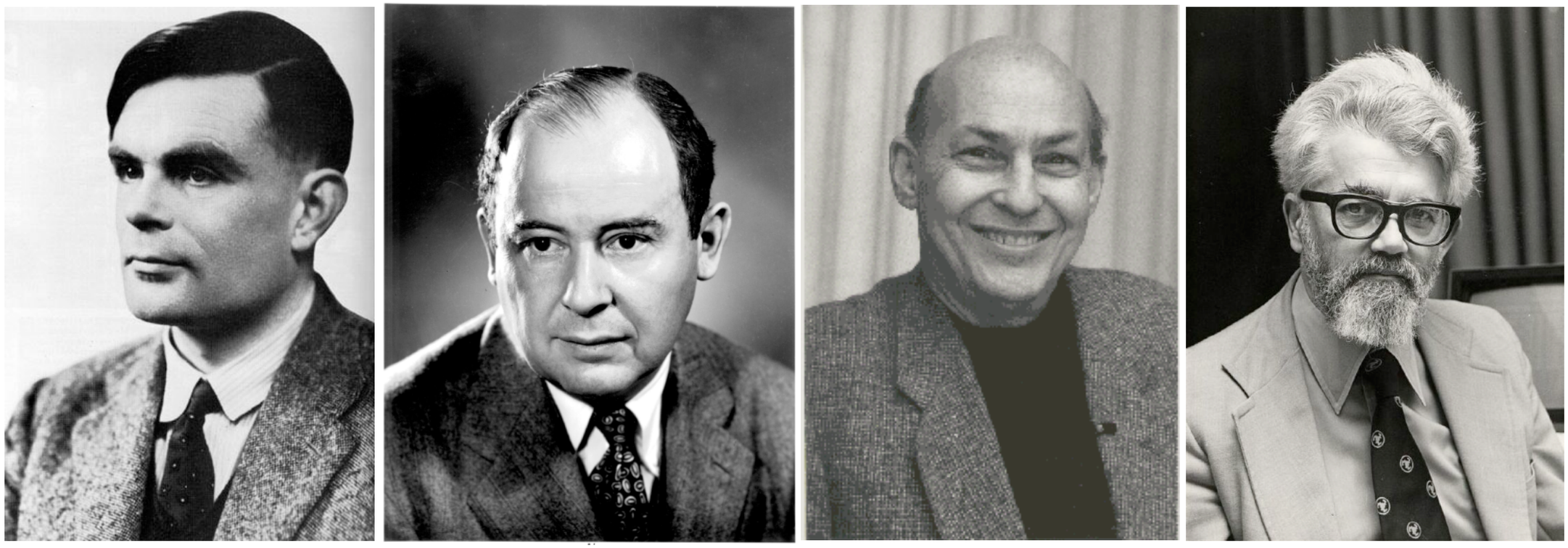
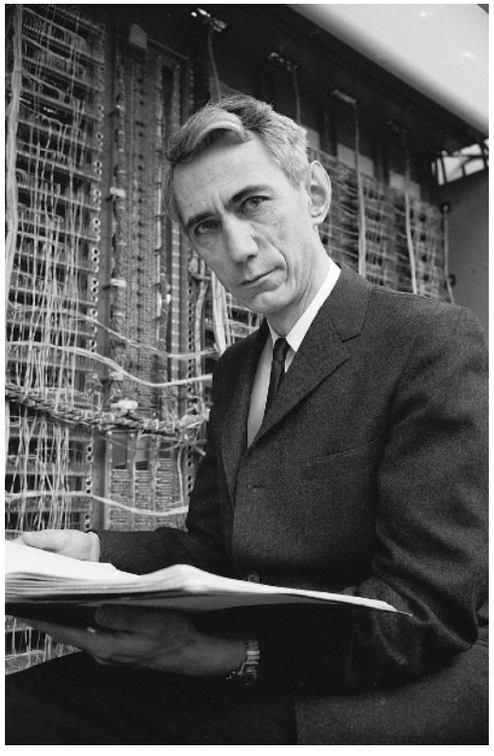
Artificial Intelligence



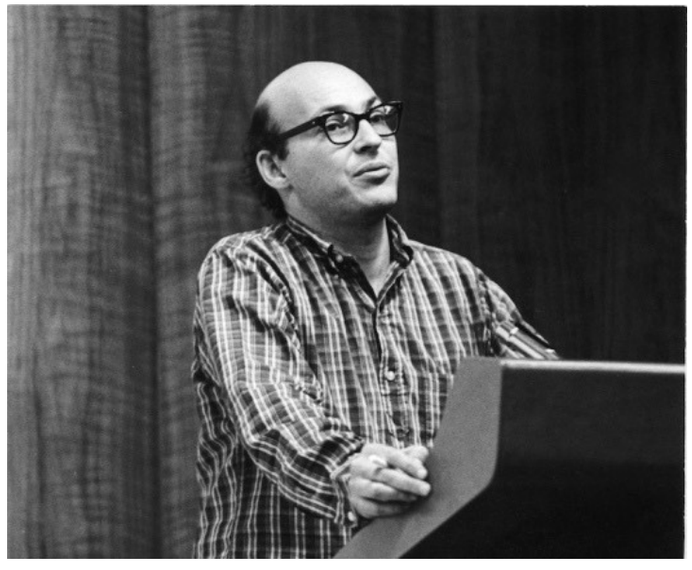
Alan Turing | John von Neumann | Marvin Minsky | John McCarthy

Among the most challenging scientific questions of our time are the corresponding analytic and synthetic problems: How does the brain function? Can we design a machine which will simulate a brain?
-- *Automata Studies*, 1956



I confidently expect that within a matter of 10 or 15 years, something will emerge from the laboratory which is not too far from the robot of science fiction fame.
— Claude Shannon, 1961

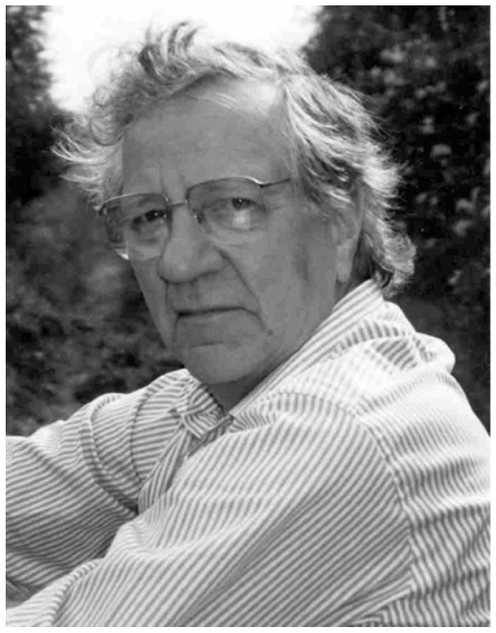
Machines will be capable, within twenty years, of doing any work that a man can do.
— Herbert Simon, 1965



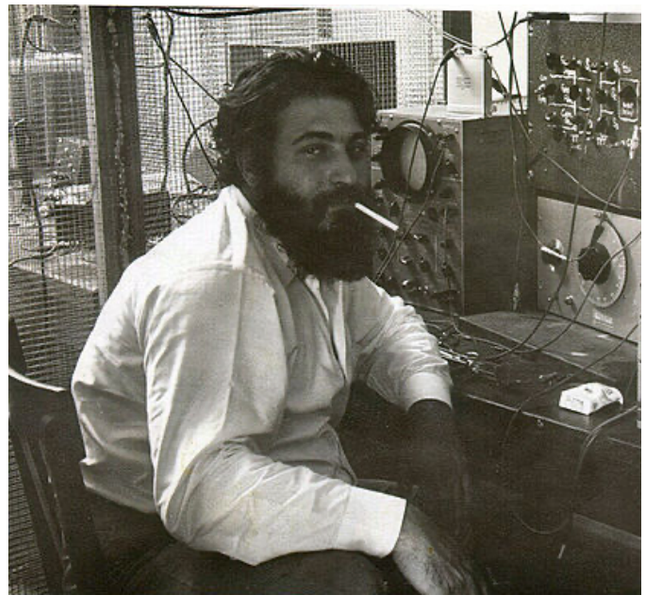
Within a generation...the problem of creating ‘artificial intelligence’ will be substantially solved.
— Marvin Minsky, 1967

Neuroscience

Stephen Kuffler



Horace Barlow



Jerome Lettvin

David Hubel &
Torsten Wiesel

Perception, 1972, volume 1, pages 371 - 394

67

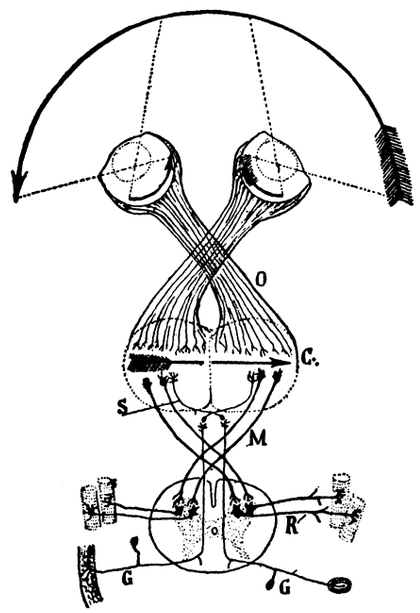
Single units and sensation: A neuron doctrine for perceptual psychology?

H B Barlow
Department of Physiology-Anatomy, University of California, Berkeley, California 94720
Received 6 December 1972

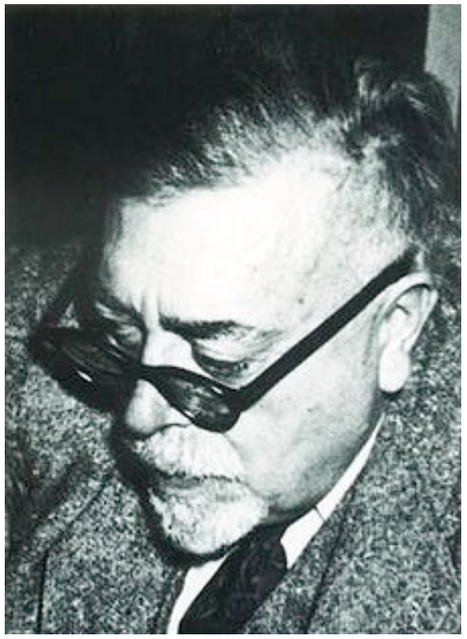
PROCEEDINGS OF THE IRE November

What the Frog's Eye Tells the Frog's Brain*

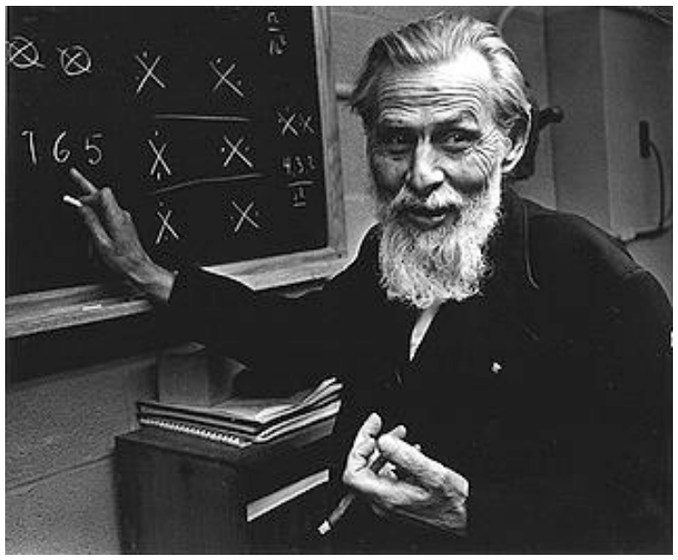
J. Y. LETTVIN†, H. R. MATURANA‡, W. S. McCULLOCH||, SENIOR MEMBER, IRE,
AND W. H. PITTS||



Cybernetics/neural networks

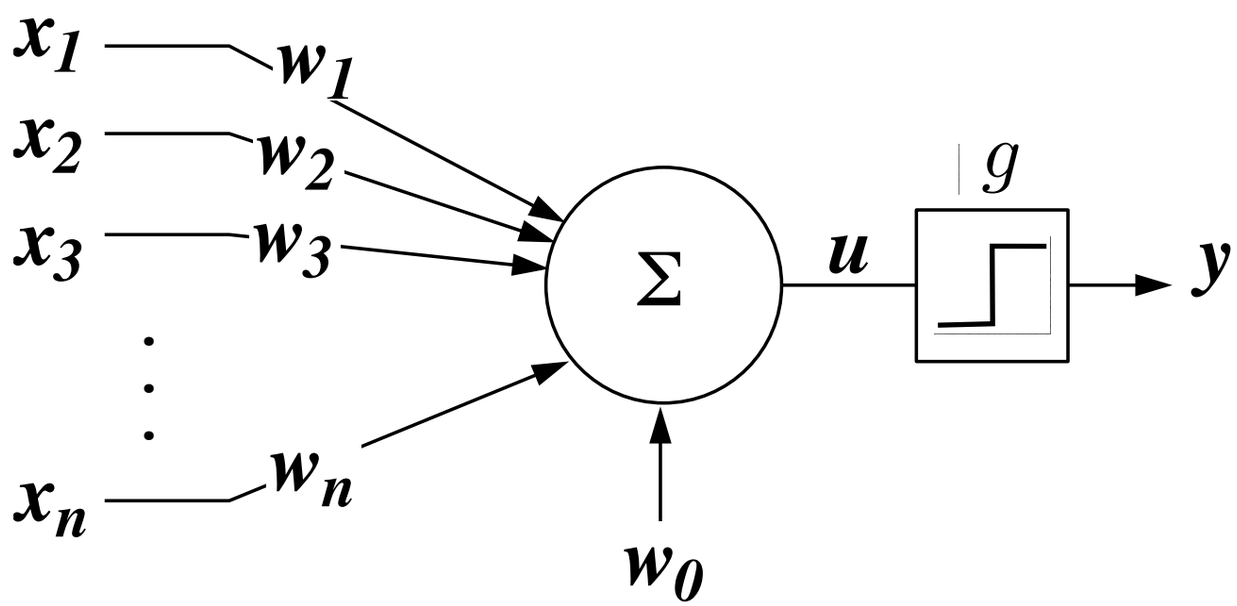


Norbert Wiener

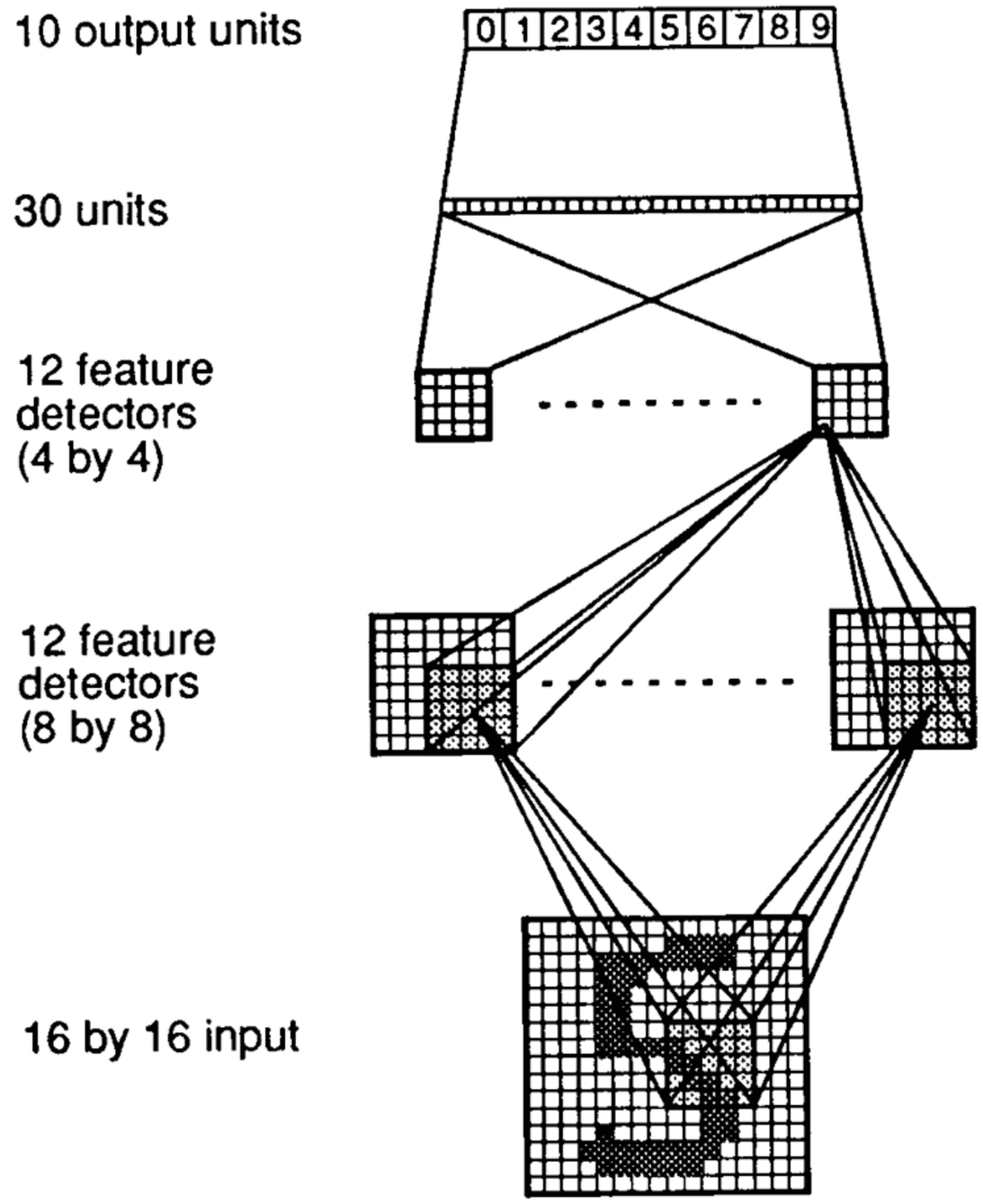


Warren McCulloch & Walter Pitts

Frank Rosenblatt



“LeNet”
(Yann LeCun et al., 1989)



‘Deep learning’
(Hinton, Ng, Bengio, Lecun, Google brain, etc.)

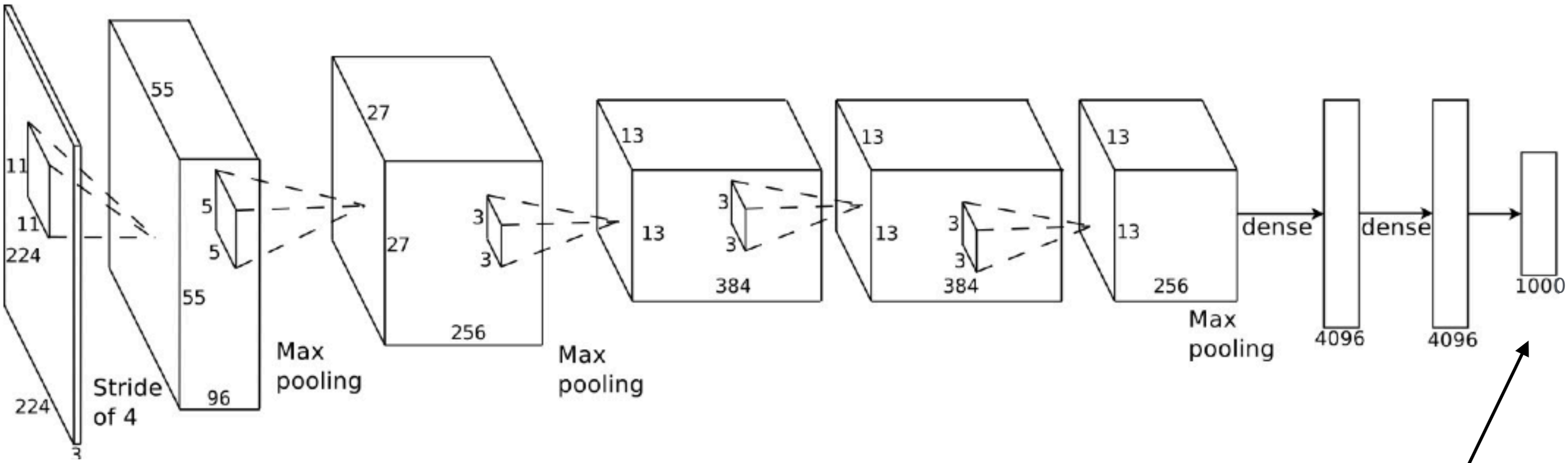
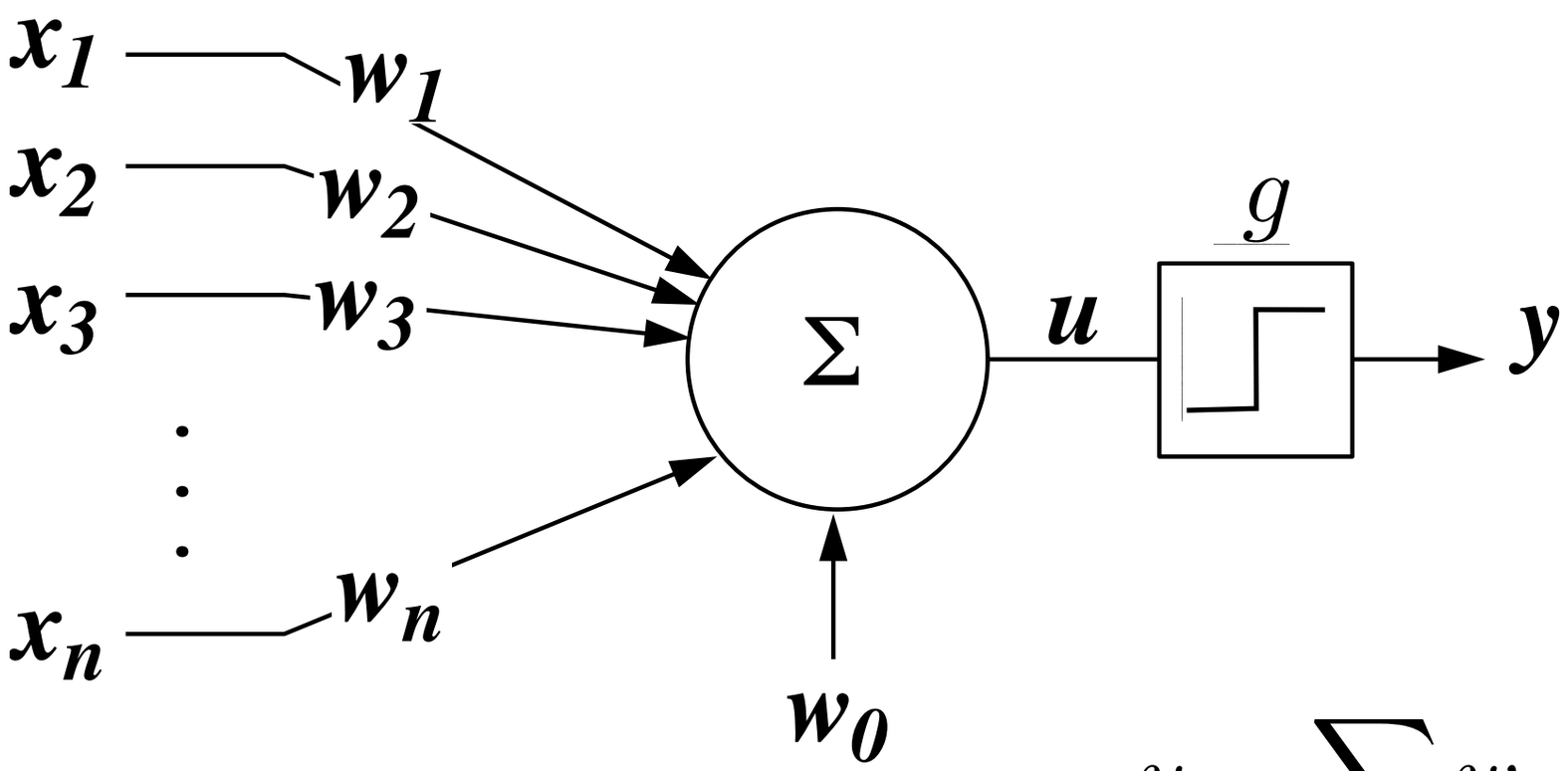


image feature extraction and pooling classification

A brief history of neural networks

1960's

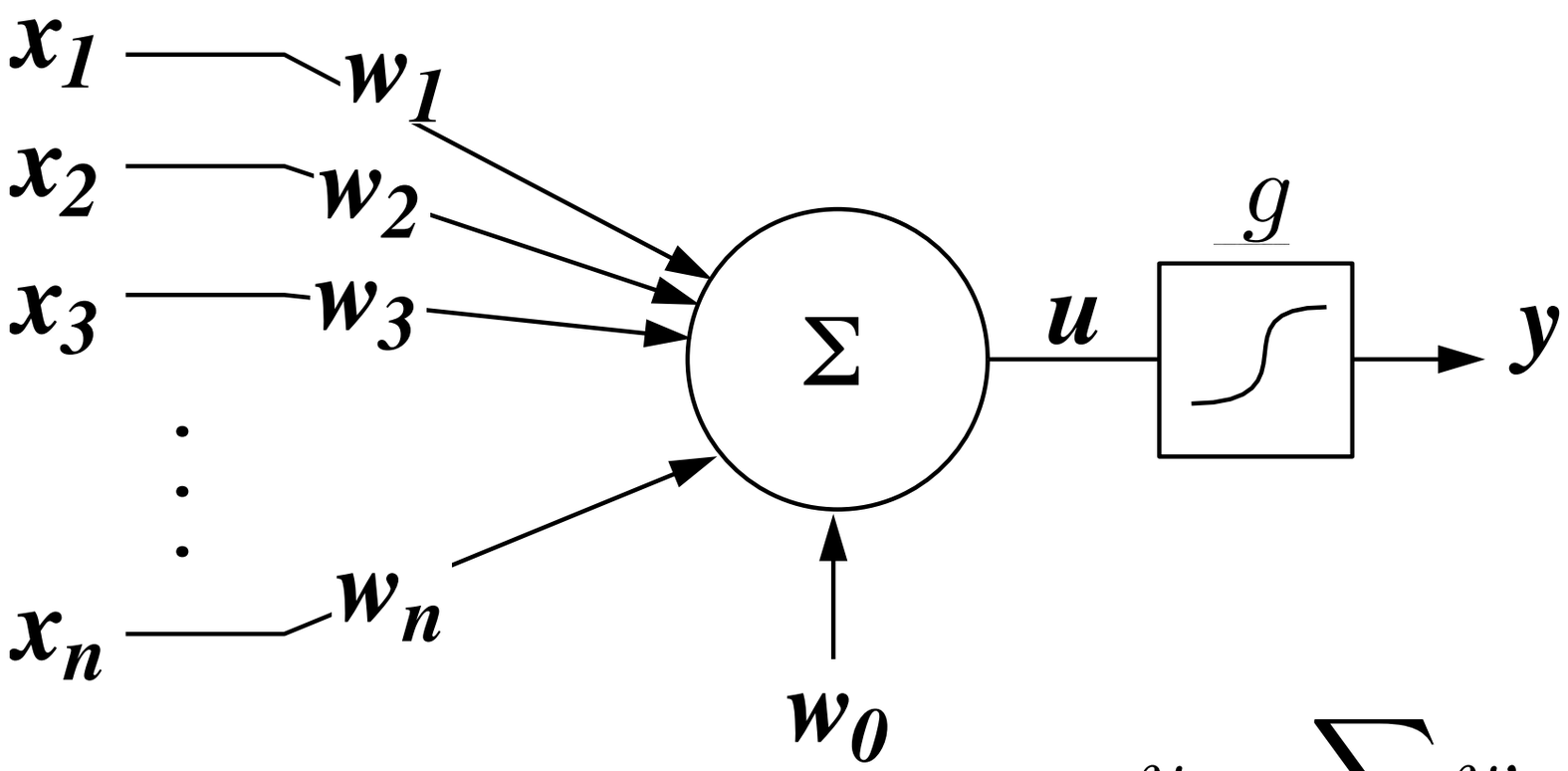


$$u = \sum_i w_i \, x_i$$

$$y = g(u)$$

A brief history of neural networks

1980's

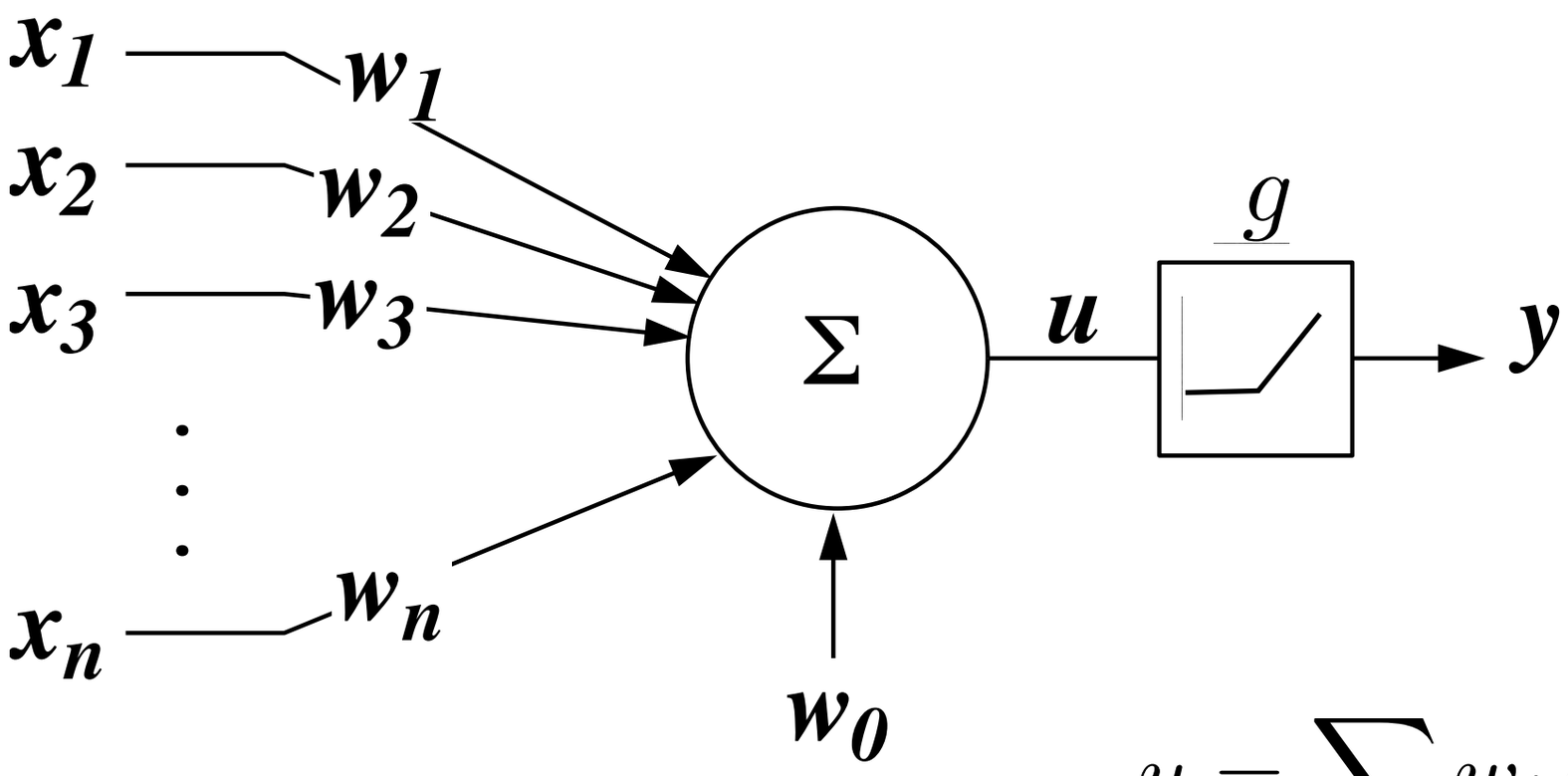


$$u = \sum_i w_i \, x_i$$

$$y = g(u)$$

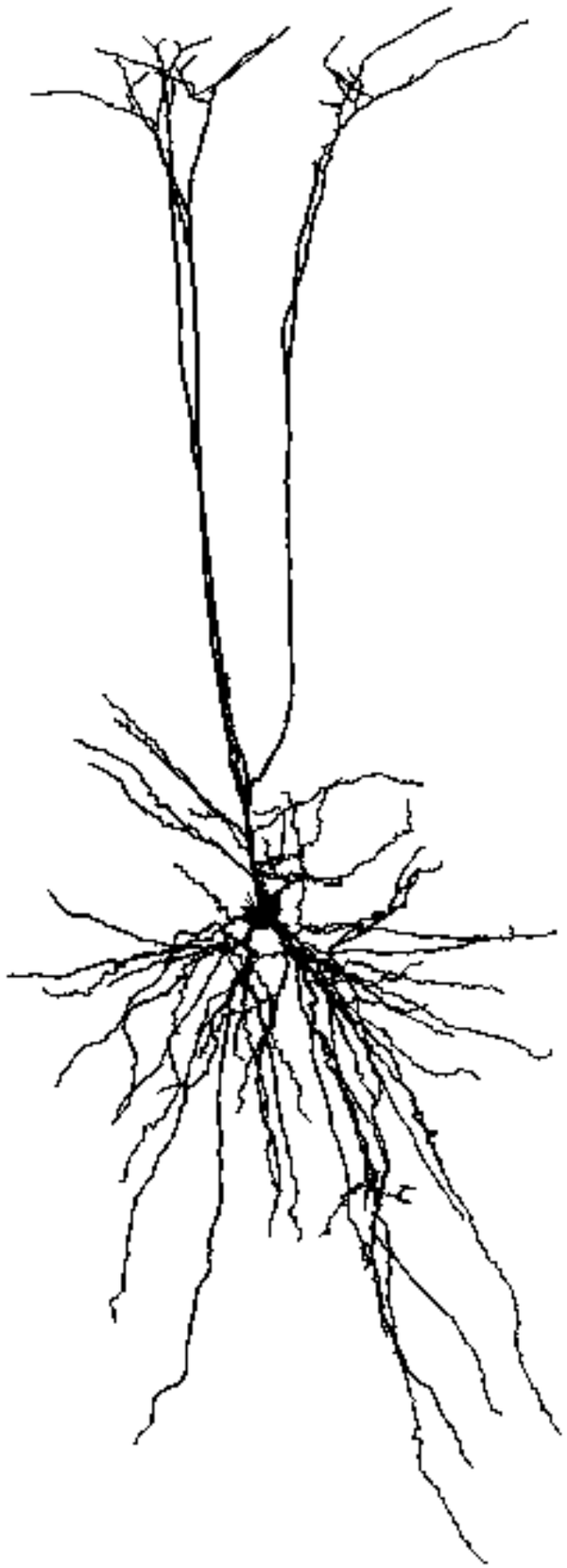
A brief history of neural networks

2000's



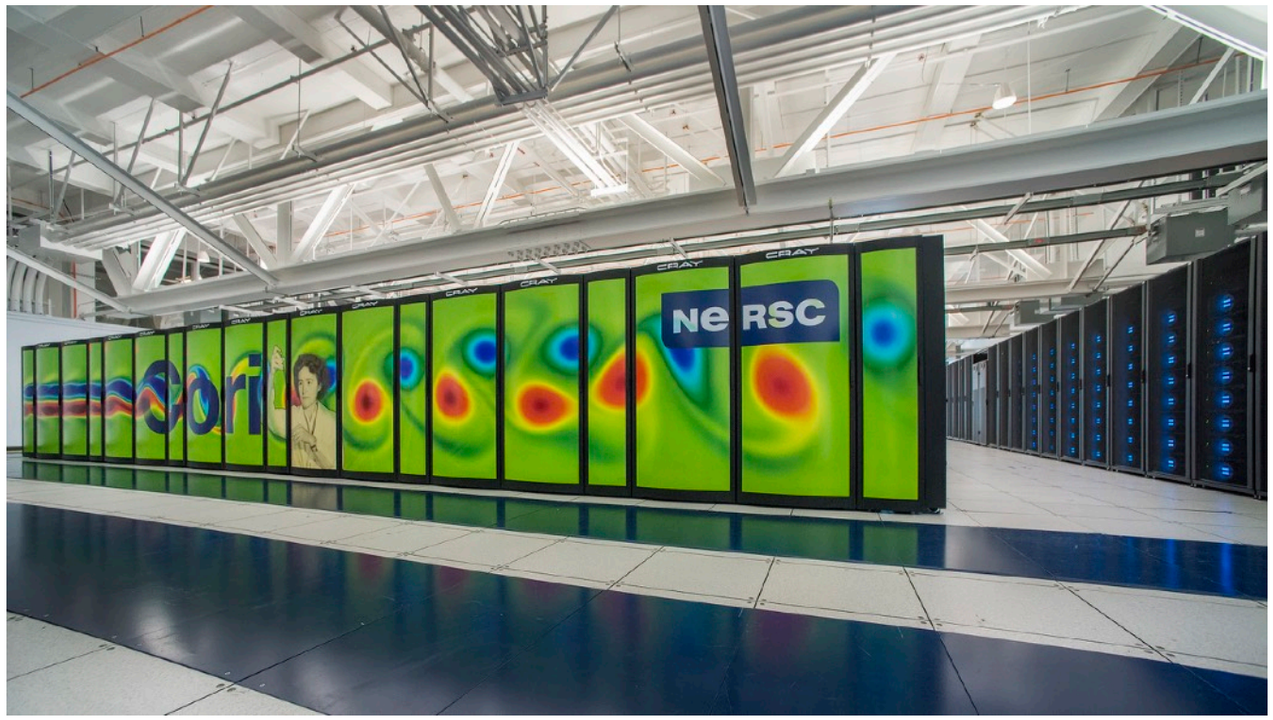
$$u = \sum_i w_i \, x_i$$

$$y = g(u)$$

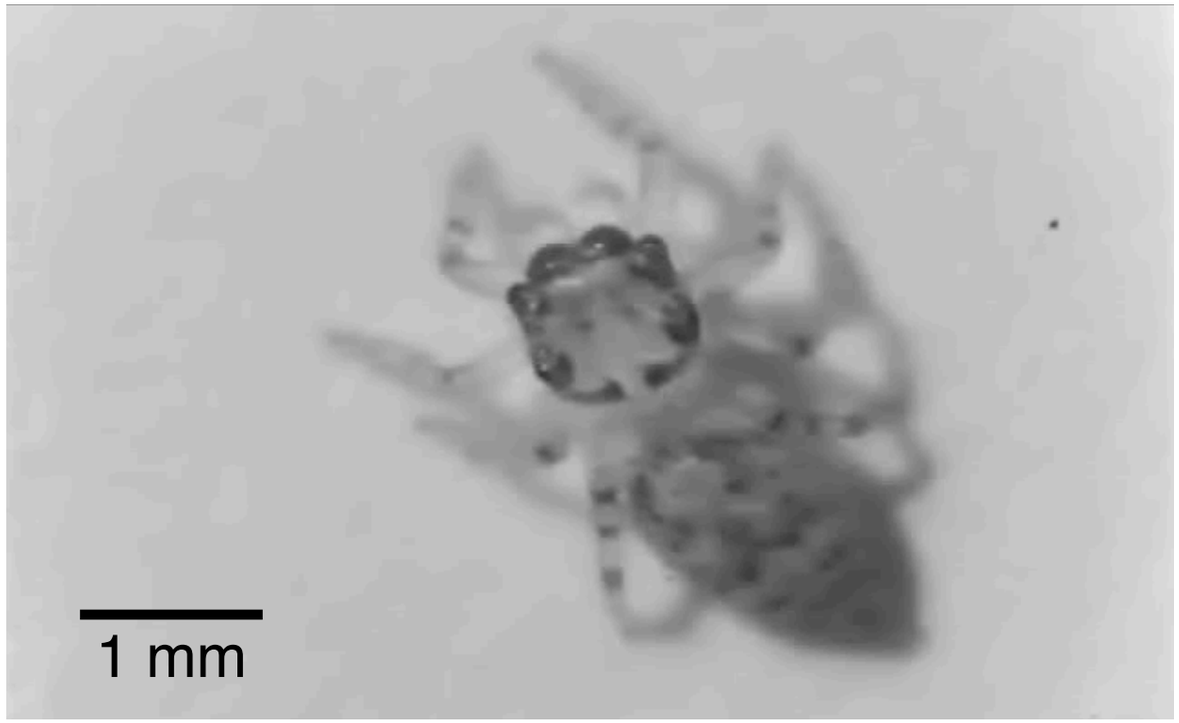


$$\sim \quad g(\sum_i w_i \, \Pi_{j \in G_i} \, x_j)$$

NERSC (Lawrence Berkeley Lab) ~ 5 MW



Jumping spider ~ 1 fly/day



(Bair & Olshausen, 1991)

What is this?

Correct label: Afghan hound

Holographic Reduced Representations

Tony Plate

Vector Symbolic Architectures

Ross Gayler

Hyperdimensional Computing

Pentti Kanerva

Plate, T. A. (1995). Holographic reduced representations. *IEEE Transactions on Neural networks, 6(3)*, 623-641.

Gayler, R. W. (2004). Vector symbolic architectures answer Jackendoff's challenges for cognitive neuroscience. arXiv:cs/0412059.

Kanerva P (2009) Hyperdimensional Computing: An Introduction to Computing in Distributed Representation with High-Dimensional Random Vectors. *Cognitive Computing, 1*: 139-159.

- Everything represented as a high-dimensional vector.
- Algebra over vectors (instead of numbers).

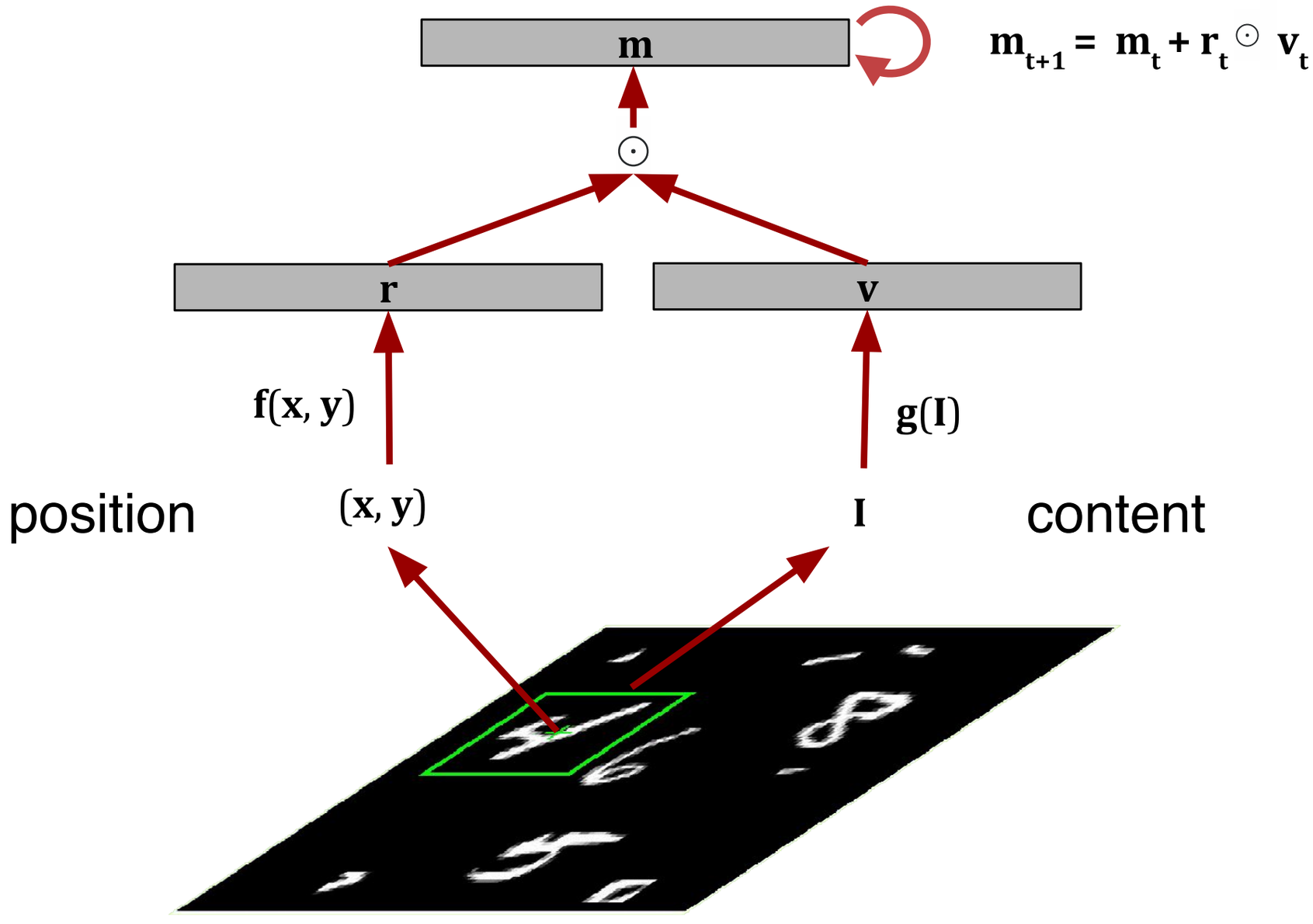
Hyperdimensional Computing

Pentti Kanerva

- The brain's circuits are high-dimensional.
- Computing elements are stochastic, not deterministic.
- No two brains are alike, yet they exhibit the same behavior.
- Learns from data/example, learns by analogy, or even "one-shot."
- Integrates signals from disparate senses.
- Allows high degree of parallelism.

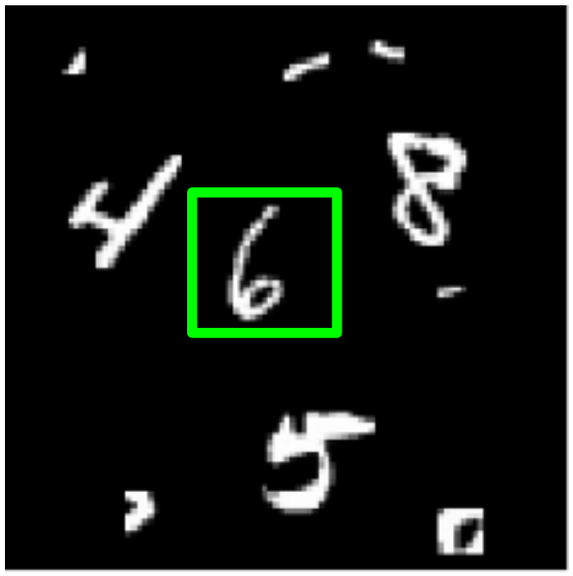
Visual working memory as a superposition of ‘what’ and ‘where’ bindings

(Eric Weiss, Ph.D. thesis)



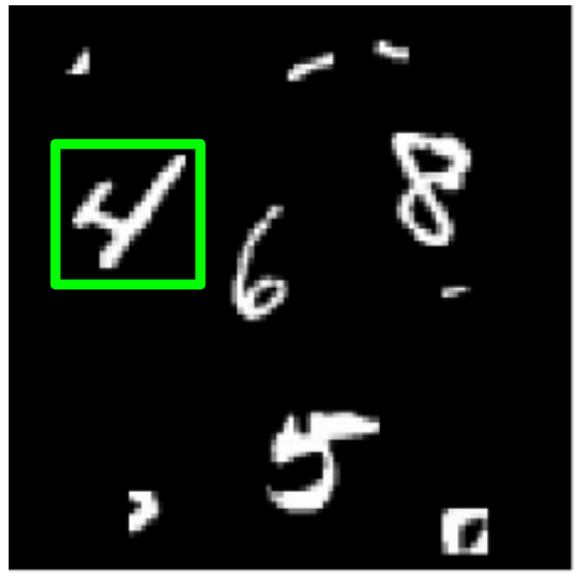
Example encoding

t=0



t=1

t=2



. . .

$$\mathbf{m} = \mathbf{v}_6 \odot \mathbf{r}_{t=0} + \mathbf{v}_5 \odot \mathbf{r}_{t=1} + \mathbf{v}_4 \odot \mathbf{r}_{t=2} + \ldots$$

Example queries

Where is the '5'?

answer = $\mathbf{v}_5^* \odot \mathbf{m}$

$= \mathbf{v}_5^* \odot (\mathbf{v}_6 \odot \mathbf{r}_{t=0} + \mathbf{v}_5 \odot \mathbf{r}_{t=1} + \mathbf{v}_4 \odot \mathbf{r}_{t=2} + \ldots)$

$\approx$ noise + $\mathbf{r}_{t=1}$ + noise + ...

What object is in the center?

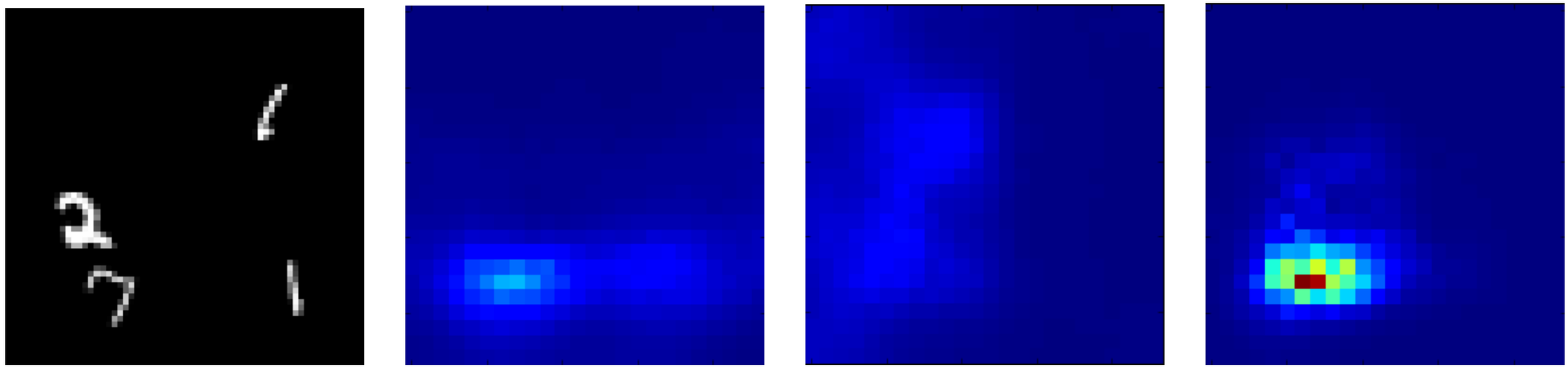
answer = $\mathbf{r}_{center}^* \odot \mathbf{m}$

$= \mathbf{r}_{center}^* \odot (\mathbf{v}_6 \odot \mathbf{r}_{t=0} + \mathbf{v}_5 \odot \mathbf{r}_{t=1} + \mathbf{v}_4 \odot \mathbf{r}_{t=2} + \ldots)$

$\approx \mathbf{v}_6$ + noise + noise + ...

Spatial reasoning

What is below a ‘2’ and to the left of a ‘1’?



(a) Example image (b) ”below a 2” (c) ”to the left of a 1” (d) Combined

$$\mathbf{a}_1 = f^{-1}(\mathbf{r}_{\mathbf{down}}\ (\mathbf{v}_2^* \odot \mathbf{m}))$$

$$\mathbf{a}_2 = f^{-1}(\mathbf{r}_{\mathbf{left}}\ (\mathbf{v}_1^* \odot \mathbf{m}))$$

$$\mathbf{a}_1 \odot \mathbf{a}_2$$

$$\text{answer} = f(\mathbf{a}_1 \odot \mathbf{a}_2) \odot \mathbf{m}$$

	Traditional computing/AI	Neural nets	HD computing
Symbolic computing with variables and binding	✓	✗	✓
Distributed representation	✗	✓	✓
Learn from data	✗	✓	✓
Robust (error-correcting)	✗	?	✓
Transparent	✓	✗	✓

Other efforts

- Berkeley/Stanford EE (Rabaey, Salahuddin, Mitra, Wong) - hardware implementation, cnFET's, PCM/RRAM
- Waterloo (Eliasmith) - SPAUN
- U Maryland (Fernmuller, Aloimonos) - event-based camera robot navigation
- BMW (Mirus, Blouw, Stewart, Conradt) - vehicle position monitoring and prediction.
- VSA online seminar series: https://sites.google.com/ltu.se/vsaonline/winter-2021
- Website: https://www.hd-computing.com