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| --- | --- | --- | --- |
| Name | I/O | Shape (bit) | Function |
| **TOP |** the main module that determines the work of the others and stores the structure of the neural network | | | |
| clk | I | 1 | clock signal |
| GO | I | 1 | Signal to start the neural network |
| we\_database | I | 1 | A high value indicates the incoming image data required to start the neural network, permission to write to the RAM of the neural network |
| dp\_database | I | 11 | Picture data |
| address\_p\_database | I | 13 | The address of the input pixel of the picture to be placed in RAM |
| STOP | O | 1 | A high value means the end of the neural network, which is saved until a new start (GO signal) |
| RESULT | O | 4 | The result of the neural network. From 4'b0 to 4'b1001 corresponds to a digit from 0 to 9 in the decimal number system, 4'b1010 means the absence of a specific digit. |
| **RAM |** FPGA internal memory module | | | |
| clk | I | 1 | clock signal |
| re\_w | I | 1 | A high value indicates a request to read weight data |
| read\_addressw | I | 9 | Address of the requested weight coefficient |
| qw | O | 99 | Weight coefficient output caused by reading |
| we\_w | I | 1 | A high value signals incoming data to write weights |
| write\_addressw | I | 9 | Address of weight to be written |
| dw | I | 99 | Write weight input |
| re\_p | I | 1 | A high value indicates a request to read intermediate picture data |
| read\_addressp | I | 13 | Address of the requested pixel of the intermediate picture |
| qp | O | 11 | Intermediate picture output caused by reading |
| we\_p | I | 1 | A high value indicates incoming data for recording an intermediate picture |
| write\_addressp | I | 13 | Address of the recorded pixel of the intermediate picture |
| dp | I | 11 | Input data of the recorded pixel of the intermediate picture |
| re\_tp | I | 1 | A high value indicates a request to read the layer's intermediate data |
| read\_addresstp | I | 12 | The address of the requested pixel of the layer's intermediate data |
| qtp | O | 22 | Layer intermediate data output caused by read |
| we\_tp | I | 1 | A high value signals incoming intermediate layer data for writing |
| write\_addresstp | I | 12 | Writable pixel address of layer intermediate data |
| dtp | I | 22 | Input writable layer intermediate data |
| **addressRAM |** module for storing addresses of weight coefficients for each layer of the neural network | | | |
| step | I | 5 | The number of the stage at which the work of the neural network is located |
| re\_RAM | O | 1 | Signal about the need to load the necessary values ​​of weight coefficients or pixels from the database into RAM |
| firstaddr | O | 13 | Address in database of the first weight value or pixel of the current layer |
| lastaddr | O | 13 | The address in the database of the last weight value or pixel of the current layer |
| **memorywork |** module for redistributing work with image and weight data between external memory and RAM | | | |
| clk | I | 1 | clock signal |
| re\_RAM | I/O | 1 | Signal about the need to load the necessary values ​​of weight coefficients or pixels from the database into RAM |
| data | I | 11 | Input picture or weight data loaded into RAM |
| address | O | 13 | Pixel address of the input image or weights loaded into RAM |
| we\_p | O | 1 | Generated signal that allows recording pixels of the input image into RAM |
| we\_w | O | 1 | Generated signal to enable writing weight data to RAM |
| nextstep | I | 1 | A high value indicates the need to increase the current value of step (the stage of the neural network) |
| dp | O | 11 | Sent data in RAM pixels of the picture |
| dw | O | 99 | Send data to RAM weights |
| addrp | O | 13 | Address of the image pixel sent to RAM |
| addrw | O | 9 | Address of weight data to be sent to RAM |
| step\_out | O | 5 | The number of the stage at which the work of the neural network is located |
| GO | I | 1 | Signal to start the neural network |
| in\_dense | I | 5 | Number of input pixels for the current dense layer |
| **border |** module for signaling the side boundaries of the input image | | | |
| clk | I | 1 | clock signal |
| go | I | 1 | Module enable signal |
| i | I | 10 | The number of the element of the input matrix, stretched into one row |
| matrix | I | 5 | The dimension of the input matrix is the number of rows or columns (their number is always the same) |
| prov | O | 2 | Module result. If equal to 2'b00 - no side borders, 2'b11 - side border to the left of the element, 2'b10 - side border to the right |
| **conv |** convolution module | | | |
| clk | I | 1 | clock signal |
| Y1 | O | 21 | Module result |
| prov | I | 2 | Information about the borders of the input image from the border module |
| matrix | I | 5 | The dimension of the input matrix is the number of rows or columns (their number is always the same) |
| matrix2 | I | 10 | matrix \* 2 |
| i | I | 10 | The number of the element of the input matrix, stretched into one row |
| w1 | I | 11 | Each value is a pixel that fell into the convolution window |
| w2 | I | 11 |
| w3 | I | 11 |
| w4 | I | 11 |
| w5 | I | 11 |
| w6 | I | 11 |
| w7 | I | 11 |
| w8 | I | 11 |
| w9 | I | 11 |
| w11 | I | 11 | Each value is a convolution weight |
| w12 | I | 11 |
| w13 | I | 11 |
| w14 | I | 11 |
| w15 | I | 11 |
| w16 | I | 11 |
| w17 | I | 11 |
| w18 | I | 11 |
| w19 | I | 11 |
| conv\_en | I | 1 | A high value signals the operation of the convolutional layer of the neural network |
| dense\_en | I | 1 | A high value signals the operation of a fully connected neural network layer |
| **conv\_TOP |** module for organizing the work of convolutional layers | | | |
| clk | I | 1 | clock signal |
| conv\_en | I | 1 | A high value indicates the operation of this module |
| STOP | O | 1 | A high value indicates the end of the module |
| memstartp | I | 13 | Address number in RAM where the first pixel of the required input image is located |
| memstartw | I | 9 | Address number in RAM where the first weight coefficient is located, starting from which the weight coefficients necessary for this stage of the layer operation are found |
| memstartzap | I | 13 | Address number in RAM, starting from which the current layer results should be loaded |
| read\_addressp | O | 13 | Address of the requested pixel of the input image |
| write\_addressp | O | 13 | Address of the pixel to be written in the output image |
| read\_addresstp | O | 12 | Address of the requested intermediate result value |
| write\_addresstp | O | 12 | Address of the intermediate result value to be written |
| read\_addressw | O | 9 | Address of the requested set of weights |
| we | O | 1 | Generated signal that allows the recording of the obtained layer results in RAM |
| re\_wb | O | 1 | Generated signal requesting weight and offset data from RAM |
| re | O | 1 | Generated signal requesting input picture data from RAM |
| we\_t | O | 1 | Generated signal that allows the recording of intermediate layer results in RAM |
| re\_t | O | 1 | Shaped signal requesting intermediate layer data from RAM |
| qp | I | 11 | Image pixel obtained by reading from RAM |
| qtp | I | 22 | Intermediate layer value obtained by reading from RAM |
| qw | I | 99 | The set of weight coefficients obtained by reading from RAM |
| dp | O | 11 | Output image pixel written to RAM |
| dtp | O | 22 | The value of the intermediate result written to RAM |
| prov | I | 2 | Information about the borders of the input image from the border module |
| matrix | I | 5 | The dimension of the input matrix is the number of rows or columns (their number is always the same) |
| matrix2 | I | 10 | matrix \* 2 |
| i\_2 | O | 10 | The number of the element of the input matrix, stretched into one row |
| lvl | I | 5 | Number of the current input picture |
| slvl | I | 2 | (The number of the resulting output picture) / 4 |
| Y1 | I | 21 | Convolution result |
| w15 | O | 11 | Weights for the convolution window |
| w14 | O | 11 |
| w16 | O | 11 |
| w13 | O | 11 |
| w17 | O | 11 |
| w12 | O | 11 |
| w18 | O | 11 |
| w11 | O | 11 |
| w19 | O | 11 |
| p1 | O | 11 | Image pixels for the convolution window |
| p2 | O | 11 |
| p3 | O | 11 |
| p8 | O | 11 |
| p7 | O | 11 |
| p4 | O | 11 |
| p5 | O | 11 |
| p9 | O | 11 |
| p6 | O | 11 |
| go | O | 1 | A high value triggers the convolutional block |
| num | I | 3 | The number of the resulting output picture |
| filt | I | 5 | (Number of input pictures) - 1 |
| bias | I | 1 | Signals the last image of the layer to calculate and upload the final result of the current layer |
| globmaxp\_en | I | 1 | A high value means the GlobalMaxPooling2D layer is working |
| **maxp |** module for organizing the work of pooling layers | | | |
| clk | I | 1 | clock signal |
| maxp\_en | I | 1 | A high value indicates the operation of this module |
| memstartp | I | 13 | Address number in RAM where the first pixel of the required input image is located |
| memstartzap | I | 13 | Address number in RAM, starting from which the current layer results should be loaded |
| read\_addressp | O | 13 | Address of the requested pixel of the input image |
| write\_addressp | O | 13 | Address of the pixel to be written in the output image |
| re | O | 1 | Generated signal requesting input picture data from RAM |
| we | O | 1 | Generated signal that allows the recording of the obtained layer results in RAM |
| qp | I | 11 | Image pixel obtained by reading from RAM |
| dp | O | 11 | Output image pixel written to RAM |
| STOP | O | 1 | A high value indicates the end of the module |
| matrix2 | I | 5 | matrix \* 2 |
| matrix | I | 10 | The dimension of the input matrix is the number of rows or columns (their number is always the same) |
| **dense |** module for organizing the work of fully connected layers | | | |
| clk | I | 1 | clock signal |
| dense\_en | I | 1 | A high value indicates the operation of this module |
| STOP | O | 1 | A high value indicates the end of the module |
| in | I | 5 | Number of input pixels for the current layer |
| out | I | 4 | Number of output pixels for the current layer |
| we | O | 1 | Generated signal that allows the recording of the obtained layer results in RAM |
| re\_p | O | 1 | Generated signal requesting input picture data from RAM |
| re\_w | O | 1 | Generated signal requesting weight data from RAM |
| read\_addressp | O | 13 | Address of the requested pixel of the input image |
| read\_addressw | O | 9 | Address of the requested set of weights |
| write\_addressp | O | 13 | Address of the pixel to be written in the output image |
| memstartp | I | 13 | Address number in RAM where the first pixel of the required input image is located |
| memstartzap | I | 13 | Address number in RAM, starting from which the current layer results should be loaded |
| qp | I | 11 | Image pixel obtained by reading from RAM |
| qw | I | 99 | The set of weight coefficients obtained by reading from RAM |
| res | O | 11 | Layer result written to RAM |
| Y1 | I | 21 | Convolution result |
| w11 | O | 11 | Weights for the convolution window |
| w12 | O | 11 |
| w13 | O | 11 |
| w14 | O | 11 |
| w15 | O | 11 |
| w16 | O | 11 |
| w17 | O | 11 |
| w18 | O | 11 |
| w19 | O | 11 |
| p11 | O | 11 | Image pixels for the convolution window |
| p12 | O | 11 |
| p13 | O | 11 |
| p14 | O | 11 |
| p15 | O | 11 |
| p16 | O | 11 |
| p17 | O | 11 |
| p18 | O | 11 |
| p19 | O | 11 |
| go | O | 1 | A high value triggers the convolutional block |
| nozero | I | 5 | Low value applies relu to the layer |
| in\_dense | I | 1 | Number of input pixels for the current layer (same as the in input) |
| **result |** a module that finds the maximum value from the input to find the final result of the neural network | | | |
| clk | I | 1 | clock signal |
| enable | I | 1 | A high value indicates the operation of this module |
| STOP | O | 1 | A high value indicates the end of the module |
| memstartp | I | 13 | Address number in RAM where the first value of the required group of values is located |
| read\_addressp | O | 13 | Address of requested value from RAM |
| qp | I | 11 | Value received by reading from RAM |
| re | O | 1 | Generated signal requesting data from RAM |
| RESULT | O | 4 | The result of the neural network. From 4'b0 to 4'b1001 corresponds to a digit from 0 to 9 in the decimal number system, 4'b1010 means the absence of a specific digit. |
| **database |** a module that stores the original image for recognition by the neural network and weight coefficients | | | |
| clk | I | 1 | clock signal |
| datata | O | 11 | Image data sent to the neural network |
| re | I | 1 | A high value requests data to be read into the neural network |
| address | I | 13 | The address where the data is read |
| we | I | 1 | A high value writes data to this module's memory |
| dp | I | 11 | Image input data for writing to the module memory |
| address\_p | I | 13 | The address where the data is written |