ITHEA

International Journal

INFORMATION MODELS & ANALYSES

2014 Volume 3 Number 2

International Journal
INFORMATION MODELS & ANALYSES
Volume 3 / 2014, Number 2

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International Journal "INFORMATION MODELS AND ANALYSES" Volume 3, Number 2, 2014

Edited by the **Institute of Information Theories and Applications FOI ITHEA**, Bulgaria, in collaboration with
Institute of Mathematics and Informatics, BAS, Bulgaria,
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Publisher: **ITHEA®**

Sofia, 1000, P.O.B. 775, Bulgaria. www.ithea.org, e-mail: info@foibg.com
Technical editor: **Ina Markova**

Printed in Bulgaria

ISSN 1314-6416 (printed) **ISSN 1314-6432 (Online)**

INDEX MATRICES WITH FUNCTION-TYPE OF ELEMENTS

Krassimir Atanassov

Abstract: *Index Matrices (IMs) are extensions of the ordinary matrices. Some of the operations and relations defined over IMs are analogous of the standard ones, while there have been defined new ones, as well. Operators that do not have analogue in matrix theory have been defined, as well. In general, the elements of an IM can be real or complex numbers, as well as propositions or predicates. In the present paper, IMs with their elements being functions, are defined and some of their properties are discussed.*

Keywords: *Function, Index matrix, Operation, Operator, Relation.*

Introduction

The concept of Index Matrix (IM) was introduced in 1984 in [Atanassov, 1984], but during the next 25 years only some of its properties have been studied (see, e.g. [Atanassov, 1987]) and in general the concept has only been used as an auxiliary tool in generalized nets theory (see [Alexieva et al., 2007; Atanassov, 1991; Atanassov, 2007; Radeva et al., 2002]) and in intuitionistic fuzzy sets theory (see [Atanassov, 1999; Atanassov, 2012]). Some authors found an application of the IMs in the area of number theory, [Leyendekkers et al., 2007].

The first step towards developing the theory of IMs was done in [Atanassov, 2010a], where the concept was defined, as follows.

Let $\mathcal{I}$ be a fixed set of indices and $\mathcal{R}$ be the set of the real numbers. By IM with index sets K and L $(K, L \subset \mathcal{I})$, we denote the object:

$$[K, L, \{f_{k_i,l_j}\}] \equiv \begin{array}{c|cccc} & l_1 & l_2 & \dots & l_n \\ \hline k_1 & a_{k_1,l_1} & a_{k_1,l_2} & \dots & a_{k_1,l_n} \\ k_2 & a_{k_2,l_1} & a_{k_2,l_2} & \dots & a_{k_2,l_n} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ k_m & a_{k_m,l_1} & a_{k_m,l_2} & \dots & a_{k_m,l_n} \end{array},$$

where $K = \{k_1, k_2, ..., k_m\},\ L = \{l_1, l_2, ..., l_n\},$ for $1 \le i \le m$, and $1 \le j \le n : a_{k_i,l_j} \in \mathcal{R}$.

Six operations, six relations and ten operators are defined over IMs in [Atanassov, 2010a; Atanassov, 2013; Atanassov et al., 2013a]. In [Atanassov, 2010a] are discussed the cases when the elements a_{k_i,l_j} are: real numbers, elements of the set $\{0, 1\}$, and propositions or predicates. In [Atanassov, 2010b], the case is described, when the elements a_{k_i,l_j} are intuitionistic fuzzy pairs (see, e.g. [Atanassov, 2012; Atanassov et al., 2013b]). Here, we discuss a new case: when the elements a_{k_i,l_j} are functions.

Let the set of all used functions be $\mathcal{F}$.

The research over IMs with function-type of elements develops in the following two cases:

- each function of set $\mathcal{F}$ has one argument and it is exactly x (i.e., it is not possible that one of the functions has argument x and another function has argument y) – let us mark the set of these functions by $\mathcal{F}^1_x$;
- each function of set $\mathcal{F}$ has one argument, but that argument might be different for the different functions or the different functions of set $\mathcal{F}$ have different numbers of arguments.

Definition of the index matrix with function-type of elements

Let all used functions from $\mathcal{F}_x^1$ have one argument and let it be exactly x. Then, the IM with Function-type of Elements (IMFE) has the form

$$[K, L, \{f_{k_i,l_j}\}] \equiv \begin{array}{c|cccc} & l_1 & l_2 & \dots & l_n \\ \hline k_1 & f_{k_1,l_1} & f_{k_1,l_2} & \dots & f_{k_1,l_n} \\ k_2 & f_{k_2,l_1} & f_{k_2,l_2} & \dots & f_{k_2,l_n} \\ \vdots & & & & \\ k_m & f_{k_m,l_1} & f_{k_m,l_2} & \dots & f_{k_m,l_n} \end{array},$$

where $K = \{k_1, k_2, ..., k_m\},\ L = \{l_1, l_2, ..., l_n\}$, for $1 \le i \le m$, and $1 \le j \le n : f_{k_i,l_j} \in \mathcal{F}_x^1$.

Standard operations over IMFEs Introduction

For the IMFEs $A = [K, L, \{f_{k_i,l_j}\}], B = [P, Q, \{g_{p_r,q_s}\}]$, the operations that are analogous of the standard IM operations are the following.

(a) addition ($+$): $A \oplus_+ B = [K \cup P, L \cup Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = \begin{cases} f_{k_i,l_j}, & \text{if } t_u = k_i \in K \text{ and } v_w = l_j \in L - Q \\ & \text{or } t_u = k_i \in K - P \text{ and } v_w = l_j \in L; \\ g_{p_r,q_s}, & \text{if } t_u = p_r \in P \text{ and } v_w = q_s \in Q - L \\ & \text{or } t_u = p_r \in P - K \text{ and } v_w = q_s \in Q; \\ f_{k_i,l_j} + g_{p_r,q_s}, & \text{if } t_u = k_i = p_r \in K \cap P \\ & \text{and } v_w = l_j = q_s \in L \cap Q; \\ \perp, & \text{otherwise} \end{cases},$$

where here and below, symbol $\perp$ denotes the lack of operation in the respective place.

(b) addition ($\times$): $A \oplus_\times B = [K \cup P, L \cup Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = \begin{cases} f_{k_i,l_j}, & \text{if } t_u = k_i \in K \text{ and } v_w = l_j \in L - Q \\ & \text{or } t_u = k_i \in K - P \text{ and } v_w = l_j \in L; \\ g_{p_r,q_s}, & \text{if } t_u = p_r \in P \text{ and } v_w = q_s \in Q - L \\ & \text{or } t_u = p_r \in P - K \text{ and } v_w = q_s \in Q; \\ f_{k_i,l_j} . g_{p_r,q_s}, & \text{if } t_u = k_i = p_r \in K \cap P \\ & \text{and } v_w = l_j = q_s \in L \cap Q \\ \perp, & \text{otherwise} \end{cases},$$

(c) termwise multiplication ($+$): $A \otimes_+ B = [K \cap P, L \cap Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = f_{k_i,l_j} + g_{p_r,q_s},$$

for $t_u = k_i = p_r \in K \cap P$ and $v_w = l_j = q_s \in L \cap Q$;

(d) termwise multiplication ($\times$): $A \otimes_{\times} B = [K \cap P, L \cap Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = f_{k_i,l_j}.g_{p_r,q_s},$$

for $t_u = k_i = p_r \in K \cap P$ and $v_w = l_j = q_s \in L \cap Q$;

(e) multiplication $A \odot B = [K \cup (P - L), Q \cup (L - P), \{c_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = \begin{cases} f_{k_i,l_j}, & \text{if } t_u = k_i \in K \text{ and } v_w = l_j \in L - P - Q \\ g_{p_r,q_s}, & \text{if } t_u = p_r \in P - L - K \text{ and } v_w = q_s \in Q \\ \sum\limits_{l_j = p_r \in L \cap P} f_{k_i,l_j}.g_{p_r,q_s}, & \text{if } t_u = k_i \in K \text{ and } v_w = q_s \in Q \\ \perp, & \text{otherwise} \end{cases}$$

(f) structural subtraction: $A \ominus B = [K - P, L - Q, \{c_{t_u,v_w}\}]$, where "–" is the set–theoretic difference operation and

$$h_{t_u,v_w} = f_{k_i,l_j}, \text{ for } t_u = k_i \in K - P \text{ and } v_w = l_j \in L - Q.$$

(g) multiplication with a constant: $\alpha.A = [K, L, \{\alpha.f_{k_i,l_j}\}]$, where α is a constant.

(h) termwise subtraction: $A - B = A \oplus_{+} (-1).B$.

For example, if we have the IMs X and Y with elements

$$f_i(x) = x^i, \;\; g_i(x) = \frac{1}{i.x}$$

for $i = 1, 2, ..., 6$, then

$$X = \begin{array}{c|ccc} & c & d & e \\ \hline a & f_1 & f_2 & f_3 \\ b & f_4 & f_5 & f_6 \end{array}, \quad Y = \begin{array}{c|cc} & c & r \\ \hline a & g_1 & g_2 \\ p & g_3 & g_4 \\ q & g_5 & g_6 \end{array},$$

then

$$X \oplus Y = \begin{array}{c|cccc} & c & d & e & r \\ \hline a & f_1 + g_1 & f_2 & f_3 & g_2 \\ b & f_4 & f_5 & f_6 & \perp \\ p & g_3 & \perp & \perp & g_4 \\ q & g_5 & \perp & \perp & g_6 \end{array} = \begin{array}{c|cccc} & c & d & e & r \\ \hline a & x + \frac{1}{x} & x^2 & x^3 & \frac{1}{2x} \\ b & x^4 & x^5 & x^6 & \perp \\ p & \frac{1}{3x} & \perp & \perp & \frac{1}{4x} \\ q & \frac{1}{5x} & \perp & \perp & \frac{1}{6x} \end{array}.$$

The problem with the "zero"-IMFE is similar to the "zero-IM": if $f_{k_i,l_j} \in \mathcal{F}$, then

$$I_{\emptyset} = [\emptyset, \emptyset, \{f_{k_i,l_j}\}].$$

Relations over IMFSs

Let everywhere, variable x obtain values in set $\mathcal{X}$ (e.g., $\mathcal{X}$ being a set of real numbers) and let $a \in \mathcal{X}$ be an arbitrary value of x. It is suitable to define for each function f with n arguments: $\nu(f) = n$.

Let the two IMFEs $A = [K, L, \{f_{k,l}\}]$ and $B = [P, Q, \{g_{p,q}\}]$ be given. We introduce the following definitions where $\subset$ and $\subseteq$ denote the relations *"strong inclusion"* and *"weak inclusion"*.

Definition 1.a: The strict relation "inclusion about dimension", when the IMFE-elements of both matrices are elements of $\mathcal{F}^1_x$, is

$$A \subset_d B \text{ iff } (((K \subset P) \,\&\, (L \subset Q)) \;\vee\; ((K \subseteq P) \,\&\, (L \subset Q))$$

$$\vee\ ((K \subset P)\ \&\ (L \subseteq Q)))\ \&\ (\forall k \in K)(\forall l \in L)(\forall a \in \mathcal{X})(f_{k,l}(a) = g_{k,l}(a)).$$

Definition 1.b: The strict relation "inclusion about dimension", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subset_d B \text{ iff } (((K \subset P)\ \&\ (L \subset Q))\ \vee\ ((K \subseteq P)\ \&\ (L \subset Q))$$

$$\vee\ ((K \subset P)\ \&\ (L \subseteq Q)))\ \&\ (\forall k \in K)(\forall l \in L)(\nu(f_{k,l}) = \nu(g_{k,l}))$$

$$\&\ (\forall a_1, ..., a_{\nu(f_{k,l})} \in \mathcal{X})(f_{k,l}(a_1, ..., a_{\nu(f_{k,l})}) = g_{k,l}(a_1, ..., a_{\nu(f_{k,l})})).$$

Definition 2.a: The non-strict relation "inclusion about dimension", when the IMFE-elements of both matrices are elements of $\mathcal{F}_x^1$, is

$$A \subseteq_d B \text{ iff } (K \subseteq P)\ \&\ (L \subseteq Q)\ \&\ (\forall k \in K)(\forall l \in L)(\forall a \in \mathcal{X})$$

$$(f_{k,l}(a) = g_{k,l}(a)).$$

Definition 2.b: The non-strict relation "inclusion about dimension", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subseteq_d B \text{ iff } (K \subseteq P)\ \&\ (L \subseteq Q)\ \&\ (\forall k \in K)(\forall l \in L)(\nu(f_{k,l}) = \nu(g_{k,l}))$$

$$\&\ (\forall a_1, ..., a_{\nu(f_{k,l})} \in \mathcal{X})(f_{k,l}(a_1, ..., a_{\nu(f_{k,l})}) = g_{k,l}(a_1, ..., a_{\nu(f_{k,l})})).$$

Definition 3.a: The strict relation "inclusion about value", when the IMFE-elements of both matrices are elements of $\mathcal{F}_x^1$, is

$$A \subset_v B \text{ iff } (K = P)\ \&\ (L = Q)\ \&\ (\forall k \in K)(\forall l \in L)(\forall a \in \mathcal{X})$$

$$(f_{k,l}(a) < g_{k,l}(a)).$$

Definition 3.b: The strict relation "inclusion about value", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subset_v B \text{ iff } (K = P)\ \&\ (L = Q)\ \&\ (\forall k \in K)(\forall l \in L)(\nu(f_{k,l}) = \nu(g_{k,l}))$$

$$\&\ (\forall a_1, ..., a_{\nu(f_{k,l})} \in \mathcal{X})(f_{k,l}(a_1, ..., a_{\nu(f_{k,l})}) < g_{k,l}(a_1, ..., a_{\nu(f_{k,l})})).$$

Definition 4.a: The non-strict relation "inclusion about value", when the IMFE-elements of both matrices are elements of $\mathcal{F}_x^1$, is

$$A \subseteq_v B \text{ iff } (K = P)\ \&\ (L = Q)\ \&\ (\forall k \in K)(\forall l \in L)(\forall a \in \mathcal{X})$$

$$(f_{k,l}(a) \leq g_{k,l}(a)).$$

Definition 4.b: The non-strict relation "inclusion about value", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subseteq_v B \text{ iff } (K = P)\ \&\ (L = Q)\ \&\ (\forall k \in K)(\forall l \in L)(\nu(f_{k,l}) = \nu(g_{k,l}))$$

$$\&\ (\forall a_1, ..., a_{\nu(f_{k,l})} \in \mathcal{X})(f_{k,l}(a_1, ..., a_{\nu(f_{k,l})}) \leq g_{k,l}(a_1, ..., a_{\nu(f_{k,l})})).$$

Definition 5.a: The strict relation "inclusion", when the IMFE-elements of both matrices are elements of $\mathcal{F}_x^1$, is

$$A \subset B \text{ iff } (((K \subset P)\ \&\ (L \subset Q))\ \vee\ ((K \subseteq P)\ \&\ (L \subset Q))$$

$$\vee\ ((K \subset P)\ \&\ (L \subseteq Q)))\ \&\ (\forall k \in K)(\forall l \in L)(\forall a \in \mathcal{X})(f_{k,l}(a) < g_{k,l}(a)).$$

Definition 5.b: The strict relation "inclusion", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subset B \text{ iff } (((K \subset P)\ \&\ (L \subset Q))\ \vee\ ((K \subseteq P)\ \&\ (L \subset Q))$$

$$\vee\ ((K \subset P)\ \&\ (L \subseteq Q)))\ \&\ (\forall k \in K)(\forall l \in L)(\nu(f_{k,l}) = \nu(g_{k,l}))$$

$$\&\ \ (\forall a_1, ..., a_{\nu(f_{k,l})} \in \mathcal{X})(f_{k,l}(a_1, ..., a_{\nu(f_{k,l})}) < g_{k,l}(a_1, ..., a_{\nu(f_{k,l})})).$$

Definition 6.a: The non-strict relation “inclusion", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subseteq B \text{ iff } (K \subseteq P)\ \&\ (L \subseteq Q)\ \&\ (\forall k \in K)(\forall l \in L)(\forall a \in \mathcal{X})$$

$$(f_{k,l}(a) \leq g_{k,l}(a)).$$

Definition 6.b: The non-strict relation “inclusion", when the IMFE-elements of both matrices are elements not only of $\mathcal{F}_x^1$, is

$$A \subseteq B \text{ iff } (K \subseteq P)\ \&\ (L \subseteq Q)\ \&\ (\forall k \in K)(\forall l \in L)(\nu(f_{k,l}) = \nu(g_{k,l}))$$

$$\&\ \ (\forall a_1, ..., a_{\nu(f_{k,l})} \in \mathcal{X})(f_{k,l}(a_1, ..., a_{\nu(f_{k,l})}) < g_{k,l}(a_1, ..., a_{\nu(f_{k,l})})).$$

It can be directly seen that for every two IMs A and B,

- if $A \subset_d B$, then $A \subseteq_d B$;
- if $A \subset_v B$, then $A \subseteq_v B$;
- if $A \subset B$, $A \subseteq_d B$, or $A \subseteq_v B$, then $A \subseteq B$;
- if $A \subset_d B$ or $A \subset_v B$, then $A \subseteq B$.

New operations over IMFEs

Three new operations are introduced, that are analogous of the operations over IMs. Now, the hierarhical operators over IM cannot be introduced over IMFE.

01 Operations “reduction" over an IMFE

First, we introduce operations $(k, \perp)$- and $(\perp, l)$-reduction of a given IM $A = [K, L, \{f_{k_i,l_j}\}]$:

$$A_{(k,\perp)} = [K - \{k\}, L, \{h_{t_u,v_w}\}]$$

where

$$h_{t_u,v_w} = f_{k_i,l_j} \text{ for } t_u = k_i \in K - \{k\} \text{ and } v_w = l_j \in L$$

and

$$A_{(\perp,l)} = [K, L - \{l\}, \{h_{t_u,v_w}\}],$$

where

$$h_{t_u,v_w} = f_{k_i,l_j} \text{ for } t_u = k_i \in K \text{ and } v_w = l_j \in L - \{l\}.$$

Second, we define

$$A_{(k,l)} = (A_{(k,\perp)})_{(\perp,l)} = (A_{(\perp,l)})_{(k,\perp)},$$

i.e.,

$$A_{(k,l)} = [K - \{k\}, L - \{l\}, \{h_{t_u,v_w}\}],$$

where

$$h_{t_u,v_w} = f_{k_i,l_j} \text{ for } t_u = k_i \in K - \{k\} \text{ and } v_w = l_j \in L - \{l\}.$$

Theorem 1. For every IMFE A and for every $k_1, k_2 \in K, l_1, l_2 \in L$,

$$(A_{(k_1,l_1)})_{(k_2,l_2)} = (A_{(k_2,l_2)})_{(k_1,l_1)}.$$

Third, let $P = \{k_1, k_2, ..., k_s\} \subseteq K$ and $Q = \{q_1, q_2, ..., q_t\} \subseteq L$. Finally, we define the following three operations:

$$A_{(P,l)} = (...((A_{(k_1,l)})_{(k_2,l)})...)_{(k_s,l)},$$

$$A_{(k,Q)} = (...((A_{(k,l_1)})_{(k,l_2)})...)_{(k,l_t)},$$

$$A_{(P,Q)} = (...((A_{(p_1,Q)})_{(p_2,Q)})...)_{(p_s,Q)} = (...((A_{(P,q_1)})_{(P,q_2)})...)_{(P,q_t)}.$$

Obviously,

$$A_{(K,L)} = I_\emptyset,$$

$$A_{(\emptyset,\emptyset)} = A.$$

Theorem 2. For every two IMs $A = [K, L, \{f_{k_i,l_j}\}], B = [P, Q, \{g_{p_r,q_s}\}]$:

$$A \subseteq_d B \text{ iff } A = B_{(P-K,Q-L)}.$$

Proof: Let $A \subseteq_d B$. Therefore, $K \subseteq P$ and $L \subseteq Q$ and for every $k \in K, l \in L$, for every $a \in X$: $f_{k,l}(a) = g_{k,l}(a)$. From the definition,

$$B_{(P-K,Q-L)} = (...((B_{(p_1,q_1)})_{(p_1,q_2)})...)_{(p_r,q_s)},$$

where $p_1, p_2, ..., p_r \in P - K$, i.e., $p_1, p_2, ..., p_r \in P$, and $p_1, p_2, ..., p_r \notin K$, and $q_1, q_2, ..., q_s \in Q - L$, i.e., $q_1, q_2, ..., q_s \in Q$, and $q_1, q_2, ..., q_s \notin L$. Therefore,

$$B_{(P-K,Q-L)} = [P - (P - K), Q - (Q - L), \{g_{k,l}\}] = [K, L, \{g_{k,l}\}] = [K, L, \{f_{k,l}\}] = A,$$

because by definition the elements of the two IMs, which are indexed by equal symbols, coincide.

For the opposite direction we obtain, that if $A = B_{(P-K,Q-L)}$, then

$$A = B_{(P-K,Q-L)} \subseteq_d B_{\emptyset,\emptyset} = B.$$

02 Operation “projection" over an IM

Let $M \subseteq K$ and $N \subseteq L$. Then,

$$pr_{M,N}A = [M, N, \{g_{k_i,l_j}\}],$$

where

$$(\forall k_i \in M)(\forall l_j \in N)(g_{k_i,l_j} = f_{k_i,l_j}).$$

Theorem 3. For every IMFE A and sets $M_1 \subseteq M_2 \subseteq K$ and $N_1 \subseteq N_2 \subseteq L$ the equality

$$pr_{M_1,N_1} pr_{M_2,N_2} A = pr_{M_1,N_1} A$$

holds.

03 "Inflating operation" over an IM

We can define "inflating operation" that is defined for index sets $K \subset P \subset \mathcal{I}$ and $L \subset Q \subset \mathcal{I}$ by

$$^{(P,Q)}A =^{(P,Q)} [K, L, \{a_{k_i,l_j}\}] = [P, Q, \{b_{p_r,q_s}\}],$$

where

$$b_{p_r,q_s} = \begin{cases} a_{k_i,l_j}, & \text{if } p_r = k_i \in K \text{ and } q_s = l_j \in L \\ \perp, & \text{otherwise} \end{cases}$$

04 Operation "substitution" over an IM

Let IM $A = [K, L, \{f_{k,l}\}]$ be given.
First, local substitution over the IM is defined for the couples of indices (p, k) and/or (q, l), respectively, by

$$[\frac{p}{k}]A = [(K - \{k\}) \cup \{p\}, L, \{f_{k,l}\}],$$

$$[\frac{q}{l}]A = [K, (L - \{l\}) \cup \{q\}, \{f_{k,l}\}],$$

Second,

$$[\frac{p}{k}\frac{q}{l}]A = [\frac{p}{k}][\frac{q}{l}]A,$$

i.e.

$$[\frac{p}{k}\frac{q}{l}]A = [(K - \{k\}) \cup \{p\}, (L - \{l\}) \cup \{q\}, \{f_{k,l}\}].$$

Obviously, for the above indices k, l, p, q:

$$[\frac{k}{p}]([\frac{p}{k}]A) = [\frac{l}{q}]([\frac{q}{l}]A) = [\frac{k}{p}\frac{l}{q}]([\frac{p}{k}\frac{q}{l}]A) = A,$$

Let the sets of indices $P = \{p_1, p_2, ..., p_m\}$, $Q = \{q_1, q_2, ..., q_n\}$ be given.
Third, for them we define sequentially:

$$[\frac{P}{K}]A = [\frac{p_1}{k_1}\frac{p_2}{k_2}...\frac{p_n}{k_n}]A,$$

$$[\frac{Q}{L}]A = ([\frac{q_1}{l_1}\frac{q_2}{l_2}...\frac{q_n}{l_n}]A),$$

$$[\frac{K}{P}\frac{Q}{L}]A = [\frac{P}{K}][\frac{Q}{L}]A,$$

i.e.,

$$[\frac{P}{K}\frac{Q}{L}]A = [\frac{p_1}{k_1}\frac{p_2}{k_2}...\frac{p_m}{k_m}\frac{q_1}{l_1}\frac{q_2}{l_2}...\frac{q_n}{l_n}]A = [P, Q, \{f_{k,l}\}]$$

Obviously, for the sets K, L, P, Q:

$$[\frac{K}{P}]([\frac{P}{K}]A) = [\frac{L}{Q}]([\frac{Q}{L}]A) = [\frac{K}{P}\frac{L}{Q}]([\frac{P}{K}\frac{Q}{L}]A) = A.$$

Theorem 4. For every four sets of indices P_1, P_2, Q_1, Q_2

$$[\frac{P_2}{P_1}\frac{Q_2}{Q_1}][\frac{P_1}{K}\frac{Q_1}{L}]A = [\frac{P_2}{K}\frac{Q_2}{L}]A.$$

Operations over IMFEs and IMs

Let the IM $A = [K, L, \{a_{k_i,l_j}\}]$, where $a_{k_i,l_j} \in \mathcal{R}$ and IMFE $F = [P, Q, \{f_{p_r,q_s}\}]$ be given. Then

(a) $A \boxplus F = [K \cup P, L \cup Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = \begin{cases} a_{k_i,l_j}.f_{p_r,q_s}, & \text{if } t_u = k_i = p_r \in K \cap P \\ & \text{and } v_w = l_j = q_s \in L \cap Q; \\ \bot, & \text{otherwise} \end{cases},$$

with elements of $\mathcal{F}^1$;

(b) $A \boxtimes F = [K \cap P, L \cap Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = a_{k_i,l_j}.f_{p_r,q_s},$$

for $t_u = k_i = p_r \in K \cap P$ and $v_w = l_j = q_s \in L \cap Q$ with elements of $\mathcal{F}^1$;

(c) $F \oplus A = [K \cup P, L \cup Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = \begin{cases} f_{p_r,q_s}(a_{k_i,l_j}), & \text{if } t_u = k_i = p_r \in K \cap P \\ & \text{and } v_w = l_j = q_s \in L \cap Q \\ \bot, & \text{otherwise} \end{cases}$$

with elements of $\mathcal{R}$;

(d) $F \otimes A = [K \cap P, L \cap Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = f_{p_r,q_s}(a_{k_i,l_j}),$$

for $t_u = k_i = p_r \in K \cap P$ and $v_w = l_j = q_s \in L \cap Q$ with elements of $\mathcal{R}$.

Let the IM $A = [K, L, \{\langle a^1_{k_i,l_j}, ..., a^n_{k_i,l_j}\rangle\}]$, for the natural number $n \geq 2$, where $a^1_{k_i,l_j}, ..., a^n_{k_i,l_j} \in \mathcal{R}$ and IMFE $F = [P, Q, \{f_{p_r,q_s}\}]$, where $f_{p_r,q_s} : \mathcal{F}^n \to \mathcal{F}$ be given. Then

(e) $F \diamondsuit_{\oplus} A = [K \cup P, L \cup Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = \begin{cases} f_{p_r,q_s}(\langle a^1_{k_i,l_j}, ..., a^n_{k_i,l_j}\rangle), & \text{if } t_u = k_i = p_r \in K \cap P \\ & \text{and } v_w = l_j = q_s \in L \cap Q \\ \bot, & \text{otherwise} \end{cases}$$

with elements of $\mathcal{R}$;

(f) $F \diamondsuit_{\otimes} A = [K \cap P, L \cap Q, \{h_{t_u,v_w}\}]$, where

$$h_{t_u,v_w} = f_{p_r,q_s}(\langle a^1_{k_i,l_j}, ..., a^n_{k_i,l_j}\rangle),$$

for $t_u = k_i = p_r \in K \cap P$ and $v_w = l_j = q_s \in L \cap Q$ with elements of $\mathcal{R}$.

Conclusion

In future, we will discuss the two other cases for the form of functions: when each function of set $\mathcal{F}$ has one argument, but it can be different for the different functions and when the functions of set $\mathcal{F}$ are different and they have different numbers of arguments.

We will use the new operations for description of some components of the artificial intelligence. For example, in [Atanassov & Sotirov, 2013] it was shown that the neural networks can be described in the form of IMs. On the basis of the present research, we will be able to introduce a new extension of the concept of neural networks, which will be described in the form of IMFE.

Acknowledgements

This work has been partially supported by the Bulgarian National Science Fund under the grant "Simulation of wild-land fire behavior" - I01/0006.

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REDUCED GENERALIZED NETS WITH CHARACTERISTICS OF THE PLACES

Velin Andonov

Abstract: *Generalized Nets with Characteristics of the Places (GNCP) are conservative extensions of the ordinary Generalized Nets (GNs). In the present paper, for the first time algorithm for transition functioning in GNCP is proposed. Some possible applications of GNCP are discussed. It is shown how GNCP can be used for evaluation of the places and to simplify the graphical structure of the net. In analogy with the concept of reduced GNs, reduced GNCP are introduced. It is proved that there exist two minimal reduced GNCP — one with characteristics of the places and one in which only the tokens obtain characteristics. An example of a reduced GNCP that describes the work of a fire company is presented.*

Keywords: *Algorithm for transition functioning, Extensions of generalized nets, Generalized nets, Reduced generalized nets.*

Introduction

Generalized Nets with Characteristics of the Places (GNCP) are conservative extensions of the ordinary Generalized Nets (GNs). They are defined in [Andonov & Atanassov, 2013]. GNCP is the ordered four-tuple

$$E = \langle\langle A, \pi_A, \pi_L, c, f, \theta_1, \theta_2\rangle, \langle K, \pi_K, \theta_K\rangle, \langle T, t^0, t^*\rangle, \langle X, Y, \Phi, \Psi, b\rangle\rangle .$$

All other components except the characteristic functions Y and Ψ are the same as in the standard GNs. For the definition of transition and GN the reader can refer to [Atanassov, 1991; Atanassov, 2007]. The characteristic function Y assigns initial characteristics to the places of the net. The function Ψ assigns characteristics to some of the places when tokens enter them. These characteristics can be the number of tokens in the place, the moment of time when they arrive or other data which is related to the place. The connection between GNCP and the Intuitionistic Fuzzy Generalized Nets of type 1 (IFGN1) and type 2 (IFGN2) is studied in [Andonov, 2013]. Two new extensions that combine the properties of GNCP on one hand, and IFGN1 and IFGN3 on the other, are introduced in [Andonov, 2013]. These are the Intuitionistic Fuzzy Generalized Nets with Characteristics of the Places of type 1(IFGNCP1) and type 3 (IFGNCP3). It is proved that the classes $\Sigma_{IFGNCP1}$ of all IFGNCP1 and $\Sigma_{IFGNCP3}$ of all IFGNCP3 are conservative extensions of the class Σ of the ordinary GNs .

GNCP can be used for evaluation of the work of the places on the basis of their characteristics. For example, let Δ_l denote the set of all good characteristics that can be assigned to place l and Ξ_l denote the set of all bad characteristics. Let $\chi^{l,t} = \langle\chi_1^l, \cdots, \chi_n^l\rangle$ be the n-tuple of the characteristics obtained by place l up to the time moment t. Let

$$I_\Delta^l(x_i^l) = \begin{cases} 1 & , \text{ if } \chi_i^l \in \Delta_l \\ 0 & , \text{ if } \chi_i^l \notin \Delta_l \end{cases}$$

and

$$I_\Xi^l(x_i^l) = \begin{cases} 1 & , \text{ if } \chi_i^l \in \Xi_l \\ 0 & , \text{ if } \chi_i^l \notin \Xi_l \end{cases} .$$

Then the characteristic function Ψ can assign to place l the ordered couple $\langle \mu_l^t, \nu_l^t \rangle$ where

$$\mu_l^t = \frac{\sum_{i=1}^{n} I_\Delta^l(\chi_i^l)}{n}$$

and

$$\nu_l^t = \frac{\sum_{i=1}^{n} I_\Xi^l(\chi_i^l)}{n}.$$

Obviously, $\mu_l^t, \nu_l^t \in [0,1]$ and $\mu_l^t + \nu_l^t = 1$. The ordered couple $\langle \mu_l^t, \nu_l^t \rangle$ is a fuzzy evaluation of place l at time t. In the more general case, we may also have characteristics that are neither good nor bad. Then for the couple $\langle \mu_l^t, \nu_l^t \rangle$ we have $\mu_l^t, \nu_l^t \in [0,1]$ and $\mu_l^t + \nu_l^t \leq 1$. The number $\pi_l^t = 1 - \mu_l^t - \nu_l^t \leq 1$ corresponds to the degree of indeterminacy. In this case $\langle \mu_l^t, \nu_l^t \rangle$ is an intuitionistic fuzzy evaluation of the place. For fuzzy and intuitionistic fuzzy sets see [Atanassov, 2012].

GNCP can also be used to simplify the graphical structure of the net. Oftentimes, in a GN we have transitions for which a place is both input and output. If tokens loop in this place or other tokens from other input places can enter it but no tokens can be transferred from this place to other output places, then we can exclude this place from the set of input places of the transition. The characteristics of the tokens that loop in this place can be assigned to the place instead. For the transition Z in Figure 1 we have two such places — l_5 and l_6. If we use characteristics for these two places, the functioning of Z can be represented by the transition Z^* on the right in Figure 1. The two circles denote that the place can obtain characteristics.

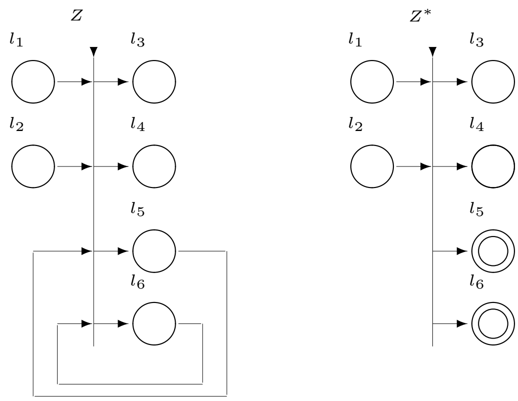

Figure 1

Algorithm for transition functioning in GNCP

The algorithms for transition and net functioning in the standard GNs can be found in [Atanassov, 2007]. Here for the first time we propose the algorithm for transition functioning in GNCP.

Algorithm A'

(A'01) The input and output places are ordered by their priorities.

(A'02) For every input place two lists are compounded. One with all tokens in the place ordered by their priorities and an empty list.

(A'03) An empty index matrix R which corresponds to the index matrix of the predicates r is generated. A value 0 (corresponding to truth-value "false") is asigned to all elements of R which:

- are in a row corresponding to empty input place;

- are in a column corresponding to full output place;
- are placed in a position (i, j) for which the current capacity of the arc between the i-th input and j-th output place is 0.

(A'04) The places are passed sequentially by order of their priorities starting with the place with the highest priority for which transfer has not occurred on the current time step and which has at least one token. For the token with highest priority from the first group we determine if it can split or not. The predicates in the row corresponding to the current input place are checked. If the token cannot split the checking of the predicates stops with the first predicate whose truth value is not 0. If the token can split, the truth values of all predicates in the row for which the elements of R are not equal to 0 are evaluated.

(A'05) Depending on the execution of the operator for permission or prohibition of tokens' splitting, the token from **(A'04)** is transferred either to all permitted output places or to the place with the highest priority for which the truth value of the corresponding predicate is 1. If a token cannot be transferred at the current time step, it is moved to the second group of the corresponding input place. The tokens which have been transferred are moved into the second group of the output places. The tokens which have entered the input place after the activation of the transition are moved to the second group too.

(A'06) The current number of tokens in every output place is increased with 1 for each token that has entered the place at the current time step. If the maximum number of tokens in an output place has been reached, the elements in the corresponding column of R are assigned value 0.

(A'07) The number of tokens in the input place is decreased by 1.

(A'08) The capacities of all arcs through which a token has passed decrement with 1. If the capacity of an arc has reached 0, value 0 is assigned to the element from the index matrix R that corresponds to this arc.

(A'09) The values of the characteristic function Φ for the corresponding output places (one or more) in which tokens have entered according to **(A'05)** are calculated. These values are assigned to the tokens.

(A'10) If there are more input places at the current time step from which tokens can be transferred, the algorithm proceeds to **(A'04)**, otherwise it proceeds to **(A'11)**.

(A'11) The values of the characteristic function Ψ for all output places to which tokens have been transferred are calculated. These values are assigned to the places.

(A'12) The current model time t' is increased with t^0.

(A'13) Is the current time moment equal or greater than $t^1 + t^2$? If the answer to the question is “no", go to go to **(A'04)**. Otherwise, terminate the functioning of the transition.

The algorithm for GNCP's functioning is the same as the general algorithm for GN's functioning denoted by *algorithm B* (see [Atanassov, 2007]), with the exception that the algorithm for transition functioning in GNCP is applied over the abstract transition. It is important to mention that in GNCP characteristics are assigned only to those output places to which tokens have been transferred at the current time step. This requirement justifies the use of characteristics of the places as a convenient way to track the changes in the places during the functioning of the net.

Reduced GNCP

GNs may or may not have some of the components in their definition. GNs which do not have some of the components form special classes called reduced GNs. For more details about the concept of reduced GNs see [Atanassov, 1991]. Let

$$\Omega = \{A, \pi_A, \pi_L, c, f, \theta_1, \theta_2, K, \pi_K, \theta_K, T, t^0, t^*, X, \Phi, b\} \cup \{A_i | 1 \leq i \leq 7\},$$

where $A_i = pr_i A$ is the i-th projection of the set A of the transitions of the net, i.e. $A_i \in \{L', L'', t_1, t_2, r, M, \square\}$. If Σ is the class of all GNs and $Y \in \Omega$, then by Σ^Y we denote the class of all GNs that do not have component

Y. They are called Y-*reduced GNs*. In [Atanassov, 1991] many assertions for the different classes of reduced GNs are proved.

Let Σ_1 and Σ_2 be subclasses of Σ. We will need the following definitions:

• $\Sigma_1 \vdash \Sigma_2$ *iff* the functioning and the results of the work of every element of Σ_2 can be described by an element of Σ_1.

• $\Sigma_1 \equiv \Sigma_2$ *iff* $\Sigma_1 \vdash \Sigma_2$ & $\Sigma_2 \vdash \Sigma_1$.

The class $\Sigma^* = \Sigma^{A_3,A_4,A_6,A_7,\pi_A,\pi_L,c,\theta_1,\theta_2,\pi_K,\theta_K,T,t^0,t^*,b}$ is the class of minimal reduced GNs (**-GNs*). The minimal reduced GNs have the form

$$E' = \langle\langle A', *, *, *, *, *, *\rangle, \langle K, *, *\rangle, *, \langle X, \Phi, *, *\rangle\rangle \,,$$

where

$$A' = \{Z' | Z' = \langle L', L'', *, *, r, *, *\rangle \& Z = \langle L', L'', t_1, t_2, r, M, \, \square \rangle \, \in A\} \,.$$

For the minimal reduced GNs the following notation is also used

$$E' = \langle A', K, X, \Phi\rangle \,.$$

The minimal elements of Σ^* are denoted by

$$E^* = \langle A^*, K^*, X^*, \Phi^*\rangle \,,$$

where A^* is the set of transitions of the form $Z^* = \langle L', L'', r'\rangle$.

The following theorem is proved in [Atanassov, 1991].

Theorem 1. $\Sigma \equiv \Sigma^*$.

To introduce the concept of reduced GNCP we need the following notation:

$$\Omega_{CP} = \{A, \pi_A, \pi_L, c, f, \theta_1, \theta_2, K, \pi_K, \theta_K, T, t^0, t^*, X, Y, \Phi, \Psi, b\} \cup \{A_i | 1 \le i \le 7\} \,,$$

where again $A_i = pr_i A$. By Σ_{CP}^Y we denote the class of those GNCP which do not have Y-component. In analogy to the standard reduced GNs they will be called Y-reduced GNCP. Again, as in the case of the reduced ordinary GNs we have

$$\Sigma_{CP}^A = \Sigma_{CP}^{A_1} = \Sigma_{CP}^{A_2} = \Sigma^K = \emptyset \,.$$

More generally, if $Y_1, Y_2, \cdots, Y_k \in \Omega_{CP}$ where $k \ge 1$ is natural number, then $\Sigma_{CP}^{Y_1,Y_2,\cdots,Y_k}$ will be called $(Y_1, Y_2, \cdots, Y_k)$-reduced class of GNCP. Now we have two classes of minimal reduced GNCP. In one of them only the tokens receive characteristics, while in the other characteristics are assigned only to the places. The class $\Sigma_{CP}^{A_3,A_4,A_6,A_7,\pi_A,\pi_L,c,\theta_1,\theta_2,\pi_K,\theta_K,T,t^0,t^*,Y,\Psi,b}$ coincides with the class Σ^*, i.e. all nets from this class have the form $E' = \langle A', K, X, \Phi\rangle$. With Σ_{CP}^* we will denote the class of minimal reduced GNCP in which only the places obtain characteristics. Formally,

$$\Sigma_{CP}^* = \Sigma_{CP}^{A_3,A_4,A_6,A_7,\pi_A,\pi_L,c,\theta_1,\theta_2,\pi_K,\theta_K,T,t^0,t^*,X,\Phi,b} \,.$$

The following theorems specify the connection between Σ, Σ_{CP}, Σ^* and Σ_{CP}^*.

Theorem 2. $\Sigma_{CP} \equiv \Sigma^*$.

Proof. In [Andonov & Atanassov, 2013] it is proved that $\Sigma_{CP} \equiv \Sigma$. From Theorem 1 we have $\Sigma \equiv \Sigma^*$. Therefore $\Sigma_{CP} \equiv \Sigma^*$.

A more detailed constructive proof, analogous to the proof of Theorem 2.2.1 in [Atanassov, 1991], would show how we can actually construct a minimal reduced GN given a GNCP.

Theorem 3. $\Sigma^* \equiv \Sigma^*_{CP}$.

Proof. First we will show that $\Sigma^*_{CP} \vdash \Sigma^*$. Let E be arbitrary minimal reduced generalized net from the class Σ^*.

$$E = \langle A, K, X, \Phi \rangle \, .$$

Every transition of E has the form $Z = \langle L', L'', r' \rangle$. Let Z be arbitrary transition of E. For simplicity, we shall consider that characteristics of the tokens are not used in the predicates of the transitions and in the characteristic function Φ. We construct a transition Z_{CP} with the same graphic structure as Z, i.e. the same number of input and output places and the same index matrix of the transitions condition. Let A_{CP} be the set of transitions obtained after repeating this procedure for all transitions of E. We will prove that the minimal reduced GNCP

$$G = \langle A_{CP}, *, *, *, *, *, * \rangle, \langle K_{CP}, *, * \rangle, *, \langle *, Y, *, \Psi, * \rangle$$

represents the functioning and the results of work of E. The set of tokens K_{CP} of G consists of the same number and types of tokens, i.e. for every token $\alpha' \in K_{CP}$ there is a corresponding token $\alpha \in K$. The function Y assigns the initial characteristics of the tokens in E to the places in which their corresponding tokens in G enter the net, i.e. if l and l_{CP} are two corresponding input places of E and G respectively, then $X_l = Y_{l_{CP}}$. The characteristic function Φ of E can be written in the form

$$\Phi = \bigcup_{l \in L - Q^I} \Phi_l = \bigcup_{Z \in A} (\bigcup_{l \in pr_2 Z} \Phi_l) \, ,$$

and similarly

$$\Psi = \bigcup_{l_{CP} \in L_{CP} - Q^I_{CP}} \Psi_{l_{CP}} = \bigcup_{Z_{CP} \in A_{CP}} (\bigcup_{l_{CP} \in pr_2 Z_{CP}} \Psi_{l_{CP}}) \, ,$$

where Q^I_{CP} is the set of input places of G and L_{CP} is the set of all places of G. The function $\Psi_{l_{CP}}$ assigns to the places of G a list of all tokens that have entered the places together with the characteristics that their corresponding tokens of E receive through the function Φ of E. If $\alpha^1_{CP}, \alpha^2_{CP}, ..., \alpha^k_{CP}$ are the tokens that have entered place l''_{CP} in G, then the characteristic of place l''_{CP} has the form

$$\text{“}\langle \langle \alpha^1_{CP}, \Phi_{l''}(\alpha^1) \rangle, \langle \alpha^2_{CP}, \Phi_{l''}(\alpha^2) \rangle, ..., \langle \alpha^k_{CP}, \Phi_{l''}(\alpha^k) \rangle \rangle\text{”} \, .$$

To prove that the so constructed reduced GNCP G represents the funtioning and the results of work of E we take two correspondig transitions $Z \in pr_1 pr_1 E$ and $Z_{CP} \in pr_1 pr_1 G$. Let $\alpha \in K$ and $\alpha_{CP} \in K_{CP}$ be two corresponding tokens that are respectively in places l' and l'_{CP}. If the token α is tranferred to output place l'', then α_{CP} is tranferred to the corresponding output place l''_{CP}. The characteristic obtained by α in l'' is assigned by the function Ψ to place l''_{CP}. If the token α cannot be transferred to any output place of Z, then α_{CP} also will not be tranferred to any output place. The case in which splitting of tokens is allowed can be verified in a similar way. From the theorem for the completeness of the GN transition it follows that $\Sigma^*_{CP} \vdash \Sigma^*$.

In the beginning of the proof we assumed that characteristics of tokens are not used in the predicates of the transition Z and in the characteristic function Φ. If such characteristics are used, then they must be substituted with the corresponding characteristics of the places in Z_{CP}. Let now G be arbitrary minimal reduced GNCP.

$$G = \langle A_{CP}, *, *, *, *, *, * \rangle, \langle K_{CP}, *, * \rangle, *, \langle *, Y, *, \Psi, * \rangle \, .$$

We will contruct a minimal reduced GN which represents the functioning and the results of the work of G. For every transition $Z_{CP} \in pr_1 pr_1 G$ (see Figure 2) we construct a corresponding transition Z (see Figure 3).

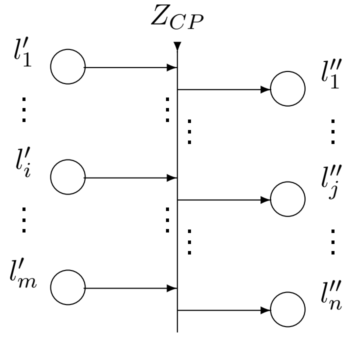

Figure 2

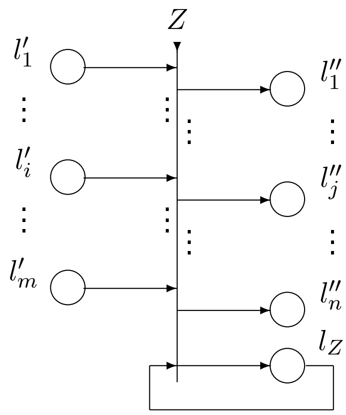

Figure 3

Again, we shall consider that characteristics of places are not used in the predicates of Z_{CP} and in the characteristic function Ψ. If $Z_{CP} = \langle L'_{CP}, L''_{CP}, r^{CP}\rangle$, then $Z = \langle L', L'', r\rangle$ where

$$L' = L'_{CP} \cup \{l_Z\}\,,$$

$$L'' = L''_{CP} \cup \{l_Z\}\,.$$

To every transition we add additional place which is input and output for the transition where a token α_Z will loop and keep as characteristics the characteristics assigned to the corresponding output places of Z_{CP}. The initial characteristic of the token α_Z is a list of the initial characteristics of the places of the transition Z_{CP}. Place l_Z has the lowest priority among the places of the transition.

If

$$r^{CP} = pr_5 Z_{CP} = [L'_{CP}, L''_{CP}, \{r^{CP}_{l_i,l_j}\}]$$

has the form of an IM, then

$$r = pr_5 Z = [L'_{CP} \cup \{l_Z\}, L''_{CP} \cup \{l_Z\}, \{r_{l_i,l_j}\}],$$

where

$$(\forall l_i \in L'_{CP})(\forall l_j \in L''_{CP})(r_{l_i,l_j} = r^{CP}_{l_i,l_j})$$

$$(\forall l_i \in L')(\forall l_j \in L'')(r_{l_i,l_Z} = r_{l_Z,l_j} = \text{“}false\text{”}),$$

$$r_{l_Z,l_Z} = \text{“}true\text{”}\,.$$

Let A be the set of transitions obtained after repeating the above procedure for all transitions of G. We will prove that the minimal reduced GN

$$E = \langle A, K, X, \Phi\rangle$$

represents the functioning and the results of work of G.

$$K = K_{CP} \bigcup \{\alpha_Z | Z \in A_{CP}\}\,.$$

The characteristic function X assigns initial characteristic $x_0^{\alpha_Z}$ only to the α_Z tokens and it is a list of all places of the transition Z and their initial characteristics in G:

$$“\langle l'_1, Y(l'_{CP,1})\rangle, \langle l'_2, Y(l'_{CP,2})\rangle, ..., \langle l''_n, Y(l''_{CP,n})\rangle”.$$

The characteristic function Φ assigns to the α_Z-tokens a list with the output places of the transition and the characteristics of their corresponding output places of G in the form

$$\Phi_{\{l_Z|Z\in A\}}(\alpha_Z) = “\{\langle l_j^{''}, \Psi(l''_{CP,j})\rangle | l_j^{''} \in L''\}”.$$

The proof that the so constructed minimal reduced GN represents the functioning and the results of the work of G is similar to the proof that $\Sigma^*_{CP} \vdash \Sigma^*$. Now all characteristics of the places of G are kept as characteristics of the α_Z tokens. Thus we obtain $\Sigma^* \equiv \Sigma^*_{CP}$.
In the beginning of the proof, we assumed that characteristics of the places are not used in the predicates of the transition Z_{CP} and in the characteristic function Ψ. If such characteristics are used, then they must be substituted with the corresponding characteristics of the tokens in Z. □
From Theorem 2 and Theorem 3 we obtain

Theorem 4. $\Sigma_{CP} \equiv \Sigma^*_{CP}$.

Example of a reduced GNCP

A GN model that represents the work of a fire company is presented in Figure 4.

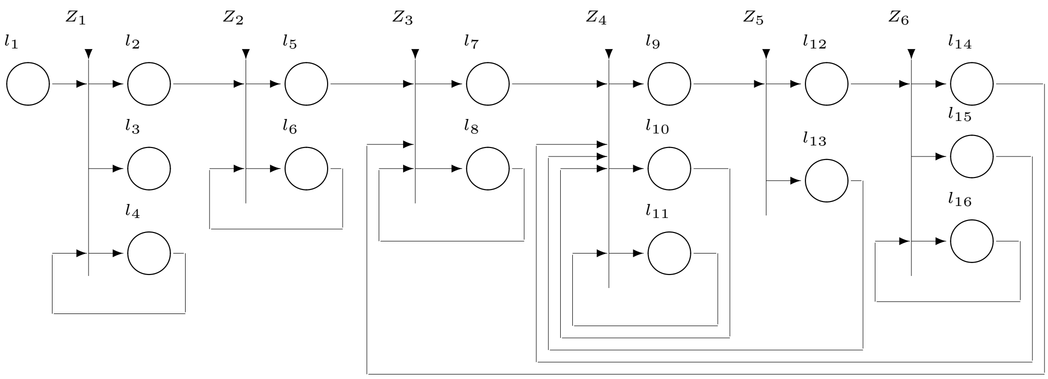

Figure 4. GN model of the process of fire extinguishing by a fire company.

Here we will contruct a reduced GNCP that describes the process of fire extinguishing by a fire company. The graphical representation of the net is in Figure 5.

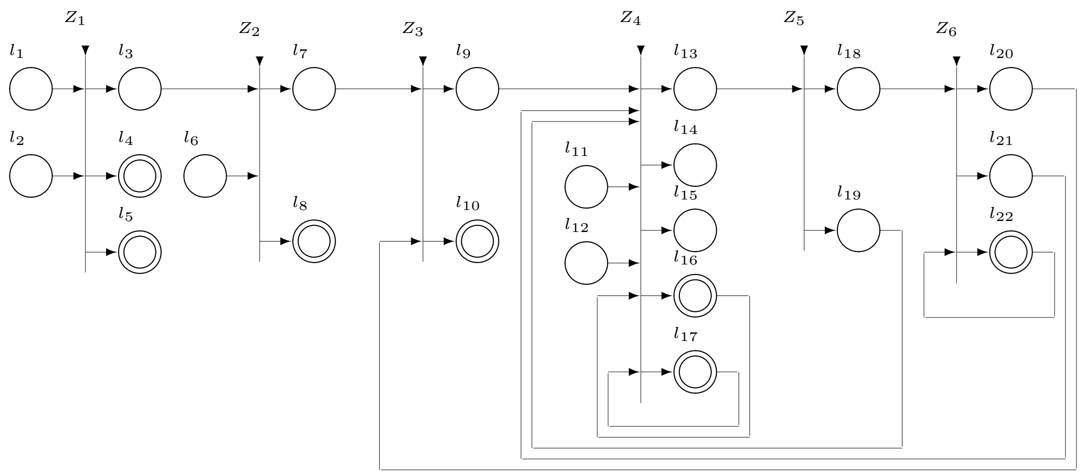

Figure 5. GNCP model of the process of fire extinguishing by a fire company.

The GNCP model presented in Figure 5 consists of six transitions and twenty two places.

- In Z_1 the alarm messages are filtered according to certain criteria.
- In Z_2 all available data for the place where a wildfire has been reported is collected. This can be coordinates, meteorological data, terrain profile etc.
- In Z_3 all available history for the place is collected.
- Z_4 represents the stuff and fire-fighting machinery.
- In Z_5 a decision is taken whether the available resources are enough to cope with the fire.
- Z_6 represents the place of the fire.

In the model we have five different types of tokens:

- α represents the alarm message;
- β represents the criteria for the correctness of the alarm messages;
- γ represents the database with data about the place where a fire is reported;
- δ represents all machinery available to the fire company;
- ϵ represents the fire-fighting stuff of the company.

The α tokens enter the net in place l_1 with initial characteristic

"alarm message".

During the functioning of the net β tokens may enter place l_2 with characteristic

"new criteria for correctness of the alarm messages".

During the functioning of the net γ tokens may enter place l_6 with initial characteristic

"new data about the coordinates, terrain profiles, meteorological conditions etc.".

During the functioning of the net δ tokens may enter place l_{11} with initial characteristic

"new machinery, type, number".

During the functioning of the net ϵ tokens may enter place l_{12} with initial characteristic

"stuff, name, decisions taken".

Token δ stays in place l_{16} in the initial time moment with characteristic

"machinery, type, number".

Token ϵ stays in place l_{17} in the initial time moment with characteristic

"stuff, name, decisions taken".

The places in Figure 5 represented by two concentric circles receive characteristics during the functioning of the net when tokens enter them. The initial characteristic of place l_5 is

"criteria for correctness of the alarm messages".

Place l_8 has initial characteristic

"database with coordinates, terrain profiles, meteorological conditions etc.".

Place l_{10} has initial characteristic

"data about previous fires".

Place l_{16} has initial characteristic

"machinery, type, number".

Place l_{17} has initial characteristic

"stuff, name, decisions taken" .

Place l_{22} does not have initial characteristic.

What follows is a formal description of the transitions of the net.

$$Z_1 = \langle \{l_1, l_2\}, \{l_3, l_4, l_5\}, r_1, \Box_1 \rangle \,,$$

where

$$r_1 = \begin{array}{c|ccc} & l_3 & l_4 & l_5 \\ \hline l_1 & W_{1,3} & W_{1,4} & false \\ l_2 & false & false & true \end{array}$$

and

$W_{1,3} =$*"The criterion shows that the alarm message is correct"*;

$W_{1,4} = \neg W_{1,3}$.

$$\square_1 = \vee(l_1, l_2)\,.$$

If according to the criteria the alarm message is false, the α token enters place l_3 without new characteristic. Place l_4 obtains the characteristic

"false alarm, source of the alarm".

When the truth value of the predicate $W_{1,3}$ is "true" the α token enters place l_2 without new characteristic. Token β enters place l_5 without characteristic. Place l_5 obtains the characteristic

"new criteria for the correctness of the signals".

$$Z_2 = \langle \{l_3, l_6\}, \{l_7, l_8\}, r_2, \square_2 \rangle\,,$$

where

$$r_2 = \begin{array}{c|cc} & l_7 & l_8 \\ \hline l_3 & true & false \\ l_6 & false & true \end{array}$$

$$\square_2 = \vee(l_3, l_6)\,.$$

Upon entering place l_7 the α token obtains the characteristic

"coordinates of the fire, meteorological conditions, terrain profile".

The γ tokens enter place l_8 without new characteristic. Instead place l_8 receives the characteristic of the γ token.

$$Z_3 = \langle \{l_7, l_{20}\}, \{l_9, l_{10}\}, r_3, \square_3 \rangle\,,$$

where

$$r_3 = \begin{array}{c|cc} & l_9 & l_{10} \\ \hline l_7 & true & false \\ l_{20} & false & true \end{array}$$

$$\square_3 = \vee(l_7, l_{20})\,.$$

The token coming from place l_{20} enters place l_{10} without characteristc. Place l_{10} receives the characteristic of the token that has entered it. Upon entering place l_9 the α token obtains the characteristic

"data about previous fires at the place".

$$Z_4 = \langle \{l_9, l_{11}, l_{12}, l_{16}, l_{17}, l_{19}, l_{21}\}, \{l_{13}, l_{14}, l_{15}, l_{16}, l_{17}\}, r_4, \square_4 \rangle,$$

where

$r_4 =$

	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}
l_9	$true$	$false$	$false$	$false$	$false$
l_{11}	$false$	$false$	$false$	$true$	$false$
l_{12}	$false$	$false$	$false$	$false$	$true$
l_{16}	$W_{16,13}$	$W_{16,14}$	$false$	$true$	$false$
l_{17}	$W_{17,13}$	$false$	$W_{17,15}$	$false$	$false$
l_{19}	$W_{19,13}$	$false$	$false$	$false$	$false$
l_{21}	$W_{21,13}$	$false$	$false$	$false$	$false$

and
$W_{16,13} =$*"A decision to send machinery is taken"*;
$W_{16,14} =$*"There is damaged machinery"*;
$W_{17,13} =$*"A decision to send more people is taken"*;
$W_{17,15} =$*"The current stuff on duty must be changed"*.

$$\square_4 = \wedge(\wedge(l_{16}, l_{17}), \vee(l_9, l_{11}, l_{12}, l_{19}, l_{21})).$$

When the truth value of the predicate $W_{17,13}$ is "true" token ϵ splits into two tokens — the original ϵ which remains in place l_{17} and ϵ' which enters place l_{13} with characteristic

"names of the fire fighting stuff sent to the place of the fire".

When the truth value of the predicate $W_{16,13}$ is "true" token δ splits into two tokens - the original δ which remains in place l_{16} and δ' which enters place l_{13} with characteristic

"type and numbers of the machinery which is sent to the place of the fire".

All tokens entering place l_{13} unite and generate a new token $\alpha_{\delta,\epsilon}$. The tokens from places l_{11} and l_{12} enter respectively places l_{16} and l_{17} where they unite with the δ and ϵ tokens. Place l_{16} obtains the characteristic

"relevant data about the machinery".

Place l_{17} obtains characteristic

"fire fighting stuff, names, decisions taken etc.".

When the truth value of the predicate $W_{16,14}$ is "true" the δ token in place l_{16} splits into two tokens - the original δ which reamains in l_{16} and a new δ'' which enters l_{14} with characteristic

"type of machinery, reason for leaving, time etc.".

When the truth value of the predicate $W_{17,15}$ is "true" the ϵ token in place l_{17} splits into two tokens - the original ϵ which reamains in l_{17} and a new ϵ'' which enters l_{15} with characteristic

"names of the people from the stuff, reason for leaving, time etc.".

$$Z_5 = \langle \{l_{13}\}, \{l_{18}, l_{19}\}, r_5, \Box_5 \rangle,$$

where

$$r_5 = \begin{array}{c|cc} & l_{18} & l_{19} \\ \hline l_{13} & true & W_{13,19} \end{array}$$

where
$W_{13,19} =$*"The resources being sent are not enough"*.

$$\Box_5 = \vee(l_{13}).$$

When the truth value of the predicate $W_{13,19}$ becomes "true" the $\alpha_{\delta,\epsilon}$ token splits into two tokens - the original which enters place l_{18} and a new token $\alpha'_{\delta,\epsilon}$ which enters place l_{19}. In place l_{18} the tokens do not obtain new characteristics. In place l_{19} the tokens obtain the characteristic

"Number of the additional stuff and machinery which is needed; type of machinery".

$$Z_6 = \langle \{l_{18}, l_{22}\}, \{l_{20}, l_{21}, l_{22}\}, r_6, \Box_6 \rangle,$$

where

$$r_6 = \begin{array}{c|ccc} & l_{20} & l_{21} & l_{22} \\ \hline l_{18} & false & false & true \\ l_{22} & W_{22,20} & W_{22,21} & true \end{array}$$

and
$W_{22,20} =$*"The fire is extinguished"*;
$W_{22,21} =$*"The resources at the place of the fire are not sufficient"*.

$$\Box_6 = \vee(l_{18}, l_{22}).$$

In place l_{22} the tokens receive the characteristic

"current state of the fire".

Upon entering place l_{20} the $\alpha_{\epsilon,\zeta}$ token obtains the characteristic

"total burnt area, duration of the wildfire, estimated damages".

When the truth value of the predicate $W_{22,21}$ is "true" the $\alpha_{\delta,\epsilon}$ tokens splits into two tokens the original which remains in place l_{22} and $\alpha''_{\delta,\epsilon}$ which enters place l_{21} with characteristic

"number of the additional stuff and machinery which is needed; type of machinery".

Place l_{22} receives characteristic

"current state of the fire, weather conditions etc".

Conclusion

Most GN models developed so far are reduced ones. The reduced GNCP proposed in this paper are convenient tool for modelling of real processes. In comparison to the reduced ordinary GNs the reduced GNCP allow us to keep all data which is relevant to some of the places in the form of characteristics of these places. We have shown that there exist two minimal reduced classes of GNs — one with characteristics of the places and one with characteristics of the tokens. In the proof of Theorem 2 we used the already established result $\Sigma \equiv \Sigma^*$ but a direct constructive proof of this result would also show how we can construct reduced GN given a GNCP. We obtained Theorem 4 as a consequence from Theorem 2 and Theorem 3. A direct constructive proof of this result should also be presented in future.

Acknowledgements

This work has been partially supported by the Bulgarian National Science Fund under the grant "Simulation of wild-land fire behavior" - I01/0006.

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ON THE ALGORITHMIC ASPECT OF THE MODIFIED WEIGHTED HAUSDORFF DISTANCE

Evgeniy Marinov

Abstract: *In this paper we introduce three formulas for calculation of the weights of the MWHD through the notion of a degree of friendship/relationship Γ. Further investigations and applications of this decision making procedures are also proposed, which are based on the few versions of weights determination procedures in the the MWHD formula stated in the current paper. As an application example we employ this formulas for Intuitionistic Fuzzy Distances.*

Keywords: *Modified weighted Hausdorff distance, Degree of friendship, Intuitionistic fuzzy sets.*

Preliminaries

In this section we give some preliminary information about modified distances and in particular, the modified Hausdorff distance. It has been used as a basis for the introduction of the modified weighted Hausdorff distance (MWHD), firstly introduced in [Marinov et al., 2012]. At the of the section we provide a brief introduction to intuitionistic fuzzy sets (IFS) and distances between them, as an example of application of the derived formulas.

01 Modified Hausdorff distance.

Let us introduce now the definition and provide some information about *modified distance* and in particular, the *modified Hausdorff distance*.

Definition 1. A mapping $\rho : Y \times Y \to \mathbb{R}_{\geq 0}$ is told *modified metric* or *modified distance* in Y if there exists a function $\phi : Y \to \mathbb{R}_{\geq 0}$ (see [Kuratowski, 1966], p. 209) with the following conditions satisfied for all $x, y, z \in Y$:

1. $\rho(x, y) \geq 0$, and equality holds iff $x = y$
2. $\rho(x, y) = \rho(y, x)$
3. $\rho(x, y) \leq \rho(x, z) + \rho(z, y) + \phi(z)$

In the last definition, the third axiom is known as the ϕ-modified triangular inequality. One easily remarks that if $\phi \equiv 0$, then the mapping ρ turns into a usual metric in Y. Dubuisson and Jain, investigating different properties of the (directed) Hausdorff metric, introduced 24 different distance measures classified according to their behaviour in presence of noise in image matching and pattern recognition. They introduced in [Dubuisson M. & Jain A.1994] a new definition of the directed Hausdorff distance h, for which the corresponding

$$H(A, B) = \max(h(A, B), h(B, A))$$

does not produce a usual metric but modified metric, called *modified Hausdorff distance*.

Definition 2. Let (X, d) be a metric space and $\mathcal{F}(X) \subset \mathcal{P}(X)$ the collection of finite subsets of X. The *directed modified Hausdorff distance* from $A = \{a_i\}_{i=1}^{|A|}$ to $B = \{b_i\}_{i=1}^{|B|}$ $(A, B \in \mathcal{F}(X))$ is given by:

$$h'_X(A,B) = \frac{1}{|A|}\sum_{a\in A}\min_{b\in B} d(a,b) \tag{1}$$

and the formula for the *modified Hausdorff distance* (MHD) between A and B by:

$$H'_X(A,B) = \max\{h'_X(A,B), h'_X(B,A)\}. \tag{2}$$

A complete proof that the so defined $H'_X(A, B)$ provides a modified distance, where $\phi(C) = \sup\{d(x, y) \mid x, y \in C\}$ from Definition 1 is the diameter of the considered subset $C \in \mathcal{F}(X)$, can be found in a more general case in [Marinov et al., 2012]. Taking into account that $d(a, B) = \min\{d(a, b) \mid b \in B\}$, the directed modified distance takes the form $h'_X(A, B) = \frac{1}{|A|}\sum\limits_{a\in A} d(a, B)$. From the last expression we get that the directed modified distance between two finite subsets A and B is exactly the *arithmetic mean* of the distances from all points $a \in A$ of the first subset to the second subset B.

Remark 1. In the above notations suppose now that A has a point a' that is pretty far from his nearest point of B, i.e. $d(a', B)$ is considerably larger in comparison with the distance of the other elements of A to B. In such a case the usual directed distance $h_X(A, B)$ is exactly $d(a', B)$, even if all points of A except a' are much closer to B. On the other hand, the modified directed distance $h'_X(A, B)$ won't be affected in such a degree if there is one (or only a few) isolated points too far from B, which provides a more realistic similarity measure for the distance between A and B.

In practice and applications it is important to be able to compare portions of subsets (objects, images, shapes) instead of looking for exact matches. That is why the above introduced modification of the Hausdorff distance compared to the usual Hausdorff distance provides an improved measure, which is less sensitive to noise. More detailed discussions about its applications and results are given in [Dubuisson M. & Jain A.1994; Takács1998].

02 Degree of friendship

Let us remind the formulas for realistic and adequately calculation priorities/weights assigned in the points of elements of $\mathcal{F}(X)$ (the collection of all finite subsets of X), on which the modified weighted Hausdorff distance (MWHD) has been introduced. The reader may refer to [Marinov et al., 2012] for more detailed information about the MWHD, its properties and application in intuitionistic fuzzy decision making procedures.
Let us consider again (X, d) and $A, B \in \mathcal{F}(X)$ as in Definition 2, in order to recall the definition of MWHD.

Definition 3. Let (X, d) be a metric space and $\mathcal{P}_0 \subset \mathcal{F}(X)$ such that $\forall A \in \mathcal{P}_0$ we choose $\{\rho^A_a\}_{a\in A} \subset (0, 1]$ such that $\sum_{a\in A} \rho^A_a = 1$. Thereby, we are given the pair $(\mathcal{P}_0, \rho)$ and for any $A, B \in \mathcal{P}_0$, let us define

$$h_\rho(A,B) := \sum_{a\in A}\rho^A_a d(a,B) \tag{3}$$

the *weighted directed distance* between A and B with weights ρ^A_a in a and ρ^B_b in b. We also introduce the *modified weighted Hausdorff distance* (MWHD) H_ρ in $\mathcal{P}_0$ between A and B as:

$$H_\rho(A,B) := \max\{h_\rho(A,B), h_\rho(B,A)\}, \tag{4}$$

which gives us obviously a map $H_\rho : \mathcal{P}_0 \times \mathcal{P}_0 \longrightarrow \mathbb{R}_{\geq 0}$.

One can easily remark that $H'(A, B)$ is actually a special case of $H_\rho(A, B)$ where $\mathcal{P}_0$ coincides with $\mathcal{F}(X) = \{U \subset X | card(U) < \infty\}$ and for every $A \in \mathcal{P}_0$ all points of A have the same weights, namely $\forall a \in A : \rho^A_a =$

$\frac{1}{|A|}$. Thus, all the points $a \in A$ of any $A \in \mathcal{P}$ are given the same weights/priorities in a regarding the membership of a to A. Taking now $B \in \mathcal{P}_0$ such that $a \in A \cap B$, it is clear that the weight in a regarding its membership to $A(\rho_a^A = \frac{1}{|A|})$ and its membership to $B(\rho_a^B = \frac{1}{|B|})$ respectively are not equal if $|A| \neq |B|$. In the general case, where the weights in the points of A are not homogeneous, ρ_a^A may be interpreted as the degree of importance or the priority of membership of the element a to the set A.

Remark 2. In decision making procedures, for instance, we may have a group of experts $A \in \mathcal{P}_0$ ($\mathcal{P}_0$ - the collection of all groups) and $a \in A$ is any individual expert belonging to the group A. Then, the opinions of the experts may differ between each other according to the priority of every expert in the given group, i.e. they have different weights. As in the above example, we may have $a \in A \cap B$, which means that an expert belongs to two different groups simultaneously and regarding his membership to any of the group his opinion has a priority ρ_a^A in the group A but priority ρ_a^B in the group B. The priorities of all members from any expert group of $\mathcal{P}_0$ are normalized, i.e. have sum equal to 1.

Considering a member a of the group A we can ask what would be the priority of his opinion/decision/judgment about any given problem? We may suppose that there is some kind of selforganization within the group. The decisions of some members are more influential, whereas other members are of little importance. Intuitively, we say that the experts, whose decisions are most important stay in more **central positions** than others. And literally that is the geometric meaning regarding the defined metric d in the underlying set X.

1. If for an expert a there are many other members of $A \subset X$, which are very close to a with respect to d, we mean that a has relatively influential decision.

2. On the other hand, if the expert a is more isolated, i.e. $d(a, A \setminus \{a\})$ is relatively large or there are only a few members that are close to a, we conclude that he is not very important as a member of the group.

In the train of thought from the above interpretations let us introduce a very natural and intuitive method for generation of the priorities/weights.

Suppose we are given a function:

$$\gamma\colon (0, \infty) \longrightarrow [0, \infty] \tag{5}$$

that is non-increasing or decreasing.

Definition 4. On the base of (5) and the underlying metric space (X, d), let us introduce the *degree of relationship* or *degree of friendship* through the following map:

$$\begin{array}{rcl} \Gamma_{d,\gamma}\colon X \times X \setminus D_X & \longrightarrow & [0, \infty] \\ (x_1, x_2) & \mapsto & \gamma(d(x_1, x_2)). \end{array} \tag{6}$$

Whereas $D_X = \{(x, x) \mid x \in X\}$ is the diagonal of the Cartesian product of X.

The above expression means that $\Gamma_{\gamma,d} := (\gamma \circ d)$. Thereby, if x_1 and x_2 are close then the value of $\Gamma_{\gamma,d}(x_1, x_2)$ is large. Otherwise, if they are far away from each other the value is small. And moreover, the value of $\Gamma_{\gamma,d}(x_1, x_2)$ is supposed to be close to 0 or equal to 0 only if x_1 and x_2 are extremely far from each other. One may note that for all $x \in X$ we have that $(x, x) \notin Dom(\Gamma_{\gamma,d})$ because $d(x, x) = 0 \notin Dom(\gamma)$. Thereby, the function $\Gamma_{\gamma,d}$ is correctly interpreted as *degree of relationship* or *degree of friendship*. When it is not misleading, we will write just Γ and omit the index γ and/or d as well .

As an example for γ can be taken $\gamma(z) = \frac{1}{z}$ and therefore for the above defined degree of friendship $\Gamma_{\gamma,d}$ we would have

$$\Gamma_{\gamma,d}(a_1, a_2) = \frac{1}{d(a_1, a_2)}, \tag{7}$$

which satisfies (5) and (6). Actually, (5) can be seen as an generalization of the last defined (7).

Definition 5. The set $A \in \mathcal{P}_0$, with $\mathcal{P}_0$ as described at the beginning of the paragraph, will be called $\Gamma_{\gamma,d}$-*degenerated* or just *degenerated* if

$$(\forall a_1, a_2 \in A)(\Gamma_{\gamma,d}(a_1, a_2) = 0) \tag{8}$$

i.e. $\Gamma_{\gamma,d} \equiv 0$ on $A \times A$, which means that all members of A are too isolated from each other. On the other hand, if all sets from $\mathcal{P}_0$ are non-degenerated we say that $\mathcal{P}_0$ is non-degenerated, that is:

$$(\forall A \in \mathcal{P}_0 \exists a_1, a_2 \in A)(\Gamma_{\gamma,d}(a_1, a_2) \neq 0)$$

Remark 3. In our interpretation example with the groups of experts a degenerated group A can be described as a very strange group, where all experts of A would have pretty different judgments and do not respect each other. They may in this case be experts with competencies in different areas of knowledge.

We suppose that only the weights $\{\rho_a^A\}_{a \in A}$ are yet unknown and namely that is what we want to define. We will then state practical algorithms assigning appropriate weights on the basis of the given distance function d and γ.

We allow some (but not all) of the normalized weights ρ_a^A, such as non-normalized weights w_a^A of A (to be defined below) to be zero. The members of A with zero weights correspond to very isolated points that can be regarded as unimportant and therefore can be neglected in the calculation of the directed modified weighted Hausdorff distances. Such points $a \in A\colon \rho_a^A = 0$ can be omitted in the calculation of the directed distance from A to any other set B. But they can not be removed completely from the underlying set as they may belong to any other set B where their weight in regard of their membership to B may be positive. That is, they may appear to be important in the set B.

03 Intuitionistic fuzzy sets and distances

As opposed to a fuzzy set in X [Zadeh, 1965], given by

$$A^{'} = \{< x, \mu_{A'}(x) > | x \in X\} \tag{9}$$

where $\mu_{A'}(x) \in [0, 1]$ is the membership function of the fuzzy set A', an intuitionistic fuzzy set (IFS) [Atanassov, 1999] A is given by

$$A = \{< x, \mu_A(x), \nu_A(x) > | x \in X\} \tag{10}$$

where: $\mu_A : X \to [0, 1]$ and $\nu_A : X \to [0, 1]$ such that

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1 \tag{11}$$

and $\mu_A(x)$, $\nu_A(x) \in [0, 1]$ denote a degree of membership and a degree of non-membership of $x \in A$, respectively. (Two approaches to the assigning memberships and non-memberships for IFSs are proposed in [Szmidt & Baldwin, 2006]).

An additional concept for each IFS in X, that is not only an obvious result of (10) and (11) but also relevant for applications, we will call

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \tag{12}$$

a *degree of uncertainty* of $x \in A$. It expresses a lack of knowledge of whether x belongs to A or not (see [Atanassov, 1999]). It is obvious that $0 \leq \pi_A(x) \leq 1$, for each $x \in X$.

Distances between IFSs are calculated in the literature in two ways, using two parameters only (e.g. [Atanassov, 1999]) or all three parameters (see [Szmidt & Kacprzyk, 2000; Atanassov et al., 2005; Szmidt & Baldwin, 2003; Szmidt & Baldwin, 2004; Deng-Feng, 2005] and [Narukawa, 2006]) describing elements belonging to the sets. Both ways are proper from the point of view of pure mathematical conditions concerning distances (all properties are fulfilled in both cases). One cannot say that both ways are equal when assessing the results obtained by the two approaches. In [Szmidt & Kacprzyk, 2000; Szmidt & Baldwin, 2003; Szmidt & Baldwin, 2004] it is shown why in the calculation of distances between IFSs one should prefer all three parameters describing IFSs. Examples of the distances between any two IFSs A and B in $X = \{x_{1,}x_2, \ldots, x_n\}$ while using three parameter representation (see [Szmidt & Kacprzyk, 2000; Szmidt & Baldwin, 2003; Szmidt & Baldwin, 2004]).

A *normalized distance* or *normalized metric* d in X is a metric such that $d\colon X \times X \to [0,1] \subset \mathbb{R}_{\geq 0}$. Sometimes it is more convenient and easier to work with normalized metrics. Every metric can be normalized (see [Adams & Franzosa, 2008]). For more detailed general properties and proofs about distances for IFSs the reader may refer to [Marinov et al., 2012].

Definition 6. Let $A, B \in IFS(X)$ be two intuitionistic fuzzy sets on the finite universe X. We can state the following standard distances between IFSs

1. With two parameters:

   - Hamming distance:

$$l_{2,IFS}(A,B) = \sum_{i=1}^{n}(|\mu_A(x_i) - \mu_B(x_i)| + |\nu_A(x_i) - \nu_B(x_i)|)$$

   - Normalized Hamming distance:

$$L_{2,IFS}(A,B) = \frac{1}{2n} l_{2,IFS}(A,B)$$

   - Euclidean distance:

$$e_{2,IFS}(A,B) = \sqrt{\sum_{i=1}^{n}(\mu_A(x_i) - \mu_B(x_i))^2 + (\nu_A(x_i) - \nu_B(x_i))^2}$$

   - Normalized Euclidean distance:

$$E_{2,IFS}(A,B) = \sqrt{\frac{1}{2n}} e_{2,IFS}(A,B)$$

2. With three parameters:

   - Hamming distance:

$$l_{3,IFS}(A,B) = \sum_{i=1}^{n}(|\mu_A(x_i) - \mu_B(x_i)| + |\nu_A(x_i) - \nu_B(x_i)| + |\pi_A(x_i) - \pi_B(x_i)|)$$

   - Normalized Hamming distance:

$$L_{3,IFS}(A,B) = \frac{1}{2n} l_{3,IFS}(A,B)$$

- Euclidean distance:

$$e_{3,IFS}(A,B) = \sqrt{\sum_{i=1}^{n}(\mu_A(x_i) - \mu_B(x_i))^2 + (\nu_A(x_i) - \nu_B(x_i))^2 + (\pi_A(x_i) - \pi_B(x_i)^2)}$$

- Normalized Euclidean distance:

$$E_{2,IFS}(A,B) = \sqrt{\frac{1}{2n}} e_{3,IFS}(A,B)$$

Remark 4. It is almost evident that for the above defined distances the following inequalities hold:

$$\begin{array}{llll} 0 \leq & l_{2,IFS}(A,B) & \leq l_{3,IFS}(A,B) & \leq 2n \\ 0 \leq & L_{2,IFS}(A,B) & \leq L_{3,IFS}(A,B) & \leq 1 \\ 0 \leq & e_{2,IFS}(A,B) & \leq e_{3,IFS}(A,B) & \leq \sqrt{2n} \\ 0 \leq & E_{2,IFS}(A,B) & \leq E_{3,IFS}(A,B) & \leq 1 \end{array}$$

Formulas for the weights determination in MWHD

Let us now introduce a few formulas for calculation of the weights in the MWHD degree of friendship algorithm through the above stated function γ and friendship degree Γ.

04 First version of weights determination formula

The following

$$w^A_{\gamma,d,a_0} := \begin{cases} 1 & \text{if } |A| = 1 \\ \sum\limits_{a \in A \setminus \{a_0\}} \Gamma_{\gamma,d}(a_0, a) & \text{if } |A| > 1 \end{cases} \tag{13}$$

we call *non-normalized weight* in a_0 regarding d, γ and its membership to A and

$$W^A_{\gamma,d} := \sum_{a_0 \in A} w^A_{\gamma,d,a_0} = \sum_{a' \neq a'' \in A} \Gamma_{\gamma,d}(a', a'') \tag{14}$$

will be called *general sum* of A with respect to d and γ, where d and γ will be omitted if it is not misleading. But as $\forall x_1, x_2 \in \cup\mathcal{P}_0\colon \Gamma_{\gamma,d}(x_1,x_2) = \Gamma_{\gamma,d}(x_2,x_1)$, i.e. $\Gamma_{\gamma,d}$ is symmetric, and rewriting (14) we get that $W^A_{\gamma,d}$ equals $\sum\limits_{a_0 \in A}(\sum\limits_{a \in A \setminus \{a_0\}} \Gamma_{\gamma,d}(a_0, a))$. If $|A| = n$ and $A = \{a_1, \ldots, a_n\}$ to emphasize the algorithmic aspect the expression of $W^A_{\gamma,d}$ may be stated in the following form:

$$W^A_{\gamma,d} = 2(\sum_{1 \leq i < j \leq |A|} \Gamma_{\gamma,d}(a_i, a_j)) \tag{15}$$

because $\forall a', a'' \in A\colon a' \neq a''$ the value of $\Gamma_{\gamma,d}(a', a'')$ is taken twice in the calculation of $W^A_{\gamma,d}$, first in regard of a' and second in regard of a'' in the sum (14). For the *normalized weights* let us introduce now the formula:

$$\rho^A_{\gamma,d,a} := \frac{w^A_{\gamma,d,a}}{W^A_{\gamma,d}} = \frac{w^A_{\gamma,d,a}}{2(\sum\limits_{1 \leq i < j \leq |A|} \Gamma_{\gamma,d}(a_i, a_j))} \tag{16}$$

Remark 5. Suppose now that γ (5) is constant, therefore Γ (6) is constant as well, i.e. $\Gamma_{\gamma,d} \equiv \alpha > 0$. Applying this in (16) we get that for any $A \in \mathcal{P}_0$:
$W^A_{\gamma,d} = 2(\sum\limits_{1 \le i < j \le n} \alpha) = 2\alpha.C^2_n = 2\alpha.n(n-1)/2 = \alpha.n(n-1)$, where C^2_n is the number of 2-combinations without repetitions from a collection of n elements. As for any $a \in A$: $w^A_{\gamma,d,a} = \sum\limits_{a' \in A \setminus \{a\}} \alpha = \alpha.(n-1)$, for the normalized weight in a we get $\rho^A_{\gamma,d,a} = \alpha.(n-1)/\alpha.n(n-1) = 1/n = 1/|A|$, which is expected for the particular case with equal weights imposed on the elements of A.

Supposing now that $\mathcal{P}_0$ is degenerated with respect to $\Gamma_{\gamma,d}$, i.e. there are degenerated subsets $A \in \mathcal{P}_0$, for which $\forall a \in A$: $w^A_{\gamma,d,a} = 0$ and therefore $W^A_{\gamma,d} = \sum_{a \in A} w^A_{\gamma,d,a} = 0$. The last expression implies that the formula (16) for $\rho^A_{\gamma,d,a}$ could not be applied for degenerated subsets of X.

05 Second version of weights determination formula

There may be some cases, when we would like some groups of experts to be designated as "degenerated" or to impose some penalty value $P_0 \ge 0$ on the too isolated members belonging to a group. Then we will certainly have that

$$P_0 = \Gamma_{\gamma,d}(x_1, x_2)$$

for all $x_1, x_2 \in \cup\mathcal{P}_0$ such that $d(x_1, x_2) \ge d_0$. Where d_0 is an appropriately chosen large enough positive constant. Therefore, we can assume for $\Gamma_{\gamma,d}$ that the following inequality is satisfied

$$0 \le P_0 \le \min\{\Gamma_{\gamma,d}(x_1, x_2) \mid x_1, x_2 \in \cup\mathcal{P}_0\} \tag{17}$$

The meaning of the penalty value P_0 is that if for $a \in A$, $d(a, A \setminus \{a\})$ is too large, say greater or equal to $d_0 > 0$, then automatically

$$\forall a' \in A \setminus \{a\}: \gamma(d(a, a')) = P_0,$$

i.e. $\gamma([d_0, \infty)) = \{P_0\}$. Note that the introduction of penalties may significantly improve the performance and the quality of results in algorithms for practical applications (see [Takács1998]). That way we have slightly modified the function γ imposing the additional condition $\gamma \ge P_0$ on its domain of definition. Therefore, for the so modified γ and $\Gamma_{\gamma,d}$ in particular we can use (13), (15) and (16) to define the non-normalized weights, general sums and the normalized weights, respectively. Note that as in the first version of the weights generation algorithm every expert group has to contain at least one element.

06 Third version of weights determination formula

Let us give now another version of the above formulas for the weights. Suppose that we want to define the function γ from (5) in the point 0 as well, i.e.

$$\gamma\colon [0, \infty) \longrightarrow [0, \infty] \tag{18}$$

In (18) γ is supposed to be non-increasing in $(0, \infty)$ and $\gamma(0)$ has to be defined in an appropriate way if applied in real problem solutions. The expression (6) and the above introduced γ provide that $Dom(\Gamma_{d,\gamma}) = X \times X$, i.e. $D_X \subset Dom(\Gamma_{d,\gamma})$. Therefore, we have that

- $\forall x \in X: \gamma(d(x, x)) = \gamma(0) = \sup Range(\gamma)$
- $\forall x \in X: (x, x) \in Dom(\Gamma_{\gamma,d})$ and $\Gamma_{\gamma,d}(x, x) = \gamma(0)$

By analogy of (13) –(16), let us introduce

$$\widetilde{w}^{A}_{\gamma,d,a_0} := \sum_{a\in A} \Gamma_{\gamma,d}(a_0, a), \tag{19}$$

which we also call *non-normalized weight* in a with respect to d, γ and its membership to A and

$$\widetilde{W}^{A}_{\gamma,d} := \sum_{a_0\in A} \widetilde{w}^{A}_{\gamma,d,a_0} = \sum_{a',a''\in A} \Gamma_{\gamma,d}(a', a'') \tag{20}$$

is the *general sum* of A corresponding to d and γ. Again because of the symmetry property of $\Gamma_{\gamma,d}$, we have that $\widetilde{W}^{A}_{\gamma,d} = 2(\sum\limits_{1\leq i<j\leq |A|} \Gamma_{\gamma,d}(a_i, a_j)) + \sum\limits_{i=1}^{|A|} \Gamma_{\gamma,d}(a_i, a_i)$ and therefore the normalized weights could be defined in the following way

$$\widetilde{\rho}^{A}_{\gamma,d,a} := \frac{\widetilde{w}^{A}_{\gamma,d,a}}{\widetilde{W}^{A}_{\gamma,d}} = \frac{\widetilde{w}^{A}_{\gamma,d,a}}{2(\sum\limits_{1\leq i<j\leq |A|} \Gamma_{\gamma,d}(a_i, a_j)) + \sum\limits_{i=1}^{|A|} \Gamma_{\gamma,d}(a_i, a_i)}. \tag{21}$$

It is obvious that the closest point of $x_0 \in X$ is x_0 itself. Thereby, if we like γ to be non-increasing on the whole domain $[0, \infty)$, $\gamma(0)$ should take the maximum value of its range. And so in the sum (19) the member $\Gamma_{\gamma,d}(a_0, a_0)$ has the greatest impact in the determination of the weight in a_0.

In the so introduced weights, if needed, we can apply the penalty value from the second version of the algorithm. Let us now check what happens when one applies the above expressions for a degenerated set $A \subset X$ whereas $P_0 = 0$. First of all, let us recall that for the chosen maximal diameter $M_0 > 0, P_0 = 0$ and $S_0 := \gamma(0) = \sup Range(\gamma) = \sup Range(\Gamma_{\gamma,d}) = \Gamma_{\gamma,d}(x, x)$ for any $x \in X$. The degeneration of A provides that $\forall a', a'' \in A\colon a' \neq a'' \Rightarrow \Gamma_{\gamma,d}(a', a'') = 0$. Thereby,

$$\forall a \in A\colon \widetilde{w}^{A}_{\gamma,d,a} = S_0 \text{ and } \widetilde{W}^{A}_{\gamma,d} = |A|S_0,$$

and hence, $\widetilde{\rho}^{A}_{\gamma,d,a} = 1/|A|$ which is exactly what we expect.

Remark 6. Let us take any A, B such that A is degenerated and B is non-degenerated. It follows almost straightforward, that

- $\forall a \in A\colon \widetilde{w}^{A}_{\gamma,d,a} = S_0 \leq \widetilde{w}^{B}_{\gamma,d,a}$
- $\widetilde{W}^{A}_{\gamma,d} = |A|S_0 < \widetilde{W}^{B}_{\gamma,d}$

As in *Remark 5* the reader can easily check that the above introduced formula for the normalized weights is again a relevant generalization for the standard modified Hausdorff distance (with equal weights) when A is non-degenerated and γ is a constant function.

Conlusion

In this paper we have introduced few versions of algorithms for calculation th the weights through the above stated function γ and friendship degree Γ. As a start point we employ the modified weighted Hausdorff distance (MWHD) notion, which was firstly defined in [Marinov et al., 2012]. Let us remind how we can apply the MWHD notion and especially the introduced here algorithms in IFS models.

Supposing that there is a problem to be estimated with respect to a few criteria $C = \{C_0, \ldots, C_n\}$. The criteria will be considered as a universe for IFS. That is, every intuitionistic fuzzy set $E \in X = IFS(C)$ can be considered to an expert estimation about the problem with respect to the above criteria. Taking a finite subset of the power set of X : $\mathcal{P}_0 \subset \mathcal{P}(X)$ to be a group of estimations of the chosen experts, one could estimate how far from each other are the decisions of the the different groups of experts.

As another exmple, we can take the universe $P = \{P_0, \ldots, P_n\}$ to be a collection of problems to be estimated. In this situation every intuitionistic fuzzy set $E \in IFS(P)$ can be considered as an expert estimation of the collection of the chosen problems P and groups of expert estimations with respect of P can be also modeled through the introduced MWHD formulas in this paper.

Acknowledgements

This paper has been partially supported by the Bulgarian National Science Fund under the Grant DFNI-I-01/0006.

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COMPARATIVE ANALYSIS OF THE LANGUAGES FOR BUSINESS RULES SPECIFICATION

Krassimir Manev, Neli Maneva

***Abstract**: One of the goals of authors of the Business Rules Approach, besides making the process of specification of software more precise and adequate, was to provide a rigorous basis for reverse engineering of business rules from existing software systems. By different reasons this goal was no more a subject of interest of the involved researchers. One of the general problems of using business rules (BRs) in the reverse engineering of software is the selection of language to present the rules, extracted from the source code. In principle, it is not impossible to use for this purpose the languages dedicated for the straightforward task – using BRs for specification of software systems. The current paper presents an overview of different such languages in order to decide whether they are appropriate for rules extraction and to outline those features which will be helpful in language comparison and selection of a specific language for BR.*

***Keywords**: software development, software modernization, software reengineering, business rules, languages for specification of business rules, automated business rules extraction, comparative analysis.*

***ACM Classification Keywords**: D.2.1 Requirements/Specifications, D.2.7 Distribution, Maintenance, and Enhancement.*

1. Introduction

In the fundamental report [Hay & Healy, 2000] the researchers from the Business Rules Group (formerly known as the GUIDE Business Rules Project) postulated, among the other goals of their project, the following:

- To provide a rigorous basis for reverse engineering business rules from existing software systems.

Then, involved too much in activities to achieve the main purpose of the project – to develop and implement the idea for specification of corporative software systems with *business rules* (BRs) – they did not implemented an approach for reverse engineering and extracting BR from existing systems.

Meanwhile, the necessity of modernization of huge amount of stable and helpful but created on old or/and outdated platforms, called *legacy systems*, became more and more important. One possibility for modernization of a legacy system is to *extract* (rather *automatically* than manually) the *business logic* of the system embedded in its program code (as well as in its database definitions and queries, if they exist) in form of BRs. This process has been called here *automatic BR extraction* (ABRE). After that the extracted rules could be (also automatically) "wearied" in the dialect of the specific domain and could be used by the client for reengineering of the legacy system or for a formal specification of a new one. For this purpose, the ABRE has to present the obtained BRs with sentences of some *formal* (or at least *well structured*) *BRs extraction language* (BREL) in order to embed them in the ontology of the client's domain.

It seems quite natural to use as BREL some of the languages for the straightforward problem – specification of systems with business rules. Unfortunately, due to different reasons, the languages proposed for specification of systems with BRs are either subset of some general purpose specification languages or specialized, but becoming more and more complicated and inappropriate for ABRE from legacy code. Anyway, in our efforts to create good BREL, we have no other possibility than to use some features of the languages dedicated to specification of software systems with BRs.

In this paper we will consider some of these languages in order to outline their features, from the point of view of ABRE process that will be helpful in the process of creating a language for ABRE. Section 2 presents briefly some of the languages used for specification of software systems with BRs. Section 3 describes the basic principles of the comparative analysis (CA) method and its application for comparison of specification languages. The performed experiments and their results are presented. In Conclusion the pros and cons of the analysis are summarized and a few ideas for future research and development work are mentioned.

2. Languages for specification with BRs

The necessity of some language for writing BRs was stressed even in the mentioned above report of the GUIDE Business Rules Project [Hay & Healy, 2000]. There, on page 12, we read:

> "Note also that each BUSINESS RULE may be *expressed in* one or more FORMAL RULE STATEMENTS. A FORMAL RULE STATEMENT is an expression of a BUSINESS RULE in a specific formal grammar. A FORMAL RULE STATEMENT must be *in the convention of* a particular FORMAL EXPRESSION TYPE, which is to say one of the formal grammars for representing BUSINESS RULES. Examples of a FORMAL EXPRESSION TYPE are structured English, IDEF1X, Oracle's CASE*Method, Object Role Modeling, Ross's notation, and so forth."

So we will consider some examples of formal (or at least structured) languages which are candidates to be used in ABRE, including the pointed by the GUIDE Business Rules Project.

2.1. "Programming languages" - like

The most popular instrument from the group of languages that are similar to programming languages is the *structured English.* It is not a formal language. But something which is very similar and very helpful is popular in the domain of Computer science under the name *pseudo code,* especially for presenting of algorithms at some informal, high level. Really, each author of book on algorithms or professor teaching Algorithms is using her/his own pseudo code and structured English has to be the core of all such pseudo codes.

As there is no formal specification for this instrument, for our discussions we will use the description, which could be considered as commonly accepted [Structuted, 2013]. By this description the structured English "*… aims at getting the benefits of both the programming logic and natural language. Program logic helps to attain precision* *while natural language helps in getting the convenience of spoken languages*." Additionally it is mentioned that: "*Structured English or "pseudo code" consists of the following elements:*

- Operation statements written as English phrases executed from the top down;
- Conditional blocks indicated by keywords such as IF (N.B. the couple of keywords IF … ENDIF, indeed), THEN, and ELSE;
- Repetition blocks indicated by keywords such as DO, WHILE, and UNTIL.

and propose to …use the following guidelines when writing Structured English:

- Statements should be clear and unambiguous;
- Use one line per logical element;
- All logic should be expressed in operational, conditional, and repetition blocks;
- Logical blocks should be indented to show relationship;
- Keywords should be capitalized.

We will accept without serious objection only the first of the requirement, **extending it** with "*as much as possible"* because including of operational instructions in English, formulated by even most experienced human being, could not be without any ambiguity.

For the third requirement we have a serious objection. From [Hay & Healy, 2000] it is clear that "fathers" of BR-approach **did not even imagine a possibility to have BRs with cyclic structure**. It is not expected the person that analyses business processes of an enterprise and formulates the rules governing it, to know the conception of Iteration (as well as recursion). So, for the purposes of the BR-approach we probably have to drop the possibility to use the repetition constructors *DO, WHILE, and UNTIL.*

The other three requirements could be classified as optional. They are a matter of syntax and the same result could be obtained in another ways, too. About the last one, it is important the keywords *IF, ENDIF, THEN* and *ELSE* to be easy recognizable and not mixed with the same words, used in operational statement as regular English words. But this could be achieved by placing a special character in front of each keyword also. For example, underscore character – _if, _endif, _then and _else. The fourth requirement is pure "cosmetic" and is dedicated just to make the specification more readable. The second requirement also seems cosmetic but in fact it is semantically important. It is introduced to separate clearly different operational statement one from the other. Practically it could be reformulated in that sense, including the possibility to use, beside a new line character, other separators, too. For example, such separator can be the common accepted in programming languages semicolon sign (;).

Let us consider as an example the rule for an employer of the enterprise to obtain paid leave of absence: In order to obtain a paid leave of absence the employer has to receive the approval of her/his closest chief which is not in absence herself/himself and the number of remaining paid absence days of the employer to be at least as much as the asked days of absence. This rule expressed by structured English will look as follows:

IF *remaining days* are at least as much as *asked days* THEN

  IF there is approval from closest chief not in absence THEN

Issue an order for leave of absence

ELSE

Refuse leave of absence

ENDIF

ELSE

Refuse leave of absence

ENDIF

Another very popular language which is “programming language” - like is the *language of flowcharts*. Essential for this language are two kinds of blocks:

- Rectangles with many inputs and one output represent operation statements, including a unique start point and one or more end points of the diagram. The corresponding sentence is written inside the rectangle;
- Rhombs with many inputs and two outputs labeled with **true** and **false**, respectively, representing conditions. The condition itself is written inside the rhomb.

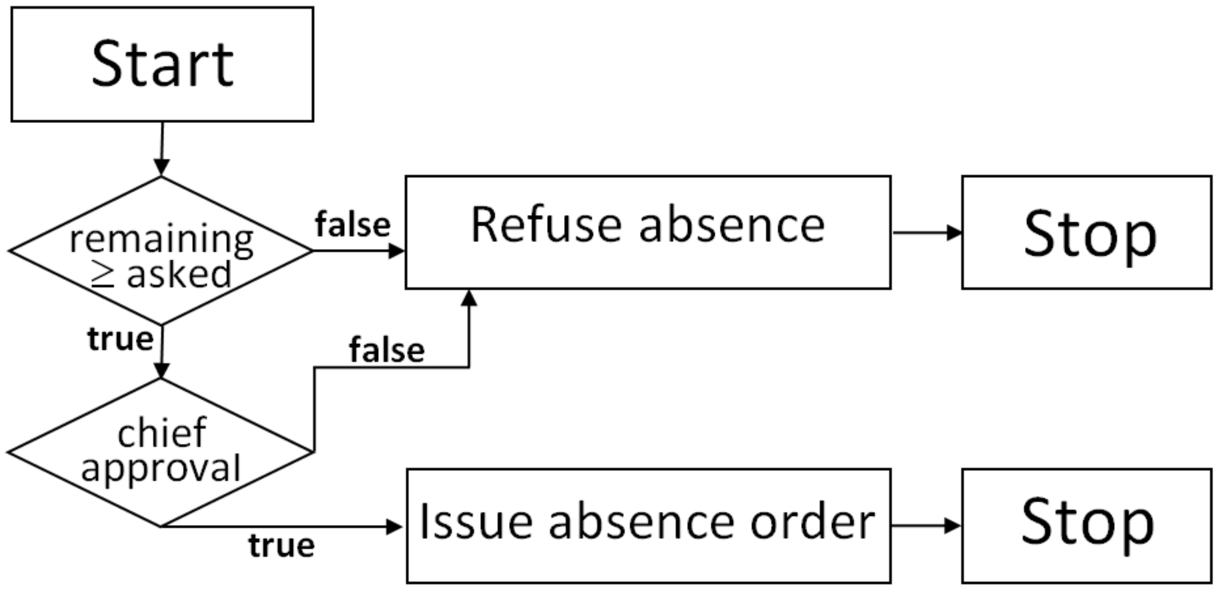

Figure 1. Presenting the business rule by a block-diagram

Rectangles and rhombs are linked with arrows that control the “flow” through the chart. The flowchart in Figure 1 represents the same rule, specified above with structured English.

There are no principle differences in expressive power of the structured English and the flowcharts language. So the structured language is more appropriate for ABRE process and flowcharts are more appropriate for visualization of the extracted rules.

2.2. "Entity relationship" - like

The languages IDEF1X [IDEF1X, 1993], Case*Method (of Oracle) [Barker, 1990] and Object-Role Modeling language, mentioned in [Hay & Healy, 2000] are representatives of a class of languages, the main purpose of which is to specify the data model (or data scheme) of an information system. To the same class could be added also the Bachman notation, Barker's Notation, EXPRESS, Martin notation, Z-notation (of Jean-Raymond Abrial), UML, Merise, etc. These languages are very popular under the general name *Entity-relationship* languages. The descriptions created with these languages are called *Entity relationship diagrams* (ERD) [Chen, 1976]. That is why we will consider very briefly the possibility to extract BRs in form of ERD.

Basically, the entity relationship languages are graphical. ERD is a graph with labels on the vertices and edges. Vertices represent entities of the modeled domain and the edge that links two vertices represents the existing between them relationship. The label of a vertex usually includes the name of the entity and its structure when the entity is a complex object. The label of an edge contains the name of the presented relationship and its type (one-to-one, one-to-many, and so on). The part of the data model of a corporative system concerned with "leave of absence asking" example, presented with ERD, is shown in the Figure 2.

It is obvious that graphical languages are very helpful for visualization of the data model of an information system and for manual processing but could not be used as input or output of some automated procedures. The relation between ERDs and the specifications which are more appropriate for automated processing has been studied in [Chen, 1997]. There the author made very interesting parallel of "ER vs. structured English" relationship and the relationship between Chinese characters (hieroglyphs) and European alphabets (which are to very high degree phonetic). In the same paper the author proposed a simple procedure for translation of an ERD to specification, written in structured English.

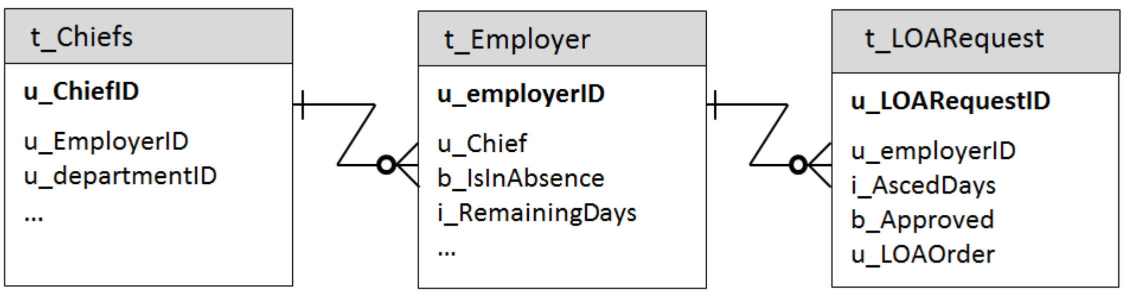

Figure 2. ERD presentation of a business rule

A similar approach could be found in the document, describing the IDEF1X language [IDEF1X, 1993]. In the Annex B of this document, called Formalization (page 130), for each IDEF1X is proposed to map it "to an equivalent set of sentences in a formal, first order language. "The author statement is that in such a way ERD could be "considered a practical, concise way to express the equivalent formal sentences".

Obviously, the graphical form of specifications with the numerous ER languages is not intrinsic negative. The serious negative feature of these languages is that they are rather "static", dedicated to specify the structure of the data of the system, not the operations with data. Of course, looking at the ERD of Figure 2 an experienced system designer could imagine what the rule for approving an employer's leave of absence request is. But in principle it will be better for the adequateness of the design not to rely on the designer's imagination.

2.3. Ross's notation

Ronald Ross is considered as a "father" of the Business Rules approach. His first works on the concept appeared in the middle of 90's of the past century, before joining to the GUIDE Business Rules Project. In parallel with developing of the concept for specification of systems with BRS, he was working on creating of a language, especially dedicated for writing BRs. As a result he has created a description tool called in that time *Ross' notation* or *Ross' method*. With the developing and ameliorating of the approach Ross developed and ameliorated his own description tool. Nowadays the notation created by Ross is popular under the name RuleSpeack (a trademark of the created and ruled by Ross company *Business Rules Solutions, LLC*).

The idea of RuleSpeak is, besides putting a particular structure on the English sentences, to introduce some limitations on the used word in order to make the structured English sentence clearer and less ambiguous. For example, it is strongly recommended to use only the word *must* instead of sophisticated phrases of obligation as *is strictly required,* as well as only *must not* instead of sophisticated phrases of defending as *is not allowed.* The notation RuleSpeak, also, strongly recommends avoiding the word *can* that gives the impression for existence of some degree of freedom. Instead it is recommended to replace the word *can* with … *may …. only if …* to eliminate any freedom.

Another principle of RuleSpeak is to keep the sentences as short as possible. So, in our example, the rule under consideration will be expressed in RuleSpeak as follows:

*The employer **may** take leave of absence **only if** received the chief's approval.*

and

*Asked days leave of absence **must be** no more than remaining days.*

2.4. OMG Semantic and Vocabulary of Business Rules

Soon after publishing the report of the GUIDE Business Rules Project it attracted the attention of the specialists from the powerful OMG which decided to support the project and to make Business Rules approach a standard of OMG for specification of systems knows as Semantic and Vocabulary of Business Rules (SVBR) [SVBR, 2008]. This standard incorporates three different specification tools – structured English, RuleSpeac and Object-Role Modeling language. With this act OMG really confirmed the expectations that a simple language concept will not be expressive enough for writing BRs.

2.5. Other BR-related languages and their comparison

A study of some BR modeling languages is presented in [Rima, 2013]. A number of BR specification languages (Simple Rule Markup Language, Semantics of Business Vocabulary and Rules, Production Rule Representation, Semantic Web Rule Language, Object Constraint Language) and Business Process specification languages

(Unified Modeling Language, Data Flow Diagram, Colored Petri Nets, Event-driven Process Chain, IDEF3, Business Process Modeling Notation) have been briefly described. The main purpose of the performed comparative analysis has been to show the representational capabilities of the selected BR specification languages and to describe which modeling aspects have been covered by them within the three layer framework, proposed for BR-based software modeling.

We think that a more flexible approach to comparison of BR languages should be developed. Next follows a brief description of our ideas.

3. An approach to comparison of languages for specification with BRs

The results of the performed study can be summarized as follows:

- There is a variety of BR specification languages, used to achieve specific goals at different stages of the software systems life cycle;
- Most of BR specification languages are especially designed and used for the purposes of the straightforward task – when a new software system should be developed from scratch and the process of requirements elicitation is just started.
- None of the existing BR specification languages has been recognized as a universal and accepted as a standard till now.

Taking into account these conclusions, we try to select a procedure for comparison of BR languages so as to meet the following requirements:

- Comparison should be flexible, easily adjusted to the context - particular circumstances, in which it is accomplished;
- The analyzed and evaluated characteristics (i.e. quality content of the BR languages) and the set of compared languages should be defined in accordance with the currently defined context;
- Comparison should be supported by a formal method and a systematic procedure for its application.

Next follows a brief description of our approach, based on the Comparative analysis method and an example, illustrating its feasibility.

3.1. The essence of the Comparative Analysis method

The method of Comparative Analysis (CA) has been introduced in [Maneva, 2007]. It shares the main objectives and methods of the Multiple Criteria Decision Making theory, trying to specify and apply them systematically.

Generally speaking, the ***Comparative Analysis*** method is a study of the quality content of a set of homogeneous objects and their mutual comparison so as to select the best, to rank them or to classify each object to one of the predefined quality categories.

For CA use in practice, we distinguish two main roles: the ***Analyst***, responsible for all aspects of CA implementation, and a ***CA customer*** - a single person or a group of individuals, tasked with making a decision in a given situation. Depending on the identified problem to be solved by a customer at a given moment, a ***case*** should be opened to determine the context of the desired comparative analysis. Each case is specified by the following 6 elements:

case = { View, Goal, Object, Competitors, Task, Level}

The ***View*** describes the CA customer's role and the perspective from which the CA will be performed. Taking into account the responsibilities and some typical tasks of the main participants in the BR extraction, the following Customer's roles have been identified [Maneva & Manev, 2011]: ***Business Analyst, Policy Maker, Software Architect,*** and ***Software Developer.*** Thus a lot of cases for comparison of BR specification languages can be further described, reflecting the specific participant's point of view to the analyzed case.

The **Goal** expresses the main customer's intentions in CA accomplishment and can be to describe, analyze, estimate, improve, or any other, formulated by the Customer, defining the case. All of these goals can be stated for the CA of languages for specification with BRs.

The **Object** represents the item under consideration. For each object for CA application a *quality model* should be created – a set of characteristics, selected to represent the quality content in this context, and the relationships among them. For the problem under consideration, the investigated Object is a BR specification language.

According to the stated goal, the set C of **Competitors, C = {C_1, C_2, ..., C_n}** – the instances of the objects to be compared – should be chosen. When the Goal is to perform the CA so as to obtain the ranking of a number of objects, the set **C** comprises those competitive objects.

The element **Task** of a case can be *Selection* (finding the best), *Ranking* (producing an ordered list), *Classification* (splitting the competitors to a few preliminary defined quality groups) or any combination of them. There are no special considerations, when we define the element ***Task*** of a case for BR language comparison.

The Depth **Level** defines the overall complexity (simple, medium or high) of the CA and depends on the importance of the problem under consideration and on the resources needed for CA implementation.

3.2. Comparison of languages for specification with BRs – a quality model

It is obvious, that the above described approach meets all stated requirements, especially for flexibility, because by definition of a case we can describe completely the current situation, specifying who, why and what exactly should be analyzed in order to make a reasonable choice to support the corresponding decision.

One of the most difficult steps in the CA use is the creation of a model, adequate to the quality content of the studied object. As we have already stated, the model comprises different quality characteristics, identified as significant for the performed comparative analysis. Usually the Analyst is responsible for object modeling made with help and guidance of the Customer, ordered the CA. For the purposes of language comparison, we have to start with constructing a quality model for the object "BR specification language". From practitioner's point of view it is important to mention, that we will stick to the incremental object modeling, described in [Maneva, 2007]. When the object "BR specification language" appears in a case for the first time, a quality model for it is created and saved as a basic (generic) one in a repository. When the same object reappears in another case, its generic quality model is invoked and modified according to the context, defined by this new case. The modification can be to add some new quality characteristics at any level of the hierarchy or to delete some characteristics. The changed version of the model is saved as a derivative model, together with the generic model, which can be enriched with some additional quality characteristics. In this way the generic model is always the complete hierarchical structure, comprising all quality characteristics ever considered.

In Table 1 is shown an initial quality model for the object “BR specification language”. It comprises two groups of quality characteristics - external and internal. Of course, for complete description of the quality model we have to provide precise definitions of all characteristics and to describe the metrics for leaves of the constructed hierarchical structure, allowing quantitative evaluations, necessary for CA Task accomplishment. So far this is beyond the scope of this paper.

Table 1.

External	stability
	fidelity
	usability
	availability of automating tools
Internal	expressiveness
	understandability
	validity
	cognitive complexity
	transformability
	degree of automation

3.3. Comparison of languages for specification with BRs – an example

The CA use can be illustrated by the next real-life ***example:*** The team, involved in a real-life modernization project, has to choose one specification language for Business rules, extracted from the source code of a legacy system.

With the help of the Analyst, a case has been defined:

case = { View, Goal, Object, Competitors, Task, Level},

where the elements, determining the context of the desired Comparative analysis, are:

- ***Goal:*** To compare some BR specification languages, recognized as appropriate.
- ***View:*** The identified point of view for this situation belongs to those participants in the modernization project, who are supposed to use a BR specification language, namely the Business Analyst and the Policy Manager.
- ***Object:*** A BR specification language.

For this case a simple linear quality model has been constructed. It comprises only three quality characteristics, considered as equivalent (i.e. having equal weights – coefficients of importance):

- *Expressiveness* – the capability of the BR language to represent concepts and communicate ideas about business organization and management;
- *Usability* – the capability of the BR language to be understood, learned and used;
- *Efficiency* - the capability of the BR language to provide appropriate results relative to the amount of the resources used.

❖ ***Competitors***: The set C of Competitors comprises the languages, identified as appropriate, e.g. mentioned above in Section 2.

❖ ***Task***: Selection – finding the most appropriate among the compared languages.

❖ ***Level***: Simple.

Following the described in [Maneva, 2007] procedure for CA use, we can find the most appropriate (in accordance with the selected quality characteristics) specification language.

Conclusion

The paper explains the need of some languages for specification with BRs for the purposes of reverse engineering of legacy system. An overview of such languages has been made. In order to facilitate the selection of a BR specification language, which is the most appropriate in a given situation, some requirements to the method of comparison have been defined. The proposed method of CA is presented and illustrated by an example.

A few possible directions of further research are:

- To study each of the identified as appropriate languages for specification with BR so as to select only a few of them to be further used (separately or in a combination);
- To continue the quality content modeling for other objects related with the CA use in the process of the BR extraction: ***products*** as additional sources of BR information (documentation, developer's and user's stories, test data and scenarios), ***processes*** like BR tracking, change management in reverse engineering, etc.

Acknowledgments

This work is supported by the National Scientific Research Fund of Bulgaria under the Contract ДТК 02-69/2009.

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METHOD OF BEHAVIORAL SOFTWARE MODELS SYNCHRONIZATION

Elena Chebanyuk

***Abstract**: A method of behavioral software models synchronization is represented in this paper. Implementing this method behavioral software models, which are changed after communication with customer, are synchronized with other software models that are represented as UML diagrams. Method of behavioral software artifacts synchronization makes the Model-Driven Development (MDD) approach more effective. For synchronization of different behavioral software models, transformation approach in the area of Model-Driven Architecture (MDA) is proposed. Synchronization operation is executed using analytical representation of initial and resulting models. Initial behavioral software model is represented by UML Use Case Diagram. Resulting behavioral software model is represented as UML Collaboration Diagram. Analytical representation of UML Use Case diagram allows considering data flows. For this representation set-theory tool operations are used. As a Collaboration Diagram usually contains more information in comparison with Use Case one, method defines two types of Use Case diagram fragments. From the beginning Use Case diagram fragments that can be transformed directly to resulting diagram constituents are considered. Then the rest of Use Case diagram fragments are processed to represents rules of placement Collaboration Diagram messages. These rules help to designate data flows, represented in Collaboration Diagram, more accuracy.*

Method, proposed in this article, can be used both separately and be a part of more complex transformation technics, methods and frameworks solving different tasks in MDA sphere. Also the example of proposed method realization for solving task “designing of Vector hodograph of density lying function” (VHDLF) is represented. A process of designing Collaboration Diagram, considering Use Case diagram and ontology knowledge analysis is represented. The constituents of Collaboration Diagram, which are designed using different sources, namely Use Case diagram, ontology knowledge and requirements specification are defined.

***Keywords:** Software model transformation, Use Case diagram, Set-theory tool, behavioral software model synchronization, Vector hodograph of density laying function.*

***ACM Classification Keywords**: D.2.2. Design Tools and Techniques, D.2.11. Software Architectures*

Introduction

Today software development process according to agile methodology becomes more widespread. One of the peculiarities of Agile is possibility to change software requirements in every development iteration.

When requirements are changed often it’s necessary to design methods for quick synchronization of software models that are renewed after communication with a customer and other software artifacts. Among software artifacts that are renewed after communication with customer are UML Use Case diagrams or their varieties (user stories).

Central software models in MDD approach are Collaboration Diagrams. These diagrams can both represent processes and define objects that are used for executing these processes. Collaboration Diagrams also are sources for refinement of algorithms, generation of test cases, analysis of objects, editing of processes and designing of static software models (Class and Packages diagrams).

Use Case and Collaboration Diagrams are examples of behavioral software models [Gupta, 2012]. They are also called Computation Independent Models (CIM) in MDA approach. The purpose of CIM models in MDA approach is to represent processes and algorithms of solving software tasks and an order of objects collaboration [Marín, 2013].

It is very important after every requirement changing to obtain actual Collaboration Diagram. As Collaboration Diagram contains more information in comparison with Use Case diagram, it is necessary to use additional sources for executing synchronization operation of these diagrams. Other sources of information for designing Collaboration Diagrams are domain knowledge, requirement specification and other behavioral software models that are represented as UML diagrams (Figure 1). Keeping this condition one can obtain a Collaboration Diagram satisfying Model Driven Engineering (MDE) approach requirements.

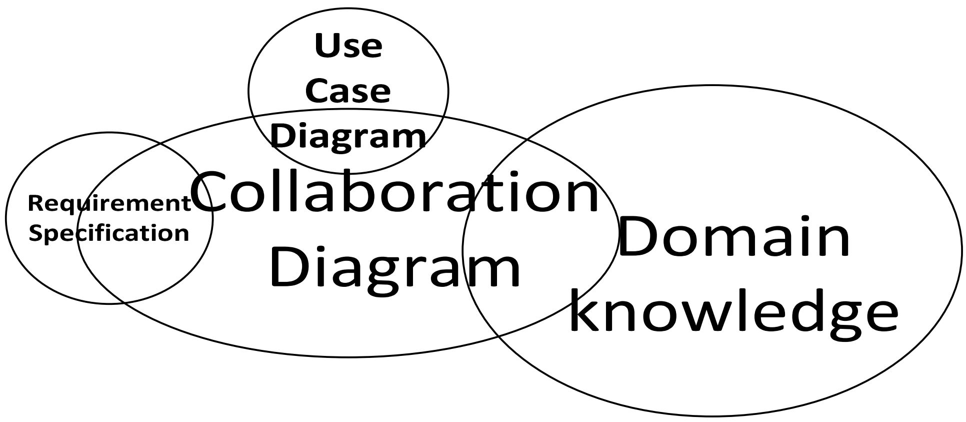


Figure 1. Information sources for designing of Collaboration Diagram

Application of approaches, allowing behavioral software models transformation helps to raise effectiveness of solving the next tasks:

- Design model transformation tools, methods and technics in MDA sphere;
- Develop techniques of software models processing and analyzing;
- Synchronize software artifacts.

An analytical representation of information about behavioral software models can be used for successful solving of the next tasks:

- Maintaining history of artifacts changing;
- Designing tools and frameworks for checking whether software model corresponds to MDE requirements;
- Checking, merging, reusing and executing other operations of software models processing;
- Designing new and extending existing notation of formats for saving information about software models (for example XMI);
- Requirements elicitation process and other activities.

That is why the task to design a method for synchronization of Collaboration Diagrams with artifacts that are changed after communication with customer using an analytical representation of input and resulting software diagram is actual.

Related works

Necessity for software artifacts synchronization is a cause of appearing series of papers that are devoted to this question.

Authors [Tombe, 2014] proposed using UML Use Case diagrams for maintaining requirements specification to capture scenario requirements as per the software maintenance tasks to be performed. Then Use Case diagrams are translated into Use Case model, from which the analysis model is derived, and then the models of the subsystem are designed from the analysis model to map into the existing architectural design of the ready system.

Paper [Daud, 2014] presents review of requirement engineering tools. Using this tools one can execute tracing requirements activities for software development process.

Authors proposed to divide the requirement engineering tools available in the market into two main categories: the commercial Requirements Engineering (RE) tools and the RE research tools. The requirement engineering tools for the comparison analysis comprises of three commercial requirement engineering tools, namely the RAQuest, QPack Tool and Enterprise Architect and four requirement engineering research tools which are the EA-Miner Tool, LRS Requirements, WikiReq system and Nocuous Ambiguity Identification (NAI). Main fourth requirement engineering activities were defined by authors, namely requirements elicitation and analysis, requirements validation and requirements management. Both the commercial and research requirement engineering tools support just a part of the requirement activities and focus on a partial solution for a particular requirements management activity.

Also involving both analytical representation of behavioral software model and transformation approaches into software development process [Chebanyuk, 2014] simplifies operations of static and behavioral software models synchronization, model transformation operations, improves model checking process, requirement validation and verification operations.

Research, presented in paper [Goknul, 2014], and has been devoted to relating requirements and design artifacts from source code. This paper presents an approach for generation and validation of traces between requirements and architecture. The approach directed for improving the currently observed practices by providing a degree of automation that allows faster trace generation and improves the precision of traces by validating them.

First, by using architectural verification, traces that otherwise would be missed in case of manual assignment and informal reasoning are discovered. Second, by using trace validation, we may reveal traces that are false positive traces.

An analytical background of approach that helps to trace requirements includes a representation of processes as subsets of Cartesian products of different sets. Other operations from the set theory tool give the schematic view of the relations between requirements and architecture. The definition of the requirements trace types formalizes the intuition that a part of software architecture is an implementation of a set of requirements. Approach proposes some iteration. Number or links may be increased after every requirements elicitation operations.

It is necessary to notice [Diskin, 2014], that the task of software artifacts synchronization is considering in MDD approach as vival. MDE approach poses several challenges for transformation tools, e.g. support of bidirectionality, instrumentality, informational symmetry, and ultimately concurrent updates. Having taxonomy of synchronization behaviors, with a clear semantics for each taxonomic unit, could help to manage these problems. Authors of paper presented a taxonomic space of model synchronization types and provided it with formal semantics. They considered computational and form a taxonomic plane classifying pairs of mutually inverse transformation operations. Also they proposed to classify relationships of organizational dominance between the models to be kept in synchronization. This allows infer the requirements for model transformations stools and theories to be applied to the problem. This knowledge can be useful both for MDE tools users and MDE tools builders for specifying MDE tools capabilities and behavior.

Collaboration Diagram designing using both Use Case diagrams and other knowledge sources

Analytical representation of Use Case diagram

Use Case diagram consists from subsystems. A set of all subsystems is denoted as follows: Ω. Consider a Use Case diagram subsystem $\omega \in \Omega$ and its constituents, namely: precedents, actors, precedents with marks <<include>> precedents with marks <<extends>> and comments.

Introduce the following notation:

A set of actors in subsystem $\omega \in \Omega$ is denoted as follows A^{ω}.

A set of precedents in subsystem $\omega \in \Omega$ is denoted as follows P^{ω}.

A set of precedents in subsystem with <<include>> mark is denoted as follows $P^{\omega}(include)$.

A set of precedents in subsystem with <<extends >> mark is denoted as follows $P^{\omega}(extends)$.

A set of comments in subsystem is denoted as follows K^{ω}.

A set of conditions transition between subsystem elements in subsystem $\omega \in \Omega$ is denoted as follows Y^{ω}.

A set of associations between elements in subsystem $\omega \in \Omega$ is denoted as follows T^{ω}.

Define $\omega \in \Omega$ as a subset of Cartasion product of the following sets: A^{ω}, P^{ω}, $P^{\omega}(include)$, $P^{\omega}(extends)$, K^{ω}, Y^{ω}, T^{ω}.

$$\begin{cases} \omega \subseteq P^{\omega} \times K^{\omega} \times A^{\omega} \times P^{\omega}(include) \times P^{\omega}(extends) \times \mathrm{Y}^{\omega} \times \mathrm{T}^{\omega} \\ P^{\omega} \times K^{\omega} \times A^{\omega} \times P^{\omega}(include) \times P^{\omega}(extends) = \{< p_1 p_2 >, < a_1 p_1 >, < a_1 k_1 p_1 >, < p_1 k_1 p_2 > \\ < p_1 \upsilon_1 p_2 >, < p_2 \tau_1 p_4 >, < p_1(include) p_3 >, < p_1(extends) p_4 >, < p_5 p_6 \bullet p_5 p_7 > \\ <^{sign} p_2{}^{sign} p_4 >\} \end{cases}, \quad (1)$$

where $p_i \in P^{\omega}, i = 1,...,7, k_1 \in K^{\omega}, a_1 \in A^{\omega}, p_3(include) \in P^{\omega}(include)$,

$p_3(extends) \in P^{\omega}(extends)$, $\upsilon_1 \in \mathrm{Y}^{\omega}$, $\tau_1 \in T^{\omega}$.

The expression $P^{\omega} \times K^{\omega} \times A^{\omega} \times P^{\omega}(include) \times P^{\omega}(extends)$ describes an analytical representation of all possible combinations of constituents for subsystem $\omega \in \Omega$.

Preparing an analytical representation using expression (1) in is necessary to consider that the order of constituents in “<” and “>” brackets corresponds to the order of Use Case diagram elements.

Matching of constituents when a Use Case diagram is transformed to Collaboration one is denoted as follows (Table. 1):

Table 1. Matching of Use Case diagram constituents to Collaboration Diagram constituents

Use Case diagram constituent	Collaboration diagram constituent	Reasoning of matching
Actor	Object	Both actors and objects make actions
Precedent	Message	Both precedent and messages serve for representing actions
Comment	Comment	The same meaning

When a Use Case diagram is transformed to Collaboration Diagram the next ***rule of precedent arrangement in Use Case diagram*** is used: the order of precedent placement should repeat the sequence of processes that should be realized in software. If the Use Case diagram precedent has less number the process, matching to this precedent should be executed before process or part of the process represented by precedent with bigger number.

Before transforming a Use Case diagram to Collaboration one, all the Use Case Diagram precedents should be numbered according to this rule. Also messages in resulting Collaboration Diagram are numbered according to this rule too.

Rules of placement messages for designing Collaboration Diagram from the Use Case one

When a Use Case Diagram precedent matches to a Collaboration Diagram message (Table 1) three cases can be considered:

- One precedent corresponds to one message;
- ONE precedent corresponds to several messages;
- Several precedents correspond to one message.

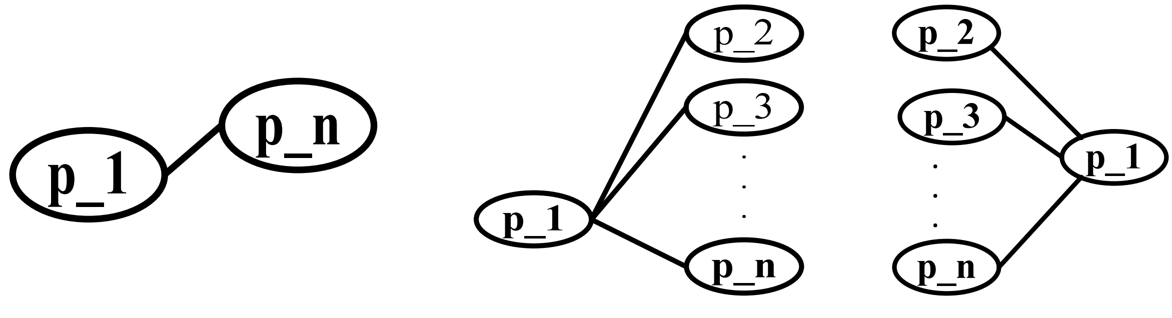
Also a precedent in Use Case diagram does not define all messages in Collaboration Diagram because a Collaboration Diagram contains more information in comparison with Use Case diagram (Figure1). Transforming Use Case diagram precedents to Collaboration Diagram messages we define rules for placement of Collaboration Diagram messages sequence. In order to do this notation of meta-language for description of problem domain processes is used [Chebanyuk, 2013].

According to this notation a sequence from *n* operations that are executed for solving some task is denoted as follows:

$$H = \{p_1 \to p_2 \to \ldots \to p_n\} \tag{2}$$

where p_i - is an operation from the sequence H. The sign $\rightarrow$ shows that sequence of operations is important.

Consider a fragment of a Use Case diagram that consist from two precedents p_1 and p_n connected by a link (Figure 2a). Define such a fragment as P^{1n}.



a) b) c)

Figure 2. Use Case diagram fragments

Analytical representation of fragment P^{1n} (Figure 2a) corresponds to the next expression: $P^{1n} =< p_1 p_n > \; where \; p_1, p_n \in P^{\omega}$.

As Use Case Diagram precedents correspond to Collaboration Diagram messages (Table 1), an analytical representation of Use Case Diagram fragment P^{1n} (Figure 2a) is denoted as follows:

$$H = \{p_1 \rightarrow P^{|} \rightarrow p_n\} \tag{3}$$

where $P^{|}$ - is a set of operations that can be executed between operations p_1 and p_n. Existence of the set $P^{|}$ is explained by the fact that Collaboration Diagram contains more information in comparison with Use Case Diagram.

The first rule of Collaboration Diagram messages placement is formulated as follows: when fragment P^{1n} (Figure 2a) of Use Case diagram is transformed to Collaboration one, message p_1 should be placed before message p_n. In some cases the set $P^{|}$ can be empty.

Formulate the second rule of Collaboration Diagram messages placement. Consider precedents that are located as it is represented in Figure 2b. From precedent p_1, n brunches are started. Every brunch links the precedent p_1 with one of the precedents p_{1+i}, $i = 2,...,n$. Denote this fragment as $P^{1(23...n)}$. An analytical form for representation such a fragment is denoted as follows:

$$P^{1(23...n)} =< p_1 p_2 \bullet p_1 p_3 ... \bullet p_1 p_n >=< p_1 \bullet (p_2 \bullet p_3 \bullet ... \bullet p_n)> \tag{4}$$

In expression (4) the order of multipliers matches with the order of precedents arrangement (see Figure 2b). In other word from the beginning operation p_1 is executed then one operation from the set $\{p_2 p_3 ... p_n\}$ is executed.

Brunching of the precedents shows that every pair of precedents p_1 and $p_i, p_i = 2,...,n$ can be represented using expression (3). But it is necessary to take into account the fact, that the choice of transition variant is determined by some condition. This condition is defined by peculiarities of concrete task. A set of all possible conditions providing transition from the precedent p_1 to precedent $p_i, p_i = 2,...,n$ is denoted as follows: $T^{p_1} \subseteq T^{\omega}$. Using (3) and $\tau_k \in T^{p_1}$ where $T^{p_1} \subseteq T^{\omega}$ an analytical representation of the Use Case Diagram fragment $P^{1(23...n)}$ (Figure 2b) is formed:

$$\begin{cases} H_1 = \tau_i \{p_1 \to P^{|}{}_1 \to p_2\} \\ H_2 = \tau_j \{p_1 \to P^{|}{}_2 \to p_3\} \\ . \\ . \\ . \\ H_n = \tau_k \{p_1 \to P^{|}{}_n \to p_n\} \end{cases} \qquad (5)$$

Every row of the expression (5) shows that if some condition from the set $T^{p_1} \subseteq T^{\omega}$ is "true", then the sequence of operations H_i, i=1,…,n is executed.

The second rule of Collaboration Diagram Messages placement is formulated as follows: if in a Use Case diagram precedent p_1 is linked with precedents $p_i, p_i = 2,...,n$ pair wise then the message p_1 should be located before any message $p_i, p_i = 2,...,n$ in corresponded Collaboration Diagram. Also the set $T^{p_1} \subseteq T^{\omega}$ of conditions should be formulated.

Reasoning by analogy formulates an analytical representation of Use Case Diagram fragment $P^{(23n)1}$ (Figure 2c).

$$P^{(23n)1} =< p_2 p_1 \bullet p_3 p_1 ... \bullet p_n p_1 >=< (p_2 \bullet p_3 \bullet ... \bullet p_n) \bullet p_1 > \qquad (6)$$

An analytical representation of the third rule of transformation a Use Case Diagram into Collaboration one is denoted as follows:

$$\begin{cases} H_1 = \tau_i \{p_2 \to P^{|}{}_1 \to p_1\} \\ H_2 = \tau_j \{p_3 \to P^{|}{}_2 \to p_1\} \\ . \\ . \\ . \\ H_n = \tau_k \{p_n \to P^{|}{}_n \to p_1\} \end{cases} \qquad (7)$$

Also a set $T^{p_2p_3\dots p_n} \subseteq T^{\omega}$ of conditions, allowing passing from the precedent $p_i, i=2,...,n$ to precedent p_1 is formed.

The third rule of Collaboration Diagram Messages placement is formulated as follows: if in a Use Case diagram precedents $p_i, i=2,...,n$ are linked with precedent p_1 pairwise then in Collaboration Diagram message p_1 should be located after all messages $p_i, i=2,...,n$. Also the set of conditions $T^{p_2p_3\dots p_n} \subseteq T^{\omega}$ should be formulated.

Consider cases of transforming Use Case Diagram fragment, looking as fragment in Figure 2a, but adding the condition that links between precedents p_1 and p_n contain marks <<include>> or <<extends>> (Figure 3)

Figure 3. Use Case Diagram fragments that have different marks between precedents

Consider a Use Case Diagram fragment where two precedents are linked with <<include>> mark (Figure 3a).

An analytical form of representation such a fragment is: $< p_1(include)p_n >$.

Formulate an analytical representation of the fourth rule of transformation a Use Case Diagram into Collaboration one. Consider expression (3). According to Use Case diagram notation if link between two precedents contains <<include>> mark, actions p_1 and p_n should executed consequently. That is why $P^{|} = \varnothing$. As a result we obtain expression:

$$H = \{p_1 \to p_n\} \tag{8}$$

The fourth rule of Collaboration Diagram Messages placement is formulated as follows: if in a Use Case Diagram precedents p_1 and p_n are linked with <<include>> mark then in corresponding Collaboration Diagram messages p_1 and p_n are located sequentially.

Consider a Use Case Diagram fragment where two precedents are linked with <<extends>> mark (Figure 3b).

An analytical representation of such a fragment is denoted as follows: $< p_1(extends)p_n >$.

An analytical representation of the fifth rule of transformation a Use Case Diagram into Collaboration one is denoted as follows:

$$H = \begin{cases} \tau_1\{p_2 \parallel p_1\} \\ \tau_2\{p_1 \to p_2\} \\ \tau_3\{p_1\} \\ \tau_4\{p_2\} \end{cases} \tag{9}$$

The sources of formulating the set $T^{p_1(extends)p_n} \subseteq T^{\omega}$ of conditions are Use Case Diagram requirement specification document and domain knowledge, namely information about business processes.

$\tau_1 = true$ if messages p_2 and p_1 are executed in parallel.

$\tau_2 = true$ if message p_1 is executed before message p_2.

$\tau_3 = true$ if existence of the message p_2 in Collaboration Diagram is not obligatory.

$\tau_4 = true$ if existence of the message p_1 in Collaboration Diagram is not obligatory.

If some conditions cannot be defined the variant $H = \{p_1 \rightarrow p_2\}$ is chosen by default.

The fifth rule of Collaboration Diagram Messages placement is formulated as follows: if in a Use Case Diagram precedents p_1 and p_2 are linked with <<extends>> mark then in corresponding Collaboration Diagram messages p_1 and p_2 are located sequentially. The order of execution and necessity of presents one of these messages can be defined more exactly by means of conditions from the set $T^{p_1(extends)p_n} \subseteq T^{\omega}$.

Consider a case when two Use Case Diagram precedents are linked by means one of some association type, namely: (1 1), (1 *), (* 1) or (* *).

An analytical form of representation such a fragment is: $< p_1^{sign} p_2^{sign} >$, where sign specifies the association type, namely 1 or *.

An analytical representation of the sixth rule of transformation a Use Case Diagram into Collaboration one is denoted as follows:

$$H = \{p_2 \xrightarrow{sign \quad sign} p_1\} \tag{10}$$

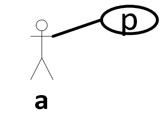
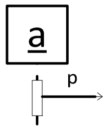
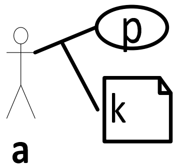
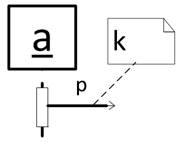
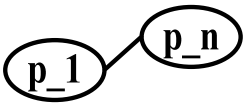
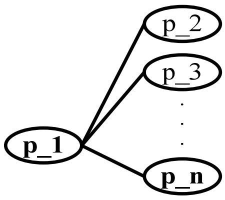
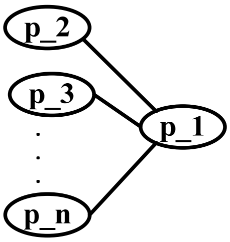
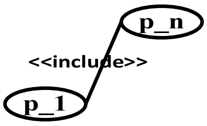
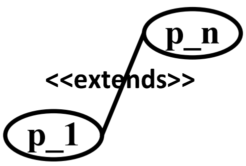
The first mark "sign" specifies multiplicity for the precedent p_1 second p_1 respectively.

The sixth rule of Collaboration Diagram Messages placement is formulated as follows: if in a Use Case Diagram precedents p_1 and p_2 are linked with multiplicity mark then sign=* can denote a collection of objects, to which message is directed.

Variants of Use Case Diagram fragments transformation to Collaboration Diagram fragments and rules

Table 2 systemizes the variants of transformation Use Case Diagram fragments to Collaboration one (rows one and two). Also the Table 2 gives an analytical representation of the rules of Collaboration Diagram Messages placement (other rows). These rules are used when direct transformation doesn't contain all necessary information for obtaining Collaboration Diagram satisfying MDE requirements.

Table 2 Matching Use Case Diagram fragments into Collaboration Diagram fragments and rules

<table>
<tr><th>Use Case diagram fragment</th><th>An analytical representation of this fragment</th><th>An analytical representation of rule defining Collaboration Diagram Messages placement</th><th>Collaboration diagram fragment</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>
</td><td>$< ap >$</td><td>-</td><td>
</td></tr>
<tr><td>
</td><td>$< akp >$</td><td>-</td><td>
</td></tr>
<tr><td>
</td><td>$< p_1 p_2 >$</td><td>$H = \{p_1 \to P^{|} \to p_n\}$</td><td>-</td></tr>
<tr><td>
</td><td>$< p_1 \bullet (p_2, p_3 ... p_n) >$</td><td>$\begin{cases} H_1 = \tau_i\{p_1 \to P^{|}{}_1 \to p_1\} \\ H_2 = \tau_j\{p_1 \to P^{|}{}_2 \to p_2\} \\ . \\ . \\ . \\ H_n = \tau_k\{p_1 \to P^{|}{}_n \to p_n\} \end{cases}$</td><td>-</td></tr>
<tr><td>
</td><td>$< (p_2, p_3 ... p_n) \bullet p_1 >$</td><td>$\begin{cases} H_1 = \tau_i\{p_2 \to P^{|}{}_1 \to p_1\} \\ H_2 = \tau_j\{p_3 \to P^{|}{}_2 \to p_1\} \\ . \\ . \\ . \\ H_n = \tau_k\{p_n \to P^{|}{}_n \to p_1\} \end{cases}$</td><td>-</td></tr>
<tr><td>
</td><td>$< (p_1 (include) p_2 >$</td><td>$H = \{p_1 \to p_n\}$</td><td>-</td></tr>
<tr><td>
</td><td>$< (p_1 (extends) p_2 >$</td><td>$H = \begin{cases} \tau_1\{p_2 \,\|\, p_1\} \\ \tau_2\{p_1 \to p_2\} \\ \tau_3\{p_1\} \\ \tau_4\{p_2\} \end{cases}$</td><td>-</td></tr>
</table>

The note: As comments' are transformed definitely they are not considered in the Table 2 (except row 2).

Method of transformation a Use Case diagram into Collaboration one

1. An analytical representation of Use Case Diagram according to expression (1) is formulated.

Introduce the denotation for the representation of precedent brunches in Use Case Diagram. Example of brunches is represented in the Figure 2b. The precedent p_1 is denoted as a root precedent. The sequence of linked precedents that are followed after the root precedent is denoted as follows:

$$^{p1\_pi}(<\mu_1>,<\mu_2>,...<\mu_n>) \tag{11}$$

where p_i – can be root precedent for the new fragment or the last precedent in chain of precedents, $<\mu_i>$ - is an element of chain number i, containing an analytical representation of a Use Case diagram fragment. *n* - number of fragments in the chain.

2. Define constituents in analytical representation of Use Case diagram that are transformed to Collaboration Diagram fragments directly (Table 2).

3. Define constituents in analytical representation of Use Case diagram that are used to formulate rules of Collaboration Diagram messages placement (Table 2).

4. Design a Collaboration Diagram using all data obtained in pervious points and other sources of information, namely requirements specification, domain knowledge, information about business processes.

5. Refine a Collaboration Diagram in order to define whether if satisfices to MDE requirements.

Designing Collaboration Diagram for solving task "Plotting of vector hodograph of density laying function" for two details that have arbitrary shape of outer contour"

Consider a Use Case Diagram that was designed after communication with customer (Figure 4) for solving this task.

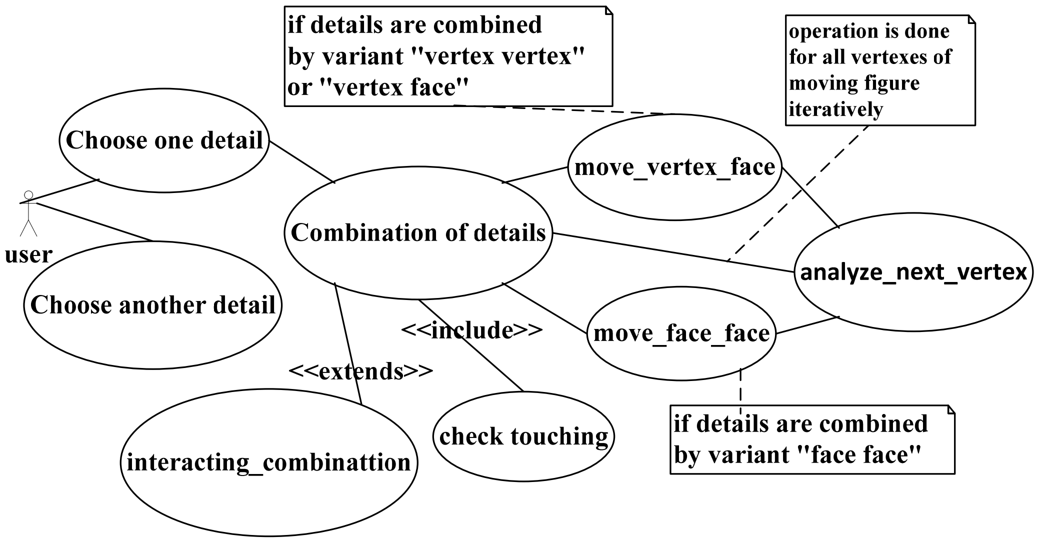


Figure 4. Use Case Diagram of task designing VHDLF defining of polygons mutual alignment on the plane

As for designing Collaboration Diagram, that meets MDE requirements, it is necessary to involve both Use Case diagram and other sources we represent ***ontology knowledge*** and ***business processes*** **description** of investigated problem domain.

Terms from the vocabulary of problem domain ontology

Pole of detail – any point inside of the detail.

Stationary detail – detail that does not move when VHGLF is defined.

Movable detail – detail that moves around stationary detail when VHGLF is defined.

Consider Figure 4. Triangle is movable detail, quadrangle is stationary ones.

Offset vector – vector that defines shifting of movable detail for defining the next point of VHGLF.

Peculiarities of business processes in considered problem domain

Represent a short description of an algorithm allowing designing VHGLF and functional requirements to application that realizes described algorithm.

The Algorithm for designing VHGLF for two kinds of details which have an arbitrary form of outer contours:

1. Two details are packed densely (Figure 5a).

2. An offset vector for next position of movable detail is defined. The principles of an offset vectors defining are shown in the Figure 5. In some cases the offset vector is defined by face of stationary detail. (Figure 5a, 5b, 5e). When this kind of moving (Figure 5c) causes intersection of details the offset vector is defined by face of movable detail (Figure 5d).

3. Movable detail is shifted on the offset vector.

4. The coordinates of movable detail pole are added into array of VHGLF coordinates.

5. Check whether the current coordinate of movable detail pole matches to the first hodograph point. If no then go to the p.2 else the designing of VHGLF is finished.

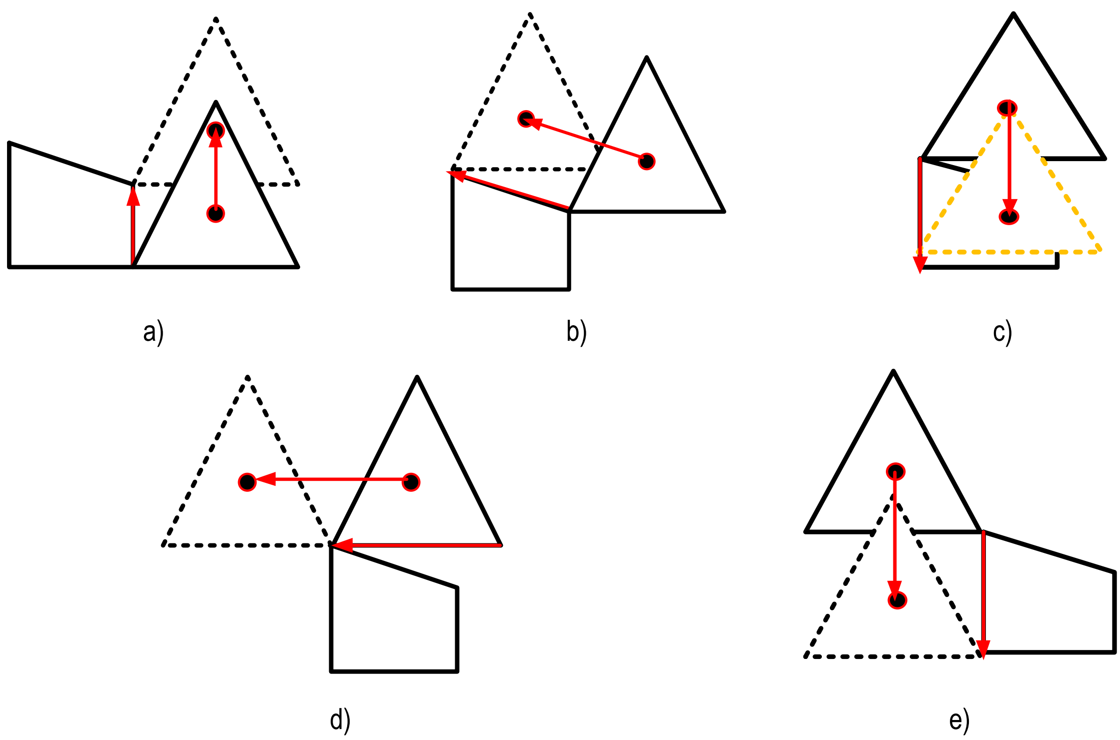


Figure 5. VHGLF designing

Represent a short description of this Use Case Diagram (Figure 4).

Use Case Diagram represents main actions that are done when VHGLF is designed.

1. Two details, namely stationary and movable are packed in laying (Figure 5a). These actions are described by Use Case diagram precedents “choose one detail” and “choose another detail” on Figure 4.

The packing of details can be done in interactive mode (fragment of the Use Case Diagram <<extends>>, and the precedent “interactive mode”) or in automated mode. Both modes require checking of condition whether details are touching in concrete point (fragment of the Use Case Diagram <<include>> and the precedent “Check touching” (Figure 4)).

The note: to design density laying for the same kind of detail one detail is chosen twice.

2. The first hodograph point is defined. It is matches with point of details intersection.

3. The next hodograph points are defined. Doing these one of two operations can be done. One operation is movement of movable detail face by stationary detail face (Figure 5a, 5b, 5e). Another one when face of movable detail is moved by vertex of stationary detail (Figure 5d). These actions are represented in precedents “move vertex face” and move “face face” of the Use Case diagram.

4. Defining whether current coordinates of movable figure pole match with the first hodograph point. This action is matches to precedent “analyze next vertex” of the Use Case diagram (Figure 3). If coordinates match the VHGLF designing is finished else go to the point 3.

Example of transformation Use Case diagram into Collaboration one

Analyzing Use Case diagram (Figure 4) consider that all its constituents are transformed to Collaboration Diagram constituents definitely.

1. Formulate an analytical representation of the Use Case diagram.

Define elements of the set for subsystem $\omega \in \Omega$, namely A^{ω}, P^{ω}, $P^{\omega}(include)$, $P^{\omega}(extends)$, K^{ω}, Υ^{ω} and T^{ω}.

$A^{\omega} = \{a_0^w = user\}$,

$$\mathrm{P}^{\omega} = \{p_0,..., p_7 \mid p_0 = choose\ one\ \det ail, p_1 = choose\ another\ \det ail, p_2 = combinatio\, n, of\ \det ails\}$$
$$p_3 = \mathrm{int}\, eractive\ combination, p_4 = check\ touching, p_5 = move\ vertex\ face, p_6 = move\ face\ vertex$$
$$p_7 = analyze\ next\ vertex\},$$

$\mathrm{P}^{\omega}(include) = \{p^w(include)_0 = p_2(include)p_3\}$,

$\mathrm{P}^{\omega}(extends) = \{p^w(extends)_0 = p_2(include)p_4\}$,

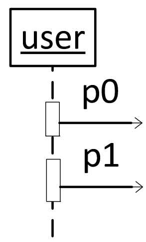
$K^{\omega} = \{k^w{}_0, k^w{}_1, k^w{}_2\}$.

Using (1) formulate an analytical representation of the Use Case diagram.

$$P^{\omega}\times K^{\omega}\times A^{\omega}\times P^{\omega}(include)\times P^{\omega}(extends)=\{<a_0p_0>,<a_0p_1>,{}^{p_0}<p_0p_2>,{}^{p_1}<p_1p_2>,$$
$$<p_2(include)p_3>,<p_2(extends)p_3>,<p_2\bullet(p_5\bullet p_6)>,{}^{p_5}<p_5p_7>,{}^{p5}<p_7p_5>{}^{p_6}<p_6p_7>,$$
$${}^{p_6}<p_7p_5>,{}^{p_7}<p_7p_5>\}$$

2. Combining p2 and p3 of the method of transforming Use Case diagram into Collaboration one form the table of Collaboration diagram fragments and rules of Collaboration diagram messages placement (Table. 3).

Table 3. Representation of Collaboration Diagram fragments and rules of message placement

Analytical representation of the Use Case Diagram fragments	Collaboration Diagram fragments and rules of messages placement
1	2
$<a_0p_0>$ $<a_0p_1>$	
${}^{p_0}<p_0p_2>,$ ${}^{p_1}<p_1p_2>,$ ${}^{p_5}<p_5p_7>,$ ${}^{p5}<p_7p_5>$ ${}^{p_6}<p_6p_7>,$ ${}^{p_6}<p_7p_5>,$ ${}^{p_7}<p_7p_5>$	$H_1=\{p_0,P_1,p_2\},P_1=\varnothing$ $H_2=\{p_1,P_2,p_2\},P_2=\varnothing$ $H_3=\{p_5,P_3,p_7\},P_3=\varnothing$ $H_4=\{p_7,P_4,p_5\},P_4=\varnothing$ $H_5=\{p_6,P_5,p_7\},P_5=\varnothing$ $H_6=\{p_7,P_6,p_5\},P_6=\varnothing$ $H_7=\{p_7,P_7,p_5\},P_7=\varnothing$
$<p_2(include)p_3>$	$H_8=\{p_2\to p_3\}$
$<p_2(extends)p_3>$	$\tau_1=false,\ \tau_2=false,\tau_3=false,\tau_4=true\ \Rightarrow H_8=\{\tau_4p_3\}$ $\text{int}eractive\ combination=true$
$<p_2\bullet(p_5\bullet p_6)>$	$\begin{cases}H_9=\tau_5\{p_2\to P^{\vert}{}_1\to p_1\},P^{\vert}{}_1=\varnothing,\tau_5=offset\ of\ moving\ \det ail\\ H_{10}=\tau_6\{p_3\to P^{\vert}{}_2\to p_1\},P^{\vert}{}_2=\varnothing,\tau_6=offset\ of\ stay\ \det ail\end{cases}$

The resulting Collaboration Diagram after executing points 4 and 5 of the proposed method is represented on Figure 6.

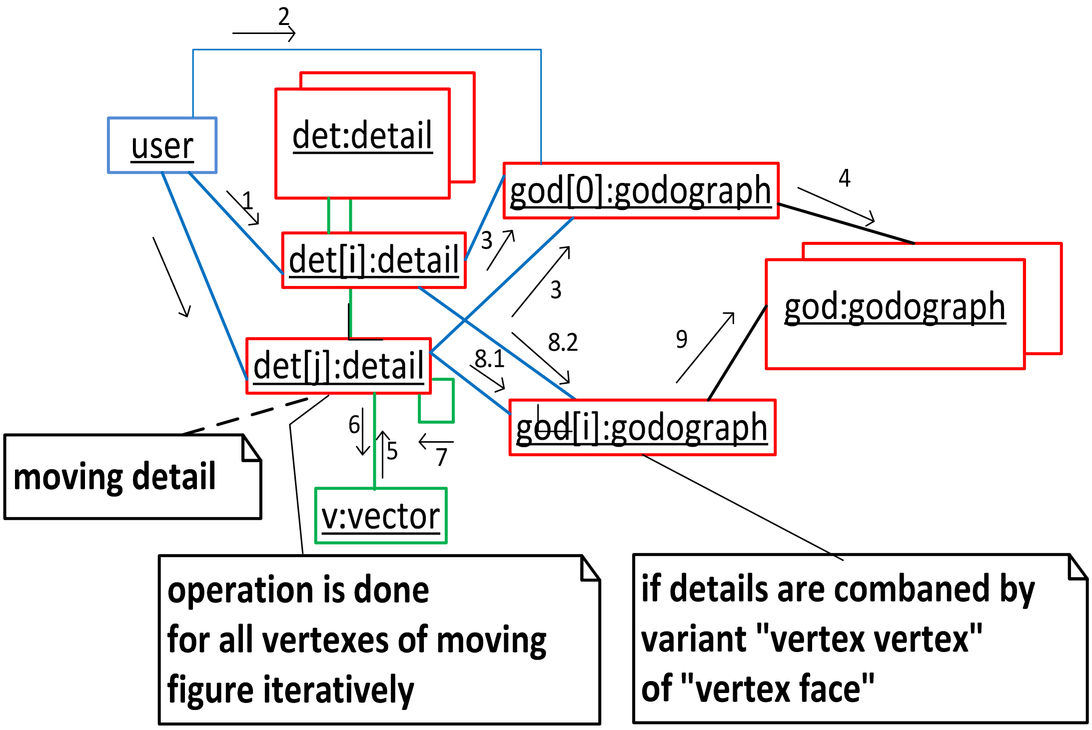


Figure 6. Collaboration Diagram of process designing of VHGLF

Represent an explanation of Collaboration Diagram messages

1. Message 1. Choose two details from an array of model's details.
2. Message 2. Define the first point of VHGLF in interactive mode.
3. Message 3. Define the first point of VHGLF in automated mode.
4. Message 4. Add the first point to the array of hodograph points.
5. Message 5, 6, 7. Define an offset vector analyzing positional relationship of the details (Figure 5).
6. Message 8.1, 8.2. Moving detail1 (detail2) define the next point of VHGLF by means of calculation coordinates of intersection point.
7. Message 9. Add a point to the array of hodograph points.

Objects and messages that are defined from the Use Case Diagram are marked by blue color.

Objects and messages that are defined from the ontology knowledge are marked by green color.

Objects and messages that are defined from the ontology vocabulary are marked by red color.

Conclusion

The method of synchronization software artifacts that are changed after communication with customer is represented in this paper. Input behavioral software models are represented as Use Case diagram or its varieties and resulting model is Collaboration Diagram.

Involving this method into software development process let's to achieve the next advantages in MDD approach:

- Obtain behavioral software models that correspond to requirement specification;
- Allow further synchronization of software artifacts that are changed after Collaboration Diagram modifying [Chebanyuk, 2014].

An analytical apparatus for the representation of Use Case diagrams allows:

- Design tools for management software artifacts history;
- Generate new notation and formats for saving information about Use Case diagram;
- Design or modify techniques, tools and methods for merging, comparing, reusing, converting or changing software models.

Rules of Collaboration Diagram Messages placement can be used for:

- Checking whether behavioral software models meet MDE requirements, namely completeness of future software processes representation, validity and being non contradictory;
- Refinement other software artifacts, that describe software behavior;
- Save information about problem domain processes and interconnections between objects.

Using of the proposed approach for maintaining requirements specification to capture scenario requirements [Tombe, 2014] lets to improve tools for forming of an analytical models and designing of UML diagrams.

The review of environments of requirement engineering tools, presented in paper [Daud, 2014] shows that both the commercial and research RE tools support just a part of the requirement activities. Method of synchronization software models helps both designing new and improving existing methods for behavioral software models transformation and focus on a partial solution for a particular requirements management activity.

Involving analytical representation of behavioral software diagrams into requirement tracing activities one can simplify model conversion operations improve model checking process, requirement validation and verification operations [Goknul, 2014].

Further exploration

Design an analytical apparatus and a framework for matching software requirements to architecture constituents. This framework will allow modifying architecture constituents after changing of requirements in automated mode. In order to achieve this goal it is necessary to do the following:

- Design an analytical apparatus for representation both static and dynamic models;
- Propose, check and verify mechanism for defining fully and partially matching elements of different software models types.

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INFORMATIONAL MODELS OF THE ADVANCED SYSTEMS OF RADIOACCESS TO THE TELECOMMUNICATIONS NETWORKS COMPARISON

Sergey Mikhailov, Sergey Shreyner

***Abstract**: Informational models of the advanced systems of radioaccess to the telecommunications networks comparison. LTE (Long Term Evolution) technology compared with the 802.1x protocol family.*

***Keywords**: wireless networks, WPAN, WMAN, LTE, HSDPA, OFDM.*

***ACM Classification Keywords**: C.2 Computer-Communication Networks; C.2.1 Network Architecture and Design – Wireless communication.*

Introduction

Building effective wireless radio systems to telecommunication networks has always been a daunting task, and its relevance is not lost over time, and acquires new contours. Currently, wireless radios technologies appear abound, and before network operator is to choose technologies optimally, solving the problem delivery of any kind of traffic to their subscribers. Naturally, generic solution to this problem does not exist: each technology has its range of application, its advantages and disadvantages.

Comparison of Basic Standards

At the moment there are the following wireless standards. All of them are divided into four broad categories:

– WPAN (Wireless personal area network);

– WLAN (Wireless Local Area Network);

– WMAN (Wireless Metropolitan Area Networks);

– WWAN (Wireless Wide Area Network).

Category WLAN intended for communication between a varieties of devices. It, like LAN, is based on twisted pair or fiber. This category is characterized by high speed data transmission over short distances. Interaction devices are described by family of standards IEEE 802.11. The data technology Wi-Fi is related to this standard [Baklanov, 2008].

Category WPAN - wireless network is designed to communicate wirelessly between various types of devices in a limited area (e.g. within the apartment, office workplace). Standards that define the methods of network operation are described in the family specifications IEEE 802.15. To this standard relate Bluetooth technology and ZigBee technology.

The category WMAN – can be attributed to a variety of different technologies – these are terrestrial Radio and television broadcasting, and cellular communications and tranking system. Note that the based on the standards wireless local area networks quite successfully build a Metropolitan Area Network. This category includes: WiMax, 3G, LTE (Long Term Evolution) [Semenov, 2005].

Global Network WWAN Wireless is different from WLAN wireless local area networks so that provide data transmission which is used in wireless mobile communication technologies, such as the UMTS, GPRS, CDMA2000, GSM, CDPD, Mobitex, HSDPA, 3G, LTE. Appropriate communication services offered, are usually on a fee basis by operators of regional, national or even a global scale. WWAN technology enables the user to gain access to the World Wide Web, use e-mail and connect to virtual private networks from anywhere within the coverage of a wireless carrier. Many modern laptops have integrated adapters WWAN (for example, HSDPA).

Currently the market of Ukraine has the prospect of a new technology LTE. LTE is a standard for wireless data communications technology and an evolution of the GSM/UMTS standards. The goal of LTE was to increase the capacity and speed of wireless data networks using new DSP (digital signal processing) techniques and modulations that were developed around the turn of the millennium. A further goal was the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture. The LTE wireless interface is incompatible with 2G and 3G networks, so that it must be operated on a separate wireless spectrum.

In its radio components new methods of modulation are used: OFDM. OFDM in its primary form is considered as a digital modulation technique, and not a multi-user channel access method, since it is utilized for transferring one bit stream over one communication channel using one sequence of OFDM symbols. However, OFDM can be combined with multiple accesses using time, frequency or coding separation of the users.

In orthogonal frequency-division multiple accesses (OFDMA), frequency-division multiple accesses is achieved by assigning different OFDM sub-channels to different users. OFDMA supports differentiated quality of service by assigning different number of sub-carriers to different users in a similar fashion as in CDMA, and thus complex packet scheduling or Media Access Control schemes can be avoided. OFDMA is used in:

– The mobility mode of the IEEE 802.16 Wireless MAN standard, commonly referred to as WiMAX;
– The IEEE 802.20 mobile Wireless MAN standard, commonly referred to as MBWA;
– The 3GPP Long Term Evolution (LTE) fourth generation mobile broadband standard downlink. The radio interface was formerly named High Speed OFDM Packet Access (HSOPA), now named Evolved UMTS Terrestrial Radio Access (E-UTRA);
– The now defunct Qualcomm/3GPP2 Ultra Mobile Broadband (UMB) project, intended as a successor of CDMA2000, but replaced by LTE.

OFDMA is also a candidate access method for the IEEE 802.22 Wireless Regional Area Networks (WRAN). The project aims at designing the first cognitive radio based standard operating in the VHF-low UHF spectrum (TV spectrum).

In Multi-carrier code division multiple accesses (MC-CDMA), also known as OFDM-CDMA, OFDM is combined with CDMA spread spectrum communication for coding separation of the users. Co-channel interference can be mitigated, meaning that manual fixed channel allocation (FCA) frequency planning is simplified, or complex dynamic channel allocation (DCA) schemes are avoided.

In OFDM based wide area broadcasting, receivers can benefit from receiving signals from several spatially dispersed transmitters simultaneously, since transmitters will only destructively interfere with each other on a limited number of sub-carriers, whereas in general they will actually reinforce coverage over a wide area. This is very beneficial in many countries, as it permits the operation of national single-frequency networks (SFN), where many transmitters send the same signal simultaneously over the same channel frequency. SFNs utilize the available spectrum more effectively than conventional multi-frequency broadcast networks (MFN), where program content is replicated on different carrier frequencies. SFNs also result in a diversity gain in receivers situated midway between the transmitters. The coverage area is increased and the outage probability decreased in comparison to an MFN, due to increased received signal strength averaged over all sub-carriers.

Although the guard interval only contains redundant data, which means that it reduces the capacity, some OFDM-based systems, such as some of the broadcasting systems, deliberately use a long guard interval in order to allow the transmitters to be spaced farther apart in an SFN, and longer guard intervals allow larger SFN cell-sizes. A rule of thumb for the maximum distance between transmitters in an SFN is equal to the distance a signal travels during the guard interval – for instance, a guard interval of 200 microseconds would allow transmitters to be spaced 60 km apart.

A single frequency network is a form of transmitter macro diversity. The concept can be further utilized in dynamic single-frequency networks (DSFN), where the SFN grouping is changed from timeslot to timeslot.

OFDM may be combined with other forms of space diversity, for example antenna arrays and MIMO channels. This is done in the IEEE802.11 Wireless LAN standard.

MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) and/or to achieve a diversity gain that improves the link reliability (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+.

MIMO technology, which was used in the HSPA + (2x2 antennas) has been further developed (4x4 antennas and more, depending on the release and supporting 3GPP terminals). This technology allows more bandwidth radio interface [Tanenbaum, 2005].

As in many other areas, wireless data is no universal technology. Under each specific task a definite technology is suited. If the task is to provide broadband access to the user - it is more suitable WiMax, LTE as the technology was originally developed for this purpose.

However, if the task is to provide broadband access in a limited space, the technology Wi-Fi, Bluetooth or WiMax is equally well suited for decision, provided that a low level of interference or noise doesn't existent. And for the introduction of wireless alarm systems or CCTV is more suitable Wi-Fi, ZigBee because this issue is quite well developed. In Table 1 has been carried comparison of wireless standards.

Every of these technologies have its own advantages and disadvantages. The main advantage of all these technologies is that they are wirelesses, and therefore do not need to pull the cable. From Table 1 can be concluded that technologies: Wi-Fi, Bluetooth and ZigBee working in one frequency band 2/4 GHz, than that interfere with one other. WiMax operates in the band from 1.5 GHz to 20 GHz.

The advantages of Bluetooth and ZigBee devices are low cost and low energy costs to the disadvantage belong a short range and low bandwidth.

Among the advantages of Wi-Fi is that the devices are widely circulated in the market, which ensures compatibility of the equipment thanks to mandatory certification of equipment logo Wi-Fi. Because of low cost and ease of installation, Wi-Fi is often used to provide customers' fast Internet access. The disadvantage is that in the range of 2,4 GHz running a variety of devices, such as devices that support Bluetooth, and even microwave ovens, which degrades the electromagnetic compatibility and interfere with the work of Wi-Fi. Wi-Fi system is a short-acting, usually covering 20-300 of meters that uses unlicensed frequency bands to provide access to the network.

Usually Wi-Fi is used by users to access of their own network, which may not be connected to the Internet. If WiMAX, LTE can be compared to mobile communications, the Wi-Fi is more like a landline cordless phone.

WiMAX allows you to access the Internet at high speeds, with much greater coverage than Wi-Fi-networks. This allows the use of technology as a "mainline channel", a continuation of that traditional DSL and leased lines, as well as local area networks. As a result, this approach allows you to create scalable, high-speed networks within the framework of cities [IEEE, 2010].

The advantage of LTE is high bandwidth in 326 Mbit/s, and large radius of action up 5 to 100 km. Given that the technology is relatively new, there are prospects for development in a given direction.

The LTE specification provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s and QoS provisions permitting a transfer latency of less than 5 ms in the radio access network. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency division duplexing (FDD) and time-division duplexing (TDD). The IP-based network architecture, called the Evolved Packet Core (EPC) and designed to replace the GPRS Core Network, supports seamless handovers for both voice and data to cell towers with older network technology such as GSM, UMTS and CDMA2000.

The simpler architecture results in lower operating costs (for example, each E-UTRA cell will support up to four times the data and voice capacity supported by HSPA).

Considering that is formally referred to as LTE 4G generation, which can be called the first stage of 3G + and implement hardware 3G, by modernizing only the software.

Table 1. Comparison of Wireless Standards

Technology	Standard	Category	Throughput	Action radius	Frequencies	Cost
Wi-Fi	802.11a	WLAN	up to 54 Mbit/s	up to 300 m	5,0 GHz	from $30
Wi-Fi	802.11b	WLAN	up to 11 Mbit/s	up to 300 m	2,4 GHz	from $30

Wi-Fi	802.11g	WLAN	up to 54 Mbit/s	up to 300 m	2,4 GHz	from $30
Wi-Fi	802.11n	WLAN	up to 450 Mbit/s	up to 300 m	2,4 GHz, 5 GHz	from $30
Bluetooth 1.1	802.15.1	WPAN	up to 1 Mbit/s	up to 10 m	2,4 GHz	from $10
Bluetooth 2.0	802.15.3	WPAN	up to 2.1 Mbit/s	up to 100 m	2,4 GHz	from $10
Bluetooth 3.0	802.11	WPAN	3-24 Mbit/s	up to 100 m	2,4 GHz	from $10
Bluetooth 4.0	802.11	WPAN	up to 0.26 Mbit/s	up to 100 m	2,4 GHz	from $10
ZigBee	802.15.4	WPAN	20 – 250 Mbit/s	up to 100 m	868 MHz, 915 MHz, 2,4 GHz	from $45
WiMax	802.16d	WMAN	up to 75 Mbit/s	25-80 km	1,5-20 GHz	from $90
WiMax2	802.16m	WMAN	up to 75 Mbit/s	25-80 km	1,5-20 GHz	from $90
LTE	3GPP LTE	WMAN	up to 326,4 Mbit/s	up to 5 up to 100 km	800 MHz, 1,8 GHz, 2,6 GHz	from $50

Conclusion

The report represents a comparative analysis of promising wireless radio systems for telecommunications networks. A special attention was paid to perspective of a new technology LTE based on the protocol 3GPP LTE. Technology allows working at long distances, at high data rates.

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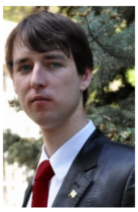
Major Fields of Scientific Research: improvement of radioaccess systems for computer telecommunications networks



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Major Fields of Scientific Research: improvement of radioaccess systems for computer telecommunications networks

IT-COMMUNICATORS FOR MEDICINE

Ozar Mintser, Volodymyr Romanov, Igor Galelyuka, Oleksandr Voronenko

***Abstract**: Relationships and communication between doctors and patients is a very important problem in medicine. Analysis of possible interrelated directions of development and application of communicators in emergency and family medicine was performed. According to the first direction the IT communicators are intended for supporting alternative communication with the people lost temporarily or permanently possibility to speak. According to the second direction proposed communicators have databases included detailed information about types of diseases and traumas, and by results of analysis of injured person symptoms or feelings the software subsystem generates some variants of possible diseases or traumas diagnosis. It is proposed to apply special hardware-software means, particularly IT communicators to simplify the communication of doctors with patients (particularly with voice limitation) and increase treatment efficiency beginning from the first contact. Proposed IT communicators are used in family and emergency medicine for supporting first contact of doctors with patients (with voice limitation) and getting information about patient state, for example, during the preliminary examination of patients. Application of proposed modern computer devices and information technologies in medicine makes it possible to reduce a number of cognitive problems, increase the efficiency of the first contact of patients with doctors, quickly give a diagnosis and correctly select methods of treatment.*

***Keywords**: IT communicators, problems of cognitivism in medicine, family medicine, speciality application-dependent software.*

***ACM Classification Keywords**: J.3 Life and Medical Sciences - Health*

Introduction

Relationships and communication between doctors and patients is a very important problem in medicine. Ability of correct communication during the disease or separate stage of disease helps to diagnose, prognoses a clinical behavior, and accelerate the recovery.

Communication problems between a doctor and a patient influence correctness of the diagnoses and quality of a doctor aid, and complicate the medical treatment. In addition during the communication the problems of adequate understanding or cognitive problems appear too. These cognitive problems are connected with the avalanche of new medical data. Therefore it is very important to apply creative intelligent thinking and modern IT of trans-disciplinary knowledge transferring. Relations between doctors and patients are not restricted only to communication. Making a diagnosis, patient state examination, interpretation of the data received from a patient, treatment planning, and treatment evaluation are very important too.

Methods of evaluation and correction of diagnosis influence treatment planning and treatment effectiveness. Preliminarily it is possible to divide evaluation methods into subjective (based on communication) and objective (based on examination of a patient, and data of the laboratory, and instrument investigations).

It is proposed to apply special hardware-software means, particularly IT communicators to simplify the communication of doctors with patients (particularly with voice limitation) and increase treatment efficiency beginning from the first contact.

Work objective is analyses of possibilities of application of IT communicators for solving the cognitive problems of doctor-patient communication.

Received results

One version of the IT communicators was proposed in [Sergienko, 2013]. It is a mobile tablet computer with special application-dependent software.

Technical requirements for the development of speciality application-dependent software of IT communicator are rather simple. For this purposes it is needed a single core tablet computer with 10 in sensor monitor, clock frequency 1.2 GHz, RAM 512 MB, ROM 4 GB, OS Android 4.0. In addition it is possible to apply a monitor smaller than 10 in, but its application complicates data reading.

IT communicators are used for the following purposes:

1. In medicine: for supporting first contact of doctors with patients (with voice limitation), and getting information about patient state, for example, during the preliminary examination of patients. Particularly it is very important for family doctors because they are the firsts who examine patients with different diseases. Sometimes family doctors have no enough knowledge and experience to diagnose.
2. To make emergency medical aid for patients with voice limitation: in this case the IT communicators help patients to communicate with doctors.

Special application-dependent software consists of two subsystems. The first subsystem is used for the first contact of a doctor and a patient. The second subsystem is used for alternative communication of doctors with patient lost temporarily or permanently possibility of speaking.

The means of first contact medicine were analyzed. On this base technical requirements for the application-dependent software of the first subsystem were developed. There are many handbooks for family doctors issued as ordinary books. Unlike to modern mobile IT means it is rather difficult to use ordinary handbooks for supporting doctors to make diagnosis of injured or fall ill persons.

Sometimes knowledge and practical experience of family doctors are restricted and they may not know symptoms of some diseases and proper methods of first aid. It is known that correct first aid assigns efficiency of treatment and reduces probability of complication. Application of modern IT when making the first examination of an injured person helps to increase the probability of correct first aid.

The developed subsystem of IT communicator contains a data base with detailed information on majority of diseases and traumas, its symptoms, diagnostic methods and first aid actions.

The other aim of IT communicator is to support alternative communication with voice and motion limited patients. The idea of alternative communication is rather simple. Voice limited patient needs communication with surroundings in any way. The process of establishing relations with additional means helps patient with voice limitation to express his needs and wishes. Communicators for alternative communication are used to help voice limitation patients to understand surroundings clearly.

It was analyzed existing means for the communication with such patients. You can find below overview of some modern communicators for voice limitation people which used to nurse the sick and treatment.

The simple means of the communication are the following:

1. Paper, blackboard, cards. The means are used for only voice limitation patients without loss of motion.
2. Tables with repetitive words or phrases classified according to subjects.
3. Sign language for only voice limitation patients without loss of motion.
4. Short form messages by gesture, changing look of the face, winking, etc.
5. Simple signals such as bell, dot-and-dash, etc.

Above means have restricted use for communication in hospitals, domestic life, etc.

More extended and rather simple means for communication of voice limitation patients are the following;

1. Figure 1 shows the smart computer device GoTalk. It is the pad with 9/25/32 cells. Each cell contains audio text, supported with icons. If patient presses selected icon the audio text is reproduced.
2. So called medicine-social service of emergency aid for people with limited capacity “life button”.

Figure 1. Smart device GoTalk

There are enough high-tech and multifunctional means for communication of people with move and voice limitation. Some of them convert text to voice. But all of them have some restrictions. Firstly, users of such means are to be possessed of special knowledge and skill to work with computer software. They need to install it. Secondary, this means are rather expensive.

Of course there are high-tech smart eye controlled computer devices based on a video camera. Video camera tracks the patient's eye move and converts it to the computer monitor cursor move. Winking of eye is converted by device to mouth operation. The devices by Israel Company EyeTech or devices of EyeWriter family are a good example of such communicators.

The IT communicator designed in the V.M. Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine and in Shupyk National Medical Academy of Postgraduate Education makes it possible communication doctors and patients with move and voice limitation. Figure 2 shows the main menu of the smart communicator. There are five menu items: needs, recourse, pain, emergency aid, and keyboard.

Menu item “Needs” means for screening list of patient needs, particularly needs of eating, drinking, sleeping, pain relief, establish silence, hygienic procedure, etc. Menu item “Recourse” means for screening a list of patient recourse, particularly keep silence; speak loudly, on/off radio or TV, close/open window, etc. It is possible to extend these lists.

Menu item “Pain” helps a patient to specify the centre of pain location. The human body icon or its separate parts (hands, arms, head, feet, legs, torso, etc.) are displayed for the pain location, as Figure 3 shows. Voice commentary of these icons is possible. Pain location first of all is very important for protecting move limitation patients from decubitus.

Menu item “Emergency aid” means for emergency doctor call. The call is attended by the audible alarm.

Menu item “Keyboard” means for adding needs or recourses missing in menu bars. It is possible to convert written by patient needs to voice.

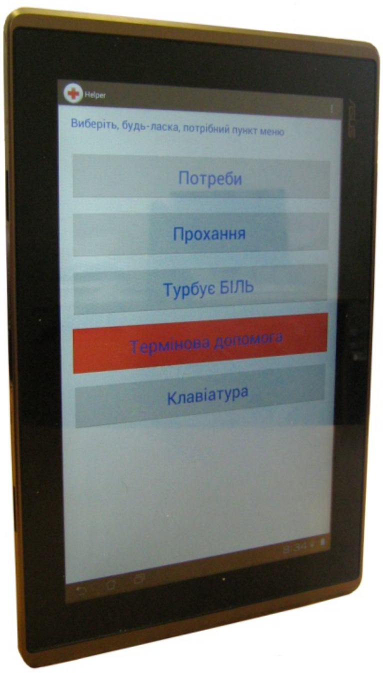

Figure 2. Main window

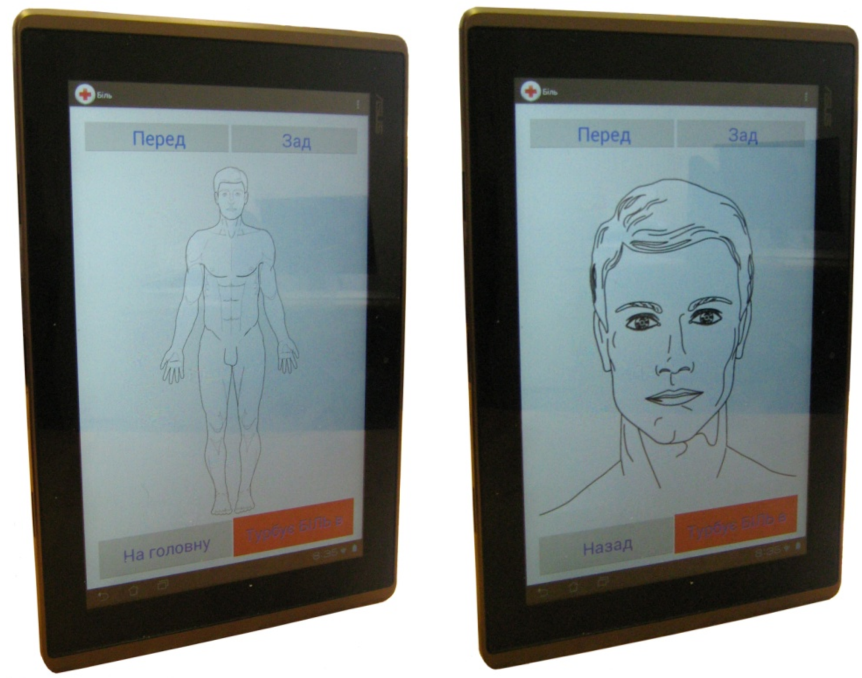

Figure 3. Pain location windows

It is necessary to add that IT communicator stores the patient medical history of pain, location of the pain, etc. This makes it possible to get pain dynamics, and on this base check validity of patient information and confirm diagnosis. If not, patient is needed in additional examination.

Conclusion

1. Application of modern computer devices and IT in medicine makes it possible to reduce a number of cognitive problems, increase efficiency of the first contact of patients with doctors, and quickly give a diagnosis, and correctly select methods of treatment.

2. IT communicators are very important in family medicine to make clear communication of doctors and patients to improve quality of the first aid.

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Acknowledgement

The paper is published with partial support by the project ITHEA XXI of the ITHEA ISS (www.ithea.org) and the ADUIS (www.aduis.com.ua).

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HIERARCHICAL TWO LAYERS CONTROL COMMUTATOR FOR IMPLEMENTATION OF FULLY NON-CONFLICT SCHEDULE

Kiril Kolchakov, Vladimir Monov

Abstract: *In this paper, an algorithm is developed for a full non-conflict schedule obtained through the activation of diagonals of sub- matrices in switching nodes of type Crossbar. The size of sub matrices in the Crossbar is optimized. Finite automats are designed for two layers control of sub-matrices a comparison with known algorithms with diagonal activation of connection matrix is done.*

Keywords: *Network nodes, Crossbar switch, Conflict elimination, Packet messages, finite automat.*

ACM Classification Keywords: *C.2.1 Network Architecture and Design, C.4 Performance of Systems Conference topic: Information Modeling, Distributed and Telecommunication Systems*

Introduction

The traffic via Crossbar switching nodes is casual and depends on the users. The formulation of the conflict issue during operation of the switching nodes is as follows: the dimensions of the switches in the switching nodes are N x N, where N sources of packet messages are connected to N receivers via the switch of the switching node. The switching node traffic is random by nature and depends on the users. Conflicts are available in the following two cases:

- When one source of message requests communication to two or more message receivers;
- When one message receiver receives communication requests from two or more message sources.

The evasion of conflicts is directly related to the switching node performance.

The status of the switch of the switching node is represented with the so called connection matrix. For N x N dimensional switch the dimension of the connection matrix T is N x N also, where every element T_{ij} = 1 if the connection request from i- source to j- receiver exists. In the opposite case T_{ij} = 0.

A conflict situation arises if any row of the connection matrix has more than a single 1, which corresponds to the case when one source requests a connection with more than one receiver. The presence of more than a single 1 in any column of the matrix T also indicates a conflict situation, it means that two or more sources have requested a connection with the same receiver [Kolchakov and Tashev, 2012], [Kolchakov K., 2012].

Description of algorithm ADAJS (Algorithm with diagonal activations of joint sub-switching matrices)

The connections matrix T with N x N size, where N is being the degree of two, is divided into sub matrices (S) with dimension n x n, (n also is a degree of two), i.e.:

$$T = [\, S_{ij} \,],\ i = 1\text{-}\ n,\ j = 1\text{-}\ n.$$

The sets of sub matrices located along the main diagonal are processed simultaneously in each of the diagonals. For submatritces in diagonals parallel to the main one, the principle of reconciliation is used. The idea of synthesis of the algorithm ADAJS (Algorithm with diagonal activations of joint sub-switching matrices) is based on the knowledge that the diagonal sub matrices with requests for service in the matrix T are non-conflict in the diagonal where they are located [Kolchakov and Monov, 2013].

There are diagonals with sub matrices of requests that are non-conflict to one another.

Figure 1 shows joint couple of non-conflict diagonals with sub matrices of requests for service and the main diagonal of sub matrices that cannot be jointed with anyone else.

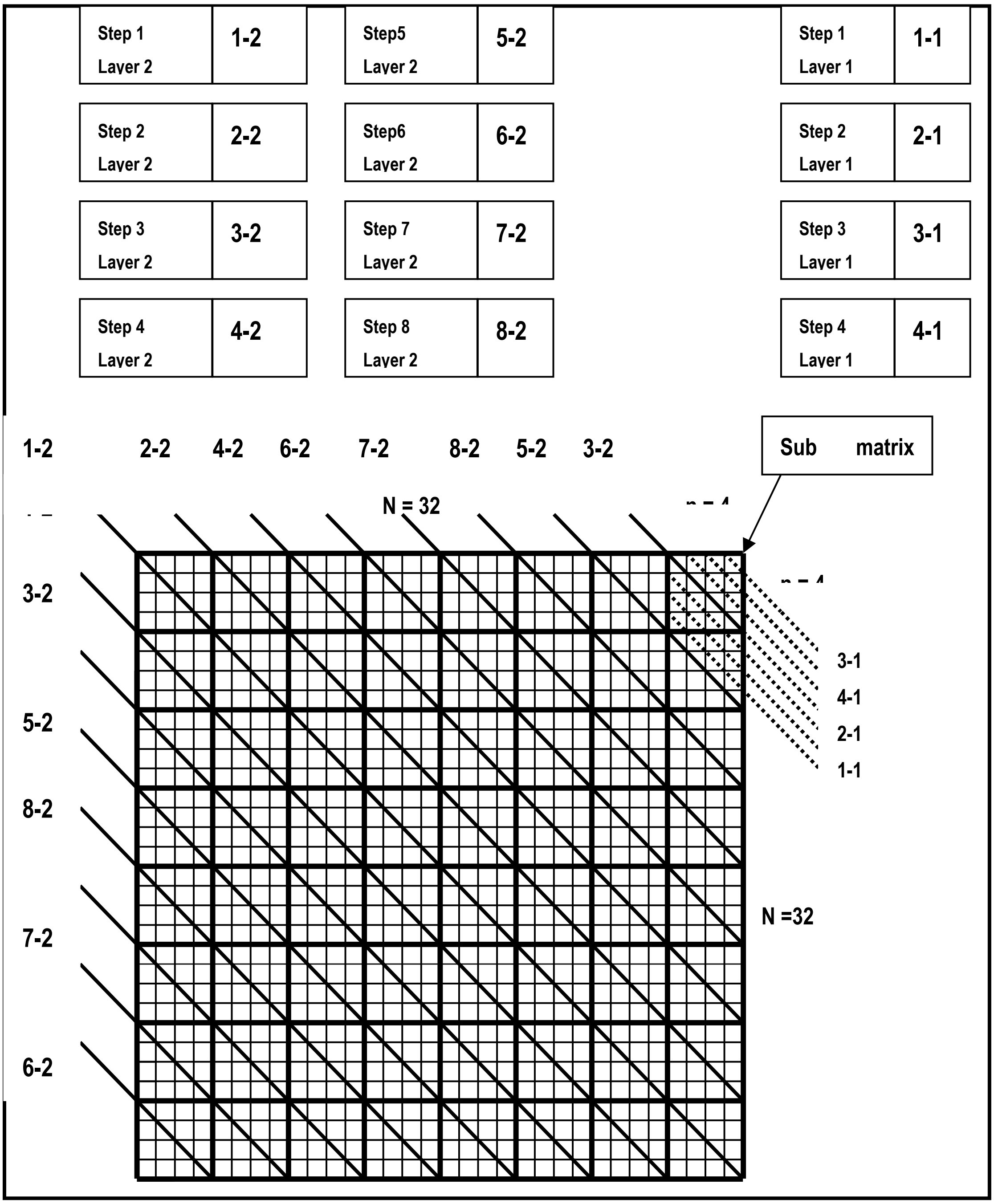

Figure 1. Diagonal activation of joint sub matrices (Layer 2+ Layer 1)

The whole process of the implementation of ADAJS algorithm for obtaining a non-conflict schedule is divided into steps. The first step refers to the main diagonal sub matrices processed simultaneously and without conflict. The next steps are related to the reconciliation of the diagonals parallel to the main diagonal by pairs (Figure 1). The analytical description of the steps shown on Figure 1 is as follows:

Step1 : S_{11}, S_{22}, S_{33}, S_{44}, S_{55}, S_{66}, S_{77}, S_{88} **Step 5 :** S_{17}, S_{28}, S_{31}, S_{42}, S_{53}, S_{64}, S_{75}, S_{86}

Step2 : S_{81}, S_{12}, S_{23}, S_{34}, S_{45}, S_{56}, S_{67}, S_{78} **Step 6 :** S_{61}, S_{72}, S_{83}, S_{14}, S_{25}, S_{36}, S_{47}, S_{58}

Step3 : S_{18}, S_{21}, S_{32}, S_{43}, S_{54}, S_{65}, S_{76}, S_{87} **Step 7 :** S_{51}, S_{62}, S_{73}, S_{84}, S_{15}, S_{26}, S_{37}, S_{48}

Step4 : S_{71}, S_{82}, S_{13}, S_{24}, S_{35}, S_{46}, S_{57}, S_{68} **Step 8 :** S_{41}, S_{52}, S_{63}, S_{74}, S_{85}, S_{16}, S_{27}, S_{38}

T = [S_{ij}] , i = 1 - 8, j = 1 - 8

The size (n) of the sub matrix determines the number of steps (I) as follows

$$I = N/n. \quad (1)$$

For N = const., I = f (n), where $1 < n \leq N / 2$.

Sub-matrix optimal size

The goal is to determine the optimal size of the sub matrix related to performance of the software model SMADAJS. A clear minimum of the operating time (TW) is seen for n = 4 for N = 128, 256, 512, 1024 and 2048. It can be concluded that for size N up to 2048, the optimal sub matrix size is n opt = 4. In order to reduce CPU work controlling the requests execution in a switching node of type Crossbar, it is appropriate to synthesize a finite automat. It will take care to handle the individual sub matrices. Then CPU will be limited to initialize the finite automat during the work of the algorithm ADAJS for the respective sub matrix only.

In our case the optimal size of the sub matrix is n opt = 4. Therefore, the finite automat shell replaces CPU for a sub matrix 4 x 4. Figure 2 shows the four steps of the algorithm for sub matrix 4 x 4 corresponding to the four states of the finite automat - A1 to A4. A state A0 should be available for the initial reboot of the finite automat. In state A0 all requests in the sub matrix are not allowed.

Realization of ADAJS algorithm via hierarchical two layers control with finite automata for commutator of type Crossbar

The algorithm ADAJS contains naturally hierarchical two layers control of type "master – slave" itself. Layer 1 (slave) is the layer where the sub matrices are processed. Layer 2 (master) is the layer where the diagonals of sub matrices are processed.

In our case a Moore finite automat is suitable, because each state corresponds to an output signal that is not affected by the input word, as in the case of Mealy automat [M.Schaller and K. Svozil, 1996].

Figure 3 shows the state transition graph of the synthesized Moore automat for control of the sub matrix presented in Figure 2. Using Z_1 signal, the automat passes through the states from A_0 to A_4 and each state A_1 to A_4, corresponds to an output signal $St._1$ (Step1) to $St._4$ (Step4) which controls the connection sub matrix directly.

Using Z_2 signal, the automat goes to A0 state with an output signal R which is an indication for CPU switching node that the automat is free and could be started at any time.

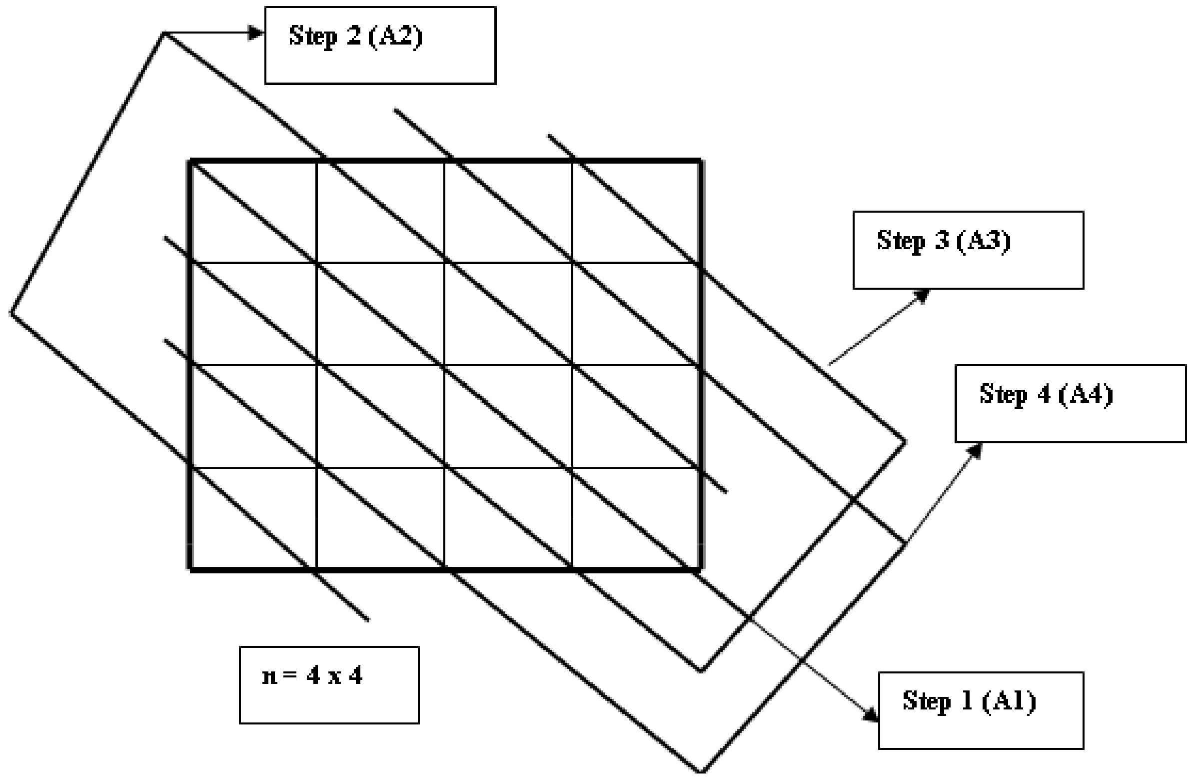

Figure 2. Sub matrix 4 x 4(optimal size) - (Layer 1)

Each sub matrix is controlled by Moore finite automat with five states (Figure 3). This is the first layer control (Layer 1).

Figure 4 shows a graph of transitions of Moore finite automat. This finite automat controls the joint diagonals of the sub matrices described in steps 1 through 8 on the second level (Layer 2) of Figure 1.

The difference between the graph of transitions of the automaton of Layer 1 (Figure 3) and that of Layer 2 (Figure 4) is the number of states.

We denote by τ the residence time of finite automat of Layer 1 in each of its states. For finite automat on the second level (Layer 2) this time is n.τ and since n opt = 4, it is obtained **4τ**.

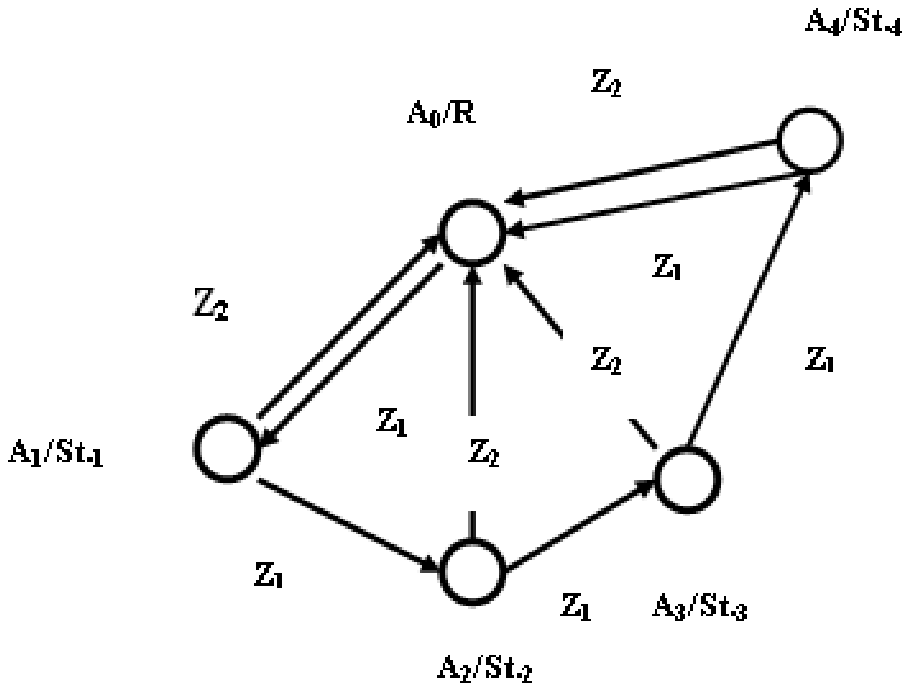

Figure 3. Graph of the transitions (Layer 1)

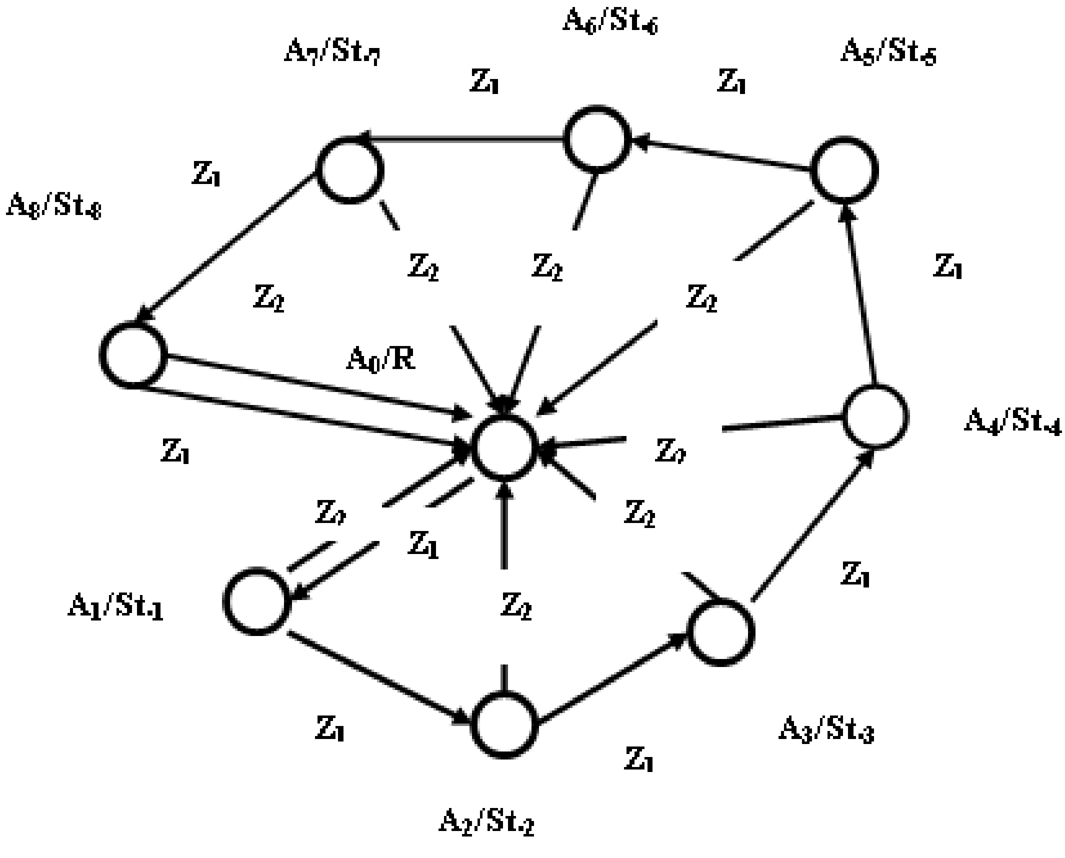

Figure 4. Graph of the transitions (Layer 2)

Comparison with other algorithms, with diagonal activation of the connection matrix

Table 1 represents a comparison between the results of algorithms with a diagonal matrix activation of connection matrix in terms of number of control levels, number of states of finite automata used in the implementation and operation time.

Table 1. Comparison between algorithms with a diagonal matrix activation of connection matrix

Algorithm	Layers	FA - states	operation time
ADA	1	2N	(2N-1).τ
AJDA	1	N+1	N.τ
ADAJS	2	5 (Layer 1), N/4+1 (Layer 2)	N.τ

The advantage of the hierarchical two layers control for ADAJS is that the number of states of the finite automata of the second level is four times less than the states of AJDA finite automata.

In terms of running time ADAJS is almost twice faster than ADA and equal to AJDA.

Conclusion

The hiearchical two layers control commutator of type Crossbar by finite automata releases the communication processor from the requests processing tasks and ensures fully non-conflict requests execution. This control requires number of states of layer 2 control four times less than AJDA and eight times less than ADA which are with one layer control.

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Major Fields of Scientific Research: Distributed Information Systems Design.

APPLICATION OF FIBER-OPTICAL MODULATORS AS MEASURING DEVICES IN BIOINFORMATICS RESEARCHES

Oleksandr Ryabtsov

Abstract: *The article is devoted to application of optical devices based on tensosensitive properties of liquid crystals for gathering physical data of biological objects in bioinformatics researches. Graphical results of prototype's test are presented and usage recommendations done.*

Keywords: *biological researches, measuring devices, fiber optics, liquid crystals.*

ACM Classification Keywords: *J.3 Life and Medical Sciences – Bioinformatics; C.4 Performance of Systems - Measurement techniques*

Introduction

Bioinformatics, as the science studying informational processes in various biological systems, represents today the integration of huge set of the different databases, algorithms, computing and statistical methods which are intended to decide the problems, arising in molecular biology and experimental genetics during the analysis of the collected knowledge about live beings nature.

The further development of highly-effective biotechnologies is impossible without permanent perfection of the technical toolkit, allowing to obtain primary biological data and to carry out researches of molecule-genetic systems of cells and fabrics. That is why the problem of integration of modern biotechnical tools for gathering of experimental data with up-to-date IT-technologies for their analysis is actual now as never before.

Thereupon application of optical technologies in bioinformatics deserves our special attention. It is well known that the optical devices allows to exclude the erroneous measuring readings caused by external electromagnetic fields which are inevitably imposed to any valuable electric signal from sensors, probes and analyzers involved in process of collecting biological object's information.

All space of the modern world is penetrated both useful and parasitic electromagnetic fields. Effects of different industrial fields, climatic influences, radio noises from various communications, also their combination, fluctuation and interference, is unavailable to the strict mathematical analysis. However they are present in a signal spectrum of any biometric systems, despite of efforts undertaken to their elimination or essential reduction by shielding, filtration, balancing, compensation, equalization, etc.

Application of optical modulating devices for bioinformatics purposes

One of the ways to except these spectrum errors and, thereby, to increase the reliability of the collected information about biological objects, is deployment of optical systems which signals, as the form of optical radiation, are not affected to external electromagnetic fields.

Besides, fields produced by conductivity currents in electric chains of measuring devices placed in tight proximity to studied biological objects inevitably deforms their inwardness. In particular, powerful electrical field can break the electrochemical balance of biological cells. That will lead to incorrect data in especially exact cellular researches. It mostly concerns the measuring tools and sensors invited and applied at the initial stages of development of biotechnologies, for example, the device for immersing of electrodes in a biological fabric [Dzhagupov et al., 1988].

At the present stage of researches it is expedient to replace obsolete electrical tools for gathering biological information with corresponding optical converters such as optical cells which are sensitive to variations of temperature, pressure or chemical composition.

For example, it is possible to get trustworthy information about frequency and filling of live being's pulse by means of optical device represented on the figure 1. This device can also carry out functions of the measuring optical converter of small transversal forces and vibrations. In particular, it can be used as modern replacement for piezoelectrical pulse transeducer introduced in [Dzhagupov et al., 1985]. The basis of device (fig.1) is a tightly closed hollow case 1, filled up by special optical transparent substance 2 with tensosensitive properties. For example, case can be filled by MBBA ("methoxybenziliden-butylamin") also known as Nematic Liquid Crystal (NLC) [Chandrasekar, 1989]. The case 1 equipped with flexible film membrane 3 where convex pelot 4 is placed in the middle for centering and aligning applied forces.

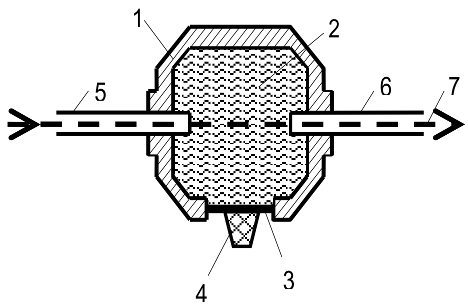

Figure1. Optical sensitive cell for measurement of forces, pressures and vibrations in biological researches

As known, hydrodynamic properties of NLC are similar to properties of isotropic liquids, i.e. for any directions the equation of indissolubility and the Navier-Stocks equation of movement are fair. Therefore, according to theory of elasticity of liquid crystals, any applied outer forces, which dynamical range is matched to membrane's stiffness, will strain liquid crystal molecules that will lead to deviation of NLC optical director due to molecules reorientation.

The variation of optical properties will cause the modulation of NLC polarization angle. Accordingly it will influence to intensity and phase of polarized optical radiation, extending from input fiber-optic light-guide 5 to output fiber light-guide 6 through the optical gap in the case 1 filled the sensitive liquid crystal substance (see fig.1).

Cholesteric Liquid Crystals (ChLC), such as “cholesterilmiristat”, can be used also as optical medium for this device. Helical ChLC molecules allow to reflecting an incident light selectively as well as diffraction grating. In this case optical pattern of this device should be changed to reflecting type. At the fixed angles of incident light the pitch P of ChLC molecula’s helix can be simply expressed as [Titov et al., 1998]:

$$P = \lambda_{max} / n \tag{1}$$

where λ_{max} is maximum of a wavelength of reflected light, and n is refractive index of a ChLC substance.

If optical vector of ChLC medium substance directed perpendicularly to the membrane and helix pitch P is changing as a function of applied outer force so these varying conditions of interference will lead to variation of a spectral maximum of reflected light beam due to well known optical effect of “selective reflection”. That, accordingly, will effect to intensity and a phase of light beam 7, transiting the sensor case 1. For ChLC reflecting medium the position of fiber-optic light-guides 5 and 6 should be changed to axial.

Both examined optical devices are related to optical modulators of a luminous flux. Prototype’s test has demonstrated the possibility of its usage for measuring of small force, pressures and vibration. Experimental diagram of the relative value of intensity of through-passing light from LED source as function of mechanical force (or pressure) applied to membrane’s pelot 4 is shown on the figure 2.

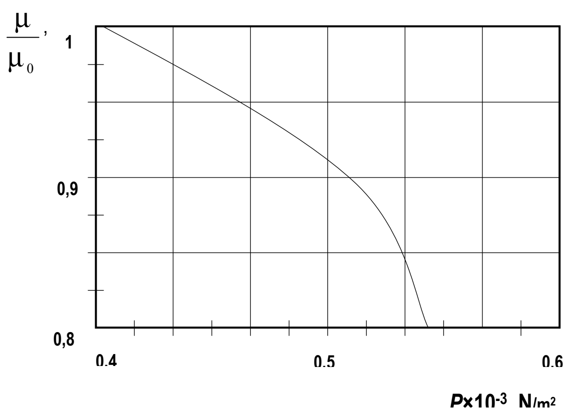

Figure 2. Graph of the relative intensity of through-passing light against the force (pressure) applied to pelot.

Conclusion

Advantages of these offered devices consists of possibility to deploy computing equipment away from explored biological object, as far as necessary, according to length of the used fiber-optic line. That allows complete eliminating any parasitic effect from exterior electromagnetic fields to the gained information.

One more advantage of devices' application consists in the following. Many biological processes, such as functioning of cellular diaphragms, DNA creation, transmission of nervous impulses, muscles contraction, creation of atherosclerotic plaques, proceed with participation of materials and substances which are staying in the "mezo-phase", i.e. they have a property of a liquid crystals [Chandrasekar, 1989]. It means that these materials can be immediately used as sensitive media of the optical transducers. Thus presented application of optical engineering in bioinformation science is not restricted to the considered constructions only.

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Major Fields of Scientific Research: Informatics, Optical communications and measuring

METHOD FOR CONTROLLING STATE CHANNEL WIRELESS NETWORKS UNDER A PRIORI UNCERTAINTY

Sergey Zaitsev

Abstract*: A method of monitoring the state of the radio channel using statistical information of the turbo decoder, the use of which in the adaptive system will allow carrying out its restructuring under varying random actions.*

Keywords: *information technologies, a priori uncertainty, wireless networks, turbo codes.*

ACM Classification Keywords*: H.4 Information system applications, H.4.3 Communications Applications, G.1.6 Optimization, I.6 Simulation and modeling, K.6.4 System management*

Introduction

Promising direction of development in the field of telecommunications is to develop a software defined radio (SDR), principle of which is based on the hardware and software implementation [Maier, 2005]. There are currently plans to design means having an open architecture construction: media themselves can produce some manufacturers, and the functions and modes of operation will determine the third-party software. Analysis of possible guidelines for constructing these wireless facilities shows [Uhm, 2006] that these tools you plan to use spread spectrum techniques and effective signal adaptive signal-code structures based on the use of turbo codes. The use of turbo codes (TC) as a correction because the noise immunity characteristics of close to the theoretical values [Berrou, 1993].

Due to increased demand for quality voice and data wireless channels it is necessary to build wireless networking equipment, parameters and structure of the physical layer which would vary with changes in the characteristics of the signal propagation medium under the action of powerful noises. This can be achieved by using SDR to permit dynamic change of its parameters or structures depending on the analysis of the information transmission channel. Influence of powerful interference gives rise to uncertainty in the decision-making process in the processing of the transmitted information sequence. There is need to assess the uncertainty (risk) and to develop an adaptive system that will adaptively change its parameters.

The aim is to develop a method for monitoring the state of the channel wireless networks under a priori uncertainty.

Description the problem of parametric adaptation of the wireless networks

Formulate the problem of parametric adaptation of the wireless networks (wireless system), which will act as the object of adaptation. The wireless system will have a number of adapted parameters by which can be controlled by her work: $P = (p_1, p_2, ..., p_n)$.

Wireless system to work affected by the environment, having exposure parameters $Z = (z_1, z_2, ..., z_n)$. Influence of environment on the control object can be characterized by using the estimated parameters $E = (e_1, e_2, ..., e_n)$, which will be a function of the parameters and the parameters exposure parameters:

$$E = f(Z, P).$$

The purpose of adaptation defines requirements that will be imposed on the parameters which define the efficiency of the system. Such requirements are specified as constraints on the values that can take the estimated parameters Y of the adaptive system. Constraints on the values of the estimated parameters may be stored either as equalities $G(E)=0$ or inequalities $H(E)\geq 0$ as. Target species such restrictions define the scope of admissible controls that will be a finite set:

$$S:\begin{cases} G(E)=0 \\ H(E)\geq 0 \end{cases}.$$

In the process of the adaptive system must satisfy the condition $E\in S$ that guarantees the application of the process control system only allowed configurations (control solution).

Besides the restrictions that define the domain S, in the adaptive system can be set to minimize the condition $Q(E)\rightarrow \min$ which would provide the best method of finding the management of the system using a variety of management solutions S:

$$Q(E)\rightarrow \min,\ P\in S.$$

Graphically, this approach to management constraints shown on the Figure 1.

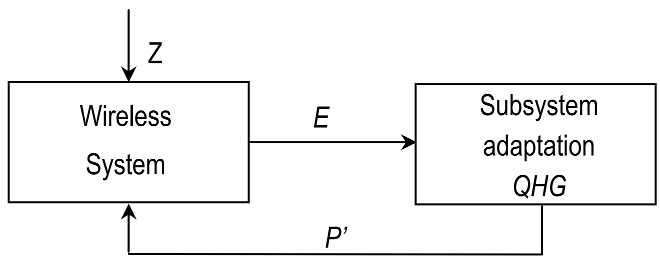

Figure 1. Control system with constraints

Availability minimization conditions in the future will allow talking about more effective or less effective process control, i.e. allowing quantifying the effectiveness of a strategy of adaptation.

The process of adaptive management system will be a series of changes over time adapted system parameters P:

$$P_0\rightarrow P_1\rightarrow P_2\rightarrow \ldots \rightarrow P_N.$$

Algorithm for finding the optimal solutions will bind successive solutions to be obtained in the management of: $P_N=f(P_{N-1})$, where f – algorithm (strategy) management determines the transition from the state P_{N-1} as to P_N.

In order to determine the set of parameters adapted TC, which may change during the session, and to further understand the method of obtaining the estimated parameter for wireless networks with TC.

Description of the principle of turbo coding-decoding

Consider the block diagram of the encoder and decoder TC. Figures 2 and 3 are block diagrams of the encoder and decoder TC (one iteration) that were prepared by parallel connection of two component encoders and decoders, respectively. As the component codes have been applied recursive systematic convolution codes (RSCC) [Qi, 1999].

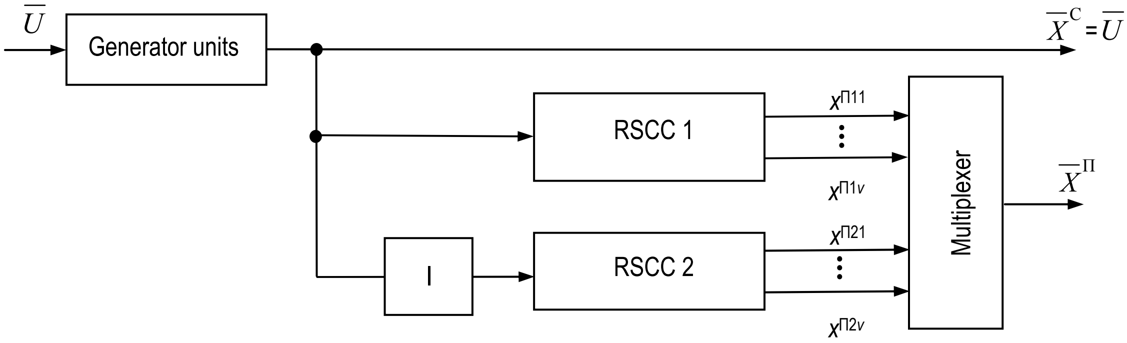

Figure 2. Block diagram of the two-component encoder TC

Information sequence $\overline{U}$ divided into blocks of length *N* symbols $\overline{U} = (u_1; u_2; u_3 \ldots u_t \ldots u_N)$, where *t* – current index, *N* - the size of the information unit. Further, it enters the systemic output of the encoder, as well as two parallel RSCC, wherein the second through interleaving block (I). It is assumed that the encoder circuit TC RSCC uses a rate 1 / n of the form: $(1,\, g_1/g_0, \ldots, g_{n-1}/g_0)$, where g_0 – polynomial generator feedback, and $g_1, \ldots, g_{n-1}$ – polynomial generators of direct links. In the structure of the codec can be used pseudo, S-random, block, diagonal and others interleaving the block types [Robertson, 2006].

The sequence at the encoder output has the form of TC: $\overline{Y} = (\overline{Y}^{C}, \overline{Y}^{\Pi})$. Where $\overline{Y}^{C} = \overline{U}$ – systematic encoder output, and $\overline{Y}^{\Pi} = (\overline{Y}^{\Pi 1}, \overline{Y}^{\Pi 2})$ – verification TC output of the encoder. Herewith $\overline{Y}^{\Pi 1} = (\overline{Y}^{\Pi 11}, \ldots, \overline{Y}^{\Pi 1v})$ – output of the first screening RSCC, $\overline{Y}^{\Pi 2} = (\overline{Y}^{\Pi 21}, \ldots, \overline{Y}^{\Pi 2v})$ – output of the second test RSCC, *v* - the total number of parity of each encoder RSCC TC. A multiplexer is required for adjusting the encoding rate in accordance with a puncturing matrix [Robertson, 2006].

TC decoder is composed of two decoders, the two interleaving blocks (I) and two blocks of deinterleaving (D) [Robertson, 2006]. Each decoder uses «soft» input and a «soft» output (SISO (soft input-soft output)).

At the decoders 1 and 2 (fig. 3) supplied sequentially $\overline{X}^{1} = (L_c \overline{X}^{C1}, L_c \overline{X}^{\Pi 1}) = (L_c x_t^{C1}, L_c x_t^{\Pi 11}, \ldots, L_c x_t^{\Pi 1v})$ – the first decoder, where $\overline{X}^{\Pi 1} = (\overline{X}^{\Pi 11}, \ldots, \overline{X}^{\Pi 1v})$, respectively $\overline{X}^{2} = (L_c \overline{X}^{C2}, L_c \overline{X}^{\Pi 2}) = (L_c x_t^{C2}, L_c x_t^{\Pi 21}, \ldots, L_c x_t^{\Pi 2v})$ – for another decoder, where $\overline{X}^{\Pi 2} = (\overline{X}^{\Pi 21}, \ldots, \overline{X}^{\Pi 2v})$. $\overline{X}^{C1} = \overline{X}^{C}$, $\overline{X}^{C2}$ – systematic sequence of characters after applying an appropriate interleaving operation. $\overline{X}^{\Pi 1}, \overline{X}^{\Pi 2}$ – sequence of parity, v - the number of polynomial generators of direct links RSCC, L_c – parameter channel “reliability” [Khan, 2000].

Each decoder computes the likelihood function $L^{1}(y_t^{C}), L^{2}(y_t^{C})$, then – “external” information: $L_e^{1}(y_t^{C}), L_e^{2}(y_t^{C})$, using basic decoding algorithms TC [Khan, 2000]. The output of the block move «external» information used by the first decoder as a priori second decoder – $L_a^{2}(y_t^{C})$. “External” information given iteration of the second decoder after deinterleaving operations (D) is used as a priori for the first decoder next iteration.

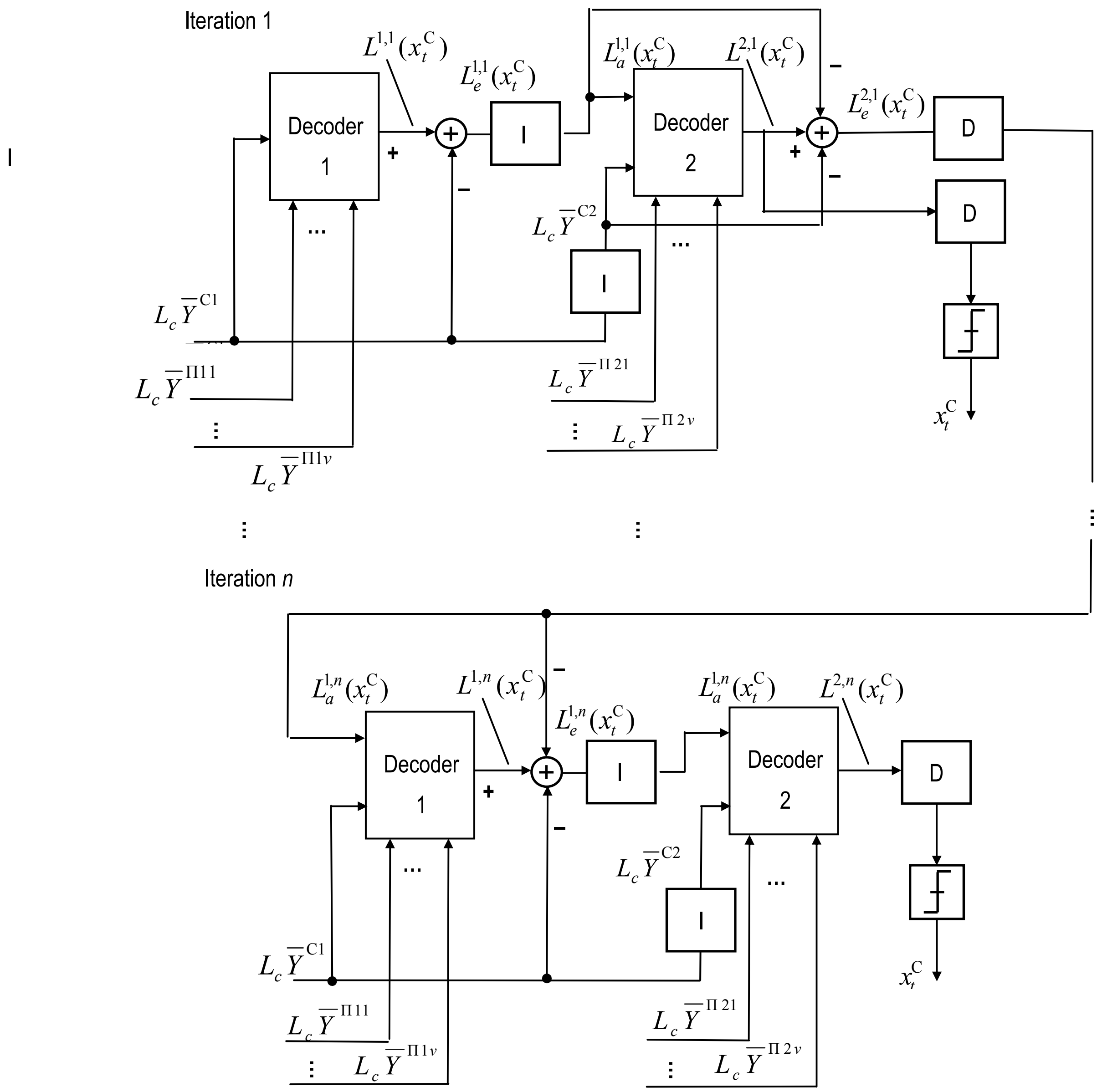

Figure 3. Block diagram of the two-component decoder TC

Descriptions of controlling state channel wireless networks under a priori uncertainty

Condition monitoring system (receipt of estimated parameters), it can be done in several ways:

- Directly estimating parameter signal-to-noise ratio ( ) by analysis of variance channel samples taken;
- To carry out an indirect assessment of the impact analysis results by channel decoding process.

Assessing the impact of the channel (receiving perturbation parameters Z) can occur by analysis of variance channel samples taken. According to the obtained numerical value of the dispersion parameter assessment. After information processing at the decoder is completed, the channel information will be updated (decoder performs correction of information bits) which gives the possibility to specify a value for subsequent sequential decoder, etc.

As a method of evaluation of the second type (getting the estimated parameter E – estimation subsystem decode) the following approach, suitable for iterative decoding process. To recover the information sequence TC decoder uses an iterative decoding. The process of iterative decoding is a sequential processing data according to the channel information a priori. Thus, the output of each serial decoder is a function of the values of channel data and a priori information:

$$y^C = f(L_C \overline{X}, L_a),$$

where L_a – priori information about the value of information bits obtained in the previous step decoding, $L_C \overline{X}$ – decision value of the information bits based on the received channel data. The first argument of this function for each decoder will remain constant, and the second will vary from one to another sequential decoder.

The unit value of the information bits will fit positive statistic $L^i(x_t^{\mathrm{C}})$, $i \in \overline{1,D}$, $t \in \overline{1,N}$, and zero – negative, where *D* – total number of decoders that are involved in the iterative decoding process. Changing the sign of a priori information in the transition to aposteriori $L_e^i(x_t^{\mathrm{C}})$ will be a prerequisite for changing decisions regarding the value of the information bit.

If in the process of decoding the number of sign changes $L_a^i(x_t^{\mathrm{C}}) \to L_e^i(x_t^{\mathrm{C}})$ is zero, it can be argued that the tough decisions about the decoded bits. After each subsequent decoder value of the likelihood function of the transmitted bits will decrease (if it was transmitted bits "0") or increase (if it was transmitted bits "1"). A situation may arise in the case of large values of the noise variance in the channel that in the process of decoding the number of sign changes $L_a^i(x_t^{\mathrm{C}}) \to L_e^i(x_t^{\mathrm{C}})$ after the procedures of iterative decoding of all the decoders D is not equal to zero, resulting in an uncertainty about the value of the transmitted bits. This results in a decoding error probability of 0.5. Thus, there are four events.

Event 1 - A_1. Number of sign changes $L_a^i(x_t^{\mathrm{C}}) \to L_e^i(x_t^{\mathrm{C}})$, $i \in \overline{1,D}$ in the process of iterative decoding after the *i*-th decoder is equal to zero. Made a tough decision that was handed bit $x_t^{\mathrm{C}} = 0$.

Event 2 - A_2. Number of sign changes $L_a^i(x_t^{\mathrm{C}}) \to L_e^i(x_t^{\mathrm{C}})$, $i \in \overline{1,D}$ in the process of iterative decoding after the *i*-th decoder is equal to zero. Made a tough decision that was handed bit $x_t^{\mathrm{C}} = 0$.

Event 3 - A_3. Number of sign changes $L_a^i(x_t^{\mathrm{C}}) \to L_e^i(x_t^{\mathrm{C}})$, $i \in \overline{1,D}$ in the process of iterative decoding after the *i*-th decoder is equal to zero. Made a tough decision that was handed bit $x_t^{\mathrm{C}} = 1$.

Event 4 - A_4. Number of sign changes $L_a^i(x_t^{\mathrm{C}}) \to L_e^i(x_t^{\mathrm{C}})$, $i \in \overline{1,D}$ in the process of iterative decoding after the *i*-th decoder is equal to zero. Made a tough decision that was handed bit $x_t^{\mathrm{C}} = 0$.

Probability $P(A_1)$ and $P(A_2)$ will be the greater, and the likelihood $P(A_3)$ and $P(A_4)$ the smaller, the smaller the dispersion channel interference. With increasing values of noise variance in the channel $P(A_1)$ and $P(A_2)$ will reduce the likelihood probability $P(A_3)$ and $P(A_4)$ increase.

Given the above, we obtain a quantitative characterization of the state channel, using an estimate of uncertainty decoding. Obviously, the decoding ambiguity will be greater, the greater the value of noise variance, and the smaller, the smaller the value of noise variance in the channel. Status information transmission channel is characterized by a signal-to-noise ratio (the ratio of signal energy to the total noise power spectral density – Eb/GΣ) in the channel.

Obtain a quantitative estimate of the uncertainty from the change of sign in the iterative decoding process.

For this we use the following algorithm.

– Formation matrix *LA* size $D \times N$.

$$LA = \begin{bmatrix} L_a^1(x_1^C) & L_a^1(x_2^C) & \dots & L_a^1(x_N^C) \\ L_a^2(x_1^C) & L_a^2(x_2^C) & \dots & L_a^2(x_N^C) \\ \vdots & \vdots & \vdots & \vdots \\ L_a^D(x_1^C) & L_a^D(x_2^C) & \dots & L_a^D(x_N^C) \end{bmatrix}. \quad (1)$$

– Payment $L^i(x_1^C)$, $i \in \overline{1,D}$, $t \in \overline{1,N}$ all the decoder and for all bit blocks *N*.

– Formation matrix *L* size $D \times N$.

$$L = \begin{bmatrix} L^1(x_1^C) & L^1(x_2^C) & \dots & L^1(x_N^C) \\ L^2(x_1^C) & L^2(x_2^C) & \dots & L^2(x_N^C) \\ \vdots & \vdots & \vdots & \vdots \\ L^D(x_1^C) & L^D(x_2^C) & \dots & L^D(x_N^C) \end{bmatrix}. \quad (2)$$

– Calculations $L_e^i(x_1^C)$, $i \in \overline{1,D}$, $t \in \overline{1,N}$ all the decoder and for all bit blocks *N*.

– Formation matrix *LE* size $D \times N$.

$$LE = \begin{bmatrix} L_e^1(x_1^C) & L_e^1(x_2^C) & \dots & L_e^1(x_N^C) \\ L_e^2(x_1^C) & L_e^2(x_2^C) & \dots & L_e^2(x_N^C) \\ \vdots & \vdots & \vdots & \vdots \\ L_e^D(x_1^C) & L_e^D(x_2^C) & \dots & L_e^D(x_N^C) \end{bmatrix}. \quad (3)$$

– Formation matrix L^* size $D \times N$, using (1), (3).

$$L^* = \begin{bmatrix} L_a^1(x_1^C)L_e^1(x_1^C) & L_a^1(x_2^C)L_e^1(x_2^C) & \dots & L_a^1(x_N^C)L_e^1(x_N^C) \\ L_a^2(x_1^C)L_e^2(x_1^C) & L_a^2(x_2^C)L_e^2(x_2^C) & \dots & L_a^2(x_N^C)L_e^2(x_N^C) \\ \vdots & \vdots & \vdots & \vdots \\ L_a^D(x_1^C)L_e^D(x_1^C) & L_a^D(x_2^C)L_e^D(x_2^C) & \dots & L_a^D(x_N^C)L_e^D(x_N^C) \end{bmatrix}. \quad (4)$$

7. Looping: if $L_a^i(x_t^C)L_e^i(x_t^C) < 1$, то $C_L = C_L + 1$.

Number of sign changes on the *i*-th sequential decoder *j*-th iteration of decoding – C_{Lij}. The value will be calculated as the total number of sign changes in the transitions $L_a^i(x_t^C) \to L_e^i(x_t^C)$ for all N information bits processed by the *i*-th decoder *j*-th iteration of the TC.

In the simulation result found that in the processing unit bit length information N value C_L can take values ranging from 0 to $N/2$. Exception to the rule is the first decoder. Its value is always taken equal C_L value due to the fact that prior to the decoding procedure value L_a for all data bits is zero, i.e. not taken any positive or negative value.

As previously noted, an iterative decoding process in which an improvement of the result. For the value C_L of improvements in performance will be shown that the sequence of values C_L is conditionally decreasing nearby. “Conditional” because, in general, the numerical sequence is decreasing, but her next item may not always be less than the previous one.

If the value C_L of acquired value of zero, then we can say that at this decoder for each data bit clear decision, otherwise – a decision on the value of some bits is still pending, but it can be made to the following consecutive decoders.

Uncertainty decoding the entire subsystem is denoted as F. This value can be defined as the sum of the $L_a^i(x_t^C)L_e^i(x_t^C) < 1$ all serial decoders:

$$F = \sum_{j=1}^{I}\sum_{i=1}^{2} C_{Lij} , \qquad (5)$$

where *I* – number of decoding iterations.

Value F characterizes the plausibility of data obtained by decoding block. The smaller the numerical value, the more reliable data block has been decoded. In the robot subsystem decoding are two extreme cases.

1. The transmission channel is not affected by interference or the influence of the transmitted information so small as to be negligible.

2. The transmission channel affects the transmitted information so that decoding becomes impossible to correct. In the first case, the value will make its smallest value is numerically equal to the number of transmitted information bits: $F^{(-)} = N$.

This situation corresponds to the case when the sequence has been successfully adopted decoded at the first decoder, the first sequential iteration.

In the second case, the value will take its maximum value which can be calculated as follows:

$$F^{(+)} = \frac{N}{2}(2I+1).$$

Parameter value for the actual process of iterative decoding will take values in the range between the two limits: $F^{(-)} \le F \le F^{(+)}$. Assessment of the proposed values for the analysis should be carried out as follows. First, the value C_L of analyzes on the final decoder. If it is below a certain, predetermined maximum level, the decoding process is considered completed successfully. Second, obtained in this case, the values can be compared with similar values for the decoding process is successfully completed. Higher quality wills this process, the value for which you will be less.

In practice it is more convenient to use a value F^* which is calculated as follows:

$$F^* = \frac{F - F^{(-)}}{F^{(+)} - F^{(-)}} \cdot 100\% = \frac{F - N}{N(I - 0,5)} \cdot 100\% . \qquad (6)$$

For the quantity value F^* of 100% corresponds to the absolute inefficiencies and 0% - absolute effectiveness during processing subsystem decoding the information block.

Obtain the value F^* of value for each individual decoding iteration. Assessment of the uncertainty decoding the first iteration is denoted as F_1. This value can be defined as the sum of the $L_a^i(x_t^C)L_e^i(x_t^C) < 1$ two sequential decoder:

$$F_1 = \sum_{i=1}^{2} C_{Li1} \,. \tag{7}$$

Let $F_1' = F_1$ – the number of sign changes $L_a^i(x_t^C) \to L_e^i(x_t^C)$ on the 1st iteration $F_2' = F_1 + F_2$ - the number of sign changes $L_a^i(x_t^C) \to L_e^i(x_t^C)$ on the 2nd iteration – decoding iteration 1.

Estimation of uncertainty decoding for the second iteration is calculated:

$$F_2 = 2(F_1 - N)N/3 + 2F_2N/3 \,. \tag{8}$$

To simplify (8), we introduce a replacement $m = (F_1 - N)/(N(I_1 - 0{,}5))$, as a result of the expression (8) will have the form:

$$F_2 = m/3 + 2F_2N/3 \,. \tag{9}$$

Estimation of uncertainty for the third iteration of decoding is determined according to the following relationship:

$$F_3 = 2(F_1 - N)N/5 + 2F_2N/5 + 2F_3N/5 \,. \tag{10}$$

Or after simplification:

$$F_3 = m/5 + 2F_2N/5 + 2F_3N/5 \,. \tag{11}$$

Similarly, for the fourth iteration:

$$F_4 = m/7 + 2F_2N/7 + 2F_3N/7 + 2F_4N/7 \,. \tag{12}$$

Analyzing (9), (11), (12), you can see some dependence and obtain a formula for estimating uncertainty for any decoding iteration:

$$F_J = \frac{m}{2I_j - 1} + \sum_{i=2}^{J} \frac{2F_i}{(2I_J - 1)N} \,. \tag{13}$$

Specificity object adaptation (wireless system TC) will be adapted to determine the parameters by changing which progress can be adaptive management. Such adjustment parameters include:

– Polynomial generators RSCC;
– The length of the input data block;
– The type of unit permutation;
– Coding rate;
– Matrix perforations;
– The number of decoding iterations;
– Decoding algorithm.

Analysis of simulation results

Figure 4 shows a graph of estimating uncertainty F_J of SNR E_b/G_0 for different decoding iterations, the resulting simulation. Unused turbo code with regular interleaver, the decoding algorithm Map, the number of bits in the block $N = 1000$. Figure 5 shows the same relationship, but a turbo code used in a pseudo-random interleaver.

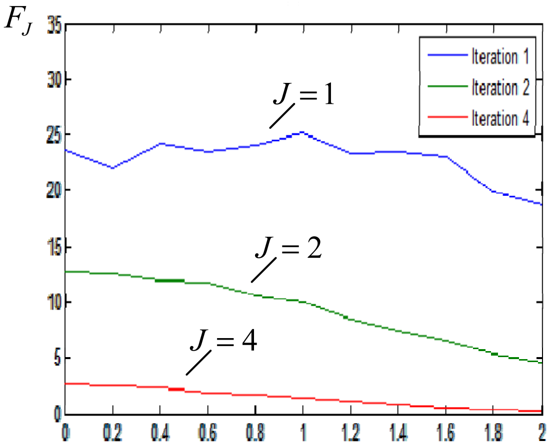

Fig. 4. Estimating uncertainty F_J of SNR E_b/G_0 for different decoding iterations

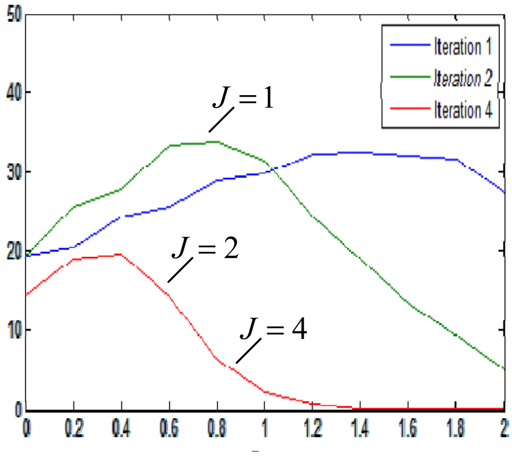

Fig. 5. Estimating uncertainty F_J of SNR E_b/G_0 for different decoding iterations

Conclusion

This paper presents a method of monitoring the state of the radio channel using statistical information of the turbo decoder, the use of which in the adaptive system will allow carrying out its restructuring under varying random actions.

For further development of an adaptive system with turbo codes is necessary to analyze a fixed set of system configurations that will occur between switching and develop a strategy for adaptive behavior in the state space.

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ABOUT USAGE POSSIBILITY OF PRINCIPLES OF EXCITATIONS TRANSMISSION BY NERVE FIBERS FOR TELECOMMUNICATIONS

Galina Gayvoronska, Maxim Solomitsky

Annotation: *Analysis of physiological properties of the nerve fibers, associated with their specialized function – excitation transmission, is done. Possibility in principle of the same principles' usage in the communication channels is established. It is shown that characteristics of nerve fibers as communication channels are comparable to characteristics of existing wire transmission media of information in telecommunications. Prospectivity of research of excitations transmission principles as the basis for implementation of communication channels is established.*

Keywords: *nerve fibers, medullated (myelinic) nerve fiber, communication channel, conductor, propagation velocity.*

Keywords classification of ACM: *B.4.1 Data Communications Devices, B.4.2 Input/Output Devices, B.4.3 Interconnections (Subsystems), H.1.2 User/Machine Systems*

«Seldom do more than a few of nature's secrets give way at one time.
It will be all too easy for our somewhat artificial prosperity to collapse overnight
when it is realized that the use of a few exciting words like
information, entropy, redundancy, do not solve all our problems»

Claude E. Shannon

Introduction

Throughout last several decades of rapid development of science and technics it is still actual the problem of research and usage of human potential for the purpose of understanding and adopting the mechanisms realized and successfully functioned in human throughout millennia. However not all is so simple: the human body represents the whole galaxy which is not explored yet even a half. As for researches about physiological features of the person from the telecommunications point of view – results of such researches were not found in the open press.

The article subject is to fill in this gap and represents logic continuation of researches associated with process of information perception and processing by the person and information technology. These researches are carried out by the authors group of the information-communication technologies' department representing professor Gayvoronska scientific school. Some results of these researches have been presented to the ITHEA International Scientific Society at the III International conference "Natural Information Technologies" where authors' report about possibility of information technology usage for satisfaction of the human basic natural needs has been noted as the best. Positive in all respects results of these researches have strengthened authors group in expediency of their further development. This article is devoted to the research of principles of excitations transmission by human nerve fibers in order to define possibility of these principles usage as a prototype for implementation of similarly functioning telecommunication systems.

At the comparison of the basic physiological properties of nerve and muscular tissues according to [Georgieva, 1981] it is defined that excitability and liability of nerve fiber is higher and the refractory period is shorter than of the muscular tissue. This is caused by the higher level of metabolic processes in the nerve. That is velocity of excitation propagation and impulse transfer by nerve fibers excels velocity of other conductors of the human body – muscular tissues. This is especially important at the research of nerve fibers as communication channels. Therefore nerve fibers at the process of excitation propagation are the object of the research.

Physiological properties of the nerve fibers

As it is known, the nerve is the complex formation consisting of great number of nerve fibers – axons (nerve-cell processes), involved in the common connective tissue membrane, bearing excitation to the central nervous system or from it to the periphery. Depending on histological features of constitution, nerve fibers are distinguished between medullated (myelinic) and nonmyelinated.

The myelinic fiber (Figure 1) consists of an axis cylinder coated by myelinic and neurilemma. A surface of the axis cylinder is presented by plasma membrane. The cylinder contains axoplasm.

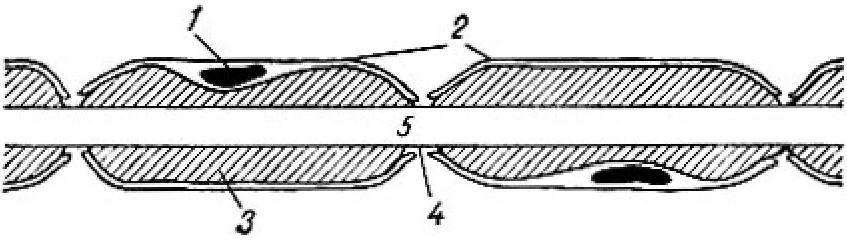

Figure 1. Structure of the myelinated nerve fiber (schema).
1 – nucleus of neurilemma lash; 2 – neurilemma; 3 – myeline; 4 – Ranvier's constriction; 5 – axoplasm

Excitation transmission is specialized function of nerve fibers. A possibility of nerve fibers to propagate excitation in the form of nervous impulses is determined by their constitution reminding a construction of electrical cable: axons playing the role of conductor for the transmission of electromagnetic signals bearing the information, axon's myelin sheath, representing membrane of lemmocyte coiled on the axon in some layers, is functioning as isolating shell of the cable. Lipoprotein myelin, possessing dielectric properties, is major component of myelin sheath. The myelin sheath coats the fiber not uninterruptedly along all its length, but forms similarity of the sectionalizing joint, tightly strung on the axon like on the bolt of e.g. electrical cable. There are only small electrically bare fields between the next myelin joints. Current can easily stream through them from the axon to the outside medium and back. In this way current stimulates membrane and invokes generation of action potential only in the bare fields of the axon which has received the name of Ranvier's constrictions. The length of interconstrictions sectors depends on diameter of the fiber and ranges from $0{,}2\cdot10^{-3}$ m (0,2 mm) to $1\cdot10^{-3}$-$2\cdot10^{-3}$ m (1-2 mm). Thus nervous impulse propagates through the myelinated fiber by hops – from one Ranvier's constriction to the following.

Nonmyelinated nerve fibers have no myelin sheath; they are coated only by lemmocytes. There is 15 nanometers (150 ampere) cleft filled with intercellular fluid between lemmocytes and the axial cylinder. According to such features of the constitution, the superficial membrane of the axial cylinder is intercommunicated with medium, surrounding nerve fiber (intercellular fluid).

Excitation propagates through the nerve fibers at the expense of the small circular currents arising inside the fiber and surrounding it fluid (Figure 2). Nowadays this thesis of German physiologist Herman has received theoretical and experimental verification. The current propagates from plus to minus between excited and unexcited sectors of nerve fibers in the axoplasm and surrounding fluid. That leads to initiation of so-called small or circular currents. Circular currents when leaving nerve fiber consistently excite its sectors (1, 2 and etc). Irritant action of circular currents weakens in process of moving off from the excitation locus (sectors 3 and 4) and they start being incapable to invoke excitation. Thus, in case of consecutive spread of excitation through the each sector of nerve, fiber nervous impulses are being transmitted with decay at the expense of continuously running wave.

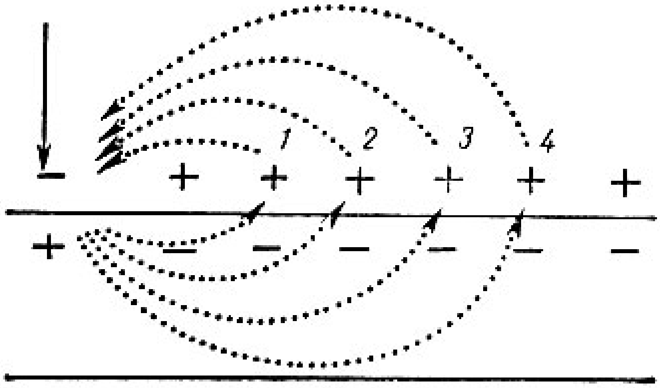

Figure 2. Schema of the excitation propagation through the nerve fiber at the expense of small circular currents. Vertical arrow marks place of irritation's infliction. Circular arrows show moving direction of electric current in the fiber and surrounding fluid

Because of histological features of medullated nerve fibers' constitution, in particular due to presence of the myelin sheath having high resistivity, electric currents can enter into specified fibers and leave them only in the field of Ranvier's constriction (Figure 3).

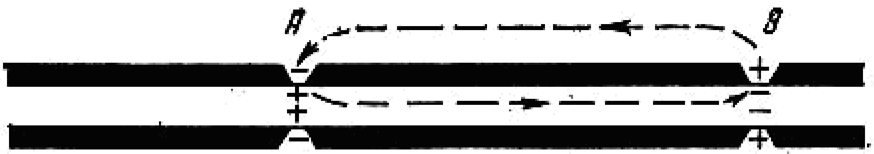

Figure 3. Saltation mode of excitation propagation in medullated nerve fiber from constriction to constriction. Arrows show direction of the current arising between excited (A) and next resting (B) constriction

At the irritation's infliction there is a depolarization in the field of the nearest Ranvier's constriction – A. The next Ranvier's constriction – B is in polarization state. There is difference of potentials between constrictions. It leads to appearance of circular currents (see Figure 2). Ion current runs from plus to minus in the axoplasm and surrounding medium. Yield of circular currents in constriction B leads to its depolarization and firing. Then subsequent Ranvier's constrictions become excited at the expense of circular currents. Thus, in the medullated nerve fibers, excitation is transmitting by hop (saltation) – from one Ranvier's constriction to another.

Saltation is more economic transmission mode, than excitation propagation through the nonmyelinated nerve fibers. Excitation propagates through the medullated nerve fibers without decay, thus propagation velocity of excitation through them is much higher, than through the nonmyelinated fibers. That leads to the conclusion that in case of organization of communication channels it is expedient to use principles of impulses transfer just by myelinic fibers.

Excitation is being transmitted only by one nerve fiber (isolated transmission of excitation is provided by myelin sheath in medullated nerve fibers and by high resistivity of fluid surrounding nerves in nonmyelinated fibers) without propagation on the next fibers. It causes realization of strictly coordinated reflex activity in the organism. From the point of view of fiber as communication channel this fact satisfies natural demand of address delivery of the information. The nerve trunk consists of great number of nerve fibers. That leads to analogy with organization of group communication channels, bundles of lines in telecommunication networks, as well correlates with features of realization of fiber-optical communication channels.

Comparison of impulses propagation's features by nerve fibers and by communication channels

Completed analysis leads to the conclusion about the possibility in principle to develop communication channels with information transfer principles similar to excitation transmission by medullated nerve fibers. However, realization of such systems should be preceded by serious research of experts in field of physics, biology and telecommunications in order to receive necessary theoretical justification and its experimental verification. Thus, there is a natural question about expediency of carrying out of such laborious researches. For now there is only one convincing argument in favour of the telecommunication systems' organization on the basis of excitation propagation's principles of myelinic nerve fibers. It is absence of decay. For sure, this is essential advantage. However, it is not true to interpret this factor as exhaustive.

In order to formulate hypothesis about usage possibility of excitations transmission's principles of human nerve fibers as a prototype for realization of similarly functioning telecommunication systems, it is necessary to estimate velocity of impulses propagation by nerve fibers and to compare this value with velocity of impulses propagation by conductors of telecommunication communication channels.

At present time at designing of telecommunication systems and networks following types of communication channels are used: wire (aluminum, copper and fiber-optic); wire and wireless radio channels of terrestrial and satellite communication; wireless laser (including infrared). As the myelinic fiber in principle can be considered only as the prototype of the wire/cable communication channel, the analysis of characteristics of wireless and radio channels, as well as their subsequent comparison with the nerve fibers, is not necessary. Conductors, in the capacity of which we examine the nerve fibers, of existing telecommunications are quartz glass for fibers of optical cables and copper (thin copper) or aluminum core for electrical cables.

Most of people suppose that information propagates with the speed of light in the fiber-optic cables. For its definition in vacuum value of $3{\cdot}10^8$ m/s is usually used, however, in spite of the fact that optical fiber is carrying out transmission of light impulses, actual data transfer speed is much more low (approximately for 31 percent below the speed of light in vacuum). According to [Yirka, 2013] propagation velocity of light in quartz glass, of which fibers of optical cables are made, is $0{,}69{\cdot}c$, where c –value of the speed of light in vacuum.

According to [Baziev, 2011] propagation velocity of current by the copper conductor (radius $1{,}115{\cdot}10^{-3}$ m) is $2{,}423{\cdot}10^8$ m/s, by the thin copper conductor (radius $2{,}5{\cdot}10^{-4}$ m) – $3{,}89{\cdot}10^8$ m/s, by the aluminum conductor (radius $0{,}85{\cdot}10^{-3}$ m) – $2{,}52{\cdot}10^8$ m/s.

According to [Georgieva, 1981] propagation velocity of excitation by the nerve fiber with diameter $12{\cdot}10^{-6}$-$22{\cdot}10^{-6}$ m is 70-120 m/s, while by nerve fiber with diameter $8{\cdot}10^{-6}$-$12{\cdot}10^{-6}$ m – 40-70 m/s. That is, the more diameter of the fiber, the higher propagation velocity of excitation in it. So, there are grounds to suspect that, if to enlarge diameter of nerve fiber to the value at least corresponding to the dimensions of existing metal conductors (i.e. to enlarge diameter of the fiber a minimum in 1000 times), it will possible to receive transfer velocity of excitation by nerve fibers, at least, comparable to those in the modern telecommunication systems. Moreover, nerve fiber can reproduce up to 2500 impulses per second. In view of the fact that e.g. realization of quadrature amplitude modulation 4096-QAM allows transmission of 12 bits per one change of a symbol (impulse value), it is possible to receive acceptable for practice bandwidth velocity in communication channels organized by analogy to the nerve fibers. Especially at the organization of systems, similar to the nerve trunks, consisting of big number of fibers, in order to transfer information in determined direction.

Conclusion

Impulses propagation is the specialized function of the nerve fibers. This is determined by their constitution, reminding construction of the electrical cable, and leads to the conclusion about expediency to research principles of impulses transfer by nerves as basis for realization of communication channels. This hypothesis is authenticated by given in the article, and comparable to conductors of existing telecommunications, characteristics of excitation's propagation velocity of the nerve fibers and reproduction velocity of impulses. Besides it, myelinic fiber conducts impulse in saltation mode through Ranvier's constrictions without decay, what is very important. This mechanism allows spending less energy at the transmission, therefore realization of the described in the article methods in technics could open up new horizons of its development as a whole, and perspective directions in telecommunications in particular.

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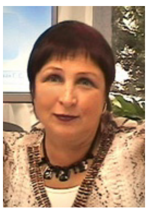

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TABLE OF CONTENTS