COGNITIVE MEMORY
HUMAN AND MACHINE

by

BERNARD WIDROW

JUAN CARLOS ARAGON

INFORMATION SYSTEMS LABORATORY
DEPT. OF ELECTRICAL ENGINEERING
STANFORD UNIVERSITY

February 1, 2007

THE 3 HOWS

- **How does human memory work ?**
- **How could I build a memory like that ?**
- **How could I use it to solve practical problems ?**

SOME PERTINENT QUESTIONS…

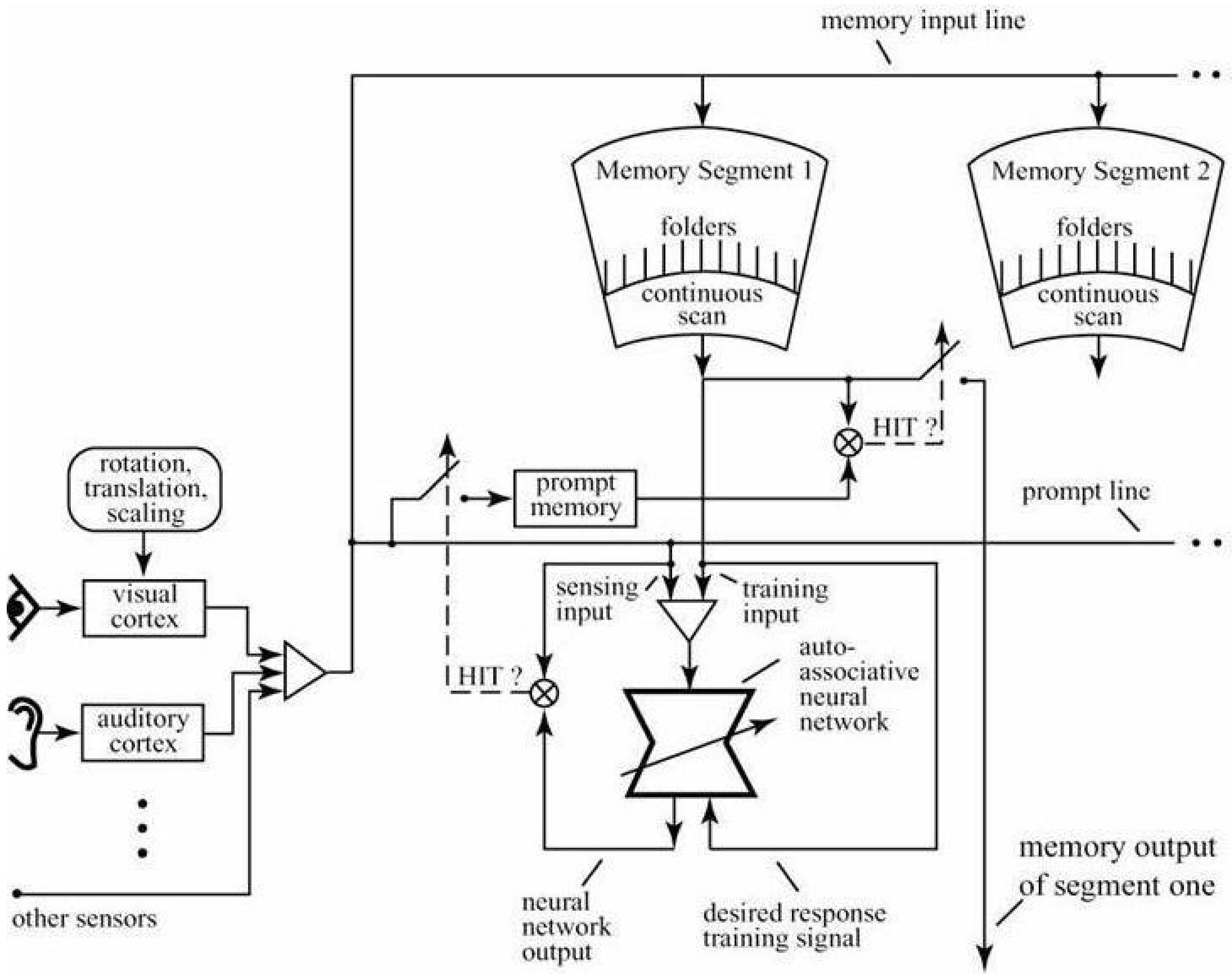
What would we like to do ?

- Design a memory system that is as simple as possible, but behaves like and emulates human memory.

Why would we like to do this ?

- To develop a new kind of memory for computers, adjunct to existing forms of memory, to facilitate solutions to problems in artificial intelligence, pattern recognition, speech recognition, control systems etc.

- To advance cognitive science with new insight into the working of human memory.

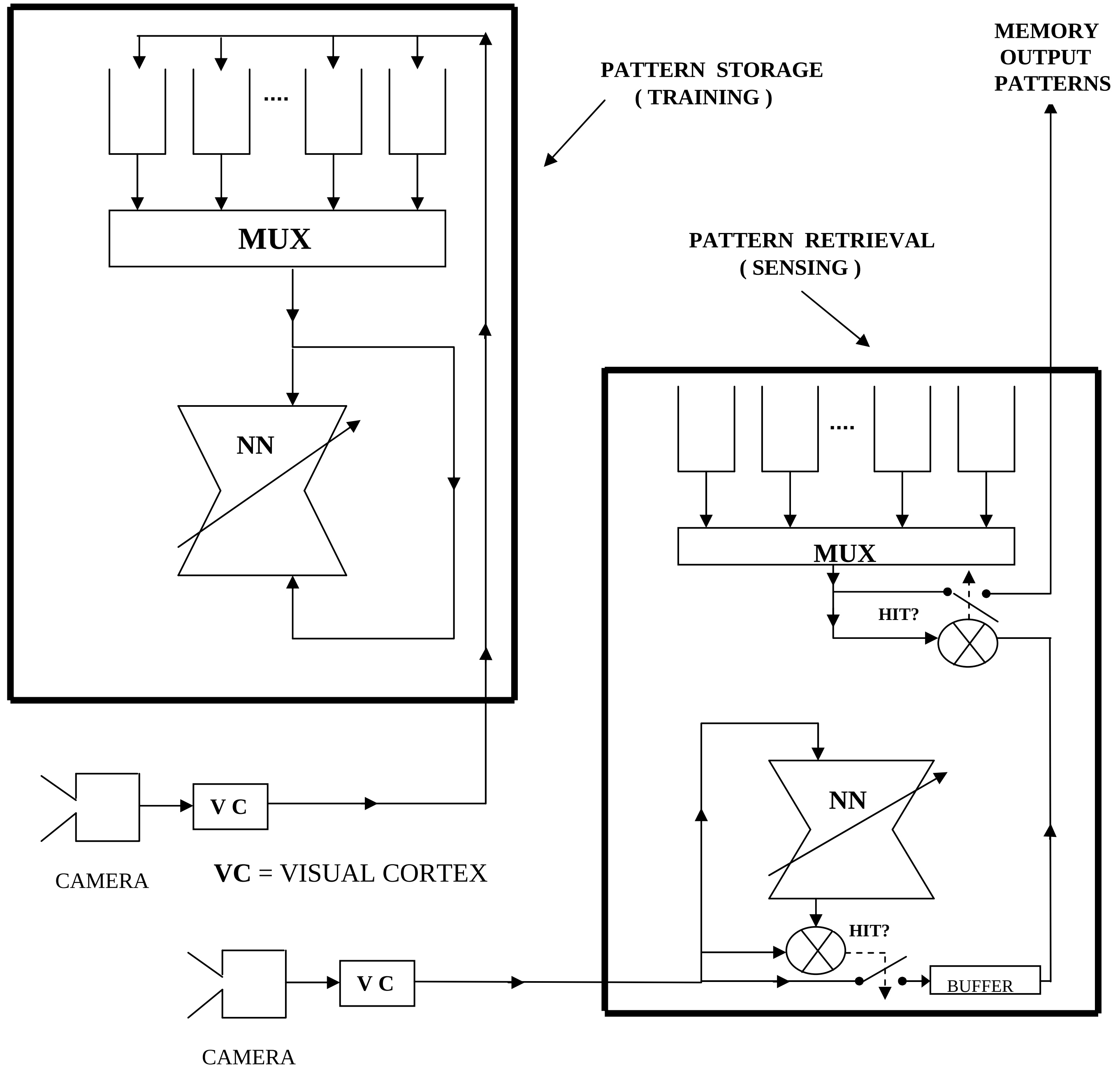


A Cognitive Memory System

SALIENT FEATURES OF COGNITIVE MEMORY

- Stores sensory patterns (visual, auditory, tactile; radar, sonar, etc.).
- Stores patterns wherever space is available, not in specified memory locations.
- Stores simultaneously sensed input patterns in the same folder (e.g., simultaneous visual and auditory patterns are stored together).
- Data recovery is in response to “prompt” input patterns (e.g., a visual or auditory input pattern would trigger recall).
- Autoassociative neural networks are used in the data retrieval system.

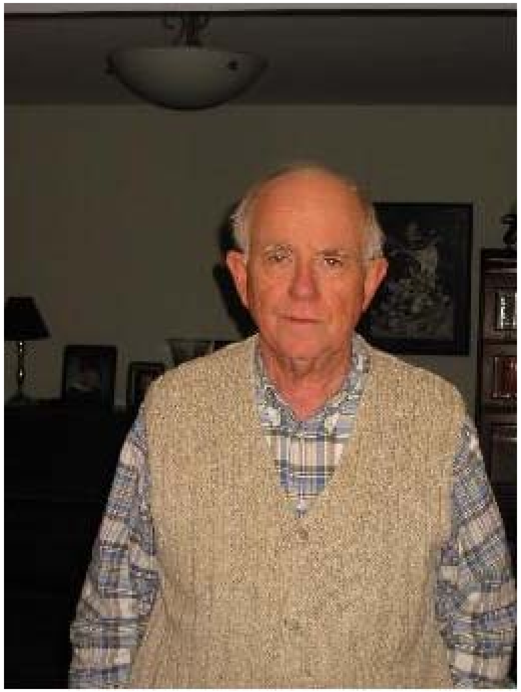
A SIMPLE COGNITIVE MEMORY FOR PATTERN RECOGNITION

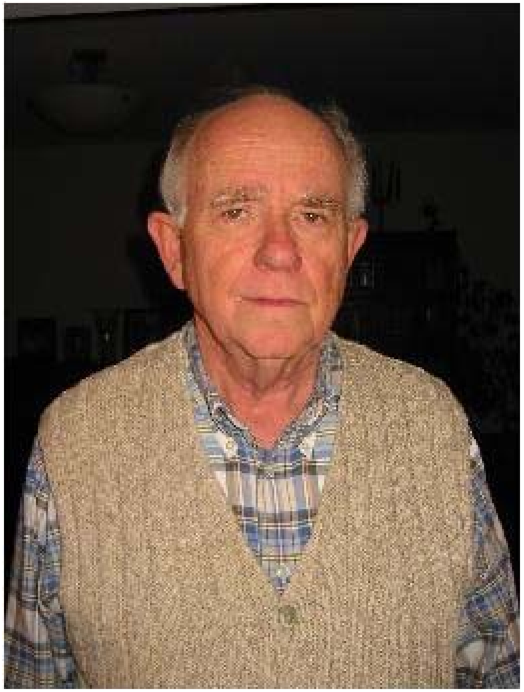


A SIMPLE COGNITIVE MEMORY FOR PATTERN RECOGNITION

FACE RECOGNITION

THREE PHOTOS OF BERNARD WIDROW USED FOR TRAINING





A PHOTO OF JUAN CARLOS ARAGON, VICTOR ELIASHBERG, AND BERNARD WIDROW USED FOR SENSING

FACE DETECTION

Training (low resolution, 20x20 pixel images)

- One image of a person's face was trained in
- The image was adjusted by
  - Rotation (2° increments, 7 angles)
  - Translation (left/right, up/down, 1 pixel increments, 9 positions)
  - Brightness (5 levels of intensity)
- Total number of training patterns = 315
- Training time 12 minutes on AMD 64 bit Athlon 2.6 GHz computer for 0.25% MSE

FACE DETECTION

Sensing (low resolution, 20x20 pixel images)

- Each input pattern was adjusted by
  - Scaling (6 window sizes)
  - Translation (90 pixel increments)

- Errors with background were ~8X greater than with a person's face

- 60 patterns per second through neural network

- Autoassociative neural network has total of 1100 neurons distributed over 3 layers
  - 400 neurons, 400 weights per neuron, first layer
  - 300 neurons, 400 weights per neuron, second layer
  - 400 neurons, 300 weights per neuron, third layer

FACE RECOGNITION

Training (high resolution, 50x50 pixel images)

- All 3 images of Widrow's face were trained in
- Each image was adjusted by
  - Rotation (2° increments, 7 angles)
  - Translation (left/right, up/down, 1 pixel increments, 25 positions)
  - Scaling (3 window sizes)

- Total number of training patterns = 1575

- Training time 2.6 hours in AMD 64 bit Athlon 2.6 GHz computer for 0.25% MSE

FACE RECOGNITION

Sensing (high resolution, 50x50 pixel images)

- Each input pattern was adjusted by
  - Scaling (6 window sizes)
  - Translation (2 pixel increments, 25 positions)
  - Brightness (6 levels of intensity)

- Optimization was done for each detected face

- Errors with unidentified faces were ~4X greater than with Widrow's face

- 5 patterns per second through neural network

- Autoassociative neural network
  - 1800 neurons, 2500 weights per neuron, first layer
  - 1500 neurons, 1800 weights per neuron, second layer
  - 2500 neurons, 1500 weights per neuron, third layer
  - Total 5800 neurons, 10,950,000 weights

(a)

(b)

SENSING PATTERNS OBTAINED FROM WIDROW'S FACE WITH TWO WINDOW SIZES, (a) STRAIGHT UP, AND (b) ROTATED

FACE RECOGNITION VIDEO

COGNITIVE MEMORY DEMONSTRATION
FACE RECOGNITION

DETAILS OF THE LARGEST PATTERN RECOGNITION JOB PERFORMED SO FAR BY COGNITIVE MEMORY

- **Image Database**:

  The pictures were obtained from a collection of photographs distributed by NIST for the Face Recognition Grand Challenge (FRGC) version 1. From this collection of photographs we used the “controlled still images” for training and verification purposes.
- A set of photographs of 75 persons were selected from this set for training purposes.
- Another set of 300 photographs of persons NOT trained-in were selected for sensing purposes.
- Finally a set of 75 photographs of the persons trained-in were selected for sensing purposes (cross-correlation). It should be noted that these photographs were different from the photographs used for training.
- The total number of photographs were 75 for training and 375 for sensing.
- The autoassociative neural network that was trained and sensed had 3 layers distributed as follows:

  - 2000 neurons in the first layer

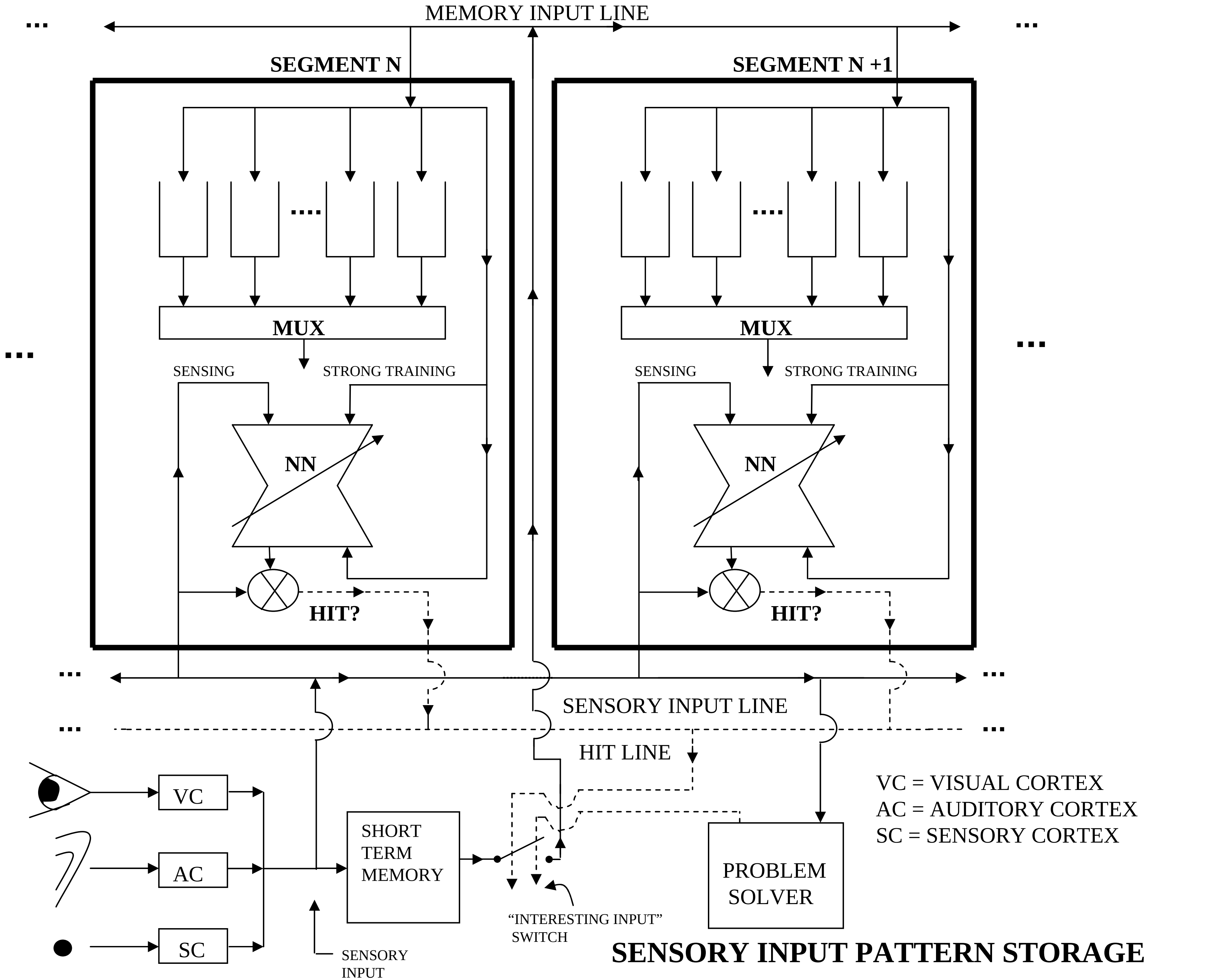
  - 1500 neurons in the second layer

  - 10000 neurons in he last layer (we used a big retina in this case)
- The amount of weights in the network was 38 million. The retina size was 100 by 100 in this case.
- The results were that the 75 people trained in were recognized and identified without error, while the 300 people not trained-in were rejected by the cognitive memory system.

A MODEL OF HUMAN MEMORY

SENSORY INPUT PATTERN STORAGE

- Sensory input patterns come from eyes, ears, tactile, olfactory, vestibular and other sensors.
- Incoming patterns are stored in empty folders, wherever they are located.
- Sequences of patterns, like videos are stored in the same folder.
- Visual, auditory, and other sensory patterns that were received at the same time are stored in the same folder.
- Only “interesting” input patterns are stored in the memory.They remain for the rest of one’s life. An eidetic stores everything, interesting or not.
- Sensory input patterns go to short term memory and, if interesting, are transferred to main memory and recorded for life.
- Short term memory (of the order of a few seconds) is used in the determination of what is interesting. The problem solver can also decide what is interesting.
- Autoassociative neural networks are used in the pattern retrieval process.
- Pattern retrieval occurs in response to prompt patterns.
- Prompt patterns may come from sensory inputs.
- The memory is organized in the form of independent segments to make possible a very large storage capacity.


MEMORY INPUT LINE
SEGMENT N
SEGMENT N +1
MUX
MUX
SENSING
STRONG TRAINING
SENSING
STRONG TRAINING
NN
NN
HIT?
HIT?
SENSORY INPUT LINE
HIT LINE
VC
AC
SC
SHORT TERM MEMORY
SENSORY INPUT
"INTERESTING INPUT" SWITCH
PROBLEM SOLVER
VC = VISUAL CORTEX
AC = AUDITORY CORTEX
SC = SENSORY CORTEX
SENSORY INPUT PATTERN STORAGE

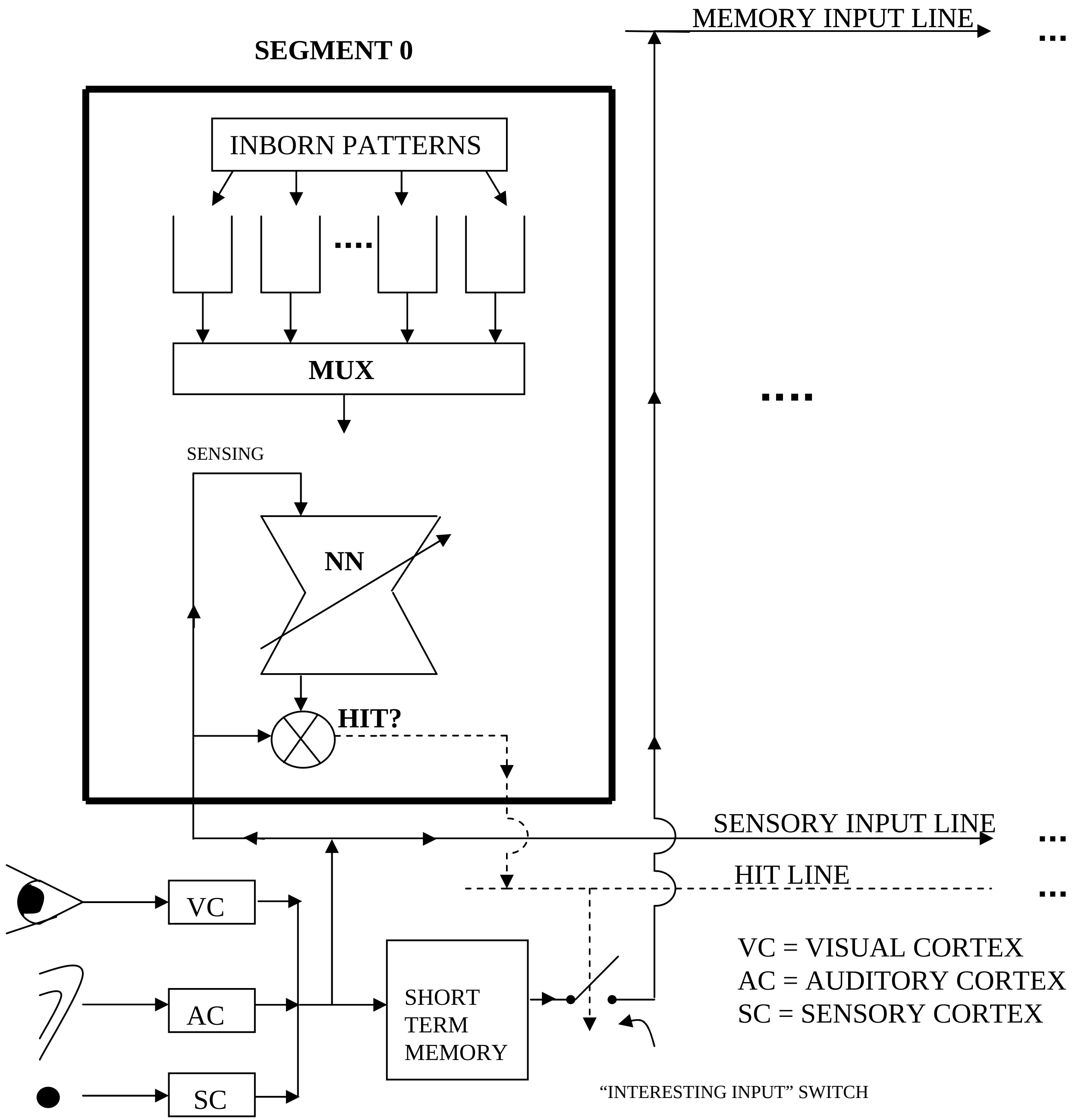
INBORN PATTERN STORAGE

- Inborn knowledge in the form of patterns is pre-loaded in the developing brain's memory and remains intact throughout one's lifetime.
- Examples of inborn knowledge :

  (a) A bird building a nest involves complex construction in "safe" places such as roof tops, tree tops,telephone poles, etc.

  (b) Baby horse walking and finding lunch within half hour of birth.

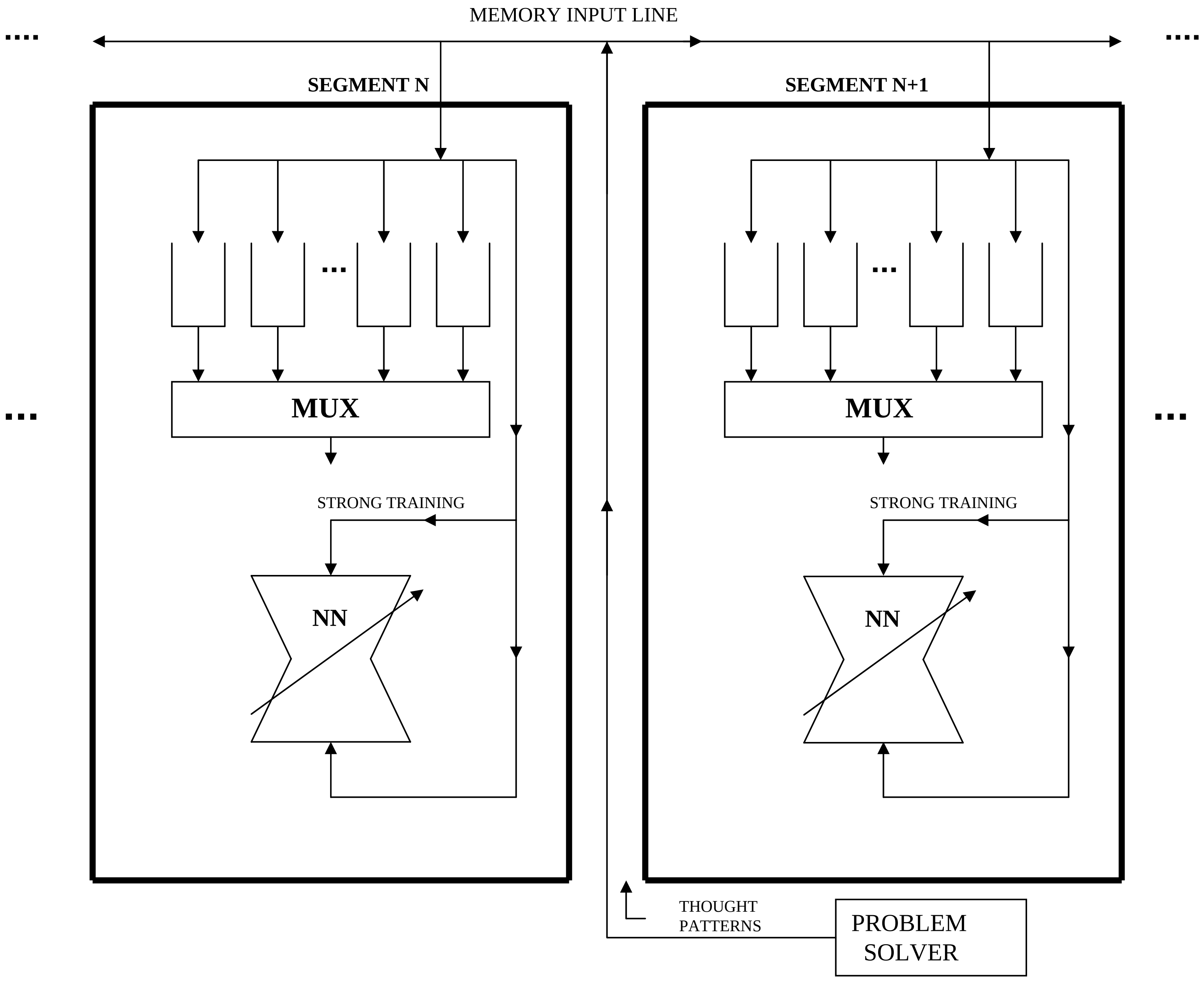
  (c) Human baby sucking, crying, peeing and pooping.
- It is conjectured that the memory storage means for inborn knowledge is the same as for sensory knowledge gained during a lifetime.
- It is conjectured that the memory retrieval means for inborn data is the same as for sensory input data.
- Inborn patterns are stored in folders in "memory segment 0".



INBORN PATTERN STORAGE

THOUGHT PATTERN STORAGE

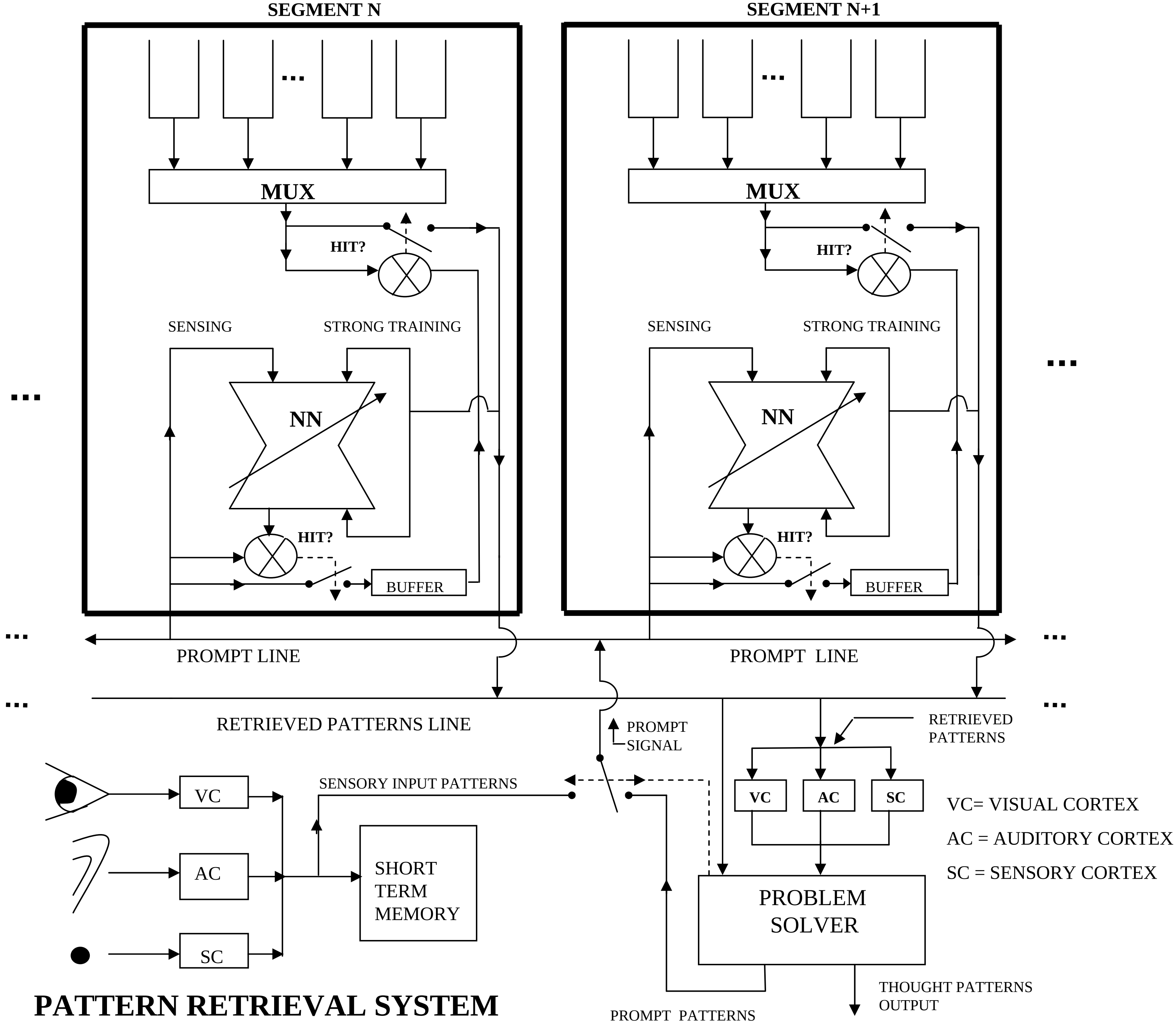
- Thought patterns are also stored in memory. Storage means and retrieval means for thought patterns are the same as for sensory input patterns.
- Thought patterns come from the “problem solver”.
- The design of the problem solver is not yet part of this study, but could be thought of as a mechanism based on Arthur Samuel’s checker player.
- Thought patterns are always interesting and stored in empty memory locations.
- Storage of thought patterns takes precedence over storage of sensory input patterns.



THOUGHT PATTERN STORAGE

PATTERN RETRIEVAL SYSTEM

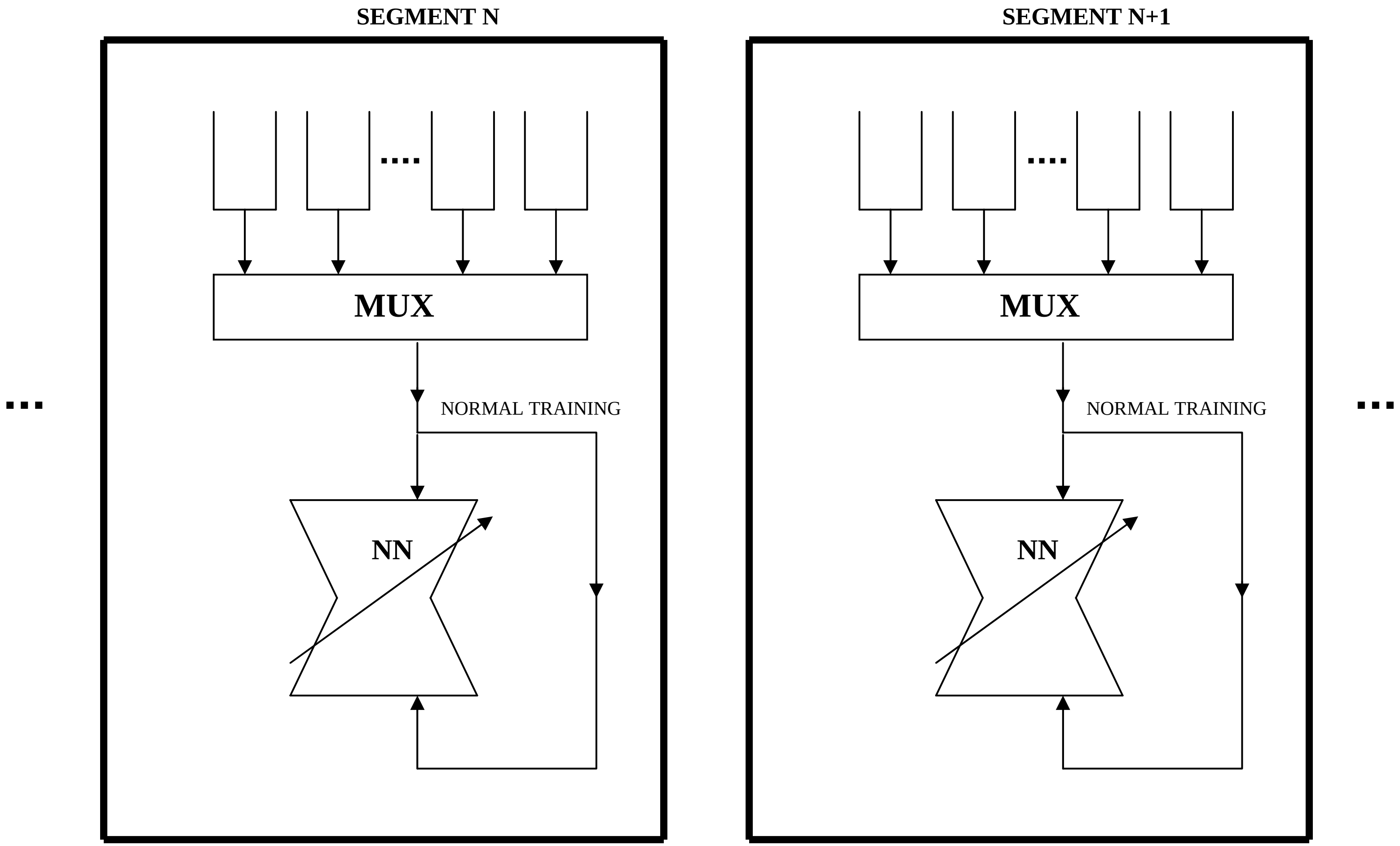
- Patterns stored in memory can be retrieved without knowledge of their storage location.
- Autoassociative neural networks are part of the retrieval mechanism.
- Autoassociative neural networks are trained by using their input patterns as both input and desired response patterns.They are trained to produce outputs that are reproductions of their inputs.
- Once trained, autoassociative networks produce small input/output differences when presented with patterns that were trained in, but large differences when presented with patterns that were not trained in. Déjà Vu ? Hit or no hit ?
- Autoassociative networks are trained with all the patterns stored in the connected memory folders.
- The autoassociative networks are prompted with sensory input patterns or thought patterns. Visual input patterns for example are rotated, translated, scaled, brightened, contrasted, etc. by the “visual cortex” VC while attempting to make a hit. If there is a hit, the hit pattern is saved and compared with the contents of all the connected memory folders.The patterns of the folder containing the hit pattern are retrieved and sent to the problem solver which is the memory output “customer”.
- These patterns in turn may be used as prompts to retrieve other folders.This type of feedback could cause a “chain reaction” resulting in the retrieval of many interrelated folders.(I have been speaking with someone for ten minutes but what is his name? Oh, now I remember. Its Jonathan Jones.)



PATTERN RETRIEVAL SYSTEM

TRAINING DURING NON-REM SLEEP

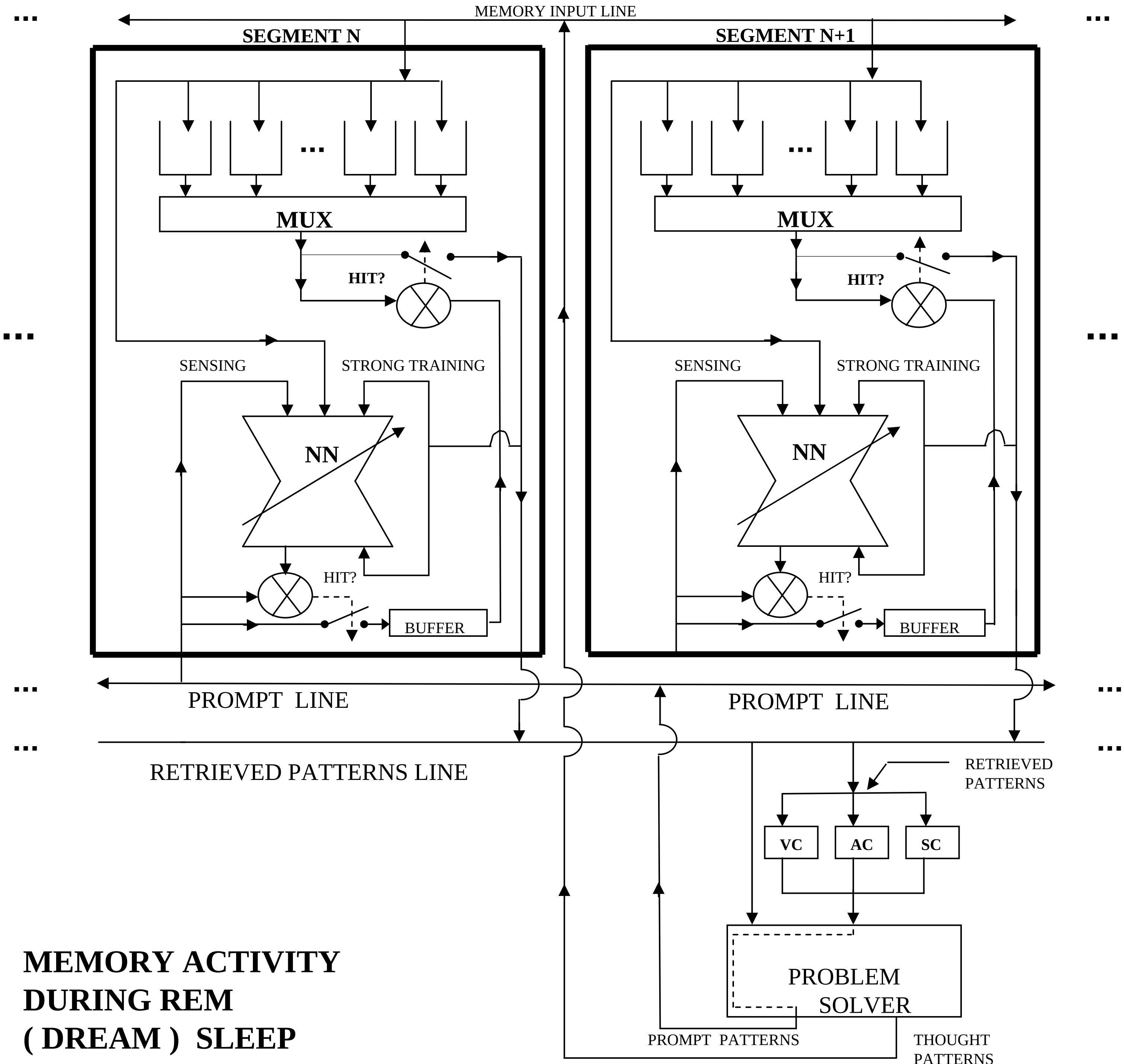
- It is speculated that the autoassociative neural networks are trained during non-REM sleep.
- Multiplexers sense the memory folders, sequentially feeding the pattern contents to the autoassociative networks for training.
- The training process initiates automatically once the brain is in “sleep mode”. This continues throughout the night during periods of non-REM sleep.



TRAINING DURING NON-REM SLEEP

MEMORY ACTIVITY DURING REM SLEEP

- Every 90 minutes or so during the night, the brain goes into “REM mode”. Each episode of REM lasts for about 20 - 30 minutes, increasing as the night progresses.
- It is generally believed that during REM (Rapid Eye Movement) sleep, the person is dreaming.
- The body is paralyzed during REM sleep, probably to prevent the person from acting out the dream.
- During REM, contents are pulled from memory prompted by thought patterns from the problem solver. Memory contents provide further prompts to retrieve further related contents. This is a “chain reaction”. The retrieved memory contents are available to the problem solver.
- The memory contents are juxtaposed and intermingled in strange ways, creating fantasies that are dreams.The dreams themselves are stored in new memory locations.
- During REM, the autoassociative neural networks are trained hard when dream patterns are stored and when patterns are drawn from the memory folders. These networks are both sensed and trained during REM.
- Brain activity during REM is similar to that of wide-awake consciousness, according to EEG and FMRI. The difference is that during REM, the sensory inputs from the eyes, ears,etc are shut off.



MEMORY ACTIVITY DURING REM (DREAM) SLEEP

SPECULATION ON THE REM STATE

- It is speculated that the purpose of REM sleep is **problem solving**.Uninhibited thought can be highly creative.
- During a night's sleep, episodes of REM take place about every 90 minutes or so. Upon awaking one is generally unaware of having dreamt unless waking in the middle of a dream. To retrieve an unaware dream from memory, one needs an appropriate prompt.This is the function of psychoanalysis.
- It is speculated that schizophrenia is an abnormal condition under which the subject is awake and conscious and in REM sleep at the same time, with fantasized images superposed on top of real-time visual, auditory, etc. inputs.This is hallucination. The fantasized images are drawn from memory spontaneously, without prompting.
- Under hypnosis, a normal subject is awake and conscious and in REM sleep at the same time, a state induced by the hypnotist. The subject responds to visual and auditory inputs from the hypnotist that serve as prompts. The hypnotist can have a two way interaction with the subject, and can store and retrieve information in and from the subject's memory.

SPECULATION ABOUT SEEING, HEARING, WALKING, SPEAKING, ETC.

- Seeing involves processing and recording new visual images and making associations with pre-recorded images stored in memory. Vision and memory are intertwined.
- Hearing and understanding speech involves processing and recording new auditory images and making associations with pre-recorded auditory images stored in memory. Hearing and speech understanding and memory are intertwined.
- While walking, sensory signals from all over the body deliver to the brain information about the mechanical state of the body. These sensory signals acts as prompts to the memory that, in turn, provides muscle control signals that enable walking. This works like a lookup table. Muscle control signals are not computed in real time but are pulled from memory. Control planning is also pulled from memory.
- While speaking, muscle control of the vocal tract is pulled from memory in response to prompts. The brain does not compute these control signals in real time.

SPECULATION ABOUT FEATURE DETECTION

- Hubel and Wiesel's discovery of cat cortical cells that respond to vertical and horizontal lines suggest importance of feature detection.
- Julesz's work with random dot stereograms and experiments with an eidetic subject suggest that the visual process involves the total image in full detail (not just features) and that pattern association is critical.

SPECULATION ABOUT LEARNING

- Learning involves storing patterns in memory.
- Supervised learning, unsupervised learning, learning with a critic, bayesian learning are all useful concepts but probably have little to do with human learning.

SPECULATION ABOUT MEMORY FAILURE

- Ageing causes slow death of neurons and the dendritic tree, with insufficient rate of replacement. This affects memory retrieval as it becomes more difficult to continue training the brain’s neural networks. Old data and newly recorded data gradually become inaccessible. Old data lasts the longest.
- Alzheimer’s disease with associated plaques and tangles in the neurons and dendritic tree has the effect of accelerated ageing of these brain structures, makes neural training more difficult, gradually becoming impossible, thereby making old and new memories but especially new memories more and more inaccessible.
- Brain injury like in the movie ‘Memento’ cuts the link to the “memory input line” and prevents the formation of new memories. Short-term memory still works. Recall of old memories still works, and neural training still works.
- The eidetic memory stores everything : stuck switch.

SPECULATION ABOUT THE MECHANISMS OF STORAGE AND RETRIEVAL

- At the moment of conception, DNA is taken from the mother and father to form a new cell. That is the start of a new living animal.
- The DNA of the new cell contains the information (the “blue print”) needed to construct the living animal.
- The DNA contains the information to construct the body, the internal organs, including the brain. The DNA also contains the inborn information that will be pre-loaded in the developing brain.
- Inborn information is stored in DNA.
- The mechanism for storage and retrieval of the information gained during a lifetime is the same as that for storage and retrieval of inborn information.

WILD GUESSES:

- All information stored in memory is stored in DNA. The DNA that stores this information may be located in the glial cells of the brain.
- Stored information is not stored in the neurons and dendritic tree.The neurons and the dendritic tree play a key role in association and retrieval of stored information.