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TRABALHO DE MICROELETRÔNICA 1
PROJETO APLICATIVO

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TRABALHO DE MICROELETRÔNICA 1
PROJETO APLICATIVO

Trabalho de laboratório orientado pela professora Doutora Sibilla França, da disciplina de Microeletrônica I, do curso de Engenharia Elétrica da Universidade Federal do Paraná.

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SUMÁRIO

INTRODUÇÃO

Este projeto aplicativo fundamenta-se no conhecimento adquirido em sala de aula, na matéria de Microeletrônica 1, do curso de Engenharia Elétrica da Universidade Federal do Paraná, matéria ministrada pela Professora Doutora Sibilla França.

A proposta deste relatório é documentar e formalizar o projeto desenvolvido para a conclusão da matéria. O qual tem por objetivo aplicar todos os conceitos vistos e apresentados em sala de aula sobre VHDL. Serão realizadas simulações prévias para verificar o funcionamento do código, também será implementado o circuito e feito *upload* para o kit de desenvolvimento.

Para executar esta tarefa será utilizado um computador, cabo USB e uma placa FPGA Nexys 2 Spartan 3 e os softwares Xilinx ISE e Digilent Adept 2.

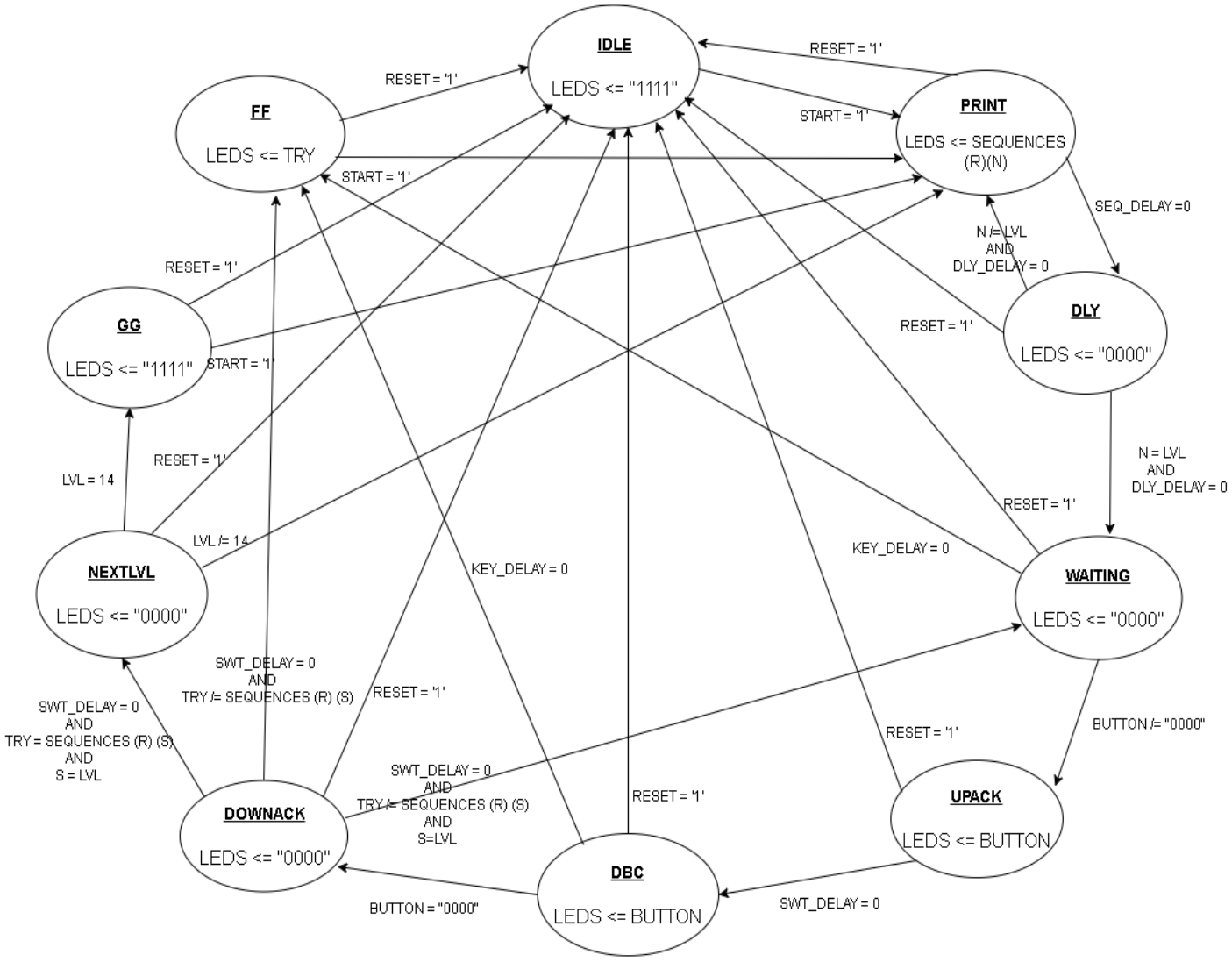
OBJETIVO

O objetivo deste projeto é utilizar o software Xilinx ISE para criar o código em VHDL que cumpra o desafio proposto.

Neste projeto a tarefa é implementar o jogo Genius em FPGA. O projeto deverá cumprir os seguintes requisitos: Ao ligar o dispositivo, uma mensagem de inicialização deverá ser apresentada nos displays de 7 segmentos: “PROJETO APLICATIVO - ED”. Um rolamento das letras através dos 4 displays deverá garantir a visualização da mensagem inicial; O início do jogo se dará através do acionamento de um botão do kit; Para representar as quatro cores deverá ser utilizado os quatro leds do kit NEXYS2; Disponibilizar a primeira sequência e verificar se o jogador pressionou o botão correto (por exemplo, LED0 – SW0) dentro do tempo máximo de 5 segundos; Repetir o primeiro sinal e acrescentar mais um (utilizar 14 sequências). Verificar a sequência inserida pelo jogador; A cada acerto, o jogador soma 01 ponto. Esta pontuação deverá ser mostrada nos displays de 7 segmentos e em um monitor com resolução de 800x600 (usar saída VGA do kit); No monitor, também deverá ser exibida a sequência luminosa, utilizando as cores verde, amarelo, azul e vermelho; O acionamento de um mecanismo mecânico do kit deverá permitir a reinicialização do dispositivo de forma a iniciar-se novo; O botão INICIAR não reinicia o jogo; Utilizar dois switches para selecionar o nível de dificuldade do jogo (00 – fácil, 01 – médio, 10 – difícil); Se o jogador acertar todas as sequências, uma mensagem deve aparecer nos displays de 7 segmentos indicando que o jogador ganhou como, por exemplo, “PARABENS”; A mensagem também deve aparecer no monitor (ou as iniciais da mensagem); Se o jogador errar alguma das sequências, uma mensagem deve aparecer nos displays de 7 segmentos indicando que o jogador perdeu como, por exemplo, “GAME OVER”. Um rolamento das letras através dos 4 displays deverá garantir a visualização da mensagem final.

1. ELABORAÇÃO DA MÁQUINA DE ESTADOS

A fim de definir os estados, condições de transição e valores de saída para cada momento do jogo, o diagrama a seguir foi desenvolvido exemplificando o funcionamento do projeto, buscando cumprir o objetivo proposto.



Buscando melhor organizar o código e a máquina de estados em si, foram criados um total de 10 estados responsáveis por controlar o andamento do jogo e decidir, mediante a alterações na entrada, qual será o próximo estado do sistema. Para não sobrecarregar um estado com muitas funções, tal divisão foi realizada de forma que cada estado possuisse um objetivo específico bem definido e assim pudesse ser melhor compreendido e testado durante as etapas de desenvolvimento e simulação.

2. DESENVOLVIMENTO

2.1. JOGO GENIUS

Para o desenvolvimento do projeto aplicativo do jogo Genius, foram implementados 2 *packages*, 3 *modules*, 1 *testbench* e 1 *implementation constraints file*. Os trechos mais relevantes de alguns desses códigos serão comentados neste capítulo. Todos estes códigos VHDL encontram-se na íntegra na sessão de anexos deste relatório.

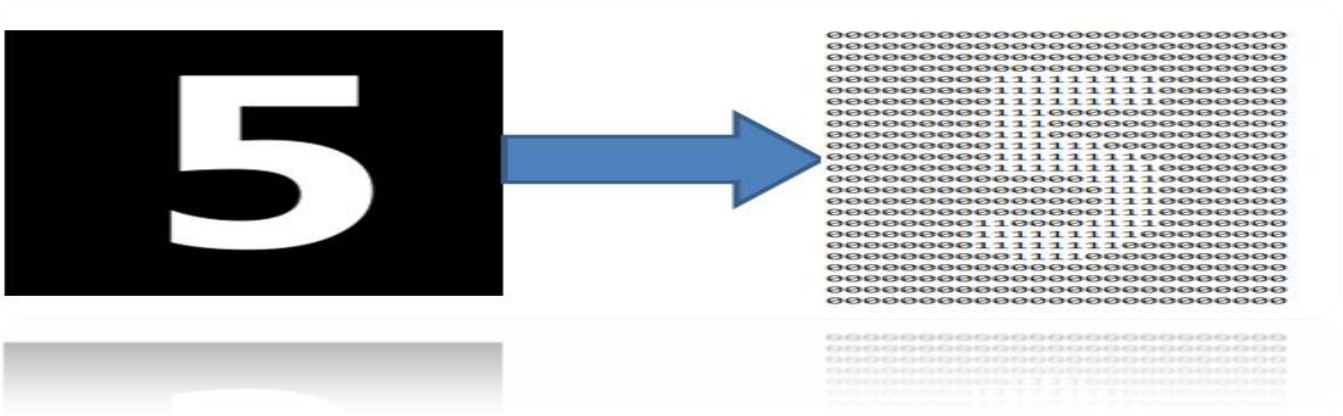
2.1.1. Rom_characters.vhd

```
1  -- Package que define as constantes com o desenho de cada um dos caracteres utilizados
2  -- Números: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
3  -- Letras: F, G
4  -- Constantes de 200x200 pixels
5
6  library IEEE;
7  use IEEE.STD_LOGIC_1164.all;
8
9  package rom_characters is
10
11    constant h: integer := 200;
12    constant v: integer := 200;
13    type char_data is array (0 to v-1) of std_logic_vector (0 to h-1);
14
15    constant zero: char_data := (
16 "00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
17 "00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
18 "00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
19 "00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
20 "00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

Este *package* define um *type* chamado “char_data” que cria um arranjo de vetores, visando criar uma memória com o desenho de cada um dos caracteres utilizados na exibição do placar e de siglas no VGA (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, G, F). Cada caractere possui 200x200 *pixels* e foi primeiramente desenhado, para então ser convertido em um desenho em texto formado por bits ‘0’ e ‘1’, que representam as áreas em preto e em branco, respectivamente, a serem mostradas na tela de jogo.

O esquema a seguir exemplifica este processo, que foi realizado com auxílio do software Gimp[4] e o site Dcode[5].

Conversão de imagem para matriz binária



2.1.2. Global_pack.vhd

Parte 1

```
1  -- Package global que implementa os tipos necessários no projeto, bem como procedures e constantes
2
3  library IEEE;
4  use IEEE.STD_LOGIC_1164.all;
5  use work.rom_characters.all;
6
7  package global_pack is
8
9     type states is (idle, print, dly, waiting, upack, dbc, downack, nextlvl, gg, ff); -- Estados da máquina
10    type pa_ed is array (22 downto 0) of std_logic_vector (6 downto 0); -- Arranjo da mensagem inicial
11    type score is array (3 downto 0) of std_logic_vector (6 downto 0); -- Arranjo da pontuação
12    type enable is array (3 downto 0) of std_logic_vector (3 downto 0); -- Arranjo dos estados dos anodos
13    type sequence is array (14 downto 0) of std_logic_vector (3 downto 0); -- Arranjo de uma sequência
14
15    -- Constantes que definem as sequências possiveis de 14 cores para o jogo
16    constant seq0: sequence := ("0001","1000","0001","0010","0100","1000","1000",
17    "0100","0010","0001","0001","0010","0100","1000", "0000");
18
19    constant seq1: sequence := ("0001","1000","0001","0010","0100","0010","0100",
20    "1000","0001","1000","0001","0100","0010","1000", "0000");
21
22    constant seq2: sequence := ("0010","1000","0001","0010","0100","0010","1000",
23    "0100","1000","0001","0001","0010","0100","0001", "0000");
24
25    constant seq3: sequence := ("0100","0010","0001","0010","1000","1000","0100",
26    "0001","0010","1000","0001","0010","0100","0100", "0000");
27
28    constant seq4: sequence := ("0001","0001","1000","0010","0100","1000","1000",
29    "1000","0010","0100","0001","0010","0100","0010", "0000");
30
31    constant seq5: sequence := ("0100","1000","0010","0010","0100","1000","1000",
32    "0100","0010","0001","1000","0010","0001","0001", "0000");
33
34    constant seq6: sequence := ("1000","0010","0010","0010","0100","1000","0001",
35    "0100","1000","0100","0001","0010","0100","0100", "0000");
36
37    constant seq7: sequence := ("0001","1000","0010","0010","0100","1000","1000",
38    "0100","0001","0010","0001","0001","1000","1000", "0000");
39
40    constant seq8: sequence := ("0010","0001","0100","0001","0010","1000","0100",
41    "0100","1000","0001","1000","0010","0100","0010", "0000");
42
43    constant seq9: sequence := ("0100","1000","0001","0010","0010","1000","0001",
44    "0100","1000","0001","0010","0001","0100","0001", "0000");
45
46    type mult_seq is array (9 downto 0) of sequence; -- Arranjo das 10 sequências pré-definidas
47
48    constant sequences: mult_seq := (seq9, seq8, seq7, seq6, seq5, seq4, seq3, seq2, seq1, seq0);
49
50    -- Declaração da procedure que imprime os caracteres na região superior do monitor
51    procedure characters (h_count, v_count: in integer;
52                          first_char, secon_char: in char_data;
53                          red: out std_logic_vector (2 downto 0);
54                          green: out std_logic_vector (2 downto 0);
55                          blue: out std_logic_vector (1 downto 0));
56
57 end global_pack;
```

O *global_pack* trata-se de um *package* criado com o intuito de definir alguns novos *types* necessários ao projeto, bem como reunir e organizar constants e disponibilizar uma procedure que é utilizada muitas vezes dentro do component responsável pela parte de VGA do projeto.

(continuação)

O *type* “states” define os estados da máquina que controlaram o andamento do jogo.

O *type* “pa_ed” define um arranjo que corresponde ao código para mostrar a mensagem inicial “Projeto Aplicativo – ED” nos displays de sete segmentos.

O *type* “score” é um arranjo para exibição da pontuação do jogador nos displays de sete segmentos.

O *type* “enable” é um arranjo para multiplexação dos anodos dos displays, já que os catodos dos mesmos são curto-circuitados.

O *type* “sequence” é um arranjo que cria um vetor em que cada posição é um nibble, correspondente a uma das cores e ao estado dos LEDs na saída. Este type implementa as sequências do jogo.

Por último, o *type* “sequences” é um arranjo do *type* “sequence” criado anteriormente, o que cria uma matriz com dez possibilidades de sequências, que foram criadas e definidas como constants. Sendo assim, ganha-se uma maior dinâmica no jogo já que o jogador não ficará preso a uma única sequência de cores que seria facilmente memorizada.

Parte 2

```
59  package body global_pack is
60
61     -- Procedure que recebe os valores de caracteres e estabelece a lógica para impressão na tela
62     procedure characters (h_count, v_count: in integer;
63                           first_char, secon_char: in char_data;
64                           red: out std_logic_vector (2 downto 0);
65                           green: out std_logic_vector (2 downto 0);
66                           blue: out std_logic_vector (1 downto 0)) is
67
68     begin
69
70        if (h_count>250 and h_count<400 and v_count>50 and v_count<250) then
71           if (first_char(v_count-50)(h_count-225)='1') then
72              red := (others => '1');
73              green := (others => '1');
74              blue := (others => '1');
75           else
76              red := (others => '0');
77              green := (others => '0');
78              blue := (others => '0');
79           end if;
80        elsif (h_count>400 and h_count<550 and v_count>50 and v_count<250) then
81           if (secon_char(v_count-50)(h_count-375)='1') then
82              red := (others => '1');
83              green := (others => '1');
84              blue := (others => '1');
85           else
86              red := (others => '0');
87              green := (others => '0');
88              blue := (others => '0');
89           end if;
90        end if;
91
92     end characters;
93
94  end package body;
```

A *procedure* descrita no *package body* acima realiza a função de posicionar números e letras no monitor, para exibição do placar e das siglas de vitória e derrota. Para tal, ela requer quais serão os dois caracteres e qual é contagem horizontal e vertical do VGA.

2.1.3. Genius.vhd

Parte 1

```
 6  library ieee;
 7  use ieee.std_logic_1164.all;
 8  use work.global_pack.all;
 9
10  entity Genius is
11
12     generic ( d: integer := 5000000; -- Tempo de 100 ms
13               p: integer := 500000; -- Tempo de 10 ms
14               e: integer := 50000000; -- Tempo de 1 s
15               m: integer := 25000000; -- Tempo de 500 ms
16               h: integer := 10000000; -- Tempo de 200 ms
17               T: integer := 250000000); -- Tempo de 5 s
18     port ( clk, start, reset: in std_logic; -- Clock, Start e Reset
19            diff: in std_logic_vector (1 downto 0); -- Chaves seletoras de dificuldade
20            button: in std_logic_vector (3 downto 0); -- Push-buttons do jogo
21            display: out std_logic_vector (6 downto 0); -- Segmentos dos displays
22            anode: out std_logic_vector (3 downto 0); -- Anodos dos displays
23            leds: out std_logic_vector (3 downto 0); -- Leds de visualização
24            h_sync: out std_logic; -- Sinal de sincronização horizontal
25            v_sync: out std_logic; -- Sinal de sincronização vertical
26            red: out std_logic_vector (2 downto 0); -- Bits vermelho do VGA
27            green: out std_logic_vector (2 downto 0); -- Bits verde do VGA
28            blue: out std_logic_vector (1 downto 0) ); -- Bits azul do VGA
29
30  end Genius;
```

Neste trecho inicial do código principal, são declarados alguns valores do tipo GENERIC, para definição de constantes de tempo a serem utilizadas no projeto. São eles:

d – Tempo utilizado para promover um delay entre a exibição de uma cor e outra (100ms);
p – Tempo de debouncing no reconhecimento das transições dos push-buttons (10ms);
e – Tempo de exibição de cada cor para a dificuldade fácil (1s);
m – Tempo de exibição de cada cor para a dificuldade média (0,5s);
h – Tempo de exibição de cada cor para a dificuldade difícil (0,2s);
T – Tempo limite de espera por uma entrada do jogador (5s).

Além disso, as entradas e saídas do jogo são declaradas, de acordo com as especificações do kit de desenvolvimento e do projeto:

ENTRADAS: Clock, chave de start, chave de reset, chaves seletoras da dificuldade do jogo e botões para repetição da sequência por parte do jogador (1 botão para cada cor).

SAÍDAS: Catodos dos segmentos dos displays, anodos dos displays, LEDs (1 para cada cor), sincronização horizontal do VGA, sincronização vertical do VGA e os bits para cada uma das cores do RGB (3 para vermelho e verde, 2 para o azul, cujo o olho humano é menos sensível).

Parte 2

```
69  begin
70
71      -- Processo que implementa a lógica de estados do jogo
72      process(clk, pr_state, reset, start, seq_delay, diff)
73      begin
74
75      if (reset = '1') then
76
77          pr_state<=idle; -- Estado inicial em espera do jogo
78
79      elsif (rising_edge(clk)) then
80
81          -- Verificação da posição das chaves de dificuldade e atribuição ao sinal
82          if ( diff="00" ) then
83              seq_delay<=e;
84          elsif ( diff="01" ) then
85              seq_delay<=m;
86          elsif ( diff="10" ) then
87              seq_delay<=h;
88          else
89              seq_delay<=e;
90          end if;
91
92          -- Case dos estados da máquina
93          case pr_state is
```

Devido a dificuldades encontradas na implementação prática de um código de máquinas de estado com dois process no kit de desenvolvimento, decidiu-se por implementar a máquina de estados utilizando somente um process.

No trecho em destaque, encontra-se a lógica que verifica se o reset do jogo foi acionado e, em caso, positivo, passa o estado da máquina para idle. Caso o reset não esteja pressionado e ocorra um pulso de subida do clock, verifica-se o estado das chaves seletoras de dificuldade e dependendo do seu estado o valor de tempo adequado é repassado para o signal responsável pela contagem. Isto permite que a dificuldade do jogo seja alterada a qualquer momento, caso o jogador julgue necessário.

Estado **idle**

```
95          -- Estado inicial de espera da máquina
96          when idle => leds<="1111";
97                       nibble<="1111";
98                       lvl<=1;
99                       n<=0;
100                      s<=1;
101                      r<=0;
102
103                      if ( start='1' ) then
104                        pr_state<=print;
105                      end if;
```

O estado *idle* é o estado inicial do jogo, no qual se aguarda que o usuário mude o modo da chave start para ‘1’. Enquanto em *idle*, os ponteiros relacionados a posição das sequências e chaves esperadas são mantidos em seus valores iniciais, e os LEDs permanecem todos acesos.

Estado **print**

```
116         -- Estado que imprime as posições das sequências pré-definidas
117         when print => leds<=sequences(r)(n);
118                       nibble<=sequences(r)(n);
119                       dly_delay<=d;
120                       try<="0000";
121
122                       if ( seq_delay>0 ) then
123                           seq_delay<=seq_delay-1;
124                       else
125                           pr_state<=dly;
126                       end if;
```

O estado *print* é responsável pela exibição da sequência do jogo nos LEDs do kit, através dos ponteiros “r” e “n”, que definem qual sequência e qual posição dela deverá ser mostrada, respectivamente. Através do *signal* “nibble”, este valor é repassado para o componente do VGA, que pode então decidir qual cor deverá ser exibida na tela, durante o tempo definido pela posição das chaves de dificuldade.

Estado **dly**

```
119         -- Estado de delay entre a impressão de cada cor
120         when dly => leds<="0000";
121                     nibble<="0000";
122
123                     if ( dly_delay>0 ) then
124                        dly_delay<=dly_delay-1;
125                     else
126                        if ( n=lvl ) then
127                           pr_state<=waiting;
128                        else
129                           pr_state<=print;
130                           n<=n+1;
131                        end if;
132                     end if;
```

O estado *dly* serve para inserir um pequeno *delay* entre a exibição de cada cor, permitindo que o jogador perceba caso ocorra de uma mesma cor se repetir. Além disso, este estado verifica se já foram impressas todas as cores devidas de acordo com o nível atual ou se o jogo deve voltar a imprimir mais cores.

Estado **waiting**

```
153         -- Estado que aguarda que o jogador pressione um botão
154         when waiting => leds<="0000";
155                         nibble<="0000";
156                         swt_delay<=p;
157
158                         if ( key_delay>0 ) then
159                           key_delay<=key_delay-1;
160                         else
161                           pr_state<=ff;
162                         end if;
163
164                         if ( button/="0000" ) then
165                           try<=button;
166                           pr_state<=upack;
167                         end if;
```

Após mostrar todas as cores necessárias, o jogo entra no estado *waiting* e aguarda que o jogador pressione algum botão, buscando repetir a sequência mostrada. Caso nenhum *push-button* seja pressionado dentro de 5s, o jogo vai para o estado de derrota, denominado *ff*. Se algum botão for pressionado, o estado dos *push-buttons* é armazenado no *signal try* e a máquina avança para o próximo estado.

Estado **upack**

```
169         -- Estado de debouncing para o reconhecimento da subida do botão
170         when upack => leds<=button;
171                       nibble<=button;
172
173                       if ( swt_delay>0 ) then
174                           swt_delay<=swt_delay-1;
175                       else
176                           pr_state<=dbc;
177                       end if;
```

No estado *upack*, o jogo aguarda que uma contagem de *debouncing* seja concluída, evitando que possíveis “repiques” sejam identificados como várias pressionadas do botão. Terminado esta contagem de 10ms, o jogo avança para o estado seguinte.

Estado **dbc**

```
179         -- Estado que aguarda que o jogador solte o botão pressionado
180         when dbc => leds<=button;
181                     nibble<=button;
182                     swt_delay<=p;
183
184                     if ( key_delay>0 ) then
185                        key_delay<=key_delay-1;
186                     else
187                        pr_state<=ff;
188                     end if;
189
190                     if ( button="0000" ) then
191                        pr_state<=downack;
192                     end if;
```

Em *dbc*, espera-se que o jogador solte o botão pressionado anteriormente, para que então o jogo avance. Caso o *push-button* pressionado não seja solto dentro do tempo de 5s (contado a partir do momento em que o jogo entra em *waiting*), o jogo irá para o estado de derrota. Se o botão seja liberado dentro do tempo, a máquina de estados avança.

Estado **downack**

```
194       -- Estado de debouncing para o reconhecimento da descida do botão
195       -- Este estado também verifica se o botão correto foi pressionado
196       when downack => leds<="0000";
197                       nibble<="0000";
198
199                       if ( swt_delay>0 ) then
200                         swt_delay<=swt_delay-1;
201                       else
202                         key_delay<=T;
203                         if ( try=sequences(r)(s) ) then
204                            if ( s=lvl ) then
205                               pr_state<=nextlvl;
206                            else
207                               s<=s+1;
208                               pr_state<=waiting;
209                            end if;
210                         else
211                            pr_state<=ff;
212                         end if;
213                       end if;
```

O estado *downack*, semelhante ao estado *upack*, realiza uma contagem de debouncing de 10ms após detectado que o botão voltou ao normal. Feito isso, é verificado se a tentativa do jogador, armazenada em *try*, está de acordo com o que fora impresso. Um ponteiro diferente, denominado “s”, é utilizado para controlar quantos botões espera-se que o jogador pressione a fim de repetir a sequência apresentada. Se a sequência estiver correta e for a última cor esperada, o jogo segue para *nextlvl*. Caso o botão pressionado pelo jogador esteja correto mas ainda não for o último esperado, o jogo volta para o estado *waiting*. Por fim, se o botão pressionado não for aquele da cor correspondente, o jogo vai para o estado de derrota.

Estado **nextlvl**

```
215       -- Estado que incrementa o nível atual do jogo
216       when nextlvl => leds<="0000";
217                       nibble<="0000";
218
219                       if ( lvl=14 ) then
220                         pr_state<=gg;
221                       else
222                         pr_state<=print;
223                         lvl<=lvl+1;
224                         n<=0;
225                         s<=1;
226                       end if;
```

O estado *nextlvl* verifica se o nível atual é o último e, em caso afirmativo, atualiza o estado da máquina para o estado *gg* de vitória. Caso o jogador tenha repetido a sequência com sucesso mas ainda existam níveis a serem jogados, o jogo volta para o estado *print* e o nível do jogo é incrementado, assim como os ponteiros voltam ao valor inicial.

Estado **gg**

```
219         -- Estado final de vitória
220         when gg => leds<="1111";
221                    nibble<="1111";
222
223                    if ( start='1' ) then
224                       pr_state<=print;
225                       key_delay<=T;
226                       lvl<=1;
227                       n<=0;
228                       s<=1;
229                       r<=r+1;
230                       if (r=9) then
231                          r<=0;
232                       end if;
233                    end if;
```

Quando em *gg*, o jogo encontra-se no estado de vitória e aguarda que o jogador mude o estado da chave *start* para ‘1’ de modo a recomeçar o jogo. Se isso acontecer, o nível do jogo volta para 1 e a sequência a ser jogada a seguir muda, pois o ponteiro “r” é incrementado.

Estado **ff**

```
235         -- Estado final de derrota
236         when ff => leds<=try;
237                    nibble<=try;
238
239                    if ( start='1' ) then
240                      pr_state<=print;
241                      key_delay<=T;
242                      lvl<=1;
243                      n<=0;
244                      s<=1;
245                      r<=r+1;
246                      if (r=9) then
247                         r<=0;
248                      end if;
249                    end if;
250
251         end case;
```

O estado *ff* é o estado de derrota do jogo, quando o jogador erra uma cor da sequência ou demora muito tempo para repeti-la. Da mesma forma como em gg, espera-se que *start* vá para ‘1’ para reinicializar o jogo e mudar a sequência a ser exibida nesta próxima rodada.

2.1.4. Decoder.vhd

Parte 1

```
1  library IEEE;
2  use IEEE.STD_LOGIC_1164.ALL;
3  use work.global_pack.all;
4
5  entity Decoder is
6
7     generic ( f: integer := 4000; -- Tempo de multiplexação
8               l: integer := 25000000); -- Clock de rolagem do display
9     port ( clk, reset: in std_logic; -- Clock, Reset
10           display: out std_logic_vector (6 downto 0); -- Segmentos dos displays (catodos)
11           anode: out std_logic_vector (3 downto 0); -- Anodos dos displays
12           pr_state: in states; -- Estado atual da máquina
13           lvl: in integer range 1 to 14); -- Nível atual do jogo
14
15 end Decoder;
```

No início do código do decoder para os displays de sete segmentos, tem-se a declaração das entradas e saídas do component. Cabe destacar os tempos de rolagem do display (0,5s) e o tempo para multiplexação dos anodos (80us).

(continuação...)

Os catodos e os anodos também são declarados, juntamente com as entradas oriundas do código principal, “pr_state” e “lvl” que repassarão o nível e estado atuais do jogo.

Parte 2

```
31  begin
32
33      -- Processo que realização a multiplexação e impressão dos valores nos displays
34      process(clk, lvl, reset, pr_state)
35      begin
36
37          if ( reset='1' ) then
38              i<=3;
39              j<=19;
40              count_l<=1;
41              count_f<=f;
42
43          elsif ( rising_edge(clk) ) then
44              count_f<=count_f-1;
45              count_l<=count_l-1;
46              if (count_f=0) then
47                  count_f<=f;
48                  i<=i-1;
49                  if (i=0) then
50                      i<=3;
51                  end if;
52              end if;
53              if (count_l=0) then
54                  count_l<=1;
55                  j<=j-1;
56                  if (j=0) then
57                      j<=19;
58                  end if;
59              end if;
60          end if;
```

Este *process* contém a lógica para multiplexação e rolamento da mensagem inicial nos displays de sete segmentos. Utilizando dois contadores, a multiplexação é realizada percorrendo as posições do vetor de enables que habilita cada um dos anodos por vez. Já a rolagem é feita somando-se um o signal “j” a variável “i”, o que promove um deslocamento dentro do vetor da mensagem das quatro posições que são exibidas nos displays.

Parte 3

```
62        -- Case que verifica o nível atual e repassa o valor adequado de pontuação para exibição
63        case lvl is
64
65              when 1 => pont <= ("1111111","0000001","0000001","1111111");
66
67              when 2 => pont <= ("1111111","0000001","1001111","1111111");
68
69              when 3 => pont <= ("1111111","0000001","0010010","1111111");
70
71              when 4 => pont <= ("1111111","0000001","0000110","1111111");
72
73              when 5 => pont <= ("1111111","0000001","1001100","1111111");
74
75              when 6 => pont <= ("1111111","0000001","0100100","1111111");
76
77              when 7 => pont <= ("1111111","0000001","0100000","1111111");
78
79              when 8 => pont <= ("1111111","0000001","0001111","1111111");
80
81              when 9 => pont <= ("1111111","0000001","0000000","1111111");
82
83              when 10 => pont <= ("1111111","0000001","0000100","1111111");
84
85              when 11 => pont <= ("1111111","1001111","0000001","1111111");
86
87              when 12 => pont <= ("1111111","1001111","1001111","1111111");
88
89              when 13 => pont <= ("1111111","1001111","0010010","1111111");
90
```

No *case* acima, tem-se a definição do que o signal “pont” irá receber com base no nível atual do jogo correspondente a pontuação, a fim de decodificar os números decimais para exibição nos displays. Este sinal será transmitido aos catodos caso se esteja num estado onde a pontuação deve ser exibida.

Parte 4

```
 95        -- Case que vericia o estado atual da máquina e o que deve ser exibido nos displays
 96        case pr_state is
 97
 98              when idle =>  display <= projeto_aplic(i+j);
 99
100              when ff => display <= gameover(i);
101
102              when gg => display <= win(i);
103
104              when others => display <= pont(i);
105
106        end case;
107
108        -- Atribuição aos anodos do modo atual para multiplexação
109        anode <= anodos(i);
110
111     end process;
112
113
114  end Behavioral;
```

Neste *case*, sensível ao estado presente da máquina, verifica-se o que os displays devem exibir no momento (mensagem inicial, pontuação, mensagem “GG” ou mensagem “FF”).

2.1.5. VGA.vhd

Parte 1

```
1  library ieee;
2  use ieee.std_logic_1164.all;
3  use work.global_pack.all;
4  use work.rom_characters.all;
5
6  entity VGA is
7
8    generic(
9      h_pulse  :  integer   := 120; -- Largura do pulso de sincronização horizontal em pixels
10     h_bp     :  integer   := 64; -- Largura do back porch horizontal em pixels
11     h_pixels :  integer   := 800; -- Largura de display horizontal em pixels
12     h_fp     :  integer   := 56; -- Largura do front porch horizontal em pixels
13     h_pol    :  std_logic := '1'; -- Polaridade da sincronização horizontal (1 = positiva, 0 = negativa)
14     v_pulse  :  integer   := 6; -- Largura do pulso de sincronização vertical em linhas
15     v_bp     :  integer   := 23; -- Largura do back porch vertical em linhas
16     v_pixels :  integer   := 600; -- Largura de display vertical em linhas
17     v_fp     :  integer   := 37; -- Largura do front porch vertical em linhas
18     v_pol    :  std_logic := '1'); --Polaridade da sincronização vertical (1 = positiva, 0 = negativa)
19
20   port(
21     clk       :  in   std_logic; -- Pixel clock
22     reset     :  in   std_logic;  -- Reset
23     nibble    :  in   std_logic_vector (3 downto 0); -- Estado dos leds
24     lvl       :  in   integer range 1 to 14; -- Nível atual do jogo
25     pr_state  :  in   states; -- Estado da máquina
26     h_sync    :  out  std_logic; -- Pulso de sincronização horizontal
27     v_sync    :  out  std_logic; -- Pulso de sincronização vertical
28     red       :  out  std_logic_vector (2 downto 0); -- Bits do vermelho do VGA
29     green     :  out  std_logic_vector (2 downto 0); -- Bits do verde do VGA
30     blue      :  out  std_logic_vector (1 downto 0)); -- Bits do azul do VGA
31
32 end VGA;
```

Tomando como base o controlador VGA em VHDL disponibilizado no site eewiki[3], e também o datasheet do kit de desenvolvimento nexys 2[6], desenvolveu-se um código para exibir as sequências de cores e pontuações do jogo através do VGA.

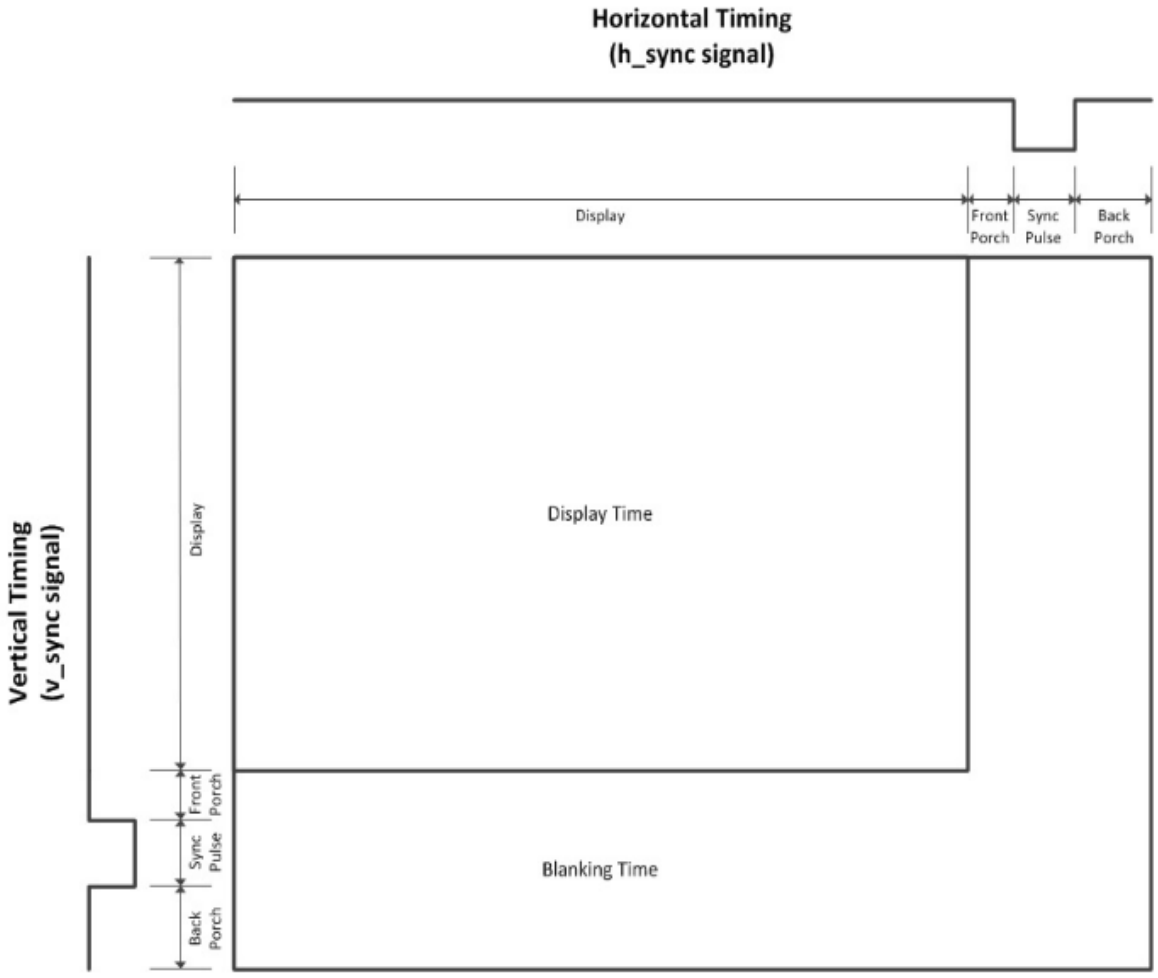
Foi decidido utilizar a resolução 800x600 (72Hz) para implementação do VGA já que tal resolução necessita de um *pixel clock* de 50Mhz, que coincide com o clock disponível no kit de desenvolvimento.

O VGA requer, fora os bits do RGB para definir cor do *pixel*, dois sinais de sincronização que permitem a correta atualização do monitor e varredura das linhas. O VGA funciona percorrendo uma linha completa e então avançando verticalmente para baixo, sendo assim, o sinal de sincronização horizontal ocorre com muito mais frequência que o vertical.

Fora o pulso de sincronização, existem dois intervalos de tempo, denominados de *back porch* e *front porch*, antes e depois do pulso de sincronização, em que nenhum *pixel* é atualizado. Todos esses tempos variam de resolução a resolução, bem como a polaridade do pulso. Sendo assim, os valores desses intervalos de tempo para a resolução escolhida, em função dos *pixels* e linhas, foram devidamente declarados como *generic,* tanto para a horizontal, como vertical.

Além disso, as entradas de clock e reset também foram declaradas, bem como as saídas (RGB e *sync*) e as entradas referente ao estado atual e ao nível do jogo, para permitir a implementação da lógica do que deve ser impresso na tela.

Esquemático de monitor VGA e sinais de sincronização



Este esquema[3] exemplifica melhor o funcionamento do sistema VGA descrito anteriormente, mostrando os tempos de display, *front porch,* pulso de *sync* e *back porch*. Quando estamos no "*Display Time"*, estamos no período de tempo em que os *pixels* recebem os dados RGB para formação da imagem. Em *"Blanking Time"*, nada é enviado para tela pois nos encontramos no tempo de atualização, onde é preciso manter os bits RGB em '0'.

Parte 2

```
34  architecture behavior of VGA is
35
36    constant  h_period  :  integer := h_pulse + h_bp + h_pixels + h_fp;
37    constant  v_period  :  integer := v_pulse + v_bp + v_pixels + v_fp;
38    shared variable h_count  :  integer range 0 to h_period - 1 := 0;
39    shared variable v_count  :  integer range 0 to v_period - 1 := 0;
40    shared variable red_var : std_logic_vector (2 downto 0) := ( others => '0');
41    shared variable green_var : std_logic_vector (2 downto 0) := ( others => '0');
42    shared variable blue_var : std_logic_vector (1 downto 0) := ( others => '0');
43
44  begin
45
46    process(clk, reset, pr_state)
47    begin
48
49      -- Reinicia o VGA em caso de reset
50      if(reset = '1') then
51        h_count := 0;
52        v_count := 0;
53        h_sync <= not h_pol;
54        v_sync <= not v_pol;
55
56      elsif(rising_edge(clk)) then
57
58        -- Contadores
59        if(h_count < h_period - 1) then
60          h_count := h_count + 1;
61        else
62          h_count := 0;
63          if(v_count < v_period - 1) then
64            v_count := v_count + 1;
65          else
66            v_count := 0;
67          end if;
68        end if;
69
70        -- Sincronização Horizontal
71        if(h_count < h_pixels + h_fp or h_count > h_pixels + h_fp + h_pulse) then
72          h_sync <= not h_pol;
73        else
74          h_sync <= h_pol;
75        end if;
76
77        -- Sincronização Vertical
78        if(v_count < v_pixels + v_fp or v_count > v_pixels + v_fp + v_pulse) then
79          v_sync <= not v_pol;
80        else
81          v_sync <= v_pol;
82        end if;
```

O *process* do VGA verifica a presença do *reset* e, em caso afirmativo, mantém a tela apagada, sem envio de nenhum sinal. Caso contrário, a contagem horizontal é atualizada a cada subida do clock e a contagem vertical a cada vez que se chega no fim da linha. Utilizando esses contadores, é possível determinar em que posição da área de display o sistema encontra-se e definir qual deve ser o valor do pulsos de sincronização e dos bits RGB.

Parte 3

```
84        -- Verifica se está dentro da área de impressao do display e implementa a lógica para cada estado
85        if(h_count < h_pixels and v_count < v_pixels) then
86
87           if (v_count>300) then
88              if (nibble="1000") then
89                 if (h_count<200) then
90                    red <= "111";
91                    green <= "000";
92                    blue <= "00";
93                 else
94                    red <= (others => '0');
95                    green <= (others => '0');
96                    blue <= (others => '0');
97                 end if;
98              elsif (nibble="0100") then
99                 if (h_count>200 and h_count<400) then
100                   red <= "000";
101                   green <= "000";
102                   blue <= "11";
103                else
104                   red <= (others => '0');
105                   green <= (others => '0');
106                   blue <= (others => '0');
107                end if;
```

Este trecho exemplifica como foi implementada a lógica para saber o que deve ser impresso na tela de acordo com a posição que estamos e a cor atual da sequência. Para isso, o *signal* “nibble” é utilizado, repassando o estado dos LEDs e por consequência qual cor deve ser impressa. Cada uma das cores possui uma região retangular 200x300 na parte inferior da tela.

2.2. ANÁLISE DOS RESULTADOS

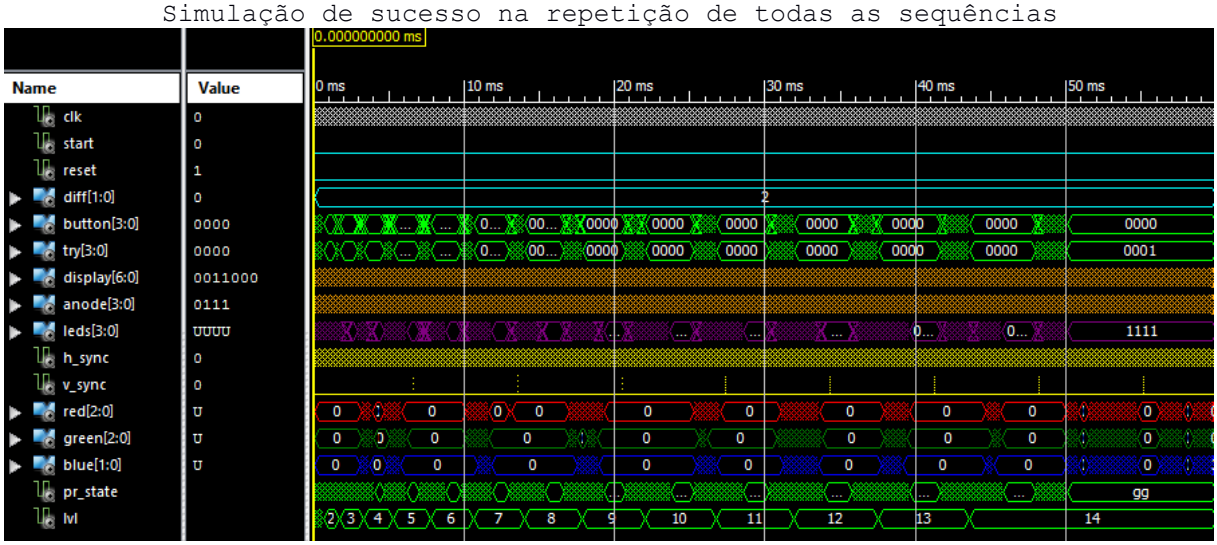
2.2.1. Testbench.vhd

```
114         reset<='1';
115         button<="0000";
116         diff<="00";
117         start<='0';
118         wait for 100 ns;
119         reset<='0';
120         diff<="10";
121         start<='1';
122         wait for 100 ns;
123         start<='0';
124         wait for 600 us;
125         button<="1000";
126         wait for 50 us;
127         button<="0000";
128         wait for 900 us;
129         button<="1000";
130         wait for 50 us;
131         button<="0000";
132         wait for 100 us;
133         button<="0100";
134         wait for 50 us;
135         button<="0000";
136         wait for 1200 us;
137         button<="1000";
138         wait for 50 us;
139         button<="0000";
140         wait for 100 us;
141         button<="0100";
```

O *testbench* do projeto completo foi implementado de modo a simular o pressionamento dos botões e das chaves de start e dificiculdade, verificando o comportamento do sistema de acordo com as mudanças de entrada.

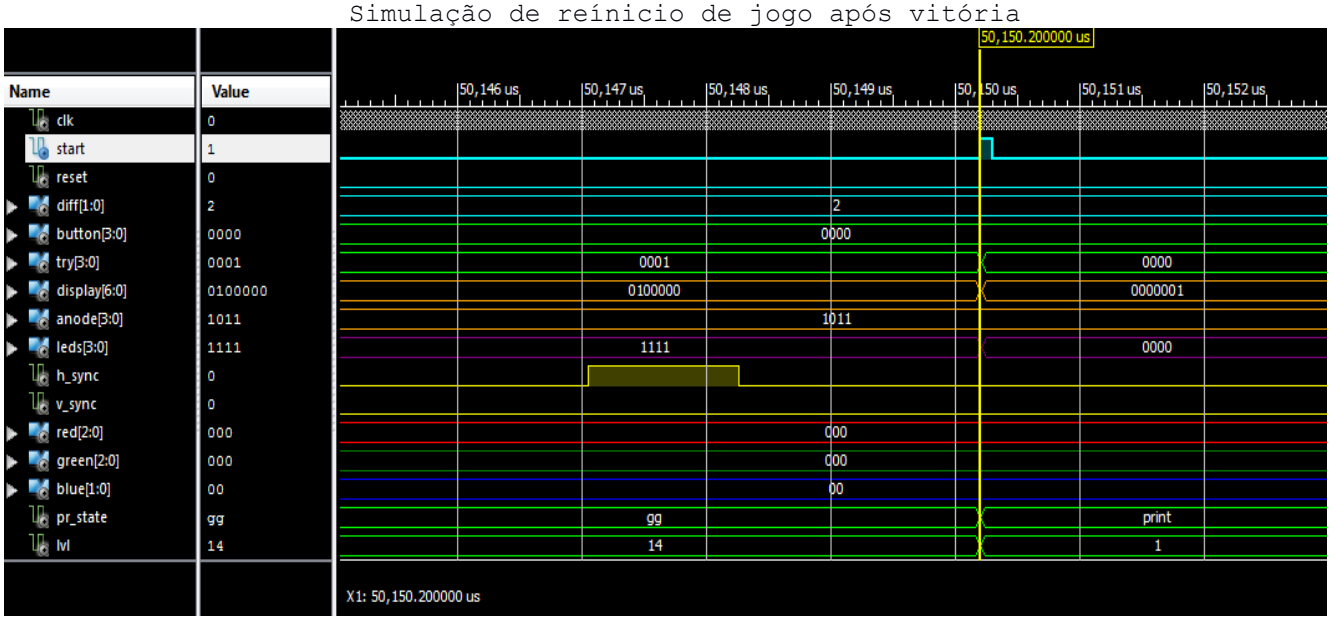
2.2.2. Simulações

Simulação de sucesso na repetição de todas as sequências



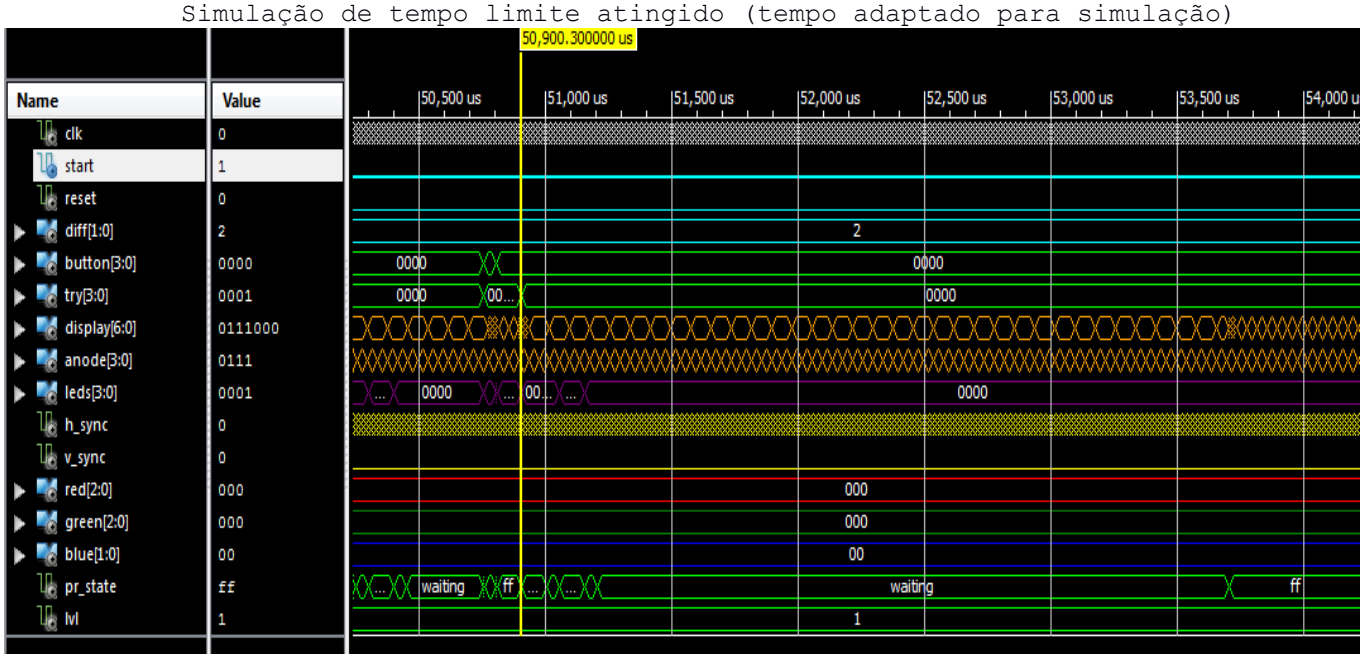
Esta primeira simulação verifica se o jogo evolui de maneira adequada ao receber corretamente as repetições das sequências de cores. Podemos verificar no último sinal (*lvl)* que o jogo avançou até o nível de dificuldade 14 e após se repetir a última sequência corretamente o jogo avançou e permaneceu no estado de vitória “gg”. É possível notar também que o tempo para avançar de nível aumenta progressivamente, já que mais tempo é despendido imprimindo a sequência de cores e mais tempo faz-se necessário para que o jogador repita a sequência utilizando os *push-buttons*. Um detalhe é a velocidade da ocorrência da sincronização horizontal do VGA em relação a vertical, conforme esperado.

Simulação de reínicio de jogo após vitória



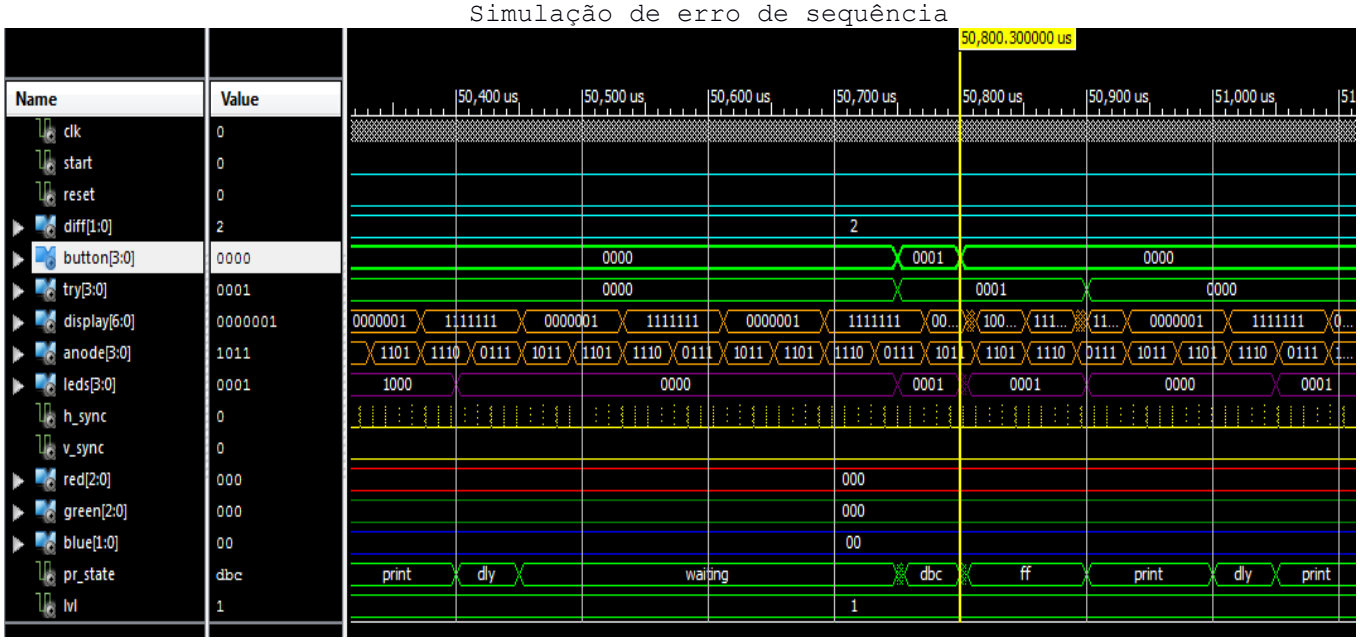
Nesta simulação verificou-se o reinício adequado do jogo após a vitória, onde a chave *start* tem seu estado alterado e então o jogo vai para o estado *print* conforme esperado. Pode-se ver também que o display zera a pontuação e notamos o pulso se sincronização horizontal ocorrendo. Além disso, vemos que os LEDs vão para “0000”, pois no ínicio de todas as sequências existe uma etapa a mais em que os LEDs permancem apagados, gerando um tempo para o jogador preparar-se para jogar equivalente ao de impressão de uma cor para o nível selecionado.

Simulação de tempo limite atingido (tempo adaptado para simulação)



Nesta simulação, verificou-se que após imprimir uma cor e aguardar o jogador por um tempo maior que o limite, o jogo automaticamente vai para o estado de derrota, pois nenhum botão foi pressionado dentro do intervalo especificado.

Simulação de erro de sequência



Nesta última etapa de testes, vericou-se que após um erro na repetição da sequência o jogo vai para o estado de derrota “ff”. No começo da simulação a esquerda, a sequência “1000” é mostrada pelos LEDs e após algum tempo o jogador pressiona o botão errado, enviando a tentativa como “0001”, que também é impressa, o que permite ao jogador visualizar que cor inseriu. Após o *debouncing* do botão, verificou-se o erro e mudou-se para o estado “ff”.

2.2.3 Análise de utilização de recursos

Genius Project Status (11/29/2016 - 00:44:08)			
Project File:	Genius.xise	**Parser Errors:**	No Errors
Module Name:	Genius	**Implementation State:**	Programming File Generated
Target Device:	xc3s500e-5fg320	**• Errors:**	No Errors
Product Version:	ISE 14.7	**• Warnings:**	No Warnings
Design Goal:	Timing Performance	**• Routing Results:**	All Signals Completely Routed
Design Strategy:	Performance without IOB Packing	**• Timing Constraints:**	All Constraints Met
Environment:	System Settings	**• Final Timing Score:**	0 (Timing Report)

Device Utilization Summary [-]				
Logic Utilization	**Used**	**Available**	**Utilization**	**Note(s)**
Number of Slice Flip Flops	1,355	9,312	14%	
Number of 4 input LUTs	5,254	9,312	56%	
Number of occupied Slices	2,743	4,656	58%	
Number of Slices containing only related logic	2,743	2,743	100%	
Number of Slices containing unrelated logic	0	2,743	0%	
Total Number of 4 input LUTs	5,280	9,312	56%	
Number used as logic	5,254			
Number used as a route-thru	26			
Number of bonded IOBs	34	232	14%	
Number of BUFGMUXs	1	24	4%	
Average Fanout of Non-Clock Nets	3.67			

Performance Summary [-]			
Final Timing Score:	0 (Setup: 0, Hold: 0)	**Pinout Data:**	Pinout Report
Routing Results:	All Signals Completely Routed	**Clock Data:**	Clock Report
Timing Constraints:	All Constraints Met		

Após compilado e implementado o *design* do projeto, o relatório de consumo acima foi gerado permitindo a análise da alocação de recursos. Em comparação com os outros projetos já realizados, o projeto aplicativo do jogo Genius teve um consumo muito maior. Tal consumo de recursos deu-se, sobretudo, graças a exigência para implementação da impressão de caracteres 200x200 *pixels* no VGA, e também pelo tamanho e quantidade dos contadores (e consequentemente comparadores) para gerar as bases de tempo necessárias ao jogo. Ao se retirar o trecho de pontuação do VGA e diminuir as constantes de tempo, o consumo de recursos da VGA caiu para em torno de 3 vezes do que o consumo aqui apresentado.

CONCLUSÕES

Com este trabalho pudemos comprovar o funcionamento prático do código de descrição de hardware transferindo o arquivo.bit para a FPGA Nexys 2 Spartan 3.

Pudemos praticar e aprimorar os conhecimentos de linguagem VHDL, de utilização dos softwares Xilinx ISE e Digilent Adept 2 e também verificar a robustez do software ao gerar automaticamente arquivos de simulação e permitir que pudéssemos analisar os resultados gerados através do gráfico da simulação, antes mesmo de sua implementação prática.

O conceito de máquina de estados, demonstrou-se importantíssimo para o desenvolvimento de soluções onde temos diferentes estados possíveis para o sistema, e variáveis de entrada que coordenam a alteração dos mesmos. Através do diagrama de estados, foi possível obter uma noção geral do projeto e definir todas as possíveis transações, permitindo então realizar a implementação do projeto em VHDL.

As funções de bibliotecas do sistema, *package, component* e *procedure* também foram extremamente úteis do ponto de vista de permitir distribuir-se melhor os componentes do jogo e criar trechos de lógica e tipos reutilizáveis em todos os outros códigos do projeto.

Não menos importante, o kit de desenvolvimento mostrou toda a capacidade que possui ao suportar a implementação de tal projeto, que demandou uma quantidade razoável de recursos da FPGA.

Por fim, ao término deste projeto aplicativo, comprova-se o quão rica de possibilidades e útil é a linguagem VHDL, permitindo que engenheiros e demais entusiastas possam descrever *hardwares* para operar nas mais diversas funcões e finalidades, sendo este um dos pilares da área de sistemas embarcados.

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ANEXOS

Genius.vhd

```
-- Código Principal do Projeto Aplicativo de Microeletrônica - Jogo Genius
-- Prof: Dr. Sibilla Batista da Luz França
-- Alunos: Erik Nayan e Diego Molina
-- Versão final: 29/11/2016

library ieee;
use ieee.std_logic_1164.all;
use work.global_pack.all;

entity Genius is

	generic ( d: integer := 5000000; -- Tempo de 100 ms
                                  p: integer := 500000; -- Tempo de 10 ms
                                  e: integer := 50000000; -- Tempo de 1 s
                                  m: integer := 25000000; -- Tempo de 500 ms
                                  h: integer := 10000000; -- Tempo de 200 ms
                                  T: integer := 250000000); -- Tempo de 5 s
	port ( clk, start, reset: in std_logic; -- Clock, Start e Reset
                           diff: in std_logic_vector (1 downto 0); -- Chaves seletoras de
dificuldade
                           button: in std_logic_vector (3 downto 0); -- Push-buttons do
jogo
                           display: out std_logic_vector (6 downto 0); -- Segmentos dos
displays
                           anode: out std_logic_vector (3 downto 0); -- Anodos dos displays
                           leds: out std_logic_vector (3 downto 0); -- Leds de visualização
                           h_sync: out std_logic; -- Sinal de sincronização horizontal
                           v_sync: out std_logic; -- Sinal de sincronização vertical
                           red: out std_logic_vector (2 downto 0); -- Bits vermelho do VGA
                           green: out std_logic_vector (2 downto 0); -- Bits verde do VGA
                           blue: out std_logic_vector (1 downto 0) ); -- Bits azul do VGA

end Genius;

architecture Behavioral of Genius is

	signal key_delay: integer range 0 to T := T; -- Delay máximo entre botões
	signal dly_delay: integer range 0 to d := d; -- Delay entre impressão de cores
	signal swt_delay: integer range 0 to p := p; -- Tempo de debouncing para os push-
buttons
	signal seq_delay: integer range 0 to e := e; -- Tempo de impressão de cada cor
	signal r: integer range 0 to 9:= 0; -- Ponteiro da matriz de sequências
	signal s: integer range 1 to 14 := 1; -- Ponteiro de espera de botões
	signal n: integer range 0 to 14 := 0; -- Ponteiro de impressao de sequência
	signal lvl: integer range 1 to 14 := 1; -- Nível atual do jogo
	signal nibble: std_logic_vector (3 downto 0) := "0000"; -- Repassa o estado dos leds
	signal try: std_logic_vector (3 downto 0) := "0000"; -- Armazena a tentativa do
jogador
	signal pr_state: states := idle; -- Estado da máquina

	-- Declaração do componente Decoder que controla os displays de 7 segmentos
	component Decoder is
		port ( clk, reset: in std_logic;
                                  display: out std_logic_vector (6 downto 0);
                                  anode: out std_logic_vector (3 downto 0);
                                  pr_state: in states;
                                  lvl: in integer range 1 to 14);
	end component;

	-- Declaração do componente VGA que controla a exibição no monitor
	component VGA is
		port(     clk: in std_logic;
                                  reset: in std_logic;
                                  nibble: in std_logic_vector (3 downto 0);
                                  lvl: in integer range 1 to 14;
                                  pr_state: in states;
                                  h_sync: out std_logic;
                                  v_sync: out std_logic;
                                  red: out std_logic_vector (2 downto 0);
                                  green: out std_logic_vector (2 downto 0);
                                  blue: out std_logic_vector (1 downto 0));
```

```
        end component;

begin

        -- Processo que implementa a lógica de estados do jogo
        process(clk, pr_state, reset, start, seq_delay, diff)
        begin

        if (reset = '1') then

                pr_state<=idle; -- Estado inicial em espera do jogo

        elsif (rising_edge(clk)) then

                -- Verificação da posição das chaves de dificuldade e atribuição ao sinal
                if ( diff="00" ) then
                        seq_delay<=e;
                elsif ( diff="01" ) then
                        seq_delay<=m;
                elsif ( diff="10" ) then
                        seq_delay<=h;
                else
                        seq_delay<=e;
                end if;

                -- Case dos estados da máquina
                case pr_state is

                -- Estado inicial de espera da máquina
                when idle => leds<="1111";
                                                        nibble<="1111";
                                                        lvl<=1;
                                                        n<=0;
                                                        s<=1;
                                                        r<=0;

                                                        if ( start='1' ) then
                                                                pr_state<=print;
                                                        end if;

                -- Estado que imprime as posições das sequências pré-definidas
           when print => leds<=sequences(r)(n);
                                                         nibble<=sequences(r)(n);
                                                         dly_delay<=d;
                                                         try<="0000";

                                                         if ( seq_delay>0 ) then

        seq_delay<=seq_delay-1;
                                                         else
                                                                        pr_state<=dly;
                                                         end if;

                -- Estado de delay entre a impressão de cada cor
                when dly => leds<="0000";
                                                        nibble<="0000";

                                                        if ( dly_delay>0 ) then
                                                                dly_delay<=dly_delay-1;
                                                        else
                                                                if ( n=lvl ) then
                                                                        pr_state<=waiting;
                                                                else
                                                                        pr_state<=print;
                                                                        n<=n+1;
                                                                end if;
                                                        end if;

                -- Estado que aguarda que o jogador pressione um botão
                when waiting => leds<="0000";
                                                            nibble<="0000";
                                                               swt_delay<=p;

                                                               if ( key_delay>0 ) then

        key_delay<=key_delay-1;
```

```
                                                                        else
                                                                                pr_state<=ff;
                                                                        end if;

                                                                        if ( button/="0000" ) then
                                                                                try<=button;
                                                                                pr_state<=upack;
                                                                        end if;

                        -- Estado de debouncing para o reconhecimento da subida do botão
                        when upack => leds<=button;
                                                                nibble<=button;

                                                                if ( swt_delay>0 ) then

                swt_delay<=swt_delay-1;
                                                                else
                                                                                pr_state<=dbc;
                                                                end if;

                        -- Estado que aguarda que o jogador solte o botão pressionado
                        when dbc => leds<=button;
                                                        nibble<=button;
                                                        swt_delay<=p;

                                                        if ( key_delay>0 ) then
                                                                key_delay<=key_delay-1;
                                                        else
                                                                pr_state<=ff;
                                                        end if;

                                                        if ( button="0000" ) then
                                                                pr_state<=downack;
                                                        end if;

                        -- Estado de debouncing para o reconhecimento da descida do botão
                        -- Este estado também verifica se o botão correto foi pressionado
                        when downack => leds<="0000";
                                                                nibble<="0000";

                                                                if ( swt_delay>0 ) then

                swt_delay<=swt_delay-1;
                                                                else
                                                                        key_delay<=T;
                                                                        if (
try=sequences(r)(s) ) then
                                                                                        if (

s=lvl ) then
                                                                                                pr_state<=n
                                                                                        else
                                                                                                s<=s+1;
                                                                                                pr_state<=w
                                                                                        end if;
                                                                        else

                pr_state<=ff;
                                                                                end if;
                                                                end if;

                        -- Estado que incrementa o nível atual do jogo
                        when nextlvl => leds<="0000";
                                                                nibble<="0000";

                                                                if ( lvl=14 ) then
                                                                        pr_state<=gg;
                                                                else
                                                                        pr_state<=print;
                                                                        lvl<=lvl+1;
                                                                        n<=0;
                                                                        s<=1;
                                                                end if;

                        -- Estado final de vitória
                        when gg => leds<="1111";
                                                        nibble<="1111";
```

```
                                                        if ( start='1' ) then
                                                                pr_state<=print;
                                                                key_delay<=T;
                                                                lvl<=1;
                                                                n<=0;
                                                                s<=1;
                                                                r<=r+1;
                                                                if (r=9) then
                                                                        r<=0;
                                                                end if;
                                                        end if;

                        -- Estado final de derrota
                        when ff => leds<=try;
                                                nibble<=try;

                                                         if ( start='1' ) then
                                                                pr_state<=print;
                                                                key_delay<=T;
                                                                lvl<=1;
                                                                n<=0;
                                                                s<=1;
                                                                r<=r+1;
                                                                if (r=9) then
                                                                        r<=0;
                                                                end if;
                                                         end if;

                        end case;

                end if;

                end process;

                -- Associação dos componentes com os respectivos E/S e sinais internos
                disp: Decoder port map(clk, reset, display, anode, pr_state, lvl);
                monitor: VGA port map (clk, reset, nibble, lvl, pr_state, h_sync, v_sync, red,
green, blue);

end Behavioral;
```

Decoder.vhd

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
use work.global_pack.all;

entity Decoder is

        generic ( f: integer := 4000; -- Tempo de multiplexação
                                        l: integer := 25000000); -- Clock de rolagem do display
        port ( clk, reset: in std_logic; -- Clock, Reset
               display: out std_logic_vector (6 downto 0); -- Segmentos dos displays
(catodos)
                                anode: out std_logic_vector (3 downto 0); -- Anodos dos displays
                                pr_state: in states; -- Estado atual da máquina
                                lvl: in integer range 1 to 14); -- Nível atual do jogo

end Decoder;

architecture Behavioral of Decoder is

        signal i: integer range 0 to 3 := 3; -- Ponteiro de multiplexação dos displays
        signal j: integer range 0 to 19 := 19; -- Ponteiro para rolagem da mensagem
        signal count_f: integer range 0 to f := f; -- Contador de rolagem
        signal count_l: integer range 0 to l := l; -- Contador de multiplexação
        signal pont: score := ("1111111","1111111","1111111","1111111"); -- Sinal para
exibição da pontuação
        constant anodos: enable := ("0111","1011","1101","1110"); -- Modos dos anodos
        constant gameover: score := ("0111000","0001000","1001111","1110001"); -- Mensagem
de "GG"
        constant win: score := ("1111111","0100000","0100000","1111111"); -- Mensagem de
"FF"
        constant projeto_aplic: pa_ed :=
("0011000","1111010","0000001","1000011","0110000","1110000","0000001",
```

```
        "1111111","0001000","0011000","1110001","1001111","0110001","0001000","1110000","100
1111","1000001",
        "0000001","1111110","0110000","1000010","1111111","1111111"); -- Mensagem "Projeto
Aplicativo - ED"

begin

        -- Processo que realização a multiplexação e impressão dos valores nos displays
        process(clk, lvl, reset, pr_state)
        begin

                if ( reset='1' ) then
                        i<=3;
                        j<=19;
                        count_l<=l;
                        count_f<=f;

                elsif ( rising_edge(clk) ) then
                        count_f<=count_f-1;
                        count_l<=count_l-1;
                        if (count_f=0) then
                                count_f<=f;
                                i<=i-1;
                                if (i=0) then
                                        i<=3;
                                end if;
                        end if;
                        if (count_l=0) then
                                count_l<=l;
                                j<=j-1;
                                if (j=0) then
                                        j<=19;
                                end if;
                        end if;
                end if;

                -- Case que verifica o nível atual e repassa o valor adequado de pontuação
para exibição
                case lvl is

                                        when 1 => pont <=
("1111111","0000001","0000001","1111111");

                                        when 2 => pont <=
("1111111","0000001","1001111","1111111");

                                        when 3 => pont <=
("1111111","0000001","0010010","1111111");

                                        when 4 => pont <=
("1111111","0000001","0000110","1111111");

                                        when 5 => pont <=
("1111111","0000001","1001100","1111111");

                                        when 6 => pont <=
("1111111","0000001","0100100","1111111");

                                        when 7 => pont <=
("1111111","0000001","0100000","1111111");

                                        when 8 => pont <=
("1111111","0000001","0001111","1111111");

                                        when 9 => pont <=
("1111111","0000001","0000000","1111111");

                                        when 10 => pont <=
("1111111","0000001","0000100","1111111");

                                        when 11 => pont <=
("1111111","1001111","0000001","1111111");

                                        when 12 => pont <=
("1111111","1001111","1001111","1111111");
```

```
                                    when 13 => pont <=
("1111111","1001111","0010010","1111111");

                                    when 14 => pont <=
("1111111","1001111","0000110","1111111");

                    end case;

                    -- Case que vericia o estado atual da máquina e o que deve ser exibido nos
displays
                    case pr_state is

                                    when idle =>  display <= projeto_aplic(i+j);

                                when ff => display <= gameover(i);

                                    when gg => display <= win(i);

                                    when others => display <= pont(i);

                    end case;

                    -- Atribuição aos anodos do modo atual para multiplexação
                    anode <= anodos(i);

          end process;


end Behavioral;
```

VGA.vhd

```
library ieee;
use ieee.std_logic_1164.all;
use work.global_pack.all;
use work.rom_characters.all;

entity VGA is

  generic(
    h_pulse  :  integer   := 120; -- Largura do pulso de sincronização horizontal em pixels
    h_bp     :  integer   := 64; -- Largura do back porch horizontal em pixels
    h_pixels :  integer   := 800; -- Largura de display horizontal em pixels
    h_fp     :  integer   := 56; -- Largura do front porch horizontal em pixels
    h_pol    :  std_logic := '1'; -- Polaridade da sincronização horizontal (1 = positiva, 0 =
negativa)
    v_pulse  :  integer   := 6; -- Largura do pulso de sincronização vertical em linhas
    v_bp     :  integer   := 23; -- Largura do back porch vertical em linhas
    v_pixels :  integer   := 600; -- Largura de display vertical em linhas
    v_fp     :  integer   := 37; -- Largura do front porch vertical em linhas
    v_pol    :  std_logic := '1'); --Polaridade da sincronização vertical (1 = positiva, 0 =
negativa)

  port(
    clk              :  in   std_logic; -- Pixel clock
    reset     :  in   std_logic;  -- Reset
          nibble    :  in   std_logic_vector (3 downto 0); -- Estado dos leds
          lvl       :  in    integer range 1 to 14; -- Nível atual do jogo
          pr_state  :  in   states; -- Estado da máquina
    h_sync    :  out  std_logic; -- Pulso de sincronização horizontal
    v_sync    :  out  std_logic; -- Pulso de sincronização vertical
          red       :  out  std_logic_vector (2 downto 0); -- Bits do vermelho do VGA
    green     :  out  std_logic_vector (2 downto 0); -- Bits do verde do VGA
    blue      :  out  std_logic_vector (1 downto 0));    -- Bits do azul do VGA

end VGA;

architecture behavior of VGA is

  constant  h_period  :  integer := h_pulse + h_bp + h_pixels + h_fp;  -- Número total de
pixels em uma linha
  constant  v_period  :  integer := v_pulse + v_bp + v_pixels + v_fp;  -- Número total de
linhas em uma coluna
  shared variable h_count  :  integer range 0 to h_period - 1 := 0;  -- Contador horizontal
  shared variable v_count  :  integer range 0 to v_period - 1 := 0;  -- Contador vertical
```

```
  shared variable red_var : std_logic_vector (2 downto 0) := ( others => '0'); -- Variável
para procedure de caracteres
  shared variable green_var : std_logic_vector (2 downto 0) := ( others => '0'); -- Variável
para procedure de caracteres
  shared variable blue_var : std_logic_vector (1 downto 0) := ( others => '0'); -- Variável
para procedure de caracteres

begin

  process(clk, reset, pr_state)
  begin

          -- Reinicia o VGA em caso de reset
    if(reset = '1') then
      h_count := 0;
      v_count := 0;
      h_sync <= not h_pol;
      v_sync <= not v_pol;

    elsif(rising_edge(clk)) then

      -- Contadores
      if(h_count < h_period - 1) then
        h_count := h_count + 1;
      else
        h_count := 0;
        if(v_count < v_period - 1) then
          v_count := v_count + 1;
        else
          v_count := 0;
        end if;
      end if;

      -- Sincronização Horizontal
      if(h_count < h_pixels + h_fp or h_count > h_pixels + h_fp + h_pulse) then
        h_sync <= not h_pol;
      else
        h_sync <= h_pol;
      end if;

      -- Sincronização Vertical
      if(v_count < v_pixels + v_fp or v_count > v_pixels + v_fp + v_pulse) then
        v_sync <= not v_pol;
      else
        v_sync <= v_pol;
      end if;

      -- Verifica se está dentro da área de impressao do display e implementa a lógica para
cada estado
      if(h_count < h_pixels and v_count < v_pixels) then

                              if (v_count>300) then
                                        if (nibble="1000") then
                                                  if (h_count<200) then
                                                            red <= "111";
                                                            green <= "000";
                                                            blue <= "00";
                                                  else
                                                            red <= (others => '0');
                                                            green <= (others => '0');
                                                            blue <= (others => '0');
                                                  end if;
                                        elsif (nibble="0100") then
                                                  if (h_count>200 and h_count<400) then
                                                            red <= "000";
                                                            green <= "000";
                                                            blue <= "11";
                                                  else
                                                            red <= (others => '0');
                                                            green <= (others => '0');
                                                            blue <= (others => '0');
                                                  end if;
                                        elsif (nibble="0010") then
                                                  if (h_count>400 and h_count<600) then
                                                            red <= "111";
                                                            green <= "111";
```

```
                                        blue <= "00";
                                else
                                        red <= (others => '0');
                                        green <= (others => '0');
                                        blue <= (others => '0');
                                end if;
                        elsif (nibble="0001") then
                                if (h_count>600 and h_count<800) then
                                        red <= "000";
                                        green <= "111";
                                        blue <= "00";
                                else
                                        red <= (others => '0');
                                        green <= (others => '0');
                                        blue <= (others => '0');
                                end if;
                        elsif (nibble="1111") then
                                if (h_count<200) then
                                        red <= "111";
                                        green <= "000";
                                        blue <= "00";
                                elsif (h_count>200 and h_count<400) then
                                        red <= "000";
                                        green <= "000";
                                        blue <= "11";
                                elsif (h_count>400 and h_count<600) then
                                        red <= "111";
                                        green <= "111";
                                        blue <= "00";
                                elsif (h_count>600 and h_count<800) then
                                        red <= "000";
                                        green <= "111";
                                        blue <= "00";
                                end if;
                        end if;

                else
                        if (pr_state=idle) then
                                if (h_count<200) then
                                        red <= "111";
                                        green <= "000";
                                        blue <= "00";
                                elsif (h_count>200 and h_count<400) then
                                        red <= "000";
                                        green <= "000";
                                        blue <= "11";
                                elsif (h_count>400 and h_count<600) then
                                        red <= "111";
                                        green <= "111";
                                        blue <= "00";
                                elsif (h_count>600 and h_count<800) then
                                        red <= "000";
                                        green <= "111";
                                        blue <= "00";
                                end if;
                        elsif (pr_state=ff) then
                                if (h_count>250 and h_count<400 and v_count>50
and v_count<250) then
                                        if (F(v_count-50)(h_count-225)='1')
then
                                                red <= (others => '1');
                                                green <= (others => '1');
                                                blue <= (others => '1');
                                        else
                                                red <= (others => '0');
                                                green <= (others => '0');
                                                blue <= (others => '0');
                                        end if;
                                elsif (h_count>400 and h_count<550 and
v_count>50 and v_count<250) then
                                        if (F(v_count-50)(h_count-375)='1')
then
                                                red <= (others => '1');
                                                green <= (others => '1');
                                                blue <= (others => '1');
                                        else
```

```
                                                red <= (others => '0');
                                                green <= (others => '0');
                                                blue <= (others => '0');
                                        end if;
                                end if;
                        elsif (pr_state=gg) then
                                if (h_count>250 and h_count<400 and v_count>50
and v_count<250) then
                                        if (G(v_count-50)(h_count-225)='1')
then
                                                red <= (others => '1');
                                                green <= (others => '1');
                                                blue <= (others => '1');
                                        else
                                                red <= (others => '0');
                                                green <= (others => '0');
                                                blue <= (others => '0');
                                        end if;
                                elsif (h_count>400 and h_count<550 and
v_count>50 and v_count<250) then
                                        if (G(v_count-50)(h_count-375)='1')
then
                                                red <= (others => '1');
                                                green <= (others => '1');
                                                blue <= (others => '1');
                                        else
                                                red <= (others => '0');
                                                green <= (others => '0');
                                                blue <= (others => '0');
                                        end if;
                                end if;
                        else

                                -- Case que verifica o level e chama procedure
para impressão dos devidos caracteres
                                case lvl is

                                when 1 => characters (h_count, v_count, zero,
zero, red_var, green_var, blue_var);

                                when 2 => characters (h_count, v_count, zero,
one, red_var, green_var, blue_var);

                                when 3 => characters (h_count, v_count, zero,
two, red_var, green_var, blue_var);

                                when 4 => characters (h_count, v_count, zero,
three, red_var, green_var, blue_var);

                                when 5 => characters (h_count, v_count, zero,
four, red_var, green_var, blue_var);

                                when 6 => characters (h_count, v_count, zero,
five, red_var, green_var, blue_var);

                                when 7 => characters (h_count, v_count, zero,
six, red_var, green_var, blue_var);

                                when 8 => characters (h_count, v_count, zero,
seven, red_var, green_var, blue_var);

                                when 9 => characters (h_count, v_count, zero,
eight, red_var, green_var, blue_var);

                                when 10 => characters (h_count, v_count, zero,
nine, red_var, green_var, blue_var);

                                when 11 => characters (h_count, v_count, one,
zero, red_var, green_var, blue_var);

                                when 12 => characters (h_count, v_count, one,
one, red_var, green_var, blue_var);

                                when 13 => characters (h_count, v_count, one,
two, red_var, green_var, blue_var);
```

```
                                                when 14 => characters (h_count, v_count, one,
three, red_var, green_var, blue_var);

                                                end case;

                                                -- Associação das variáveis com as saidas RGB
                                                red <= red_var;
                                                green <= green_var;
                                                blue <= blue_var;

                                        end if;

                                end if;

                        -- Tempo em que nada é enviado no RGB
      else
                                red <= (others => '0');
                                green <= (others => '0');
                                blue <= (others => '0');
      end if;

    end if;
  end process;

end behavior;
```

Nexys2.ucf

```
NET "LEDs(0)" LOC = "J14";
NET "LEDs(1)" LOC = "J15";
NET "LEDs(2)" LOC = "K15";
NET "LEDs(3)" LOC = "K14";

NET "display(6)" LOC = "L18";
NET "display(5)" LOC = "F18";
NET "display(4)" LOC = "D17";
NET "display(3)" LOC = "D16";
NET "display(2)" LOC = "G14";
NET "display(1)" LOC = "J17";
NET "display(0)" LOC = "H14";

NET "anode(0)" LOC = "F17";
NET "anode(1)" LOC = "H17";
NET "anode(2)" LOC = "C18";
NET "anode(3)" LOC = "F15";

NET "red(0)" LOC = "R9";
NET "red(1)" LOC = "T8";
NET "red(2)" LOC = "R8";
NET "green(0)" LOC = "N8";
NET "green(1)" LOC = "P8";
NET "green(2)" LOC = "P6";
NET "blue(0)" LOC = "U5";
NET "blue(1)" LOC = "U4";

NET "h_sync" LOC = "T4";
NET "v_sync" LOC = "U3";

NET "clk" LOC = "B8";

NET "diff(0)" LOC = "K18";
NET "diff(1)" LOC = "K17";

NET "button(0)" LOC = "B18";
NET "button(1)" LOC = "D18";
NET "button(2)" LOC = "E18";
NET "button(3)" LOC = "H13";

NET "start" LOC = "G18";
NET "reset" LOC = "H18";
```

Genius_TB.vhd

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY Genius_TB IS
END Genius_TB;

ARCHITECTURE behavior OF Genius_TB IS

    COMPONENT Genius
    PORT(
         clk : IN  std_logic;
         start : IN  std_logic;
         reset : IN  std_logic;
         diff : IN  std_logic_vector(1 downto 0);
         button : IN  std_logic_vector(3 downto 0);
         display : OUT  std_logic_vector(6 downto 0);
         anode : OUT  std_logic_vector(3 downto 0);
         leds : OUT  std_logic_vector(3 downto 0);
         h_sync : OUT  std_logic;
         v_sync : OUT  std_logic;
         red : OUT  std_logic_vector(2 downto 0);
         green : OUT  std_logic_vector(2 downto 0);
         blue : OUT  std_logic_vector(1 downto 0)
        );
    END COMPONENT;

   --Inputs
   signal clk : std_logic := '0';
   signal start : std_logic := '0';
   signal reset : std_logic := '0';
   signal diff : std_logic_vector(1 downto 0) := (others => '0');
   signal button : std_logic_vector(3 downto 0) := (others => '0');

          --Outputs
   signal display : std_logic_vector(6 downto 0);
   signal anode : std_logic_vector(3 downto 0);
   signal leds : std_logic_vector(3 downto 0);
   signal h_sync : std_logic;
   signal v_sync : std_logic;
   signal red : std_logic_vector(2 downto 0);
   signal green : std_logic_vector(2 downto 0);
   signal blue : std_logic_vector(1 downto 0);

   -- Clock period definitions
   constant clk_period : time := 10 ns;

BEGIN

          -- Instantiate the Unit Under Test (UUT)
   uut: Genius PORT MAP (
          clk => clk,
          start => start,
          reset => reset,
          diff => diff,
          button => button,
          display => display,
          anode => anode,
          leds => leds,
          h_sync => h_sync,
          v_sync => v_sync,
          red => red,
          green => green,
          blue => blue
        );

   -- Clock process definitions
   clk_process :process
   begin
                   clk <= '0';
                   wait for clk_period/2;
                   clk <= '1';
                   wait for clk_period/2;
   end process;
```

```
-- Stimulus process
stim_proc: process
begin
                reset<='1';
                button<="0000";
                diff<="00";
                start<='0';
   wait for 100 ns;
                reset<='0';
                diff<="10";
                start<='1';
                wait for 100 ns;
                start<='0';
                wait for 600 us;
                button<="1000";
                wait for 50 us;
                button<="0000";
                wait for 900 us;
                button<="1000";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0100";
                wait for 50 us;
                button<="0000";
                wait for 1200 us;
                button<="1000";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0100";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0010";
                wait for 50 us;
                button<="0000";
                wait for 1500 us;
                button<="1000";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0100";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0010";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0001";
                wait for 50 us;
                button<="0000";
                wait for 1800 us;
                button<="1000";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0100";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0010";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0001";
                wait for 50 us;
                button<="0000";
                wait for 100 us;
                button<="0001";
                wait for 50 us;
                button<="0000";
                wait for 2100 us;
```

```
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 2400 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 2700 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
```

```
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 3000 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 3300 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
```

```
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 3600 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 3900 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
```

```
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 4200 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0100";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0010";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="0001";
wait for 50 us;
button<="0000";
wait for 100 us;
button<="1000";
wait for 50 us;
button<="0000";
wait for 4500 us;
```

```
                    button<="1000";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0100";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0010";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0001";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0001";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0010";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0100";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="1000";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="1000";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0100";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0010";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0001";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="1000";
                    wait for 50 us;
                    button<="0000";
                    wait for 100 us;
                    button<="0001";
                    wait for 50 us;
                    button<="0000";

                    wait for 100 us;
                    start<='1';
                    wait for 100 ns;
                    start<='0';
                    wait for 600 us;
                    button<="0001";
                    wait for 50 us;
                    button<="0000";

                    wait for 100 us;
                    start<='1';
                    wait for 100 ns;
                    start<='0';
                    wait for 5 ms;

        wait;
    end process;

END;
```

Global_pack.vhd

```
-- Package global que implementa os tipos necessários no projeto, bem como procedures e
constantes

library IEEE;
use IEEE.STD_LOGIC_1164.all;
use work.rom_characters.all;

package global_pack is

	type states is (idle, print, dly, waiting, upack, dbc, downack, nextlvl, gg, ff); --
Estados da máquina
	type pa_ed is array (22 downto 0) of std_logic_vector (6 downto 0); -- Arranjo da
mensagem inicial
	type score is array (3 downto 0) of std_logic_vector (6 downto 0); -- Arranjo da
pontuação
	type enable is array (3 downto 0) of std_logic_vector (3 downto 0); -- Arranjo dos
estados dos anodos
	type sequence is array (14 downto 0) of std_logic_vector (3 downto 0); -- Arranjo de
uma sequência

	-- Constantes que definem as sequências possiveis de 14 cores para o jogo
	constant seq0: sequence := ("0001","1000","0001","0010","0100","1000","1000",
	"0100","0010","0001","0001","0010","0100","1000", "0000");

	constant seq1: sequence := ("0001","1000","0001","0010","0100","0010","0100",
	"1000","0001","1000","0001","0100","0010","1000", "0000");

	constant seq2: sequence := ("0010","1000","0001","0010","0100","0010","1000",
	"0100","1000","0001","0001","0010","0100","0001", "0000");

	constant seq3: sequence := ("0100","0010","0001","0010","1000","1000","0100",
	"0001","0010","1000","0001","0010","0100","0100", "0000");

	constant seq4: sequence := ("0001","0001","1000","0010","0100","1000","1000",
	"1000","0010","0100","0001","0010","0100","0010", "0000");

	constant seq5: sequence := ("0100","1000","0010","0010","0100","1000","1000",
	"0100","0010","0001","1000","0010","0001","0001", "0000");

	constant seq6: sequence := ("1000","0010","0010","0010","0100","1000","0001",
	"0100","1000","0100","0001","0010","0100","0100", "0000");

	constant seq7: sequence := ("0001","1000","0010","0010","0100","1000","1000",
	"0100","0001","0010","0001","0001","1000","1000", "0000");

	constant seq8: sequence := ("0010","0001","0100","0001","0010","1000","0100",
	"0100","1000","0001","1000","0010","0100","0010", "0000");

	constant seq9: sequence := ("0100","1000","0001","0010","0010","1000","0001",
	"0100","1000","0001","0010","0001","0100","0001", "0000");

	type mult_seq is array (9 downto 0) of sequence; -- Arranjo das 10 sequências pré-
definidas

	constant sequences: mult_seq := (seq9, seq8, seq7, seq6, seq5, seq4, seq3, seq2,
seq1, seq0); -- Constante com as 10 sequências criadas

	-- Declaração da procedure que imprime os caracteres na região superior do monitor
	procedure characters (h_count, v_count: in integer;
                                                                    first_char,
secon_char: in char_data;
                                                                    red: out
std_logic_vector (2 downto 0);
                                                                    green: out
std_logic_vector (2 downto 0);
                                                                    blue: out
std_logic_vector (1 downto 0));


end global_pack;

package body global_pack is
```

```
          -- Procedure que recebe os valores de caracteres e estabelece a lógica para
impressão na tela
          procedure characters (h_count, v_count: in integer;
                                                                              first_char,
secon_char: in char_data;
                                                                              red: out
std_logic_vector (2 downto 0);
                                                                              green: out
std_logic_vector (2 downto 0);
                                                                              blue: out
std_logic_vector (1 downto 0)) is

          begin

                    if (h_count>250 and h_count<400 and v_count>50 and v_count<250) then
                              if (first_char(v_count-50)(h_count-225)='1') then
                                        red := (others => '1');
                                        green := (others => '1');
                                        blue := (others => '1');
                              else
                                        red := (others => '0');
                                        green := (others => '0');
                                        blue := (others => '0');
                              end if;
                    elsif (h_count>400 and h_count<550 and v_count>50 and v_count<250) then
                              if (secon_char(v_count-50)(h_count-375)='1') then
                                        red := (others => '1');
                                        green := (others => '1');
                                        blue := (others => '1');
                              else
                                        red := (others => '0');
                                        green := (others => '0');
                                        blue := (others => '0');
                              end if;
                    end if;

          end characters;

end package body;
```

Rom_characters.vhd

```
-- Package que define as constantes com o desenho de cada um dos caracteres utilizados
-- Números: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
-- Letras: F, G
-- Constantes de 200x200 pixels

library IEEE;
use IEEE.STD_LOGIC_1164.all;

package rom_characters is

          constant h: integer := 200;
          constant v: integer := 200;
          type char_data is array (0 to v-1) of std_logic_vector (0 to h-1);

          constant zero: char_data := (
"000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000",
"000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000",
"000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000",
"000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
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0000000000000",
"000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
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```

"00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
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"0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
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"0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
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