# Evolutionary Design of the Closed Loop Control on the Basis of NN-ANARX Model Using Genetic Algoritm

# Principles of Genetic Algorithms

*Initial* ***Population*** *– a set of strings called* ***Chromosomes***

*[0 1 0 1 1 0 1 0 … 0 1 1 1 0 1]*
*[0 0 0 0 1 1 1 0 … 1 1 0 1 0 1]*
…
*[0 1 0 0 0 0 1 0 … 1 1 1 1 0 1]*

*Calculation of* ***fitness function,***

*sort Chromosomes and choose the best ones*

# Principles of Genetic Algorithms

*Formation of new generation:*

*1. Crossover*

*[0 1 0 1 1 0 1 0 … | 0 1 0 1 0 1]*

*[1 0 0 0 0 1 1 0 … | 1 0 1 1 1 1]*

*at random places*

*[0 1 0 1 1 0 1 0 … 0 0 1 1 1 1]*

*[1 0 0 0 0 1 1 0 … 1 1 0 1 0 1]*

*2. Mutation* *[0 1 1 1 1 0 1 0 … 0 1 1 1 0 1]*

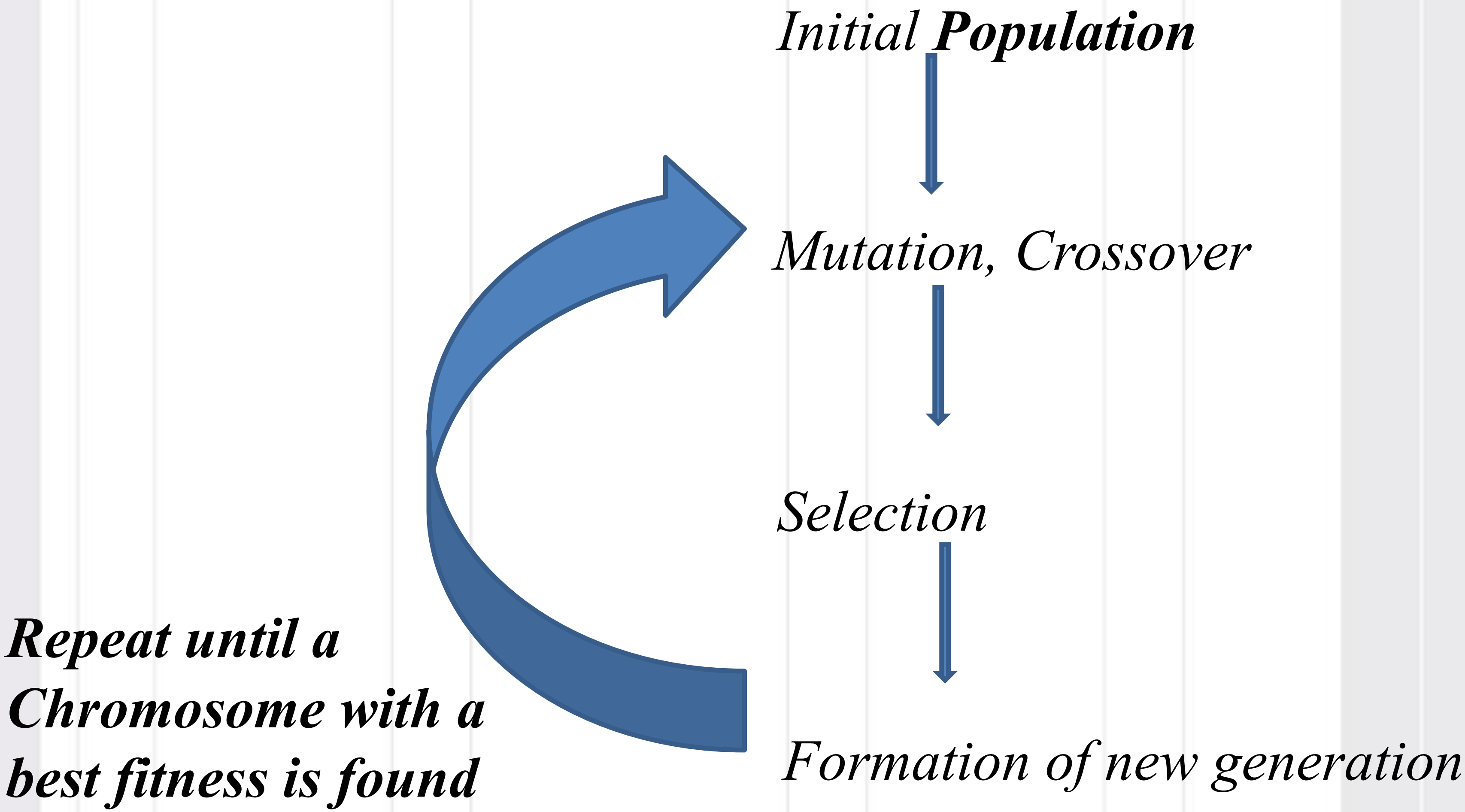
*at random places (~1%)*

*[0 1 0 1 1 0 0 0 … 0 1 1 1 0 1]*

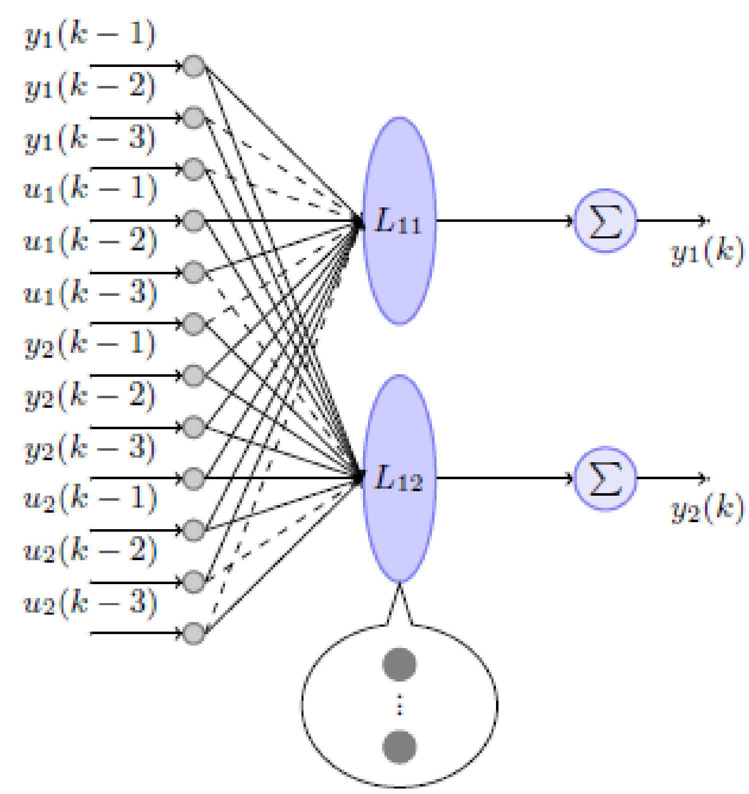
*"Best Parents" are used in crossover and mutation more frequently*

*3. "New Blood" – some absolutely new chromosomes*

# Principles of Genetic Algorithms



# Principles of Genetic Algorithms for selection of Neural Network's Structure




For fully connected NN-NARX

$$gene = [111111111111\ 111111111111]$$

For custom structure NN

$$gene = [110101111001\ 111111111001]$$

*Fitness function – for example, MSE*

# *ANARX model*

**NARX (Nonlinear Autoregressive Exogenous) model:**

$$y(t+n) = f\big(y(t), y(t+1), \ldots, y(t+n-1), u(t), u(t+1), \ldots, u(t+n-1)\big)$$

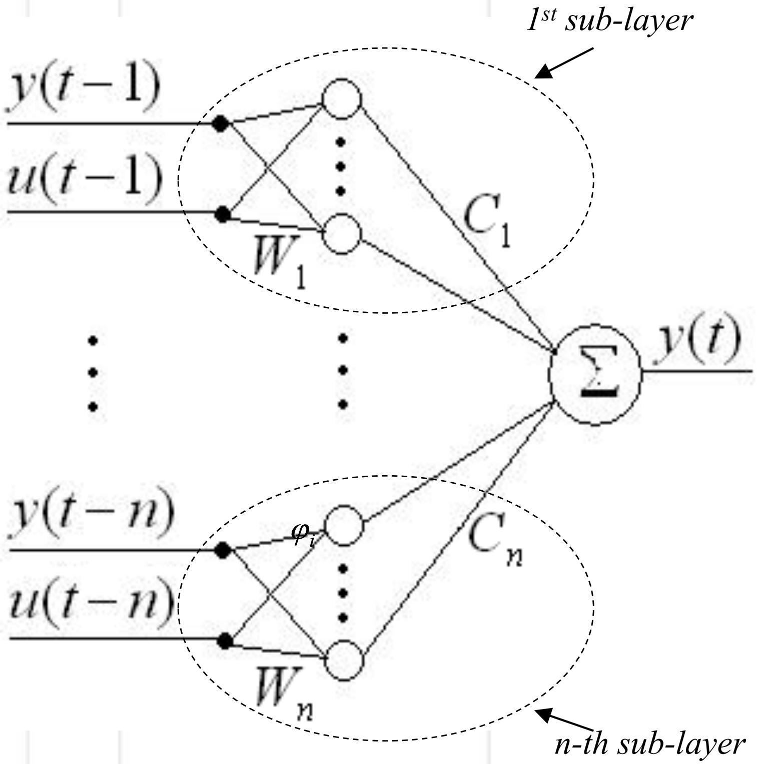
**ANARX (Additive Nonlinear Autoregressive Exogenous) model:**

$$y(t+n) = f_1\big(y(t), u(t)\big) + f_2\big(y(t+1), u(t+1)\big) + \ldots + f_n\big(y(t+n-1), u(t+n-1)\big)$$

or

$$y(t+n) = \sum_{i=1}^{n} f_i\big(y(t+i-1), u(t+i-1)\big)$$

# NN-based ANARX model (NN-ANARX)




$$y(t+n) = \sum_{i=1}^{n} C_i \varphi_i \left( W_i \cdot \left[ y(t+i-1), u(t+i-1) \right]^T \right)$$

$\varphi_i$ *is a sigmoid function*

# *ANARX Model based Dynamic Output Feedback Linearization Algorithm*

**ANARX model**

$$y(t+n)=\sum_{i=1}^{n} f_i(y(t+i-1),u(t+i-1))$$

**NN-ANARX model**

$$y(t+n)=\sum_{i=1}^{n} C_i\varphi_i\left(W_i\cdot\left[y(t+i-1),u(t+i-1)\right]^T\right)$$

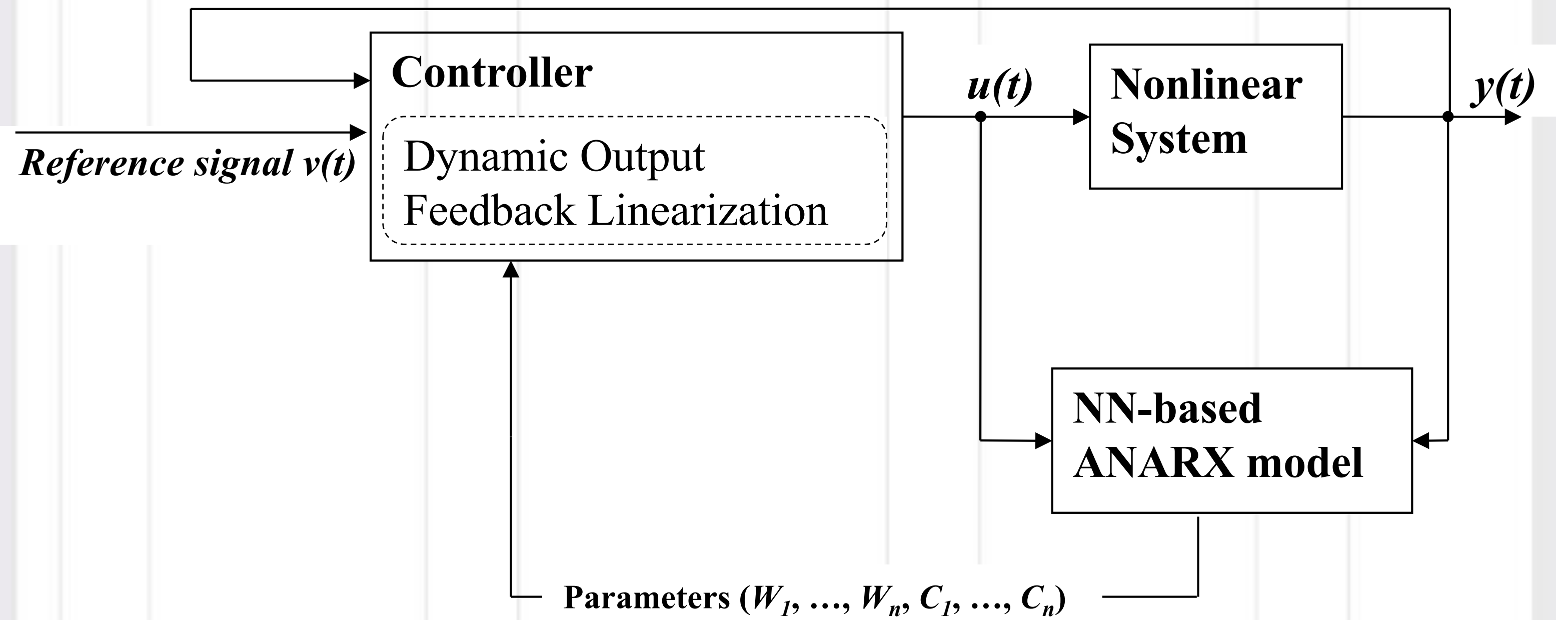
$$\begin{cases} F=f_1\big(y(t),u(t)\big)=\eta_1(t) \\ \eta_1(t+1)=\eta_2(t)-f_2\big(y(t),u(t)\big) \\ \vdots \\ \eta_{n-2}(t+1)=\eta_{n-1}(t)-f_{n-1}\big(y(t),u(t)\big) \\ \eta_{n-1}(t+1)=v(t)-f_n\big(y(t),u(t)\big) \end{cases}$$

**NN** ⇒

$$\begin{cases} F=C_1\varphi_1\left(W_1\cdot\left[y(t),u(t)\right]^T\right)=\eta_1(t) \\ \eta_1(t+1)=\eta_2(t)-C_2\varphi_2\left(W_2\cdot\left[y(t),u(t)\right]^T\right) \\ \vdots \\ \eta_{n-2}(t+1)=\eta_{n-1}(t)-C_{n-1}\varphi_{n-1}\left(W_{n-1}\cdot\left[y(t),u(t)\right]^T\right) \\ \eta_{n-1}(t+1)=v(t)-C_n\varphi_n\left(W_n\cdot\left[y(t),u(t)\right]^T\right) \end{cases}$$

$$y(t+n)=v(t)$$

# *NN-ANARX Model based Control of Nonlinear Systems*



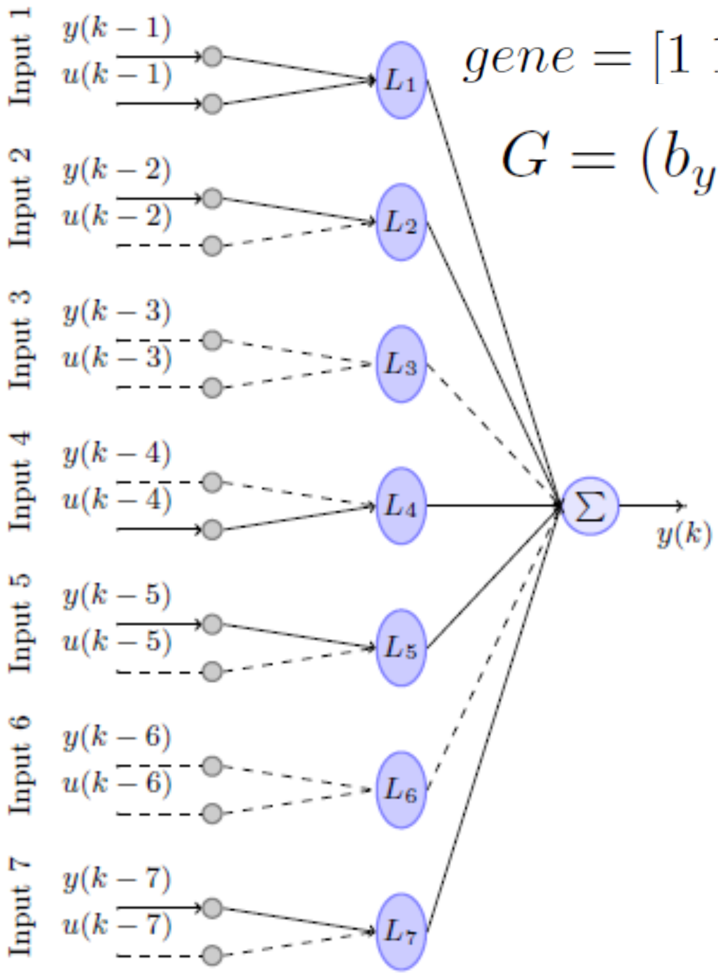
# *Problems to be solved*

- *A little or no knowledge about structure of the system is given a priori*
- *A set of neural networks must be trained to find an optimal structure*
- *Quality of the model depends on the choice of initial parameters*
- *Quality of the model should be evaluated in the closed loop*

*These problems can be solved using **GA**.*

# *GA for structural identification*

NN-ANARX structure may be easily coded as a gene.
Consider an example (custom structure model):




$$gene = [1\,1 \quad 1\,0 \quad 0\,0 \quad 0\,1 \quad 1\,0 \quad 0\,0 \quad 1\,0]$$

$$G = (b_{y1}, b_{u1}, b_{y2}, b_{u2}, \ldots b_{yn}, b_{un},)$$

# *Dynamic controller based on custom structure model*

$$F = C_1 W_1 \left[ b_{y1} y(t), b_{u1} u(t) \right]^T = \eta_1(t)$$

$$\eta_1(t+1) = \eta_2(t) - C_2 \phi_2 \left( W_2 \left( b_{y2} x_1(t), b_{u1} u(t) \right)^T \right)$$

$$\dots$$

$$\eta_{n-2}(t+1) = \eta_{n-1}(t) - C_{n-1} \phi_{n-1} \left( W_{n-1} \left( b_{y,n-1} x_1(t), b_{u,n-1} u(t) \right)^T \right)$$

$$\eta_{n-1}(t+1) = \nu(t) - C_n \phi_n \left( W_n \left( b_{y,n} x_1(t), b_{u,n} u(t) \right)^T \right)$$

Gene:

$$G = (b_{y1}, b_{u1}, b_{y2}, b_{u2}, \dots b_{yn}, b_{un}, )$$

# *Fitness function*

Model structure optimization is based on fitness function consisting of 2 parameters:

- Error of the closed-loop control system
- Order of the model

All of the criteria are normalized

# *Numerical evaluation of the criteria*

- $e = 1 - e^{-k \cdot mse}$
- $\hat{o}_i = \frac{o_i}{\|o\|}$ where $\|.\| := \max(|o_1|, \ldots, |o_n|)$

**<u>Evaluation function</u>:** $f = k_1 \cdot e + k_2 \cdot \hat{o}$

with $k_1 + k_2 = 1$