

CM1K hardware

User's Manual



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COGNIMEM
Technologies, Inc.

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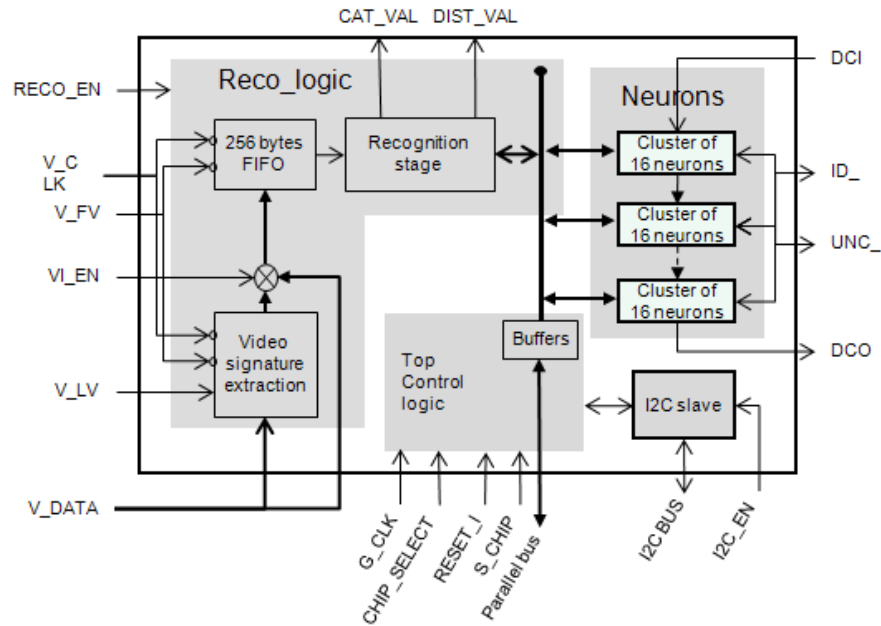
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2 Architecture of the CM1K

CM1K is a high-performance pattern recognition chip featuring a network of 1024 neurons operating in parallel. Also, the chip embeds a recognition engine ready to classify a digital signal received directly from a sensor.

The CM1K is composed of the following modules

- Top control logic (NSR and RSR registers, Ready and Busy control signals)
- Clusters of 16 neurons
- Recognition stage (optional usage)
- I2C slave (optional usage)



2.1 Top Control logic

- Synchronize communication between the clusters of neurons, the recognition state machine and the I2C slave.
- Inter-module communication is made through a bi-directional parallel bus of 25 wires: data strobe (DS), read/write (RW_), 5-bit register (REG), 16-bit data (DATA), ready (RDY)
- Inter-neuron communication also uses two additional lines indicating the global status of the neural network: identified recognition (ID), uncertain recognition (UNC).
- Communication with external control unit can be made through the same parallel bus or the serial I2C bus.

2.2 Cluster of Neurons

- 16 identical neurons operating in parallel.
- All neurons have the same behavior and execute the instructions in parallel independent from the cluster or even chip they belong to.
- No controller or supervisor
- Selection of one out of two classifiers: K-Nearest Neighbor (KNN) or Radial Basis Function (RBF)
- Recognition time is independent of the number of neurons in use
 - o Recognition status in 2 clock cycles after the broadcast of the last vector component
 - o Distance and Category readout in 36 clock cycles per firing neuron

- Automatic model generator built into the neurons
 - o Learn in 18 clock cycles after the broadcast of the last vector component
- Save and Restore of the contents of the neurons in 258 clock cycle per neuron
- Simple Register Transfer Level instruction set through of 15 registers
- Most operations execute in 1 clock cycle except for Write LCOMP, Write CAT, Read CAT and Read DIST which can take up to 19 clock cycles.
- Daisy-chain connectivity between the neurons of multiple CM1K chips to build networks with thousands of neurons .

2.3 Recognition stage (optional usage)

- Enabled physically with RECO_EN pin and activated programmatically via a control command
- Vectors received through the digital input bus are continuously recognized and the response can be snooped directly from control lines or is readable through registers.
- Recognition is made in 37 clock cycles from the receipt of the last component of a vector.
- If the input signal is a video signal, the vector is extracted by the recognition stage from a user-defined region of interest.

2.4 I2C slave controller (optional usage)

- Enabled physically with I2C_EN pin
- Receives the serial signal on the I2C_CLK and I2C-DATA lines and convert it into a combination of DS, RW_, REG and DATA signals compatible with the parallel neuron bus.

3 The neural network

The CogniMem chip is a fully parallel silicon neural network: it is a chain of identical elements (i.e. neurons) addressed in parallel and which have their own “genetic” material to learn and recall patterns without running a single line of code and without reporting to any supervising unit. In addition, the neurons fully collaborate with each other through a bi-directional and parallel neuron bus which is the key to accuracy, adaptivity and speed performance. Indeed each neuron incorporates information from all the other neurons into its own learning logic and into its response logic.

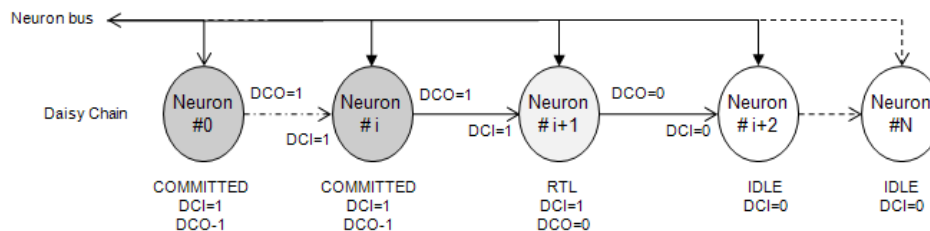
The neurons can learn and recognize input vectors autonomously and in parallel. If several neurons recognize a pattern (i.e. “fire”), their responses can be retrieved automatically in increasing order of distance (equivalent to a decreasing order of confidence). The information which can be read from a firing neuron includes its distance, category and neuron identifier. If the response of several or all firing neurons is polled, this data can be consolidated to make a more sophisticated decision weighing the cost of uncertainty or else. Note that if a “best-match” response is sufficient for an application, the CM1K chip comes with a recognition stage which is optimized to return this limited response 38 clock cycles after the receipt of a vector on the digital input bus of the chip.

This paragraph gives a brief overview of the neural network functionality. For a detailed description of the neuron’s behavior and their interactions, please refer to the manual CogniMem Reference Guide.

3.1 A chain of identical neurons

A neuron can have three states in the chain: IDLE, Ready-To-Learn (RTL) or COMMITTED. It becomes committed as soon as it learns a pattern and its category register is written with a value different from 0. Its Daisy-Chain-Out (DCO) control line automatically rises, changing its status from Ready-To-Learn to Committed. The next neuron in the chain becomes the Ready-To-Learn. It has its **Daisy-Chain-In (DCI)** high and **Daisy-Chain-Out (DCO)** low.

The transfer of the DCI-DCO from one neuron to the next is activated the same way whether the two consecutive neurons belong to a same cluster or not, and even belong to a same chip or not.



3.1.1 Parallel access to the neurons

All the neurons decode and execute the commands received through the neuron bus in parallel. This is a key enabler of the CM1K chip to deliver a recognition time independent of the number of committed neurons in the chain.

3.1.2 Sequential access to the neurons

The CM1K has the ability to save and restore the contents of its committed neurons, which is a representation of the knowledge they have built autonomously by learning examples. In order to read the knowledge stored in the neurons or load a knowledge file to the neurons, a special operation mode called Save and Restore allows accessing the neurons sequentially in the chain.

3.2 The neuron parallel bus

The neurons receive and execute instructions simultaneously through a bi-directional parallel bus composed of 26 lines:

3.2.1 Command and control lines

DS	Data strobe line
RW_	Read/Write line (default is Read with RW_=1)
REG	5 bit register address
DATA	16-bit register data
RDY	Ready control line mixing the ready output signal of all the neurons in the chain and indicating that the neurons are all ready to execute a new command
ID_	Control line mixing the ready output signal of all the neurons in the chain and indicating that neurons have identified the last vector and that these neurons are all in agreement for its classification.
UNC_	Control line mixing the ready output signal of all the neurons in the chain and indicating that neurons have identified the last vector but that these neurons are in disagreement with its classification. This line is an in/out line because used as an input during the execution of certain Write register.

The neurons sample a new command on the positive edge of the system clock and pull down their RDY line for the duration of its execution. Upon completion, the RDY line is pulled back up on the positive edge of the system clock.

A Write command (DS, RW_=0, REG, DATA) must be stable on the positive edge of the system clock and released before the next positive edge of the system clock.

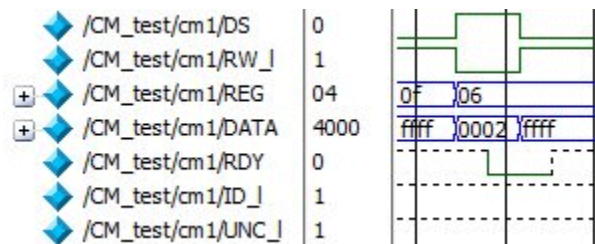
A Read command (DS, RW_=1, REG) must be stable on the positive edge of the system clock and released before the next positive edge of the system clock. DATA is stable when the RDY control line is pulled high.

3.2.2 Timings

Depending on the REG address and also the status of the neurons on the chain, the Read and Write commands can take between 1 and 19 clock cycles.

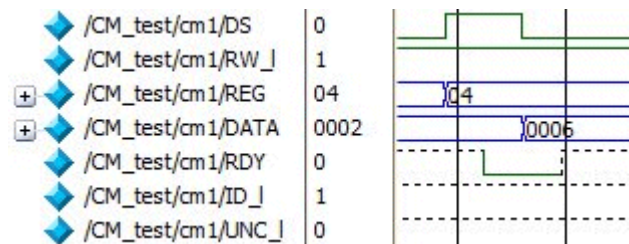
Write in one cycle

(REG 0x06 is the MINIF register)



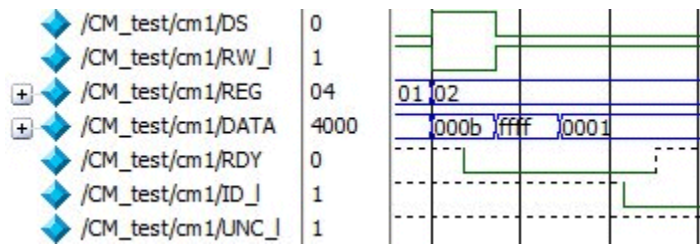
Read in one clock cycle

(REG 0x04 is the CAT register, read in this case in SR mode)



Write in two cycles

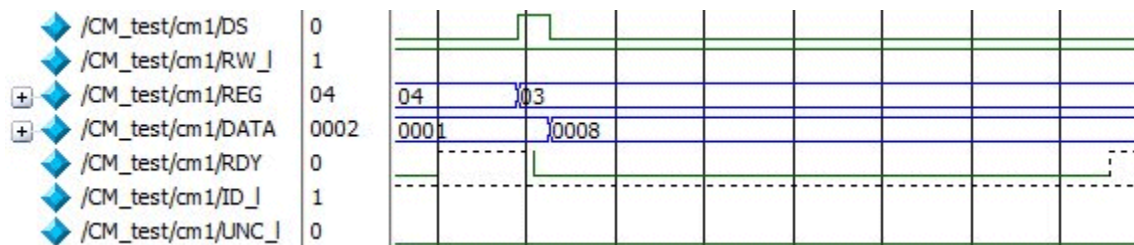
(REG 0x02 is the LCOMP register)



Remark: When the DS signal is asserted the DATA bus must be the input value (i.e. 0x000b). It then is switched to a tri-state mode (i.e. 0xFFFF). During the second and last cycle of the Write LCOMP the firing neurons output their category value and DATA represents their resulting bit-per-bit AND combination (i.e. 0x0001). If this value is different from the category of one of the firing neurons, the UNC_L line is pulled down (not the case illustrated in the above diagram)

Read in sixteen cycles

(REG 0x03 is the DIST register)



3.3 The control registers

3.3.1 Operation modes: Normal versus Save and Restore

The Save-and-Restore (SR) mode is used to save and restore the contents of the neurons in the least amount of time. This feature is essential to transfer knowledge bases between hardware platforms, but also make backup prior to training on additional examples.

Under the SR mode, the neurons become dummy memories limited to the execution of read register and write register functions taking one system cycle each. The automatic model generator and search and sort algorithm are disabled. The SR mode is set in bit 4 of the NSR register.

3.3.2 Register descriptions

	Description	Addr	Normal mode	SR mode	Value range/ Default
NSR	<p>Network Status Register Bit[1:0], reserved Bit[2], UNC (Uncertain, read-only) Bit[3], ID status (Identified, read-only) Bit[4], SR status (default=normal) Bit[5], KNN classifier (default=RBF)</p> <p>The ID and UNC bits are updated internally after each Write Last Comp command. ID is high if all firing neurons report the same category. UNC is high if several neurons fire but disagree with the category.</p> <p>KNN is a recognition mode and should not be activated while learning.</p>	0x0D	RW	W	16-Bit/ 0x00
GCR	<p>Bit [6:0]= Global Context Register Bit[7]= Norm , 0 for L1, 1 for Lsup</p>	0x0B	RW		16-bit/ 0x0001
MINIF	Minimum Influence Field	0x06	RW	RW	16-bit/ 0x0002
MAXIF	Maximum Influence Field	0x07	RW		16-bit/ 0x4000
NCR	<p>Neuron Context Register Bit [6:0]= Context value between 0 and 128 Bit[7]= neuron Norm , 0 for L1, 1 for Lsup</p> <p>Bit[15:8] are used to store bit [23:16] of the neuron identifier</p>	0x00		RW	16-bit*/ 0x0001
COMP	<p>Component Writes to the neuron memory at the current index, updates the distance register and increments the index.</p>	0x01	W	RW	8-bit/ 0x00

	Description	Addr	Normal mode	SR mode	Value range/ Default
LCOMP	Last Component Writes to the neuron memory at the current index, updates the distance register and launch the neuron associative logic. The fire, ID, UNC flags and NSR registers are updated.	0x02	W		8-bit/ 0x00
INDEXCOMP	Component index Set the neuron memory index to an input value which can range between 0 and 255.	0x03	W	W	8-bit/ 0x00
DIST	Distance register. This register is updated by the neuron. Can range between 0 and 65535 (0xFFFF) A distance 0 means that the vector matches exactly the model of a firing neuron. The higher the distance, the farther the vector from the model. A distance of 0xFFFF means that no neuron recognizes the last input vector. Must be read after writing CM_LCOMP and before reading CM_CAT	0x03	R	R	16-bit/ 0xFFFF
CAT	Category register Can range between 1 and 32766 (0x7FFE) Bit 15 is a flag indicating if the firing neuron is degenerated. A category of 0xFFFF means that no neuron is firing and recognizes the last input vector. If category is greater than 32768, it indicates that the firing neuron is degenerated. Must be read after the DIST register.	0x04	RW	RW	16-bit/ 0xFFFF
AIF	Active Influence Field In normal mode, this register is updated by the learning logic of the neuron.	0x05		RW	16-bit/ 0x4000

	Description	Addr	Normal mode	SR mode	Value range/Default
NID	<p>Neuron Identifier</p> <p>This register can be read after the category register.</p> <p>*bit[23:16] of the neuron identifier are stored in the unused upper byte of the NCR register.</p> <p>It is the subject of an Erratum at the end of this manual.</p>	0x0A	R	R	24-bit*/ 0x000000
POWERSAVE	<p>Ensure that the data lines are in tri-state and do not draw current from the pull-up resistors. This register can be written whenever the neurons are not used.</p>	0x0E	W		n/a
FORGET	<p>Clear the neuron's category register, resetting its status to idle. The value written to this register is discarded.</p> <p>Note that the neuron's memory is not cleared, but its index is reset to point at the first component and this component will be overwritten by the next Write COMP.</p>	0x0F	W		n/a
NCOUNT	<p><u>Normal mode</u>: Number of committed neurons. Is equal to 0xFFFF if all neurons of the chain are committed.</p> <p><u>SR mode</u>: Index of the neuron pointed in the chain. This index increments automatically after each Read or Write CAT, and is reset to 0 after a Write RESETCHAIN</p>	0x0F	R	R	16-bit (see Errata)
RESET CHAIN	<p>Points to the first neuron of the chain. The value written to this register is discarded.</p>	0x0C		W	n/a

3.3.3 Neuron behavior per instruction

The following table describes how the content of a neuron is updated depending on its state in the chain of neurons. The content is divided into three types of items: memory, registers and control lines.

Memory	Idle	Ready to Learn	Committed
Component 0		Takes the value of the 1 st Write COMP occurring after a Write LCOMP.	Can only be changed by a reset or restore operation. Reset the distance register
		The memory index is incremented by 1 to point to the next component.	The memory index is incremented by 1 to point to the next component.
Component 1		Takes the value of the next Write Comp or Write LCOMP.	Can only be changed by a reset or restore operation.
		The memory index is incremented by 1 after a Write Comp, or is reset to 0 after a Write LCOMP.	The memory index is incremented by 1 after a Write Comp, or is reset to 0 after a Write LCOMP.
...			
Component 255		Takes the value of the next Write Comp or Write LCOMP. The memory index is reset to 0.	Can only be changed by a reset or restore operation.

Registers	Idle	Ready to Learn	Committed & nselect
Context	Takes the value of the Write GCR.	Takes the value of the Write GCR.	
		Current value is saved if the neuron gets committed after a Write CAT.	Can only be changed by a reset or restore operation.
Minimum Influence Field	Takes the value of the Write MINIF.	Takes the value of the Write GCR.	
Maximum Influence Field	Takes the value of Write MAXIF.	Takes the value of the Write GCR.	
Distance			The difference between the pointed Component and the input value is accumulated after each Write Comp or Write LCOMP.

Category		Value is written if no committed neuron fires and has its own category equal to value. The neuron status switches from RTL to Committed.	
Active Influence Field			Inherits the smallest distance value of the firing neurons

3.3.4 [Commands changing the RTL neuron in chain](#)

Memory cell index change	Normal mode	Save and Restore mode
Write COMP	Index + 1	Index + 1
Write LCOMP	Index =0	
Write INDEXCOMP	Index=k	Index=k
Write TESTCOMP		Index + 1
Write NSR	Index=0	Index=0
Write CAT		Index=0
Read CAT		Index=0

3.4 Test Registers

The following registers are used solely for the purpose of testing the memory of all the neurons in a minimum number of clock cycles. TESTCOMP allows filling the memory of all the neurons in a chain in 256 cycles (i.e. one per component). TESTCAT allows committing all the neurons in a chain in one cycle.

3.4.1 Description

	Description	Addr	normal mode	SR mode	Value range	Default Value
TESTCOMP	Test Component Write the pointed component of all neurons with the input value. Useful for test routines.	0x08		W	8-bit	0x00
TESTCAT	Test Category Write the same category to all the neurons. Useful for test routines. Writing the value 0 to this register is equivalent to writing the FORGET register except that it does not reset the neuron count.	0x09		W	16-bit	0x0000

3.4.2 Usage

The Write TESTCOMP and Write TESTCAT commands are used in the test benches written to test the CM1K HDL design.

A typical usage example is the counting of the number of neurons in a chain of CM1K

Part 1: Commit all the neurons in 2 cycles

- Write NSR 0x10 Set the SR mode
- Write TESTCAT Value Commit all the neurons with a same category value

Part2: Read the category of the neurons until end of chain is reached

- Write RESETCHAIN Point to the 1st neuron in chain
- Ncount=0
- Do Loop
 - o Read CAT)
 - o Ncount++
- Until CAT=0xFFFF (**Ncount-1**) is the number of neurons in the chain
- Write NSR 0x00 Cancel the SR mode

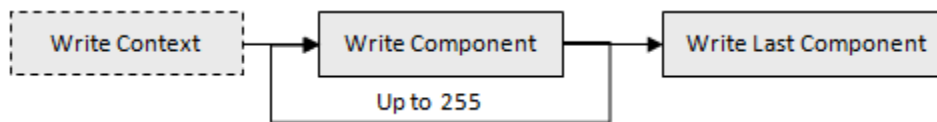
3.5 Programming sequences

This paragraph describes the typical programming sequences to use the neurons in standard mode and save and restore mode.

- Broadcast a vector to all the neurons (whether to learn or recognize it)
- Recognize the last broadcasted vector
- Learn the last broadcasted vector
- Save the content of all the neurons
- Read the content of a specific neuron
- Load the content of the neurons

3.5.1 Vector broadcasting

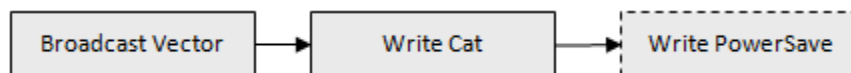
The memory of the neurons is 256 bytes long so the vectors to learn or recognize can be composed of up to 256 components of 8-bit value.



- 1) Write Context (optional)
If the new vector must be associated to a context different than the current value of the Global Context or if the distance norm coded in bit 7 of the context must be changed
- 2) Up to 255 Write Component
Write all the components of the input vector but the last one in the Ready-To-Learn.
For all the committed neurons with a context equal to the Global Context, their distance register is updated after each Write Component according to the Norm in use.
- 3) 1 Write Last Component
For all the committed neurons with a context value equal to the Global Context register, their distance register is updated and represents the distance between the input vector and the prototype stored in their memory. Furthermore, if their distance falls in their influence field, the neurons “fire” meaning that they are ready to respond to further inquiry about the vector such as a Read DIST or Read CAT commands.

3.5.2 Learn a vector

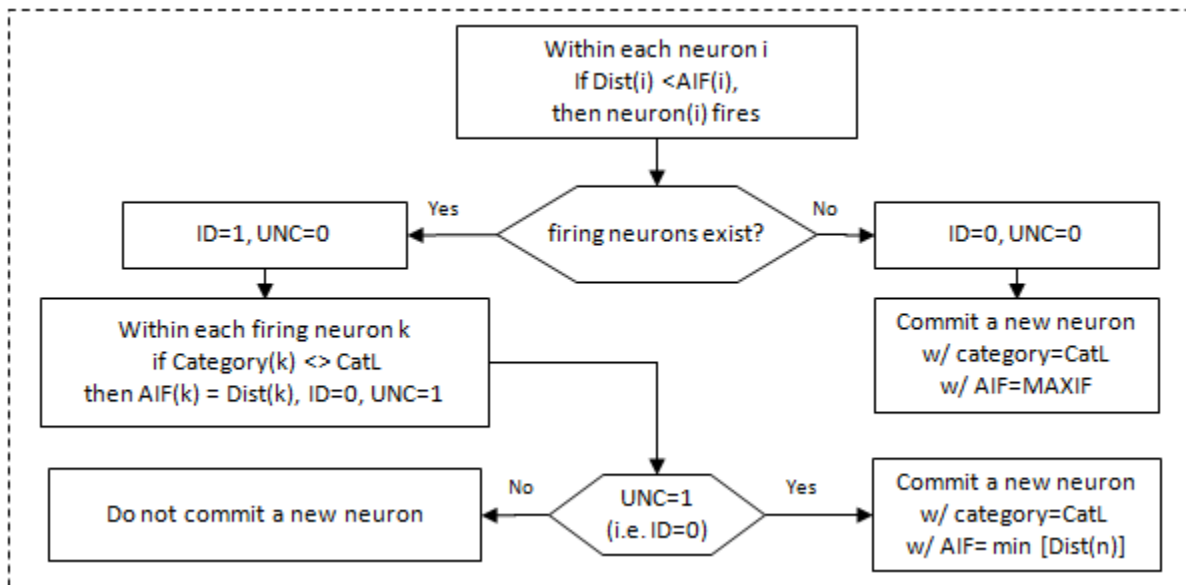
All the neurons have their internal learning logic and teaching a vector is as simple as broadcasting its components and then writing its category value. Optionally, the PowerSave register can be written to set the data lines in tri-state mode so they do not draw current.



If this combined information (vector and category) represents novelty to the existing neurons, the Ready-To-Learn neuron becomes committed. It stores the instructed category in its category register. Its influence field is set to the smallest distance register of the committed neurons belonging to the same context, or the Minimum Influence Field whichever is greater, or the Maximum influence field whichever is smaller.

The next neuron in the chain turns from idle to RTL (ready-to-learn).

If there are neurons which recognized the vector with a category other than the instructed category, they automatically reduce their influence field to prevent such erroneous recognition in the future.



Remark #1: If the network is full, a learning operation will have no effect. You can detect that all the neurons of the network are already committed by executing the Read NCOUNT command which will then return the value 0xFFFF.

Remark #2: If an application requires to change learning settings such as the Minimum and Maximum Influence Fields, this must be done prior to the broadcast of the vector to learn.

Example

Let's take the example of an input vector equal to a series going from 00 to 99. This vector has a length of 100 components. Its first 99 components are written in sequence to the CM_COMP register and its last and 100th component is written to the CM_LCOMP register.

Broadcast the vector, learn as category 33 and read the number of committed neurons.

Sequence
For (i = 0; i < 99, i++) Write CM_COMP, Vector(i);
Write CM_LCOMP, Vector(99)
Write CM_CAT, 33
Read CM_NCOUNT, ncount

Ncount will not be incremented if a committed neuron with a category register equal to 33 already recognizes Vector. Note that this does not mean that the content of the neurons has not changed. Indeed, no new neuron has been committed but existing committed neurons may have reduced their influence fields.

3.5.3 Recognize a vector

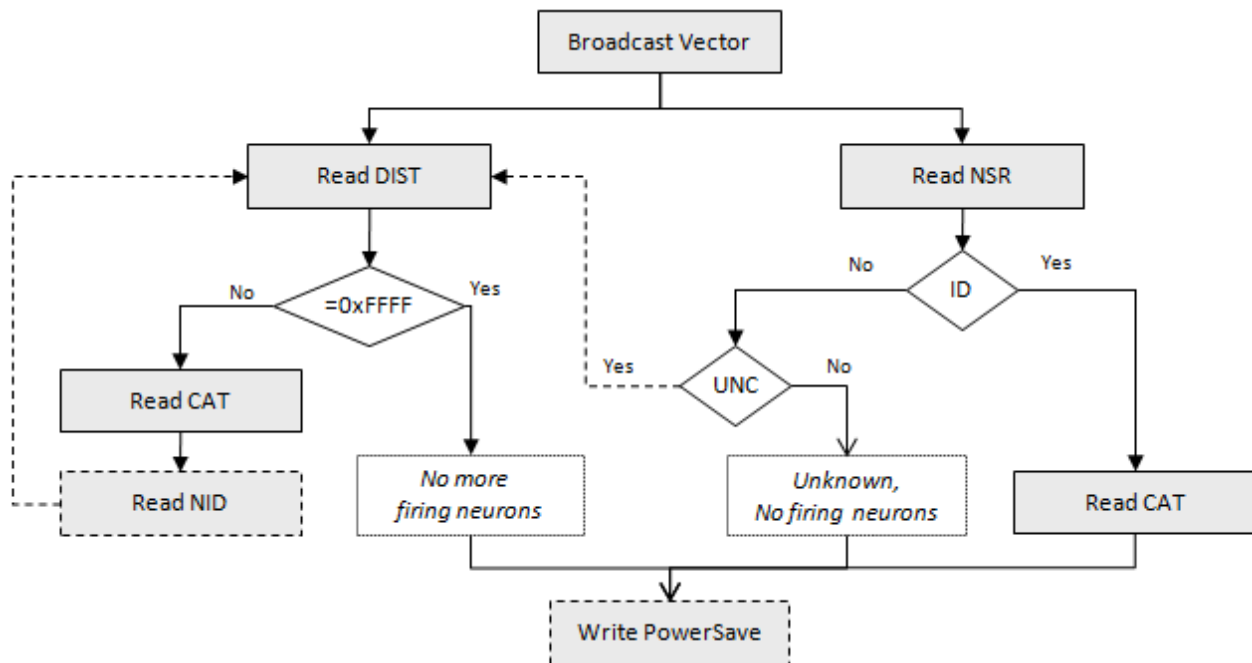
A vector broadcasted to the neuron bus is evaluated by all the committed neurons in parallel. The CogniMem network can exercise two types of classifiers: Radial Basis Function Network (RBF) or K_Nearest Neighbor classifier (KNN). The KNN classifier always returns a response, when the RBF classifier discriminates case of positive identification, uncertainty and unknown.

KNN	RBF
The KNN classifier discards the relationship between the distance and influence field of a neuron. As a consequence, all the neurons fire and their distance and category can be read in sequence per increasing order of distance.	The RBF classifier uses the Influence Field of the neurons at the time of the recognition. A neuron fires only if the distance calculated between the input vector and its vector in memory is less than its influence field.

In either cases, the response of the neurons can be accessed by a succession of (Read DIST, followed by Read CAT and optionally Read NID registers). The first distance quantifies the difference between the input vector and the neuron with the closest pattern. The category of this neuron is the category with the highest confidence level. The second distance quantifies the difference between the input vector and the neuron with the second closest pattern. The category of this neuron is the category with the second highest confidence level, and so on. In the case of the RBF classifier, all the firing neurons have been read when Read DIST returns the value 0xFFFF.

The following diagram illustrates the three levels of response which can be delivered by the neurons through the readout of the registers NSR, DIST, CAT and NID. They are listed per increasing number of system cycles:

- Conformity, or status of the recognition (identified, uncertain or unknown)
- Best match in distance and its associated category
- All possible matches listed per increasing distance values.



3.5.3.1 Response level 1: Classification status

As soon as the last component of a vector is broadcasted to the neurons, the ID and UNC lines are updated as well as bit 2 and 3 of the Network Status Register (NSR).

ID=0 and UNC=0 NSR[3:0] = 0	Unknown classification no neuron recognizes the input vector and has fired
ID=1 NSR[3:0]=8	Identified classification one or several neurons recognize the vector and agree with its category value
UNC=1 NSR[3:0]=4	Uncertain classification one or several neurons recognize the vector but disagree with its category value.

3.5.3.2 Response level 2: Best-match

The first Read DIST command occurring after a Write Last Component returns the distance register of the neuron with the smallest distance, equivalent to the best match. If this distance is equal to 0, this is an exact match.

If ID=1, the category of the neuron is the only recognized category. This value is obtained with a Read CAT command.

If UNC=1, other neurons have recognized the broadcasted vector. They may have a distance register equal or greater than the first firing neuron, but they surely do not have the same category value. Depending on the cost of the mistake of the application, a Response level 3 might be useful.

3.5.3.3 Response type 3: Multiple matches

Examining the distance and category of all the firing neurons can be of interest to reinforce the accuracy of a decision. This is done by reading consecutively the DIST and CAT registers. Each of these sequences retrieves the response of the next firing neuron in a list ordered per increasing distance value (equivalent to decreasing confidence levels).

If two neurons fire with the same distance but different category, their individual response are read as follows: Read Dist, Read Cat, Read Dist, Read Cat. The second Read Dist return the same value as the first Read Dist but is necessary to access the category register of the second neuron.

If two neurons fire with the same distance and same category, only the response of the first one is read. The first Read Dist will notify both neurons to stay in query, but both will output their category at the following Read Cat and therefore exclude themselves from the next query. A second Read Dist will return the next higher distance value if applicable.

Remark 1: Reading the identifier of the neuron is optional. This feature can be useful to review the content of the neuron(s) which recognize the vector.

Remark 2: In the event that two or more neurons fire with a same distance and a same category, they will all output their identical category at the same time upon execution the Read Cat command. This means that only the lowest identifier of these neurons will be retrieved.

Remark 3: A Write Category command can be executed immediately after a Read Distance + Read Category sequence without having to re-enter the vector. This can be useful for applications such as in predictive maintenance or target tracking where you want to know what is recognized prior to learning a novelty.

Rules have to be established on a “per application” basis depending on the cost of a mistake, the requirements for a minimum throughput, minimum false negative, etc.

Example 1

Let’s take the example of an input vector equal to a series going from 00 to 99. This vector has a length of 100 components. Its first 99 components are written in sequence to the CM_COMP register and its last and 100th component is written to the CM_LCOMP register.

Recognition consists of broadcasting the vector and reading successively the distance and category registers of the neurons until their response is equal to xFFF meaning that all firing neurons have reported their results.

Sequence
For (i = 0; i<99, i++) Write CM_COMP, Vector(i);
Write CM_LCOMP, Vector(99)
Read response of 1 st neuron:
Read CM_DIST
Read CM_CAT
Read response of 2 nd neuron:
Read CM_DIST
Read CM_CAT

Example 2

Let’s take the example of a recognition where a vector is recognized by the firing neurons:

Distance	5	12	13	15	38	39
Category	8	7	7	7	3	5

The best match is a reference pattern of category 8 recognized with a distance 5. However, category 7 is recognized next within a close distance by three firing neurons.

If the cost of an inaccurate recognition is low, the response of the 1st neuron with category 8 is the simplest to retrieve (and very fast). On the contrary, if the application cannot afford a false-positive, it might be wiser to involve some statistics and assume that category 7 is the dominant category and should be the one selected for a final decision. More sophisticated rules can be deployed including the analysis of the histogram of the categories, and more. Some applications might even consider the generation of a “response” vector composed of all the “firing” categories (i.e. 8,7,7,7,3,5) and to be classified by another set of neurons taught to classify the “response” vectors. CogniMem can handle up to 127 subsets of neurons trained for different purposes. These subsets are called Contexts.

3.5.3.4 Recognition clock cycles

(Level 1) Conformity detection	(Level 2) Best match	(Level 3) Detailed matches
Read NSR (1 cycle)	Read Dist (18 cycles) Read Cat (19 cycles) Read Nid (1 cycle, optional)	Loop N Read Dist (18 cycles) Read Cat (19 cycles)
1 clock cycles	37 clock cycles	N*37 clock cycles

Example

Let's take the example of a knowledge composed of neurons with 100 components each.

Sequence
Write CM_NSR, 16 Write CM_RESECHAIN, 0 Read CM_NCOUNT For (i=0; i<NCOUNT; i++) { Read CM_NCR, context For (i = 0; i<100, i++) Read CM_COMP, Vector1(i); Read CM_AIF, aif Read CM_MINIF, minif Read CM_CAT, cat } Write CM_NSR, 0

Example

Let's take the example of a knowledge composed of 2 neurons with 100 components each, a same context value equal to 2 and their respective AIF of x135 and x456 and categories of x33 and x22:

Sequence
Write CM_FORGET, 0
Write CM_NSR, 16
Write CM_RESECHAIN, 0
For (i = 0; i<100, i++) Write CM_COMP, Vector1(i);
Write CM_NCR, x2
Write CM_AIF, x135
Write CM_CAT, x33
For (i = 0; i<100, i++) Write CM_COMP, Vector2(i);
Write CM_NCR, x2
Write CM_AIF, x456
Write CM_CAT, x22
Write CM_NSR, 0

3.5.6 Reading the contents of a single specific neuron

Reading the contents of a specific neuron is made in the following order:

- The first operation consists of setting the CM1K chip in Save_and_Restore mode and pointing to the first neuron of the chain
- In order to point to the i^{th} neuron in the chain, $(i-1)$ consecutives Read CM_CAT are necessary
- You can then read the i^{th} neuron's components, context, minimum influence field and active influence field in any order. The category register must be read last because the instruction automatically points to the next neuron in the chain.
- Finally, the last operation consists of setting the CM1K chip back to the normal mode.

Let's take the example of the neuron #Index

Sequence
Write CM_NSR, 16
Write CM_RESECHAIN, 0
For (i=0; i<Index-1; i++) Read CM_CAT
Read CM_NCR, context
For (i = 0; i<100, i++) Read CM_COMP, Vector1(i);
Read CM_AIF, aif
Read CM_CAT, cat
Write CM_NSR, 0

3.5.7 Writing the contents of a single specific neuron

It is possible to edit the content of a specific neuron in Save_and_Restore mode, **except for its Category register**. Failure to follow this rule will introduce a discrepancy in the automatic internal numbering of the neurons and report an incorrect neuron count.

Let's take the example of the neuron #Index for which you want to change the context and the components.

Sequence
Write CM_NSR, 16
Write CM_RESECHAIN, 0
For (i=0; i<Index-1; i++) Read CM_CAT
Write CM_NCR, new_context
For (i = 0; i<100, i++) Write CM_COMP, Vector1(i);
Write CM_NSR, 0

3.5.8 Typical operation latency

Operation	Execution	Timing
Broadcast a vector of N components	N Write commands	N+3 clock cycles
Learn the last broadcasted vector	1 Write command	18 cc
Recognize the last broadcasted vector	2 Read commands	37 cc (per firing neuron)
Save N neurons	3 Write commands + (258*N) Read commands	3+(258*N) clock cycles
Restore N neurons	3 + (258*N) Write commands	3+(258*N) clock cycles

4.1 Control registers

The registers of the recognition logic are enabled if the pin RECO_EN is high, and whether the VI_EN pin is high or low. If RECO_EN is low, any attempt to read a register of the recognition logic returns 0xFFFF.

4.1.1 Recognition Status Register

	Description	Addr	Access	Value range	Default value
RSR ⁽¹⁾	Recognition Status Register (see below) Bit[2-5] are updated continuously on the positive edge of the clock. Bit{15::6} are unused	0x1C	R/W	16-Bit	0x00

Bit	ABBREV	Description	R/W	default
0	RECO_ACTIVE	Enable or disable the continuous recognition of the signal received on the digital input bus of the chip.	W	0
1	OUTPUT_EN	Enable the output of the category to the DATA lines (only if S_CHIP=1).	W	0
2	UNC	Status of the last recognition is uncertain, meaning that the firing neurons do not recognize the same category. Remark: The output register RTCAT correspond to the category of the best match. Additional categories can be obtained by stopping the recognition logic and executing successive read of the CM_DIST and CM_CAT registers.	R	0
3	ID	Status of the last recognition is identified, meaning that all firing neurons recognize the same category.	R	0
4	V_FV	copy of V_FV signal	R	0
5	Reco_Active	high while recognition is being executed	R	0

Remark: The prerequisite to set the RECO_ACTIVE are that the pin RECO_EN must be high and that the neurons hold a knowledge base. This knowledge can be built on the chip itself by teaching the neurons in real-time, or it can be loaded from a file saved at an earlier time. In the latter case, RECO_ACTIVE must be turned off while the neurons are restored.

4.1.2 Recognition output registers

	Description	Addr	Access	Value range	Default value
RTDIST ⁽²⁾	Real-time distance, or distance of top firing neuron	0x1D	R	16-bit	
RTCAT ⁽²⁾	Real-time category, or category of top firing neuron	0x1E	R	16-bit	

Remark 1: The CM_RTDIST and CM_RTCAT registers remains unchanged until the next rise of the DIST_VAL and CAT_VAL pulses.

Remark 2: The distance and category returned by the recognition logic are the ones of the neuron with the best match. If you want to read the response of additional firing neurons you need to stop temporarily the recognition logic as follow: set RECO_ACTIVE to 0, read N additional DIST and CAT registers and set RECO_ACTIVE back to 1. Similarly, if you want to read the identifier of the firing neuron, the reco logic must also be stopped temporarily.

Remark 3: The UNC_ line or the bit 3 of the RSR register are both an indicator that more than one neuron recognize the input vector.

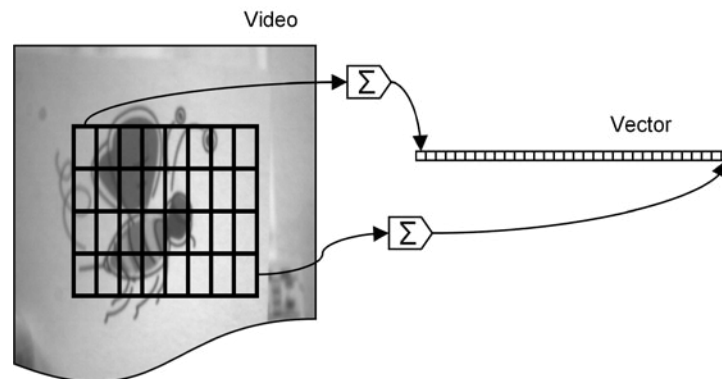
4.1.3 Video input registers

If the pin VI_EN of the CM1K chip is high, a video signal can be sent directly to the digital input bus. In this case the chip extracts a signature vector from a region of interest in the video frame as the video signal as it is received. The region of interest is described by the registers described below.

	Description	Addr	Access	Value range	Default value
TOP	Left corner of the ROI in pixels	0x11	R/W	16-bit	200
LEFT	Top corner of the ROI in pixels	0x12	R/W	16-bit	120
WIDTH	Nominal width of the ROI in pixels	0x13	R/W	16-bit	340
HEIGHT	Nominal height of the ROI in pixels	0x14	R/W	16-bit	220
BWIDTH	Width of a primitive block in pixels	0x15	R/W	16-bit	20
BHEIGHT	Height of a primitive block in pixels	0x16	R/W	16-bit	20
ROIINIT	Reset the ROI to default	0x1F	W	n/a	0

The ROI nominal size must fit a number of primitive blocks less than or equal to 256. The relationship between the four parameters is : $NWIDTH = n * BWIDTH$, $NHEIGHT = m * BHEIGHT$ and $n * m \leq 256$.

BWIDTH and BHEIGHT define the maximum size of a square block such that 256 of them fit at the most in the region [NWIDTH , NHEIGHT]. As a result, the region with a size [NWidth, NHeight] can be divided into up to 256 square blocks of equal size [BWIDTH, BHEIGHT]. The pixels of block #i are averaged to produce the i^{th} component of the signature vector.



4.2 Programming sequences

4.2.1 Size the region of interest

Size a region of interest with a size of 32 x 32 divided into internal blocks of 2 x 2

Sequence
Write CM_NWIDTH, 32
Write CM_NHEIGHT, 32
Write CM_BWIDTH, 2
Write CM_BHEIGHT, 2

4.2.2 Move the region of interest

Move the region of interest to the location (10,12) and learn it as category 33

Sequence
Write CM_LEFT, 10
Write CM_TOP, 12
Write CM_RSR, 1
Write CM_CAT, 33

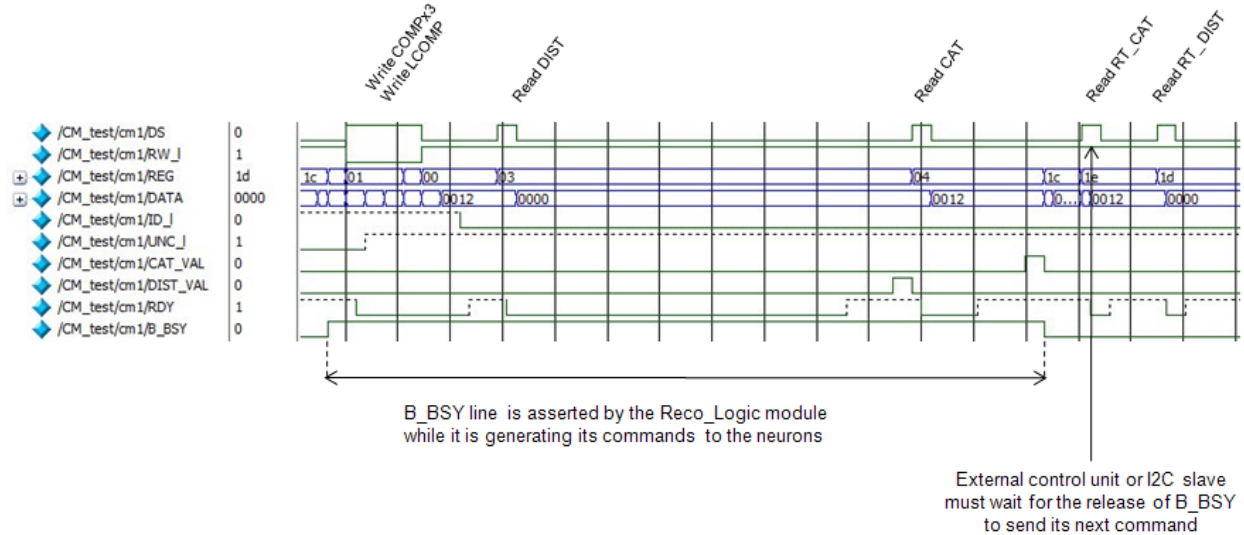
4.2.3 Recognize the region of interest

As soon as bit 0 of the RSR is high, the region of interest in the next frame is recognized. The result of the recognition is latched in the RT_DIST and RT_CAT registers until a next frame occurs.

Sequence
Write CM_RSR, 1
Read CM_RTCAT
Read CM_RTDIST

4.3 Timing constraints

When active, the reco_logic becomes the master controller of the neurons, sending them commands to recognize the vectors received continuously on the digital input bus. To ensure that the recognition sequence is not interrupted by an external controller, the reco_logic rises the B_BSY signal and the CM1K will discard any command received while B_BSY is high.



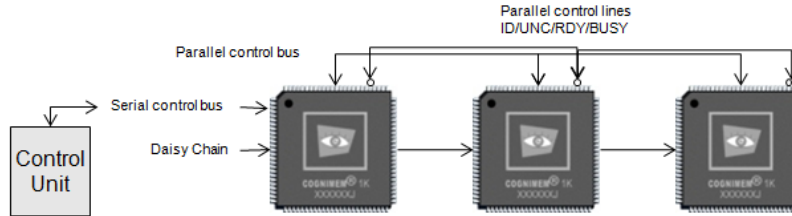
- B_BSY rises on the negative edge of the system clock as soon as frame valid falls
- B_BSY falls on the negative edge of the system clock when the CAT_VALID signal.

The only time available to receive and execute an external command is between the fall of the CAT_VAL pulse and the next rise of F_FV.

If this command is an I2C command, its execution includes the serial decoding/encoding and timing may become short. Since we can assume that the most relevant registers when the recognition stage is active are the RT_DIST and RT_CAT, the CM1K I2C controller has been designed to handle them in a special way to waive the timing constraints mentioned above. They can be read at any time, but this is not true for the other registers such as CM_LEFT and CM_TOP for example which allow changing the position of the ROI.

5 The optional I2C slave controller

The CM1K features a serial interface slave with the SlaveID 0x94 and running at 100 or 400 Kbit per second. In a configuration with N CM1K chips daisy-chained together, only one of them can enable its I2C controller. The latter will convert the commands received through the I2C lines into commands transmitted over the parallel control bus.



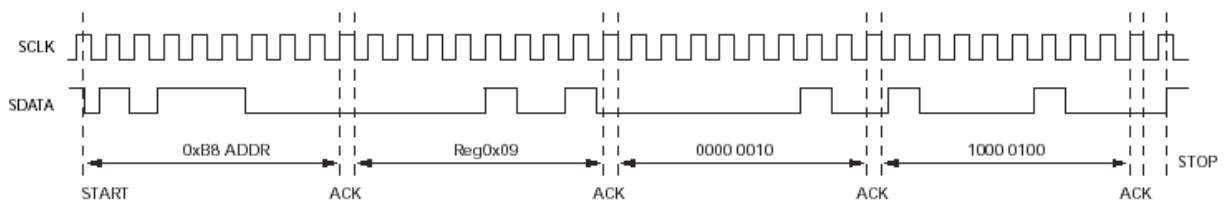
The two-wire serial interface defines several different transmission codes, as follows:

- A start bit
- The slave device 8-bit address (bit 0 determines if the request is a read (bit = “0”) or a write (bit = “1”))
- An acknowledge bit
- An eight-bit message (The CM1K uses 16-bit data for its internal registers, thus requiring two 8-bit transfers per read or write command)
- A stop bit

5.1 Write sequence

Step	Master	Slave
1	A typical write sequence begins by a master sending a start bit followed by the CM1K slave address 0x94.	
2		If the address is not equal to 0x94 the request is ignored by the CM1K. Otherwise it returns an acknowledge bit to the master.
3	The master then transfers the 8-bit address of the register to write.	
4		The slave sends an acknowledge bit to indicate that the register address has been received.
5	The master transfers the lower byte of the 16-bit data to write.	
6		The slave sends an acknowledge bit.
7	The master transfers the upper byte of the 16-bit data to write.	
8		The slave sends an acknowledge bit.
9	The master stops the request by sending a stop bit.	

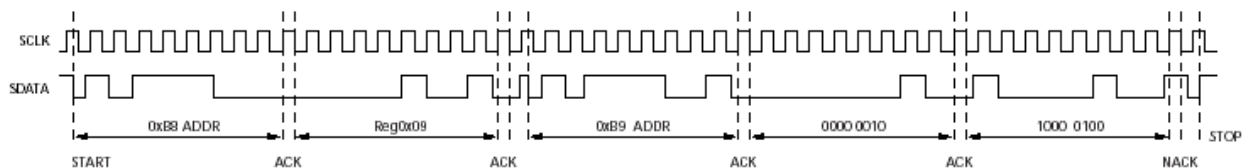
Example: The waveform below illustrates a Write command. The value 0x0284 is written to a register 0x09 of a device with a slave address 0xB8 (not a CM1K).



5.2 Read sequence

Step	Master	Slave
1	A typical read sequence begins by a master sending a start bit followed by the CM1K slave address 0x94.	
2		If the address is not equal to 0x94 the request is ignored by the CM1K. Otherwise it returns an acknowledge bit to the master.
3	The master then transfers the 8-bit address of the register to read.	
4		The slave sends an acknowledge bit to indicate that the register address has been received.
5	The master sends a start bit followed by the CM1K slave address 0x94 incremented by 1 (i.e. 0x95) to specify that a read is about to happen from the register.	
6		The slave sends an acknowledge bit.
7	The master clocks out the lower byte of the 16-bit data read from the register. The master sends an acknowledge bit after the eight-bit transfer.	
8	The master clocks out the upper byte of the 16-bit data read from the register. The master sends an acknowledge bit after the eight-bit transfer.	
9	The data transfer is stopped when the master sends a no-acknowledge bit.	

Example: The waveform below illustrates a Read command. The value 0x0284 is read back from the register 0x09 of a device with a slave address 0xB8 (not a CM1K).



5.3 Summary and Timing constraints

Sequence from the master	Write	Read
Start sequence	Write Slave Address + bit[0]=0 Write 8-bit Register value	Write Slave Address + bit[0]=0 Write 8-bit Register value Resend Start
Request	Write most significant 8-bit of the register's data value Write least significant 8-bit of the register's data value	Write Slave Address + bit[0]=1 Read most significant 8-bit of the register's data value Read least significant 8-bit of the register's data value
Stop sequence	STOP signal	NACK signal

The B_BSY signal is the CM1K is pulled high during the processing of an I2C request.

Remark: If the reco_logic is running, sending an I2C request might not fit within the $\sim B_BSY$ time frame which starts at the fall of V_FV and finishes at the rise of CAT_VAL. The RTDIST and RTCAT registers can be read at any time over the I2C bus because their access does not require any interruption of CM1K parallel bus, but any other command must be submitted carefully when B_BSY is low and RDY is high.

5.4 I2C transmission codes

5.4.1 Bus Idle State

The bus is idle when both the data and clock lines are HIGH. Control of the bus is initiated with a start bit, and the bus is released with a stop bit. Only the master can generate the start and stop bits.

5.4.2 Start Bit

The start bit is defined as a HIGH-to-LOW transition of the data line while the clock line is HIGH.

5.4.3 Stop Bit

The stop bit is defined as a LOW-to-HIGH transition of the data line while the clock line is HIGH.

5.4.4 Acknowledge Bit

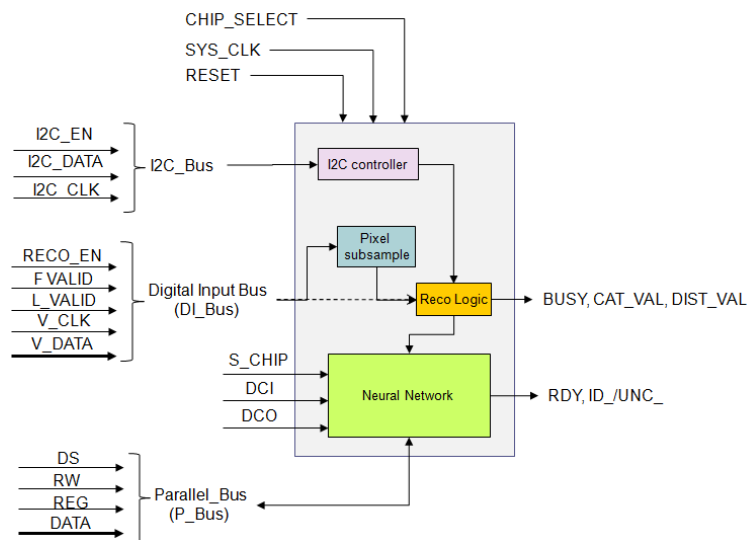
The master generates the acknowledge clock pulse. The transmitter (which is the master when writing, or the slave when reading) releases the data line, and the receiver indicates an acknowledge bit by pulling the data line low during the acknowledge clock pulse.

5.4.5 No-Acknowledge Bit

The no-acknowledge bit is generated when the data line is not pulled down by the receiver during the acknowledge clock pulse. A no-acknowledge bit is used to terminate a read sequence.

6 CM1K buses and control lines

This chapter describes the buses, control lines and interrupt lines of the CM1K chip.



	Symbol	Type	Description
Configuration lines	VCC		Core power supply (1.2v)
	VCCIO		IO power supply line (3.3 v)
	GND		Ground line
	S_CHIP		Single chip mode
	DCI	Input	Daisy Chain In
	DCO	Output	Daisy Chain Out
	I2C_EN	Input	I2C enable
	RECO_EN	Input	Recognition enable
	V_EN	Input	Video enable
Clock and Reset	G_CLK	Input	System clock
	G_RESET_		Hardware reset
	CHIP_SELECT_	Input	Enable chip activity
Parallel bus	DS	Bidir	Data strobe line
	R/W_	Bidir	Read/Write
	REG[0:4]	Bidir	Register
	DATA[0-15]	Bidir	Data
	UNC_	Bidir	Uncertain_low line
Neuron output lines	ID_	Bidir	Identified_low line
	RDY	Bidir	Ready line
I2C bus	I2C_SDA	Bidir	I2C serial data line
	I2C_SDK	Input	I2C clock
Digital input bus	V_CLK	Input	Video clock
	V_FV	Input	Video frame valid
	V_LV	Input	Video line valid
	V_DATA[0:7]	Input	Video data line 0
Output lines	DIST_VAL	Output	Distance valid line
	CAT_VAL	Output	Category valid line
	B_BSY	Output	Bus busy line

6.1 Clocks, power-up and reset

6.1.1 G Reset, global reset

The CM1K is reset at power-up by pulling down the G_RESET_I pin for a minimum of 5 clock cycles. An internal reset signal is then sustained for 255 clock cycles to filter any bouncing of the G_RESET_I external pulse. It is propagated internally to the neurons, the recognition stage and the i2c slave controller so all registers are set to their default values. In a multi-chip configuration, the same G_RESET_ must be connected to all chips.

6.1.2 G Clk, system clock

The CM1K operates at a typical system clock of 27 MHz. If multiple CM1K are connected in parallel the typical system clock is 16 Mhz.

6.1.3 CHIP_SELECT_I, power saving control line

The CHIP_SELECT line controls the propagation of the system clock G_CLK to the neurons, the reco_logic and the i2c slave controller of the chip. It is pulled low by default letting the clock run continuously.

Pulling up the the CHIP_SELECT_I line when the CM1K is unused reduces considerably its power consumption (from 500 mW to 25 mW). On the other hand the timings to pull CHIP_SELECT_I back down and let the system clock pass through must be accurate: (1) It must be pulled down on a negative edge of G_CLK when the external data strobe (DS) is pulled up at the latest. (2) It must be released on the negative edge of the system clock following the rise of the RDY signal at the earliest or the fall of the B_BSY signal.

6.1.4 Neural network BiDir lines (parallel bus)

The parallel bus is used to transmit the Read Register and Write Register commands to all the neurons for simultaneous execution. These commands can be received from two types of sources:

- An external master controller
- One of the two internal master controllers residing in the CM1K chip and which comprise the recognition stage or the I2C slave controller. This second case is only relevant in an architecture with multiple daisy-chained chips where one of them has its pin I2C_EN high and/or RECO_EN high. The bus lines become bidirectional to allow the neurons of the different chips to receive the commands and mix their responses on the bus during the learning or recognition operations.

DS	Data strobe signal
RW_	Read/Write signal
REG	5-bit register value
DATA	16-bit data value

RDY	Ready control signal
ID	Identified control signal
UNC	Uncertain control signal necessary to learn

The neurons sample these signals on the positive edge of the system clock G_CLK. Their setup time must be at least 5 nanoseconds before the positive edge of G-Clock. The hold time must be at least 5 nanoseconds after the

positive edge of the clock. The signals have to be released before the next positive edge of the clock to ensure that the data bus becomes bi-directional for proper execution of the commands requiring snooping of the bus.

Up to eight CM1K running at a system clock of 16Mhz can be connected to the same parallel bus without any re-drive. Beyond a chain of 8 CM1K chips, buffers must be inserted.

6.1.5 DS

The data strobe line, D, must be asserted when the RDY line is low and at the negative edge of the system clock. It must be released at the next negative edge of the system clock.

6.1.6 RW

The Read/Write line, RW_, must be low to write and high to read. It is low by default. This signal must be asserted at the negative edge of the system clock. It must be released at the next negative edge of the system clock.

6.1.7 REG[4:0]

The five Register lines, REG, represents the address of a 5-bit register.

6.1.8 DATA[15:0]

The 16 Data lines, DATA, represents the value of the selected register to either write or be read. These lines are connected to open collectors so the default output value is 0xFFFF. In the case of a Write command (RW_ high), these lines must be asserted at the negative edge of the system clock but released at the next negative edge of the system clock.

6.1.9 UNC

The Uncertain line, UNC_, line is bidirectional and shall not be driven. It is an output during a recognition operation and an input during a learning operation.

UNC_ is pulled down when the neurons recognizing the last input vector have different categories. This update occurs each time a Write LCOMP is executed whether it is initiated by an external controller or by the internal recognition logic of the chip. The UNC_ line is released at the next Write COMP.

During a Write CAT, this line is asserted by the neurons if the last input vector is recognized as a novelty and must be stored into a new neuron.

6.2 Neural network input lines

6.2.1 S_CHIP

By default the S_CHIP pin is pulled down to configure the parallel bus (DS, RW_I, REG and DATA) as bidirectional and allow the neurons of multiple CM1K chips to receive commands synchronously and interact with one another.

If an architecture uses a single CM1K chip connected to a control unit via its I2C bus, then its parallel bus can be disabled, thus reducing considerably the power consumption. If the reco logic of the chip is activate, it is possible to overwrite the settings of the DATA lines through the RSR register. In that case, the RT_CAT register is latched on the DATA lines at each CAT_VAL pulse.

6.2.2 DCI

Until the DCI line of a CM1K chip is high, its neurons are idle. As soon as the DCI line rises, the neurons of the chip become active, meaning ready to learn and recognize.

In a configuration with multiple chips, the Daisy-Chain-In (DCI) line of the first CM1K chip must be high. For the subsequent chips, the connection between their DCO and DCI lines allows to physically arrange them in a chain. The DCI line of a CM1K must be connected to the DCO of the previous CM1K chip in the chain. Its status is then controlled by the neurons of the previous chip.

6.3 Neural network output lines

6.3.1 DCO

The Daisy-Chain-Out (DCO) line of a CM1K must be connected to the DCI of the next CM1K chip in the chain, if applicable. It is low by default and will rise when the last neuron of the chip gets committed. If this line is connected to the DCI of another CM1K chip, the later will awake its neurons to become Ready-To-Learn.

6.3.2 ID

The Identified line, ID_, is pulled down when all the neurons recognizing the last input vector are all in agreement and return the same category. This line is updated each time the last component of a vector is broadcasted to the neurons either through a Write LCOMP command or through the real-time recognition logic of the CM1K.

6.3.3 RDY

The Ready line, RDY, is pulled down by the neurons during the execution of a command and released upon its termination. It is updated at the positive edge of the system clock G_CLK whether or not the command is recognized by the neurons.

6.4 Digital Input Bus

The digital input bus is composed of 10 or 11 lines depending if the input signal is a video signal or not.

VCLK	Video or Vector Input Digital Clock
V_FV	Video or Vector Valid control signal
V_LV	Video Line Valid control signal (discard if input is not video)
V_DATA	Video or Vector Data

6.4.1 RECO_EN

Recognition_Enable enables the use of the V_DATA input bus and the real-time recognition engine. If several CM1K chips are connected in parallel, only one chip can have its RECO_EN pin set to 1. In addition, if the chain of CM1Ks shall receive its command from an external host over its I2C lines, the chip with its pin I2C_EN=1 must be the same as the chip with its pin RECO_EN=1.

This pin is connected to an internal pull-up so it is enabled by default. For power-savings consideration, it should be grounded if unused.

6.4.2 VI_EN

Video_Enable indicates if the digital input bus receives a video signal and if consequently the recognition engine is in charge of generating the vector broadcasted to the neurons. If changed dynamically, the status of this pin must be changed at the negative edge of V_CLK.

This pin is connected to an internal pull-up so it is enabled by default. For power-savings consideration, it should be grounded if unused.

6.4.3 V_Clk, sensor Clock

Optionally, the CM1K can receive vector data directly on its digital input bus. It is then sampled at the external clock rate V_Clk. A typical clock rate for V_Clk is 27 Mhz. A maximum clock rate of 44 Mhz has been successfully tested.

- If the pin VI_EN=0, V_CLK is the sampling clock for the input V_DATA bus and it does not have to be a periodic signal.
- If the pin VI_EN=1, V_CLK is the Video clock signal (up to 27 Mhz) of the sensor.

6.4.4 V_FV

Video Frame Valid or Vector Feature Valid.

If V_EN=1, V_FV stands for Frame valid and is a synchronization signal supplied by the video sensor.

If V_EN=0, V_FV stands for Feature Valid. It must be set high for the duration of the vector data input on V_DATA bus. V_FV must stay low for a minimum of N + 37 cycles of G_CLK with N being the number of V_DATA sampled during V_FV high. Note that the CAT_VAL pulse occurs one cycle after the N + 37 cycles. V_FV must be changed at the negative edge of V_CLK.

6.4.5 V_LV

Video Line Valid signal of the sensor (used if VI_EN=1 only)

6.4.6 V_DATA

Video Data or Vector Data depending on the VI_EN settings:

If VI_EN=0, this 8-bit data signal can come from a sensor or be generated by an external controller.

If VI_EN=1, this 8-bit data signal must be connected to the 8 highest bit of the video signal.

6.5 Recognition stage output lines

6.5.1 B_BSY

The Bus Busy line is asserted during the execution of an internal cycle such as a reset cycle, a recognition cycle, an I2C read or write command received from an external controller, etc. An external master controller must verify that B_BSY is low prior to sending a command. Otherwise the command will be discarded. This signal is updated at the negative edge of the G_CLK.

6.5.2 DIST_VAL

The Distance Valid signal rises on the negative edge of G_CLK when the real time distance (Addr 0x01D) of the last recognition is available on the DATA output bus. This strobe lasts one clock cycle.

6.5.3 CAT_VAL

The Category Valid signal rises on the negative edge of G_CLK when the real-time category (Addr 0x1E) of the last recognition is available on the DATA output bus. This strobe lasts one clock cycle.

6.6 I2C serial bus

The CM1K I2C slave controller can receive commands from an external I2C master controller operating at a speed of 100 or 400 Kbit per second. It is enabled by setting the I2C_EN pin to 1. It converts the clock and serial data received on the I2C_SCK and I2C_SDA pins into an internal data strobe signal (DS), Read/Write signal (RW_), register value (REG) and data value (DATA). If the STANDALONE pin is set to 0, these signals are also be broadcasted to the bidirectional parallel bus of the chip for use by the other CM1K chips.

6.6.1 I2C EN

I2C_EN enables the CM1K to communicate with an external I2C master controller. If several CM1K chips are connected in parallel, only one chip can have its I2C_EN pin set to 1. In addition, if the chain of CM1Ks shall recognize a video or other digital signal received by one of them through its digital bus, the chip with its pin RECO_EN=1 must be the same as the chip with its pin I2C_EN=1.

This pin is connected to an internal pull-up so it is enabled by default. For power-savings consideration, it should be grounded if unused.

6.6.2 I2C CLK

Serial Clock. Must be connected to a pull-up resistor of 4.7 KOhms.

6.6.3 I2C DATA

Serial Data. Must be connected to a pull-up resistor of 4.7 KOhms.

7 Timing constraints

7.1 Registers Access Latency

The following table reports the number of clock cycles (cc) necessary to read and write the registers of the CM1K chip. The cycles are counted from the first rising edge of the system clock upon the receipt of the DS signal, to the rising edge of the READY signal upon execution of the command.

Accessing most registers takes a single clock cycle. In Learn and Recognition mode, reading and writing the LCOMP, DIST and CAT registers can take between 3 and 19 clock cycles depending on the content of the neuron at the time of the execution. This means that two neurons can execute a same instruction in different number of clock cycles. For example a neuron which does not recognize an input pattern will execute the RDIST instruction in 1 cycle, when a neuron which recognizes the pattern (i.e. fires) will participate to the Search and Sort race for up to 16 clock cycles. The status of the Ready line indicates when all the neurons have finished the execution of an instruction and can receive a new one.

Addr	Register	Description	Learn and Recognition mode		Save and Restore mode	
			Write cycles	Read cycles	Write cycles	Read cycles
0x00	NCR	Neuron Context Register			1	1
0x01	COMP	Component	1		1	1
0x02	LCOMP	Last Component	1 if no neurons 3 otherwise			
0x03	DIST	Distance		18		1
0x04	CAT	Category	1 if ID, 19 otherwise	3 if ID, 19 otherwise	1	1
0x05	AIF	Active Influence Field			1	1
0x06	MINIF	Minimum Influence Field	1	1		1
0x07	MAXIF	Maximum Influence Field	1	1		
0x08	TESTCOMP	Test Component			1	
0x09	TESTCAT	Test Category			1	
0x0A	NID	Neuron Identifier		1		1
0x0B	GCR	Global Context Register	1	1		
0x0C	RESETCHAIN				1	
0x0D	NSR	Network Status Register	1	1		
0x0F	FORGET	Clear the neurons	2			
0x0F	NCOUNT	Committed neurons	1	1		
0x11	TOP	Left corner of the ROI	1	1		
0x12	LEFT	Top corner of the ROI	1	1		
0x13	WIDTH	Width of the ROI	1	1		
0x14	HEIGHT	Height of the ROI	1	1		
0x15	BWIDTH	Width of a block	1	1		
0x16	BHEIGHT	Height of a block	1	1		
0x1C	RSR	Recognition Status	1	1		
0x1D	RTDIST	Distance of 1 st firing neuron		1		
0x1E	RTCAT	Category of 1 st firing neuron		1		
0x1F	ROIINIT	Reset the ROI to default	1			

7.2 Typical Timings Constraints

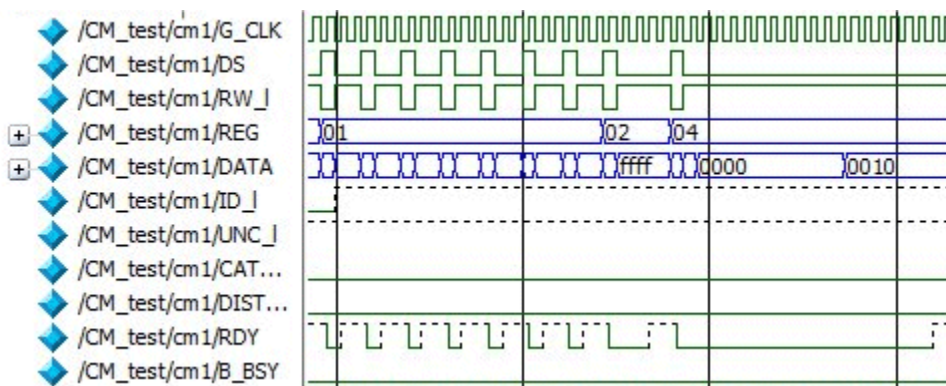
In the example below, a vector of 8 components is learned and then recognized. The resolution of the diagrams does not allow reading the DATA values of the components and the category, but this is not important for understanding the timing constraints of the chip.

The DS, RW_, REG and DATA signals are updated at the negative edge of the system clock (G_CLK) so that they are stable when the neurons read them at the next positive edge of G_CLK. The RDY signal is then immediately pulled down by the neurons and released at the first positive edge of G_CLK following the completion of the command. The duration during which the RDY signal is low represents the execution time of the command.

In the case of a Read command, the output DATA is ready to be read when RDY rises.

7.2.1 Learn a vector

The sequence of instructions consists of 7 Write COMP, 1 Write LCOMP, and 1 Write CAT.



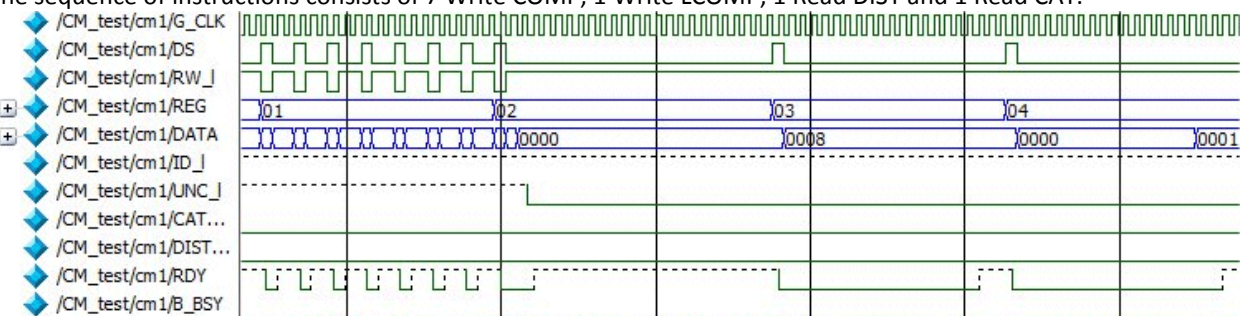
When REG is equal to 01, each DS pulse triggers a Write COMP lasting one cycle of G_CLK. The RDY signal has the same duration as the DS only shifted by one half clock cycle.

When REG is equal to 02, the DS pulse triggers a Write LCOMP. The RDY signal is pulled down for 3 cycles. The fact that both lines ID_ and UNC_ are pulled up indicates that the input vector is not recognized by any existing neuron. The subsequent Write CAT command will necessarily commit a new neuron.

When REG is equal to 04, the DS pulse triggers a Write CAT. The RDY signal is pulled down for 19 cycles.

7.2.2 Recognize a vector

The sequence of instructions consists of 7 Write COMP, 1 Write LCOMP, 1 Read DIST and 1 Read CAT.



When REG is equal to 01, each DS pulse triggers a Write COMP. The RDY signal is pulled down for one cycle.

When REG is equal to 02, the DS pulse triggers a Write LCOMP. The RDY signal is pulled down for 3 cycles. The UNC_L is pulled down at the last negative edge of G_CLK before RDY is pulled back up. This indicates that the input vector is recognized by more than one neuron and that different categories are identified.

When REG is equal to 03 and RW_I remains high, the DS pulse triggers a Read DIST. The RDY signal is pulled down for 18 cycles which is the duration of the Search and Sort looking for the firing neuron with the smallest distance value. This distance is equal to 08.

When REG is equal to 04 and RW_I remains high, the DS pulse triggers a Read CAT. The RDY signal is pulled down for 19 cycles which is the duration of the Search and Sort looking for the firing neuron with a distance register equal to 08 and the smallest category value. This category is equal to 01.

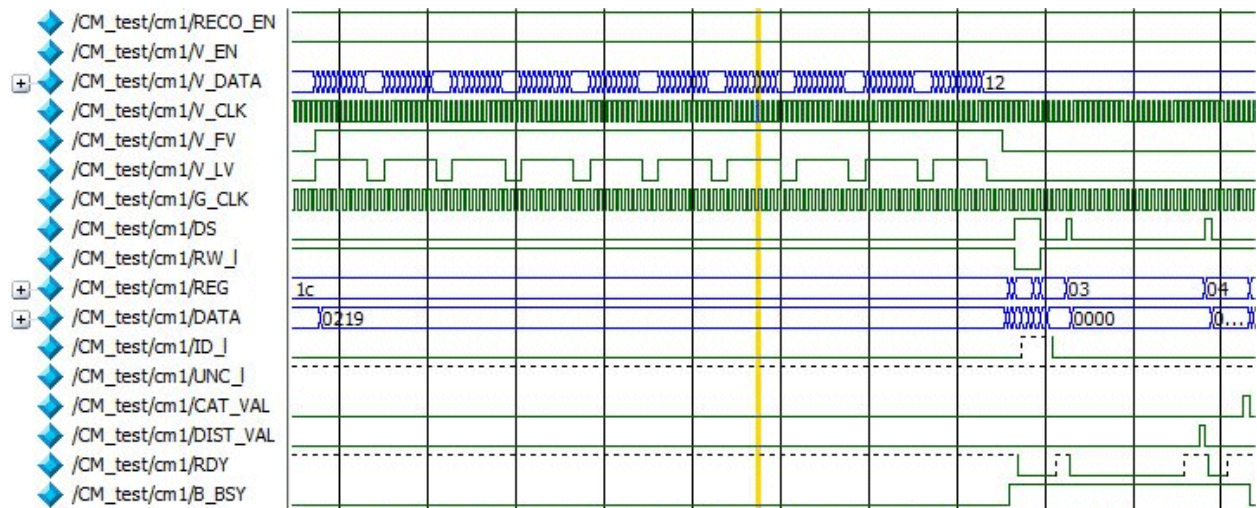
Remark: Since it is known that the recognition status is uncertain (UNC_L is low), executing another series of Read DIST followed by Read CAT would report the distance and category of the next neuron with the smallest distance.

7.2.3 Recognizing a vector received through the digital video bus

In the following example, RECO_EN and V_EN are both pulled up so the reco_logic of the chip can continuously recognize the video data received through the V_CLK, V_FV, V_LV and V_DATA.

Immediately after the fall of V_FV, the B_BSY line rises indicating that the recognition stage is active and communicating with the neurons.

The DS, RW_I, REG and DATA seen in the above diagram are generated internally by the reco_logic stage and broadcasted to the parallel bus so the neurons of all the CM1K chips in the chain can participate to the recognition (and not only the neurons of the CM1K with the active recognition stage).



The first DS is sustained for four clock cycles to broadcast a vector of four components to the neurons. The REG register is equal to 01 during the first 3 cycles to execute a Write COMP. It is then switched to the value 02 to execute a Write LCOMP. The ID_I signal falls two clock cycles later indicating that the vector is recognized with certainty by the firing neurons. The RDY signal falls as soon as the neurons start executing the first Write COMP and remains low until the Write LCOMP is completed.

The second DS triggers a Read DIST. The RDY signal is pulled down for 18 cycles which is the duration of the Search and Sort looking for the firing neuron with the smallest distance value. This distance is equal to 00 indicating an exact match. The DIST_VAL pulse rises one clock cycle after the RDY signal to notify that DATA has been latched to the RT_DIST register of the reco_logic.

The third DS triggers a Read CAT. The RDY signal is pulled down for 3 cycles only because a Search and Sort is not necessary (it would extend the execution by 16 more cycles). This is no surprise since the ID_I signal has already indicated that the input vector is recognized with certainty. The CAT_VAL pulse rises one clock cycle after the RDY signal to notify that DATA has been latched to the RT_CAT register of the reco_logic.

7.3 Basic Operation Latency

7.3.1 Formulas

Operation	Clock cycles
Learn a vector of length L	$L+3 + 18$
Best match of a vector of length L	$L+3+37$
Get the N top match of a vector of length L	$L+3+N*37$
Save N neurons	$3+(L+3)*N$
Restore N neurons	$3+(L+3)*N$

7.3.2 Examples with vectors of 256 bytes

Basic Operations	Clock cycles	usec
Learn a vector of length L	277	10.26
Best match of a vector of length L	294	10.89
Get the N top match of a vector of length L	438	16.22
Save N neurons	260	9.63
Restore N neurons	260	9.63

7.3.3 Examples with vectors of 64 bytes

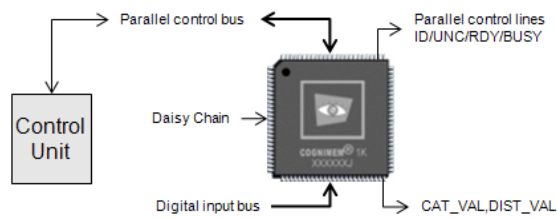
Basic Operations	Clock cycles	usec
Learn a vector of length L	85	3.15
Best match of a vector of length L	102	3.78
Get the N top match of a vector of length L	246	9.11
Save N neurons	68	2.52
Restore N neurons	68	2.52

8 Single and Multiple Chip Configurations

One of the benefits of the CM1K architecture is that you can cascade multiple chips in parallel to expand the size of the neural network by increment of 1024 neurons. The behavior of the neurons in a single-chip or multiple-chips configuration remains the same. The recognition logic on the other hand can only be activated on one chip of the chain.

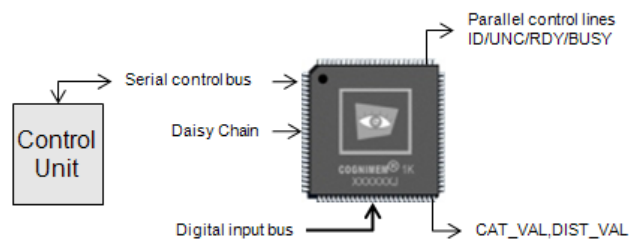
8.1 Single chip

8.1.1 Interface through the parallel bus (a)



The CM1K can learn and recognize vector data transmitted by the control unit through its parallel control bus (DS, RW_, REG, DATA). If the RECO_EN pin is set to 1, vector data can be transmitted through the digital input bus and the response of the neuron with the best match latched to registers. Note that if an application simply needs to monitor the recognition status, the parallel control lines, CAT_VAL and DIST_VAL can be sufficient outputs.

8.1.2 Interface through serial bus (b)



The CM1K can learn and recognize vector data transmitted by the control unit through the serial bus (I2C_CLK and I2C_DATA). If the RECO_EN pin is set to 1, vector data can be transmitted through the digital input bus and the response of the neuron with the best match latched to registers. Note that if an application simply needs to monitor the recognition status, the parallel control lines, CAT_VAL and DIST_VAL can be sufficient outputs.

In the case of a single chip, it is recommended to set its S_CHIP pin to 1 in order to lower its power consumption. Indeed, the neurons of a single chip do not have to output and multiplex their data with other chips. Also, when S_CHIP=1 and the recognition logic is active, the value of the best distance and category can be read directly on the DATA bus when the DIST_VAL and CAT_VAL lines pulse.

8.1.3 CM1K configuration lines

	First CM1K in chain	Other CM1Ks
S_CHIP	1	n/a
G_CLK	Typical 27 Mhz	n/a
DCI	1	n/a
I2C_EN	0 in config (a), 1 in config (b)	n/a
RECO_EN	Optional	n/a
V_CLK, V_FV, V_DATA	Used if RECO_EN=1	n/a
V_EN	Used if RECO_EN=1	n/a
V_LV	Equiv to line valid if V_EN=1, unused otherwise	n/a
CAT_VALID, DIST_VALID	Active if RECO_EN=1 and if the register RSR[1]=1	

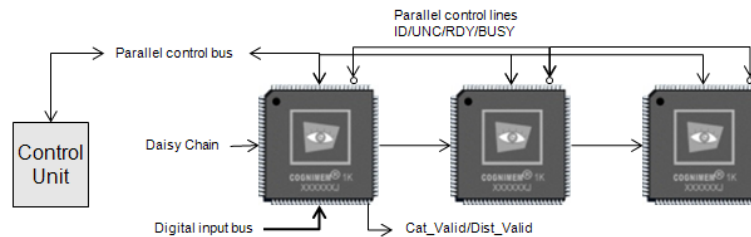
8.2 Multiple chip configurations

When multiple CM1K are connected in parallel to expand the size of the neural network, their S_CHIP pin must be set to 0. This setting turns the neuron parallel bus (DS, RW_, REG, DATA) into a bidirectional bus allowing the neurons of different chips to automatically interact with one another when necessary.

8.2.1 Control through parallel bus (a)

A chain of CM1K can learn and recognize vector data transmitted by the control unit through the parallel control bus (DS, RW_, REG, DATA). The control unit can also edit the network global registers and read the detailed response of all the firing neurons if necessary.

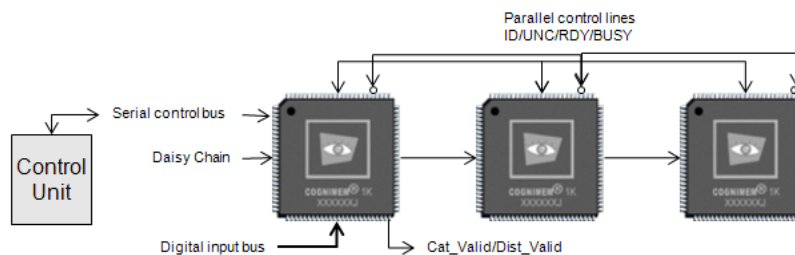
As an option if the RECO_EN pin is set to 1, vector data can be transmitted through the digital input bus and the response of the neuron with the best match latched to registers by the recognition stage. Note that if an application simply needs to monitor the recognition status, the parallel control lines, CAT_VAL and DIST_VAL output by the first chip can be sufficient outputs.



8.2.2 Control through serial bus (b)

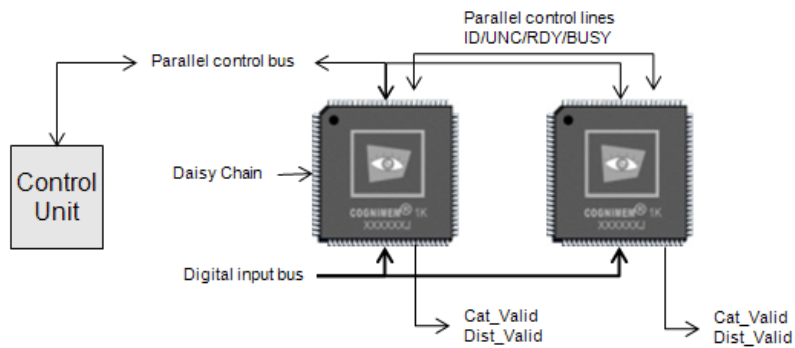
If an application requires a low connectivity to a chain of neurons, the control unit can interface to the first CM1K of the chain via its serial bus (i.e. 2 lines). The CM1K converts the serial data to a (DS, RW_, REG and DATA) which is then transmitted to all the CM1K chips through the bi-directional parallel control bus.

As an option if the RECO_EN pin is set to 1, vector data can be transmitted through the digital input bus and the response of the neuron with the best match latched to registers by the recognition stage. Note that if an application simply needs to monitor the recognition status, the parallel control lines, CAT_VAL and DIST_VAL output by the first chip can be sufficient outputs.



8.2.3 Control through parallel bus and separate recognition stages (c)

Multiple CM1K chips can be used to recognize different regions of interest in a same image, or to recognize a same region but against different knowledge loaded in the CM1K chips.



8.2.4 CM1K configuration lines

	First CM1K in chain	Other CM1Ks
S_CHIP	0	0
DCI	1	DCO of previous CM1K in config (a) and (b) 1 in config (e)
I2C_EN	0 in config (a) and (e) 1 in config (b)	0
RECO_EN	Optional in config (a) and (b) 1 in config (e)	0 in config (a) and (b) 1 in config (e)
V_CLK, V_FV, V_DATA	Used if RECO_EN=1	n/a
V_EN	Used if RECO_EN=1	n/a
V_LV	Equiv to line valid if V_EN=1, unused otherwise	n/a
CAT_VALID, DIST_VALID	Active if RECO_EN=1 and if the register RSR[1]=1	n/a

17	VCC			Core power supply (1.2v)
18	V_DATA[0]	Input		Video data line 0
19	V_DATA[1]	Input		Video data line 1
20	VCC			Core power supply (1.2v)
21	V_DATA[2]	Input		Video data line 2
22	VCC			Core power supply (1.2v)
23	V_DATA[3]	Input		Video data line 3
24	V_DATA[4]	Input		Video data line 4
25	V_DATA[5]	Input		Video data line 5
26	V_DATA[6]	Input		Video data line 6
27	V_DATA[7]	Input		Video data line 7
28	V_LV	Input		Video line valid
29	VCC			Core power supply (1.2v)
30	V_FV	Input		Video frame valid if V_EN=1; Vector valid if V_EN=0;
31	VCC			Core power supply (1.2v)
32	VCCIO			IO power supply line (3.3 v)
33	V_CLK	Input		Video clock if V_EN=1; Vector sampling clock if V_EN=0;
34	VCCIO			IO power supply line (3.3 v)
35	VCC			Core power supply (1.2v)
36	REG[0]	Bidir	PU	Register line 0
37	REG[1]	Bidir	PU	Register line 1
38	VCC			Core power supply (1.2v)
39	VCCIO			IO power supply line (3.3 v)
40	REG[2]	Bidir	PU	Register line 2
41	REG[3]	Bidir	PU	Register line 3
42	VCC			Core power supply (1.2v)
43	REG[4]	Bidir	PU	Register line 4
44	VCCIO			IO power supply line (3.3 v)
45	VCC			Core power supply (1.2v)
46	RECO_EN	Input	PU	Recognition enable
47	R/W_	Bidir	PU	Read/Write low line (Read=1; Write=0)
48	VCCIO			IO power supply line (3.3 v)
49	UNC_	Bidir	PU	Uncertain_low line
50	ID_	Bidir	PU	Identified_low line
51	VCCIO			IO power supply line (3.3 v)
52	RDY	Bidir	PU	Ready line
53	DS	Bidir	PU	Data strobe line
54	VCCIO			IO power supply line (3.3 v)
55	VCC			Core power supply (1.2v)
56	VCC			Core power supply (1.2v)
57	GND			Ground line
58	DIST_VAL	Output		Distance valid line
59	VCCIO			IO power supply line (3.3 v)
60	VCC			Core power supply (1.2v)
61	VCC			Core power supply (1.2v)
62	DCO	Output		Daisy Chain Out
63	DATA[0]	Bidir	PU	Data line 0
64	VCCIO			IO power supply line (3.3 v)
65	DATA[1]	Bidir	PU	Data line 1

66	VCC			Core power supply (1.2v)
67	DATA[2]	Bidir	PU	Data line 2
68	VCCIO			IO power supply line (3.3 v)
69	DATA[3]	Bidir	PU	Data line 3
70	VCC			Core power supply (1.2v)
71	VCCIO			IO power supply line (3.3 v)
72	VCC			Core power supply (1.2v)
73	DATA[4]	Bidir	PU	Data line 4
74	VCCIO			IO power supply line (3.3 v)
75	DATA[5]	Bidir	PU	Data line 5
76	DATA[6]	Bidir	PU	Data line 6
77	VCCIO			IO power supply line (3.3 v)
78	DATA[7]	Bidir	PU	Data line 7
79	VCCIO			IO power supply line (3.3 v)
80	DATA[8]	Bidir	PU	Data line 8
81	DATA[9]	Bidir	PU	Data line 9
82	VCCIO			IO power supply line (3.3 v)
83	VCC			Core power supply (1.2v)
84	DATA[10]	Bidir	PU	Data line 10
85	VCC			Core power supply (1.2v)
86	VCCIO			IO power supply line (3.3 v)
87	DATA[11]	Bidir	PU	Data line 11
88	DATA[12]	Bidir	PU	Data line 12
89	VCC			Core power supply (1.2v)
90	GND			Ground line
91	DATA[13]	Bidir	PU	Data line 13
92	VCC			Core power supply (1.2v)
93	DATA[14]	Bidir	PU	Data line 14
94	VCC			Core power supply (1.2v)
95	DATA[15]	Bidir	PU	Data line 15
96	CAT_VAL	Output		Category valid line
97	B_BSY	Output		Bus busy line
98	VCC			Core power supply (1.2v)
99	S_CHIP		PU	Single chip line
100	RSVD			Reserved

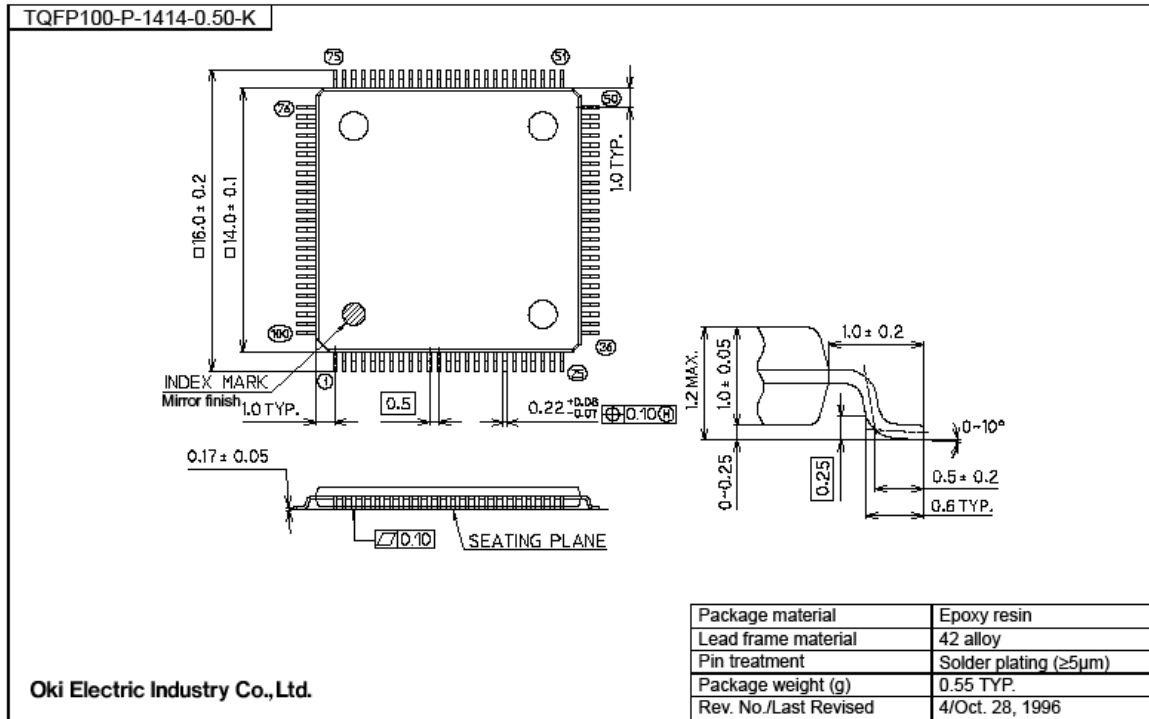
Same listing ordered per category

Symbol	Type	Pull	Pin #	Description
B_BSY	Output		97	Bus busy line
CAT_VAL	Output		96	Category valid line
DATA[0]	Bidir	PU	63	Data line 0
DATA[1]	Bidir	PU	65	Data line 1
DATA[10]	Bidir	PU	84	Data line 10
DATA[11]	Bidir	PU	87	Data line 11
DATA[12]	Bidir	PU	88	Data line 12
DATA[13]	Bidir	PU	91	Data line 13
DATA[14]	Bidir	PU	93	Data line 14
DATA[15]	Bidir	PU	95	Data line 15
DATA[2]	Bidir	PU	67	Data line 2
DATA[3]	Bidir	PU	69	Data line 3

DATA[4]	Bidir	PU	73	Data line 4
DATA[5]	Bidir	PU	75	Data line 5
DATA[6]	Bidir	PU	76	Data line 6
DATA[7]	Bidir	PU	78	Data line 7
DATA[8]	Bidir	PU	80	Data line 8
DATA[9]	Bidir	PU	81	Data line 9
DCI	Input	PU	13	Daisy Chain In
DCO	Output		62	Diasy Chain Out
DIST_VAL	Output		58	Distance valid line
DS	Bidir	PU	53	Data strobe line
G_CLK	Input		8	Master clock. Up to 27 Mhz for a single chip. Up to 13.5 Mhz for a multiple-chip configuration.
G_Reset_			3	Global reset_low line
GND			57, 90	Grond line
I2C_EN	Input	PU	5	I2C enable
I2C_SDA	IO	PU	15	I2C serial data line
I2C_SDK	Input		10	I2C clock (100 Kbit or 400 Kbit. 3.4 Mbit under certain conditions)
ID_	Bidir	PU	50	Identified_low line
R/W_	Bidir	PU	47	Read/Write low line (Read=1; Write=0)
RDY	Bidir	PU	52	Ready line
RECO_EN	Input	PU	46	Recognition enable
REG[0]	Bidir	PU	36	Register line 0
REG[1]	Bidir	PU	37	Register line 1
REG[2]	Bidir	PU	40	Register line 2
REG[3]	Bidir	PU	41	Register line 3
REG[4]	Bidir	PU	43	Register line 4
RSVD			1, 100	Reserved
S_CHIP		PU	99	Single chip line
Chip_Select_	Input	PD	6	Enable chip activity
UNC_	Bidir	PU	49	Uncertain_low line
V_CLK	Input		33	Video clock if V_EN=1; Vector sampling clock if V_EN=0;
V_DATA[0]	Input		18	Video data line 0
V_DATA[1]	Input		19	Video data line 1
V_DATA[2]	Input		21	Video data line 2
V_DATA[3]	Input		23	Video data line 3
V_DATA[4]	Input		24	Video data line 4
V_DATA[5]	Input		25	Video data line 5
V_DATA[6]	Input		26	Video data line 6
V_DATA[7]	Input		27	Video data line 7
V_EN	Input	PU	16	Video enable
V_FV	Input		30	Video frame valid if V_EN=1; Vector valid if V_EN=0;
V_LV	Input		28	Video line valid
VCC			4,11,14,17,20,22,29,31,35,38,42,45,55,56,60,61,66,70,72,83,85,89,92,94,98	Core power supply (1.2v)
VCCIO			2,7,9,12,32,34,39,44,48,51,54,59,64,68,71,74,77,79,82,86	IO power supply line (3.3 v)

9.2 Mechanical specifications

Die size..... 8 mm x 8 mm
 Process Geometry Technology: 130 nm
 Packaging: 100 pin TQFP
 Chip size..... 14 mm x 14 mm



9.3 Electrical Specifications

All signals are LVTTTL (3.3 volts)

Vcc IO, Power supply for IO	3.3V for IO
Vcc CorePower supply for core.....	1.2 V for core
Max operating clock frequency	27 Mhz in single chip configuration (S_CHIP=1)
.....	16 Mhz otherwise
Video/Vector clock frequency	up to 27 Mhz
Operating temperature range	0 – 70 C
Open Drain max sink current (I _{OL}):.....	16 mA
Power consumption.....	Idle mode 5 mW
.....	Busy mode (continuous recognition with all neurons committed)
.....	approx 275 mW at 1.2V / 27 Mhz
Output Capacitance	10 pF
Interface levels	LVTTTL
CM1K fan out	8

9.3.1 [Power saving tips](#)

Since the DATA bus is pulled-up inside the chip, the broadcast of a value other than 0xFFFF on this bus increases power consumption and this until the execution of another command releasing the bus (i.e. by returning a data value of 0xFFFF). Such command can be Write NSR executed in 1 clock cycle.

The RECO_EN, VI_EN and I2C_EN pins of the chip are pulled-up by default. If their functionality is not used, these pins should be grounded.

10 FAQ

10.1 Hardware design

The CM1K does not learn

- The neurons will not learn if the UNC_ line is driven. Verify that it is in tri-state during a learning operation.

10.2 Operation

The CM1K does not learn, nor recognize my vectors when I know it should

- Verify that the neurons are not in Save-and-Restore mode by reading the Network Status Register (NSR). If it is equal to 16 (0x10) then the neurons behave as dummy memories and cannot learn nor recognize.
- Verify that the Global Context Register (GCR) is set to the proper value. If you have learned your vectors while the GCR was equal to A, they will not be recognize if the GCR at the time of the recognition is different from A or 0.

11 Appendix A: Heard about ZISC before?

ZISC stands for Zero Instruction Set Computer and is a neural network chip which was invented jointly by a team of engineers at IBM France and Guy Paillet in 1993. Both parties share the patents applied for during the design of this chip. The chip was manufactured by IBM between 1993 and 1999 and marketed consecutively as the ZISC36 and ZISC78 chips. Following the termination of the manufacturing of the ZISC chip by IBM, Guy Paillet has never stopped working on the next generation of the neural network chip. As a result of these efforts, CogniMem LTD (Hong Kong) released the CM1K chip (CM1K) in August 2007. Following is a specification chart comparing the ZISC and the CM1K chip.

ZISC and CM1K comparative chart

Feature	ZISC78	CM1K
Number of neurons per chip	78	1024
Neuron memory size	64 bytes	256 bytes
Distance register	16-bit	16-bit
Category value	15 bit	15 bit
Degenerated neuron flag	Yes	Yes
Context values	128	128
Norms to calculate distance	L1 and Lsup	L1 and Lsup
Choice of classifier	RBF and KNN	RBF and KNN
Minimum and Maximum Influence fields	Yes	Yes
Parallel bus access (single and inter-chip)	74 lines	28 lines
Packaging	LQFP 100	TQFP 100
Dye size	4.66 mm x 4.66 mm	8 mm x 8 mm
Operating clock frequency (max)	33 Mhz	27 Mhz
Power supply	3.3V for IO; 2.5 V for core	3.3V for IO; 1.2 V for core
Power saving mode	Yes	Yes
Neuron Identifier register		24-bit
Index Component register		8-bit
I2C serial access (100, 400 Kbit per second)		2 lines
Digital input bus for built-in recognition logic (optional use)		10 lines for signal 11 lines for video
Digital input bus clock frequency (max)		27 Mhz

12 Appendix B: Errata

12.1 05-11-2011, RNCOUNT limited to 16-bit value

Because the DATA bus is a 16-bit bus, the Write NCOUNT command will return a truncated value if an architecture includes a chain of more than 63 CM1K chips or a total of 65,535 neurons. Indeed the neuron count will only report the lowest 16-bit of this count. The following table describes the work around this erratum:

If chain <= 63 CM1K	If chain > 63 CM1K
- Read NCOUNT, ncount	- Write NSR, 16
	- Read NCR, n1
	- Read NID, n2
	- Write NSR, 0
	- $N = (n1[15:8]*0xFFFF)+n2$

Description: If a chain has more than 65,535 neurons reading the number of committed neurons requires to set the network to Save and Restore mode in order to point to the last committed neuron and read its context and identifier registers. If more than 65,535 neurons are committed at this time, the upper byte of the context value actually contains bits[23:15] of the neuron identifier. The final number of committed neurons reported on 24 bits is equal to NCR_value[15:8] appended to NID_value[15:0].

12.2 08-03-2011, NID incorrect if firing neurons with same distance and category

If two or more neurons report the same distance, their response is sorted per increasing order of category.

If one or more of these neurons have the same category, the readout of the Category register will exclude them all at once from the next search and sort.

- ➔ Note that if you are interested in surveying the histogram of the distances and a probability density function, the neurons with the same distance and same category will be accounted as one.

Furthermore, if you read immediately after the NID register, it will report the logical AND of the identifiers of the firing neurons with this same distance and category. Under such circumstances, the NID is useless.

- ➔ Reading the NID register is useful if you want to display the content of the neuron recognizing a pattern. If you cannot comprehend such content, it probably means that the NID is incorrect for the reason mentioned above.
- ➔ Reading the NID register is useful in the case of a K-Nearest Neighbor classification. If for some reason, the trained vectors cannot have different category values, the NID has a good probability to report an erroneous NID, especially if the number of trained vectors is large.
- ➔ Since the NID starts at the value 1, a readout of the value 0 is immediately an indicator that several neurons have the same last reported category and distance values.

Example #1: Neurons with the same category

Firing neurons			Response readout
Neuron 1	Distance=128	Category=1	Read Distance= 128
Neuron2	Distance=128	Category=1	Read Category=1
Neuron3	Distance=128	Category=1	Read Identifier= 0
Neuron4	Distance=130	Category=1	Read Distance= 130
			Read Category=1
			Read Identifier= 4

Neuron 1, 2 and 3 output their identical category on the parallel bus at the same time and all three disconnect from the next search and sort. The identifier is not representative since it reports the logical AND between the identifier of the Neuron 1, 2 and 3.

Example #2: Neurons with different categories

Firing neurons			Response readout
Neuron 1	Distance=128	Category=10	Read Distance= 128
Neuron2	Distance=128	Category=20	Read Category=10
Neuron3	Distance=128	Category=30	Read Identifier= 1
Neuron4	Distance=130	Category=40	Read Distance= 128
			Read Category=20
			Read Identifier= 2
			Read Distance= 128
			Read Category=30
			Read Identifier= 3
			Read Distance= 130
			Read Category=40
			Read Identifier= 4

Each neuron is accounted for!

13 What is new in this manual ?

13.1 Revision from 02/17/2012

- UNC_ line must not be driven
- New FAQ chapter

13.2 Revision from 11/1/2011

- New power savings tip in chapter 9
- Correction of an erroneous address for the NID register in the table “Registers Access Latency”
- Improved description of the I2C protocol

13.3 Revision from 10/19/2011

- Write PowerSave: new register setting the data lines in tri-state mode so they do not draw current from the pull-up resistors. This register should be written at the end of typical programming sequences such as learn a vector, recognize a vector, etc.
- KNN is a recognition behavior and should not be set during a learning sequence..

13.4 Revision from 10/13/2011

- Better description of the requested timings for the DS, RW_, REG and DATA lines. In particular DS, RW_ and DATA must be released before the second positive edge of the system clock after the rise of DS.

13.5 Revision from 10/04/2011

- Write FORGET register takes 2 clock cycles

13.6 Revision from 09/23/2011

- Addition of a comment limiting the possible value range of the CAT register to [0, 0x7FFE]
- Addition of a Erratum regarding the readout of the neuron identifier in the case of firing neurons with the same distance and same category
- Addition of the MINIF register in the recommended Save and Restore procedures