Illustrations for "Sparse Distribute Memory and Related Models."
Copyright © 1993 and 2002 by Pentti Kanerva <pkanerva@rni.org>
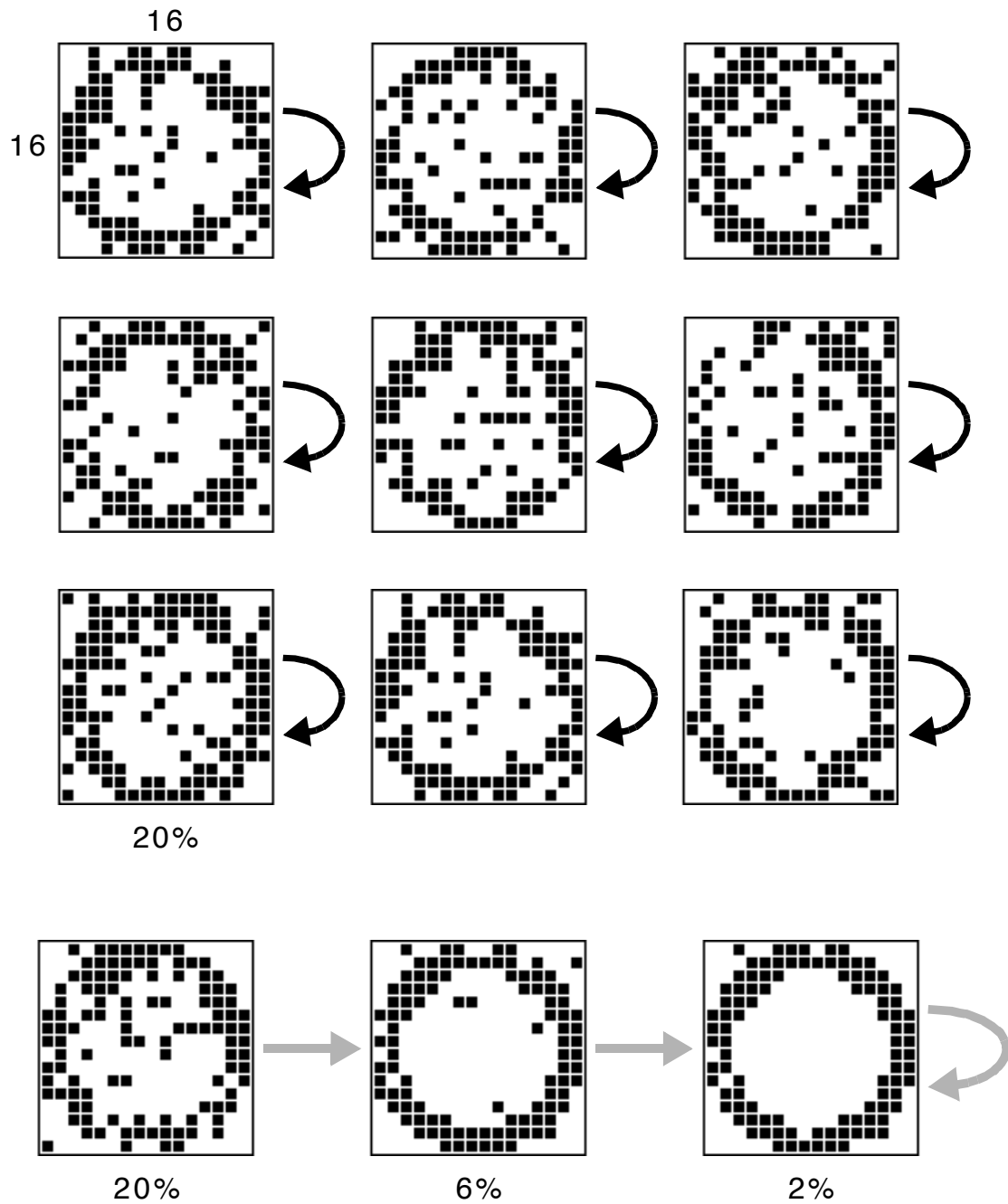.

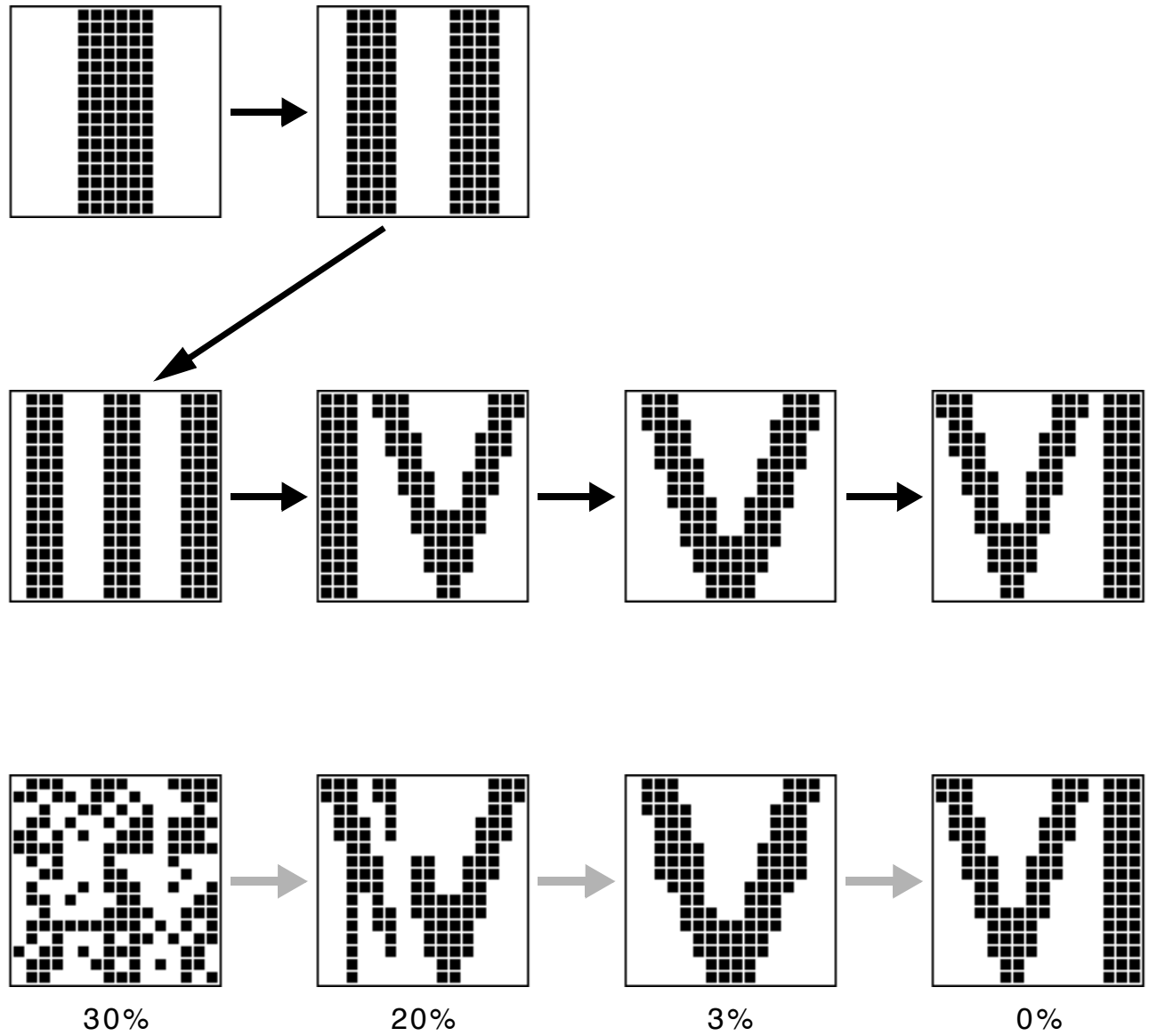**Figure 3.1.** Nine noisy words (20% noise) are stored, and the tenth is used as a retrieval cue.

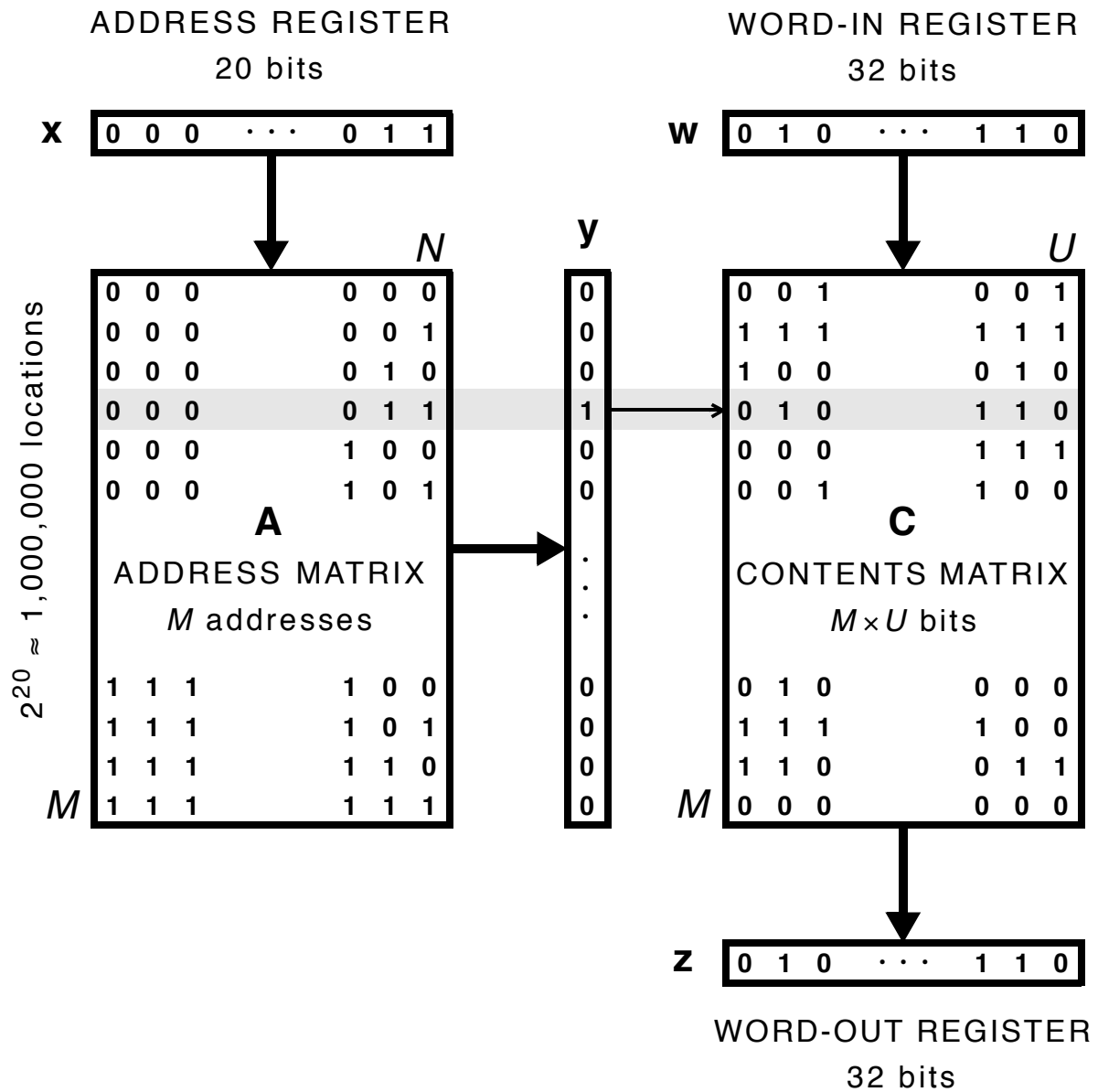**Figure 3.2.** Recalling a stored sequence with a noisy (30% noise) retrieval cue.

ADDRESS REGISTER
20 bits

WORD-IN REGISTER
32 bits

x | 0 0 0 · · · 0 1 1 |

w | 0 1 0 · · · 1 1 0 |

$2^{20} \approx 1,000,000$ locations

N

y

U

```
0 0 0        0 0 0       0        0 0 1        0 0 1
0 0 0        0 0 1       0        1 1 1        1 1 1
0 0 0        0 1 0       0        1 0 0        0 1 0
0 0 0        0 1 1       1        0 1 0        1 1 0
0 0 0        1 0 0       0        0 0 0        1 1 1
0 0 0        1 0 1       0        0 0 1        1 0 0
```

A

ADDRESS MATRIX

M addresses

C

CONTENTS MATRIX

$M \times U$ bits

```
1 1 1        1 0 0       0        0 1 0        0 0 0
1 1 1        1 0 1       0        1 1 1        1 0 0
1 1 1        1 1 0       0        1 1 0        0 1 1
M 1 1 1      1 1 1       0     M  0 0 0        0 0 0
```

z | 0 1 0 · · · 1 1 0 |

WORD-OUT REGISTER
32 bits

Figure 3.3. Organization of a random-access memory. The selected memory location is shown by shading.

ADDRESS REGISTER
1,000 bits

WORD-IN REGISTER
1,000 bits

x | 1 0 0 · · · 1 0 1

w | 0 1 0 · · · 1 1 0

d

y

N

0 1 0	1 0 1
1 0 1	0 0 1
0 1 0	0 1 1
0 0 0	1 0 1
1 1 1	0 0 1
0 0 0	1 1 0

A

ADDRESS MATRIX
M hard addresses

1 1 1	0 0 0
1 0 0	1 0 0
1 0 0	0 1 0
M | 0 1 1 | 0 1 1 |

1,000,000 hard locations

d

| 501 |
| 444 |
| 550 |
| 447 |
| 493 |
| 531 |
| . |
| . |
| . |
| 480 |
| 446 |
| 512 |
| 498 |

y

| 0 |
| 1 |
| 0 |
| 1 |
| 0 |
| 0 |
| . |
| . |
| . |
| 0 |
| 1 |
| 0 |
| 0 |

U

0 2 –2	4 0 0
–1 –1 –1	1 3 –1
1 1 –3	–1 1 1
–2 4 2	0 2 0
–1 1 1	–3 –1 –1
2 0 –4	0 2 0

C

CONTENTS MATRIX
$M \times U$ counters

1 3 –1	3 –3 5
–1 1 –1	1 1 –1
2 0 –4	0 6 –4
M | 0 0 0 | 0 0 0 |

Hamming distances

Activations ($d \leq 447$)

s | –445 379 –201 · · · 77 611 –517

Sums

z | 0 1 0 · · · 1 1 0

WORD-OUT REGISTER
1,000 bit s

Figure 3.4. Organization of a sparse distributed memory. The first selected memory location is
shown by shading.
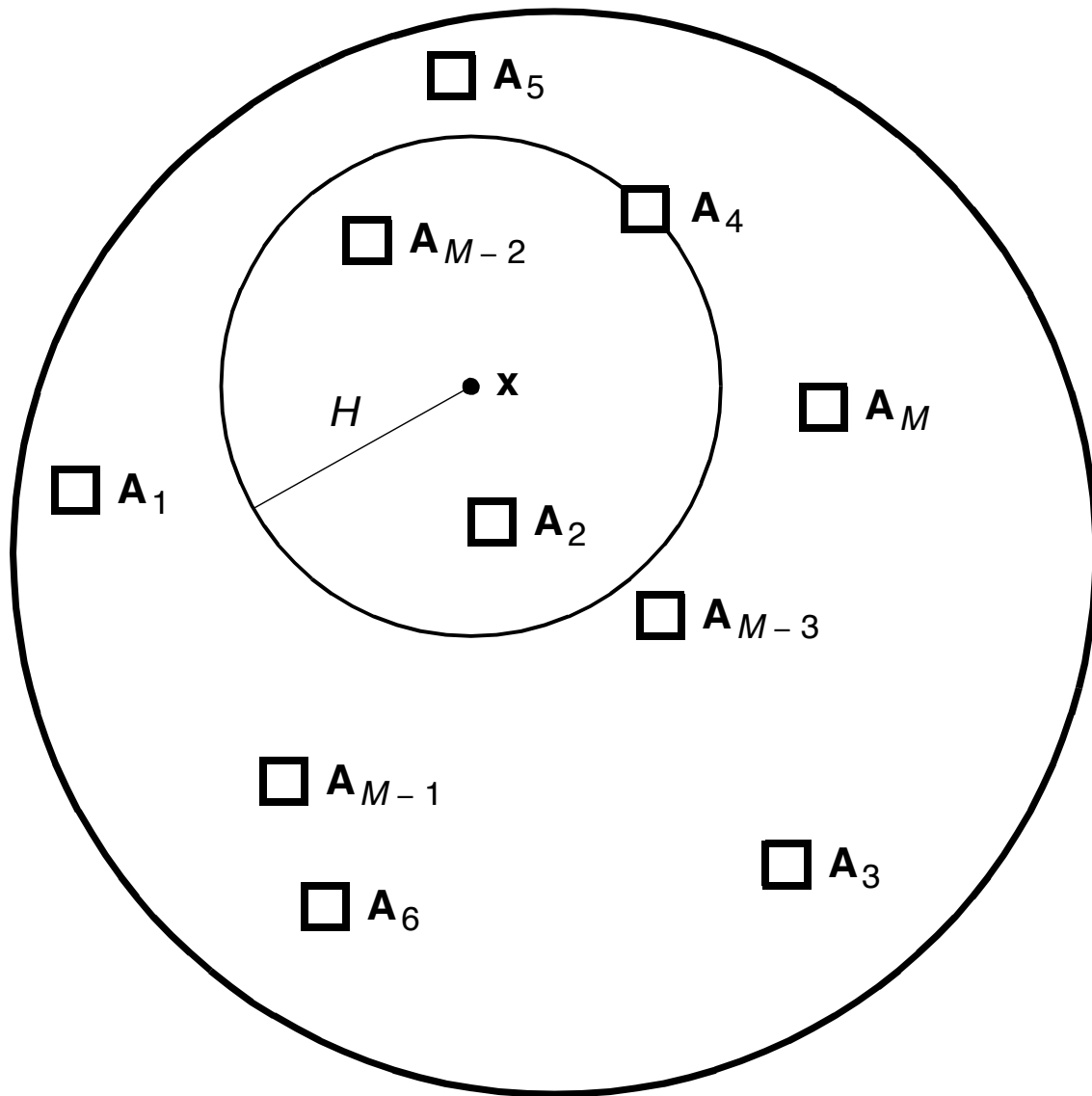
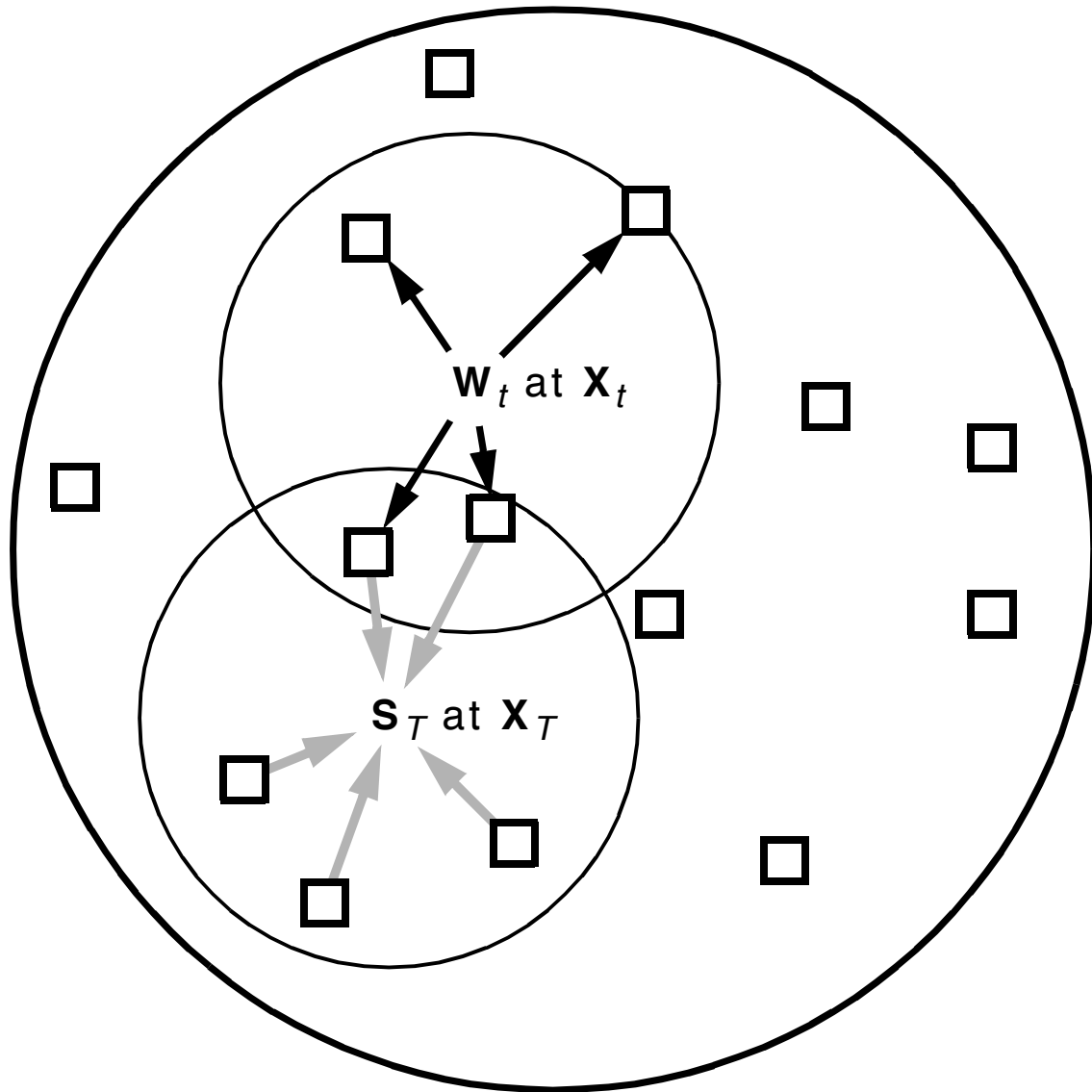**Figure 3.5.** Address space, hard locations, and the set activated by **x**. *H* is the (Hamming) radius of activation.

Figure 3.6. Activation overlaps as weights for stored words. When reading at $\mathbf{X}_T$, the sum $\mathbf{S}_T$ includes one copy of the word $\mathbf{W}_t$ from each hard location in the activation overlap (two copies in the figure).
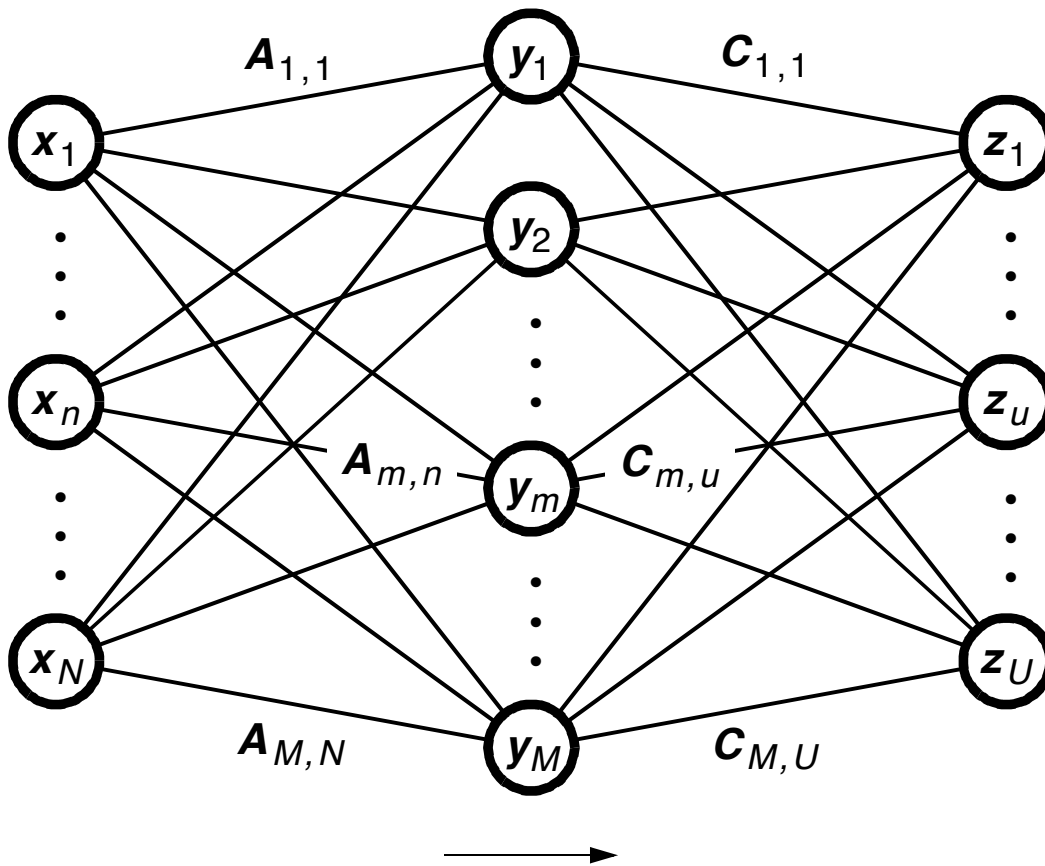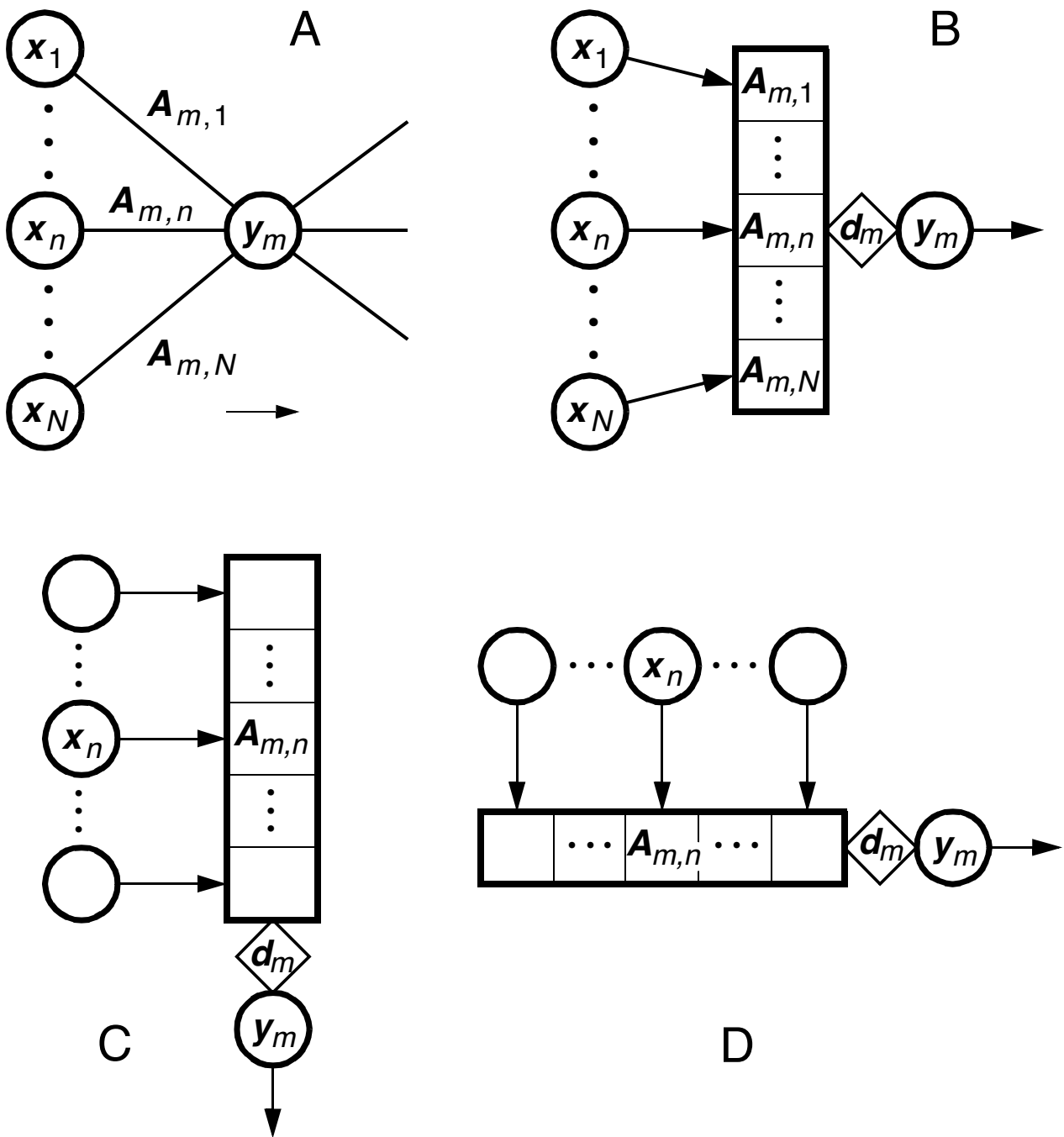
Figure 3.7. Feed-forward artificial neural network.
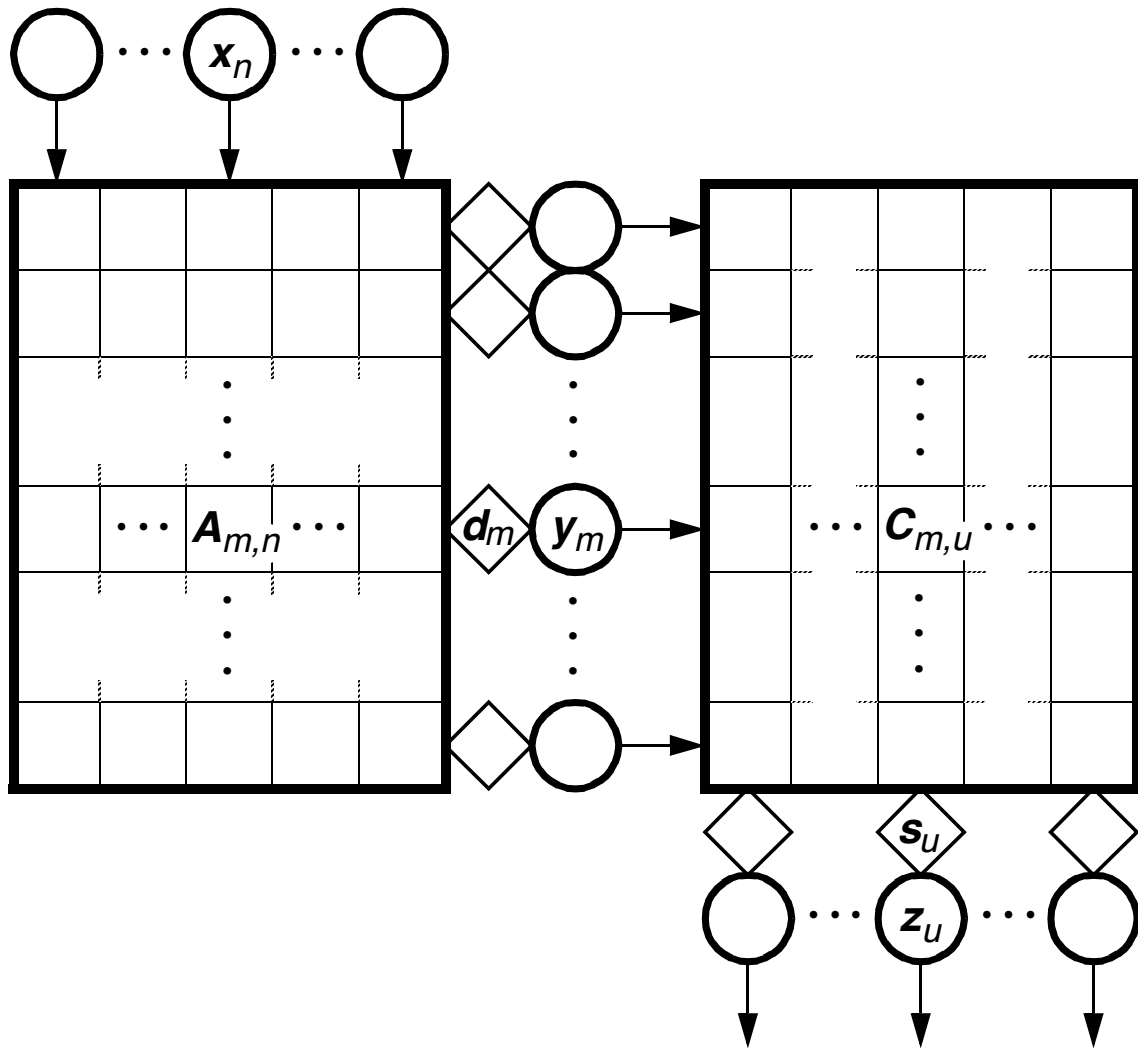
Figure 3.8. Four views of an artificial neuron.

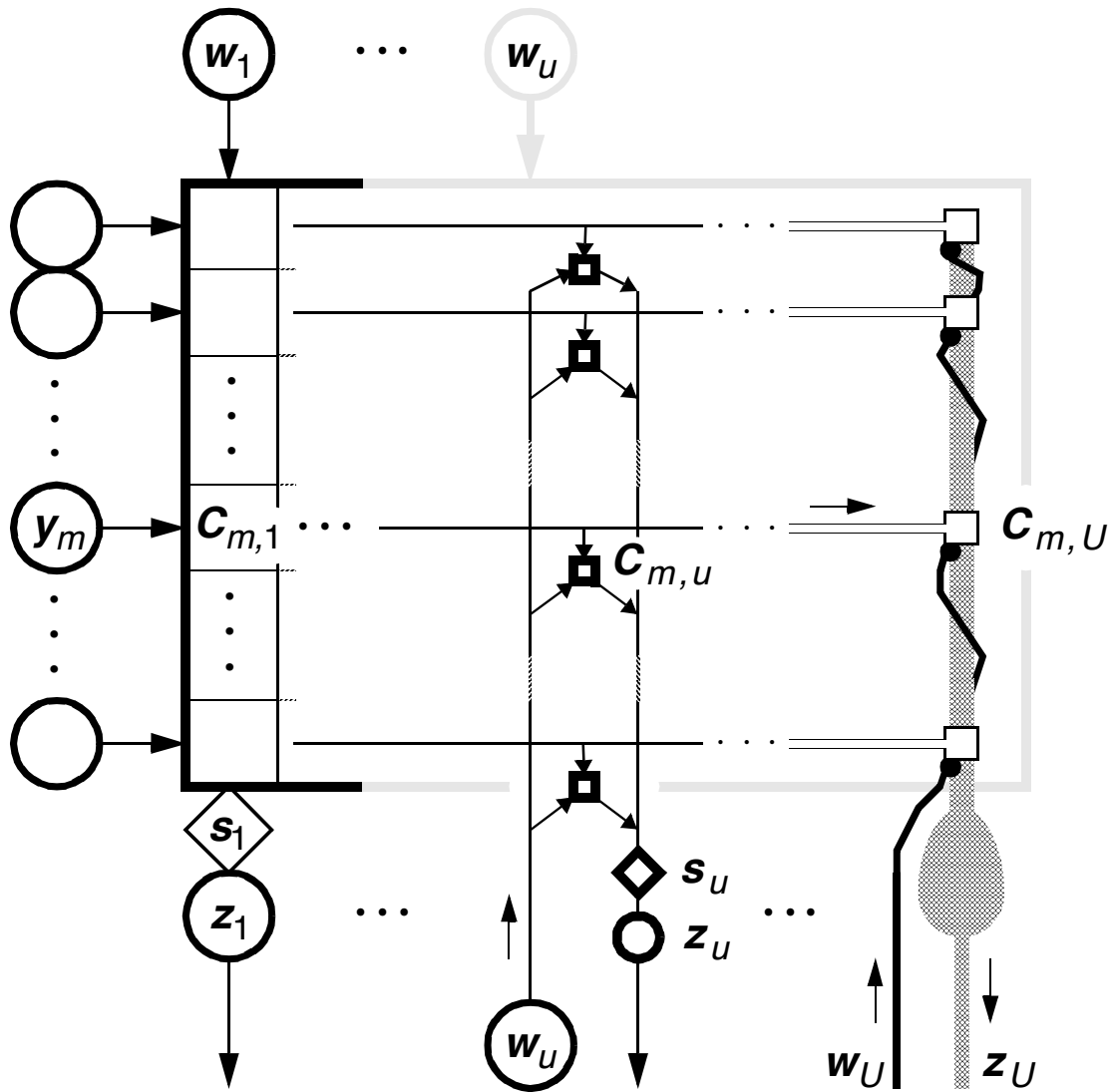**Figure 3.9.** Sparse distributed memory as an artificial neural network (Fig. 3.7 redrawn in the style of Fig. 3.4).

Figure 3.10. Connections to an output neuron. Three output units are shown. The first unit is drawn as a column through the contents matrix $\mathbf{C}$, the middle unit shows the connections explicitly, and the last unit corresponds to Figure 3.11.
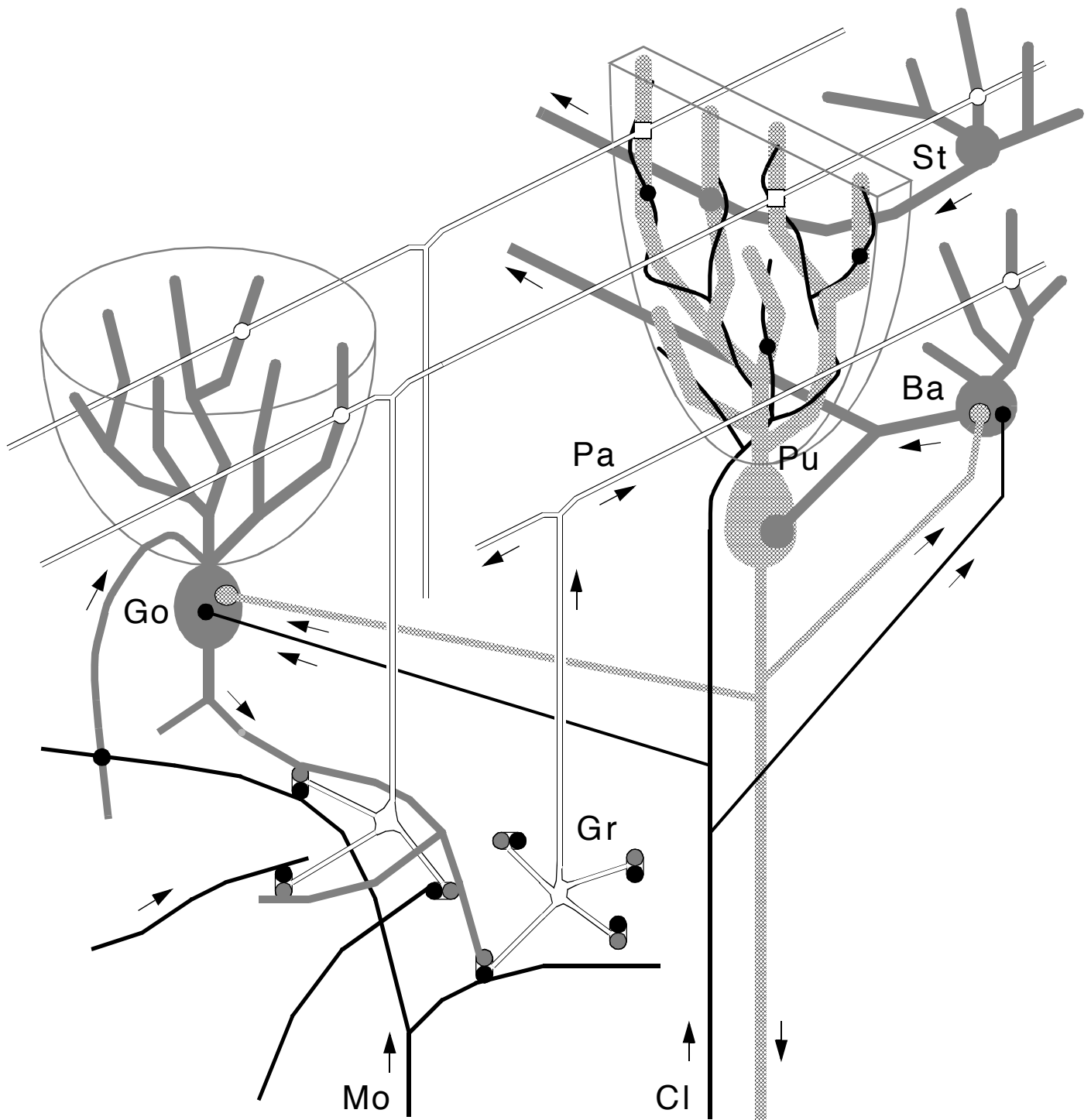
Figure 3.11. Sketch of the cortex of the cerebellum. Ba = basket cell, Cl = climbing fiber (black), Go = Golgi cell, Gr = granule cell, Mo = mossy fiber (black), Pa = Parallel fiber, Pu = Purkinje cell (cross-hatched), St = stellate cell. Synapses are shown with small circles and squares of the axon's "color." Excitatory synapses are black or white, inhibitory synapses are cross-hatched or gray.
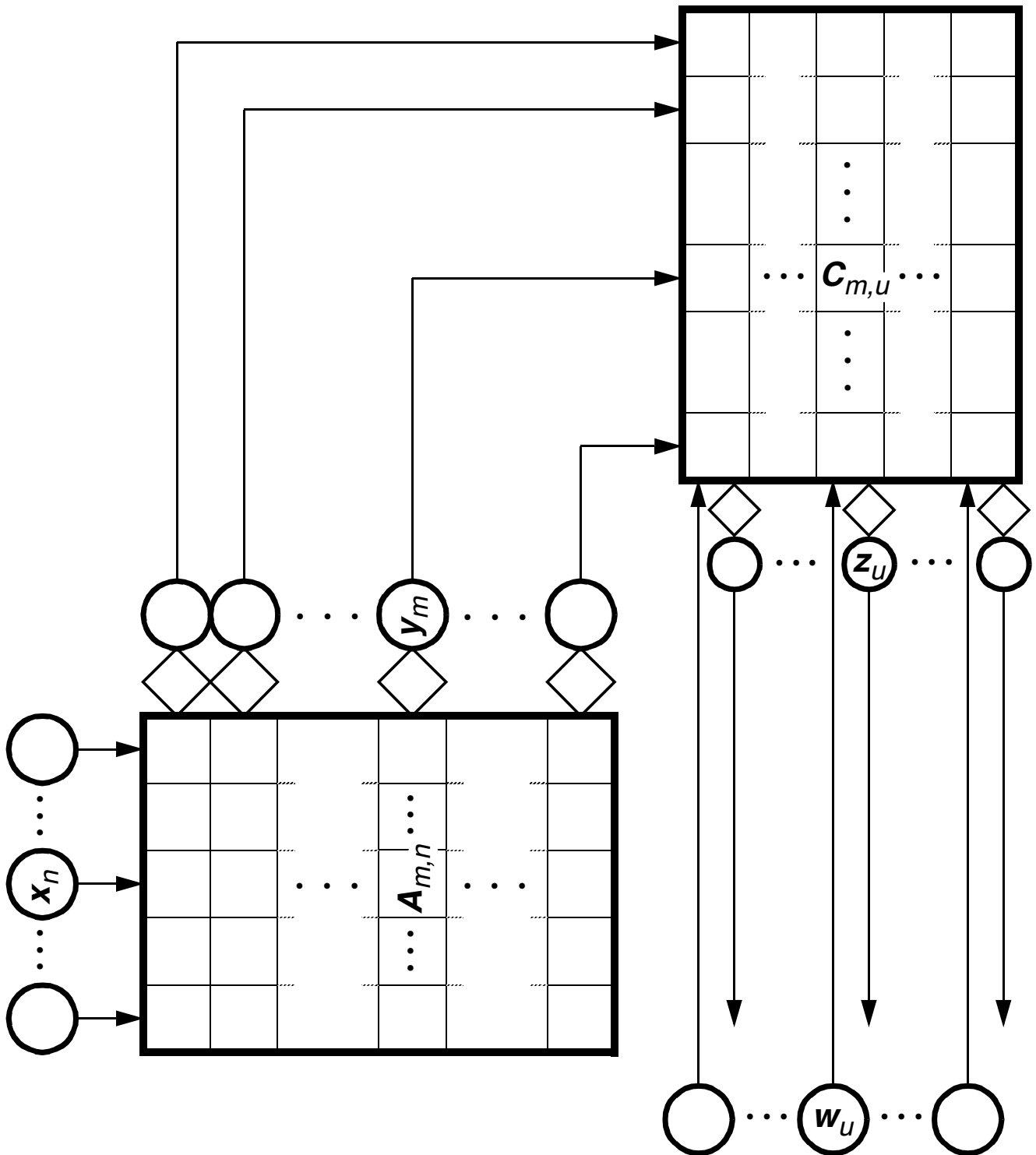
Figure 3.12. Sparse distributed memory's resemblance to the cerebellum (Fig. 3.9 redrawn in the style of Fig. 3.11; see also Fig. 3.10).