

Relazione—CARLO MAGGI

Introduzione

Spiegazione generale componente

L'obiettivo del progetto di reti logiche è quello di realizzare un componente hardware che legge una sequenza di parole (byte) dalla memoria, filtra ogni parola della sequenza, in base ad una funzione di filtro, e scrive la sequenza filtrata in memoria. Il filtro può essere di ordine 3 o di ordine 5 e per poter funzionare gli servono 7 coefficienti. In base al suo ordine cambiano i parametri della funzione di filtro, che sono 'n', i coefficienti e 'l'.

Le parole da filtrare, le parole filtrate, e i coefficienti sono tutti rappresentati da un singolo byte con codifica in complemento a 2. Quindi i loro valori spaziano da -128 a 127.

Funzione di filtro

La funzione di filtro è la seguente: $f'(i) = (1/n) * \sum C_j * f[j+i]$ con j che va da -l e +l.

Per il filtro di ordine 3: $n=12$, $l=2$. Per il filtro di ordine 5: $n=60$, $l=3$. Se per esempio i coefficienti fossero [0, 1, 2, 3, 4, 5, 6] allora C_0 si riferisce a 3 e $C(-3)$ a 0, ovvero bisogna immaginarsi che l selezioni i coefficienti a partire da quello centrale. Si può quindi subito notare che se il filtro e' di ordine 3, nella computazione della parola filtrata non verranno mai presi in considerazione il primo e l'ultimo coefficiente.

Se immaginiamo di vedere la memoria come una sequenza di celle, ognuna dotata di un opportuno indirizzo n, $f(n)$ restituisce il contenuto della cella di indirizzo n, mentre $f'(n)$ restituisce il contenuto della cella di indirizzo n filtrato.

Importante quindi notare che il filtro sta semplicemente applicando una serie di moltiplicazioni, sommando il risultato di ogni moltiplicazione, e infine normalizzando il risultato.

Funzionamento generale del componente

Per comprendere meglio come il componente funziona, si può schematizzare la memoria su cui esso lavora nel seguente modo:

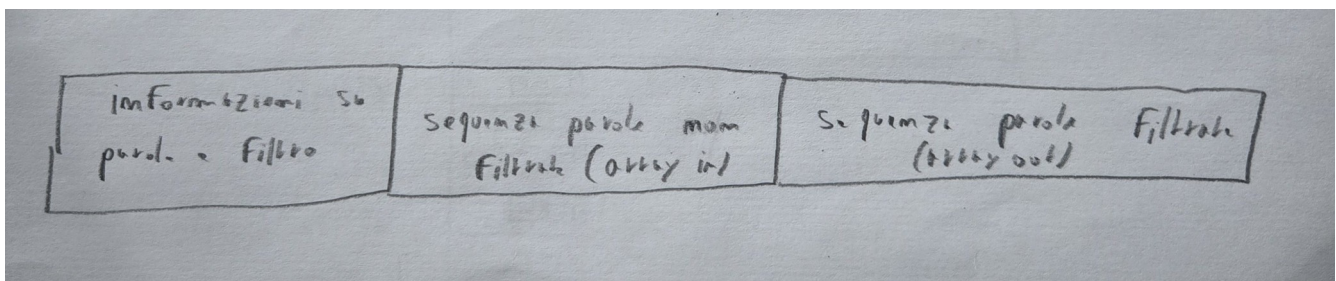


Immagine 1

La prima parte della memoria, denominata “informazioni su parole e filtro” contiene informazioni per il corretto funzionamento del filtro, cioè il numero di parole da filtrare, il tipo di filtro da usare (ordine 3 o ordine 5) e i coefficienti.

La seconda parte della memoria, denominata “sequenza parole non filtrate (array in)” contiene la sequenza di parole (byte) da filtrare.

La terza parte della memoria, denominata “sequenza parole filtrate (array out)” contiene la sequenza di parole filtrate. Questa parte risulterà quindi vuota all’inizio dell’elaborazione, e si riempirà man mano fino a riempirsi completamente al suo termine. Ovviamente la sua lunghezza risulterà uguale alla sequenza di parole non filtrate, dato che la funzione di filtro applicata dal componente produce per ogni parola non filtrata, una ed una sola parola filtrata.

Il funzionamento del componente può essere schematizzato nel seguente modo:

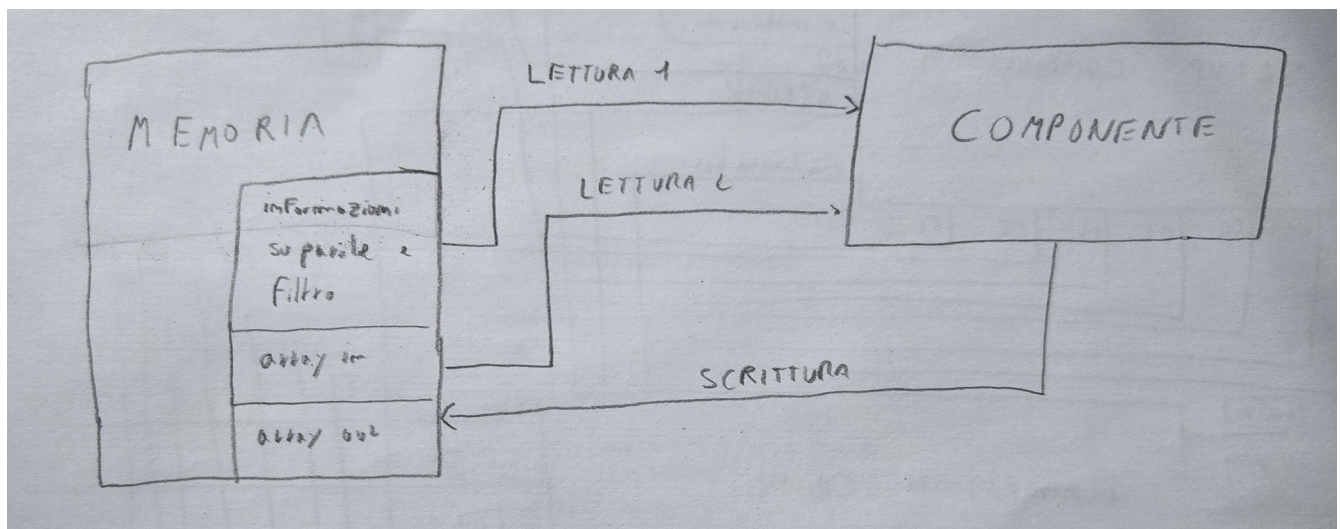


Immagine 2

Il componente ha 2 fasi di funzionamento. Nella prima fase legge dalla memoria tutte le informazioni sul filtro da utilizzare e la lunghezza della sequenza di parole da filtrare. Nella seconda fase avviene

l'elaborazione vera e propria, cioè vengono lette, una alla volta, tutte le parole della sequenza di input, e per ognuna di esse viene prodotta la parola filtrata, mediante applicazione della funzione di filtro, e scritta sulla sequenza di output.

Per informazioni più dettagliate riguardo al componente, come per esempio le varie porte di input, porte di output, approssimazioni riguardo alla normalizzazione nella funzione di filtro e altro, si rimanda alla specifica del progetto.

Scelte progettuali

Per la realizzazione del componente, ho scelto un approccio di basso livello, senza quindi usare, se non in determinati casi in cui era necessario, una descrizione behavioural (uso di processi) dei sotto-componenti. Questo perchè, per puri scopi didattici, mi piace capire a fondo il mio componente, cosa che sarebbe stata compromessa se avessi usato principalmente processi. Non ho di conseguenza usato macchine a stati finiti o cose del genere, ma unicamente un approccio strettamente strutturale.

Questo approccio ha portato alla suddivisione del componente in 3 livelli di astrazione. Il livello 1, quello più basso, descrive il componente dettagliatamente e sono presenti tutti i sotto-componenti elementari con i loro relativi collegamenti. Una volta descritti tutti i componenti del livello 1, gli ho uniti in dei macro-componenti, cioè i componenti del livello 2. Collegati tutti i componenti del livello 2, gli ho uniti a loro volta in dei macro-componenti, cioè i componenti del livello 3. Infine, una volta collegati i componenti del livello 3, gli ho uniti in un unico macro-componente, il componente finale.

Prima di scrivere il codice vhdl ho fatto un disegno per ogni livello di astrazione, che verranno mostrati nella sezione "Architettura".

Architettura

Nota 1: i segnali all'interno di un riquadro sono i segnali di input o output del componente principale.

Nota 2: l'intero circuito è sincronizzato con il segnale di clock.

Nota 3: all'interno del componente principale è presente un segnale chiamato 'clear' la cui funzione è esattamente la stessa del segnale di reset. Il segnale viene attivato prima dell'inizio di ogni elaborazione in quanto non è detto che chi usi il modulo applichi il reset prima di alzare il segnale di start.

Nota 4: l'architettura viene descritta in maniera informale e facilmente comprensibile, per maggiori dettagli riguardo a quest'ultima si rimanda al codice sorgente vhdl del componente.

Livello di astrazione 3

Si tratta del livello di astrazione più alto, appena sotto il componente principale. Si può quindi immaginare il componente principale come una scatola nera che racchiude questo livello. Il disegno è il seguente:

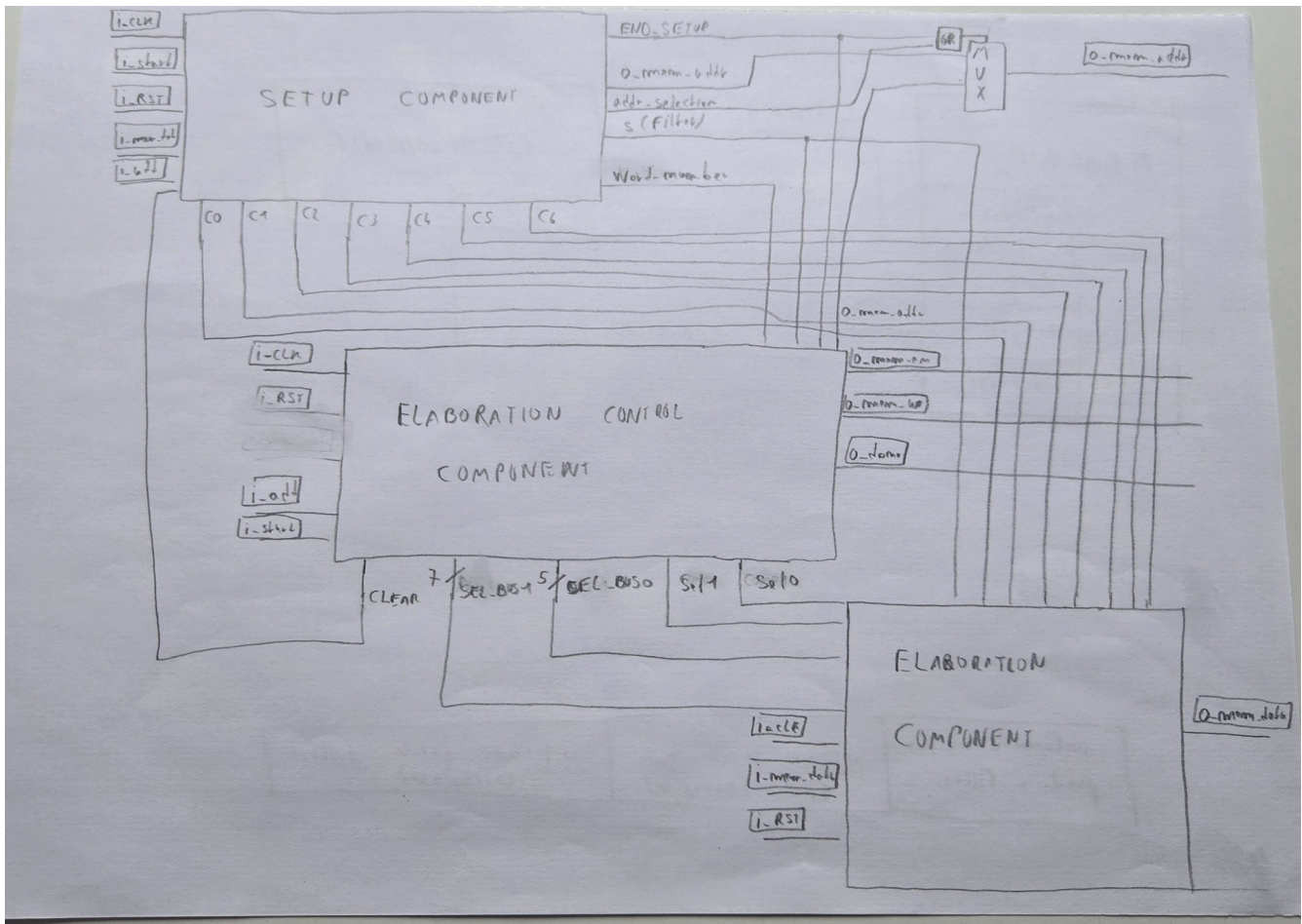


Immagine 3

Come si può vedere dal disegno, sono presenti 3 componenti, ognuno dei quali ha una specifica e fondamentale funzione e dai quali si può dedurre il comportamento generale del componente principale: in una prima fase avviene la lettura delle informazioni relative al filtro da usare e alla lunghezza della sequenza di parole da filtrare (fase preambolo), e in una seconda fase avviene la vera e propria elaborazione, ovvero il filtraggio di ogni parola e la scrittura in memoria (fase di elaborazione). Di seguito viene descritto ciascun componente:

1) Setup component

Componente responsabile della fase di preambolo. Ha quindi la funzione di leggere i primi 17 byte di memoria e di salvare in opportuni registri o flip-flop la lunghezza della sequenza di parole

(word_number), il tipo di filtro usato (s) e i 7 coefficienti in base al filtro selezionato (c0, ..., c6). Queste informazioni vengono poi trasmesse agli altri componenti.

Oltre che a questi segnali si ha: o_mem_addr che rappresenta l'indirizzo di memoria al quale si accede, end_setup che viene alzato una volta finita la fase di preambolo, facendo quindi avviare la fase di elaborazione, e addr_selection che insieme a end_setup controllano l'indirizzo di memoria al quale si accede.

Il mux serve a selezionare l'indirizzo di memoria al quale si vuole accedere, che cambia in base alla fase in cui ci si trova.

Per poter funzionare, al componente serve i_clk, per la sincronizzazione con il segnale di clock, i_rst, per poter effettuare un reset di tutti gli elementi di memoria, i_start, per farlo avviare, i_mem_data, per poter leggere le informazioni, clear, stessa funzione di i_reset ma non controllato esternamente, i_add, che rappresenta l'indirizzo di memoria di partenza.

I sotto componenti di cui è composto sono:

Input selection component 1

Internal memory component

2) Elaboration control component

Componente responsabile del controllo dell'elaborazione. Gestisce il conteggio delle parole da filtrare, seleziona le parole da filtrare e le instrada verso i coefficienti per le quali devono essere moltiplicate, controlla la scrittura in memoria e infine si occupa di alzare il segnale di o_done se l'elaborazione giunge al suo termine e di conseguenza anche clear e o_mem_en.

I segnali di output con il loro relativo scopo, trascurando quelli ovvi, sono:

sel0: se attivo viene selezionato 0 al posto di i_mem_data. Questo avviene quando nel computo della parola filtrata si accede a byte di memoria a sinistra della prima parola da filtrare.

sel1: stessa cosa di prima ma per accessi a byte di memoria a destra dell'ultima parola da filtrare.

sel_bus0: segnale che instrada correttamente le parole in ingresso nel caso di filtro modulo 3.

sel_bus1: segnale che instrada correttamente le parole in ingresso nel caso di filtro modulo 5.

I segnali di output elencati precedentemente servono appunto per 'controllare' il componente elaborativo vero e proprio, cioè quello che implementa la funzione di filtro.

clear: come un reset. Viene attivato ogni qualvolta i_start viene portato a 0 e disattivato se portato a 1, in modo da garantire un reset prima di ogni successiva elaborazione.

Il componente si avvia appena il segnale di end_setup si alza.

I sotto componenti di cui è composto sono:

Word counter component

Input selection component 2

Command controller

Comparator component

3) Elaboration component

Componente che implementa la funzione di filtro. Il suo unico obiettivo è produrre il valore della parola filtrata sull'uscita o_mem_data. Il suo controllore gestisce tutto il resto. Importante notare che quando si computa la funzione si lavora su 16 bit e 18 bit, non su 8 bit. Questo perchè la moltiplicazione dei vari valori e la loro successiva somma può produrre al massimo il valore 114688.

I sotto componenti di cui è composto sono:

Selection elaboration component

Multiplication component

Final calculation component

Livello di astrazione 2

Livello di astrazione inferiore al terzo. Sono quindi presenti tutti i componenti di cui sono fatti i componenti del terzo livello e come questi sono connessi tra di loro. Il disegno è il seguente:

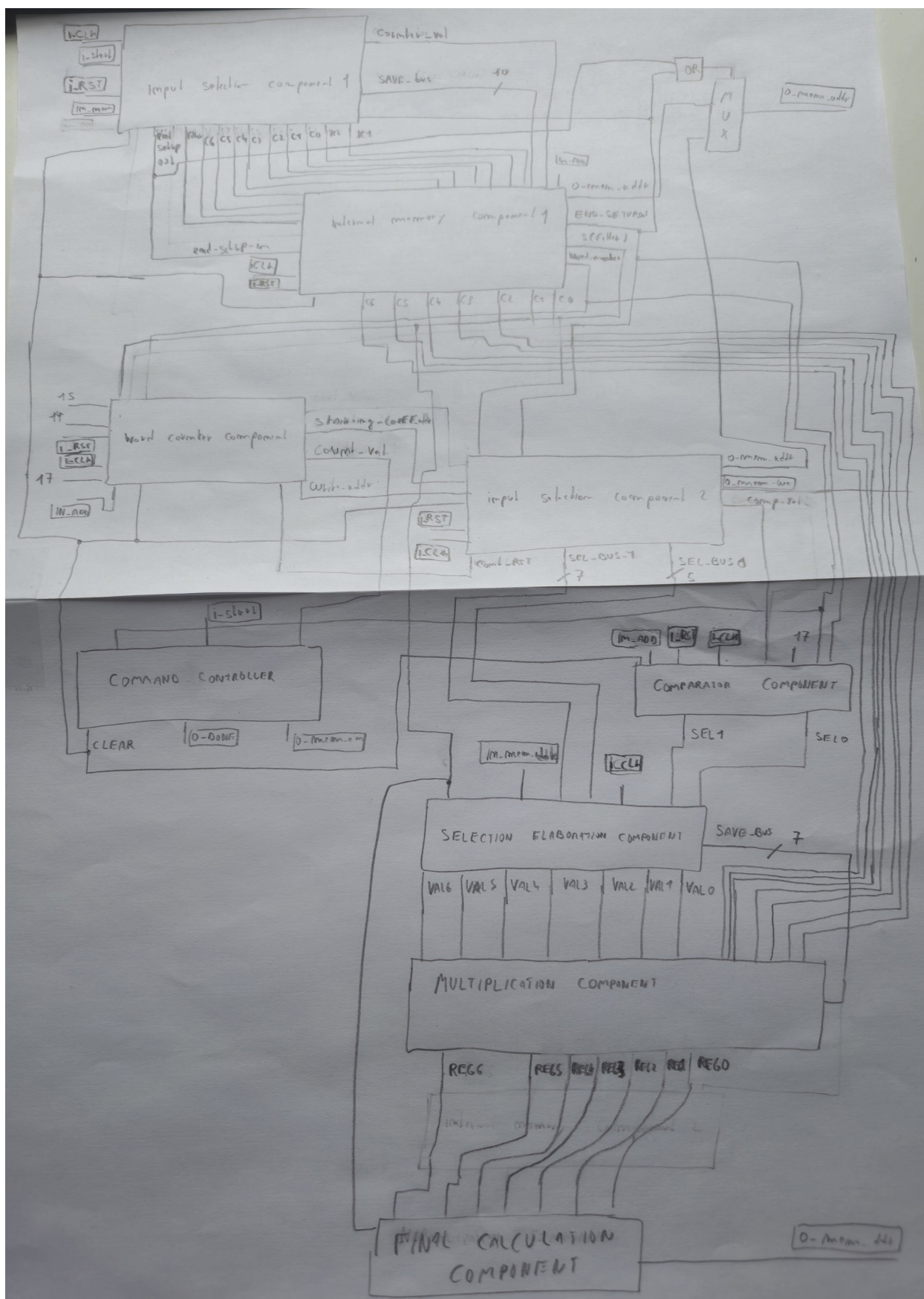


Immagine 4

Nota: Per ‘componenti elementari’ si intendono componenti che non hanno bisogno di essere descritti in vhdl mediante una entity per poterli usare. Questi includono tutte le porte logiche e le operazioni aritmetiche di base.

I componenti con la loro relativa funzione sono i seguenti:

1) **Input selection component 1**

Componente che seleziona i byte dalla memoria sequenzialmente, mediante un contatore, e gli instrada correttamente, mediante un decoder e degli switch (SWC).

I sotto componenti di cui è composto sono:

contatore fino a 16

1 decoder a 16 bit

10 switch

componenti elementari

2) **Internal memory component**

Componente responsabile di memorizzare le informazioni necessarie affinché la fase di elaborazione funzioni correttamente. In particolare, word_number viene memorizzato in un registro a 16 bit, i coefficienti in 7 registri a 8 bit, s e end_setup in un flip flop di tipo D. Inoltre calcola l’indirizzo di memoria al quale si vuole accedere in fase di preambolo.

I sotto componenti di cui è composto sono:

9 registri a 8 bit

1 registro a 16 bit

2 flip flop D

1 mux

componenti elementari

3) **Word counter component**

Componente che conta le parole che si stanno filtrando, produce l'indirizzo al quale si vuole scrivere la parola filtrata e l'indirizzo della prima parola da considerare nella funzione di filtro.

I sotto componenti di cui è composto sono:

contatore fino a 2^{16}

1 mux

componenti elementari

4) Input selection component 2

Componente che controlla il componente numero 7 fornendogli degli opportuni segnali, gestisce la scrittura in memoria e l'incremento del contatore del componente numero 3. Inoltre fornisce al componente numero 6 'comp_val', che non è altro che l'indirizzo della parola che si sta attualmente leggendo.

I sotto componenti di cui è composto sono:

2 contatori fino a 16

2 decoder a 16 bit

4 mux

Componenti elementari

5) Command controller

Componente che gestisce i segnali di clear e o_done. Viene comparato il valore fornito dal contatore in word counter con il numero di parole (word_number). Se il valore del contatore è maggiore allora viene alzato o_done e abbassato o_mem_en. A questo punto, appena i_start viene abbassato, si abbassa anche o_done e si alza clear.

I sotto componenti di cui è composto sono:

1 comparatore

componenti elementari

6) Comparator component

Componente che controlla se la parola che si sta leggendo nel computo della funzione di filtro ($f(j+i)$) sta a destra o a sinistra dell'ultima o della prima parola da filtrare. In caso questa condizione fosse vera alza il segnale sel0 (se sta a sx) o il segnale sel1 (se sta a dx).

I sotto componenti di cui è composto sono:

2 comparatori

1 registro a 16 bit

componenti elementari

7) Selection elaboration component

Componente che racchiude tutta la logica di selezione e instradamento dei vari $f(j+i)$ nel computo della funzione di filtraggio. Ha in ingresso i vari segnali di controllo e produce in uscita i valori selezionati (i vari $f(j+i)$).

I sotto componenti di cui è composto sono:

12 switch

19 mux

Componenti elementari

8) Multiplication component

Componente che moltiplica i vari $f(j+i)$ per i relativi coefficienti e salva i valori in dei registri. A titolo di esempio, se sto filtrando la quinta parola della sequenza (quindi $i=4$) e sto usando un filtro di ordine 5, nel registro 0 avrò $f(-3 + 4) * C(-3)$, nel registro 1 $f(-2 + 4) * C(-2)$ e così via.

I sotto componenti di cui è composto sono:

7 registri a 16 bit

Componenti elementari

9) Final calculation component

Componente che completa la funzione di filtraggio. Quindi somma i valori contenuti nei registri del componente precedente, applica la normalizzazione e tronca il valore normalizzato se necessario.

‘Troncare’ il valore normalizzato significa riportarlo a -128 se risultava inferiore a -128, riportarlo a

127 se risultava superiore a 127. Questo perchè la parola filtrata deve stare in 1 byte di memoria con codifica complemento a 2.

I sotto componenti di cui è composto sono:

Normatore

Troncatore

Componenti elementari

Livello di astrazione 1

Rappresenta il circuito al livello più basso di astrazione, quindi il livello con maggiore dettaglio. Il disegno è il seguente:

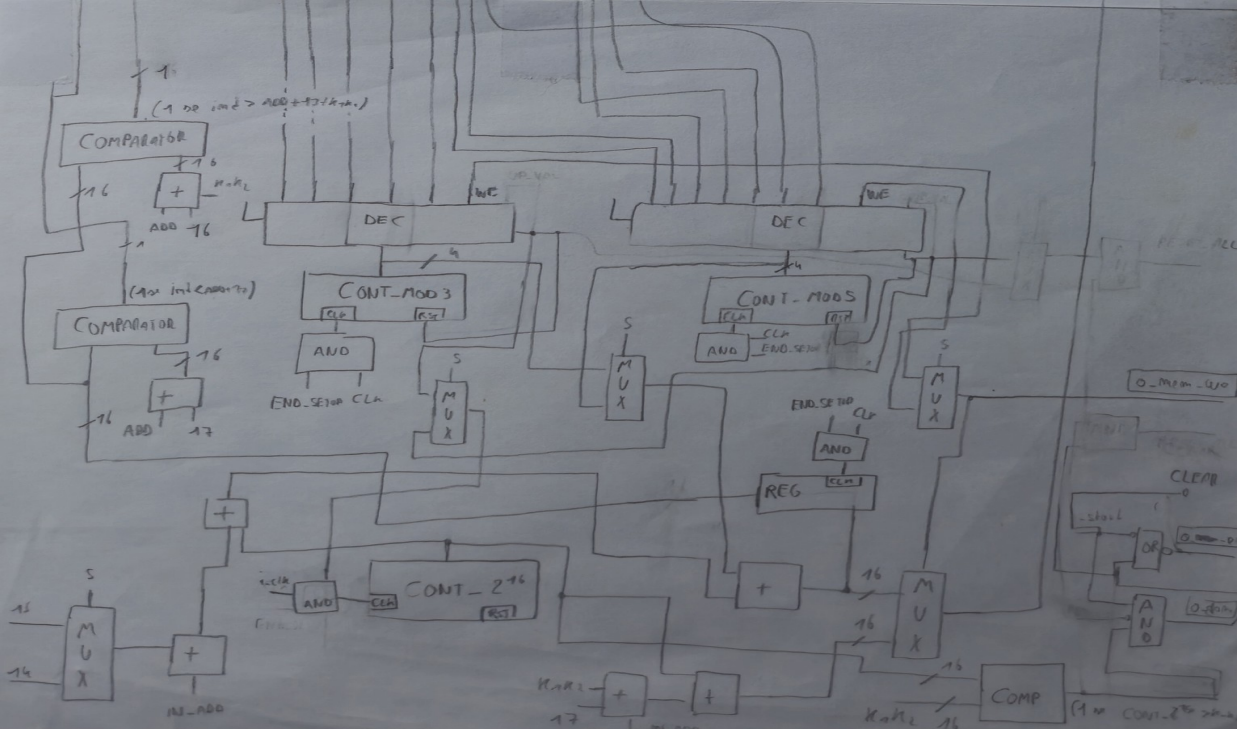
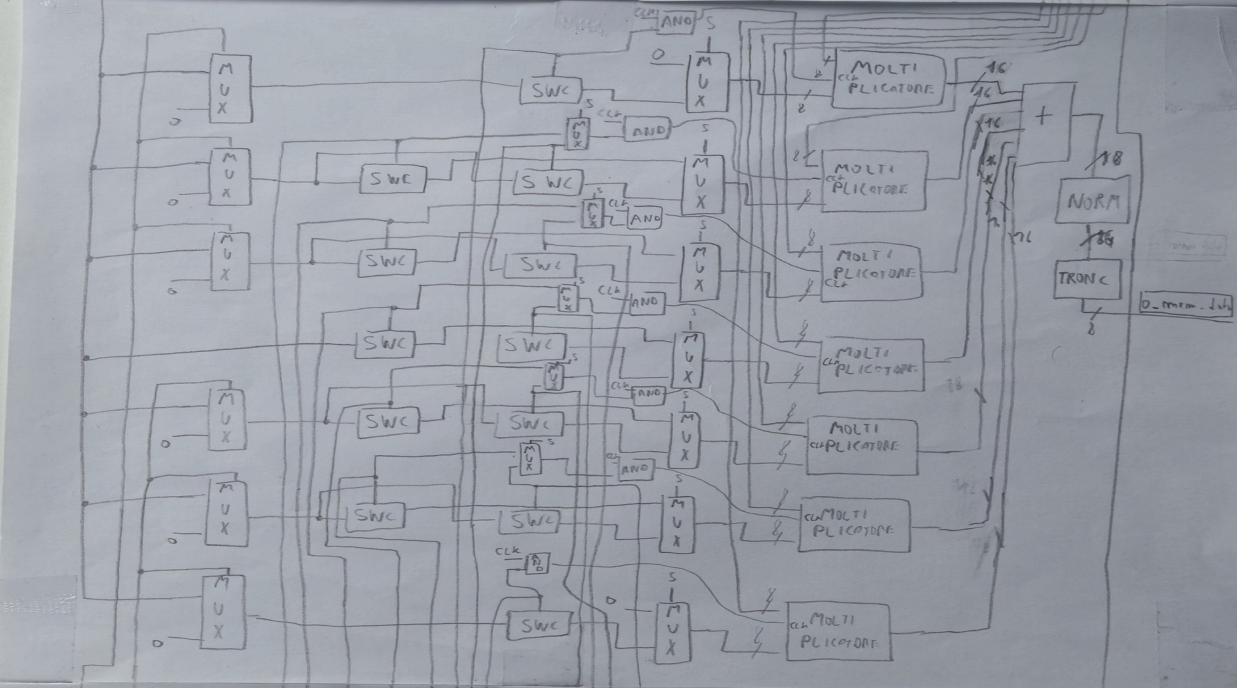
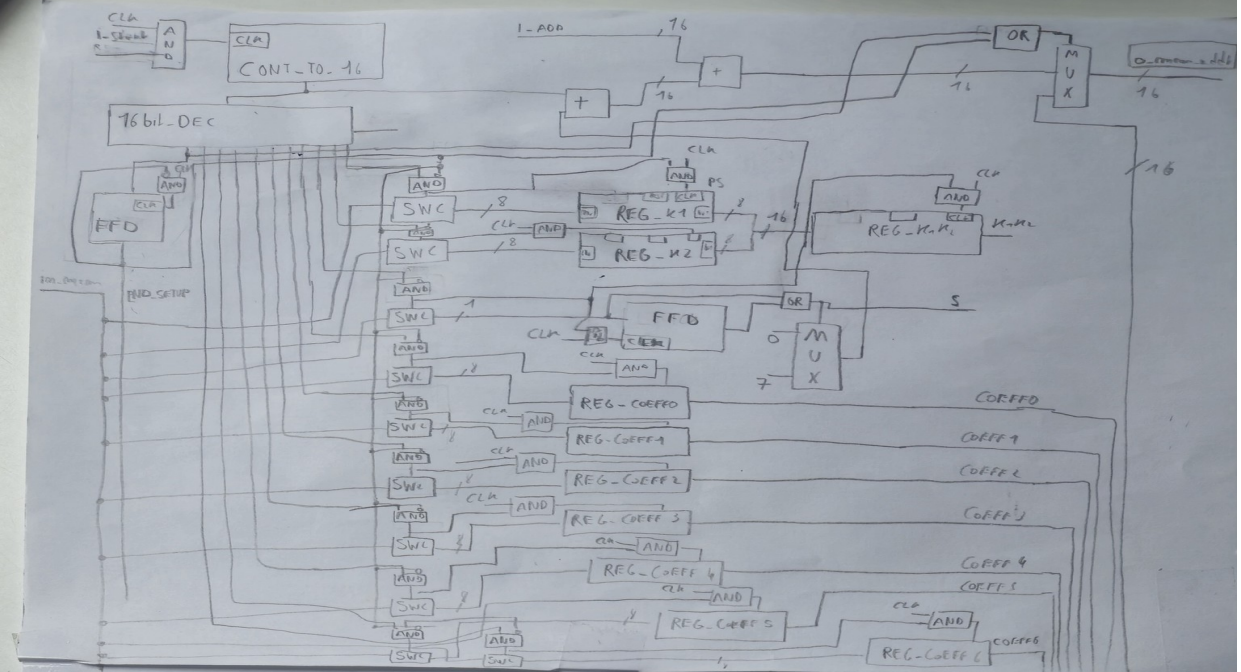


Immagine 5

Nota: nel disegno si supponga che sia sempre presente una porta di reset per gli elementi di memoria collegata a 'i_rst or clear', anche se non sono presenti esplicitamente.

Nota: viene data per scontato la definizione e la funzione di registri, flip flop e mux, essendo componenti visti esaustivamente a lezione.

Elenco dei componenti con relativa descrizione:

1) **Switch**

Componente a 3 porte, di cui 2 input e 1 output. Denominiamo i due input x e y e l'uscita z. Si ha che $z = x$ sse $y=1$, $z=0$ sse $y=0$. Come si può dedurre, y è il segnale di controllo.

2) **Comparatore**

Componente a 3 porte, di cui 2 input e 1 output. Denominiamo i due input x e y e l'uscita z. Si ha che $z=1$ sse $x < y$, $z=0$ altrimenti.

3) **Normatore**

Componente che effettua la normalizzazione del risultato della sommatoria nella funzione di filtraggio, applicando l'approssimazione descritta nella specifica. Ecco il suo disegno:

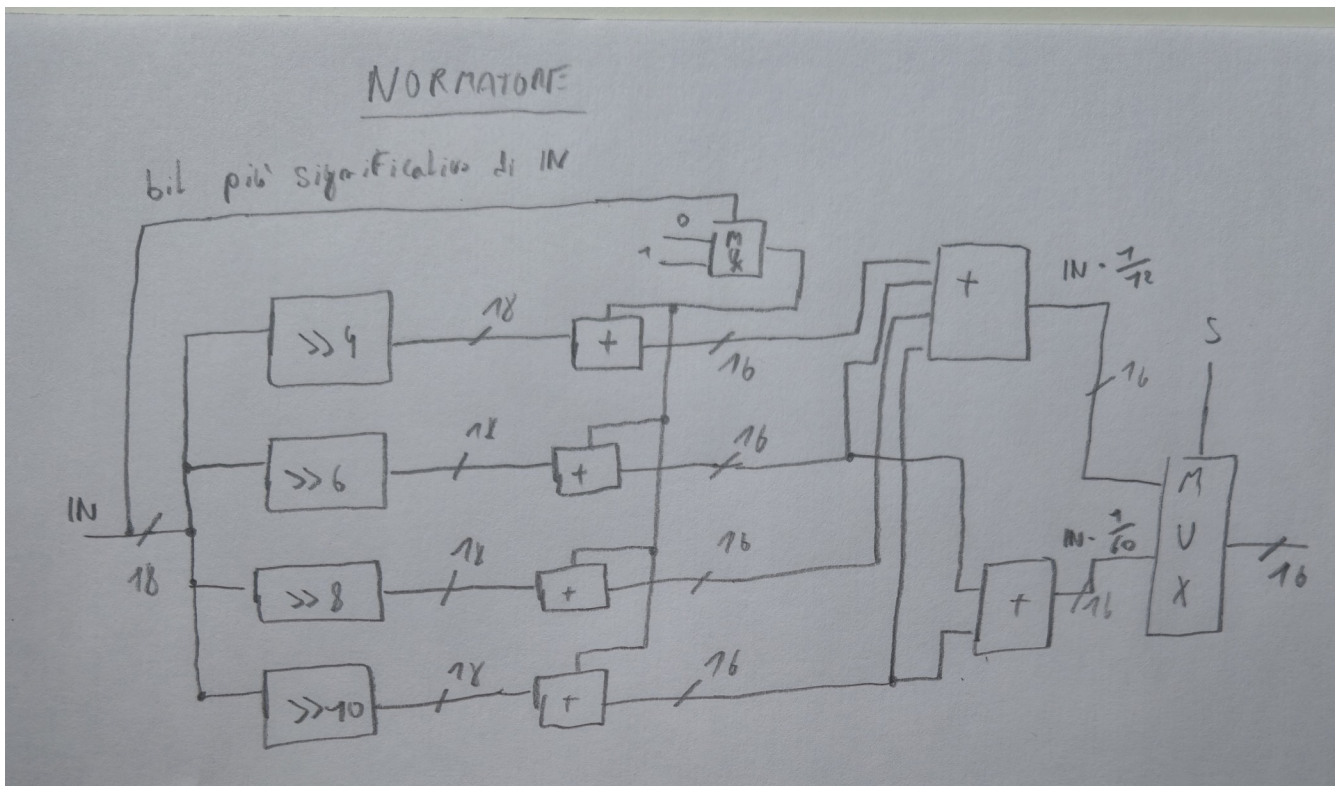


Immagine 6

Come si può osservare è presente il sotto-componente shifter. Ovvero il componente '>>n' è uno shifter che 'shifta' verso destra l'input di n posizioni. Questo serve per poter effettuare le divisioni per potenze di 2.

4) Troncatore

Semplicemente effettua il troncamento del risultato. Quindi ha 2 porte, un input e un output.
 $\text{output} = \text{input}$ se $-128 \leq \text{input} \leq 127$, $\text{output} = -128$ se $\text{input} < -128$, $\text{output} = 127$ altrimenti.

5) Componenti elementari

- Sommatore: somma i valori in input e produce il risultato in output.
- Moltiplicatore: moltiplica i valori in input e produce il risultato in output.
- Porta logica and, or, not.

Risultati sperimentali

Il tool utilizzato per costruire e simulare il componente hardware è Vivado 2024.02. Il componente realizzato funziona sia in pre sintesi (behavioural simulations) che in post sintesi (post-synthesis functional simulation) con un clock di 20ns.

Pre-sintesi

Schematic generato dal tool:

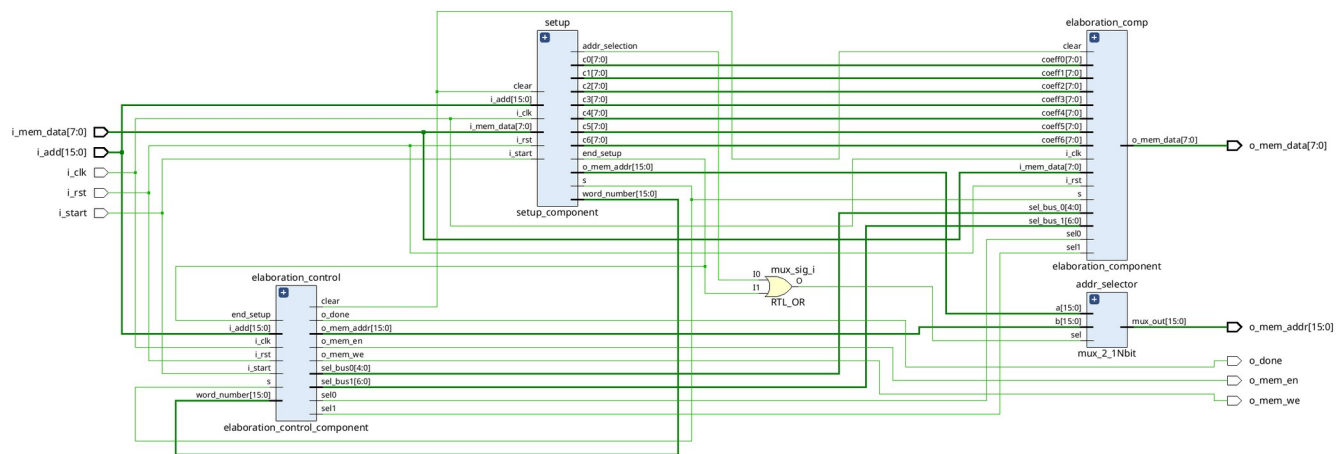


Immagine 7

Come si può osservare, lo schema rtl generato coincide con il disegno relativo al terzo livello di astrazione effettuato prima di scrivere il codice vhdl.

Post-sintesi

Project summary:

Project name: Progetto_Reti_Logiche
Project location: /home/carlo/Xilinx/Progetto_Reti_Logiche
Product family: Artix-7
Project part: xc7a12ticsg325-1L
Top module name: project_reti_logiche
Target language: VHDL
Simulator language: VHDL
Target Simulator: Vivado Simulator

Synthesis

Status: ✓ Complete
Messages: ! 29 warnings
Part: xc7a12ticsg325-1L
Strategy: Vivado Synthesis Defaults
Report Strategy: Vivado Synthesis Default Reports
Incremental synthesis: Automatically selected checkpoint

DRC Violations

[Run Implementation](#) to see DRC results

Utilization

Post-Synthesis | Post-Implementation

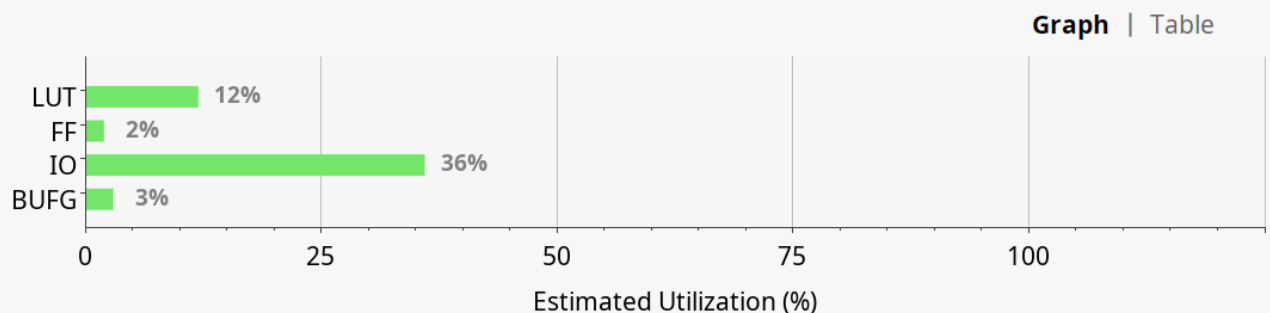


Immagine 8

28 dei 29 warning sono dovuti al componente shifter con il seguente codice di warning: [Synth 8-7129]

Questo è dovuto al fatto che quando shifto la parola, alcuni bit della parola in ingresso non vengono usati dalla logica dello shifter. Per esempio, se ho la sequenza di bit 0101 e la shifto di 2 posizioni verso destra ottengo 0001. I bit '0' e '1' all'inizio della sequenza prima di applicare lo shift sono stati buttati via, ovvero non utilizzati per produrre il risultato. Questa è la causa del warning.

L'ultimo warning è il seguente: [Synth 8-7080] Parallel synthesis criteria is not met.

Il messaggio indica che la sintesi parallela non è stata eseguita perché il design non soddisfa i criteri richiesti per sfruttare la sintesi parallela.

I warning non causano alcun malfunzionamento nel componente e possono quindi essere tralasciati.

Setup

Worst Negative Slack (WNS): 13.673 ns

Total Negative Slack (TNS): 0.000 ns

Number of Failing Endpoints: 0

Total Number of Endpoints: 149

Immagine 9

Come si può vedere dal design timing summary, il worst negative slack vale 13.673 ns. Di conseguenza il modulo progettato rispetta i 20ns di clock con un grosso margine positivo di 13.673 ns. Questo significa che il percorso più lento impiega (20 -13.673) ns, consentendo quindi il modulo di funzionare con un clock potenzialmente più basso.

Constraints

I constraint utilizzati sono all'interno di un file nominato 'constr.xdc' e sono in totale due:

Il primo definisce un vincolo di clock di 20 ns ed è il seguente:

```
"create_clock -period 20 -name clock -waveform {0 10} [get_ports i_clk]"
```

Il secondo è stato inserito a causa di una problematica che ho riscontrato durante la fase di testing del componente. In particolare, prima dell'inserimento del constraint di clock, il modulo passava tutti i test bench da me creati, mentre dopo, i test bench modulo 3 non venivano più passati. Questo mi ha portato alla conclusione che l'inserimento del vincolo di clock sul segnale i_clk ha comportato che Vivado eseguisse ottimizzazioni più aggressive per rispettare i vincoli di timing richiesti. Tali ottimizzazioni hanno però modificato la struttura di alcune celle critiche del progetto, compromettendo il corretto

funzionamento del sistema in simulazione post-sintesi funzionale. Ho quindi inserito il seguente vincolo: “set_property DONT_TOUCH TRUE [get_cells -hierarchical *setup*]”

Questo vincolo impedisce a Vivado di eseguire qualsiasi ottimizzazione sulle celle il cui nome contiene la stringa “setup”. In questo modo ho risolto il problema ripristinando il corretto funzionamento del sistema e garantendo la riuscita di tutti i test bench da me progettati.

Simulazioni

I test bench utilizzati sono raggruppati in 2 categorie: test bench di massa e test bench particolari.

I test bench di massa sono test bench con un enorme quantitativo di input, sia con filtro modulo 3 che modulo 5 e non coprono nessun caso particolare. Il loro scopo è quello di assicurarsi che il componente funzioni in maniera affidabile a fronte di grossi input variegati tra loro. Questo mi garantisce una grossa copertura di casistiche del tutto casuali.

I test bench particolari hanno invece l’obiettivo di coprire casi particolari senza dare importanza alla dimensione dell’input.

1) Test bench di massa

I test bench di massa usati sono 8 in totale, 4 con filtro modulo 3 e 4 con filtro modulo 5. Sono stati generati da un programma C da me scritto (per il codice sorgente del programma mi si contatti direttamente via e-mail). Il programma prende in ingresso il filtro che si vuole (modulo 3 o 5), i 7 coefficienti e la lunghezza della sequenza di parole. Produce in output la sequenza di input, generata casualmente, e la sequenza di output corrispondente.

Elenco dei test bench di massa:

Lunghezza sequenza: 200

Filtro: ordine 3

Coefficienti: 111, 34, -90, 107, 56, -34, 1, 1, -9, 45, 0, -45, 9, -1

Sequenza input: 72, 96, -24, 3, 43, -98, -92, 32, 63, 97, 123, 33, -97, 3, 17, 44, -63, -119, -103, -66, -14, -53, 32, -57, 120, 51, 118, -105, -30, -44, 19, -8, 99, -41, 119, -93, -12, -110, 101, -13, 62, 81, -21, 11, 38, 95, -15, -12, 100, 60, -29, -97, 40, -85, -115, -109, 31, -102, 119, 101, 40, -88, -44, 40, -23, -108, 124, 90, -25, -52, 14, -59, -93, -99, 17, 113, -13, -112, -44, 71, -125, 115, -126, 30, 124, 31, -113, -58, 122, 32, -99, 68, 90, 39, -76, -71, -34, -66, 8, -53, 48, -16, -46, 108, 99, -51, -32, 53, -43, 127, 74, 61, -128, 10, -94, 12, 17, 45, -101, 102, 39, -14, -16, 63, -31, 47, -5, 84, -108, -12, 28, -87, 50, -110, 29, -95, 108, -11, -47, -54, -9, -54, -82, -17, 104, 4, -51, -52, -95, 123, 115, -65, -69, -93, 20, 63, -119, 41, 126, 3, 84, -109, 98, -108, -64, -60, 63, 18, -71, -119, 0, -120, 41, -62, -91, 15, 71, 53, -27, 105, 6, 11, -33, -74, 12, -66, -117, 2, 89, -70, -128, 99, -80, 112, -58, 66, -128, 5, -109, -7

Sequenza output attesa: 127, 127, -128, 127, 95, -128, 6, 127, 127, 127, 127, -128, -128, 127, 127, 127, -128, -128, -66, -128, -128, 34, -128, 127, 127, 127, -128, 127, -128, 95, 127, 127, -128, 127, -128, 127, -128, 127, 90, -128, 127, 127, 127, -128, 127, 127, -108, -128, -48, 127, -128, -128, 80, -43, -128, 127, 127, -128, -128, 127, 127, -128, -128, 127, -128, -128, 127, 127, -128, -128, 127, 127, -128, -128, 127, -128, 73, -128, -128, 86, -128, 127, -128, 68, 127, -128, -128, 127, 6, -128, 127, 127, -128, -128, 127, 127, -128, -128, 127, 127, -128, 127, -128, -128, 127, 127, -128, -128, 127, -128, -128, -47, 127, -128, -128, 127, 127, -128, -128, -128, -128, 127, -128, -128, -128, 127, -128, -128, -128, 127, -98, 127, -128, 127, -128, 55, -116, 127, -128, -128, -128, 13, -128, 127, -128, -128, 127, 127, -128, 33, 127, -128, 127, -128, -128, 127, -128, -128, 127, 127, -128, 127, -128, 127, -128, 127

Lunghezza sequenza: 24

Filtro: ordine 5

Coefficienti: 11, -3, 5, 9, -4, 5, 10, -1, 3, 4, -5, 6, 1, 0

Sequenza input: 89, 91, 122, -125, -25, 26, -36, 40, 27, -36, 58, 2, 12, -70, 89, 74, 92, 14, -75, 23, 58, -105, 13, 25

Sequenza output attesa: 3, 7, -11, 19, 0, -14, 9, -1, -4, 12, -5, 1, -2, 14, -2, 5, 2, 0, 12, -3, -17, 15, -2, -6

Lunghezza sequenza: 400

Filtro: ordine 3

Coefficienti: 8, -9, 3, -10, 15, -1, 9, 1, -9, 45, 0, -45, 9, -1

Sequenza input: -126, 107, -117, -10, -117, 37, 43, -124, -69, -84, -61, -34, 24, -28, -41, 79, -102, 10, -38, 5, 66, 63, -75, -30, 93, 112, 43, 91, -28, 89, -4, -105, 99, -66, -8, 33, -114, 54, -28, -75, -70, -18, 76, 51, 99, -43, -54, -79, 5, -33, -87, 85, -35, 3, 96, 53, 7, 21, -53, 58, -86, 126, -120, -36, -93, -10, -7, -122, -107, -103, 73, 111, -99, -37, 77, -47, -68, -46, 120, -56, -22, 6, -31, 67, 124, -84, 69, 23, 71, -63, -27, -56, -25, -25, 53, -102, 15, -102, 107, -56, -83, 46, 77, 63, 0, 41, -106, 121, 69, -18, -98, -70, -99, 30, 83, -54, 96, 61, -41, 66, -122, -69, 76, 99, 78, 12, 107, 32, -124, 27, -21, -118, -53, -34, -48, -6, 80, -12, -7, 46, -100, 4, -12, -29, 99, 85, -9, -108, -126, -25, -113, -85, 103, -94, 78, 67, 69, -1, 108, 86, -85, -71, 118, 24, 61, -32, -80, -111, 83, 36, 86, 83, 47, 107, -113, 106, -111, -34, -98, -89, 107, -77, 107, 112, 6, 96, 124, 120, -8, 70, -39, -61, -97, 120, -25, 96, -73, 61, 103, -115, 66, 75, 6, 106, 39, 5, 97, -98, -32, 3, 42, -59, 16, 38, -38, 101, -108, -39, 116, 127, -67, 105, -71, 101, 36, 29, 76, -66, 79, -85, 0, 91, -107, -94, 19, 121, -98, 120, -46, 13, -72, 32, -2, -113, -74, 68, -126, 53, -35, 69, 111, 10, -34, -121, 96, 32, -48, 59, 34, -2, -112, -54, -103, -85, 125, -62, 88, -62, -74, -73, -60, 81, -42, 28, 55, -56, 99, 19, 87, -82, -1, 65, -86, 83, 52, -74, -5, 91, 39, -121, -21, -6, -30, -66, 127, 73, -34, 88, 8, 22, 71, 45, -122, -121, -128, 127, -33, 11, 28, 50, 96, 26, 5, 120, -31, 74, 109, 48, -128, -8, -26, 18, 10, -120, 106, -66, -37, 76, -80, 54, 83, -84, 120, -40, 44, 118, -54, -127, 38, -103, -31, -92, 4, 107, -108, -65, 35, 127, -24, 19, -86, 8, -19, -76, 124, -74, -90, 93, -76, -49, 106, 117, -5, 41, -27, -95, -71, 123, -110, 17, -120, 3, -127, 46,

41, 0, 80, -34, -106, 112, -7, 115, -54, -39, 52, -12, -19, -126, 111, -91, -11, -44, -80, -48, 22, 59, 109, -107, -30, -69

Sequenza output attesa: 127, -128, 127, -128, 127, 10, -87, 6, -103, 70, 34, 107, -12, -2, 114, -128, 127, -128, 109, 54, 57, -128, -15, 64, 106, -1, 36, -128, 123, -128, -91, 127, -128, 127, -31, -124, 127, -124, 32, -69, 29, 127, 38, 116, -128, -36, -128, 92, -16, -26, 127, -109, 109, 38, 11, -13, -32, -123, 121, -128, 127, -128, 127, -128, 127, 12, -68, -16, -69, 127, 127, -116, 2, 22, -50, 3, -78, 127, -127, 80, -73, -11, 114, 92, -128, 127, -128, 127, -128, 22, -112, 55, -7, 127, -128, 127, -128, 127, -128, 39, 24, 71, 87, -69, 16, -128, 127, -68, 36, -128, -52, -76, 127, 109, -60, 127, -74, -42, 68, -128, 54, 63, 127, 81, -90, 64, -92, -128, 64, -92, -24, 8, -7, 43, 54, 117, -44, 21, 7, -128, 103, -73, 39, 127, 24, -24, -128, -128, 60, -60, 65, 127, -128, 127, -86, 118, -108, 93, -26, -128, -86, 117, -26, 127, -128, -65, -128, 127, 0, 127, -23, -23, 58, -128, 127, -128, 127, -128, 34, 127, -128, 127, -47, -7, 50, -16, 65, -128, 32, -128, -11, -128, 127, -116, 127, -128, 127, -2, -128, 127, -65, 37, 92, -93, -11, 53, -128, 59, -68, 118, -81, 71, -7, -37, 127, -128, 85, 63, 127, -128, 127, -128, 127, -128, 75, 8, -128, 127, -128, 127, 39, -128, -6, -2, 127, -128, 127, -128, 127, -128, 127, -45, -69, -27, 127, -128, 127, -128, 127, 29, -32, -63, -128, 127, -38, 22, 45, -39, 27, -128, 7, -101, 37, 127, -128, 127, -128, 32, -103, 6, 127, -79, 127, -18, -85, 127, -118, 127, -128, 66, 2, -106, 127, -66, -48, -1, 54, 34, -128, 15, -45, 55, -52, 127, -5, -28, 58, -127, 59, 2, 6, -128, -78, -128, 127, -87, 127, -79, 57, 73, -54, -37, 80, -128, 127, -26, 21, -128, 27, -93, 127, 6, -128, 127, -128, 117, 34, -124, 127, -10, -108, 127, -128, 127, 13, -112, -118, 57, -128, 127, -128, 127, 127, -128, 28, -17, 127, -76, 54, -128, 103, -57, -22, 127, -128, 28, 85, -128, 81, 73, 101, -42, 6, -128, -74, -54, 127, -128, 127, -128, 127, -128, 127, -18, 64, 75, -128, -92, 127, -111, 127, -128, 24, 0, -24, 37, -128, 127, -128, 127, -128, 5, 1, 73, 92, 127, -128, 38, -128, 127

Lunghezza sequenza: 500

Filtro: ordine 5

Coefficienti: 11, -3, 5, 9, -4, 5, 10, -4, 3, -6, 10, 8, -2, 1

Sequenza input: 96, 108, -105, -38, 91, 115, 61, 38, 28, 113, 91, 27, -37, -41, -91, -105, 118, -7, 111, -83, 79, -50, -95, 123, 3, -37, 60, -40, 63, -92, 8, -85, -25, -93, -7, 82, -116, 97, -93, 76, 73, 61, 48, -103, 52, -11, -5, 58, -58, 37, 68, 20, 123, 9, 81, 54, -71, 32, -90, 103, 71, -75, -80, -106, -28, 71, 5, 23, -81, -89, 117, -62, 3, -52, -101, 105, 11, -120, -57, 99, -111, -51, 6, -118, 105, 120, 92, 27, -20, 59, 104, 34, -89, -78, -123, 99, -92, 93, -96, 55, -32, -41, 101, -92, 17, 111, -61, -109, 44, -38, -107, 15, -31, -39, 62, -72, 13, 90, 50, 107, 76, -61, -110, 29, -98, 63, 74, 16, -60, -104, -21, 88, -30, 20, -104, -19, -92, -61, 118, 97, -28, -36, 111, 79, -107, -38, 100, 31, -48, -81, -53, 74, 48, -88, -97, -126, -89, -99, 84, -116, -104, 60, 21, -77, -16, 90, 126, -83, 44, -85, 97, -9, -115, -3, 27, -5, -14, -78, 27, 102, -54, 110, 101, 97, 106, -31, -8, 6, -18, -64, 125, -48, -4, -45, -23, 73, -83, -128, -122, 73, 22, 47, 14, 22, 61, -76, -25, 68, -120, 57, 2, 88, 59, -14, -57, -24, 62, -108, 124, -108, -87, -117, 49, -10, -42, -54, 69, -2, -102, 52, -101, -108, -20, 110, 87, 73, -17, 27, -120, -106, -103, -77, 43, -45, 91, -46, -46, -99, 110, 79, 42, -115, 87, -124, -50, -111, 2, -69, -9, -63, -82, -37, -5, 62, -88, -57, 39, -61, -57, -77, -29, 2, -118, -78, 54, -99, -120, -7, 12, -112, 83, -103, -83, 120, -91, 117, 126, -23, 61, 114, -111, -124, -91, -99, 71, -75, -121, 20, -84, 86, 80, -37, -67, 66, -30, -115, -9, -115, -113, 73, 37, 81, 68, 104, -114, 68, 9, 15, -36, 74, 6, 77, 43, 113, -20, -83, 78, -86, -9, 41, 124, -59, 86, -82, -28, -60, -90, -50, -72, -32, 93, 18, 20, -62, -38, -22, 83,

-41, 24, -37, 21, -87, 103, -115, 41, -9, -3, -50, -2, 50, 84, -74, 22, 82, -107, -100, 85, -111, 64, 106, -115, 112, 12, 11, -17, -53, 5, -13, -111, 75, -85, 89, 103, 101, 40, 16, -66, 16, 34, -92, 89, 22, 13, 123, -2, -85, 116, 127, 117, 2, -53, -57, -20, 67, -101, 103, 46, 28, 32, -55, 93, 120, 56, 44, -93, 75, 65, -8, -77, -10, -106, 109, -110, -83, -34, 48, -20, -81, 31, -122, -44, -14, -73, -65, 94, 68, 57, 94, -60, 53, 57, -93, -14, -25, -42, 40, 86, -66, -74, -51, -76, 111, -41, 44, 126, 64, -71, 4, -74, -128, -47, 71, 93, 35, -12, -80, -77, -92, 12, 88, -105, -67, -54, -2, 99, 112, -42, -23, -66, -46, -17, -35, -60, 81, 5, -83, 65, -29, -92, -117, 31, -81, -30, -79, -33, -43, -121, 13, -75, -124

Sequenza output attesa: 32, -2, -28, 11, 20, 22, 11, 1, 8, 23, 6, -5, -15, -13, -31, 9, 21, 6, 17, -22, 25, -43, 13, 24, -20, 15, -3, -2, 5, -23, 4, -23, 0, -22, 28, -8, -4, 18, -27, 42, -1, 23, -14, -15, 15, -18, 19, -1, -11, 25, 0, 19, 18, -6, 26, -18, -4, -4, -14, 42, -13, -15, -20, -23, 15, 12, 3, 2, -36, 11, 12, -20, 15, -36, 4, 28, -22, -21, 11, 2, -31, 17, -22, -3, 45, 13, 21, -8, -4, 18, 13, -11, -21, -29, -1, 13, -9, 22, -27, 27, -31, 21, 4, -27, 34, 1, -29, -2, 6, -26, -2, 6, -17, 14, 2, -18, 26, 9, 14, 26, -5, -31, -6, -5, -13, 37, 1, 0, -23, -21, 14, 8, -1, -2, -26, 1, -29, 15, 35, 6, -10, 3, 26, -8, -25, 11, 13, -3, -10, -22, 1, 23, -6, -22, -24, -25, -18, 5, 15, -41, 10, 13, -7, -7, 7, 30, 2, -9, 1, -19, 34, -32, -8, 7, -1, 4, -9, -13, 28, 2, 0, 38, 4, 29, 1, -19, 0, -4, -14, 9, 18, -21, 9, -24, 13, 3, -30, -25, -6, 24, 4, 19, -6, 12, -2, -25, 18, -11, -13, 24, -5, 31, -2, -9, -17, 10, -8, -2, 22, -45, -7, -18, 21, -8, -4, 0, 19, -23, -1, 3, -38, -3, 11, 29, 20, 4, -6, -9, -39, -12, -26, 8, 6, 3, 20, -22, -10, -7, 35, 10, -8, -11, 5, -40, 0, -22, 6, -13, 6, -22, -6, -4, 12, 4, -27, 8, -3, -15, -6, -18, 6, -8, -29, 8, 1, -32, -5, 8, -15, 0, 17, -47, 28, 3, -12, 58, -6, -1, 27, -8, -39, -14, -31, 3, 19, -36, 4, -5, -8, 41, -2, -14, -1, 9, -28, -7, -5, -38, 9, 21, 10, 24, 18, -4, -21, 23, -12, 5, 0, 14, 1, 19, 8, 19, -31, 3, 2, -24, 15, 18, 9, -5, 11, -36, 5, -27, -9, -6, -13, 17, 18, 0, 0, -20, -6, 8, 10, -8, 6, -8, -5, -1, 11, -28, 26, -15, 4, -11, 7, 20, 2, -19, 24, -6, -37, 11, -1, -21, 52, -18, -4, 31, -20, 12, -18, -7, 7, -22, 0, 9, -15, 44, 10, 20, 0, -11, -17, 15, -14, -2, 28, -13, 25, 18, -25, 4, 31, 19, 19, -18, -17, -18, 12, -2, -7, 37, -9, 19, -9, -4, 35, 9, 14, -11, -17, 27, -2, -8, -9, -18, -2, 20, -42, 3, -4, 14, -18, 0, -5, -31, 10, -11, -14, 9, 27, 6, 26, -1, -17, 25, -17, -15, 4, -15, 2, 22, 2, -23, -6, -24, 9, 23, -14, 35, 17, -7, -13, -3, -34, -15, 7, 25, 18, 2, -14, -23, -18, -13, 26, 1, -26, -2, -14, 17, 34, 5, -13, -7, -23, -1, -1, -11, 4, 22, -21, 1, 10, -23, -21, -9, 2, -18, 2, -20, 4, -23, -9, 7, -32, -4

Lunghezza sequenza: 1000

Filtro: ordine 3

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Lunghezza sequenza: 5000

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2) Test bench particolari

Si hanno 2 test bench per ogni casistica particolare. Uno con filtro di ordine 3 e l'altro con filtro di ordine 5, in modo da garantire il funzionamento in entrambi i casi.

- Coefficienti nulli

Si hanno tutti i coefficienti nulli con una generica sequenza di input. La sequenza di output sarà fatta da tutti 0.

- Valori massimi

Tutti i coefficienti e tutte le parole della sequenza di input valgono 127. Ci si aspetta quindi che nella sequenza di output si abbiano solo 127.

-Valori minimi

Tutti i coefficienti valgono 127 e tutte le parole della sequenza di input -128. Ci si aspetta quindi che nella sequenza di output si abbiano tutti -128.

- Sequenza di input nulla

Coefficienti casuali e sequenza di input composta da tutti 0. Ci si aspetta quindi tutti 0 nella sequenza di output.

- Estremi nulli

I coefficienti e la sequenza di input sono tali per cui nella sequenza di output si ha che solo l'ultimo e il primo valore della sequenza siano nulli.

- Corpo nullo

I coefficienti e la sequenza di input sono tali per cui nella sequenza di output si ha che solo l'ultimo e il primo valore della sequenza siano non nulli. Si tratta del caso duale rispetto al precedente.

Come si può dedurre l'obiettivo dei test bench particolari effettuati risulta quello di coprire i casi limiti, i casi più rari, e dunque quelli che potrebbero causare problemi inaspettati.

La totalità dei test bench effettuati garantiscono una buona affidabilità del componente in quanto vengono coperti sia casi particolari che casi in cui la dimensione dell'input diventa considerevole con una grande randomizzazione della sequenza di ingresso.

Ci tengo a precisare che ho anche testato il componente con un test bench del professore “Gianluca Palermo”, composto da numerosi scenari, in modo da coprire anche il caso con più sequenze di ingresso diverse.

Conclusioni

In questa relazione è stato presentato, nell'ambito del progetto di Reti Logiche, lo sviluppo e la realizzazione di un componente hardware con l'obiettivo di filtrare una sequenza di parole date in ingresso. Dopo un'introduzione al problema e alle scelte progettuali adottate, è stata descritta l'architettura del componente, dando rilievo agli schemi progettati sui diversi livelli di astrazioni, che sono stati fatti prima di iniziare a scrivere il codice, che è successivamente stato basato su di essi.

I risultati sperimentali hanno dimostrato che il componente genera sequenze di output corrette per i test bench a cui è stato sottoposto. La varietà dei test eseguiti suggerisce un'elevata affidabilità del sistema, confermandone il corretto funzionamento in diversi scenari, sia particolari che di massa. Tuttavia, pur avendo ottenuto riscontri positivi, non è possibile affermare con certezza la correttezza assoluta del componente, in quanto il problema di verificarne la correttezza generale rientra nei problemi indecidibili.

Nel complesso, il progetto ha permesso di approfondire la progettazione hardware e l'uso degli strumenti di sintesi e simulazione, offrendo un valido punto di partenza per un ingresso nella carriera di sviluppatori di codice vhdl e di componenti hardware.

Fonti

Vengono di seguito elencate tutte le fonti che mi hanno consentito di svolgere il progetto.

- “Introduzione al linguaggio VHDL, aspetti teorici ed esempi di progettazione” Carlo Brandolese, Politecnico di milano.

- Slide su vhdl fornite a lezione.

- Registrazioni sui tool di sintesi.

- Internet

Nota finale

L'approccio usato per affrontare e risolvere il problema deriva anche dal fatto che abbia passato molte ore su un gioco denominato "Turing Complete", il cui obiettivo è quello di insegnare ai giocatori i principi fondamentali dell'architettura dei computer e della programmazione a basso livello (assembly e linguaggio macchina) , attraverso un'esperienza interattiva basata sulla costruzione di circuiti logici con un approccio unicamente rtl e strutturale.

Il giocatore inizia con semplici porte logiche e, man mano che progredisce, deve assemblare componenti sempre più complessi, fino a progettare un vero e proprio computer funzionante, macchina per l'appunto Turing completa (da cui deriva il titolo). Il gioco consente di imparare i concetti fondamentali della logica digitale, dei circuiti sequenziali, della memoria, e infine dell'esecuzione di programmi a livello hardware, mettendosi nei panni di un progettatore di sistemi digitali.

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