov al,ATR_PELPAN or 20h ;horizontal pel panning register
                           ;(bit 5 is high to keep palette
                           ;RAM addressing on)
  out dx,al
  mov al,[BYTE pel]        ;pel pan value [0 to 8]
  out dx,al
```

0.1.3 Smooth scrolling: Bring it all together

Now we know how to perform tile refresh and smooth scrolling, it is time to bring it all together. The game and all actors are defined in a global coordinate system, which is scaled to 16 times a pixel. The higher resolution enables more precision of movements and better simulation of movement acceleration. Conversion between global, pixel and tile coordinate systems can be easily performed by bit shift operations:

- From global to pixel is shifing 4 bits to right.
- From pixel to tile is shifting 4 bits to right.
- From global to tile is shifting 8 bits to right.

The idea is to first perform all actions and movements in the global coordinate system, and then move back to pixels or tile coordinate system for video updates.

```
#define G_T_SHIFT 8   // global >> ?? = tile
#define G_P_SHIFT 4   // global >> ?? = pixels
#define SY_T_SHIFT 4  // screen y >> ?? = tile

void RFL_CalcOriginStuff (long x, long y)
{
  originxglobal = x;
  originyglobal = y;
  originxtile = originxglobal>>G_T_SHIFT;
  originytile = originyglobal>>G_T_SHIFT;
  originxscreen = originxtile<<SX_T_SHIFT;
  originyscreen = originytile<<SY_T_SHIFT;
  originmap = mapbwidthtable[originytile] + originxtile*2;

  //panning 0-15 pixels
  panx = (originxglobal>>G_P_SHIFT) & 15;
  //pan pixels 0-7 (0) or 8-15 (1)
  pansx = panx & 8;
  pany = pansy = (originyglobal>>G_P_SHIFT) & 15;
  //Start location in VRAM
  panadjust = panx/8 + ylookup[pany];
}
```

So the smooth horizontal and vertical panning should be viewed as a series 16-pixel tile refreshment and fine adjustments in the 8-pixel range. The scrolling is defined by the following steps, see also Figure 2:

- Calculate the panning in pixels for both x- and y-direction
- The y-panning is defined by adding `logical width * y` to the CRTC start address
- In case the panning in x-direction is more than 8 pixels, increase the CRTC start address by 1 byte
- the remaining pixels, ranging from 0-7, will be adjusted using horizontal pel panning

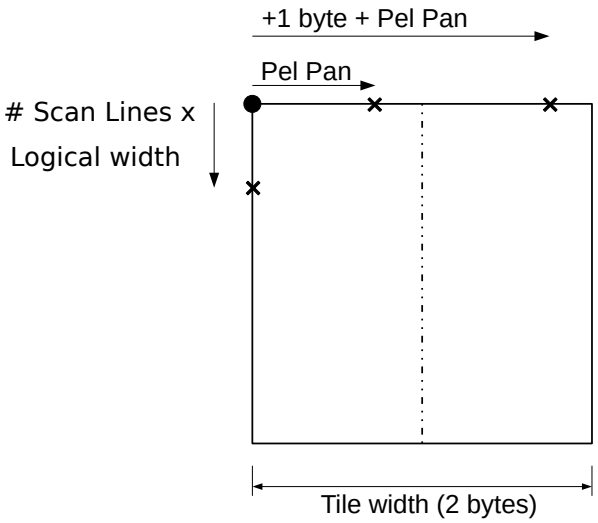


Figure 2: Smooth scrolling in EGA.

0.2 View Port and Buffer setup

Before we explain the scrolling algoritm, we first explain how the view port and buffer layout are setup. The visible viewing screen on EGA has a resolution of 320x200 pixels. If we translate this into 16x16 pixel tiles, we have a screen view size of 20x13 tiles. By making the view port one tile higher and wider than the screen (21x14 tiles), we can scroll the screen up to 16 pixels to the right or bottom side of the screen without any tile refresh by using the Start Address and Pel Pan registers. Finally, we create an update buffer that has enough space to float the view port up to two tiles in all direction. At the end of Section 0.4.3 it is explained why we need a spare buffer of 2 tiles.

So summarized, as can be seen in Figure 3, the following tile views are defined:

- Screen View size of 20x13 tiles and Port View size of 21x14 tiles.
- Buffer screen size of 22x14 tiles. This is one tile wider than the Port View, where the additional tile is used to mark a '0' at the end of each tile row. Notice that in the code the UPDATESCREENSIZE value is defined as (UPDATEWIDE * UPDATEHEIGHT + 2). The additional 2 bytes are used to store a termination indicator at the very end of the buffer screen.
- Total buffer size is stored in UPDATESIZE, which contains the UPDATESCREENSIZE and 2 two times a spare buffer to support the floating of two tiles in any direction.

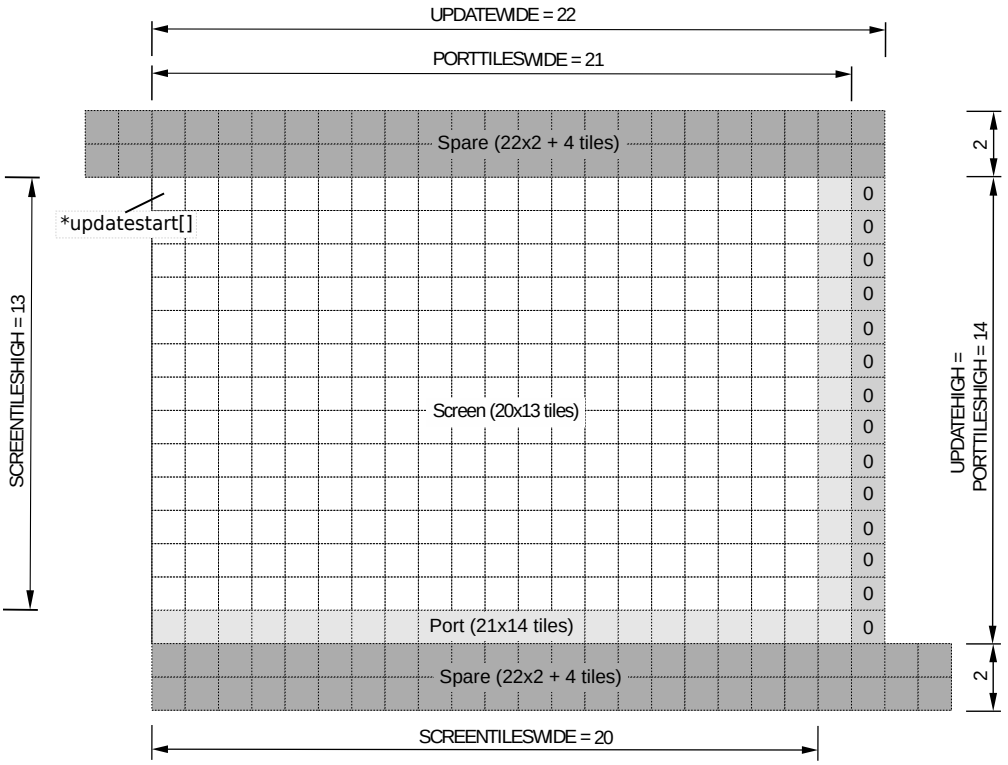


Figure 3: View and buffer port tile layout.

0.3 Screen buffer

Even if the screen is not scrolling, tile refreshes are required to support sprite animations. Since moving a sprite in this way involves first erasing it and then redrawing it, the image of the erased sprite may be visible briefly, causing flicker. This is where double buffering comes in: setting up a second buffer into which the code can draw while the first buffer is being shown on screen, which is then switched out during screen refresh. This ensures that no frame is ever displayed mid-drawing, which yields smooth, flicker-free animation.

Now, let's have a closer look at the EGA memory setup. As explained in the previous section, the view port has a size of 21x14 tiles, which is 336x224 pixels. That means the logical width in VRAM must be at least 336 pixels (42 bytes) wide. In the file `id_vw.h` the VRAM screen buffer is defined by SCREENSPACE, which is set to 64x240 bytes, or 512x240 pixels. This is more than sufficient to update one virtual screen in VRAM.

Since one screen only uses 15,360 bytes of VRAM (which is 3,840 bytes per plane), we

have more than enough space to store more than two full screens of video data. The video memory is organized into three virtual screens:

- Page 0 and 1, which are used to switch between buffer and view screen
- A master page containing all tiles, which are copied to the buffer memory when performing the screen update.

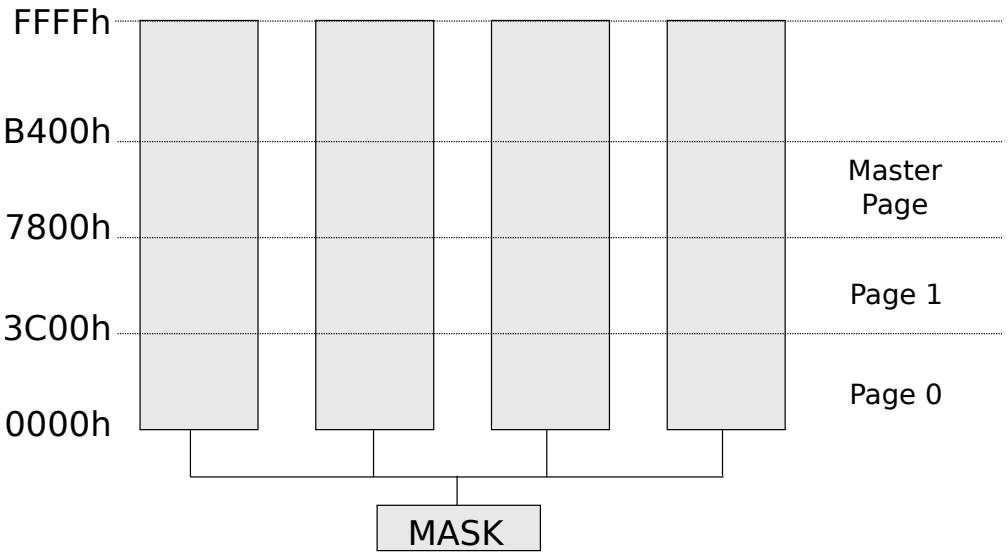


Figure 4: Virtual screen layout on EGA card.

The page that is actually displayed at any given time is selected by setting the Start Address register at which to begin fetching video data.

0.4 Life of a 2D Frame

The approach of refreshing the screen is different between the first Commander Keen games, Commander Keen 1-3, and the ones after. In the first games the algoritm keeps the screen view and buffer at fixed VRAM locations, where it performs a check which tiles are changed after the scroll. In the later games, it makes use of the moving the VRAM location and add a full row or column at the beginning or end of the view port.

0.4.1 Scroll and screen refresh in Commander Keen 1-3

In the this section we explain how the first games are working[1]. Six stages are involved in drawing a 2D scene:

1. Check if the player has moved one tile in any direction.
2. Validate which tiles have changed (both from scrolling and animated tiles), copy these respective tiles to the Master view in VRAM and mark the tiles to be updated in the next refresh.
3. Refresh the buffer view by scanning all tiles. If a tile needs to be updated, copy the tile from the master view to the buffer view in VRAM.
4. Iterate through the sprite removal list and copy corresponding image block from master view to buffer view in VRAM.
5. Iterate through the sprite list and copy corresponding sprite image block from asset location in RAM to buffer view in VRAM
6. Switch the screen and buffer view by adjusting the Start Address and Pel Panning registers.

Before we start the explanation, we first describe the most important variables and definitions used for the refresh process:

- `screenstart[]` points to the starting address (upper-left pixel) of the viewport in VRAM. As explained before we maintain three viewports in VRAM:
  - screenpage, the active displayed screen on the monitor. Note we never work or update the active screen.
  - otherpage, which is the buffer screen. This screen is updated and will be switched with the screenpage on next refresh
  - masterpage, which is used to keep both the screenpage and otherpage in sync and where we copy new tiles from memory to VRAM.
- `updatestart[]` points to the tile buffer array. It maintains which tiles needs to be updated upon next refresh. Here we have two tile buffer arrays, one for the screenpage and one for otherpage.
- `Visible screen`, which refers to the starting position of the visible screen on the monitor. This is done by setting both the `CRTR` address and `Pel Panning`. As explained above, the visible screen is within `screenstart[screenpage]`.

[1] We can only explain how the algoritm is working without code examples, since the only released code is Keen Dreams which is using the improved algoritm.

In the next six screenshots, we take you step-by-step to each of the stages. The screen has to scroll one tile to the right.

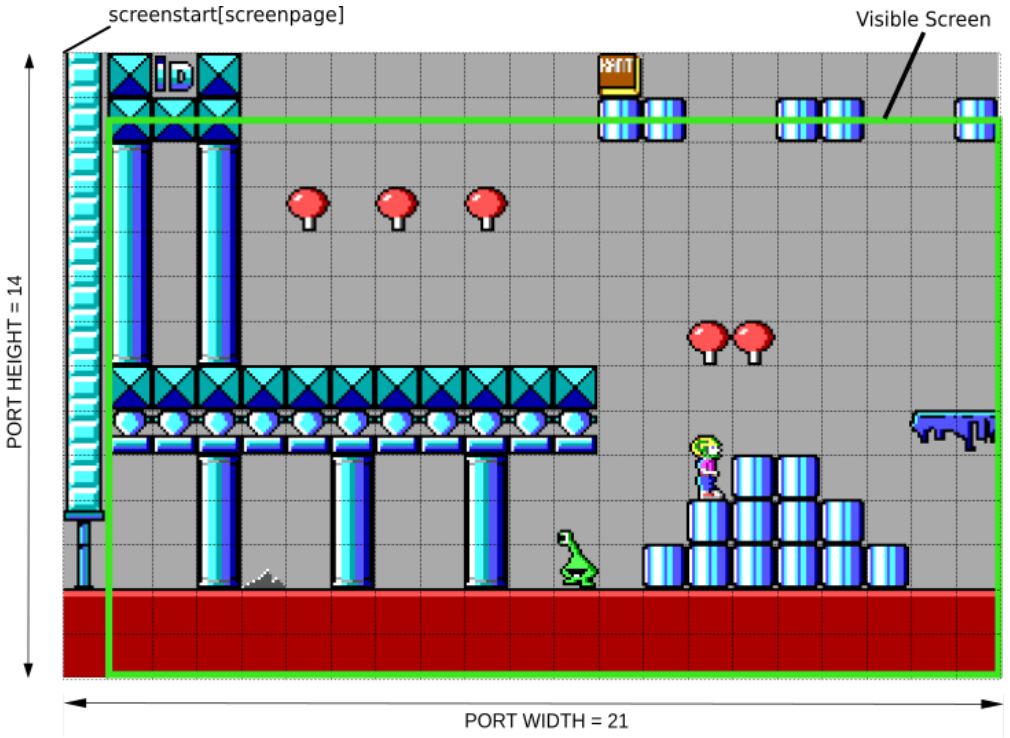


Figure 5: Step 1: Player moved to the right and forces the screen to scroll

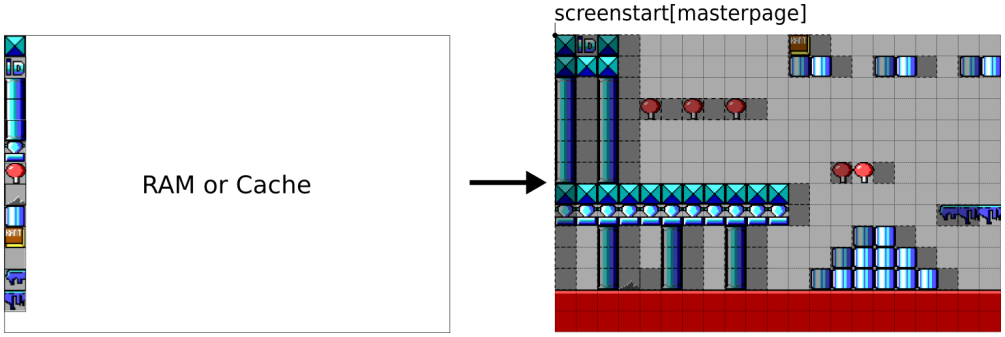


Figure 6: Step 2: Update changed tiles in masterscreen, marked in dark grey

Each tile of the buffer screen is compared with the tile on the corresponding level location. If the tile number has changed, the tile is updated by copying tile data from the asset location in memory into the corresponding location in the VRAM of the masterpage.

In parallel each tile in both tile buffer and display array will be marked with a ’1’, which means it needs to be updated upon next refresh.

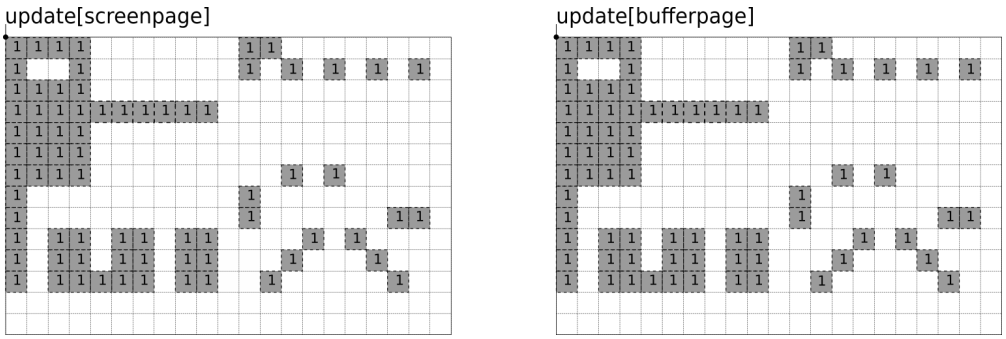


Figure 7: Mark all changed tiles with ’1’ in both tile buffer and display arrays.

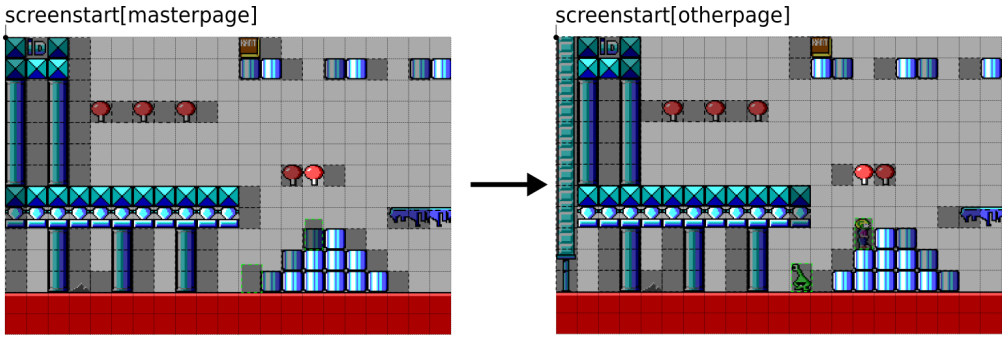


Figure 8: Step 3 and 4: Copy tiles from master to buffer screen and remove sprites

Scan all tiles in the tile buffer array and for each tile marked as '1', copy the tile from master to buffer page in VRAM.

If a sprite has moved, the previous sprite location is added to the block removal list. For each block in this list, erase the sprite by copying the width and height size of the sprite block (marked in green in Figure 8) from the master screen to the update screen, and mark the corresponding tiles only in the tile buffer array with a '2'.

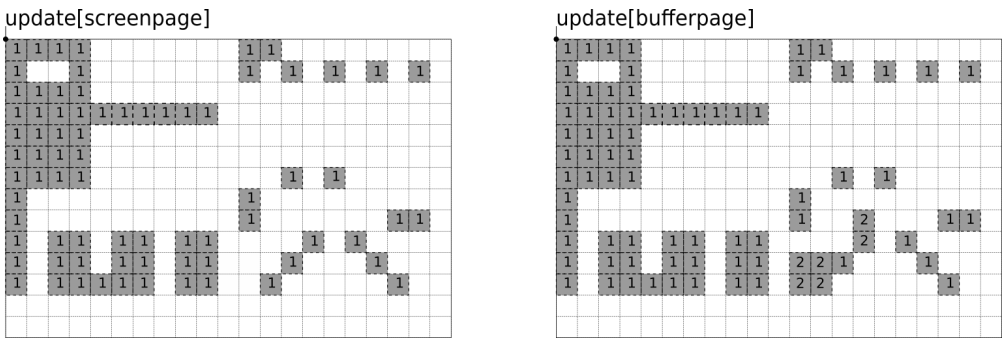


Figure 9: Mark removed sprites with '2' in tile buffer array only.

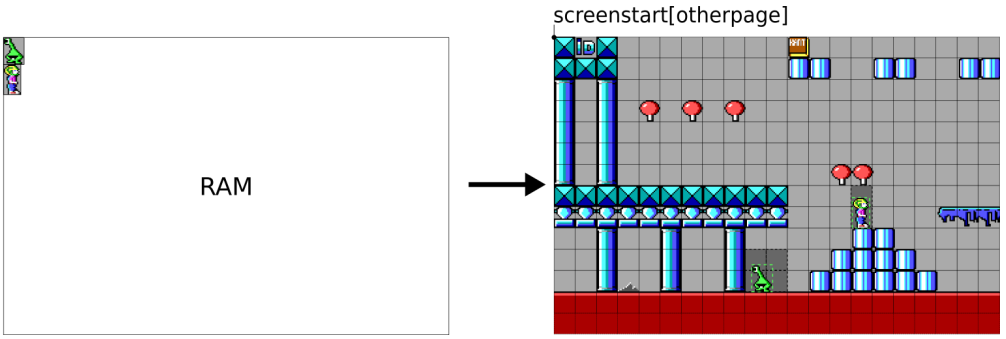
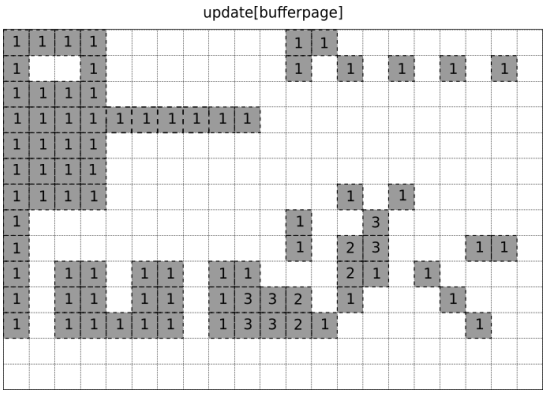


Figure 10: Step 5: Scan sprite list and copy sprite onto buffer screen

Scan the sprite list. Validate if the sprite is in the visible part of the view port and copy the sprite image into the VRAM buffer screen. Mark the corresponding tiles in the tile buffer array with a '3'.



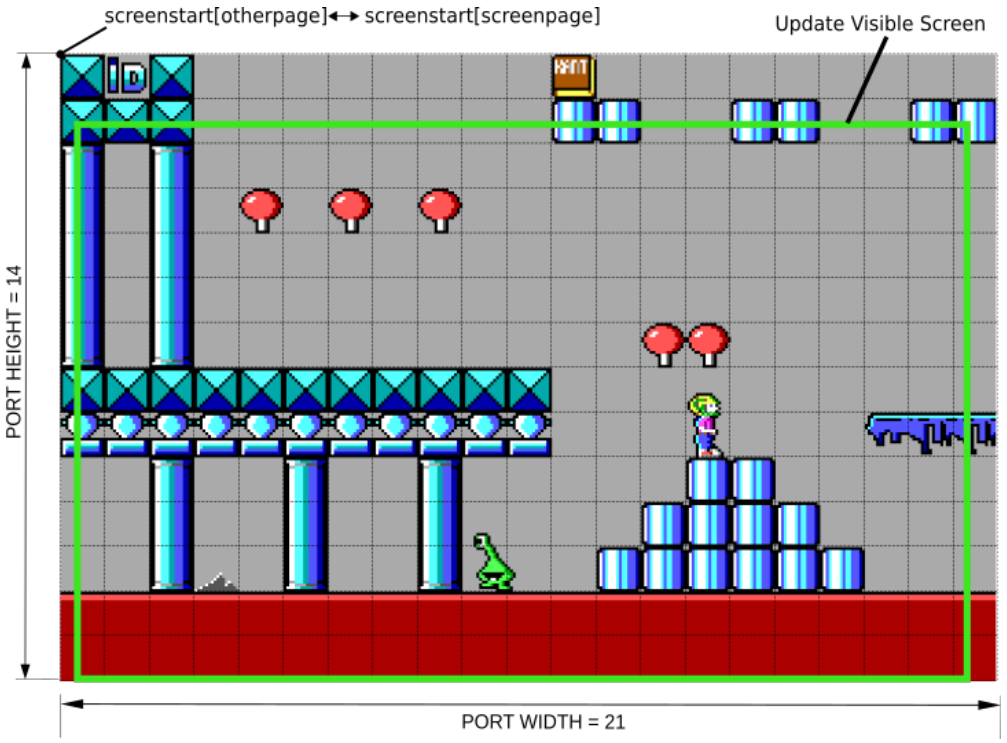
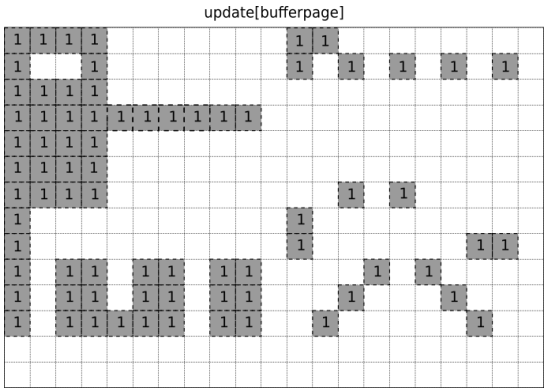


Figure 11: Step 6: Swap buffer and screen page

Point the visible screen towards the buffer screen by updating the CRTR start address and horizontal Pel Panning. The entire tile buffer array is cleared to '0'. Finally the buffer and screenpage of both the `screenstart[]` and `update[]` are swapped. Then step 1 is repeated.



Note that after swapping, the tile buffer now has marked all tiles that have changed from scrolling the screen. This makes sense as the current buffer video screen is not yet updated (it was displayed in the previous cycle, remember?).

Step 2 and 3 (except for the animated tiles) only needs to happen if Commander Keen is moving more than 16 pixels, where step 4 and 5 normally needs to happen for each refresh. So the number of drawing operations required during each refresh is controllable by the level designer. If they choose to place large regions of identical tiles (the large swathes of constant background), less redrawing (meaning: less redrawing in step 2 and 3) is required.

0.4.2 Wrap around the EGA Memory

In the later versions of Commander Keen, John Carmack explored what would happen if you push the virtual screen over de 64kB, or `0xFFFF`, border in video memory. It turned out that the EGA continues the virtual screen at `0x0000`. This means you could wrap the virtual screen around the EGA memory and only need to add a stroke of tiles on one of the edges when Commander Keen moved more than 16 pixels.

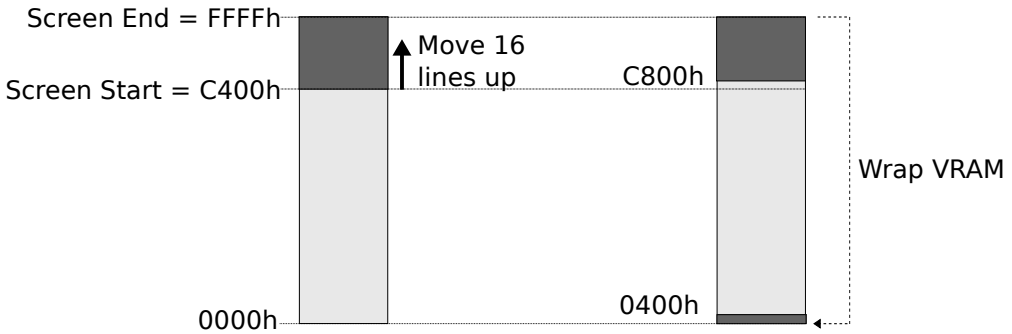
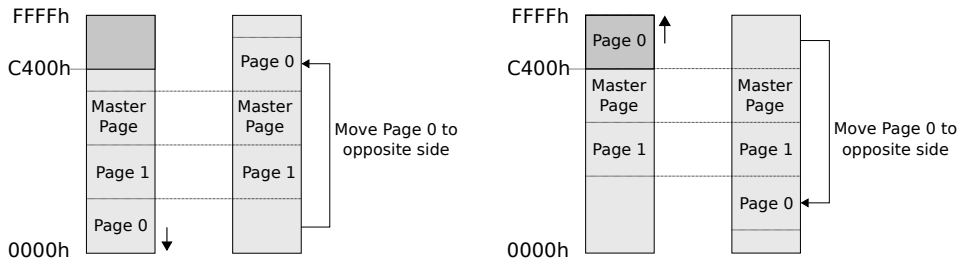


Figure 12: Wrap virtual screen around the EGA memory

There was however an issue with the introduction of Super VGA cards, which had typically more than 256kB RAM[2]. This resulted in crippled backwards compatibility and the wrapping around `0xFFFF` did not work anymore on these cards.

Luckily there was a way to resolve this issue. As you can see in Figure 4 the space between `0xB400` and `0xFFFF` is not used and contains enough space for another virtual screen. Each screen buffer has a size of `0x3C00`. In case the start address is between `0xC400` and `0xFFFF` the corresponsing screen is copied to the opposite end of the buffer, as illustrated in Figure 13.

[2] In 1989 the VESA consortium standardized an API to use Super VGA modes in a generic way. One of the first modes was 640x480 at 256 colors requiring >256kB RAM, which from a hardware constraint resulted in 512kB.



(a) Virtual pages moved down ***(b)*** Virtual pages moved up

Figure 13: Move screen to opposite end of VRAM buffer

The screen copy comes at the cost of some performance, but is not noticed during game play, also due to the fact that we can make use of copying 4 bytes in one cycle using the latches (as explain in section XXX).

```
#define SCREENSPACE    (SCREENWIDTH*240)
#define FREEEGAMEM     (0x10000l-31*SCREENSPACE)

screenmove = deltay*16*SCREENWIDTH + deltax*TILEWIDTH;
for (i=0;i<3;i++)
{
  screenstart[i]+= screenmove;
  if (compatability && screenstart[i] > (0x10000l-
   SCREENSPACE) )
  {
    //
    // move the screen to the opposite end of the buffer
    //
    screencopy = screenmove>0 ? FREEEGAMEM : -FREEEGAMEM;
    oldscreen = screenstart[i] - screenmove;
    newscreen = oldscreen + screencopy;
    screenstart[i] = newscreen + screenmove;
    // Copy the screen to new location
    VW_ScreenToScreen (oldscreen,newscreen,
       PORTTILESWIDE*2,PORTTILESHIGH*16);

    if (i==screenpage)
      VW_SetScreen(newscreen+oldpanadjust,oldpanx &
   xpanmask);
  }
}
```

0.4.3 Scroll and screen refresh in Keen Dreams

The EGA Memory wrapping results in the following improved algoritm to scroll and refresh the screen for Keen Dreams:

1. Check if the player has moved one tile in any direction.
2. In case the player moved one tile, add the respective column or row in the Master view in VRAM and flag the new tiles of column/row to be updated in the next refresh for both the screenpage and otherpage update list. Update the screenstart and tile buffer array pointers as well.
3. Refresh the buffer view by scanning all tiles. If a tile needs to be updated, copy the tile from the master view to the buffer view in VRAM.
4. Remove the opposite row/column from the Master view.
5. Iterate through the sprite removal list and copy corresponding image block from master view to buffer view in VRAM.
6. Iterate through the sprite list and copy corresponding sprite image block from asset location in RAM to buffer view in VRAM
7. Switch the screen and buffer view by adjusting the Start Address and Pel Panning registers.

As you can see, step 2 until 4 are different and the rest of the steps are the same as Commander Keen 1-3. In the next screenshots we explain only steps that are different compared to Commander Keen 1-3. In the case below the screen is forced to scroll to the left.

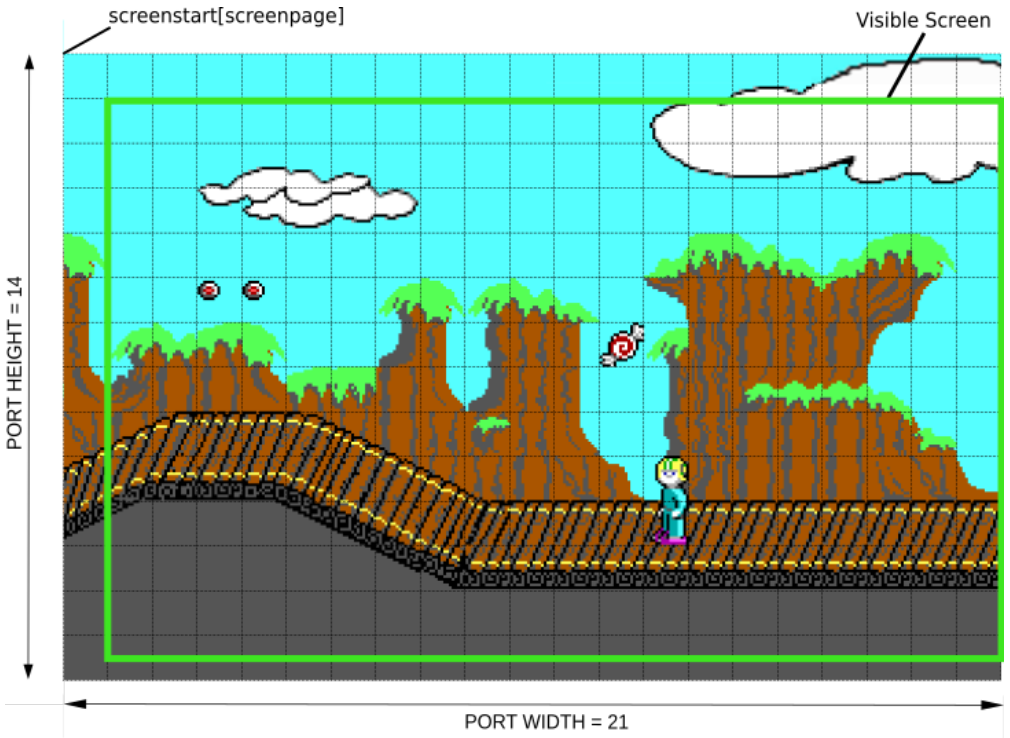


Figure 14: Step 1: Player moved to the left and forces the screen to scroll

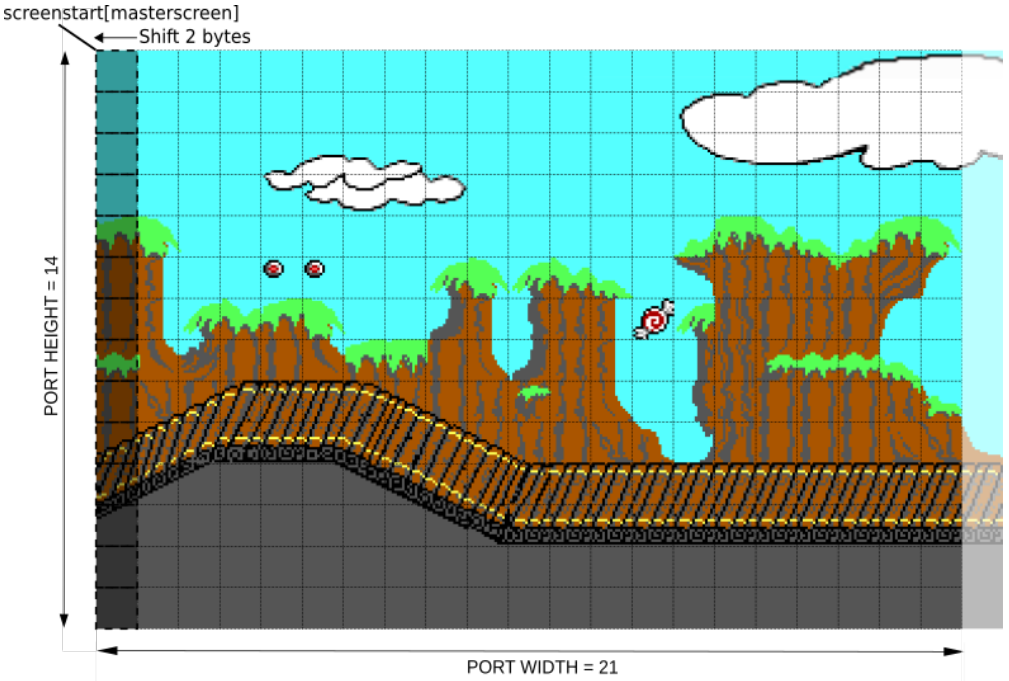
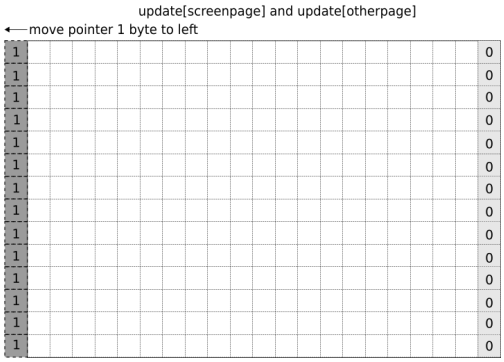


Figure 15: Step 2: Move screen start and add column to VRAM

First decrease the screenstart of all three screen locations 2 bytes (1 tile). Then copy a left-column of tiles from the asset location in memory into the corresponding location in the VRAM of the masterscreen.

In parallel decrease both tile buffer array pointers one byte and mark each tile on the left border in both buffer arrays with '1', so it is updated upon the next refresh. Finally, the most right column (which is now outside the view port) is marked with a '0'.



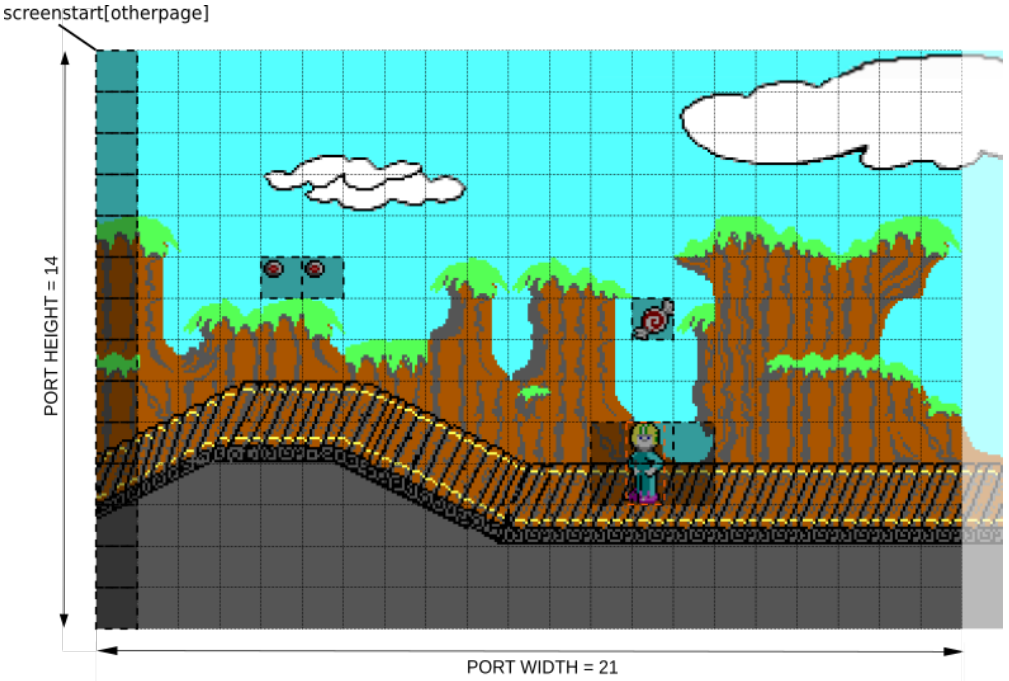
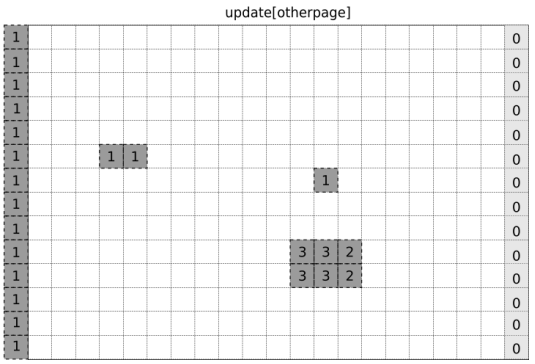


Figure 16: Step 2: Update sprites

The sprite update steps are the same as Commander Keen 1-3, meaning removal blocks will be marked with a '2' in the tile buffer array and copied from the master to the buffer screen and visible sprites are copied to the buffer screen and marked with a '3' in the tile buffer array.



Trivia : The removal blocks which are marked '2' in the tile buffer array are nowhere used in the engine .

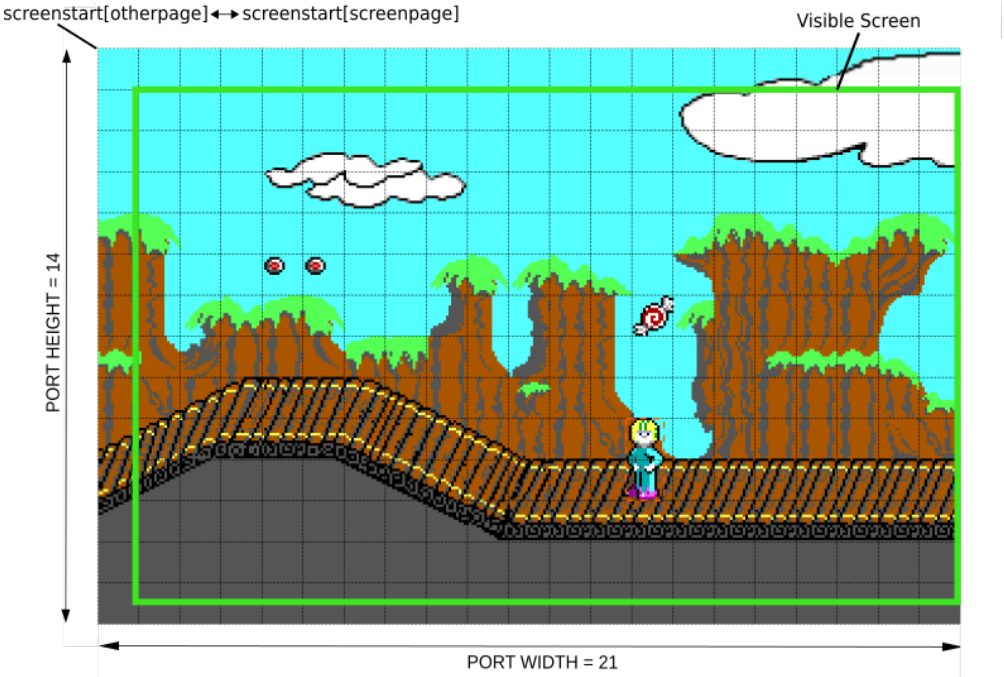
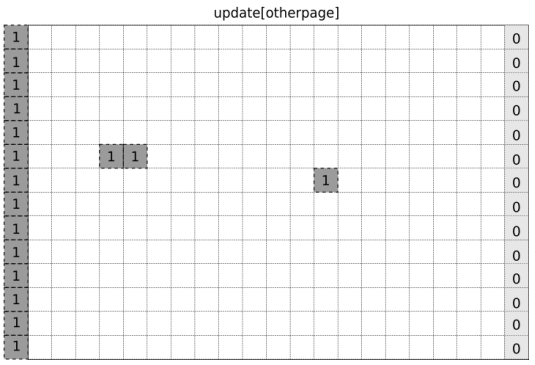


Figure 17: Step 6: Swap buffer and screen page

In the final step point the visible screen to the buffer screen by updating the CRTR start address and horizontal Pel Panning. The entire tile buffer array is cleared to '0'. Finally the buffer and screenpage of both the `screenstart[]` and `update[]` are swapped. Then step 1 is repeated.



As before, in the tile buffer array already tiles are marked by '1' (since the screenpage was not yet updated).

We now can also see why the tile array buffer is 2 tiles wider on all sides than the view port. Let's take the situation where the screen needs to scroll to the top-left, meaning 1 tile left and 1 tile up as illustrated in Figure 18. Both `*updatestart` pointers are updated and tiles are marked as '1'. After completing all tile refresh steps, the buffer screen is updated on places where the tile buffer array is marked '1'.

After the visible screen is swapped with the buffer screen, the `*updatestart[otherpage]` pointer is cleared and the pointer is resetted. However, the `*updatestart[screenpage]` is not cleared nor resetted since we did not update the screenpage (we only updated the buffer screen).

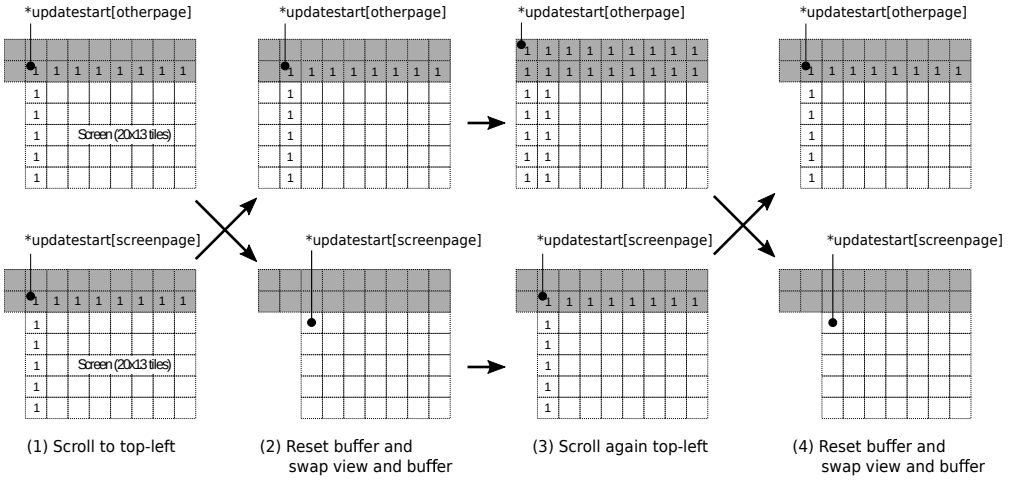


Figure 18: scroll to top-left tile

Now, if the screen needs again to scroll to the top-left you can see why we need the 2nd row for the buffer. The process will repeat, but after this cycle the `*update[otherpage]` is cleared and resetted.

0.5 Refresh video screen

Here explain with code. Focus on when to perform screen refresh (waiting for vertical retracement)

0.6 A.I.

To simulate enemies, some objects are allowed to "think" and take actions like firing, walking, or emitting sounds. These thinking objects are called "actors". Actors are programmed via a state machine. They can be aggressive, sneaky, or dumb (XXX for instance). To model their behavior, all enemies have an associated state:

0.7 Drawing Sprites

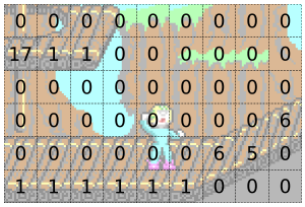
Explain how animation are performed. Should we somehow also explain sprites on other systems, like Nintendo, etc.?
Once the state of the actor is updated, it is time to render the actor on the screen. This is a two step operation.

1. Update the state and move actors within the active region.
2. Determinate if a actor has changed or moved
3. Update the actor by removing and drawing sprites to it's new position

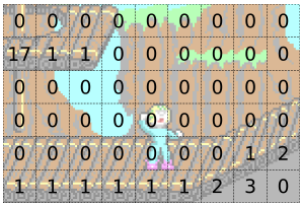
0.7.1 Visible actor determination

0.7.2 Clipping

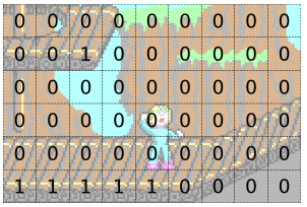
Before we draw a sprite on the screen, the engine determines if the boundaries of a sprite are hitting a wall or floor. This is called clipping and ensures an actor doesn't fall through a floor or walks through a vertical wall.
To define whether a tile is a wall or floor, a tile can be enriched with wall information. For each level map the tile info variable `tinf` contains a `NORTHWALL`, `SOUTHWALL`, `EASTWALL` and `WESTWALL` map as illustrated in Fig 19.
When the sprite boundary is hitting a wall on the right (east), it will update the sprite movement to ensure the sprite right boundary is equal to the right side of the tile as illustrated in Fig. XX. The east/west wall clipping logic is covered by `ClipToEastWalls (objtype *ob)` and `ClipToWestWalls (objtype *ob)`.



(a) Tile info map NORTHWALL



(b) Tile info map SOUTHWALL



(c) Tile info map EASTWALL

Figure 19: Tile clipping map

```
void ClipToEastWalls (objtype *ob)
{
    ...

  for (y=top;y<=bottom;y++)
  {
    map = (unsigned far *)mapsegs[1] +
      mapbwidthtable[y]/2 + ob->tileleft;

    //Check if we hit EAST wall
    if (ob->hiteast = tinf[EASTWALL+*map])
    {
      //Clip left side actor to left side
      //of next right tile
      move = ( (ob->tileleft+1)<<G_T_SHIFT ) - ob->left;
      MoveObjHoriz (ob,move);
      return;
    }
  }
}
```

The clipping for top and bottom is a bit more complex, as the engine also needs to take walking on slopes into account. After the sprite is clipped to the top or bottom of the wall tile, an offset can be applied to move a sprite up or down a slope.

```
// walltype / x coordinate (0-15)

int wallclip[8][16] = {      // the height of a given point in a tile
{ 256, 256, 256, 256, 256, 256, 256, 256, 256, 256, 256, 256, 256, 256, 256, 256},
{   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0},
{   0,0x08,0x10,0x18,0x20,0x28,0x30,0x38,0x40,0x48,0x50,0x58,0x60,0x68,0x70,0x78},
{0x80,0x88,0x90,0x98,0xa0,0xa8,0xb0,0xb8,0xc0,0xc8,0xd0,0xd8,0xe0,0xe8,0xf0,0xf8},
{   0,0x10,0x20,0x30,0x40,0x50,0x60,0x70,0x80,0x90,0xa0,0xb0,0xc0,0xd0,0xe0,0xf0},
{0x78,0x70,0x68,0x60,0x58,0x50,0x48,0x40,0x38,0x30,0x28,0x20,0x18,0x10,0x08,   0},
{0xf8,0xf0,0xe8,0xe0,0xd8,0xd0,0xc8,0xc0,0xb8,0xb0,0xa8,0xa0,0x98,0x90,0x88,0x80},
{0xf0,0xe0,0xd0,0xc0,0xb0,0xa0,0x90,0x80,0x70,0x60,0x50,0x40,0x30,0x20,0x10,   0}
};
```

When a sprite is clipped to a top or bottom tile, the corresponding midpoint pixels (0-15) and tile info map defines the offset from this top or bottom tile.

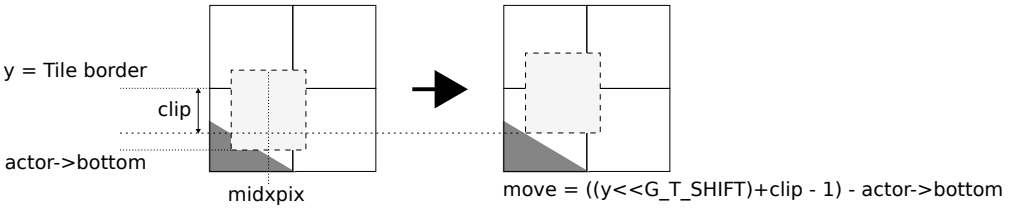


Figure 20: Clipping NORTHWALL

```
void ClipToEnds (objtype *ob)
{
  ...

  midxpix = (ob->midx&0xf0) >> 4;

  map = (unsigned far *)mapsegs[1] +
    mapbwidthtable[oldtilebottom-1]/2 + ob->tilemidx;
  for (y=oldtilebottom-1 ; y<=ob->tilebottom ; y++,map+=
   mapwidth)
  {
    //Do we hit a NORTH wall
    if (wall = tinf[NORTHWALL+*map])
    {
      //offset from tile border clip
      clip = wallclip[wall&7][midxpix];
      //Clip bottom side actor to top side tile + offset-1
      move = ( (y<<G_T_SHIFT)+clip - 1) - ob->bottom;
      if (move<0 && move>=maxmove)
      {
        ob->hitnorth = wall;
        MoveObjVert (ob,move);
        return;
      }
    }
  }
```