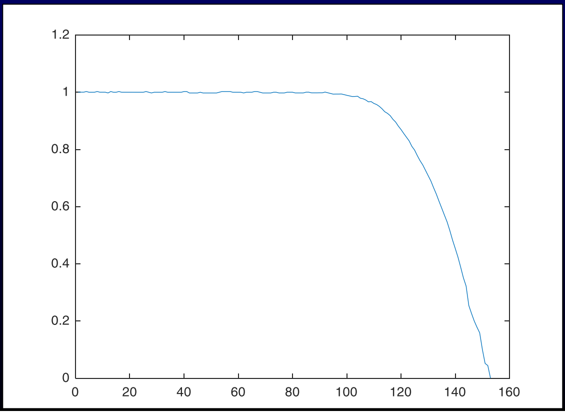
Logical Functions

- Input is k boolean bits, output is 1 bit function table; learn weights to perform logical functions
  - Minsky and Papert showed that one layer nets were impoverished in the space
  - Couldn't do Xor or EQU
- Because of multiple levels (and biases) able to do and, or, not, any logical function is possible with enough hidden units.
  - Proof by Hal White

Learning XOR

- (defvar net221 (setuplayers '(2 2 1)))
- (noise net221 .1)
- (learn net221 '((-5 -5)(-5 5)(5 -5)(5 5)) '((0)(1)(1)(0)))



Data compression?

- The "Auto-Associator" is a self-supervised model
- Input and output are the same, and hidden layer is smaller.
  - GOAL: When you put in an input, you get out the same
- If BP learns, the hidden layer becomes a "compressed Representation" of the input
- There are other more sophisticated uses of neural networks in data compression.

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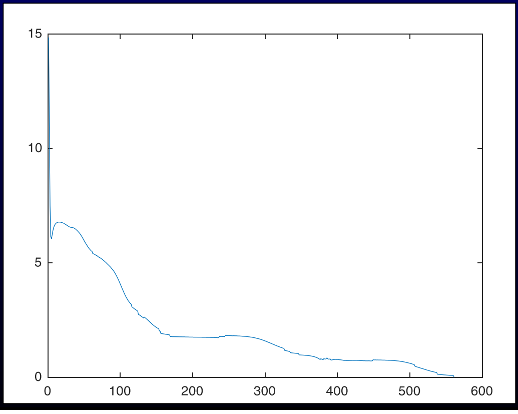
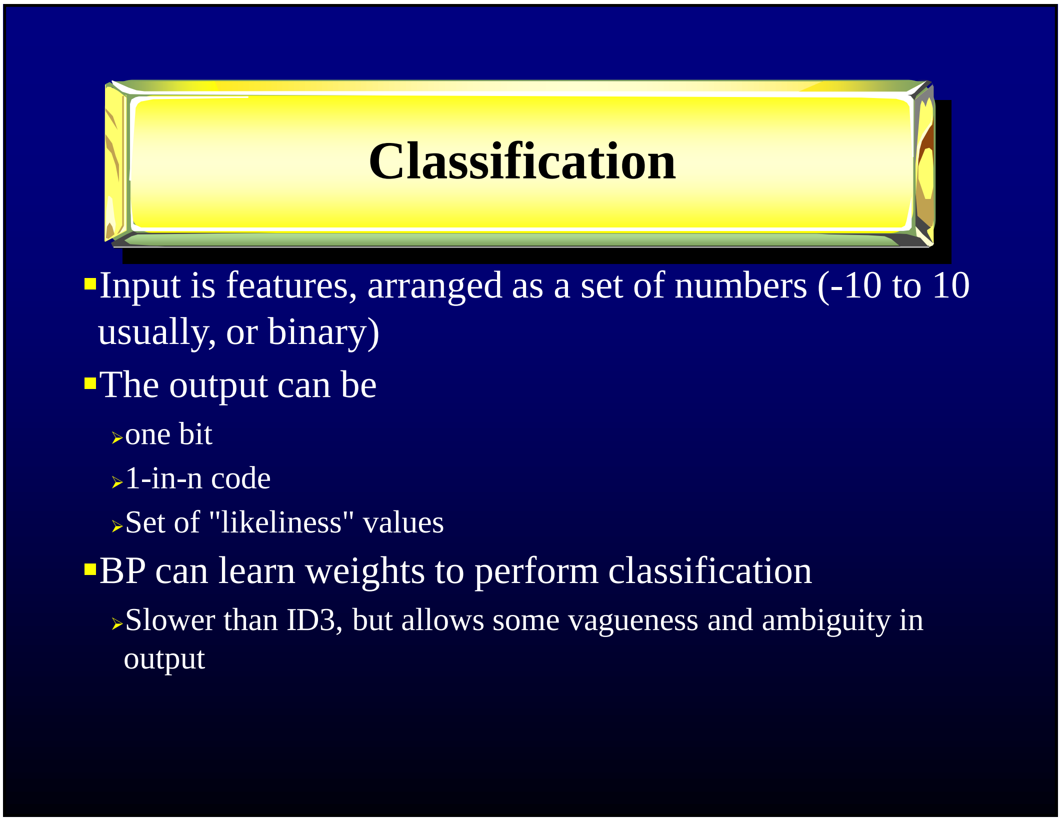
learning the 8 3 8 auto-associator

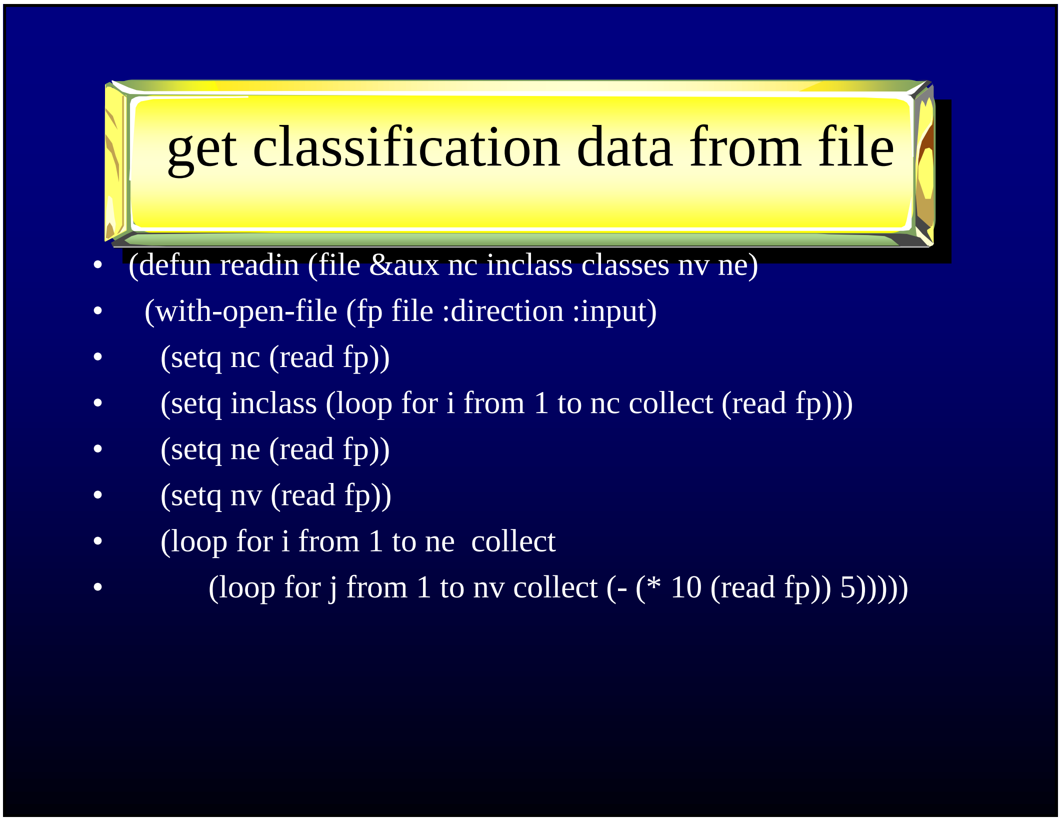
- (defvar net838 (setuplayers '(8 3 8)))
- (noise net838 .5)
- (defvar eye8 '((1 0 0 0 0 0 0 0)(0 1 0 0 0 0 0 0)(0 0 1 0 0 0 0 0)(0 0 0 1 0 0 0 0)(0 0 0 0 1 0 0 0)(0 0 0 0 0 0 1 0)(0 0 0 0 0 0 0 1)))
- (learn net838 eye8 eye8)





Classification

- Input is features, arranged as a set of numbers (-10 to 10 usually, or binary)
- The output can be
  - one bit
  - 1-in-n code
  - Set of "likeliness" values
- BP can learn weights to perform classification
  - Slower than ID3, but allows some vagueness and ambiguity in output



get classification data from file

```
•  (defun readin (file &aux nc inclass classes nv ne)
•    (with-open-file (fp file :direction :input)
•      (setq nc (read fp))
•      (setq inclass (loop for i from 1 to nc collect (read fp)))
•      (setq ne (read fp))
•      (setq nv (read fp))
•      (loop for i from 1 to ne  collect
•            (loop for j from 1 to nv collect (- (* 10 (read fp)) 5)))))
```

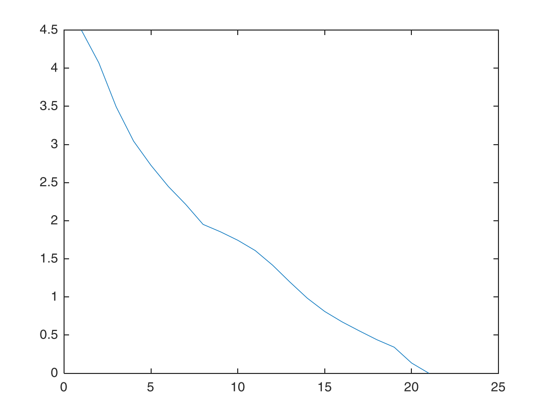
1-of-n outputs

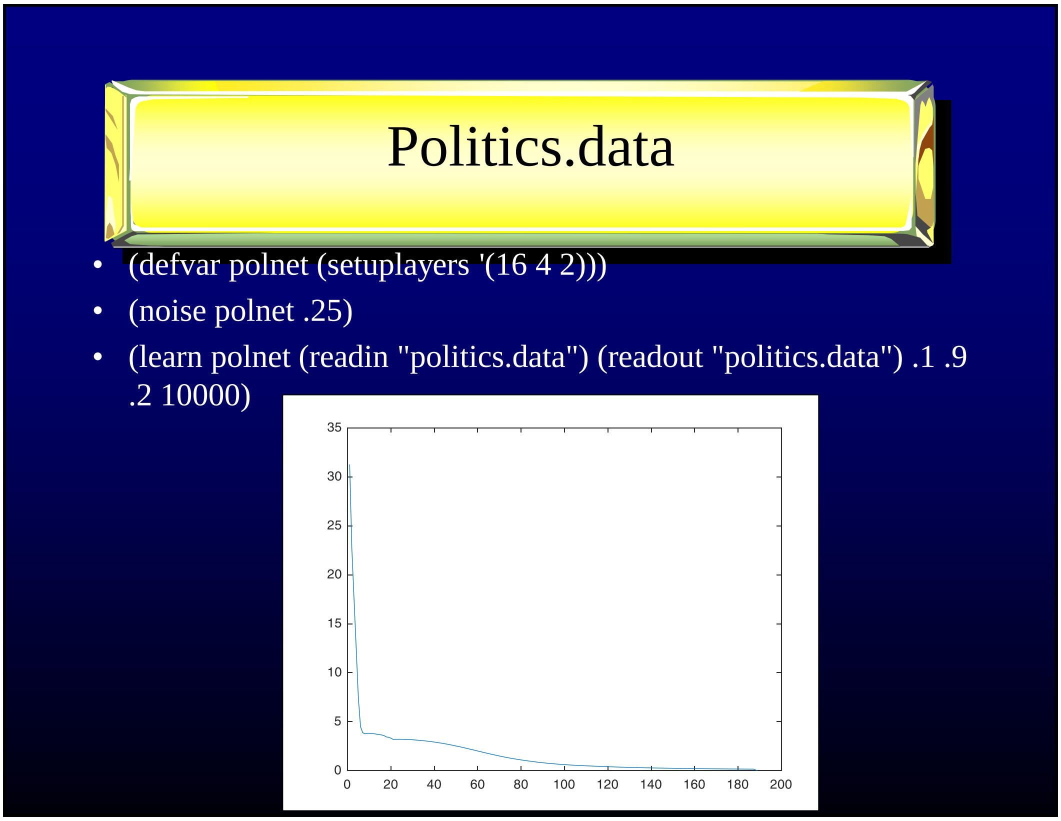
```
• (defun readout (file &aux nc inclass classes nv ne)
•   (with-open-file (fp file :direction :input)
•        (setq nc (read fp))
•         (setq nv (loop for i from 1 to nc collect i))
•          (setq inclass (loop for i from 1 to nc collect (read fp)))
•          (setq classes (loop for x in inclass as i from 1
•                                  nconc (loop for j from 1 to x collect (veq nv
  i))))))

• (defun veq (vec i) (loop for x in vec collect
•                                   (if (= x i) 1 0)))
```

Buildings.data

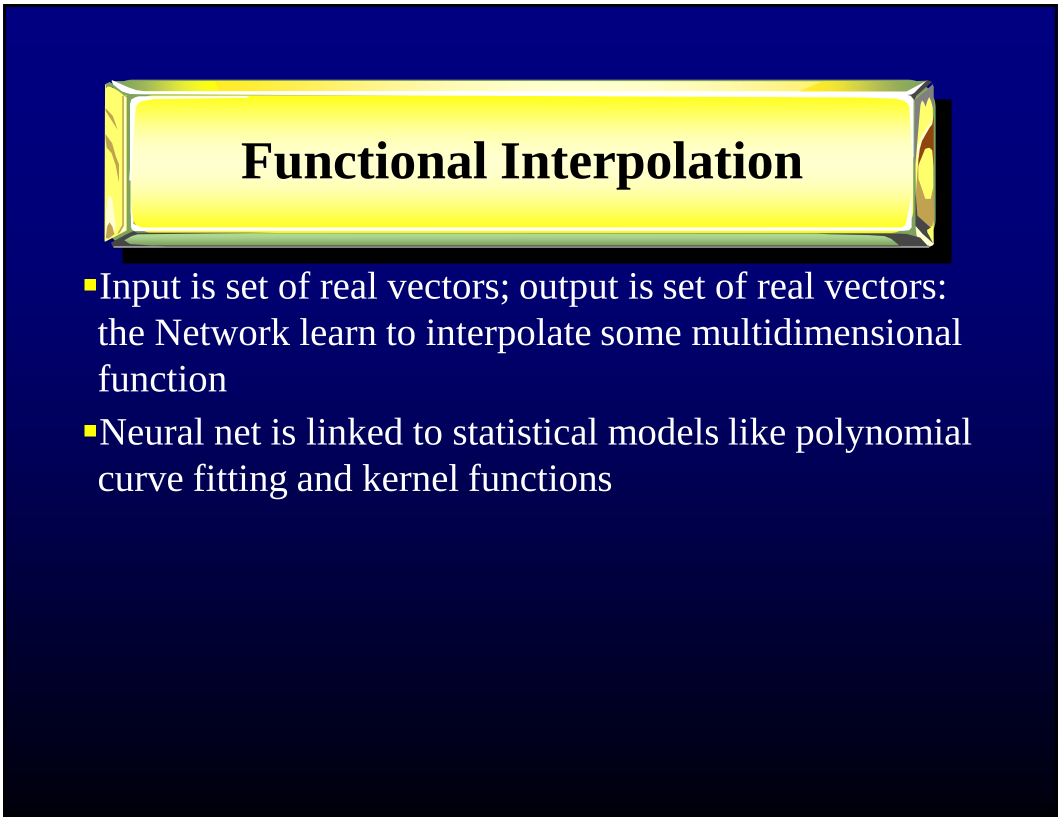
```
• (defvar net653 (setuplayers '(6 5 3)))
• (noise net653 .25)
• (learn net653 (readin "buildings.data")(readout "buildings.data"))
```





Politics.data

- (defvar polnet (setuplayers '(16 4 2)))
- (noise polnet .25)
- (learn polnet (readin "politics.data") (readout "politics.data") .1 .9 .2 10000)



Functional Interpolation

- Input is set of real vectors; output is set of real vectors: the Network learn to interpolate some multidimensional function
- Neural net is linked to statistical models like polynomial curve fitting and kernel functions

Summary of BP apps

- Input is k boolean bits, output is 1 bit function table; learn weights to perform logical function
- Input is features, output is 1-in-n code; learn weights to perform classification
  - Slower than ID3, but allows some vagueness and ambiguity in output
- Input and output are same, and hidden layer is smaller: learn to code and compress data
- Input is set of real vectors; output is set of real vectors: learn to interpolate multidimensional function (like polynomial or kernel functions)

Backprop wins Turing Award 2019

Turing Award Won by 3 Pioneers in Artificial Intelligence

From left, Yann LeCun, Geoffrey Hinton and Yoshua Bengio. The researchers worked on key developments for neural networks, which are reshaping how computer systems are built.

From left, Facebook, via Associated Press; Aaron Vincent Elkaim for The New York Times; Chad Buchanan/Getty Images