CASE-BASED REASONING CONTROL OF BIOLOGICAL WASTE WATER TREATMENT INTENDED TO BIOGAS PRODUCTS

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Main topics

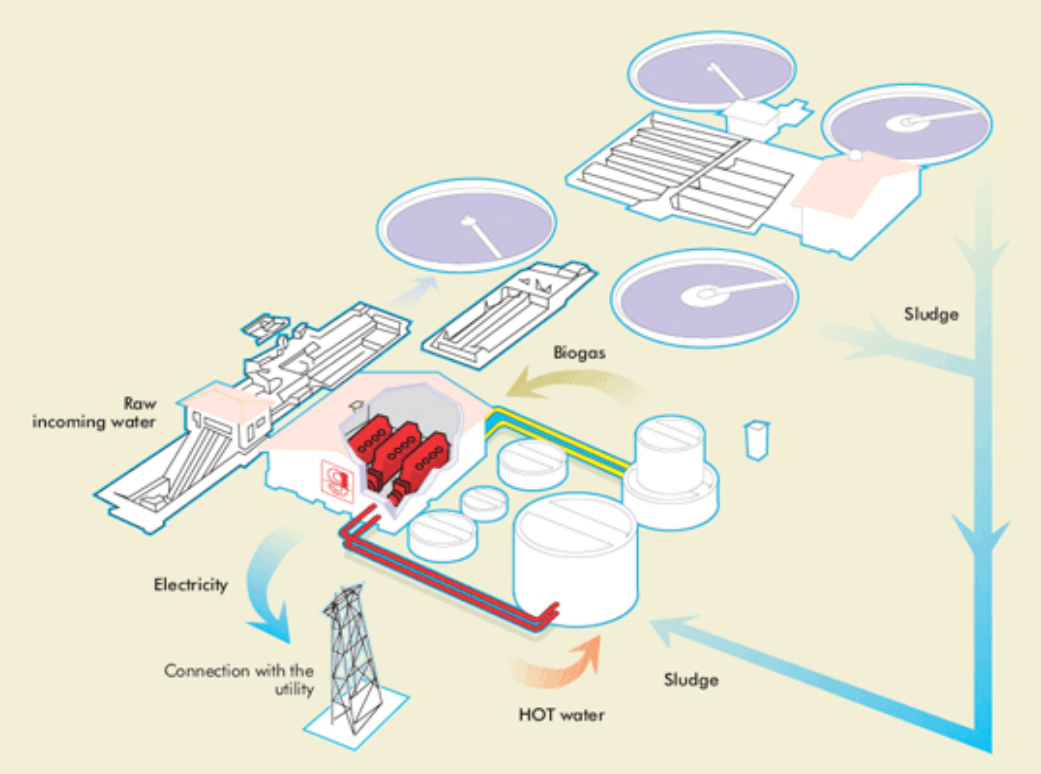
- Introduction
- Biogas from wastewater products
- Control of wastewater treatment plants (WWTP)
- Case-Based Reasoning /CBR/ approach
- Application of CBR for supervisory control of WWTP
- Conclusions

Introduction

- According to EU directives up to year 2020 in Bulgaria 16% of the energy must be produced by RES.
- The Co-generation installations using Biogas and sludge are of the promising potential sources.
- Supervisory control of wastewater facilities becomes of great importance, both for quality waste water cleaning and for sludge products used as sources for biogas.
- Current presentation describes the application of Case-Based Reasoning Supervisory Control of wastewater treatment plant.

Biogas from wastewater products

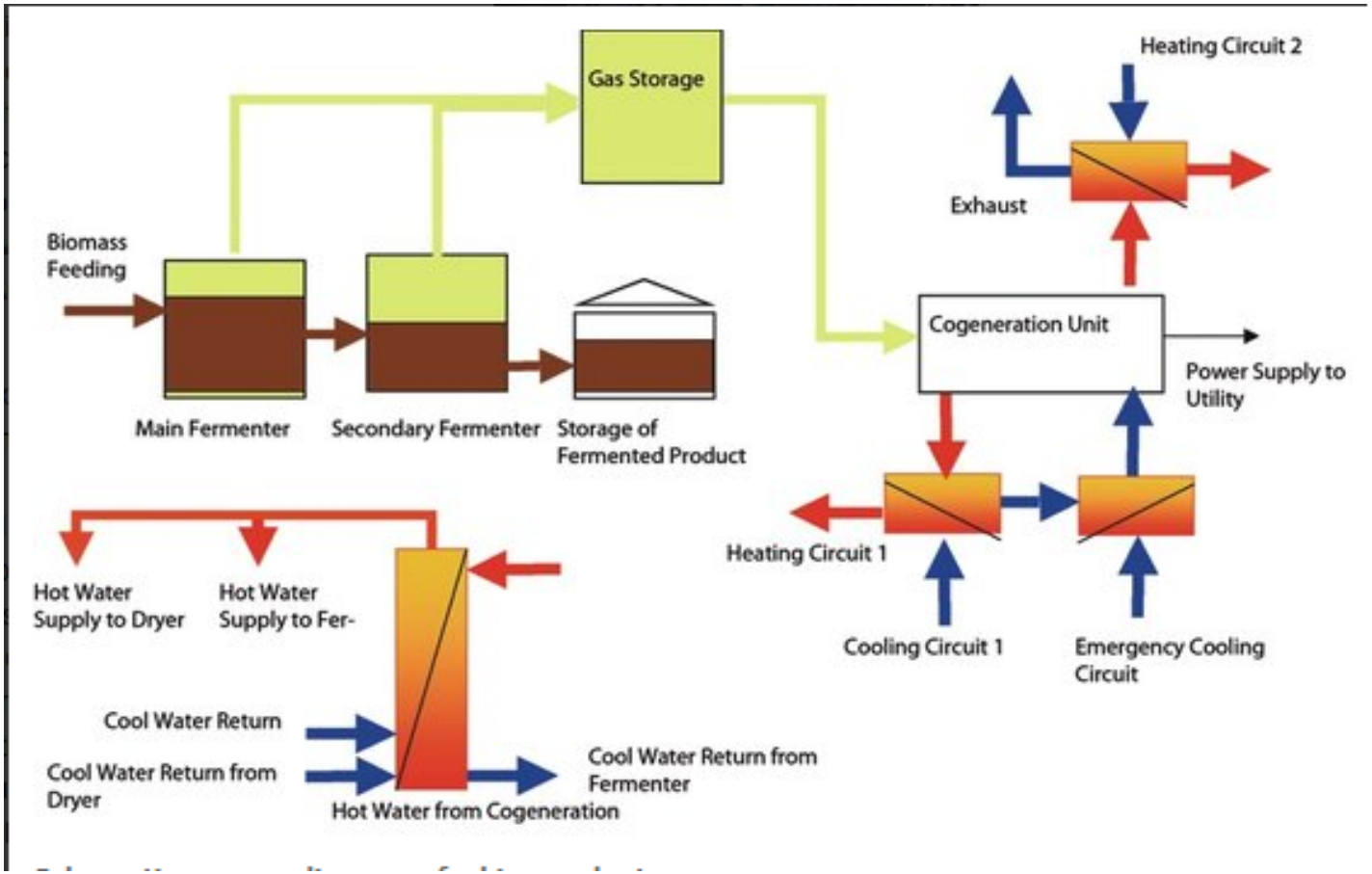
Stages of wastewater treatment



- Mechanical treatment
- Chemical treatment
- Biological treatment (anaerobic)
- Sludge treatment in fermenters
- Using biogas in Co-generation unit for electricity and hot water production

Biogas from wastewater products and biomass

Stages of biomass treatment



Biogas from wastewater products

TEDOM Co-generation Unit

- Technical data:
- Gas internal combustion engine with 6 cilinders.
- 160 kW electricity power
- 177 kW thermal power
- maximum gas consumption – 65 m^3/h

Control of WWTP

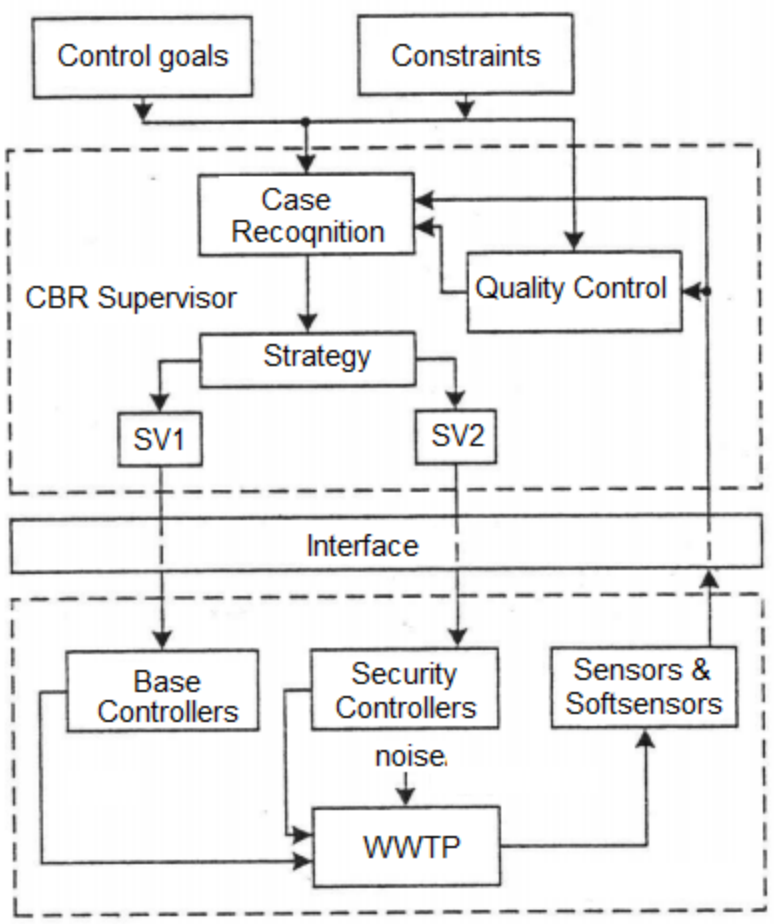
- Problems that arise in the control of wastewater treatment plants (WWTP) are constantly subject to disturbances of different nature, namely
- external:
  - resulting in changes in the debit and composition of the incoming water,
  - caused by the way of living and climate impacts,
- and internal:
  - as operator errors,
  - technical errors,
  - and equipment failure.

Control of WWTP

- Optimal control of WWTP requires for the particular condition of the disturbing inputs to minimize material and energy costs and maintenance, in compliance with legal requirements for the quality of the treated water.
- In supervisory process control the implementation of iterative procedures for finding optimal control is not recommended due to the possibility of falling into local extreme or uncertainty in terms of completion of iterative procedures.
- For the purposes of supervisory control of biological wastewater treatment in this work is proposed an approach based on precedents (Case-Based Reasoning (CBR)

Control of WWTP

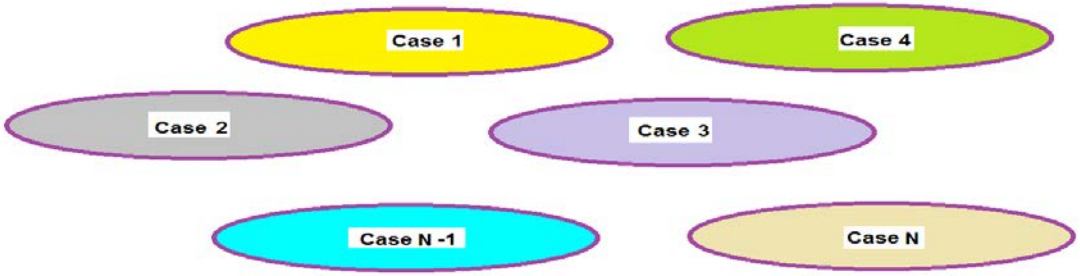
CBR Supervisory Control



- High level (Goals and Constraints
- CBR Supervisor Unit
- Interface
- WWTP with SCADA system including:
  - Sensors
  - Base Controllers
  - and Security Controllers

Case-Based Reasoning (CBR)

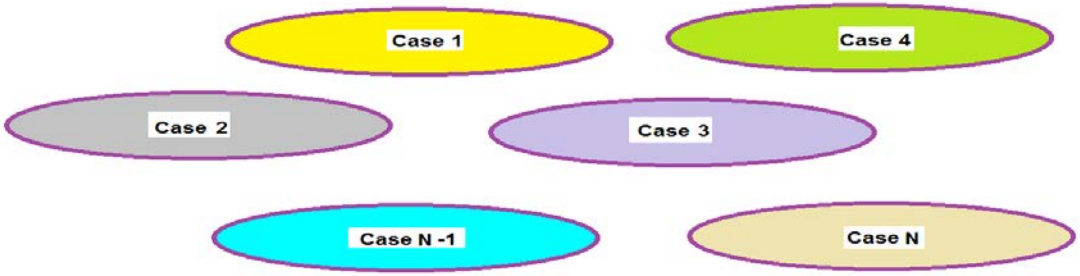
The Basics of CBR



- The method of precedents (CBR) is a method of Artificial Intelligence.
- The basic idea of CBR is that "in similar situations we take similar decisions".
- In its classic form, it is a method of non-model control and is based on the accumulated expertise. It allows the presentation and retrieval of the best solutions for specific process control.

Case-Based Reasoning

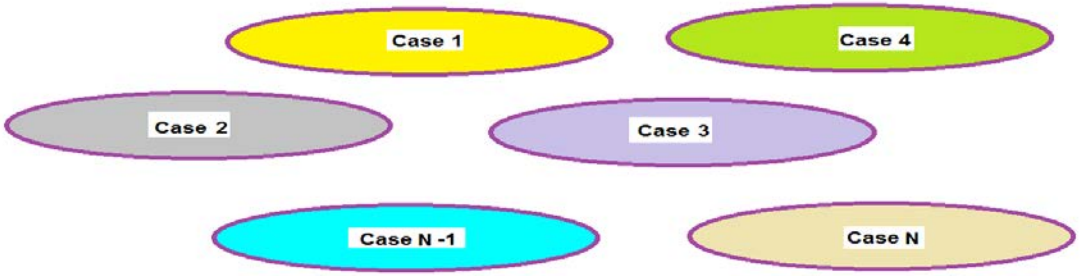
What are the CBR cases ?



- Cases are the main object in CBR systems.
- They can be represented as free text or in structural type when the cases are represented as a parts of data base (case base).
- All structural cases are described as a pair of problem-solution. The problem $\mathbf{p_i = (a_i, v_i)}$ is a structure of attributes and values, described by the 2 vectors:
- $\mathbf{a_i = (a_{i1}, a_{i2}, \ldots, a_{ir})}$ - attribute vector
- $\mathbf{v_i = (v_{i1}, v_{i2}, \ldots, v_{ir})}$ - value vector.

Case-Based Reasoning

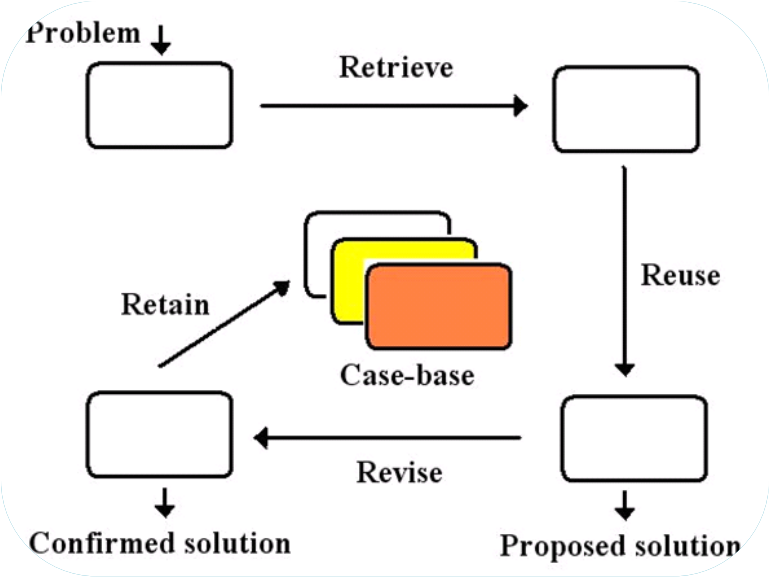
What are the CBR cases ?



- The solution $\mathbf{s_i}$ is represented as vectors, defined by the specific tasks. In multidimensional supervised control tasks, the decision includes two vectors:
- $\mathbf{s_i = (sp_i, pr_i)}$, where the first vector
- $\mathbf{sp_i = (sp_{i1}, sp_{i2},\ldots,sp_{iq})}$ consists of set-points of the controllers on first hierarchical level, and the second
- $\mathbf{pr_i = (pr_{i1},pr_{i2},\ldots,pr_{im})}$ – values of the target parameters, corresponding to the set-points.

Case-Based Reasoning

Case-Based Reasoning Stages (CBR – R4 circle)

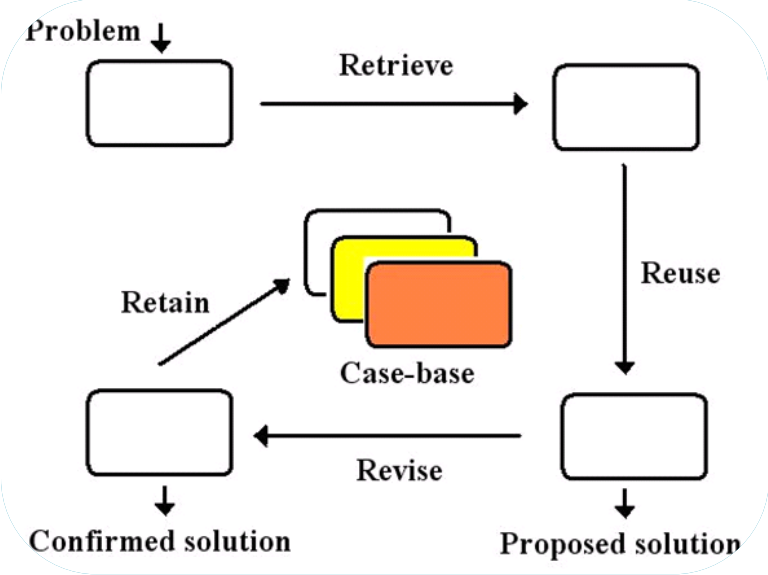


- **Retrieve** – process of extraction of one (nearest neighbor) or a group of cases (k-nearest neighbors) having closest definition to the current problem.
- The global similarity between the problems of these cases (the new $\mathbf{p_{new}}$ and the one in the case base $\mathbf{p_j}$) is presented by following expression:

$$sim(p_{new}, p_j) = \sum_{i=1}^{n} w_i sim_i(p_{new\,i}, p_{ji}) \text{ , and } \sum_{i=1}^{n} w_i = 1$$

Case-Based Reasoning

Case-Based Reasoning Stages (CBR – R4 circle)



Where $\mathbf{w_i}$ is the weight of i-th attribute $0 \le w_i \le 1$

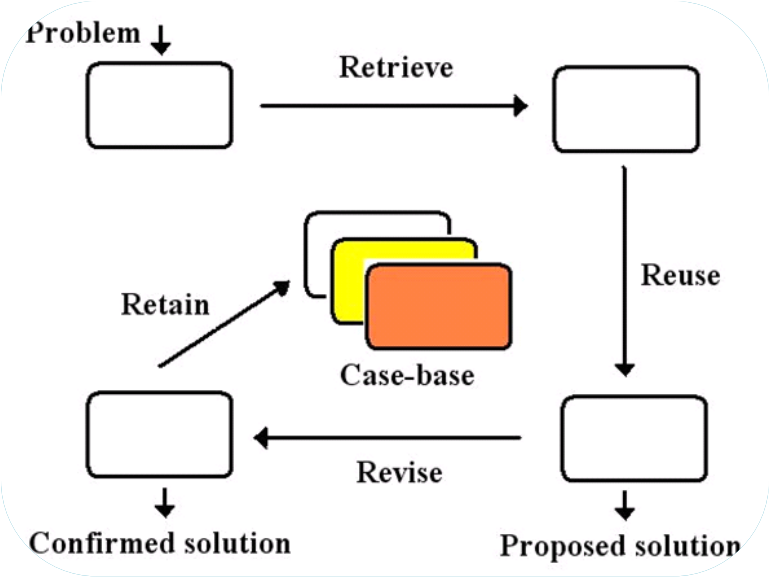
and $sim(p_{newi}, p_{ji})$ is the local similarity between i-th attributes in the case base DB.

$$sim(p_{new}, p_j) = \sum_{i=1}^{n} w_i sim_i(p_{new\,i}, p_{ji})$$

$$\sum_{i=1}^{n} w_i = 1$$

Case-Based Reasoning

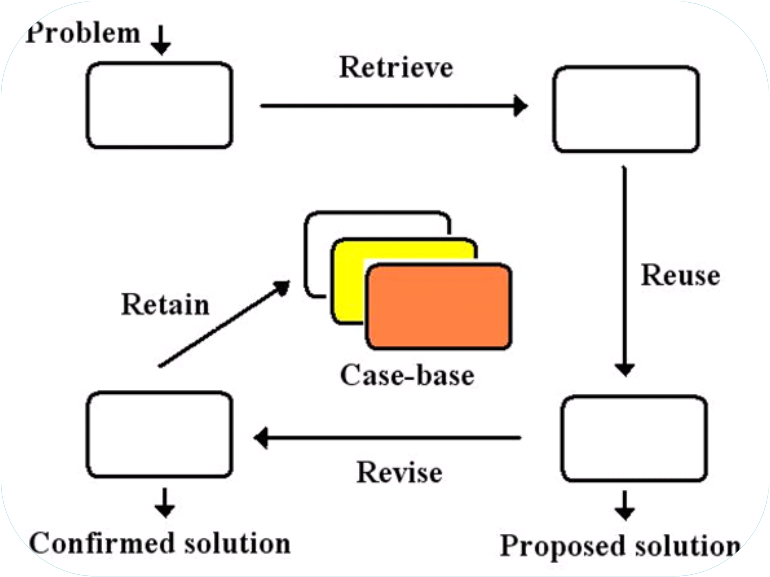
Case-Based Reasoning Stages (CBR – R4 circle)



- **Reuse** – reuse of the solutions of chosen in the first step one or k-nearest neighbors.
- - When only one nearest case is chosen, the solution of the new problem $\mathbf{s_{new}}$ will be the solution of the chosen case $\mathbf{s_{NN}}$.
- - When k-nearest neighbors are chosen, the solution of the new case is calculated on the base of adaptation of k-nearest neighbors' solutions

Case-Based Reasoning

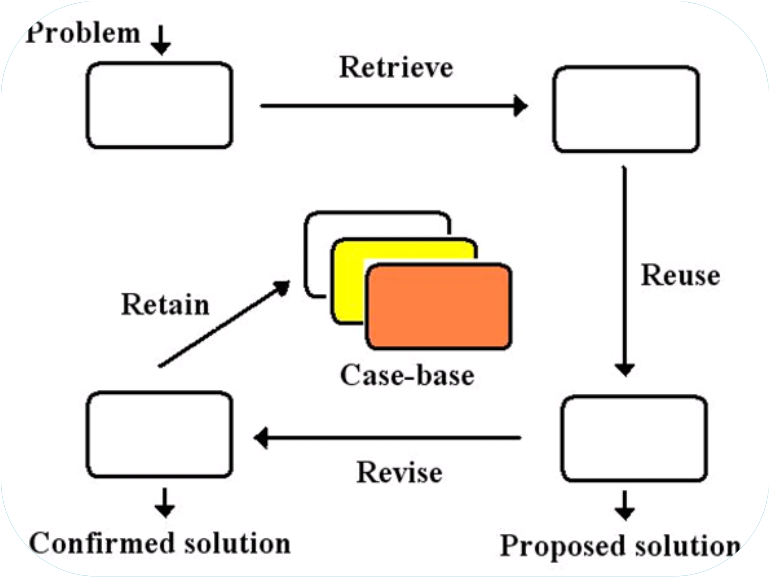
Case-Based Reasoning Stages (CBR – R4 circle)



- **Revise** – decision propriety and utility verification, made on the Reuse stage.
- This verification is mostly done by an expert or it is made based on simulation researches if there is a mathematical model available.

Case-Based Reasoning

Case-Based Reasoning Stages (CBR – R4 circle)



- **Retain** – saving (retaining) the new solution in the case base for future use, if it is successful.

Application of CBR for supervisory control of WWTP

Case structure in wastewater supervisory control

- Each case $\mathbf{c_i}$ here can be presented as a structure of "problem-solution-forecast and economic efficiency“
- $\mathbf{c_i = (p_i, s_i, pr_i, ee_i)}$
- The problem $\mathbf{p_i = (a_i, v_i)}$ consists of attributes and values vectors, as given above.
- The solution $\mathbf{s_i = (sp_{i1}, sp_{i2},\ldots,sp_{iq})}$ consists of set-points of the controllers on first hierarchical level, and the second
- $\mathbf{pr_i = (pr_{i1},pr_{i2},\ldots,pr_{im})}$ – values of the target parameters, corresponding to the set-points.
- Vector of indices characterizing the economic efficiency of the i-th case is denoted by $\mathbf{ee_i = (ee_{i1},eer_{i2},\ldots,ee_{ip})}$
-

Application of CBR for supervisory control of WWTP

Attributes describing the problem for the specific task

- The successful implementation of supervisory control setting is the ability to measure the concentrations of the most important components in the process of biological treatment.
  As attributes of the problem are selected variables that in modern WWTP are measured continuously.

$$\mathbf{a} = (Q_{in}, SNH_{in}, SNO(2), SNH(2), MLSS)$$

Q_{in} marked fuel inlet water purification,

SNH_{in} is the concentration of ammonia nitrogen in the incoming water, and its concentration is **SNH(2)** output of de-nitrification,

SNO(2) is the concentration of nitrate nitrogen output of nitrification and **MLSS** is concentration of suspended solids in the tank floor.

Application of CBR for supervisory control of WWTP

Attributes describing the solutions (decisions)

- Decision are the set-points of controllers in the first hierarchy:

$$\mathbf{s} = (DO^0, Q_a, Q_r, Q_w, Q_{carb})$$

- **DO^0** is the concentration of dissolved oxygen,
- **Q_a** is the internal recycle,
- **Q_r** is recycle of the activated sludge,
- **Q_w** is excessive sludge and
- **Q_{carb}** of external carbon.

Application of CBR for supervisory control of WWTP

Target variables

- Target variables in the treated water that match attribute values and assignments to regulators and is expected to be achieved by appropriate control are:

$$\mathbf{pr} = (\mathrm{COD_e}, \mathrm{BOD_e}, \mathrm{TN_e}, \mathrm{SNO_e}, \mathrm{SNH_e}, \mathrm{HRT}, \mathrm{SRT})$$

Variables with index “e" refer to the composition of the treated water at the outlet of the WWTP, namely: **$\mathrm{COD_e}$** is chemical oxygen demand, **$\mathrm{BOD_e}$** is biological oxygen demand, $\mathrm{TN_e}$ is the concentration of total nitrogen, **$\mathrm{SNO_e}$** - of nitrate and nitrite nitrogen and **$\mathrm{SNH_e}$** ammonium nitrogen. **HRT** and **SRT** are the times to stay relevant in the biological stage of water and sludge.

Application of CBR for supervisory control of WWTP

Indicators of economic performance

- Indicators of economic performance are:
- **Ee = (EQ, z)**
- **EQ = E_{aer} / Q_{in}** is the energy consumption for aeration **E_{aer}** relative to the cost of wastewater treatment **Q_{in}**
- **z** is an expert assessment of the costs of chemicals, which varies in the range **0 <= z <= 1.**

Application of CBR for supervisory control of WWTP

Generation of Case Base with optimal cases

1.To generate the initial DB with optimal precedent the following procedure was developed:
1.Mathematical model of biological treatment, including a description of the processes in the bioreactor according to mathematical models ASMs and in the secondary clarifier is adapted to the specific WWTPs sizes and parameters in the mathematical models on which they are most sensitive.
2.Using historical process data we choose a number of different precedents represented by attribute values, complemented by expert generated precedents in areas where there is not enough information.

Application of CBR for supervisory control of WWTP

Generation of Case Base with optimal cases

3. Off-line solution of the problem of static optimal control of biological treatment, which is worded as follows:

   For known values of attributes of a particular precedent to find optimal values of the control outputs on supervisory level that are set-points of the controllers of first hierarchical level, so as to satisfy the optimality criterion:

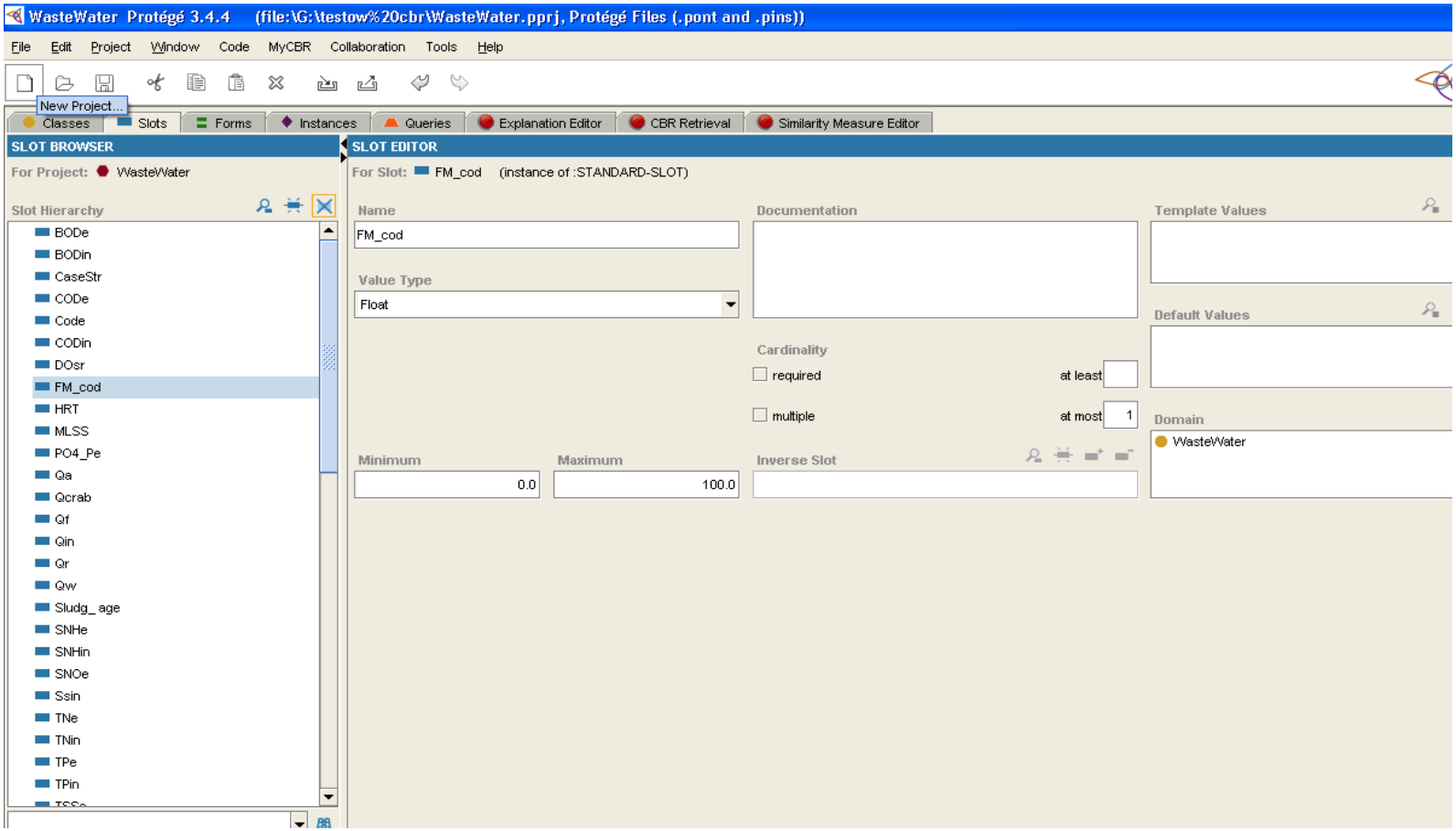
   minimum energy consumption for aeration $\mathbf{E_{aer}}$ / $\mathbf{Q_{in}}$

   and / or a minimum consumption of chemicals (**z**),

   wherein subject to the restrictions on the concentrations of the components in the purified water, level of sludge in the secondary clarifier and the concentration of dissolved oxygen.

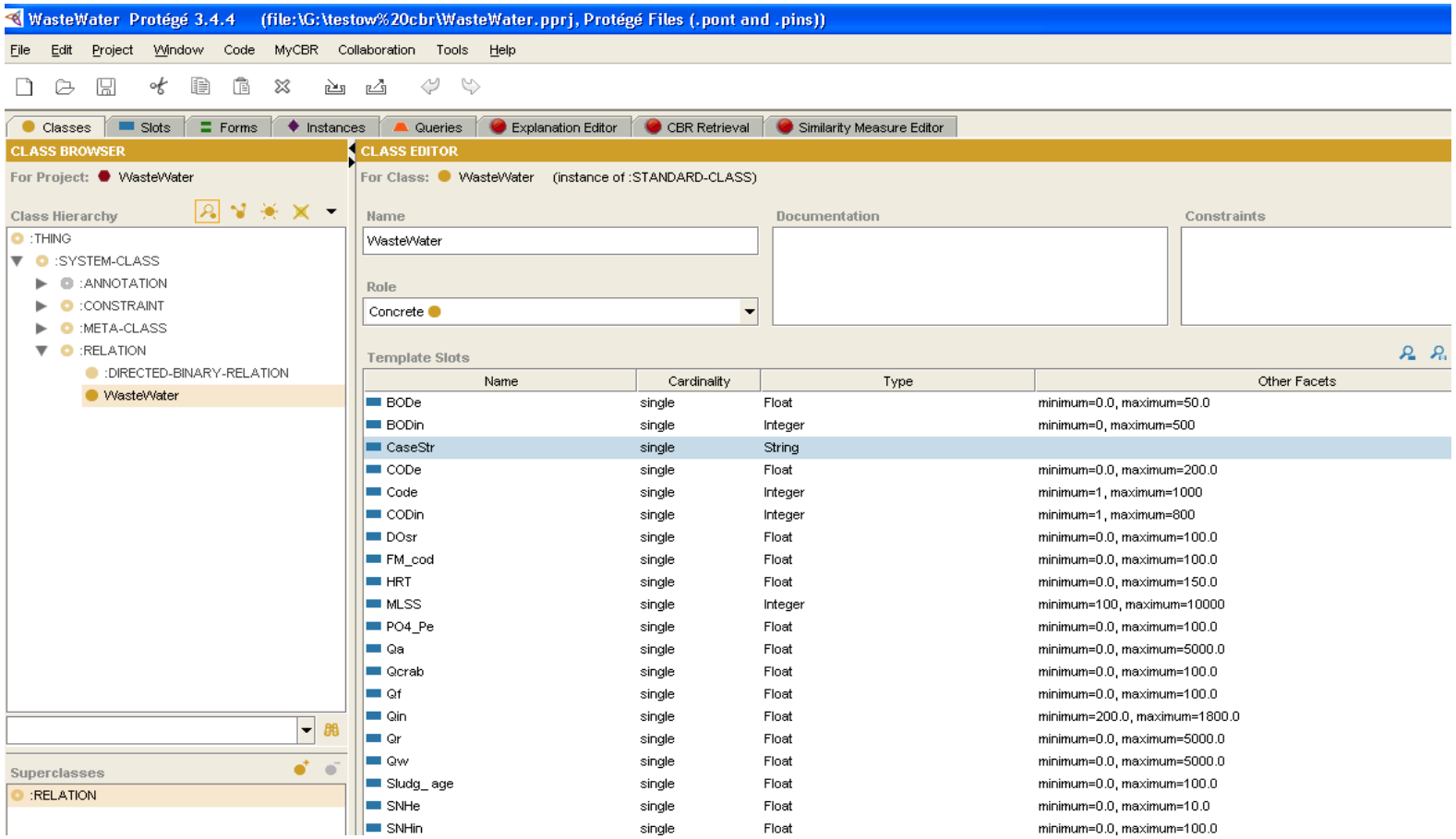
Application of CBR for supervisory control of WWTP

1. Definition of the WasteWater Class Attributes



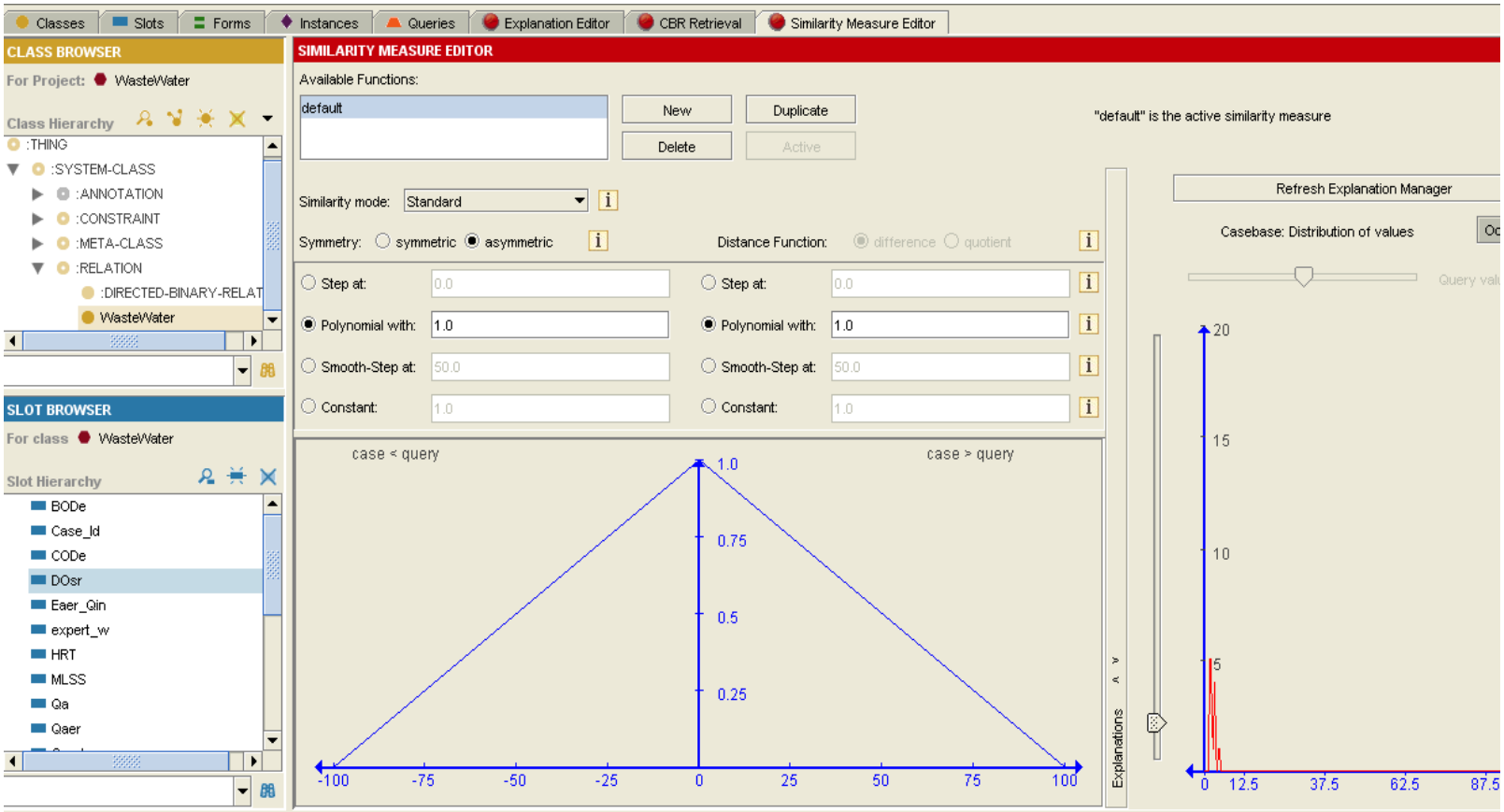
Application of CBR for supervisory control of WWTP

2. Creation of a Class and adding Attributes to the Class



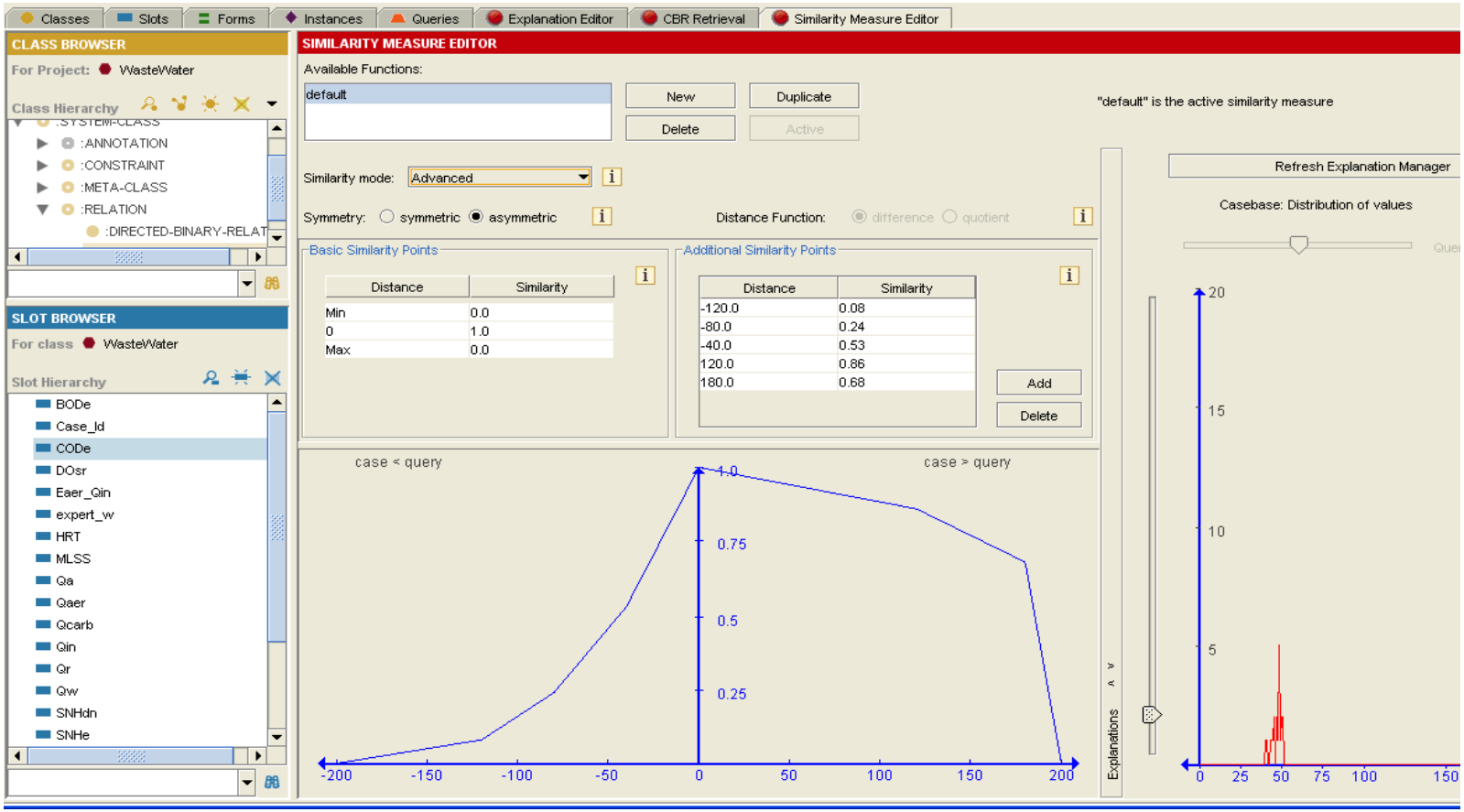
Application of CBR for supervisory control of WWTP

3. Definition of Local Similarity Function of DOsr Attribute



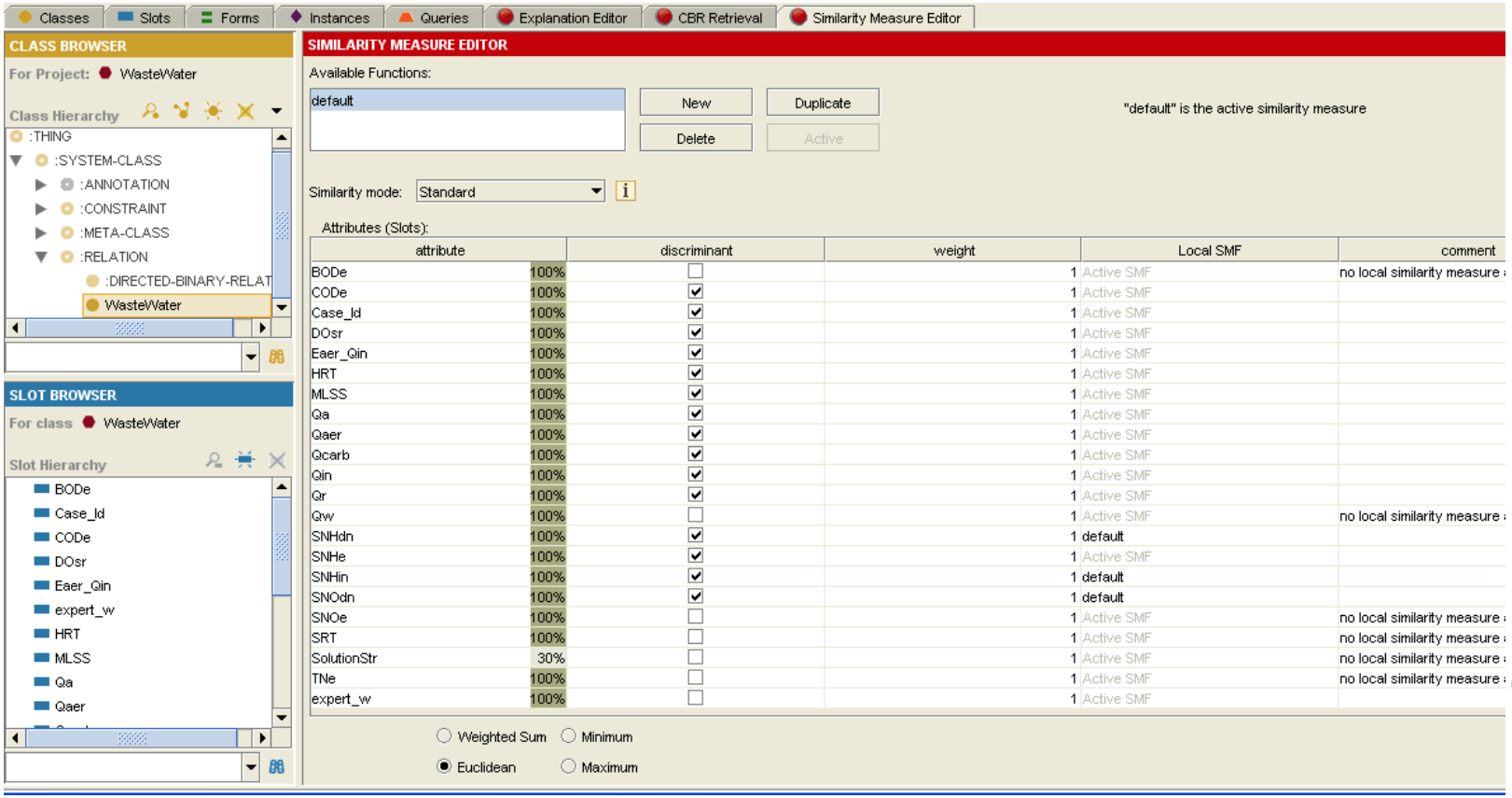
Application of CBR for supervisory control of WWTP

4. Definition of Local Similarity Function of CODe Attribute



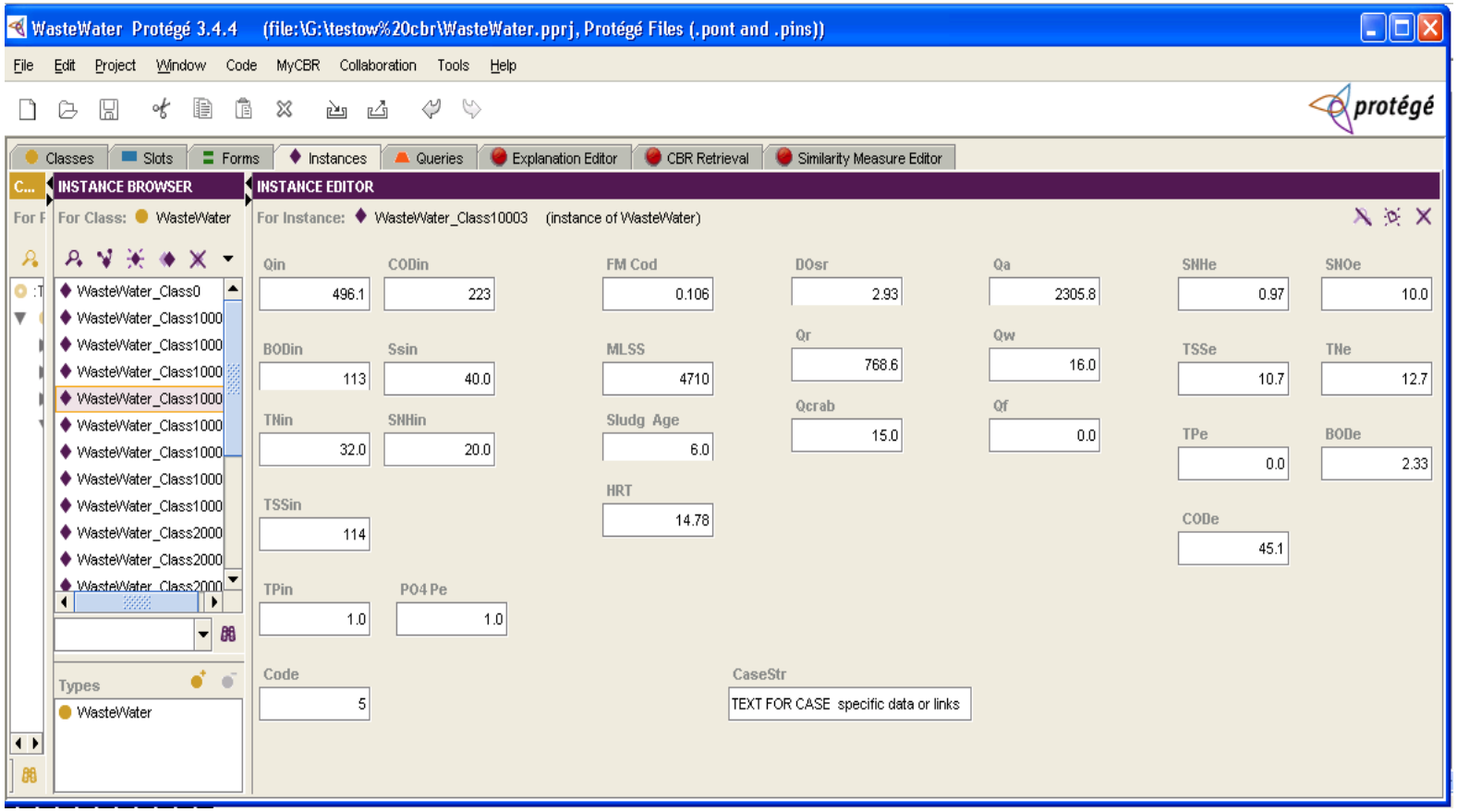
Application of CBR for supervisory control of WWTP

5. Definition of Global Similarity Function for WasteWater



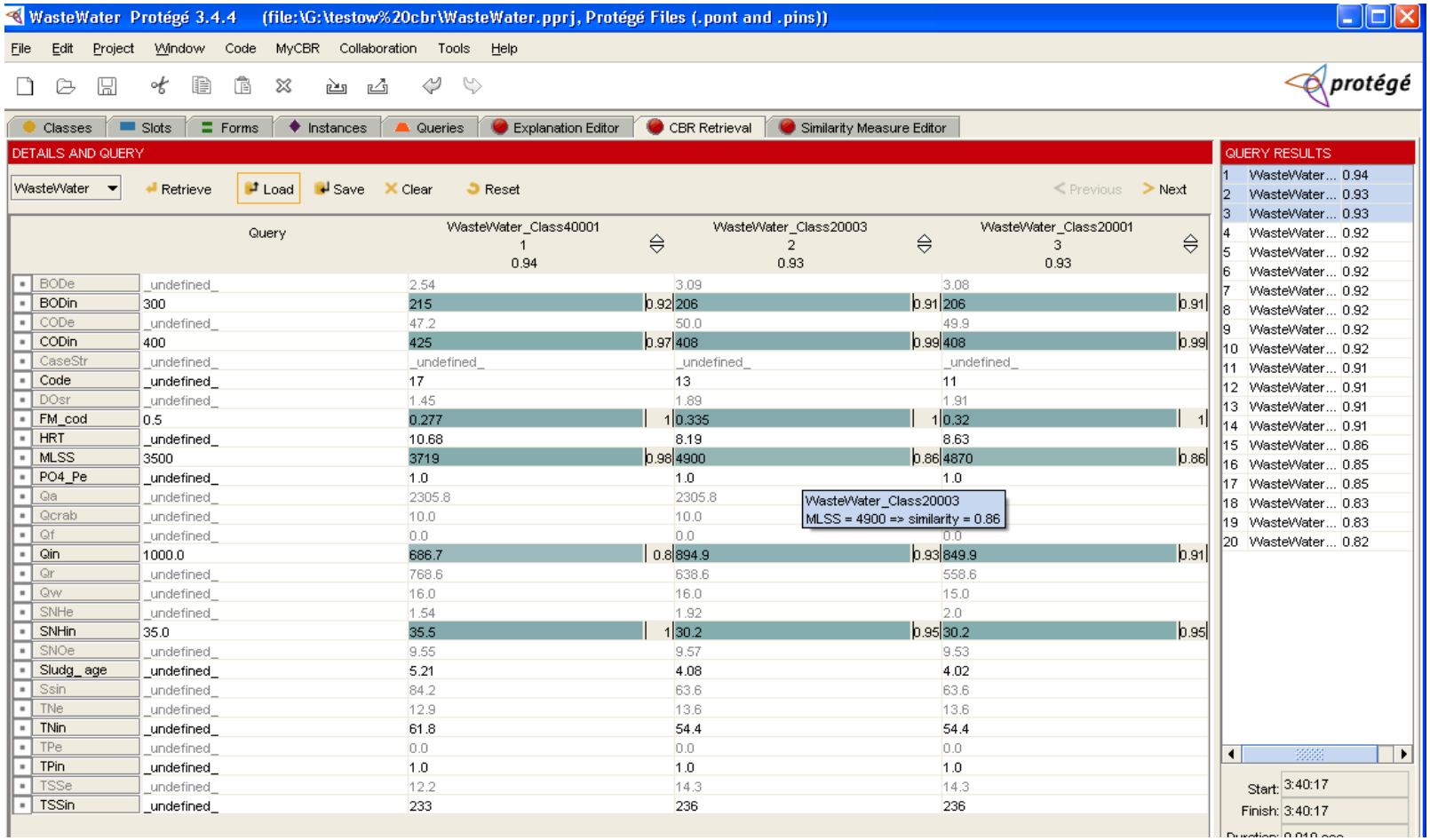
Application of CBR for supervisory control of WWTP

6. Creating Cases (instances of a Class) via Instance Editor



Application of CBR for supervisory control of WWTP

7. Case Retrieval (Query to Case Base database)



Conclusions

- An approach for supervisory control of biological purification of waste water is developed.
- The approach is based on a combination of off-line solving the optimization problem in order to form the initial Case Base and optimal real-time control using (Case Based Reasoning).
- For software implementation is used myCBR – a plug-in of ontology editor Protégé.
- If for new specific case the realized control output is optimal, this precedent (case) is added to the Case Base database with which it is updated continuously.

Conclusions

- Proposed CBR solution for optimal WWTP control guarantee the quality of purified water and biogas parameters (65% methane).
- It is applied in Co-generation units with max electricity/thermal power of 160/177 kW in town of Sliven, Varna, etc.
- Similar CBR control can be applied to Co-generation power stations, as well in other installations related to specific RES.
- For example CBR recommender systems for selecting optimal places or prices for building PV plants.

THANK YOU FOR YOUR ATTENTION!