

# Изкуствен интелект

***Тема 13: Рекурентни и локално  
рекурентни невронни мрежи  
(RNN, DRNN, LRPNN, GLRPNN, pcLRPNN)***



# Съдържание

- ❑ Обща класификация на методите
- ❑ Неврони с последователен вход. Неврони с КИХ и БИХ. Невронни мрежи с време-закъснителни вериги във входа (Time-Delay Neural Networks)
- ❑ Неврони с обратни връзки. Видове обратни връзки.
- ❑ Архитектури на рекурентни и локално рекурентни невронни мрежи
  - DRNN,
  - LRPNN,
  - GLRPNN
  - pcLRPNN...

# Класификатори

## *Discriminative approaches*

LDA

Polynomial  
classifier

TDNN  
and RNN

FFNN

SVM

Decision  
trees

## *Non-discriminative approaches*

k-NN

LVQ

SOM

PNN

GMM

HMM

## *Generative approaches*

## *Combined methods*

GMM/SVM

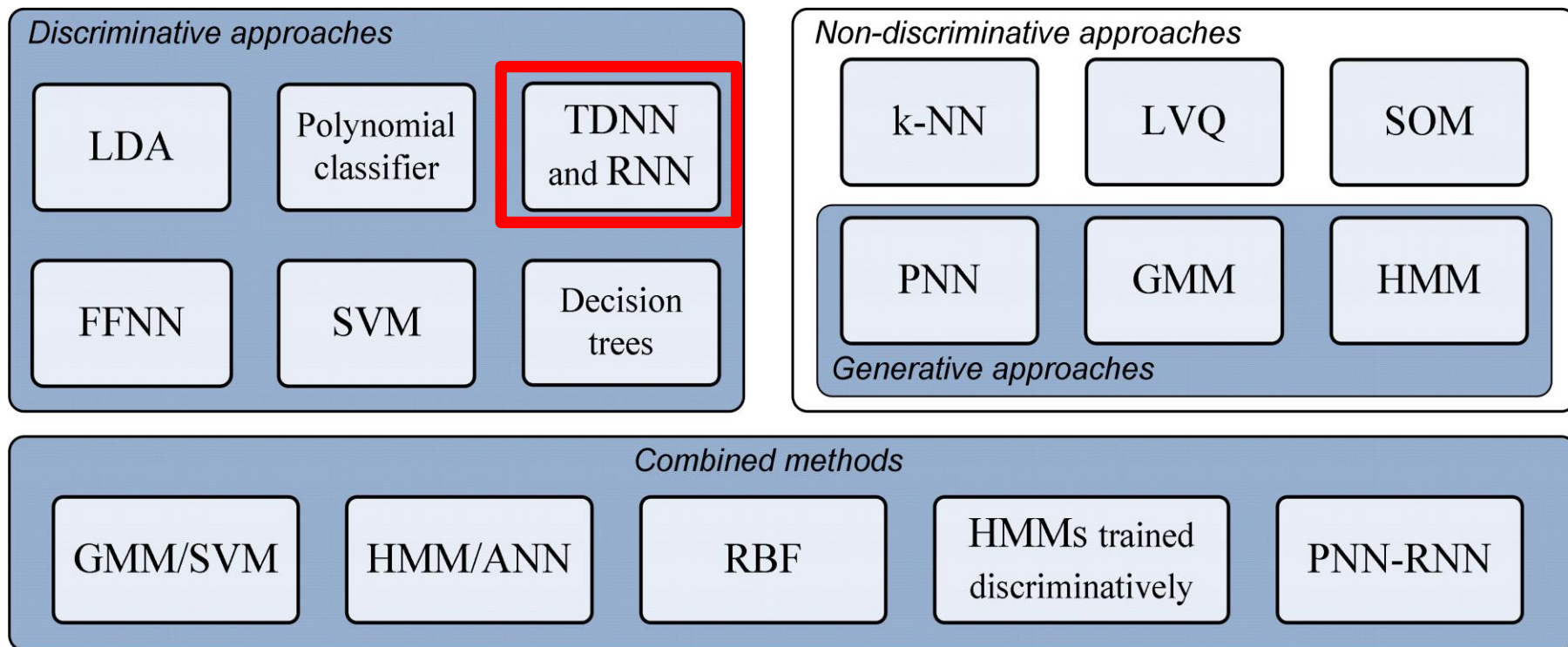
HMM/ANN

RBF

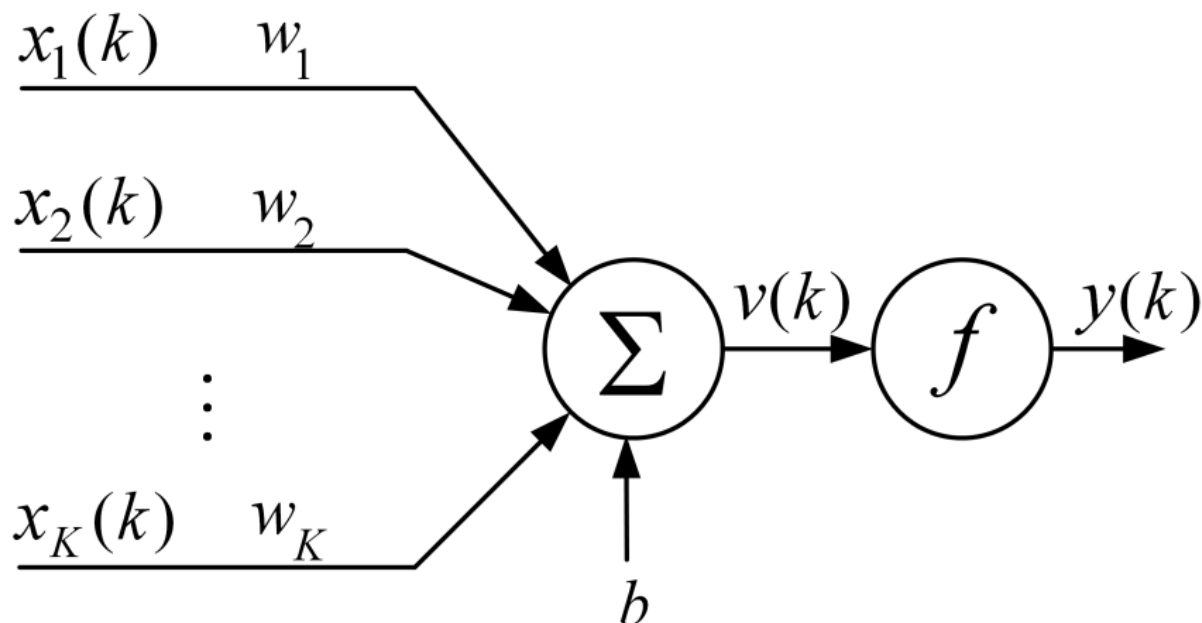
HMMs trained  
discriminatively

PNN-RNN

# Класификатори

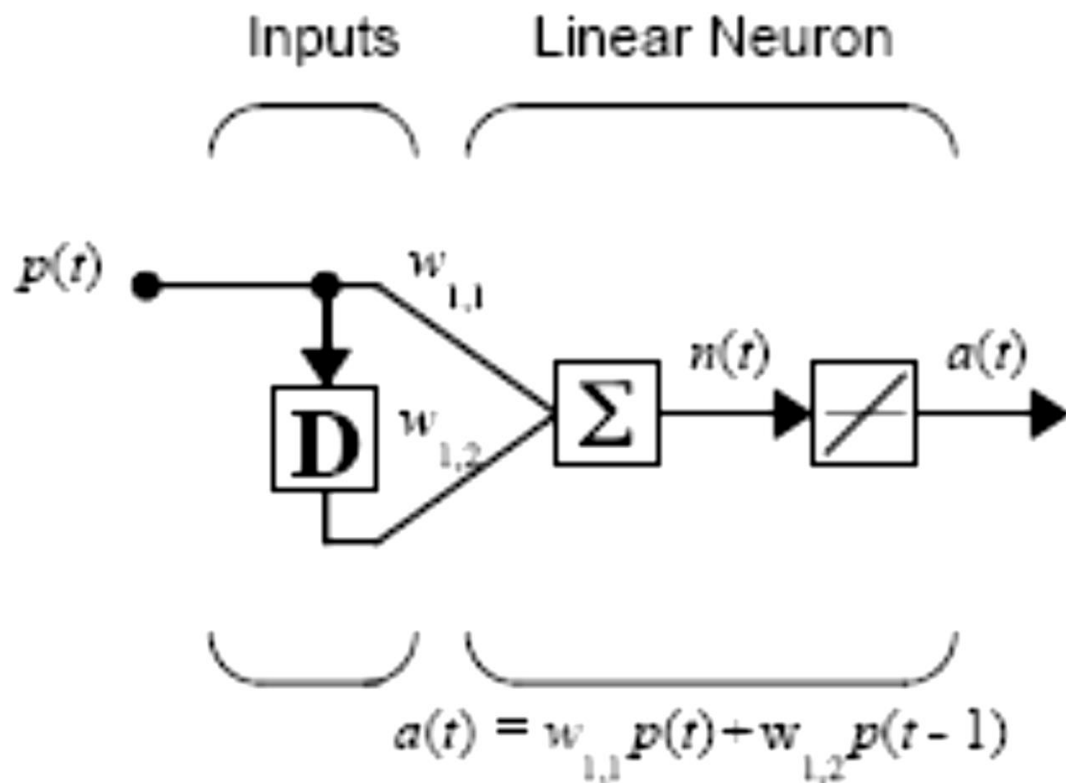


# Неврон без обратна връзка



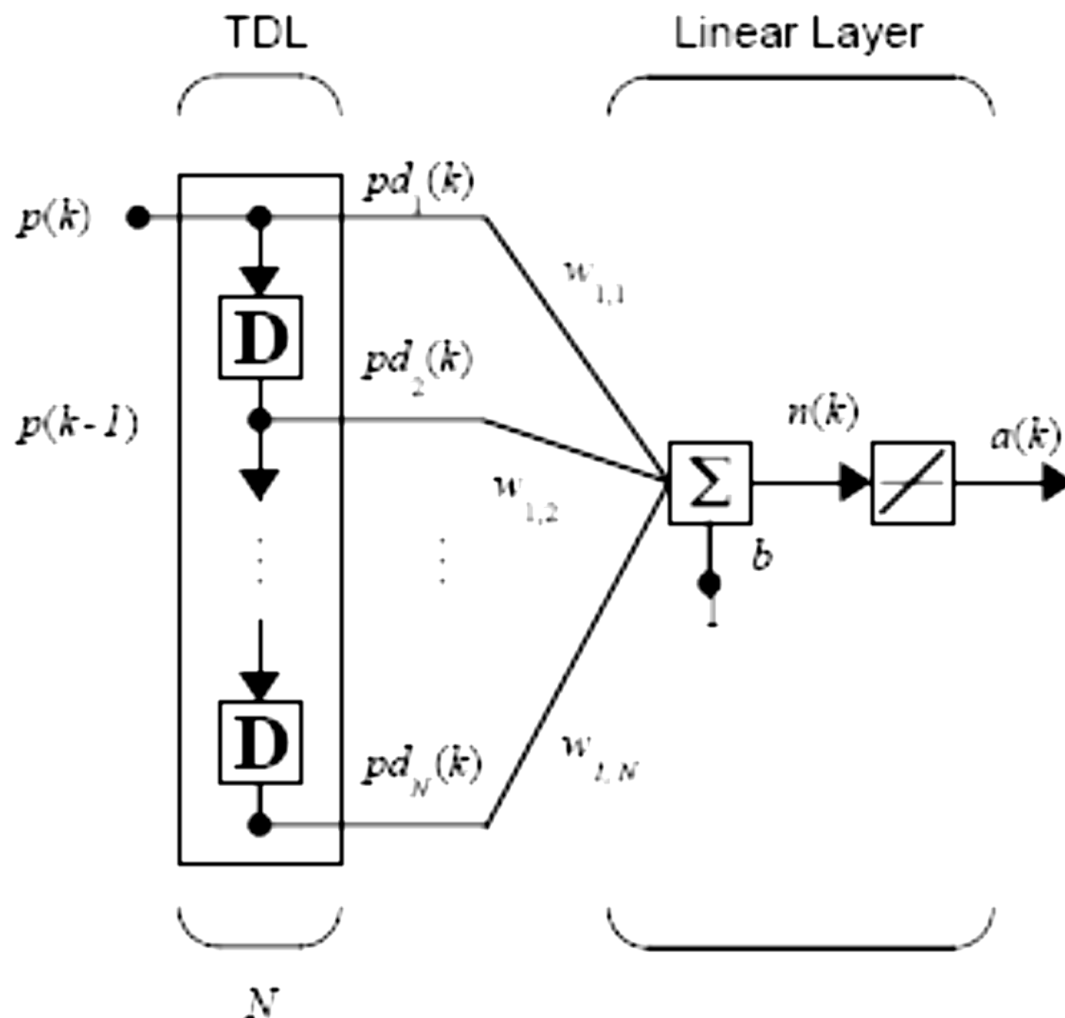
$$y(k) = f(v(k))$$
$$v(k) = \sum_{i=1}^K w_i x_i(k) + b$$

# Неврон с последователен вход

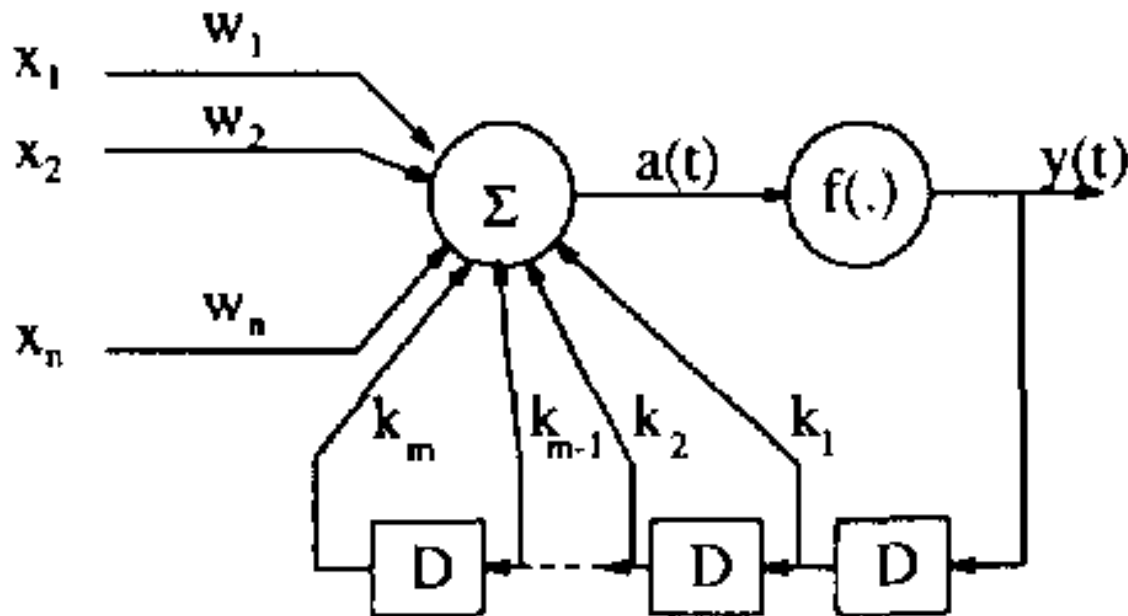


# Неврон с последователен вход

FIR Adaptive Filter

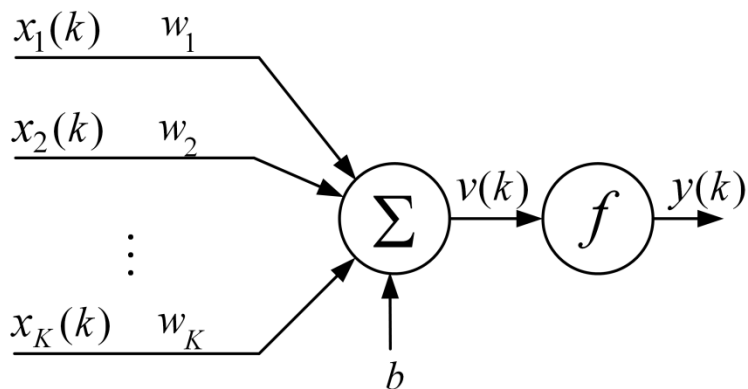


# Неврон с обратни връзки (IIR неврон)

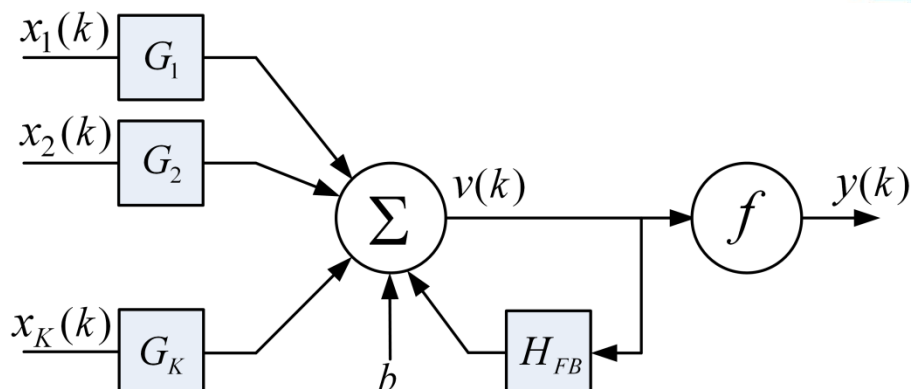




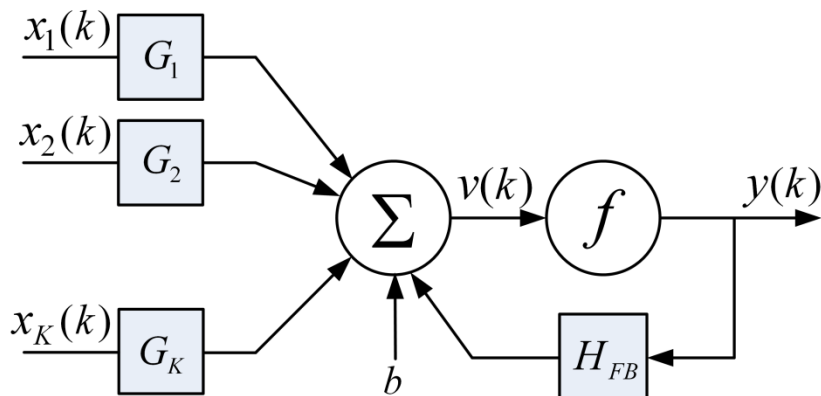
# Локално рекурентни неврони



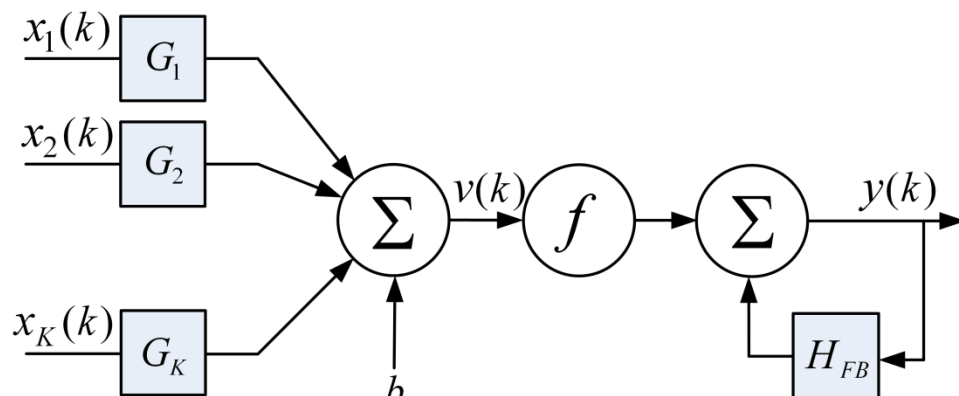
(a)



(b)



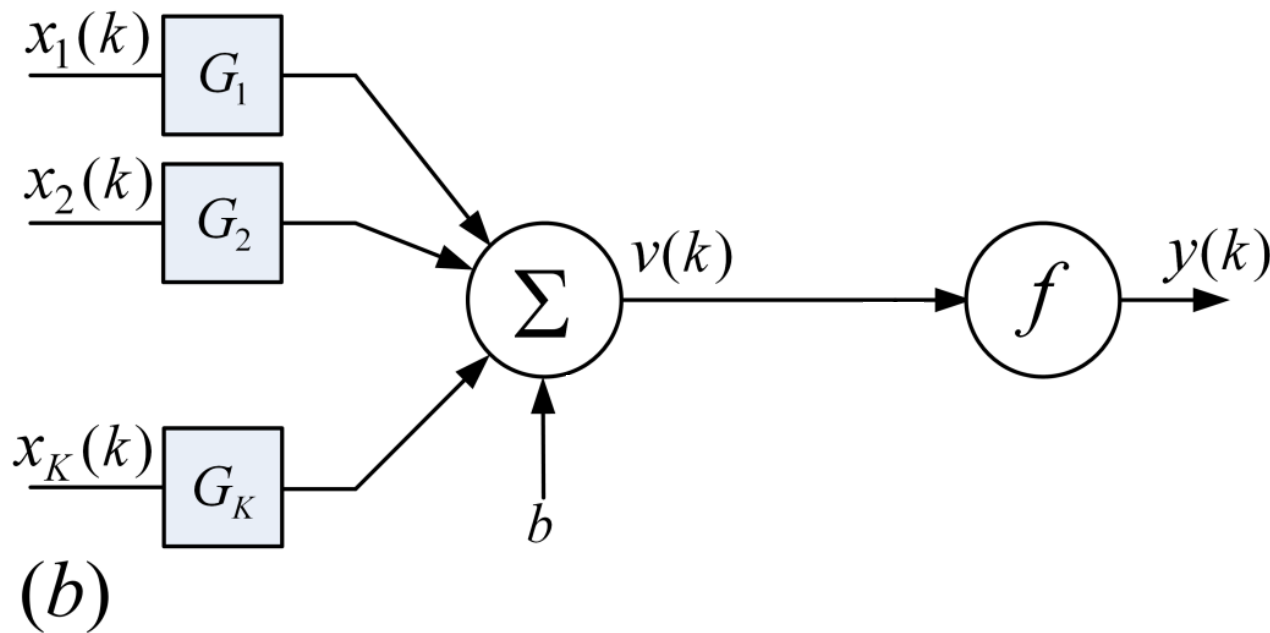
(c)



(d)

- С обратна връзка от изхода на синапса,
- С обратна връзка преди активиращата функция ,
- С обратна връзка от изхода на неврона
- С авторегресивен филтър след изхода на неврона

# Локално рекурентни неврони

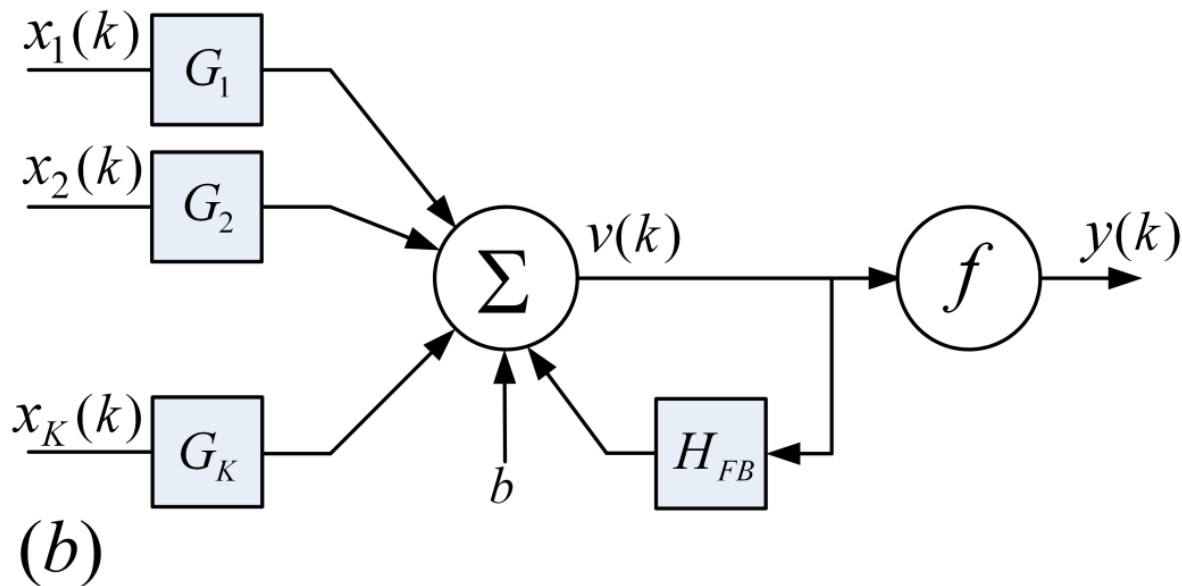


$$y(k) = f(v(k))$$

$$v(k) = \sum_{i=1}^K G_i(z^{-1})x_i(k) + b ,$$

$$G(z^{-1}) = \frac{\sum_{j=0}^{m_z} b_j z^{-j}}{\sum_{j=0}^{n_p} a_j z^{-j}}$$

# Локално рекурентни невронни мрежи

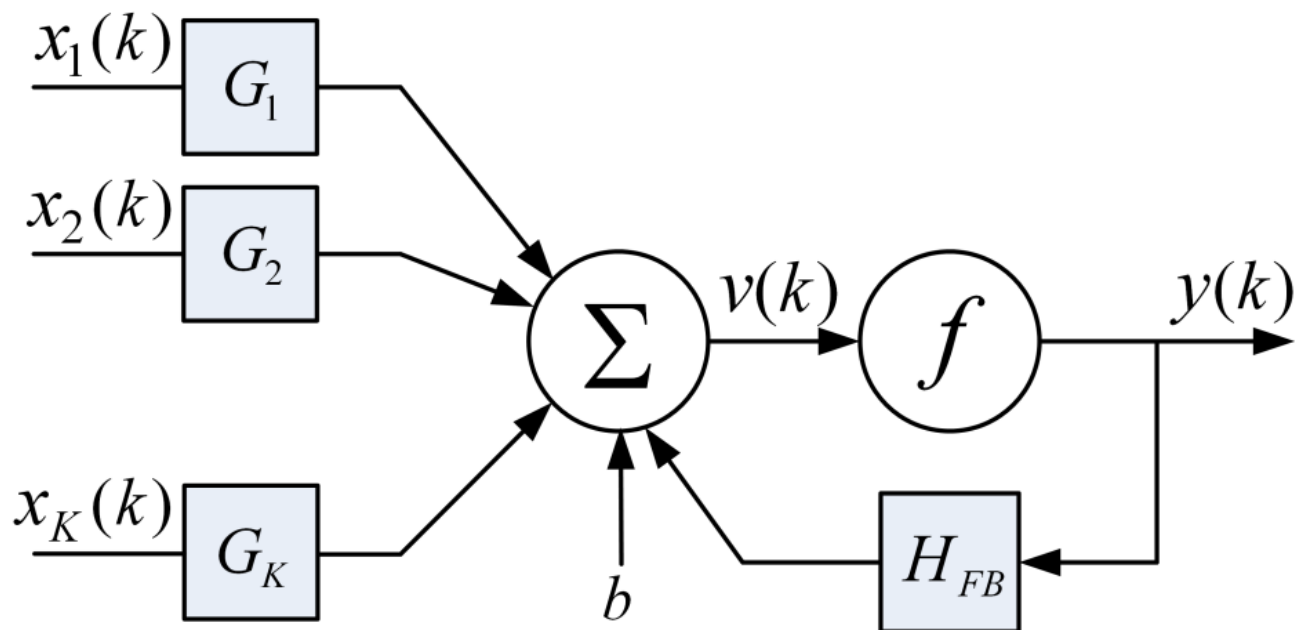


$$y(k) = f(v(k))$$

$$v(k) = \sum_{i=1}^K G_i(z^{-1})x_i(k) + H_{FB}(z^{-1})v(k-1) + b,$$

$$H_{FB}(z^{-1}) = \frac{\sum_{j=0}^{g_z} b_j z^{-j}}{\sum_{j=0}^{l_p} a_j z^{-j}}$$

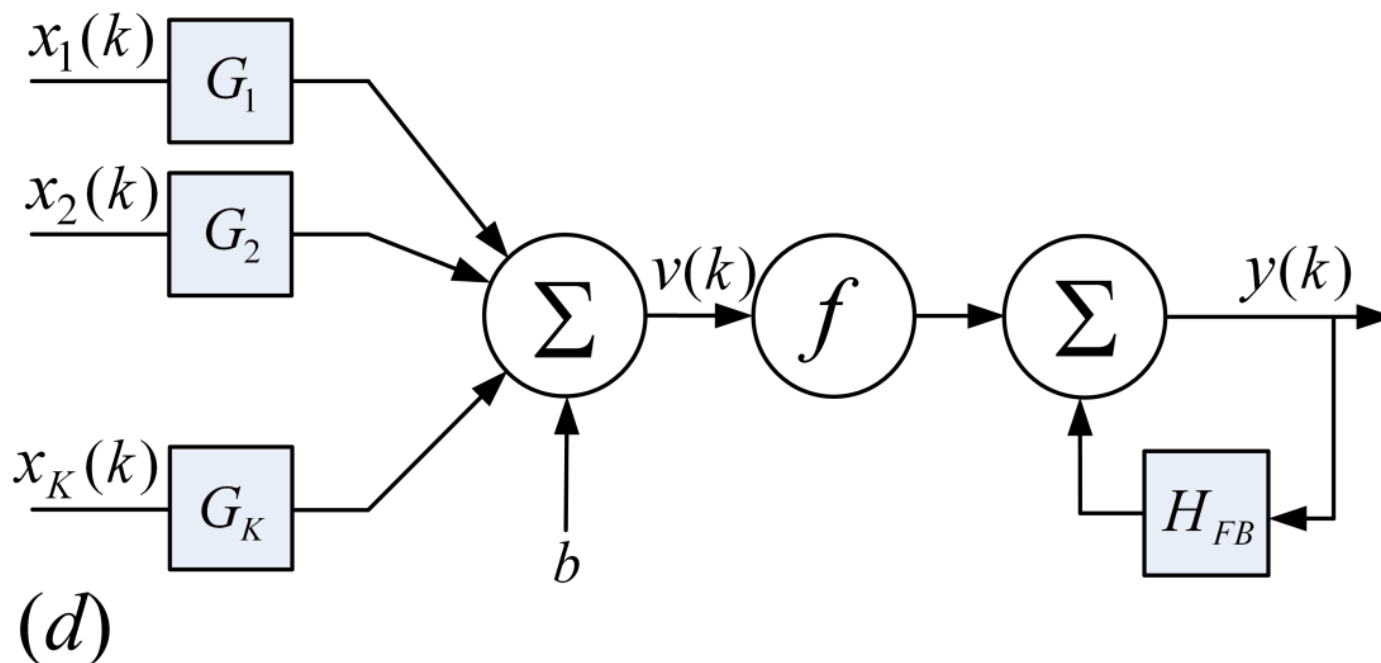
# Локално рекурентни невронни мрежи



$$y(k) = f(v(k))$$

$$v(k) = \sum_{i=1}^K G_i(z^{-1})x_i(k) + H_{FB}(z^{-1})y(k-1) + b .$$

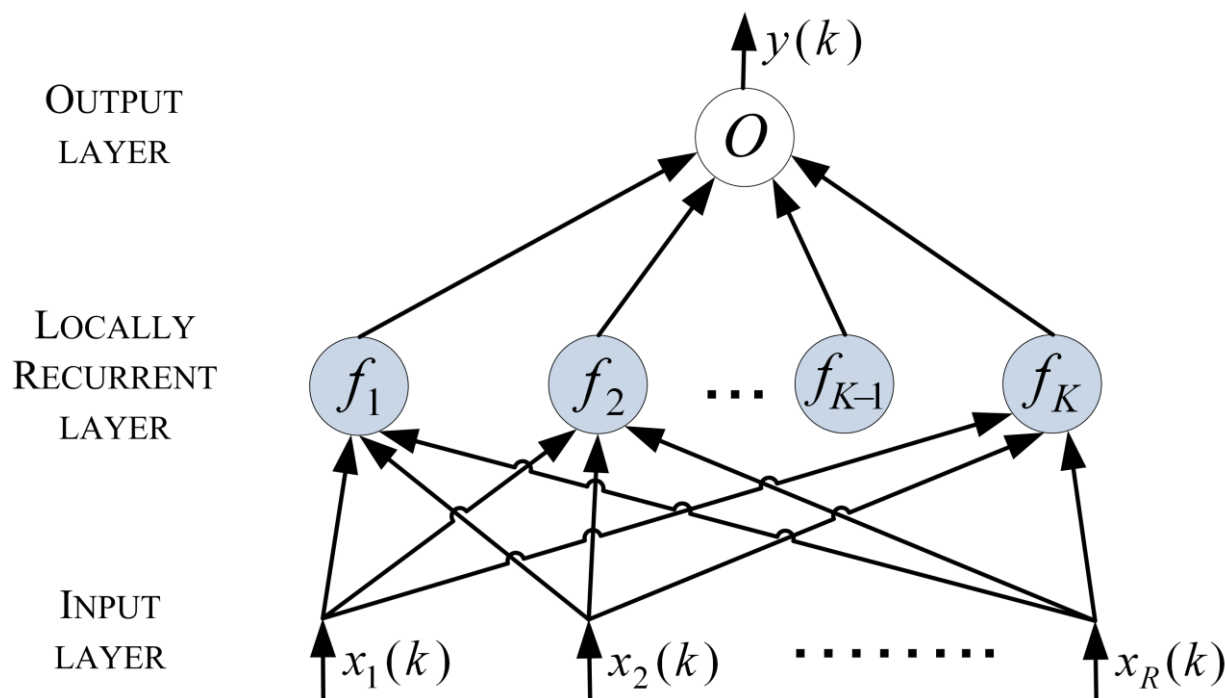
# Локално рекурентни невронни мрежи



$$y(k) = f(v(k)) + H_{FB}(z^{-1})y(k-1)$$

$$v(k) = \sum_{i=1}^K G_i(z^{-1})x_i(k) + b .$$

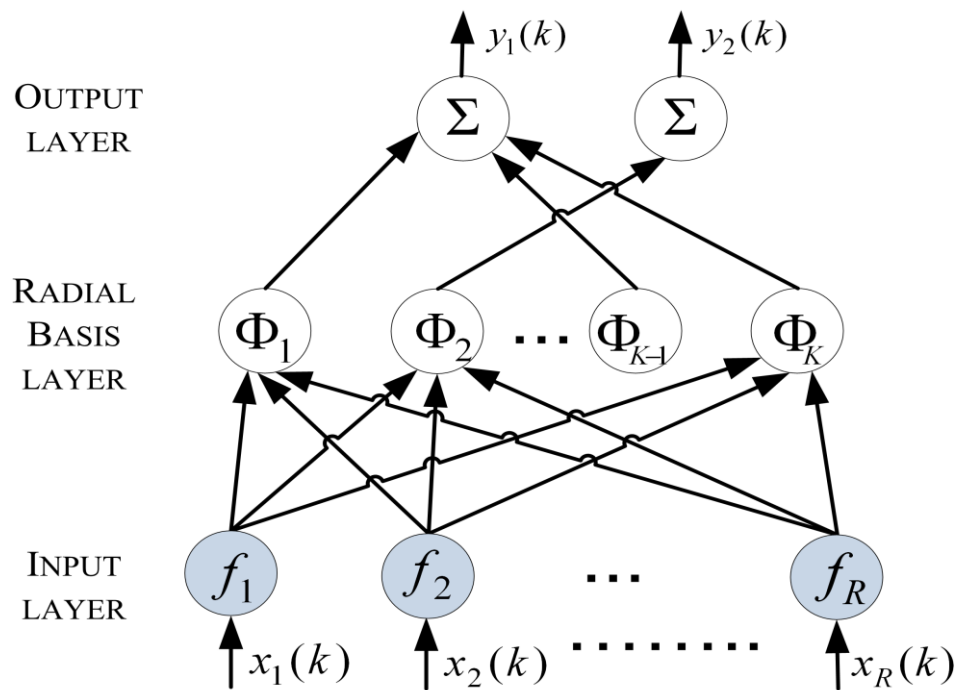
# Диагонално рекурентни невронни мрежи (DRNN)



$$y(k) = \sum_{j=1}^K w_j^O u_j(k)$$

$$u_j(k) = f_j \left( \sum_{i=1}^R w_{ij}^I x_i(k) + w_j^H u_j(k-1) \right) ,$$

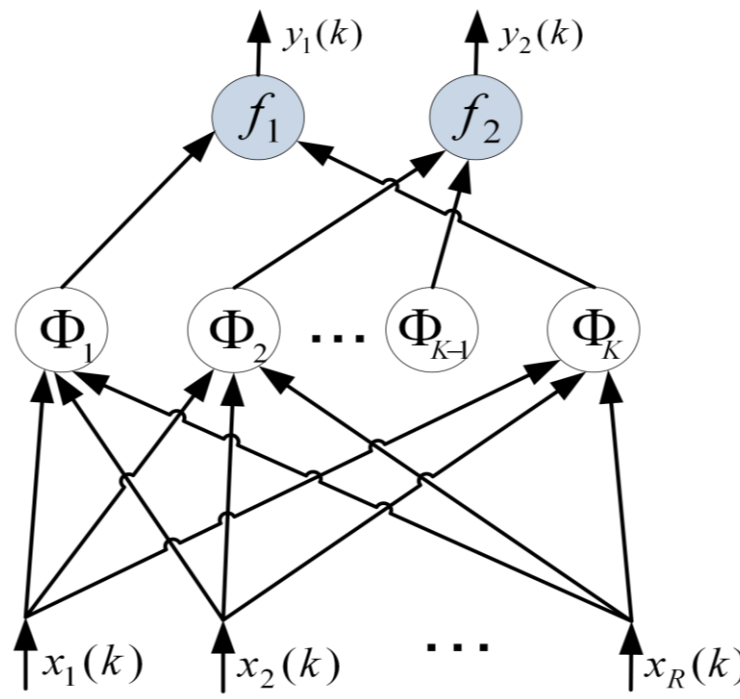
# Locally Recurrent Radial Basis Function Neural Networks



$$y_l(k) = \sum_{j=1}^{K_l} w_j^O \exp\left(-\frac{\sum_{i=1}^R (u_i(k) - \mu_{ij})^2}{\sigma_j^2}\right)$$

$$u_i(k) = f_i(x_i(k) + w_i^I u_i(k-1)) ,$$

# Locally Recurrent Radial Basis Function Neural Networks

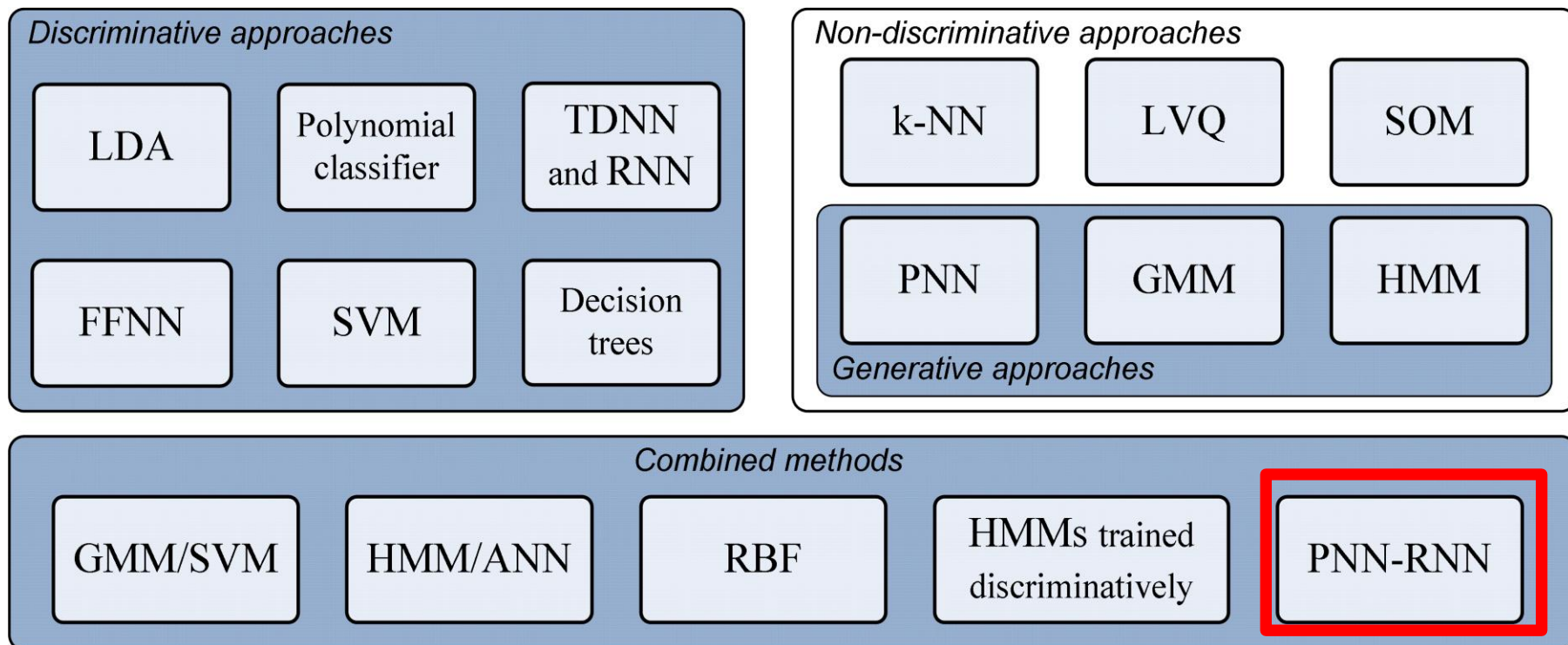


$$y_l(k) = f_l\left(\sum_{j=1}^{K_l} G_j(z^{-1})u_j(k)\right)$$

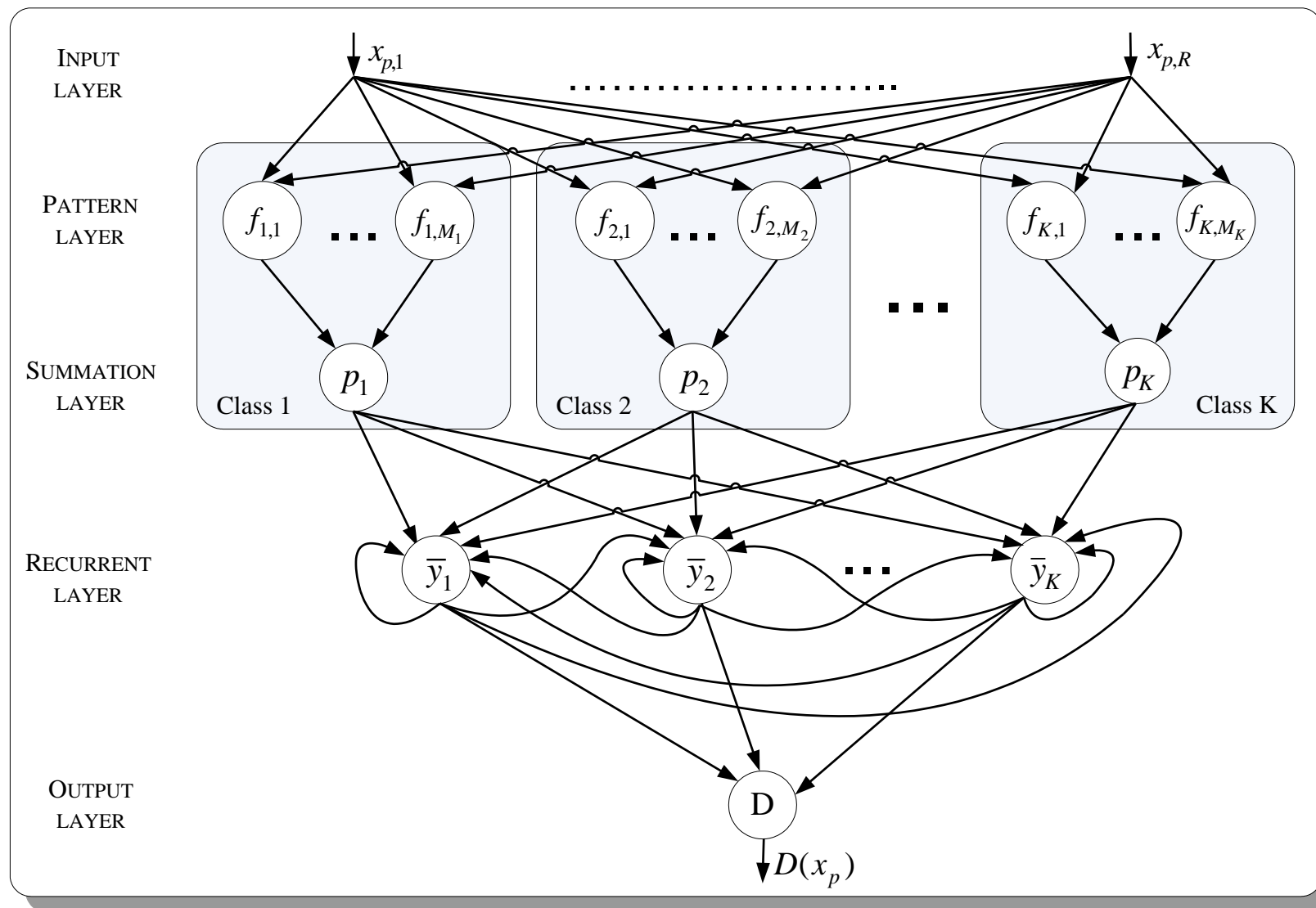
$$u_j(k) = \exp\left(-\frac{\sum_{i=1}^R (x_i(k) - \mu_{ij})^2}{\sigma_j^2}\right),$$



# Класификатори



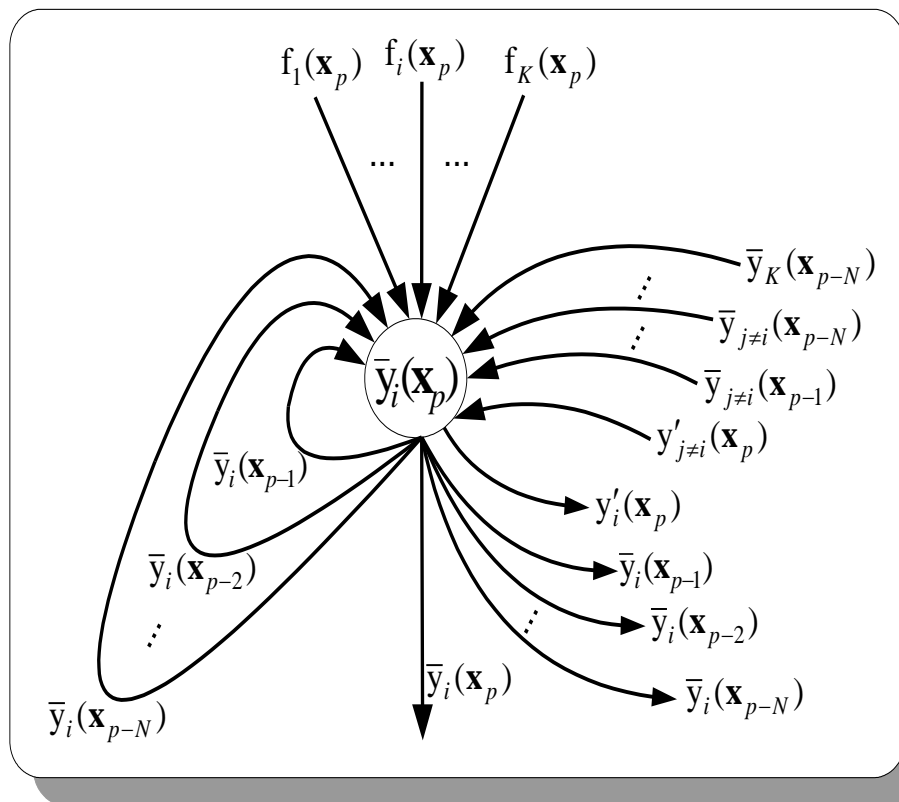
# Locally Recurrent Probabilistic Neural Networks



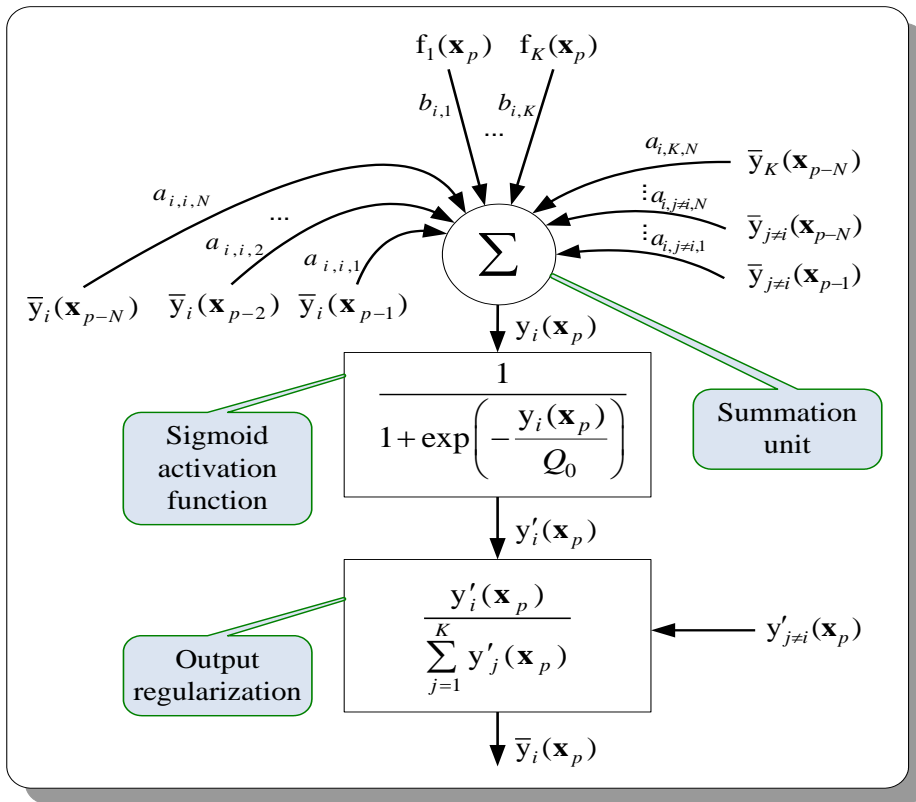
# Locally Recurrent Probabilistic Neural Networks



$i$ - неврон на рекурентния слой на LRPNN



Връзки



Вътрешна структура

# Locally Recurrent Probabilistic Neural Networks



$$f_i(\mathbf{x}_p) = \frac{1}{(2\pi)^{d/2} \sigma_i^d} \cdot \frac{1}{M_i} \sum_{j=1}^{M_i} \exp\left(-\frac{1}{2\sigma_i^2} (\mathbf{x}_p - \mathbf{x}_{ij})^T (\mathbf{x}_p - \mathbf{x}_{ij})\right)$$

$$y_i(\mathbf{x}_p) = \left[ b_{i,i} f_i(\mathbf{x}_p) - \sum_{\substack{k=1 \\ i \neq k}}^K b_{i,k} f_k(\mathbf{x}_p) \right] + \sum_{t=1}^N \left[ a_{i,i,t} \bar{y}_i(\mathbf{x}_{p-t}) - \sum_{\substack{k=1 \\ i \neq k}}^K a_{i,k,t} \bar{y}_k(\mathbf{x}_{p-t}) \right]$$

$$\bar{y}_i(\mathbf{x}_p) = \frac{\text{sgm}(y_i(\mathbf{x}_p))}{\sum_{j=1}^K \text{sgm}(y_j(\mathbf{x}_p))}$$

$$D(\mathbf{x}_p) = \underset{i}{\operatorname{argmax}} \left\{ h_i c_i \bar{y}_i(\mathbf{x}_p) \right\}$$

$$P(k_i | \mathbf{x}_p) = \frac{h_i \bar{y}_i(\mathbf{x}_p)}{\sum_{j=1}^K h_j \bar{y}_j(\mathbf{x}_p)}$$

# Locally Recurrent Probabilistic Neural Networks



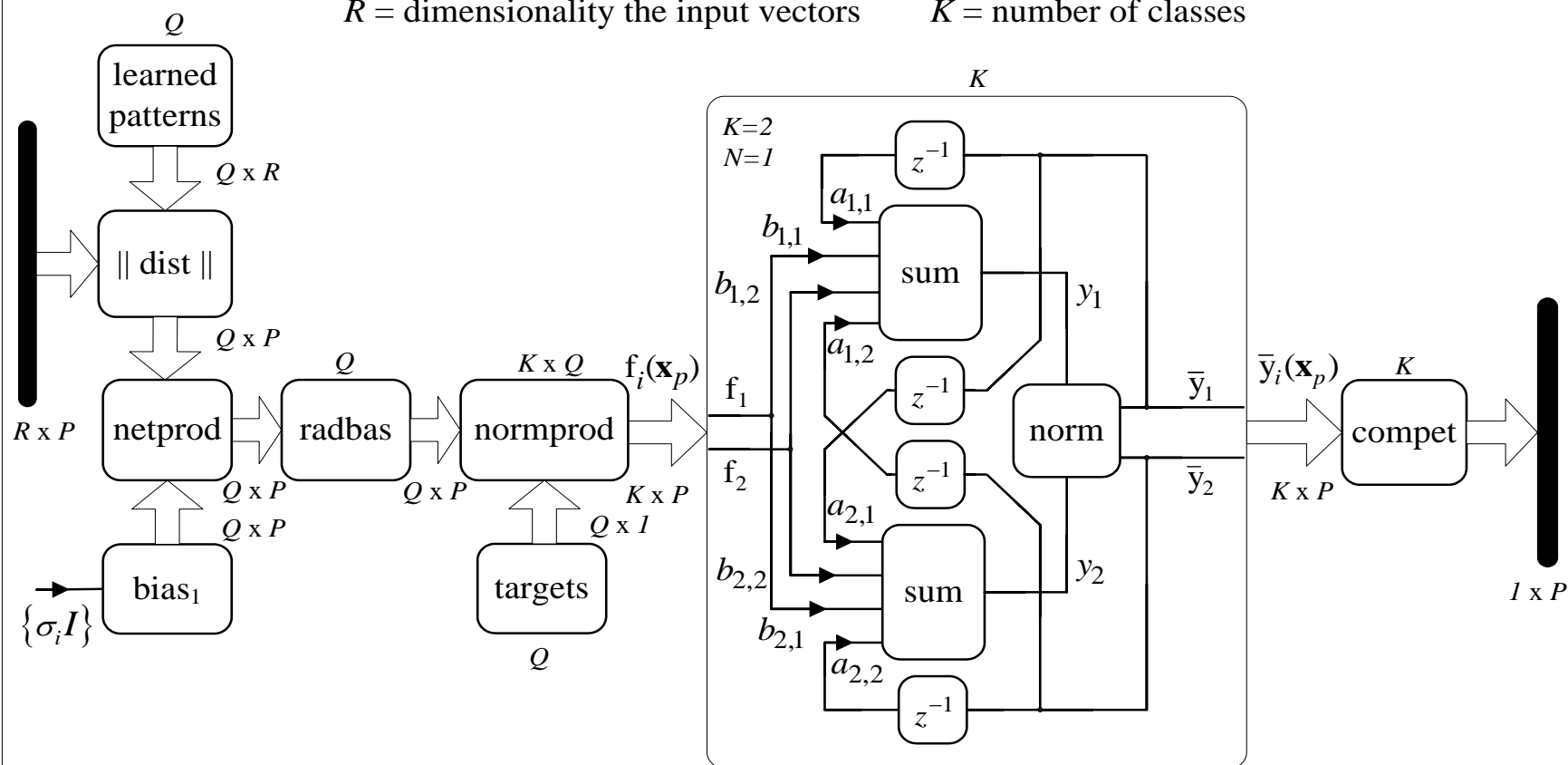
Architecture of the Locally Recurrent Probabilistic Neural Network

$P$  = number of input vectors

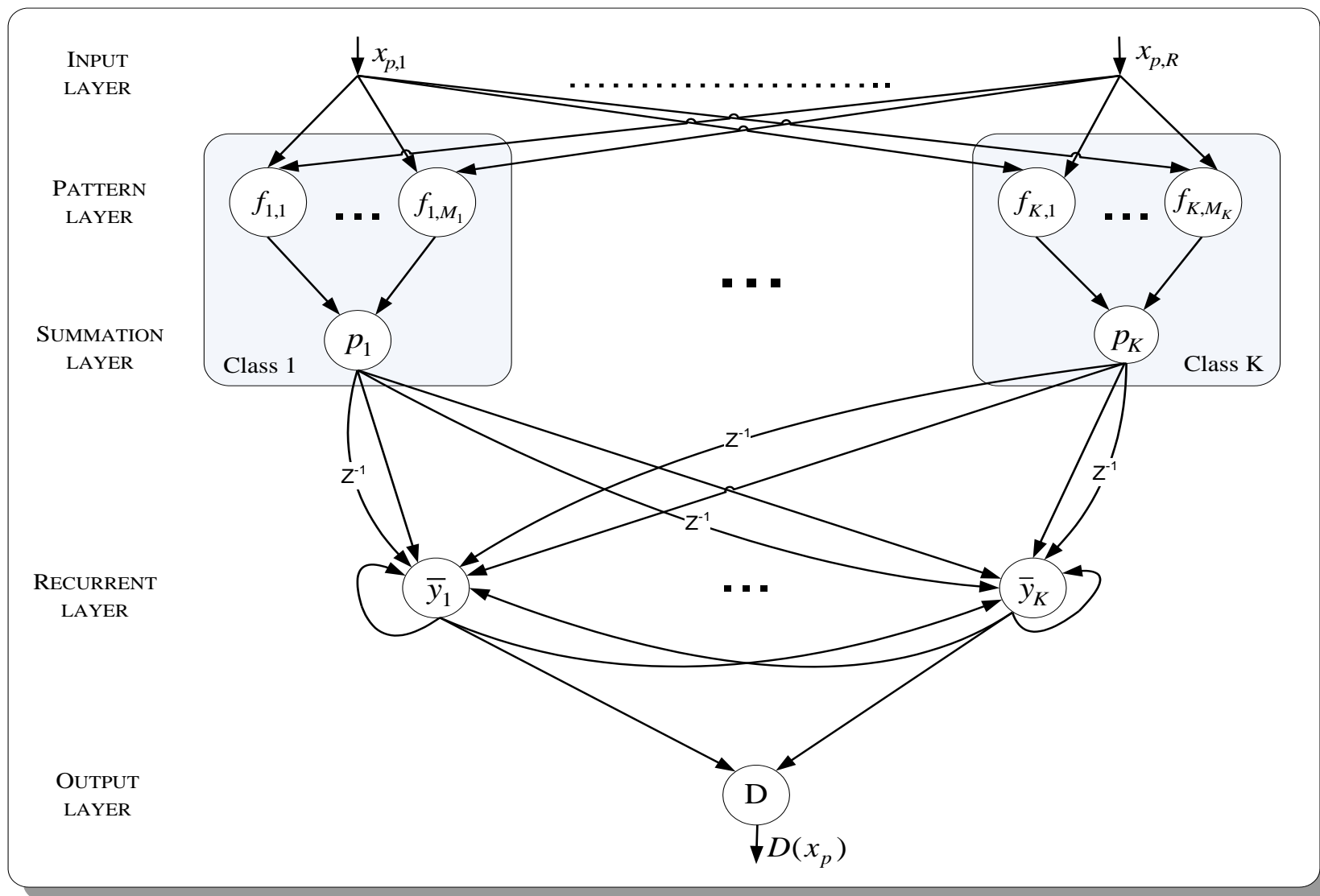
$Q$  = number of pattern units

$R$  = dimensionality the input vectors

$K$  = number of classes



# Generalized LR PNN



# Generalized LR PNN

$$f_i(\mathbf{x}_p) = \frac{1}{(2\pi)^{d/2} \sigma_i^d} \cdot \frac{1}{M_i} \sum_{j=1}^{M_i} \exp \left( -\frac{1}{2\sigma_i^2} (\mathbf{x}_p - \mathbf{x}_{ij})^T (\mathbf{x}_p - \mathbf{x}_{ij}) \right),$$

$$y_i(\mathbf{x}_p) = \sum_{t=0}^L \sum_{k=1}^K b_{i,k,t} f_k(\mathbf{x}_{p-t}) + \sum_{t=1}^N \sum_{k=1}^K a_{i,k,t} \bar{y}_k(\mathbf{x}_{p-t})$$

$$\bar{y}_i(\mathbf{x}_p) = \frac{\text{sgm}(y_i(\mathbf{x}_p))}{\sum_{j=1}^K \text{sgm}(y_j(\mathbf{x}_p))}$$

$$D(\mathbf{x}_p) = \underset{i}{\operatorname{argmax}} \left\{ h_i c_i \bar{y}_i(\mathbf{x}_p) \right\}$$

$$P(k_i | \mathbf{x}_p) = \frac{h_i \bar{y}_i(\mathbf{x}_p)}{\sum_{j=1}^K h_j \bar{y}_j(\mathbf{x}_p)}$$

# Generalized LR PNN

$$E(\mathbf{w}) = E_{lt}(\mathbf{w}) + G_{imp} E_{dif}(\mathbf{w}),$$

$$E_{lt}(\mathbf{w}) = \sum_{i=1}^K c_i P(Miss | k_i) P(k_i),$$

$$E_{dif}(\mathbf{w}) = \frac{1}{K(K-1)} \sum_{i=1}^K \sum_{\substack{j=1 \\ j \neq i}}^K \left| c_i P(Miss | k_i) P(k_i) - c_j P(Miss | k_j) P(k_j) \right|.$$

Differential Evolution метод: (1) Мутация, (2) Рекомбинация, (3) Селекция

$$\mathbf{v}_{g+1}^i = \mathbf{w}_g^{best} + \mu \left( \mathbf{w}_g^{r1} - \mathbf{w}_g^{r2} \right),$$

$$\mathbf{v}_{g+1}^i = \mathbf{w}_g^{best} + \mu \left( \mathbf{w}_g^{r1} - \mathbf{w}_g^{r2} \right) + \mu \left( \mathbf{w}_g^{r3} - \mathbf{w}_g^{r4} \right).$$

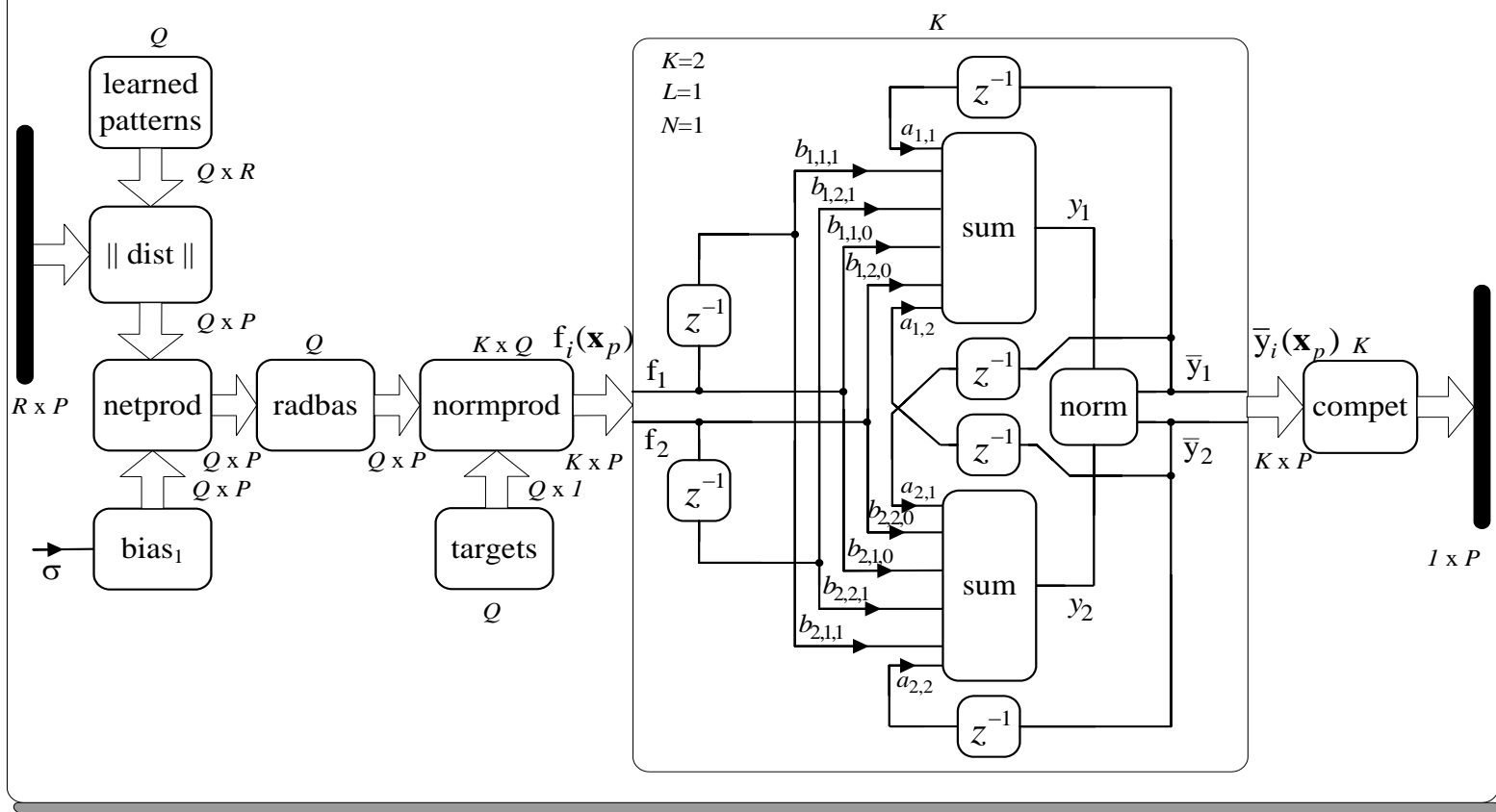


# Generalized LR PNN

## Architecture of the Generalized Locally Recurrent Probabilistic Neural Network

$P$  = number of input vectors  
 $R$  = dimensionality the input vectors

$Q$  = number of pattern units  
 $K$  = number of classes

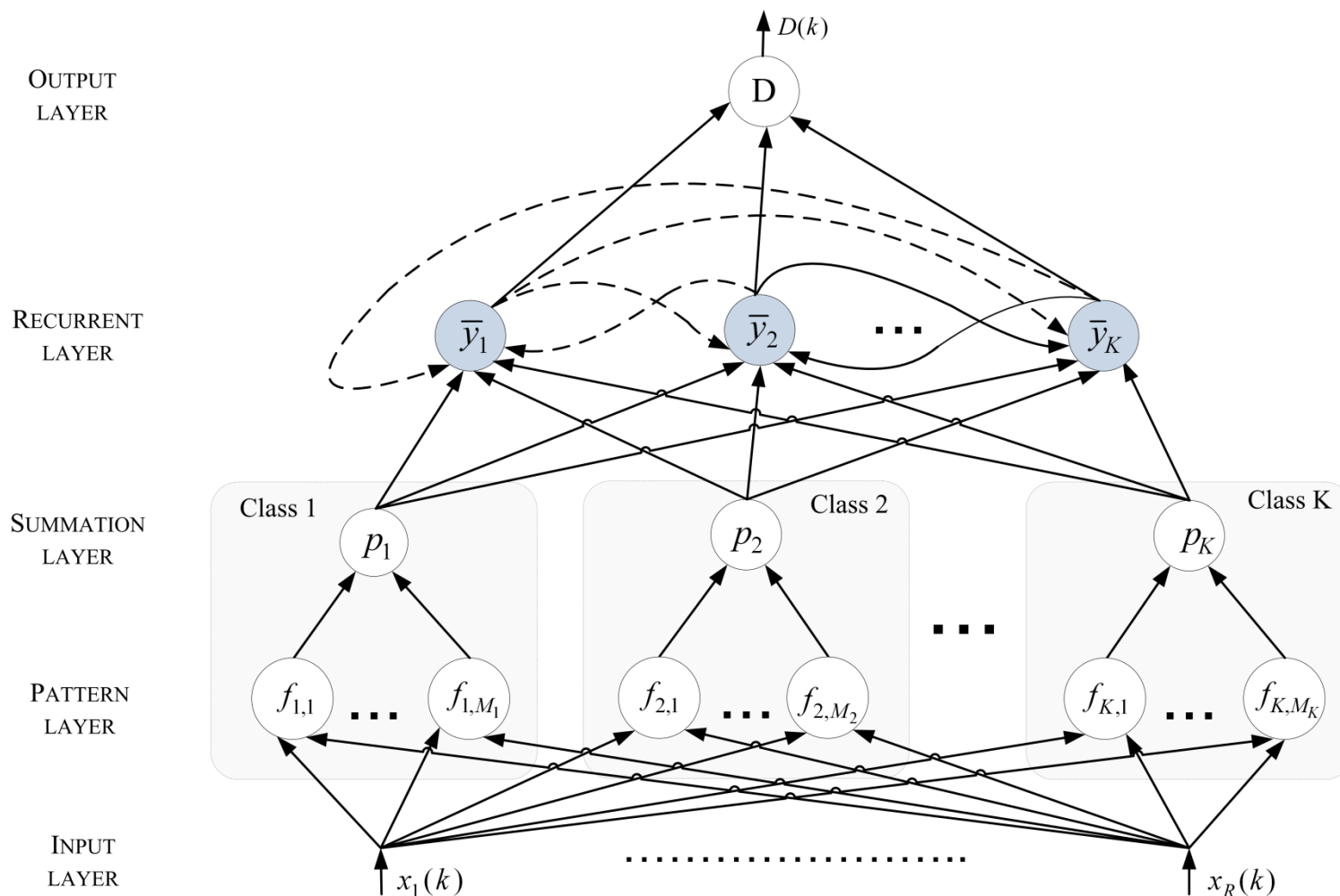


# Generalized LR PNN

The EER and  $DCF_{\text{opt}}$  depending on the architecture

	Arch. # $w^*$	FIR 4	IIR 6	DRNN 10	LR PNN 8	GLR PNN 12
Males	EER (%)	4.45	4.17	4.02	3.98	3.89
	$DCF_{\text{opt}}$	0.307	0.268	0.249	0.241	0.230
Females	EER (%)	5.32	5.22	5.00	4.91	4.70
	$DCF_{\text{opt}}$	0.447	0.424	0.421	0.389	0.378

# Partially Connected Locally Recurrent Probabilistic Neural Networks



# Partially Connected Locally Recurrent Probabilistic Neural Networks



$$p_j(\mathbf{x}(k) | j) = f_j(\mathbf{x}_k) = \frac{1}{(2\pi)^{d/2} \sigma_j^d} \cdot \frac{1}{M_j} \sum_{i=1}^{M_j} \exp\left(-\frac{1}{2\sigma_j^2} (\mathbf{x}_k - \mathbf{x}_{ij})^T (\mathbf{x}_k - \mathbf{x}_{ij})\right), j = 1, 2, \dots, K,$$

$$y_j(\mathbf{x}_k) = b_{jj} f_j(\mathbf{x}_k) - \sum_{\substack{i=1 \\ i \neq j}}^K b_{ij} f_j(\mathbf{x}_k) + \sum_{t=1}^N (a_{jjt} \bar{y}_j(\mathbf{x}_{k-t}) - \sum_{\substack{i=1 \\ i \neq j}}^K a_{ijt} \bar{y}_j(\mathbf{x}_{k-t})), j = 1, 2, \dots, K,$$

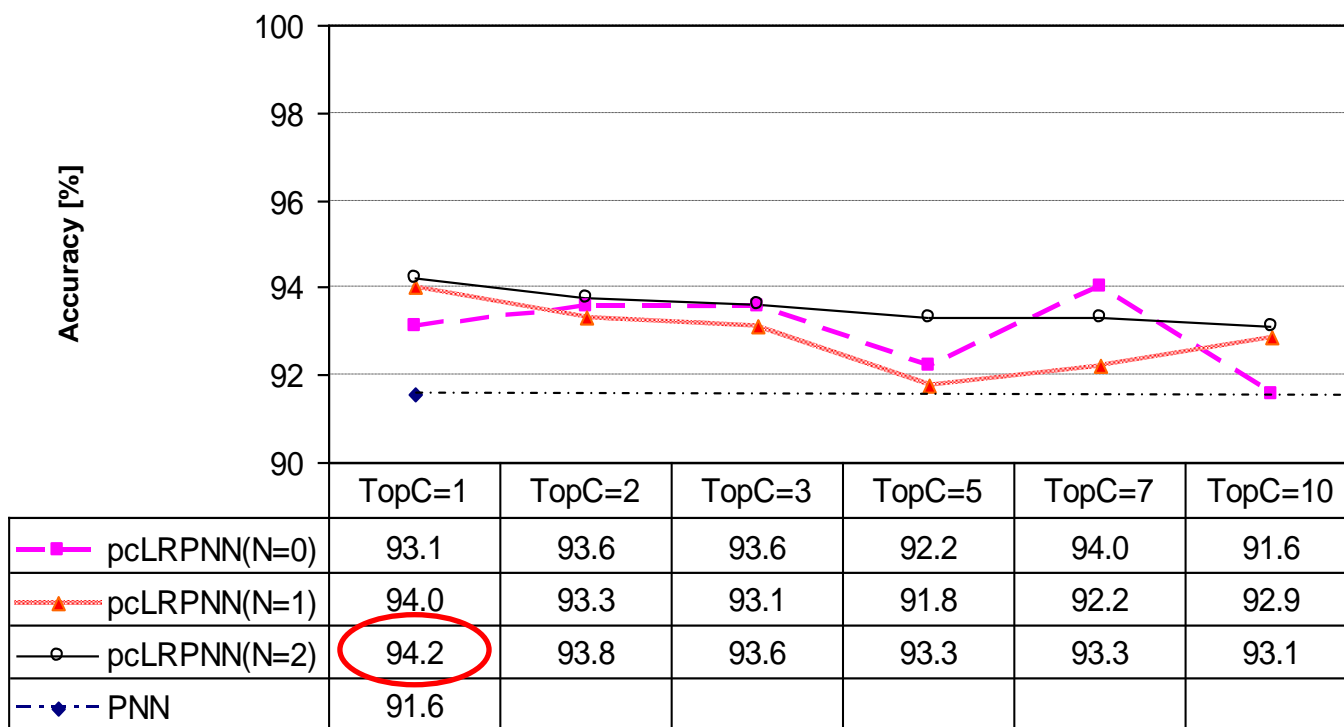
$$E(\mathbf{w}) = \sum_{i=1}^K m_i \left(1 - P(\mathbf{X}_{k_i} | k_i)\right) P(k_i) + \frac{1}{K-1} \sum_{i=1}^K \sum_{\substack{j=1 \\ j \neq i}}^K m_j P(\mathbf{X}_{k_i} | k_j) P(k_j)$$

$$\bar{y}_j(\mathbf{x}_k) = \frac{\text{sgm}(y_j(\mathbf{x}_k))}{\sum_{i=1}^K \text{sgm}(y_i(\mathbf{x}_k))}, j = 1, 2, \dots, K,$$

$$D(\mathbf{x}_k) = \underset{j}{\operatorname{argmax}} \{h_j c_j \bar{y}_j(\mathbf{x}_k)\}, j = 1, 2, \dots, K,$$

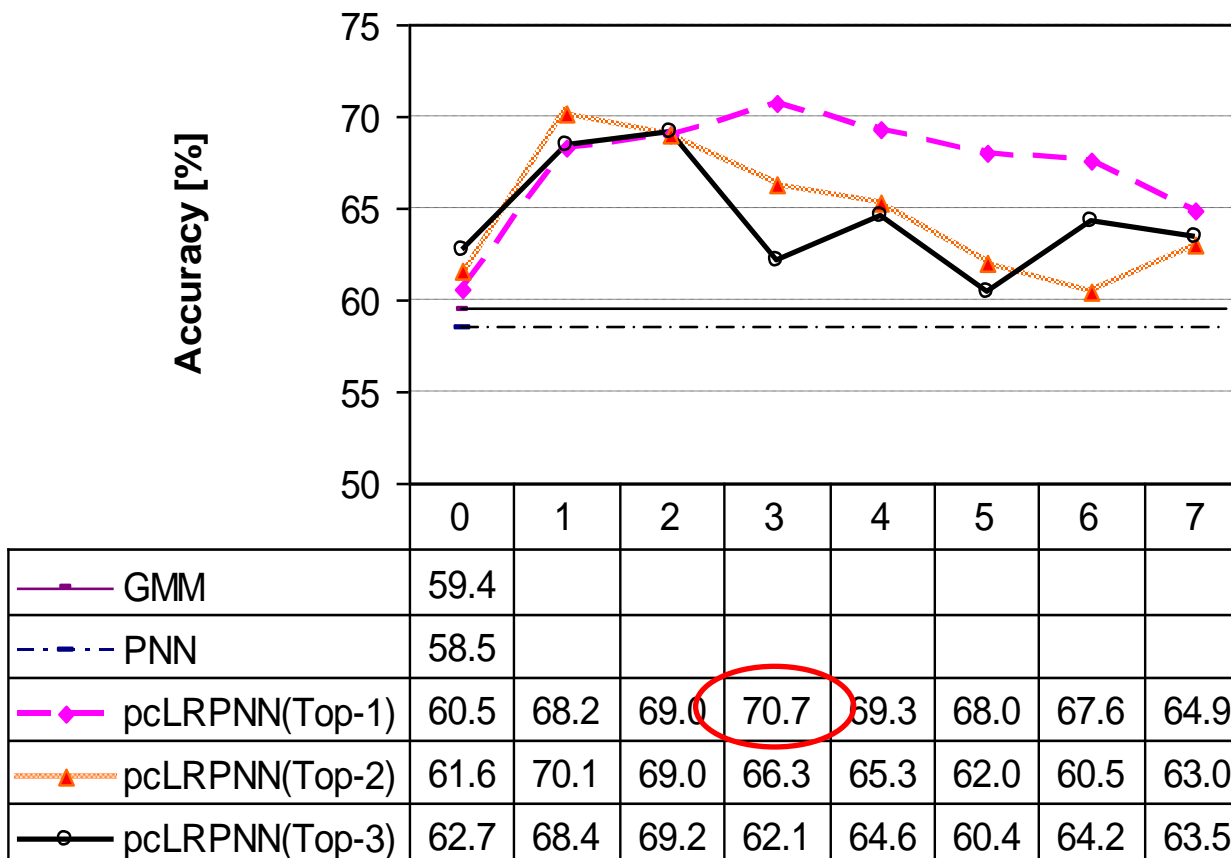
# pcLRPNN

## Идентификация на диктори

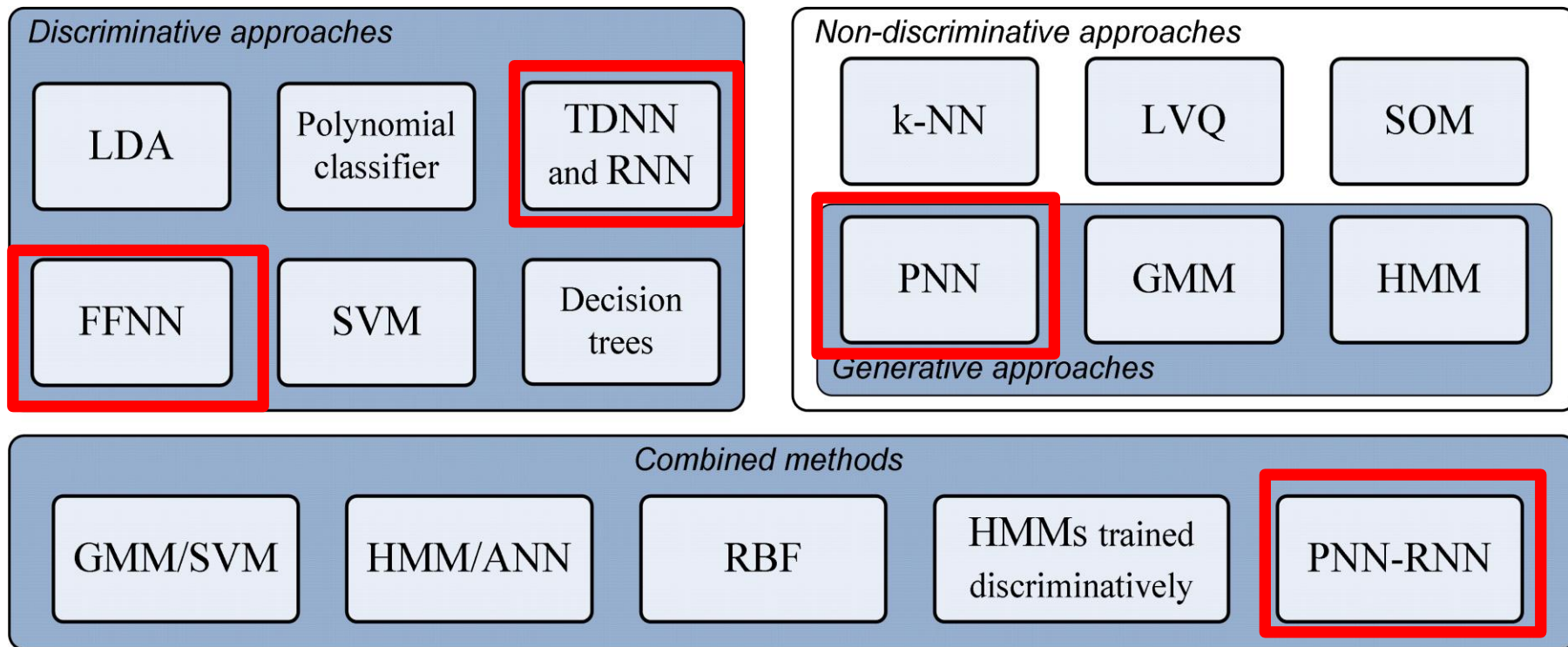


# pcLRPNN

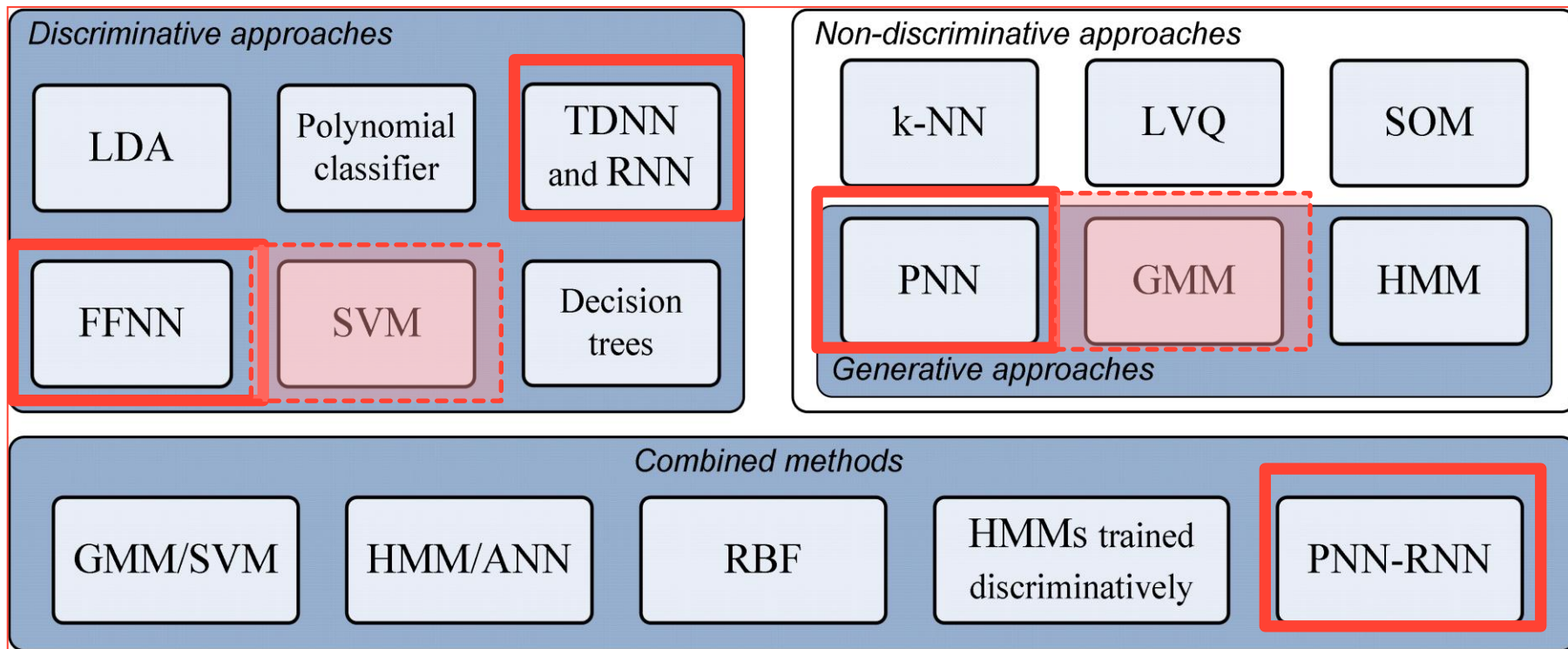
## Разпознаване на емоционална реч



# Класификатори



# Класификатори





# Съдържание– Машинно (само)обучение

- ☐ Обща класификация на методите
- ☐ Класификация с невронни мрежи. Архитектури. MLPNN и PNN.
- ☐ Неврони с обратна връзка. Рекурентни и локално рекурентни невронни мрежи (TDNN, RNN, DRNN, LRPNN, GLRPNN)
- ☐ Статистически методи. Генеративни класификатори. Класификатор със смес от Гаусови функции (Gaussian Mixture Models, GMM)
- ☐ Статистически методи. Дискриминативни класификатори. Класификатор с опорни вектори (Support Vector Machine, SVM)