Embedded Computer Architectures II (192130250)

Wednesday 30 January 2013
15 pages with 6 problems

Guidelines for the exam:

1. Answers have to be written down at the appropriate places in this questionnaire.
2. Fill in your name, studentnumber and study-programme.
3. Hand in all pages.
4. During the exam, the use of books and electronic equipment (laptop, organizers, mobile phones) is prohibited

Name: ....

Studentnumber: .... Study-programme: ....

QUESTION 1 (8 + 2 + 7 + 10 + 3 = 30 POINTS)

A palindrome is a word that is equal when read from left to right and from right to left. An example is the word 'redivider'.
We want to design a fast circuit that recognizes palindromes of length $2L+1$ (hence, of odd length where L is given) in an arbitrary stream of data, for example for recognizing 'redivider' in the sentence "…. the government as a redivider of money …..".

The input datastream consists of data-elements x_i where $-\infty < i < \infty$.

The output is a stream of Boolean values c_i where $-\infty < i < \infty$.

An output value c_i is *true* if and only if the datastream contains a palindrome of length $2L+1$ 'around x_i', e.g.. $x_{i-1} = x_{i+1}$, $x_{i-2} = x_{i+2}$, $x_{i-3} = x_{i+3}$, and so on. So, the algorithm is described by

$$c_i = \bigwedge_{k=1}^{L} (x_{i-k} = x_{i+k})$$

Hint: The operator $\wedge_{k=1}^{L}$ has the same meaning w.r.t. *logical and* ($\wedge$) as the well known operator $\sum_{k=1}^{L}$ w.r.t. *addition* (+). We remark that both "$\wedge$" and "+" are associative and commutative, thus both have the same level of freedom in the design.

a) Determine the recurrent relations of the algorithm presented above where the variables x_{i-k} and x_{i+k} are global variables.

b) How many alternatives are there for the answer of question a? (Remark: an alternative recurrent relation describes a different data dependency graph).

Number of alternatives

c) Draw the 'globally recursive dependency graph' for $L=3$, based on the result of question 1a.

(Hint: choose 'i' in the vertical direction and 'k' in the horizontal direction).

Below a possible architecture to recognize palindromes (for the case $L=3$) is described by means of a functional program **pal** (short for "palindrome"):

```
pal (State (us,ts)) x = ( State (x+>>us, True+>>ts') , last ts')

                    where
                      eqs = zipWith (==) (us!!![1,3,5]) (replicate 3 x)
                      ts' = zipWith (&&) ts eqs
```

In this definition the *state* consists of two lists (**us**, **ts**) of registers, and **x** is the next input value. The value **last ts'** is the next output of the architecture, and **(x+>>us, True+>>ts')** is the next state. Remember that **last** returns the last element of a list, and +>> adds an element **x** to the beginning of a list, throwing away the last element.
The function **zipWith** combines two lists elementwise, by means of a given operator (in this case the boolean functions for equality and for logical and), and the operation **!!!** returns the list of elements 1, 3, 5 from the list **us** (remember that the first element of a list is number zero). Finally, the function **replicate** repeats a value (here **x**) a given number of times (here 3).

d) Make a picture of the architecture that is described by the function **pal**:

e) Indicate the projection- and scheduling vector that should be used on your dependency graph to obtain the architecture of question 1d. Write down the vectors as follows: $\begin{pmatrix} i \\ k \end{pmatrix}$ where 'i' indicates the vertical dimension and 'k' the horizontal dimension.

Projection vector

Scheduling vector

QUESTION 2 **(8 + 5 + 5 + 7 = 25 POINTS)**

A system specification describes a system with two inputs and one output. The two inputs receive an infinite stream of values indicated by x and h respectively. The output delivers a stream of values indicated by y. The relation between inputs and output is given by the following expression

$$y_z = \sum_{i=0}^{N-1} x_z . h_{z+i}$$

We assume that z indicates discrete time, so y_z comes after y_{z-1}. Similar reasoning is valid for x en h.

a) Give the set of recurrent relations that describes the algorithm completely. Use global dependencies.

b) Give the implementation of a node of the dependency graph.

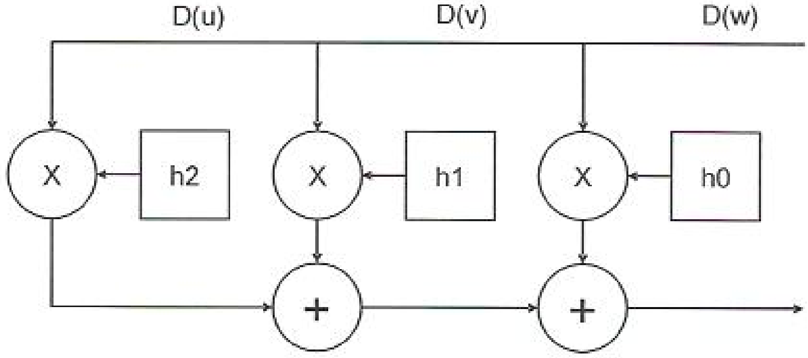
c) Draw the dependency graaf with global dependencies. Indicate the variables in the graph.

d) Give the set of recurrent relations that describes the algorithm completely. Only use local dependencies

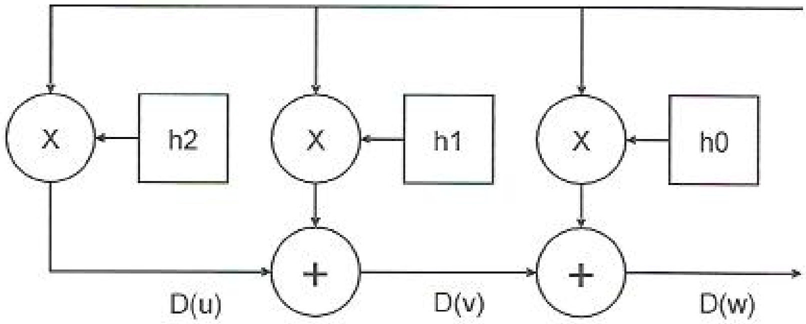
QUESTION 3 **(5 POINTS)**

Below, the filter circuits A and B are given:.

A:



B:



Both circuits have the same behavior. The following function definitions are given:

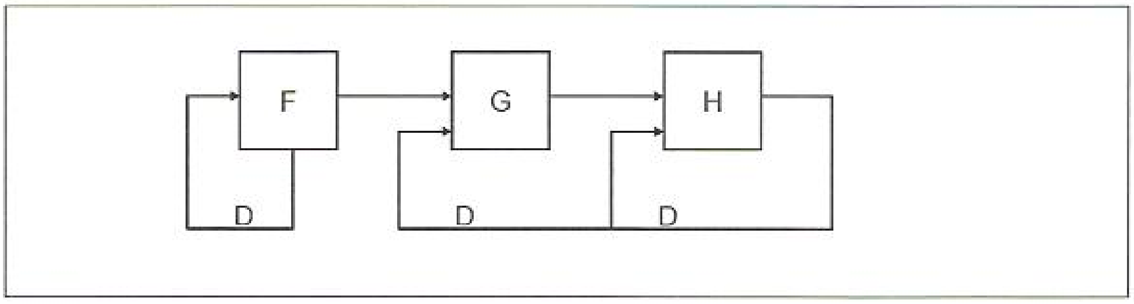
```
f1 (State [u,v,w]) x = (State [u*h2, v*h1, w*h0]    , u*x+v*x+w*x)

f2 (State [u,v,w]) x = (State [x*h2, u+x*h1, v+x*h0], w)

f3 (State [u,v,w]) x = (State [x*h2, x*h1, x*h0]    , u+v+w)

f4 (State [u,v,w]) x = (State [v,w,x]               , u*h2+v*h1+w*h0)
```

The circuits A and B are described by one of the pairs of functions below (the first function describes A, the second describes B).

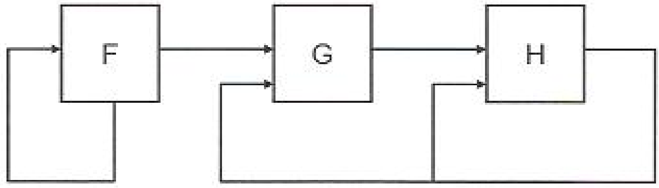
Which of the pairs below is correct?
(1) `f2, f1`
(2) `f4, f2`
(3) `f1, f3`
(4) `f3, f4`

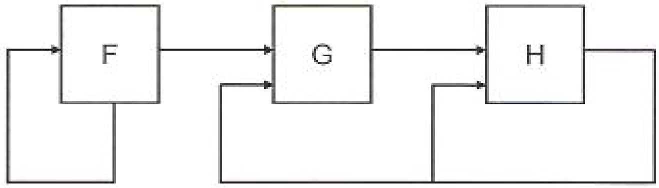
QUESTION 4 (8 PUNTEN)

Below, the following signal flow graph is given:



Deduct by means of retiming from this signal flow graph a systolic signal flow graph which means that each output should be accompanied by a delay element. Use the template below and show all intermediate steps.


F
G
H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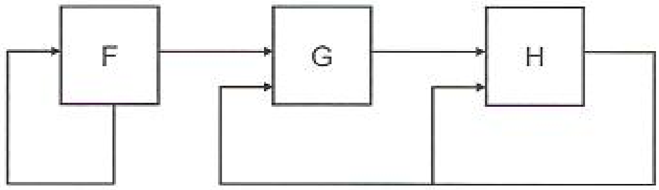
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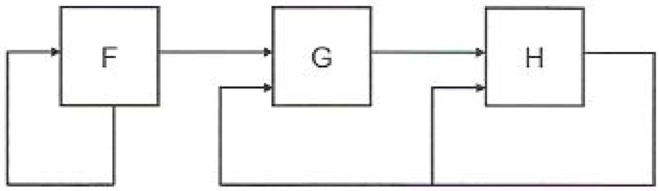
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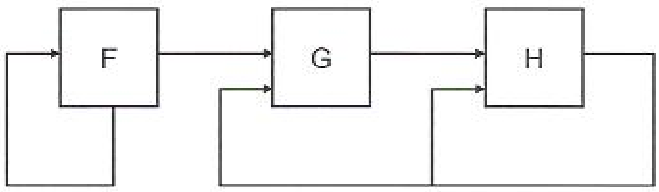
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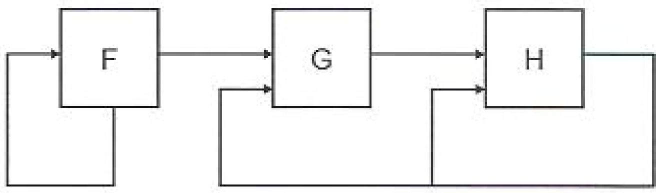
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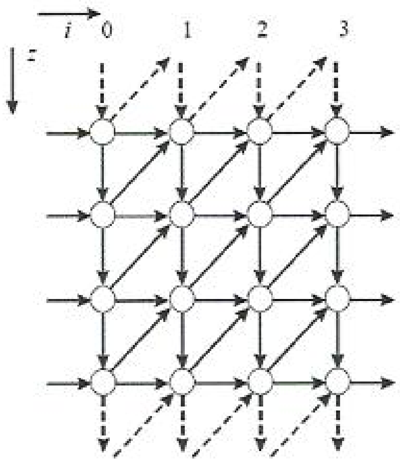
H

QUESTION 5 **(5 + 5 + 10 = 20 POINTS)**

Given is the dependency graph below, where
$(-\infty < z < \infty \quad and \quad 0 \leq i \leq 3)$



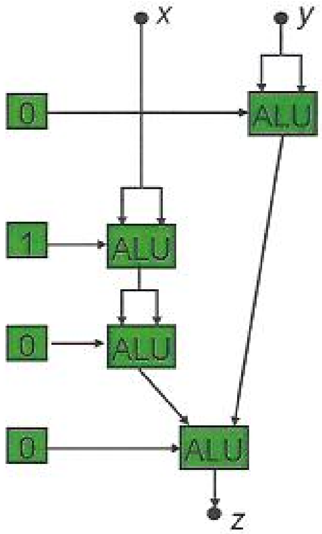
a) What (are) is the possible direction(s) of the projection vector(s)?

b) What (are) is the possible direction(s) of the scheduling vector(s)? Present this in the following format example: $\begin{pmatrix} i \\ j \end{pmatrix} = \begin{pmatrix} -3 \\ -1 \end{pmatrix}$ to $\begin{pmatrix} 2 \\ -1 \end{pmatrix}$ *clockwise*

c) Make a drawing of the signal flow graph in case the projection vector equals $\begin{pmatrix} i \\ j \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ and the scheduling vector equals $\begin{pmatrix} i \\ j \end{pmatrix} = \begin{pmatrix} 1 \\ 2 \end{pmatrix}$. Annotate the signal flow graph with the indices of the nodes and the delay operators D.

QUESTION 6 (12 PUNTEN)

Below, a dependency graph is given:



To map this dependency graph onto a processor-like architecture, the graph must be made time shift invariant.

Using the dependency graph above, determine the time shift invariant dependency graph. Indicate clearly the time zones that are introduced and the decoders and multiplexers to be used. Also indicate the control of the decoders and multiplexers. Use the templates below (multiple templates are given to illustrate the intermediate steps).

ALU

ALU

ALU

ALU

ALU

ALU

ALU

ALU

ALU

ALU

ALU

ALU
