Capabilities and Prospects of Inductive Modeling

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Layout

1. Historical aspects of IM
2. International events on IM
3. Attempt to define IM: what is it?
4. IM destination: what is this for?
5. IM explanation: basic algorithms and tools
6. Basic Theoretical Results
7. IM compared to ANN and CI
8. Real-world applications of IM
9. Main centers of IM research
10. IM development prospects

1. Historical aspects of IM

1968 First publication on GMDH:

- Івахненко О.Г. Метод групового урахування аргументів – конкурент методу стохастичної апроксимації // Автоматика. – 1968. – № 3. – С. 58-72.

- *Terminology evolution*:

  - heuristic self-organization of models (1970s)
  - inductive method of model building (1980s)
  - inductive learning algorithms for modeling (1992)
  - inductive modeling (1998)

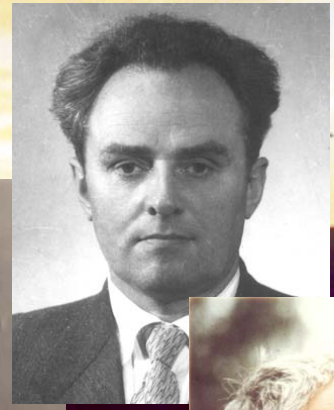
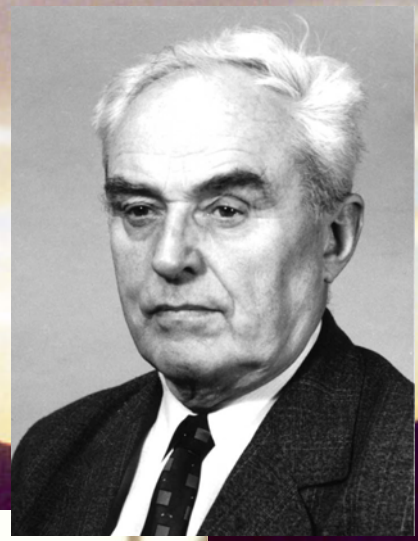
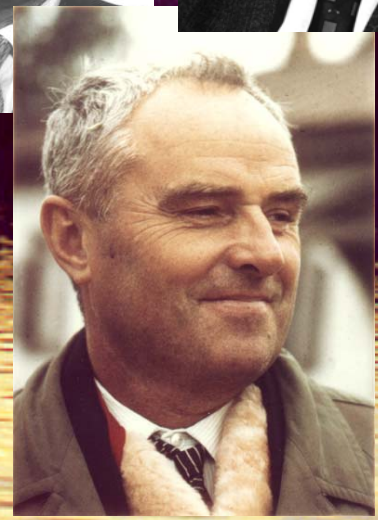
GMDH: Group Method of Data Handling

MGUA: Method of Group Using of Arguments

A.G.Ivakhnenko: GMDH originator





Main scientific results in inductive modelling theory:

- Foundations of cybernetic forecasting device construction
- Theory of models self-organization by experimental data
- Group method of data handling (GMDH) for automatic construction (self-organization) of model for complex systems
- Method of control with optimization of forecast
- Principles of noise-immunity modelling from noisy data
- Principles of polynomial networks construction
- Principle of neural networks construction with active neurons

Academician Ivakhnenko

- *Originator of the scientific school of inductive modelling*
- *Author of 44 monographs and numerous articls*
- *Prepared more than 200 Cand. Sci (Ph.D.) and 27 Doct. Sci*

2. International events on IM

- ***2002 Lviv, Ukraine***
  1st International Conference on Inductive Modelling ICIM'2002
- ***2005 Kyiv, Ukraine***
  1st International Workshop on Inductive Modelling IWIM'2002
- ***2007 Prague, Czech Republic***
  2nd International Workshop on Inductive Modelling IWIM'2007
- ***2008 Kyiv, Ukraine***
  2nd International Conference on Inductive Modelling ICIM'2008
- ***2009 Krynica, Poland***
  3rd International Workshop on Inductive Modelling IWIM'2009
- ***2010 Yevpatoria, Crimea, Ukraine***
  3rd International Conference on Inductive Modelling ICIM'2009
- *Zhukyn (near Kyiv, Ukraine)*
  Annual International Summer School on Inductive Modelling

3. Attempt to define IM: what is it?

- IM is MGUA / GMDH
- IM is a technique for model self-organization
- IM is a technology for building models from noisy data
- IM is the technology of inductive transition from data to models under uncertainty conditions:
  - small volume of noisy data
  - unknown character and level of noise
  - inexact composition of relevant arguments (factors)
  - unknown structure of relationships in an object

4. IM destination: what is this for?

IM is used for solving the following problems:

- ✓ Modelling from experimental data
- ✓ Forecasting of complex processes
- ✓ Structure and parametric identification
- ✓ Classification and pattern recognition
- ✓ Data clasterization
- ✓ Machine learning
- ✓ Data Mining
- ✓ Knowledge Discovery

5. IM explanation: algorithms and tools

Basic Principles of GMDH as an Inductive Method

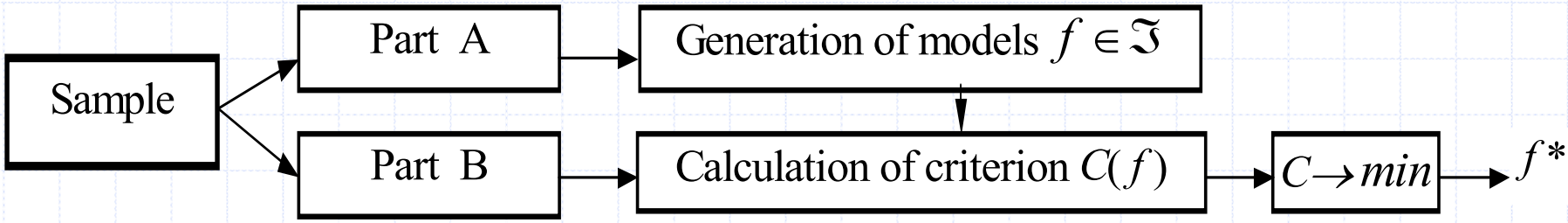
Given: data sample of n observations after m input $x_1, x_2, \ldots, x_m$ and output y variables

Find: model $y = f(x_1, x_2, \ldots, x_m, \theta)$ with *minimum variance of prediction error*

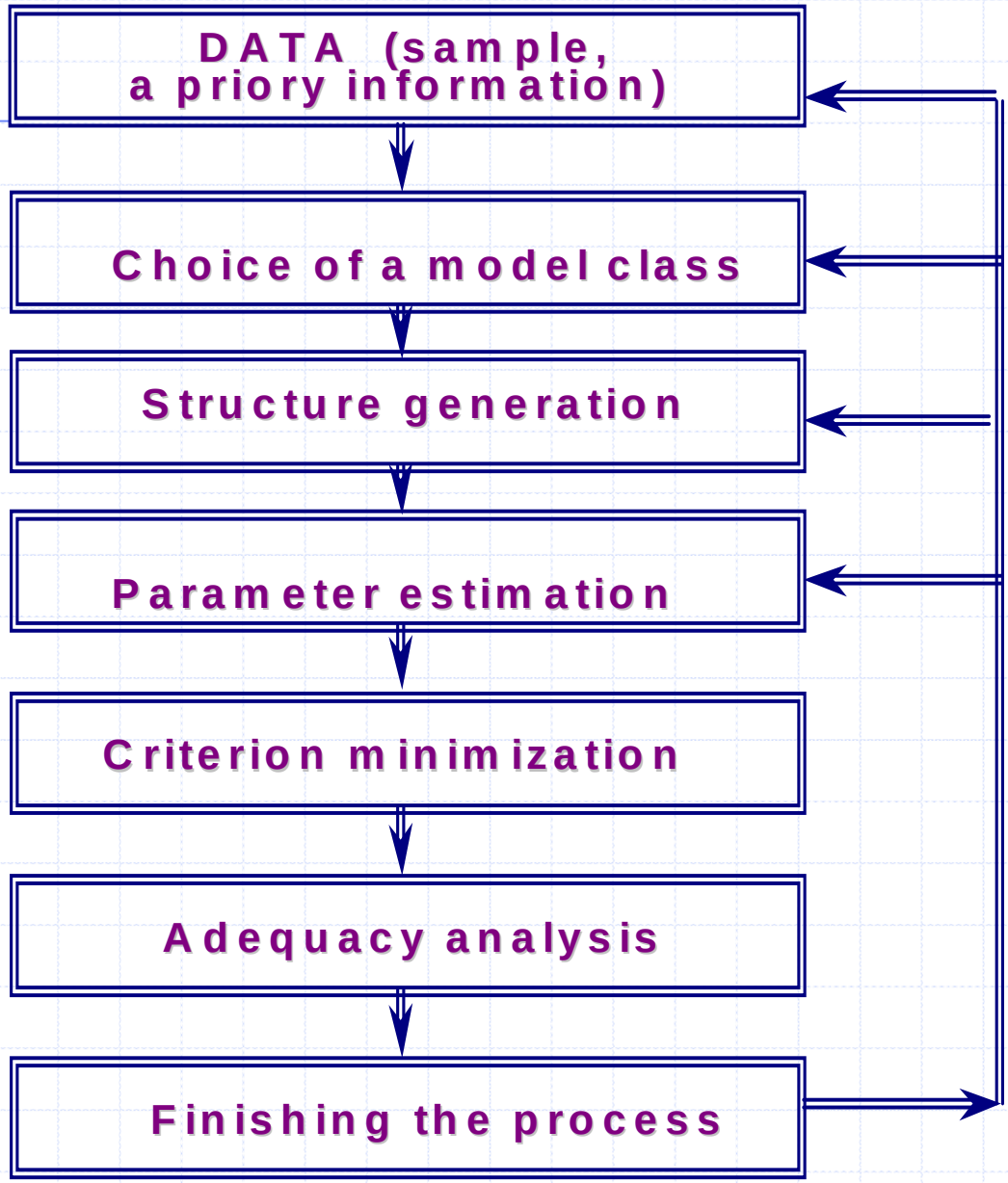
GMDH Task: $f^* = \arg\min_{f \in \Im} C(f)$, $C(f)$ – model quality criterion, $\Im$ – set of models

Basic principles of the GMDH as an ***inductive*** **method**:

1. ***generation of variants*** of the *gradually complicated structures* of models
2. ***successive selection*** of the best variants using the *freedom of decisions choice*
3. ***external addition*** (due to the *sample division*) as the selection criterion

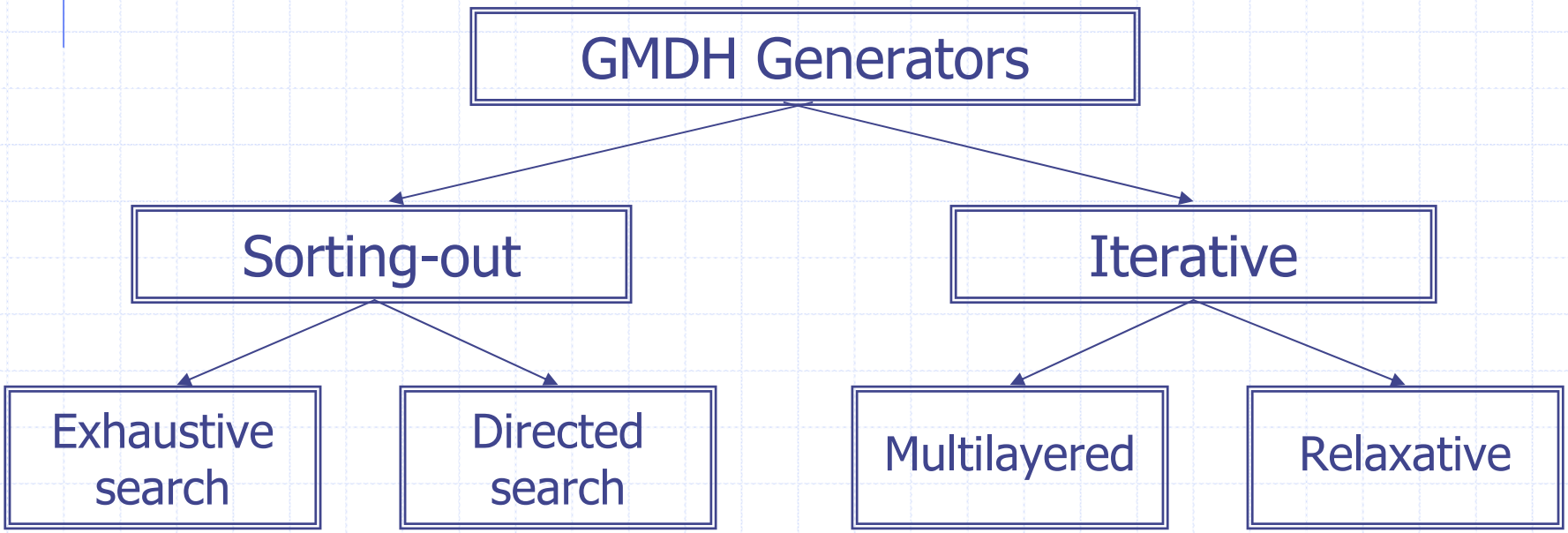


Main stages of the modeling process



GMDH features

- **Model Classes**: linear, polynomial, autoregressive, difference (dynamic), nonlinear of network type etc.
- **Parameter estimation**: Least Squares Method (LSM)
- **Model structure generators**:



Main generators of models structures

1. Combinatorial:

$$y_v = X_v\widehat{\theta}_v,\ v = 1,\ldots,2^m;\quad d = (d_1, d_2,\ldots,d_m)$$

2. Combinatorial-selective:

$$\widehat{y}_s^l = (X_{s-1}^i \mid x_s^j)\widehat{\theta}_s,\ s = \overline{1,m},\quad i,l = \overline{1,F_{s-1}}$$

3. Selective (multilayered iterative):

$$y_l^{r+1} = \vartheta_{1l}y_i^r + \vartheta_{2l}y_j^r + \vartheta_{3l}y_i^r y_j^r + \vartheta_4(y_i^r)^2 + \vartheta_5(y_j^r)^2,$$

$$r = 0,1,\ldots;\ i,j = \overline{1,F};\ l = \overline{1,C_F^2}$$

External Selection Criteria

Given sample: $W = (X \mid y)$, $X[n \times m]$, $y[n \times 1]$

Division into two subsamples:

$$W = \begin{bmatrix} W_A \\ W_B \end{bmatrix}; X = \begin{bmatrix} X_A \\ X_B \end{bmatrix}; y = \begin{bmatrix} y_A \\ y_B \end{bmatrix}; n_A + n_B = n$$

Parameter estimation for a model $y = X\theta$:

$$\widehat{\theta}_G = (X_G^T X_G)^{-1} X_G^T y_G, \quad G = A, B, W,$$

Regularity **criterion:** $$AR_B = \left\| y_B - X_B \widehat{\theta}_A \right\|^2$$

Unbiasedness **criterion:** $$CB = \left\| X_W \widehat{\theta}_A - X_W \widehat{\theta}_B \right\|^2$$

IM tools

- Information Technology ASTRID (Kyiv)
- KnowledgeMiner (Frank Lemke, Berlin)
- FAKE GAME (Pavel Kordik at al., Prague)
- GMDHshell (Oleksiy Koshulko, Kyiv)

6. Basic Theoretical Results

$$f^* = \arg\min_{f \in F} C(f).$$

F – set of model structures

C – criterion of a model quality

Structure of a model:

$$\hat{y}_f = f(X, \hat{\theta}_f)$$

Estimation of parameters:

$$\hat{\theta}_f = \arg\min_{\theta_f \in R^m} Q(\theta_f).$$

Q – criterion of the quality of model parameters estimation

- **Main concept**:

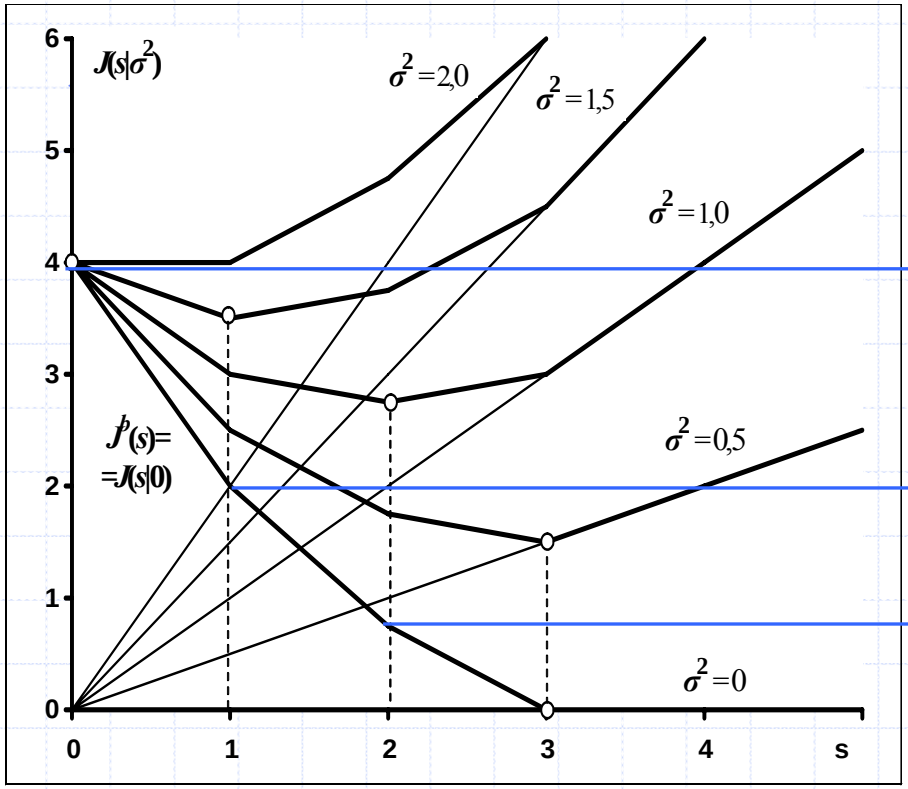
Self-organizing evolution of the model of ***optimal complexity*** under uncertainty conditions

- **Main result:**

Complexity of the optimum forecasting model depends on the level of uncertainty in the data: the higher it is, the simpler (more robust) there must be the optimum model

- **Main conclusion**:

GMDH is the method for construction of models with ***minimum variance*** of forecasting error



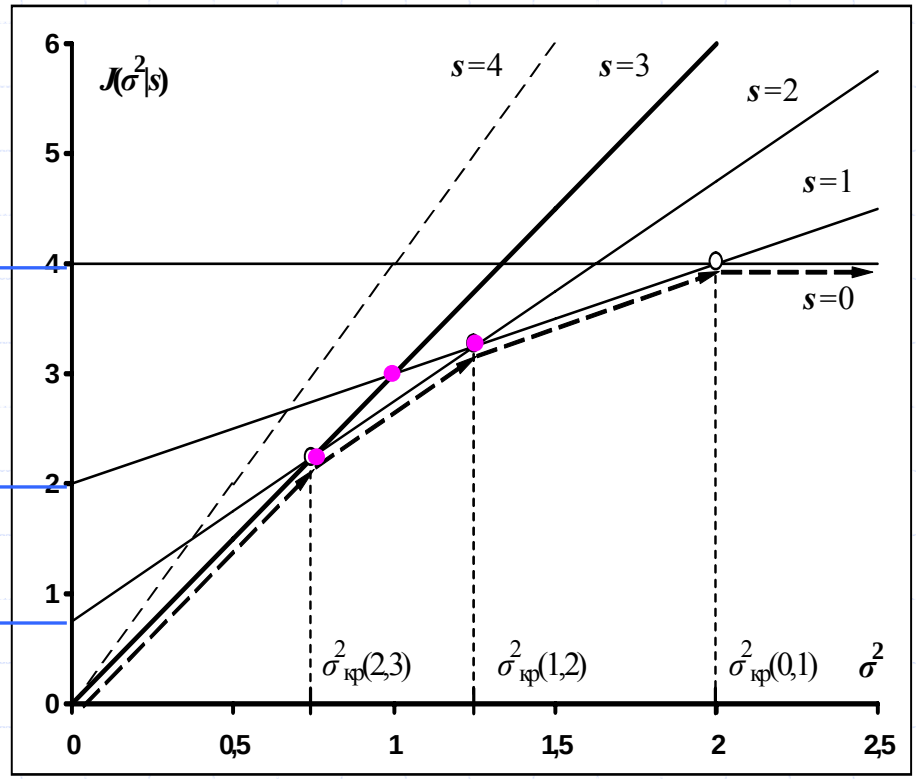
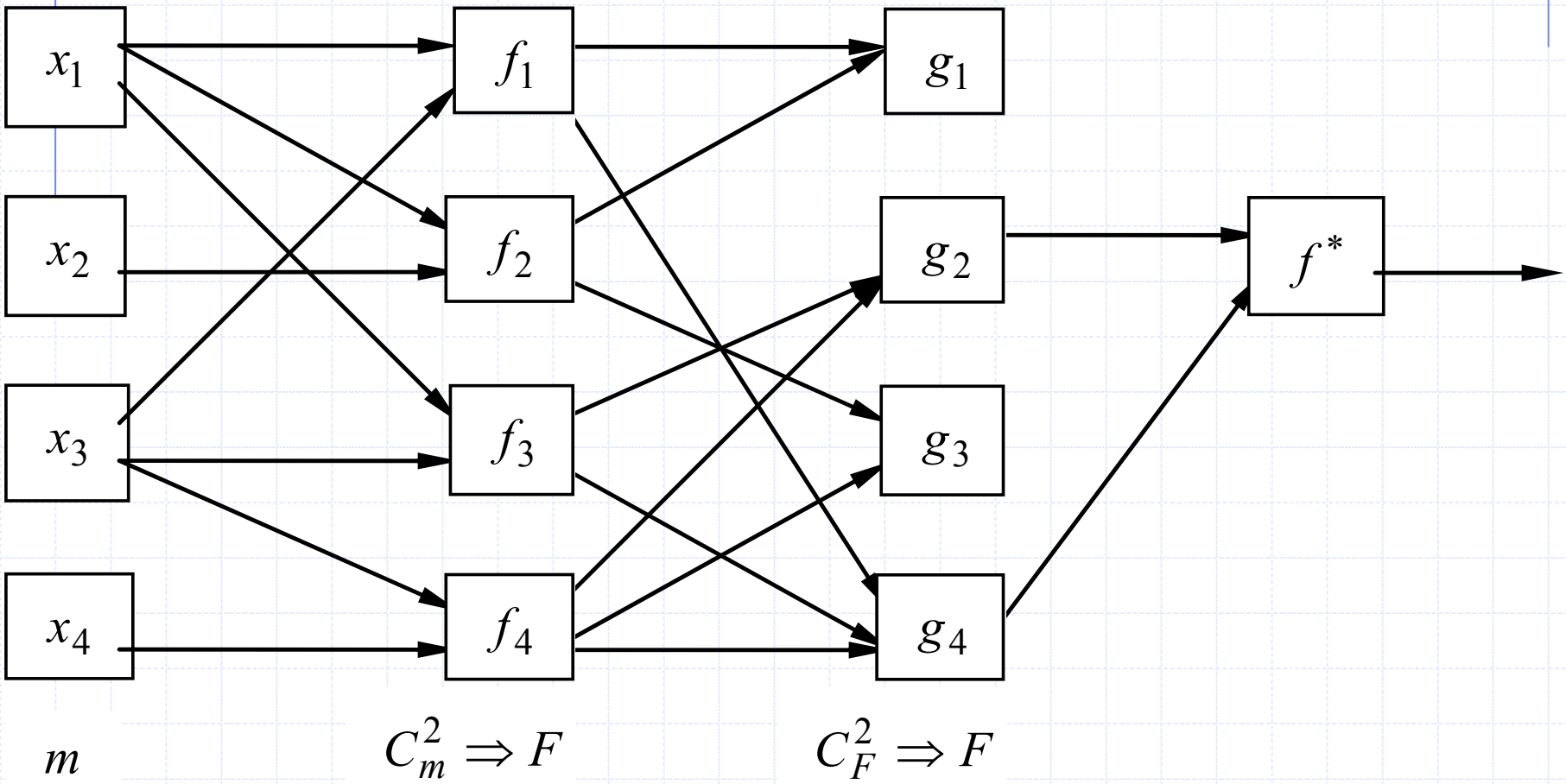


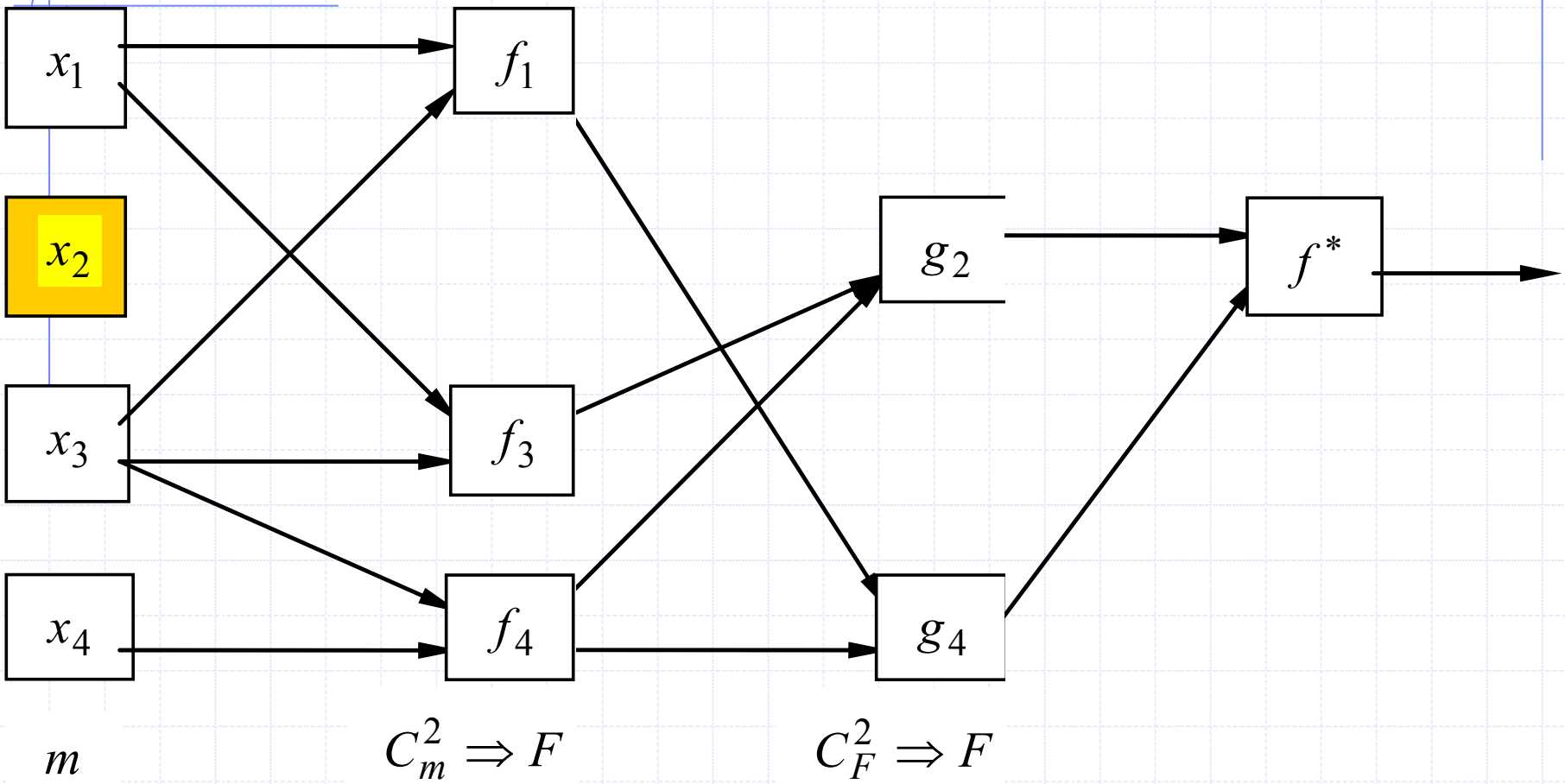
Illustration to the GMDH theory

7. IM compared to ANN and CI

Selective (multilayered) GMDH algorithm:



Optimal structure of the multilayered net



8. Real-world applications of IM

1. Prediction of tax revenues and inflation
2. Modelling of ecological processes
   - activity of microorganisms in soil under influence of heavy metals
   - irrigation of trees by processed wastewaters
   - water ecology
3. System prediction of power indicators
4. Integral evaluation of the state of the complex multidimensional systems
   - economic safety
   - investment activity
   - ecological state of water reservoirs
   - power safety
5. Technology of informative-analytical support of operative management decisions

9. Main centers of IM research

- IRTC ITS NANU, Kyiv, Ukraine
- NTUU “KPI”, Kyiv, Ukraine
- KnowledgeMiner, Berlin, Germany
- CTU in Prague, Czech
- Sichuan University, Chengdu, China

10. IM development prospects

The most promising directions:

1. Theoretical investigations
2. Integration of best developments of IM, NN and CI
3. Paralleling
4. Preprocessing
5. Ensembling
6. Intellectual interface
7. Case studes

THANK YOU!

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