technische universität dortmund

Computational Intelligence

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Prof. Dr. Günter Rudolph

Lehrstuhl für Algorithm Engineering (LS 11)

Fakultät für Informatik

TU Dortmund

Plan for Today

- Application Fields of ANNs
  - Classification
  - Prediction
  - Function Approximation
- Radial Basis Function Nets (RBF Nets)
  - Model
  - Training
- Recurrent MLP
  - Elman Nets
  - Jordan Nets

Application Fields of ANNs

Classification

given: set of training patterns (input / output) ($\tilde{x}_i$, $\tilde{y}_i$)

output = label
(e.g. class A, class B, ...)

$$f(\underbrace{x}_{\text{input (unknown)}};\ \overbrace{\underbrace{(\tilde{x}_1,\tilde{y}_1),\ldots,(\tilde{x}_m,\tilde{y}_m)}_{\text{training patterns (known)}},\ \underbrace{w_1,\ldots,w_n}_{\text{weights (learnt)}}}^{\text{parameters}}) \rightarrow \underbrace{\hat{y}}_{\text{output (guessed)}}$$

phase I:

train network

phase II:

apply network to unkown inputs for classification

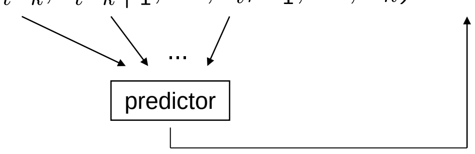
Application Fields of ANNs

Prediction of Time Series

time series x_1, x_2, x_3, ... (e.g. temperatures, exchange rates, ...)

task: given a subset of historical data, predict the future

$$f(x_{t-k}, x_{t-k+1}, \ldots, x_t; w_1, \ldots, w_n) \rightarrow \hat{x}_{t+\tau}$$



phase I:

train network

phase II:

apply network to historical inputs for predicting unkown outputs

training patterns:

historical data where true output is known;

error per pattern = $(\hat{x}_{t+\tau} - x_{t+\tau})^2$

Prediction of Time Series: <u>Example for Creating Training Data</u>

given: time series 10.5, 3.4, 5.6, 2.4, 5.9, 8.4, 3.9, 4.4, 1.7

time window: k=3

(10.5, 3.4, 5.6) 2.4 first input / output pair

known input / known output

further input / output pairs:

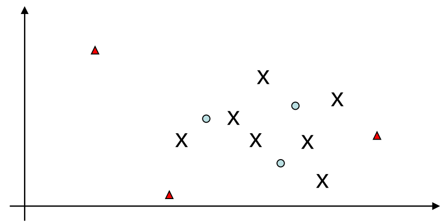
(3.4, 5.6, 2.4)	5.9
(5.6, 2.4, 5.9)	8.4
(2.4, 5.9, 8.4)	3.9
(5.9, 8.4, 3.9)	4.4
(8.4, 3.9, 4.4)	1.7

Function Approximation (the general case)

task: given training patterns (input / output), approximate unkown function

→ should give outputs close to true unkown function for arbitrary inputs

- values between training patterns are **interpolated**
- values outside convex hull of training patterns are **extrapolated**



x : input training pattern

° : input pattern where output to be interpolated

▲ : input pattern where output to be extrapolated

Definition:

A function $\phi : \mathbb{R}^n \to \mathbb{R}$ is termed **radial basis function** iff $\exists\, \varphi : \mathbb{R} \to \mathbb{R} : \forall x \in \mathbb{R}^n : \phi(x; c) = \varphi(\| x - c \|)$. □

Definition:

RBF **local** iff $\varphi(r) \to 0$ as $r \to \infty$ □

typically, || x || denotes Euclidean norm of vector x

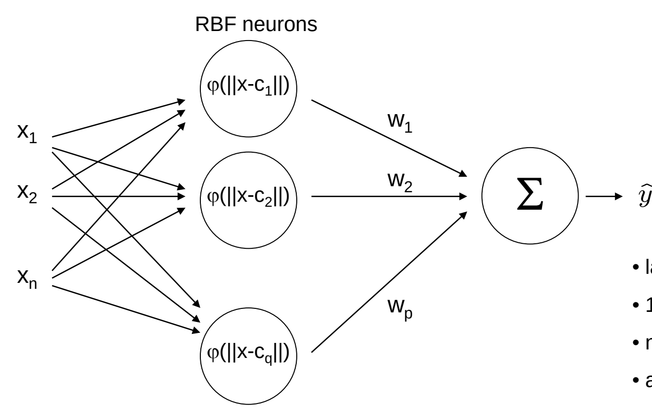
examples:

$\varphi(r) = \exp\left(-\frac{r^2}{\sigma^2}\right)$	Gaussian	unbounded	local
$\varphi(r) = \frac{3}{4}(1 - r^2) \cdot 1_{\{r \le 1\}}$	Epanechnikov	bounded	local
$\varphi(r) = \frac{\pi}{4} \cos\left(\frac{\pi}{2} r\right) \cdot 1_{\{r \le 1\}}$	Cosine	bounded	local

Definition:

A function f: $\mathbb{R}^n \to \mathbb{R}$ is termed **radial basis function net (RBF net)**

iff $f(x) = w_1\, \varphi(\| x - c_1 \|) + w_2\, \varphi(\| x - c_2 \|) + \ldots + w_p\, \varphi(\| x - c_q \|)$ □



- layered net
- 1st layer fully connected
- no weights in 1st layer
- activation functions differ

given : N training patterns (x_i, y_i) and q RBF neurons

find : weights $w_1, ..., w_q$ with minimal error

solution:

we know that $f(x_i) = y_i$ for i = 1, ..., N or equivalently

$$\sum_{k=1}^{q} \underbrace{w_k}_{\text{unknown}} \cdot \underbrace{\varphi(\|x_i - c_k\|)}_{p_{ik}\text{ known value}} = \underbrace{y_i}_{\text{known value}}$$

$$\Rightarrow \sum_{k=1}^{q} w_k \cdot p_{ik} = y_i$$

$\Rightarrow$ N linear equations with q unknowns

in matrix form: P w = y with $P = (p_{ik})$ and P: N x q, y: N x 1, w: q x 1,

case N = q: $w = P^{-1} y$ if P has full rank

case N < q: many solutions but of no practical relevance

case N > q: $w = P^{+} y$ where P^{+} is Moore-Penrose pseudo inverse

P w = y | · P‘ from left hand side (P‘ is transpose of P)

P‘P w = P‘ y | · $(P'P)^{-1}$ from left hand side

$\underbrace{(P'P)^{-1} P'P}_{\text{unit matrix}} w = \underbrace{(P'P)^{-1} P'}_{P^{+}} y$ | simplify

complexity (naive)

$w = (P'P)^{-1} P' y$

$\underbrace{\text{P‘P: } N^2 q \quad \text{inversion: } q^3 \quad \text{P‘y: } qN \quad \text{multiplication: } q^2}_{O(N^2 q)}$

remark: if N large then inaccuracies for P‘P likely

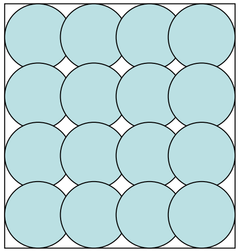
$\Rightarrow$ first analytic solution, then gradient descent starting from this solution

(gradient descent: requires differentiable basis functions!)

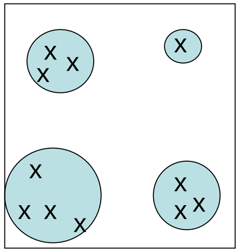
so far: tacitly assumed that RBF neurons are given

$\Rightarrow$ center c_k and radii σ considered given and known

how to choose c_k and σ ?



uniform covering



if training patterns inhomogenously distributed then first cluster analysis

choose center of basis function from each cluster, use cluster size for setting σ

advantages:

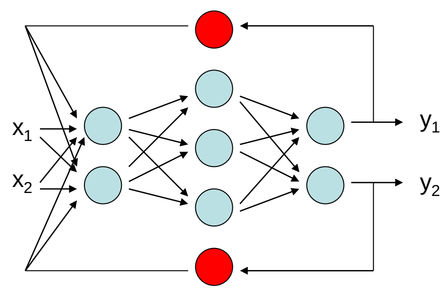
- additional training patterns → only local adjustment of weights
- optimal weights determinable in polynomial time
- regions not supported by RBF net can be identified by zero outputs

disadvantages:

- number of neurons increases exponentially with input dimension
- unable to extrapolate (since there are no centers and RBFs are local)

Jordan nets (1986)

- **context neuron**:
  reads output from some neuron at step t and feeds value into net at step t+1



Jordan net =

MLP + context neuron for each output, context neurons fully connected to input layer

Elman nets (1990)

Elman net =

MLP + context neuron for each neuron output of MLP,
context neurons fully connected to associated MLP layer

Training?

⇒ unfolding in time (“loop unrolling“)

- identical MLPs serially connected (finitely often)
- results in a large MLP with many hidden (inner) layers
- backpropagation may take a long time
- but reasonable if most recent past more important than layers far away

Why using backpropagation?

⇒ use *Evolutionary Algorithms* directly on recurrent MLP!

later!