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CONTENT ANALYZING AND SYNTHESIZING SERVICES IN A DIGITAL LIBRARY

Desislava Paneva-Marinova, Maxim Goynov, Radoslav Pavlov

***Abstract**: Current research on digital libraries (DL) is mostly focused on the generation of large collections of multimedia resources and regular tools for their indexing and retrieval. However, digital libraries should provide more than advanced content maintenance and retrieval services. They should aid the users in their content observation, knowledge acquisition and better satisfying their needs, interests and wishes. This paper presents an extension of the current DL functionality with content analyzing services. The main goal is to reach implicit and hidden data, content, rules and facts, dependences and tendencies, valid for the content in the DL repository, to synthesize and summarize the collected data in order to use them in various investigations and learning. These services also observe the DL tracking services' output and provide different inferences for the frequency of service usage, failed requests, user logs and activities, etc., assisting the DL environment maintenance through the generation of inferences about its stability, flexibility, and reliability. This interpretation of DL analyzing services is not proposed and analyzed until now. We try to push up a new research point, aiming to aid user's work in the DL environment.*

***Keywords**: Digital Libraries, Services, Content Analysis, East-Christian Iconographical Art.*

***ACM Classification Keywords**: H.3.5 Online Information Services – Web-based services, H.3.7 Digital Libraries – Collection, Dissemination, System issues*

Introduction

Digital libraries "should enable any citizen to access all human knowledge anytime and anywhere, in a friendly, multi-modal, efficient, and effective way, by overcoming barriers of distance, language, and culture and by using multiple Internet-connected devices" [Bertino et al., 2001]. The key for such an environment and its efficiency is the provisioning of strictly designed functionalities, which are powered by the observation of the users' preferences, cognitive goals, and needs in order to find optimal functionality solutions for the end users. Current DL releases mainly provide content management services such as: content creation, i.e., adding (annotating and semantic indexing), storing, editing, previewing, browsing, deleting, grouping, and managing multimedia digital objects (images, text, sound, video), collections and their descriptions; metadata management; simple and extended keyword search, complex semantic and context-based search, selection and grouping of objects; data export, etc. A natural extension of these services could be the DL content analyzing, synthesizing and summarizing services, providing content and functionality observation, mining, inference, evaluation and tracking.

Current work in DL content analysis mainly concerns the improvement of the DL content by identifying areas of knowledge that are lacking content and using external information sources to augment the existing knowledge [Carmel et al., 2008]. The DL knowledge management systems provide solutions for acquiring new knowledge by either pulling potential data from external sources or by having the data pushed directly from external content

providers. Topic-driven and user-driven focused crawling are the mainly used techniques for finding missing content [Chakrabarti et al., 1999][Pant et al., 2004][Zhuang et al., 2005].

In this paper we will present a different idea for DL content analysis. Our work focuses first on the search of implicit data/content, context, rules, facts, dependences, tendencies, etc., valid for the content in the DL repository, and the synthesizing and summarizing of the collected data in order to use them in various investigations and learning. We also analyze the DL tracking services' output in order to provide different inferences for the frequency of service usage, failed requests, user logs and activities, etc., aiding the DL environment maintenance through the generation of inferences about its stability, flexibility, and reliability.

The experiments are performed in the "Virtual Encyclopedia of the East-Christian Art" multimedia digital library (also called Bulgarian Iconography Digital Library, BIDL), whose specification is included in section 4 of the paper. Section 2 tracks current work in digital library content analysis. Section 3 formulates investigations and content analysis that are typically done in the target iconographical domain. The overview, design and implementation of the analyzing services in Bulgarian iconography digital library are presented in Section 5 and Section 6.

Current Work in Digital Library Content Analysis

The idea of digital library content analysis appeared in order to answer the question how the content of a digital library can be enhanced to better satisfy users' needs, interests, wishes. Missing content is identified by finding missing content topics in the system's query log or in a pre-defined taxonomy of required knowledge. The collection is then enhanced with new relevant knowledge, which is extracted from external sources that satisfy those missing content topics. Experiments of Carmel's team measured the precision of the system before and after content enhancement [Carmel et al., 2008]. The results demonstrate a significant improvement in the system effectiveness as a result of content enhancement and the superiority of the missing content enhancement policy over several other possible policies.

Other solutions are provided by the DL knowledge management systems that acquire new knowledge by either pulling potential data from external sources or by having the data pushed directly from external content providers. Topic-driven and user-driven focused crawling are the mainly used techniques for finding missing content (However, digital libraries that are based on active crawling methods such as CiteSeer often have missing documents in collections of archived publications, such as ACM and IEEE). The goal of the focused crawler is to selectively seek out pages that are relevant to a pre-defined set of *topics*. The topics are specified not using keywords, but using exemplary documents. Rather than collecting and indexing all accessible Web documents to be able to answer all possible ad-hoc queries, a focused crawler analyzes its crawl boundary to find the links that are likely to be most relevant for the crawl, and avoids irrelevant regions of the Web. The basic concept of a focused crawler (topical crawlers) [De Bra et al., 1994], is based on a crawling strategy that relevant Web pages contain more relevant links, and these relevant links should be explored first. Initially, the measure of relevancy was based on keywords matching; connectivity-based metrics were later introduced [Cho et al., 1998]. In [Chakrabarti et al., 1999] the concept of a focused crawler was formally introduced as a crawler that seeks, acquires, indexes, and maintains pages on a specific set of topics that represent a relatively narrow segment of the Web. This leads to significant savings in hardware and network resources, and helps keep the crawl more up-to-date.

Pant's teams developed a topical crawler [Pant et al., 2004]. Its crawler follows hyperlinks to automatically retrieve pages from the Web while biasing its search towards topically relevant portions of the Web. A trained classifier provides the crawler with the needed bias. Once a collection of Web pages has been downloaded by the crawler, the system analyzed them to find more structured information such as potential Web communities and their descriptions. The analysis process includes both lexical as well as link (graph) based analysis. The final result of the analysis is then shown as an interactive graphical report that describes various clusters (potential communities) found through the crawl, their examples, as well as authorities and hubs within each cluster.

Today, focused crawling techniques have become more important for building specialty and niche (vertical) search engines. While both the sheer volume of the Web and its highly dynamic content increasingly challenge the task of document collection, digital libraries based on crawling benefit from focused crawlers since they can quickly harvest a high-quality subset of the relevant online documents.

Most of the current focused crawling approaches perform syntactic matching, that is, they retrieve documents that contain particular keywords from the user's query. Unfortunately, this often leads to poor discovery results, because the keywords in the query can be semantically similar but syntactically different, or vice-versa. Moreover, the query matching score is calculated taking into account only the keywords from the user's query. Thus, regardless of the context, the same list of results is returned in response to a particular query. In [Pahal et al., 2007] it is offered an approach for document discovery building on a comprehensive framework for context-ontology driven focused crawling of Web documents.

Su's team presented an intelligent focused crawler algorithm [Su et al., 2005] in which they embedded ontology to evaluate the page's relevance to the topic. Compared with other algorithms using domain knowledge, this algorithm can evolve the ontology automatically during crawl process. Considering the instinct characteristics of the ontology, propagation has also been imported to accelerate the evolution of the ontology. This approach is applied in several tasks and provided an empirical evaluation which has shown promising results.

The possible interpretations of the DL content analysis beyond the crawling techniques and solutions. In our work we focused on the search of implicit data/content, context, rules, facts, dependences, tendencies, etc., valid for the content in the DL repository, and then we synthesize and summarize the collected data in order to use them in various investigations and training situations. We also analyze the DL tracking services' output in order to provide different inferences for the frequency of service usage, failed requests, user logs and activities, etc., aiding the DL environment maintenance through the generation of inferences about its stability, flexibility, and reliability. This interpretation of DL content analysis is not proposed and analyzed until now. We try to push up a new research point for the content analysis, aiding user's work in the DL environment.

Needs of Content Analysis in the Iconographical Art Domain

Analyzing iconographical artifacts is an activity performed mostly by art experts, theologians, restoration specialists, and art researchers. It subsumes, inter alia, analysis of the theological meaning of iconographical images, art analysis of the tendencies in iconography, the development in time of characters and scenes, the occurrence and activities in iconographical schools, style similarities between objects, periodizing iconographical tendencies, tracing the iconographical technologies in different time periods, iconographical schools, and authors, technological analysis of pieces of art (researching the base, ground, painting layer, polish, etc.), researching the donors' and authors' writings, authenticating the object, researching the objects' origin, current condition, state,

restoration traces, overpaintings, etc. Simple activities helping the analysis are: building (selecting) a collection of samples having certain characteristics (properties), certain values of the properties, having restrictions/rules for the property values; determining the strength of the chosen object set, the internal order and grouping of the objects, displaying the collection, choice evaluation, etc. At present this work is done by hand, which takes much time and effort.

An example of a simple task for iconographical arts critics is to make an art critical analysis of the development in time of the iconographic image of Jesus Christ in the various iconographical schools in Bulgaria. The researchers have to perform the following steps:

- Select a certain number of iconographic objects containing the image of Jesus Christ in a one-figure composition. (Note: The right choice requires selecting iconographic objects with the character or Jesus Christ Pantocrator, or Blessing Christ, or Jesus Christ enthroned, or St. Veronica, etc.)
- Arrange the iconographic objects in groups by school of iconography.
- If a school of iconography's group contains objects by an eminent author and founder of the school, place these high on the list. Among the objects designated for art critical analysis there should be at least one by a prominent author/school founder, if available.
- Ensure that the iconographic objects designated for art critical analysis are currently in good condition.
- Ensure that at least one primitive iconographic object and at least one Renaissance iconographic object are included in the iconographic objects designated for art critical analysis.
- In writing the art critical analysis compare the selected iconographic objects by contrasting clothing, gesture/s, the character proportions, object/s, the presence of other character/s and/or symbol/s, backgrounds, other element/s (e.g., clouds, etc.) in the iconography of the image of Christ. Look for changes in the iconography of these components, for example, appearance or lack of components (objects, symbols, characters, etc.), changes in the background, clothing, etc., in the selected set of samples.

Another example is the sample task for the art technique team. It has to find iconographic artifacts/objects containing the image of Jesus Christ in order to compare their specifics from a technological point of view.

Steps to be performed:

- Find all the iconographic scenes with Jesus Christ.
- Choose one iconographic scene with a Lord's Day (Holy Cross, Nativity, Epiphany, Palm Sunday, Ascension, Pentecost and Transfiguration), with the most samples (iconographic objects), minimum 6.
- Ensure the selected iconographic objects are on solid base (wood, stone and metal, bone, glass).
- Ensure only iconographic techniques (tempera, oil, mixed) are used in the painting of the iconographic objects.
- Ensure the iconographic objects contain gilding.
- Ensure the Iconographic objects are arranged by temporal characteristics, for example, century.
- In writing the analysis compare iconographic objects in one or more iconographic techniques and evaluate the quality of their execution. Look for periodisations of the employed iconographic techniques

in the selected set of samples. Examine the type and technology of the gilding and the structure of the base.

In our work we try to execute these tasks in a DL environment in order to simplify the specialists' work. These examples of analysis constitute a real case for learning-by-authoring in a scenario for technology-enhanced learning process [Pavlova-Draganova et al., 2009] in the frames of the SINUS project "Semantic Technologies for Web Services and Technology Enhanced Learning"[1]. The main goal is to demonstrate creative learning-by-doing through active authoring of specific learning materials on East-Christian iconography by learners, using multimedia and information resources delivered through the "Virtual Encyclopedia of the East-Christian Art" multimedia digital library [Paneva-Marinova et al., 2010][Pavlov et al., 2010][Pavlova-Draganova et al., 2010]. SINUS's learning analysis solutions are oriented to semantic-based grouping of iconographic objects using semantic descriptors, representing an extension of the descriptive scheme of BIDL iconographical art content.

For example, in SINUS project the subtasks of the art critics' analysis show steps (sub-goals) to be executed. These steps are presented as a formula combining one of the "Bloom's Taxonomy" verbs [Bloom et al., 1956] with a term (concept) from the ontology of the East-Christian iconographical art [Pavlova-Draganova et al., 2007] [Paneva et al., 2007]. In the SINUS learning platform the **Student** "will execute" the Bloom's verb action on the concept(s) from the ontology of the East-Christian iconographical art. For example, in step 1 the **Student** *collects* iconographical objects presenting *Iconographical character* = *Jesus Christ* in a composition type = one-figure. In step 2 the **Student** *classifies* (i.e. arranges the iconographical objects in groups) iconographical objects by a certain iconographic school. In step 3 the **Student** has *to discover-select-show* iconographical objects by a certain author type, etc. Tracking all the sub-goals clearly shows the place of the taxonomy terms of the East-Christian iconographical art ontology needed for the learning analysis.

"Virtual Encyclopedia of the Bulgarian Iconography" Multimedia Digital Library

East-Christian (Orthodox) iconographical art is recognized as one of the most significant areas of painting. Until recently it was neglected in the digital documentation and the registry of this art. But the accessibility of this valuable part of mankind's cultural and historical heritage was enhanced greatly with the appearance of the "Virtual Encyclopedia of the Bulgarian Iconography" multimedia digital library in the global virtual space (see http://bidl.cc.bas.bg/). This Internet-based environment becomes a place where iconographical objects of different kinds and origins were documented, classified, and "exhibited" in order to be widely accessible to both professional researchers and the wide public. Rare specimens, private collections, icons from difficult-to-access storages, distant churches, chapels, and monasteries, objects in a risk environment or unstable conditions, etc., are appearing for new e-exposition. The library provides services for registration, documentation, access and exploration of a practically unlimited number of East-Christian iconographical artifacts and knowledge and the end users could use this rich knowledge base through its interactive preview, objects complex search, selection, and grouping. The first release of the BIDL was developed five years ago within the national project "Digital Libraries with Multimedia Content and its Application in Bulgarian Cultural Heritage" (contract 8/21.07.2005 between the

[1] Research project № D-002-189 with the National Science Foundation of the Ministry of Education and Science. Project executors: consortium of two science organizations – the Institute of information Technologies at the Bulgarian Academy of Sciences and the Institute of Mathematics and Informatics at the Bulgarian Academy of Sciences – and one high technology software company – "Active solutions" Ltd.

Institute of Mathematics and Informatics, BAS, and the State Agency for Information Technologies and Communications). As of now, the library has been used in several cross-media, ubiquitous and technology-enhanced learning applications [Paneva-Marinova et al., 2008][Paneva-Marinova et al., 2009][Pavlov et al., 2007].

BIDL Functionality: The key for the current release of BIDL is the efficiency and the provision of strictly designed functionalities. Special attention was paid to content creation, preview, content grouping, content search (semantic, context-based, etc.), metadata management, administrative services, adaptive and personalized access to the content, multilinguality support, etc. presented in [Paneva-Marinova et al., 2010][Pavlov et al., 2010][Pavlova-Draganova et al., 2010]. Moreover, the BIDL semantic content description orders the specification of a unique descriptive scheme for iconographical art content, covering the rich semantic identification and technical features of the iconographical objects [Pavlova-Draganova et al., 2007][Paneva et al., 2007].

BIDL Content: BIDL includes several hundred specimens of Bulgarian iconographical objects from different artists, historical periods, and schools. There are also incorporated information objects, presenting iconographic techniques, authors' biographies, schools' history, terms vocabulary, etc. Several users created and driven collections are shown (for example, the unique collection of pencil-drawings of Zacharya Tsanyuv or the rich collection of icons from "Saint Trinity Church" in Bansko, etc.). The BIDL specimens are in the possession of the Bulgarian Orthodox church and the originals are currently exposed and freely accessible in acting Bulgarian churches and monastery.

The future extensions of the library are related to the content enrichment and the inclusion of wide range of artefacts of the Balkan countries. In BIDL will also be included services for aggregating iconographical content for the European digital library EUROPEANA, thus providing possibilities for pan-European access to rich digitalised collections of East Christian iconographical heritage.

Analyzing and Synthesizing Services in BIDL

An extension of the BIDL functionality is the analyzing, synthesizing and summarizing of content, maintaining content and functionality observation, mining, inference, evaluation and tracking. In BIDL these services are performed through the QlickTech® QlinView® Business Intelligence software[1]. As an analysis services provider, it is connected to the BIDL objects repository and tracking services by a preliminary created data warehouse. The QlickTech® QlinView® Business Intelligence software provides fast, powerful and visual in-memory analysis and synthesis of the data, analytical processing (OLAP), quick answering of multi-dimensional analytical queries, etc. The ETL (Extract, Transform, Load)[2] is a completely automatic process and is performed by administrator request.

[1] Business Intelligence is an architecture and a collection of integrated operational as well as decision-support applications and databases that provide easy access to a large amount of (business) data.

[2] Extract, transform, and load (ETL) is a process in database usage and especially in data warehousing that involves: extracting data from outside sources, transforming it to fit operational needs (which can include quality levels), and loading it into the end target (database or data warehouse).

The variety of generated statistical information about BIDL data extends the available visualization services, enabling the user to analyze the iconography domain as well as the library repository at the most granular level of detail required, providing unparalleled insight into the actual states and data dependencies.

For example, figure 1 depicts the synthesis of the available icons from Toma Vishanov, indicating the author's iconographic school (viz., Bansko Iconographic School), the canonical types and characters painted (i.e., Holy Spirit, Martyr, Jesus Christ, etc.), iconographic techniques and base materials used.

This information snapshot could be used for an analytical research of an author's work, for an art analysis of the emphasis, trends, and areas it covers, the priorities in their work. There is an opportunity to know their art in more detail.

There is another type of diagrams, related to tracing the integrity, status and ratio of the content distribution in the repository of the digital library. Such an example is figure 2 where a PIE diagram is depicted making a canonical sub-types analysis about the Apostle canonical type.

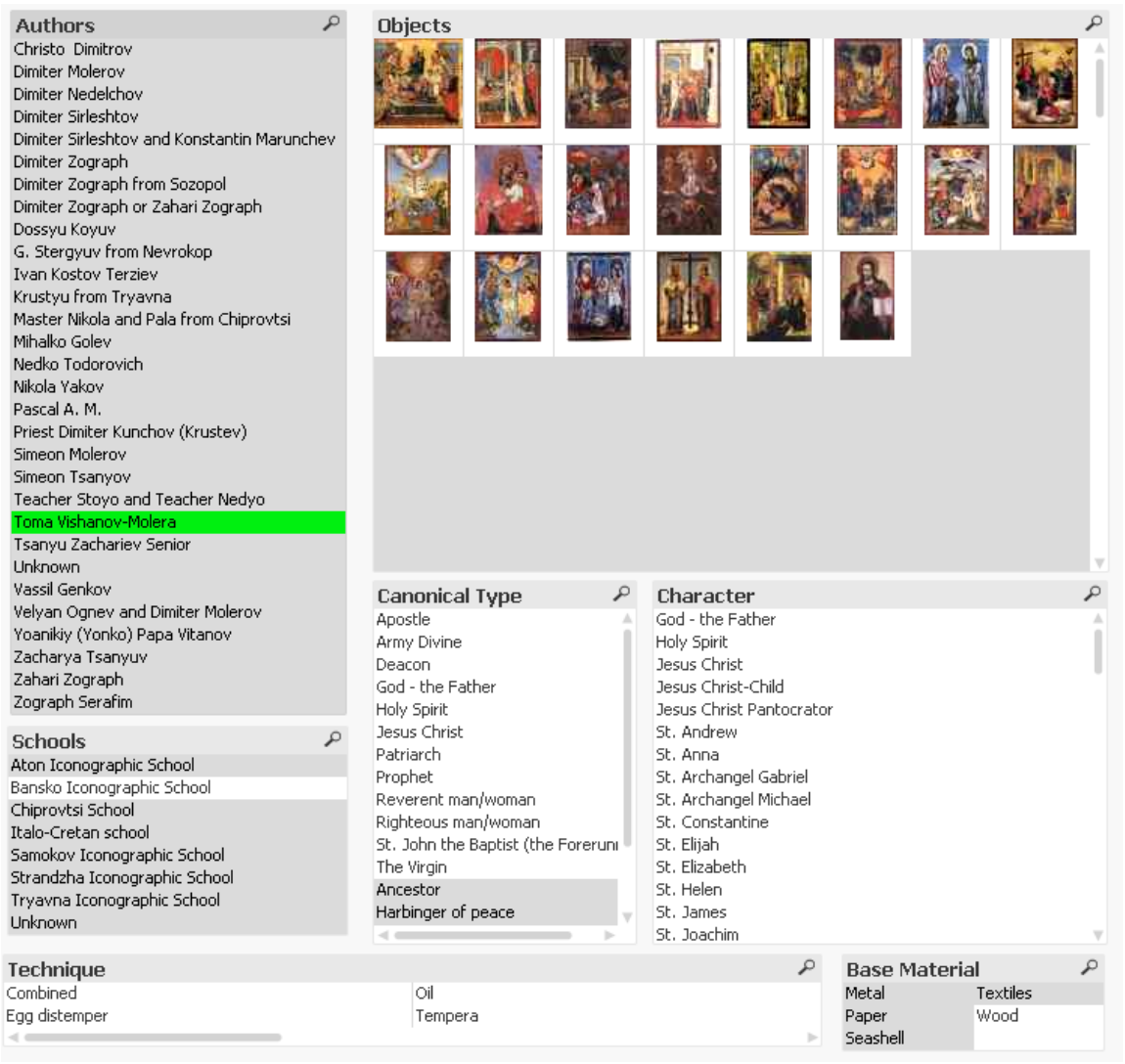

Figure 1: An overview of Toma Vishanov-Molera's specimens

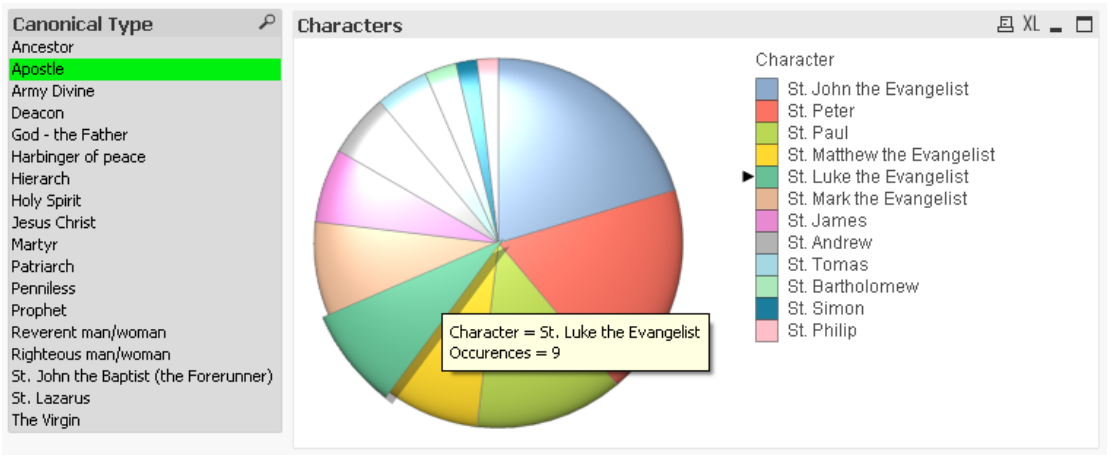

Figure 2: PIE diagram of canonical sub-types for Apostle canonical type

Figure 3 depicts the frequency of objects' preview, showing the individual objects.

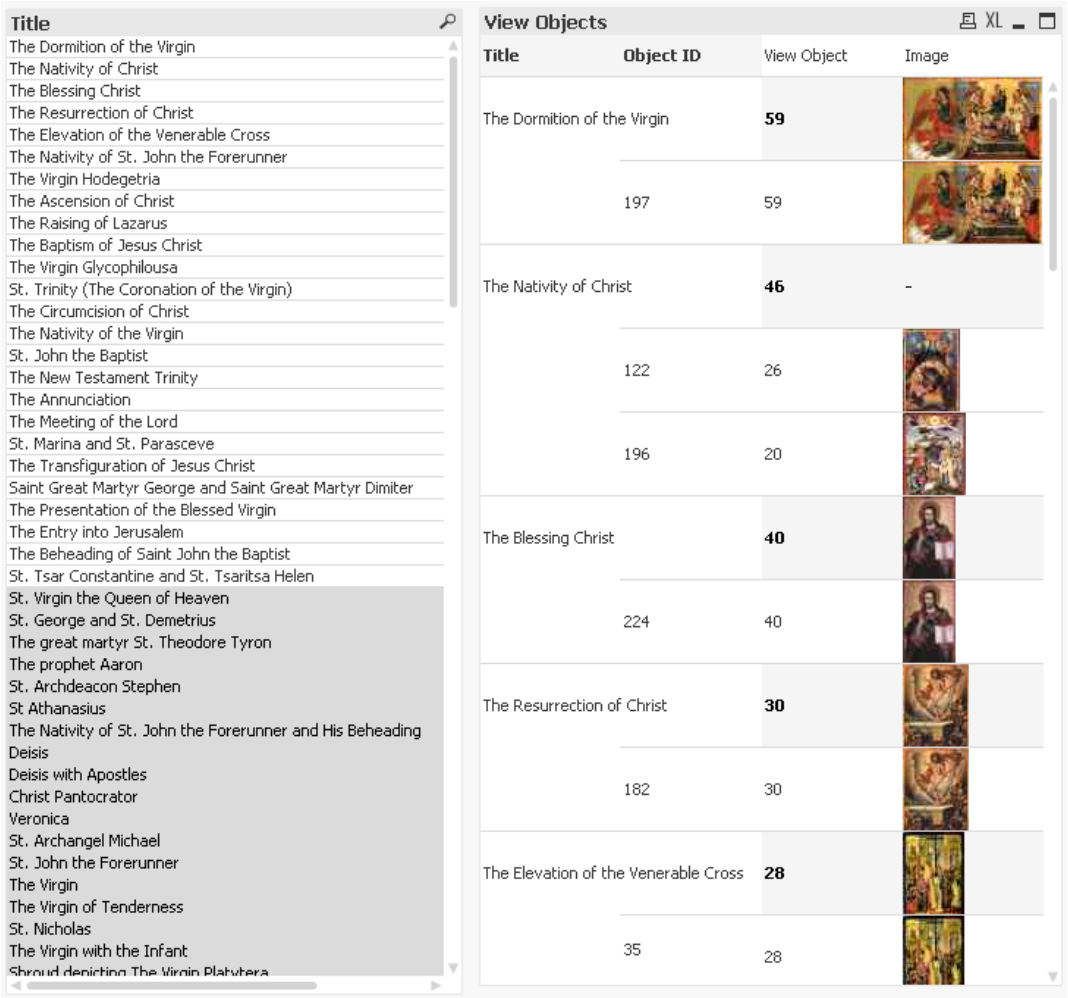

Figure 3: Frequency of objects' preview

This information can be used for making conclusions about people's interest in objects, collections and the library content, in order to further fill the repository of the library.

With the QlickTech® QlinView® Business Intelligence software we also perform a paralleled insight of the tracking services' output (BIDL objects tracking and BIDL users' activities tracking). The tracking services "spy on" the activities of add, edit, preview, search, delete, selection, export to XML, and group of MDL objects/collections, user logs, personal data changes, access level changes and user behavior, etc., in order to provide a wide range of statistic data for frequency of service usage, failed requests, etc. for internal usage and generation of inferences about stable work (stability), the flexibility, and the reliability of the environment.

Figure 4 depicts a diagram for the user's activities during a fixed period generated by QlickTech® QlinView® Business Intelligence software.

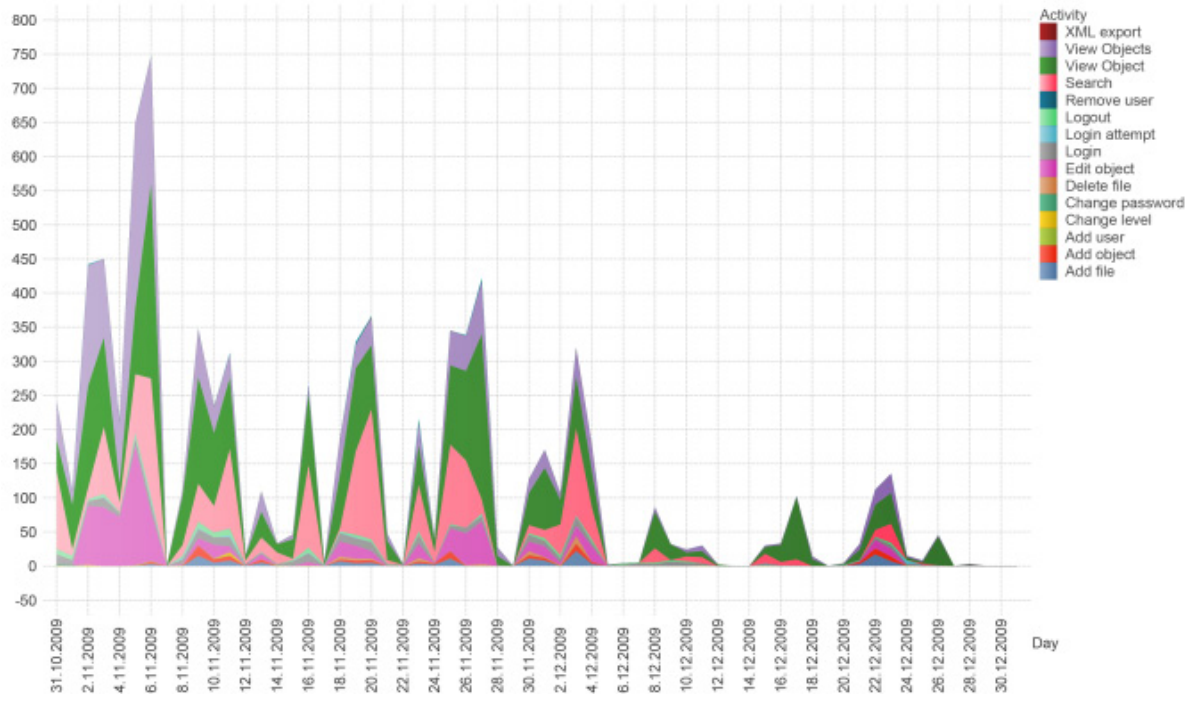

Figure 4: Users' activities during a defined period

In comparison, as depicted in figure 5, the BIDL tracking services return only data result rows, which say what occurred and when. It lacks "high-level" information about services utilization, user engagement, etc., from this data, necessary for real profound analysis.

№	User	Date	Action	Additional information
44772	admin	18.03.2011 г. 16:57:55	Login	**85.130.9.230**
44771	admin	18.03.2011 г. 16:33:56	Login	**85.130.9.230**
44770	Гост	18.03.2011 г. 11:45:32	Login attempt	**attempt with username zlatka and IP:212.56.15.130**
44769	agataluis	18.03.2011 г. 11:21:43	Logout	**46.40.102.249**
44768	agataluis	18.03.2011 г. 11:18:52	View object	St. Anthony and St. Euthymios the Great
44767	agataluis	18.03.2011 г. 11:18:50	view_term	Description ► Characters ► Character name ► Bulgarian ► **Св. Антоний Велики**
44766	agataluis	18.03.2011 г. 11:18:44	view_terms	Description ► Characters ► Character name ► Bulgarian
44765	agataluis	18.03.2011 г. 11:17:48	View object	St. John the Forerunner
44764	agataluis	18.03.2011 г. 11:17:44	View object	St. John the Forerunner
44763	agataluis	18.03.2011 г. 11:17:36	View object	Christ Pantocrator
44762	agataluis	18.03.2011 г. 11:17:08	View object	Gospel Embossment
44761	agataluis	18.03.2011 г. 11:16:46	View object	The Virgin Esphagmeni
44760	agataluis	18.03.2011 г. 11:16:41	View object	The Virgin of Tenderness
44759	agataluis	18.03.2011 г. 11:16:33	View object	St. Virgin the Queen of Heaven
44758	agataluis	18.03.2011 г. 11:16:24	View object	The Virgin with the Infant
44757	agataluis	18.03.2011 г. 11:16:12	View object	St. Virgin Playing
44756	agataluis	18.03.2011 г. 11:15:44	View object	St. Virgin Playing
44755	agataluis	18.03.2011 г. 11:13:30	View object	Royal Altar Gates
44754	agataluis	18.03.2011 г. 11:12:48	Login	**46.40.102.249**
44753	agataluis	18.03.2011 г. 11:12:36	Register	
44752	elenex	18.03.2011 г. 09:29:24	view_term	Description ► Iconographical scenes ► Iconographical scene ► Bulgarian ► **Св. Мина с житийни сц**
44751	elenex	18.03.2011 г. 09:29:21	View object	St .Minas with scenes from his life
44750	elenex	18.03.2011 г. 09:29:19	view_term	Description ► Iconographical scenes ► Iconographical scene ► Bulgarian ► **Св. Мина с житийни сц**
44749	elenex	18.03.2011 г. 09:29:16	view_terms	Description ► Iconographical scenes ► Iconographical scene ► Bulgarian
44748	elenex	18.03.2011 г. 09:29:10	view_terms	Description ► Iconographical scenes ► Iconographical scene ► Bulgarian
44747	elenex	18.03.2011 г. 09:29:03	View object	The Virgin with the Infant
44746	elenex	18.03.2011 г. 09:28:58	View object	The Virgin Glycophilousa
44745	elenex	18.03.2011 г. 09:28:48	View object	St. Martyr Menas
44744	elenex	18.03.2011 г. 09:28:42	View object	Abraham's Sacrifice
44743	elenex	18.03.2011 г. 09:28:36	View object	The Crucifix of Christ
44742	elenex	18.03.2011 г. 09:28:24	View object	St. Archangel Michael
44741	elenex	18.03.2011 г. 09:28:22	view_term	Description ► Characters ► Canonical character ► Bulgarian ► **Небесно войнство**
44740	elenex	18.03.2011 г. 09:28:20	view_terms	Description ► Characters ► Canonical character ► Bulgarian
44739	elenex	18.03.2011 г. 09:24:53	View object	Christ Pantocrator

Figure 5: Screen of the BIDL tracking services results

Implementation of the Analyzing and Synthesizing Services in BIDL

The implementation of the analyzing services in BIDL passes over the building of a special logging service, the design of a fast performing data warehouse and the defining of the ETL process.

Building the logging service for the digital library

The initial BIDL database had the structure depicted in figure 6.

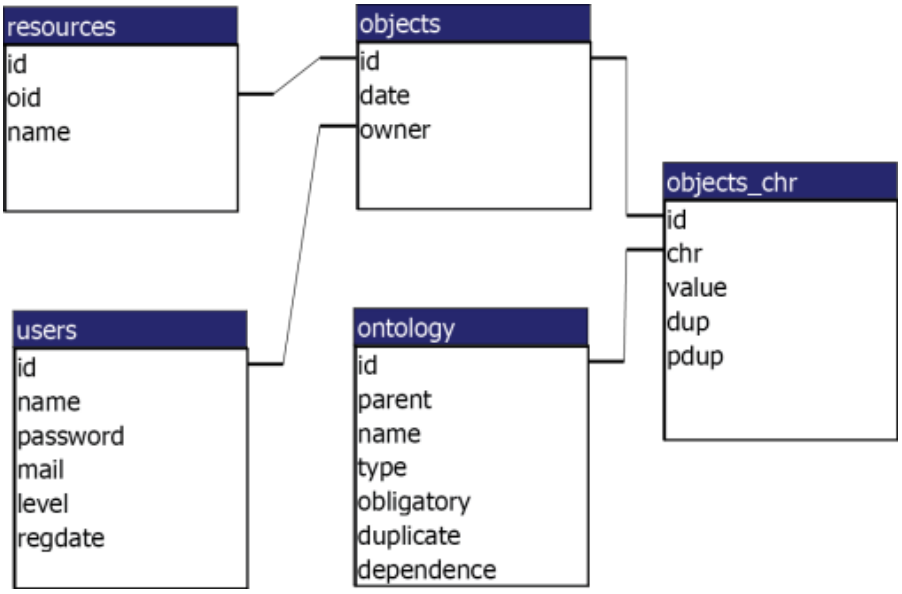

Figure 6: BIDL Database structure

There are five main tables used for storing the user data and the content data. For creating the logging service it was necessary to design another table for that database. The new table has to store all of the user activities which we are interested in. So with the new table we have a database like the one depicted in figure 7.

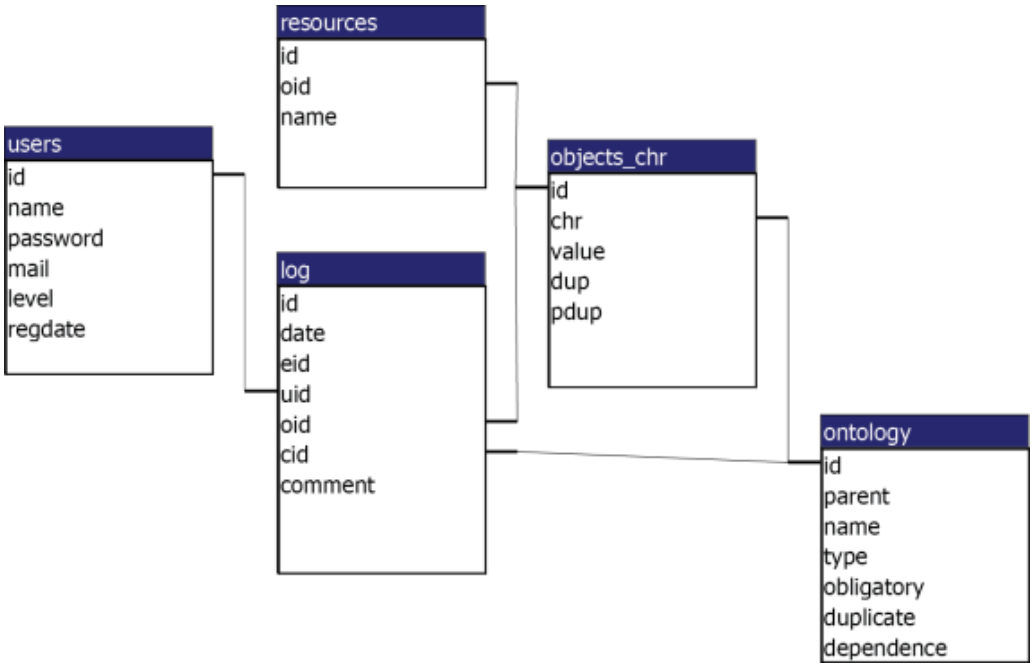

Figure 7: BIDL Database structure Updated

We have added the log table. Each row of this table represents one user activity. Each activity has:

- A unique identification number;
- A timestamp (the exact time of its execution);
- Event identification (eid – specifies the type of activity carried out by the user);
- User ID – unique user identification number (from the users table);
- Object ID – identifier of the object on which an action is performed (if any)
- Characteristic ID – identifies any concrete object characteristic that takes part in the action which the user has performed;
- Comment – provides additional information about the event.

After analyzing our needs for tracking user activities, we decided to track the following types of events (event identification – eid):

- Add file – when a new resource is added;
- Add object – when a new object is created;
- Add user – when an user registers;
- Change password – when an user changes their password;
- Delete file – a file is deleted;
- Delete object – an object is deleted;
- Edit object – an object is edited (modified);
- XML export – XML export of all objects has been performed;
- Group – the group objects service is performed (started, run);
- Login – an user has logged in;
- Login attempt – bad login attempt;
- Logout – user has logged out;
- Remove user – user has been deleted by administrator;
- Search – search action has been executed;
- Change level – user level has been changed;
- View Map – the map service has been executed;
- View Object – view object service;
- View Objects – view a list of objects;
- View Term – view the meaning of a term;
- View Terms – view a list of terms;

These types of events will help us make the various analyses of user behavior in order to improve the quality of our services according to the DL objects' interests.

Data Warehouse Design

To implement the analyzing tool for our DL, we need to design and build a fast performing data warehouse. We choose the snowflake schema for the data warehouse (see figure 8).

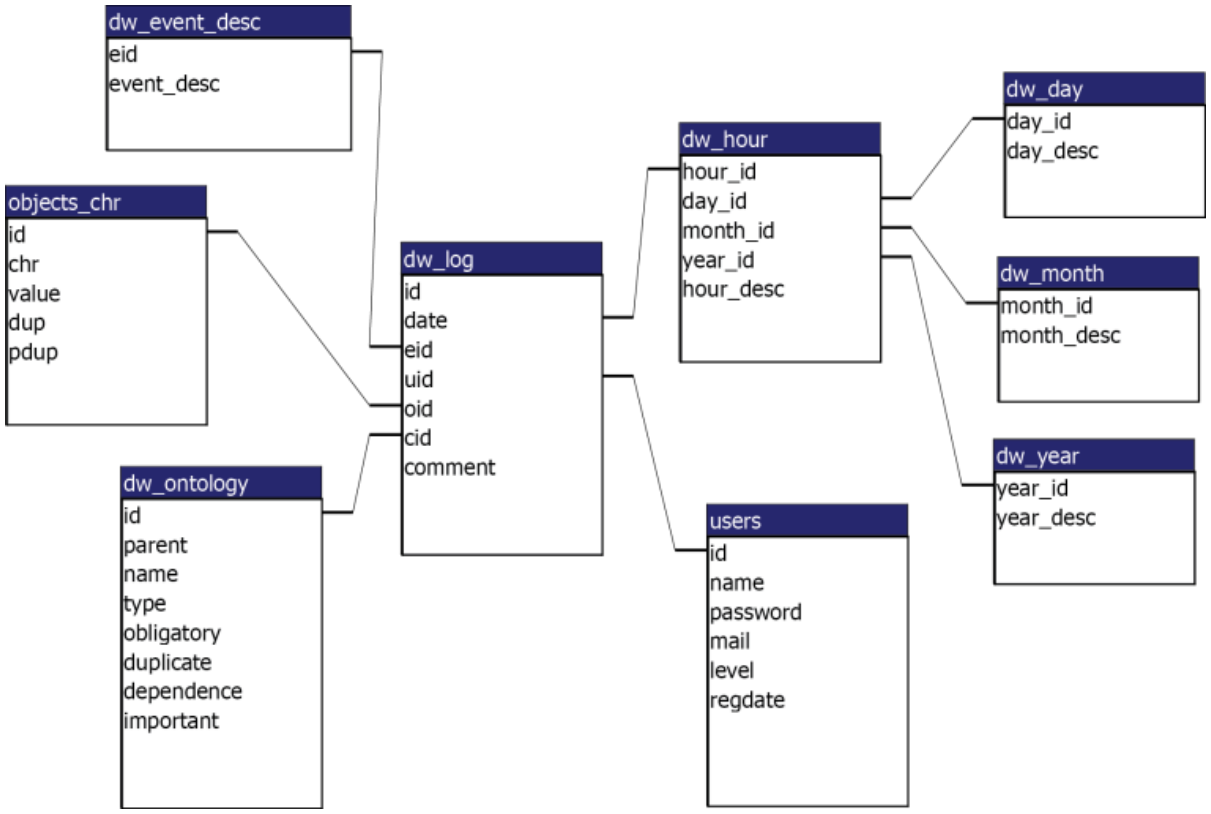

Figure 8: Snowflake schema for the BIDL data warehouse

We use the log table for the fact table of our data warehouse, and the objects, characteristics, and users as dimensional tables. Also, there are additional tables for the time separation.

We have to note that the table dw_log is different from the table log (and dw_ontology differs from ontology), regardless of the fact that they have the same attributes. The reason is that our data warehouse aims at fast performance, and that is because another process is needed before we start creating our analysis.

The ETL process (or how to build and update our data warehouse)

The purpose of this process is to make our data warehouse compatible to our database, so the data transfer from database to data warehouse becomes easy and flawless.

For example, in our case we needed to transfer the timestamp (which contained Year, Month, Day, Hour, Minute, and Second) of the log table to individual entities like: hour, month, year, day for the tables dw_log and dw_hour. We also had to extend the dw_hour table to contain not only values which are connected with one activity, but all values between the times of the first and last activity. This is a common action when building a data warehouse.

So we achieved the desired result for the current example using the PHP language:

```
while ($begin<$s3)
{
   $m1 = localtime($begin,1);
   $m2 = localtime($begin-3600,1);
   $hour_id = $begin;
   $day_id = mktime(0, 0, 0, $m1['tm_mon']+1,  $m1['tm_mday'], $m1['tm_year']+1900);
   $month_id = mktime(0, 0, 0, $m1['tm_mon']+1, 1, $m1['tm_year']+1900);
   $year_id = mktime(0, 0, 0, 1, 1, $m1['tm_year']+1900);
   $hour_desc = $m1['tm_hour'];
   $year_desc = $m1['tm_year']+1900;
   $month_desc = ($m1['tm_mon']+1) . ".$year_desc";
   $day_desc = $m1['tm_mday'].".$month_desc";
   msq("REPLACE dw_hour (hour_id, day_id, month_id, year_id, hour_desc) VALUES ($hour_id, $day_id, $month_id,
$year_id, $hour_desc)");
   if ($m1['tm_mon']!=$m2['tm_mon'] OR $first) msq("REPLACE dw_month (month_id, month_desc) VALUES
($month_id, '$month_desc')");
   if ($m1['tm_mday']!=$m2['tm_mday'] OR $first) msq("REPLACE dw_day (day_id, day_desc) VALUES ($day_id,
'$day_desc')");
   if ($m1['tm_year']!=$m2['tm_year'] OR $first) msq("REPLACE dw_year (year_id, year_desc) VALUES ($year_id,
$year_desc)");
   $begin+=3600;
   $first=0;
}
```

As seen above, we modify data and insert it into the data warehouse.

When the data warehouse is built and the ETL process is defined, we are ready to start creating our analysis through the QlickTech® QlinView® Business Intelligence software.

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AUTOMATED CONFERENCE CD-ROM BUILDER – AN OPEN SOURCE APPROACH

Stefan Karastanev

***Abstract**: This paper presents a new approach for creating conferences CD based HTML presentation of published papers for off-line reading. A couple of advances techniques has been deployed to automate process of creation like Java script engine, SQL database integration, full text search engine. The approach offers a good integration with online conference management systems for direct data exchange, friendly user interface and good compatibility with majority of contemporary HTML browsers.*

***Key Words**: Java script, SQL, PHP, Database, Open Source, Linux.*

Introduction

Creation of presentation CD for offline publishing is usually a complex task which has to solve several problems. First of them is to be as much as possible versatile in terms of machine platforms and operating systems. Second of them is to avoid installation of any specialized software components on target machine. Of course the speed of operation is important as well. This leads to deployment of HTML based techniques for reading, searching and browsing the published content, which ensures full platform and OS independence, light and convenient user interface and finally avoids any concerns about security issues.

There are known commercial conference CD builders, but they have number of disadvantages like proprietary license, lack of possibilities for integration with well known online conference management systems, necessity of availability of installed third party engines (Java Virtual Machine for example) or executable modules, which may compromise the security of the target machine.

Goals and tasks

The main goals, according to the introduction above, are to develop robust HTML based CD conference publishing system for offline reading with clear user interface, to ensure needed functionality for reading, browsing and searching the content without use of any external virtual machines or database engines, leaning only on HTML browser 's internal capabilities. The system should be based entirely on open source projects, libraries or **application programming interfaces** (API).

Research methods and models

Taking into account the constrains of the HTML and the need of generation of dynamic content there are two methods to apply to achieve the goals highlighted above – deploying of build-in Java Scrip engine available in most of popular browsers or usage of third party script engines (e.g. Macromedia Flash) which requires presence of additional plugin installed on the user's machine. In this paper the Java Scrip approach has been chosen.

There are known number of Java Script frameworks licensed under open source licenses like Dojo Toolkit [1], MooTools [2] and many others but probably most convenient and with rich functionality framework for building Javascript applications is **qooxdoo** [3]. Qooxdoo is a comprehensive and innovative framework for creating rich internet applications (RIAs). Leveraging object-oriented JavaScript allows developers to build impressive cross-browser applications. No HTML, CSS nor DOM knowledge is needed. It includes a platform-independent development tool chain, a state-of-the-art GUI toolkit and an advanced client-server communication layer. It is open source under an LGPL/EPL dual license. Despite being a pure JavaScript framework, qooxdoo is quite on par with GUI toolkits like Qt or SWT when it comes to advanced yet easy to implement user interfaces. It offers a full-blown set of widgets that are hardly distinguishable from elements of native desktop applications. Full built-in support for keyboard navigation, focus and tab handling and drag & drop is provided. Dimensions can be specified as static, auto-sizing, stretching, percentage, weighted flex or min/max or even as combination of those. All widgets are based on powerful and flexible layout managers which are a key to many of the advanced layout capabilities. Interface description is done programmatically in JavaScript for maximum performance.

No HTML has to be used and augmented to define the interface. The qooxdoo developer does not even have to know CSS to style the interface. Clean and easy-to-configure themes for appearance, colors, borders, fonts and icons allow for a full-fledged styling that even supports runtime switching.

Picking up a future rich Java Script framework solving the basic program organization and user interface tasks. The next step of the application development is to choose appropriate SQL database engine. Why SQL database? Using such approach separates code from the data which gives flexibility in usage of the application in wide variety of data sources (online conference systems, manual data entering etc.). TrimPath Query [4] has been chosen as Javascript SQL engine. This engine provides simple SQL interface with json like database storage.

The next step is to choose and integrate a full text search engine. JSSIndex java script engine has been chosen [5]. JSS is a simple search engine designed for CDROM or Web-based document collections. The documents to be indexed can be in HTML, PostScript (.ps and .ps.gz), PDF, and DjVu. The main feature of JSS is that the query engine and the index are entirely in JavaScript, and therefore require no other software than a JavaScript-enabled Web browser. JSS uses a simple inverted word list. Each individual word that appears in the corpus of documents is associated with a list of documents (or a list of pages) in which the word appears.

The inverted word list is encoded in string literals in JavaScript source code. With this trick, the search engine and the index are entirely contained in a piece of JavaScript source code that runs in the browser. For CDROM-based collections, this provides a machine-independent search capability without requiring any software installation, and without requiring a Java virtual machine. For web-based collections, this provides a simple search capability, without requiring any server-side software installation, and without consuming any server resources. The indexing piece of code is written in Lush (a high level script language). Some small modifications

has been done to improve PDF to text conversion, which has been executed on Linux machine during compilation of the published papers data.

The simplified model of the application is shown at the figure 1. All components reside in the browser's Javascript engine environment.

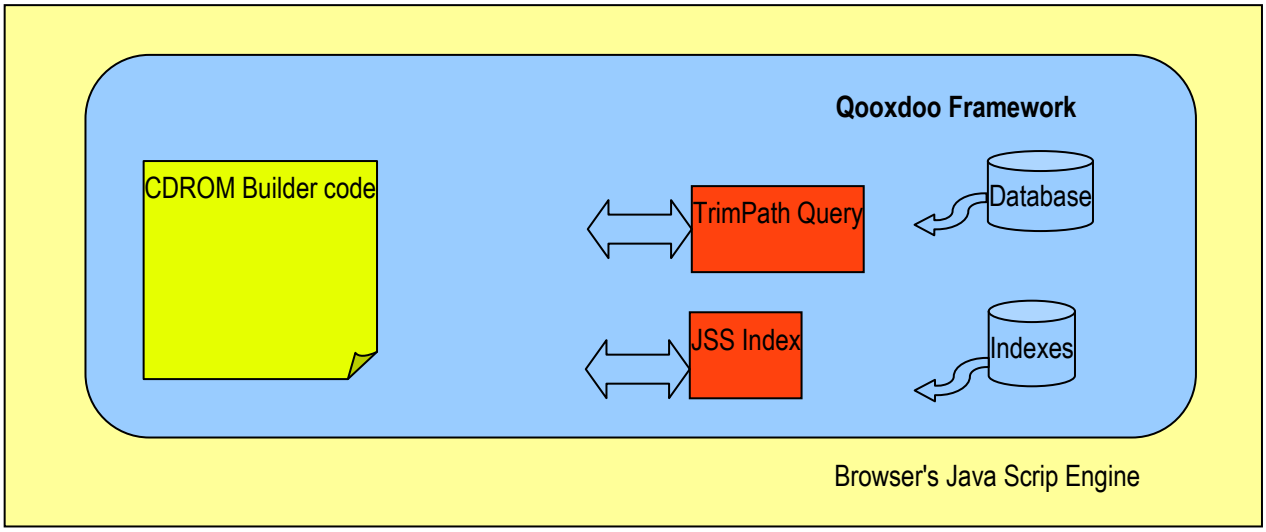


Fig.1 Application Model

- **Realizations and experiments**

The realization described in this paper is built on top of data of 11-th National Congress on Theoretical and Applied Mechanics. According to the application model, the main code is written in Java Script, which is processed by qooxdoo's framework build script to produce final optimized and compressed script. An additional proxy html file is used to load main java script file and auxiliary scripts for sql and full text search engines. The main script consists of the following important blocks:

- Main window block – initializes the qooxdoo framework, creates two containers – menu area and information area (figure 2)

- Menus block – creates the necessary menu items as **Tree List** and installs an event listener to the **Change Selection** event from the **Tree List** item. Most of the items have a static realization because they don't depend of the concrete conference but the **Section** item is specific for every realization so it's filled by the code with help of the sql queries. The code looks like the following segment :

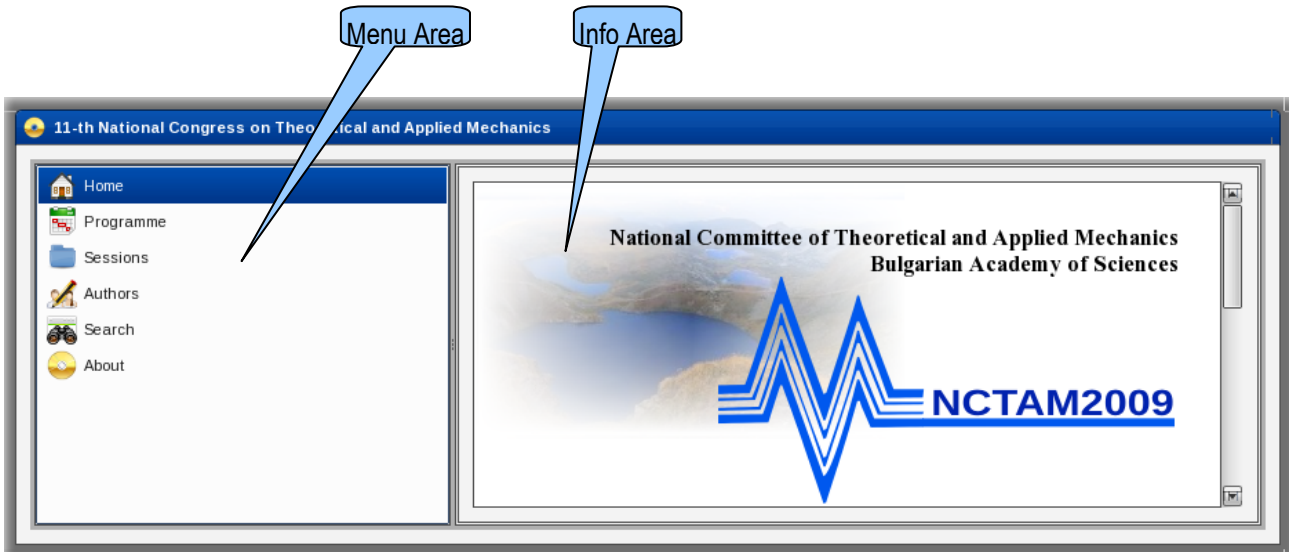


Fig.2 Main Window

```
var result = TrimPath.makeQueryLang(columnDefs).parseSQL("SELECT
tracks.setting_value,tracks.track_id,tracks.pos FROM tracks ORDER BY
tracks.pos").filter(tableData);
for (var r = 0; r < result.length; r++) {
    var item=new qx.ui.tree.TreeFile(result[r]
    ["setting_value"]).set({maxWidth:100,allowShrinkY:true});
    item.setUserData("trackId",result[r]["track_id"]);
    root.add(item);
}
```

All menu items have assigned an identifier which is used in the events processing block to identify the correct command.

- **Home** and **Programme** menu blocks – display a static HTML page in Iframe inside the information area
- **Sessions** menu block – extracts the information for articles, authors and associated PDF file for the selected Session from the json like data base. This block uses the Table Model class from the qooxdoo framework with installed event listener on every row of the table. The code looks like the following segment :

```
var trId=(data[0].getUserData("trackId"));
if(trId!=null){
  var result = TrimPath.makeQueryLang(columnDefs).parseSQL("SELECT
  papers.setting_value,papers.file_name,papers.paper_id FROM papers WHERE
  papers.track_id=="+trId+" ").filter(tableData);
  var rowData=[];
  for (var r = 0; r < result.length; r++) {
      var authors="";

      var aresult = TrimPath.makeQueryLang(columnDefs).parseSQL("SELECT * FROM
      presenters WHERE presenters.paper_id = "+result[r]["paper_id"]+" ORDER BY
      presenters.primary_contact DESC").filter(tableData);

      for (var i=0;i<aresult.length;i++){
          authors+=aresult[i]["last_name"]+" "+aresult[i]["first_name"];
          if(i<aresult.length-1)authors+=", "
      }

      rowData.push(["<center>"+result[r]
      ["setting_value"].toUpperCase()+"<br><b>"+authors+"</b></center>",result[
      r]["file_name"],"test/acroread.png"]);
      //rowData.push([ r, r+1]);

  }
  tableModel.setData(rowData);
```

The view generated by this block is illustrated at the figure below:

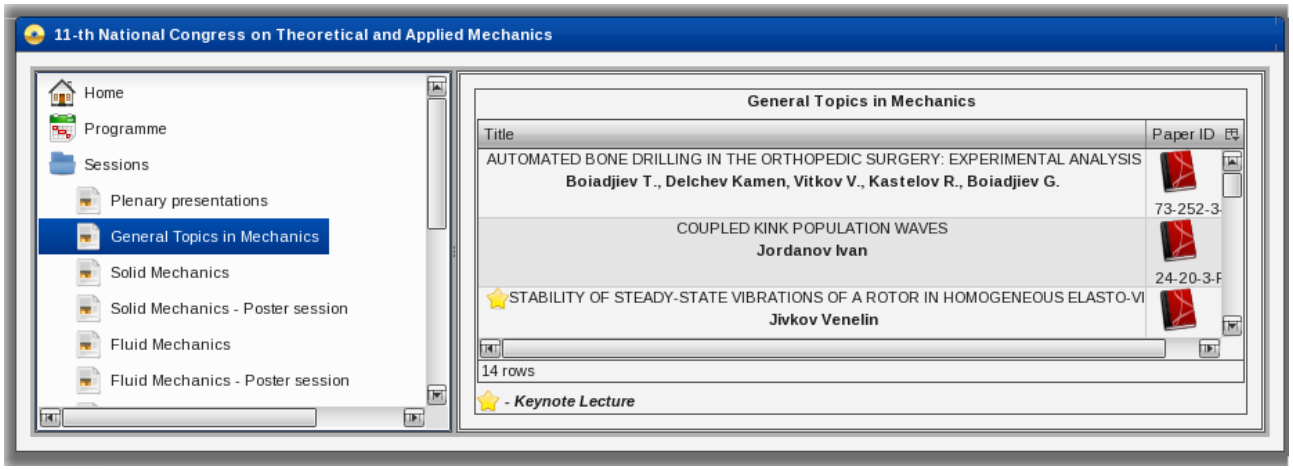


Fig. 3 Sessions menu

- **Authors** menu block – displays authors in alphabetical order. Extracts necessary data from json like database tables and shows the information in **TabView**[3] widget. The code is shown bellow:

```
var aresult = TrimPath.makeQueryLang(columnDefs).parseSQL("SELECT *
FROM presenters WHERE presenters.last_name LIKE '^"+letters[i]+"'
ORDER BY presenters.last_name").filter(tableData);
var shown=0;
for (var j=0;j<aresult.length;j++){
  var author="";
  author+=aresult[j]["last_name"]+" "+aresult[j]["first_name"];
  var result = TrimPath.makeQueryLang(columnDefs).parseSQL("SELECT
  papers.setting_value,papers.file_name,papers.paper_id FROM papers
  WHERE papers.paper_id=="+aresult[j]["paper_id"]+"
  ").filter(tableData);
  if(result.length){
    author+="<br><a href=\"resource/test/Files/"+result[0]
    ["file_name"]+"\">"+result[0]
    ["setting_value"].toUpperCase()+"</a>";
    var label=new
    qx.ui.basic.Label("<b>"+author+"</b>").set({rich:true,textAlign:"
    center",allowGrowX:true,decorator: "main"});
    if(shown&1)label.set({backgroundColor : "#E6EDFA"});
    shown++;
    pcontainer.add(label);
  }
}
```

The view generated by this block is illustrated at the figure below:

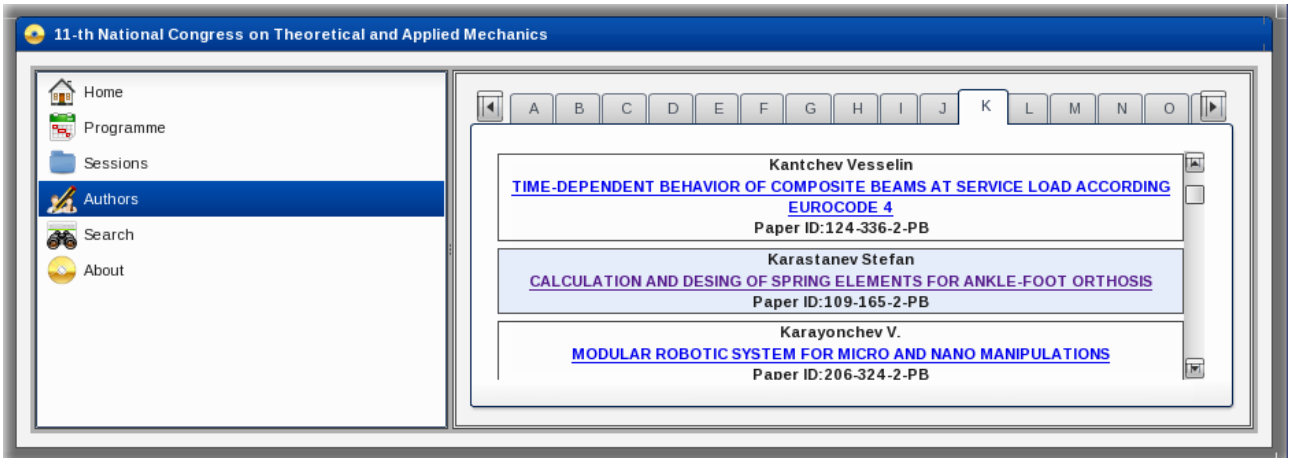
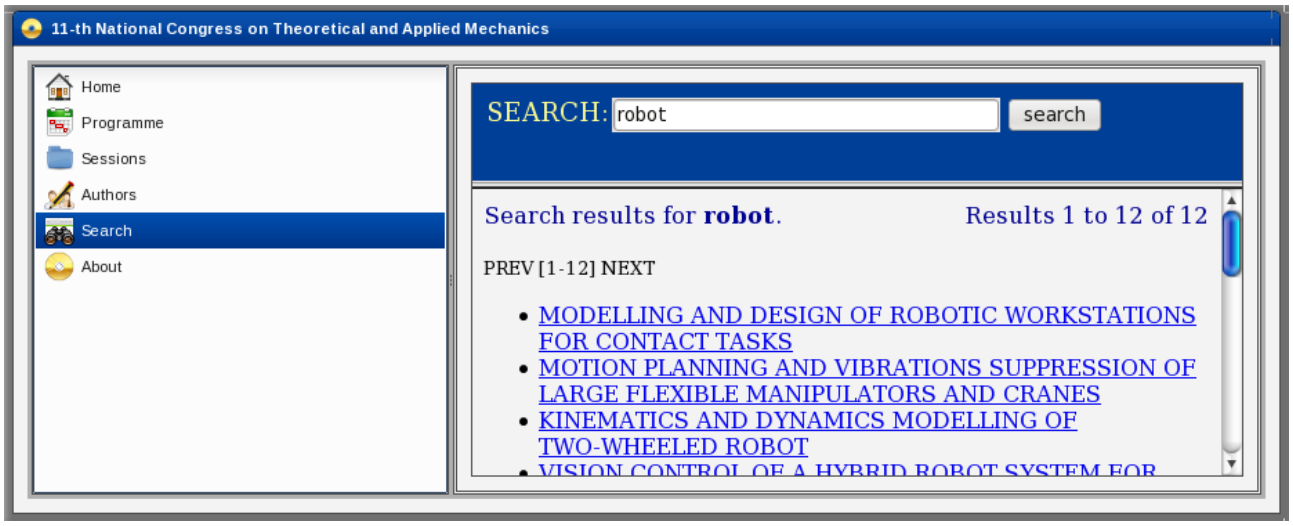


Fig. 4 Authors menu

- **Search** menu block – deploys the full text search engine by integration into an Iframe inside the view area of the application. The embedded Iframe is prepared during the application initialization phase. The search scrip has been modified for better visual integration into the application.

Search block in action is shown at the figure bellow:



- **About** menu block displays custom "About" information in popup tabbed window.

In addition to the main application of the CDROM builder system there is an optional PHP script, developed for the data extraction from particular online conference management system – Open Conference System. The script just executes properly crafted SQL queries to arrange the data from the online system in convenient form for Java Script SQL engine. The script downloads needed PDF presentation file as well.

All scripts described above have been developed and tested under Linux OS (Fedora Core 11). Tests in different environment have been done as well. The generated set of data has been tested for compatibility with different browsers (Mozilla Firefox, Google Chrome and Internet Explorer).

Conclusions

This study shows that it is possible to build an open source automated conference CDROM generator, based entirely on build-in facilities of the contemporary web browsers, without usage of any third party modules and programs. Tests which have been done show that the generated scripts provide modern user interface, stability and good performance under different web browsers and operating systems. Combination of different Javascript techniques ensures the flexibility of the system.

Acknowledgments

All data and logos used in this paper are copyrighted by Institute of Mechanics, BAS.

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OVERALL QOS REFERENCING IN TELECOMMUNICATION SYSTEMS – SOME CURRENT CONCEPTS AND OPEN ISSUES

Stoyan Poryazov, Emiliya Saranova

Abstract: *The main current concepts in overall Quality of Service (QoS) considerations in telecommunication systems, in documents of the leading standardization organizations, are found and put together. At least fifteen Open Issues for further study are formulated. Proposed are: Work Definitions of Communication and Telecommunication; A Reference Model of a Telecommunication System; Definitions of Overall Telecommunication Network and System Performance; Two Telecommunication System States' modelling approaches are described; Parameters' Classification Based on Their Values' Establishing Method is proposed, for the needs of design models; The necessity of Causal Classification of Values in Telecommunication Systems' Models is argued; The necessity of Overall Telecommunication System's Parameters' Notation System is argued and a set of requirements is listed. An initial step of such notation system, proposed and used by authors is described.*

Keywords: *Telecommunication Systems, Telecommunication Network, Overall Quality of Service, Multi-Conceptual Models, Models Scalability*

ACM Classification Keywords: *C.4 Performance of Systems, H.1.2 User/Machine Systems, I.6 Simulation and Modelling, I.6.0 General, H.1.2 User/Machine Systems, K.6 Management of Computing and Information Systems, K.6.0 Genera.*

Introduction

The aims of the paper are:

- To explain the contemporary terms, building the base of the Overall Quality of Service (QoS) Concept in Telecommunication Systems in documents of the leading standardization organizations,
- To show some latest developments in concepts and conceptual modelling of Telecommunication Systems, using informational modelling approaches;
- And to list Open Issues for further study, we are facing in our work.

We use many sources, but mainly ITU-T (International Telecommunication Union – Standardization Sector) Recommendations. ITU's role as creator of the world's most universally-recognized infocommunications standards dates back as far as the organization itself. Since its inception in 1865, the Union has been brokering industry consensus on the technologies and services that form the backbone of the world's largest, most interconnected man-made system. In 2007 alone, ITU's Telecommunication Standardization Sector (ITU-T) produced over 160 new and revised standards (ITU-T Recommendations), covering everything from core network functionality and broadband to next-generation services like IPTV (Internet Protocol Television). ITU-T

Recommendations are defining elements in information and communication technologies (ICTs) infrastructure (www.itu.int/net/ITU-T/info/Default.aspx). In this paper we use only ITU-T Recommendations in force, except [ITU-T B.13, 1993], because there is not replacement of it.

This paper is not a review of ITU-T Recommendations, as the good ones: [Jensen, 2003], [Anttalainen, 2003], [Villen-Altamirano, 2002] and [Iversen, 2010].

Documents of the following organizations are studied also: ISO (International Organization for Standardization), ETSI (European Telecommunications Standards Institute), IEC (International Electrotechnical Commission) and IETF (Internet Engineering Task Force).

1. What is Telecommunication?

The following six definitions are from [ITU-T B.13 1993]. This Recommendation is withdrawn – "deleted after its content became technically out of date". Unfortunately, better definitions are not accepted. These defined terms are basic in Informatics and Cybernetics also. After the text of definitions, we'll give some comments.

Information: Intelligence or knowledge capable of being represented in forms suitable for communication, storage or processing.
Note – Information may be represented for example by signs, symbols, pictures or sounds. [ITU-T B.13, 1993], [ITU-R/ITU-T, 2010] (term 701-01-01).

Signal: A physical phenomenon one or more of whose characteristics may vary to represent information. Note – The physical phenomenon may be for instance an electromagnetic wave or acoustic wave and the characteristic may be an electric field, a voltage or a sound pressure [ITU-T B.13 1993], [ITU-R/ITU-T, 2010] (term 701-01-02).

Transmission: The transfer of information from one point to one or more other points by means of signals. Note 1 – Transmission can be effected directly, or indirectly, with or without intermediate storage. Note 2 – The use of the English word "transmission" in the sense of "emission" in radiocommunication is deprecated.

Sending, (in telecommunication): The production of a signal at an input port of a transmission line or into a transmission medium.

Communication: Information transfer according to agreed conventions.

Telecommunication: Communication by wire, radio, optical or other electromagnetic systems. Note – The following definition is given in the International Telecommunication Convention (Nairobi, 1982): Any transmission, emission or reception of signs, signals, writing, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems.

Comment: The definition of telecommunication above is unacceptable from the Overall QoS (Quality of Service), point of view, in Telecommunication Systems, because it not includes humans, as main users of telecommunication services. It contradicts many UTU-T recommendations, considered human factors and overall QoS definitions. For example:

Quality of service (QoS) is: “Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service” [ITU-T E.800, 1994]. This is different from the “network performance”:

Network Performance: The ability of a network or network portion to provide the functions related to communications between users. NOTE 1 – Network performance applies to the network provider's planning, development, operations and maintenance and is the detailed technical part of QoSO (QoS offered/planned by service provider). NOTE 2 – Network performance parameters are meaningful to network providers and are quantifiable at the part of the network which they apply. [ITU-T E.800, 2008].

User is an entity that makes use of CE (communication entity) (e.g., initiates or answers a call, or a person or entity external to the network, which utilizes connections through the network for communication (term 2.17 in [ITU-T E.800, 2008], based on [ITU-T Q.1300, 1995]). Connection is used in the context of establishing communication between two points in a network. Note: A computer program may be a user. From the other hand, humans as telecom users determine subjective (qualitative) parameters of the QoS reflecting in the QoS experienced/perceived (QoSE) concept:

Subjective (qualitative) parameters are: “Parameters that can be expressed using human judgement and understanding may be classified as subjective or qualitative parameters. Qualitative parameters are expressed by opinion ratings.” [ITU-T E.802, 2007]

QoSE – QoS experienced/perceived by customer/user: A statement expressing the level of quality that customers/users believe they have experienced. NOTE 1 – The level of QoS experienced and/or perceived by the customer/user may be expressed by an opinion rating. NOTE 2 – QoSE has two main man components: quantitative and qualitative. The quantitative component can be influenced by the complete end-to-end system effects (network infrastructure). NOTE 3 – The qualitative component can be influenced by user expectations, ambient conditions, psychological factors, application context, etc. NOTE 4 – QoSE may also be considered as QoSD (QoS Delivered) - received and interpreted by a user with the pertinent qualitative factors influencing his/her perception of the service [ITU-T E.800, 2008].

Some authors use expression “Quality of Experience Layer” in the telecommunication system [Muntean, McManis 2004]. So “The Next Big Thing is Adaptive Web-Based Systems” [De Bra et al, 2004]. The World Wide Web Consortium (W3C) pay special attention to the development of adaptive human-computer network interface, taking into account individual human characteristics [W3C, 2003], [W3C, 2011]. Personalization of the human-computer telecommunication network interface is important research field: [Henze, Kriese, 2004], [Hewett et al, 1996], [Joffroy et al, 2007].

[ITU-T Y.2002, 2009]: The Fundamental characteristics of ubiquitous networking are: 1. IP connectivity; 2. Personalization; 2. Network Intelligence; 3. Tagging objects; 4. Smart devices. “Personalization will allow to meet the user's needs and to improve the user's service experience since delivering appropriate contents and services to the user“.

Based on these and other considerations ([Poryazov, Petkova 2004], [Dimkova, Poryazov 2009]) in this work we use other definitions of communication and telecommunication:

Definition 1: Communication is models' transfer from memory to memory. "Memory" is human or/and computer memory.

Definition 2: Telecommunication is remote communication, using electromagnetic or/and equivalent means.

Open Issue 1: These work definitions need some justifications, e.g. more formal model and memory definitions. This is issue for further study.

We make clear difference between telecommunication system and telecommunication network, see Section 2:

2. Scalable Models of Overall Telecommunication Systems

Scalability and Scalable Models

The generic non-functional recommendations for Internet traffic engineering include: usability, automation, scalability, stability, visibility, simplicity, efficiency, reliability, correctness, maintainability, extensibility, interoperability, and security [IETF RFC 3272, 2002]. In the same document scalability is described:

Scalability: Contemporary public networks are growing very fast with respect to network size and traffic volume. Therefore, a Traffic Engineering (TE) system should be scalable to remain applicable as the network evolves. In particular, a TE system should remain functional as the network expands with regard to the number of routers and links, and with respect to the traffic volume. A Traffic Engineering system should have a scalable architecture, should not adversely impair other functions and processes in a network element, and should not consume too much network resources when collecting and distributing state information or when exerting control.

Scalability: "A characteristic of a system, model or function that describes its capability to cope and perform under an increased or expanding workload. A system that scales well will be able to maintain or even increase its level of performance or efficiency when tested by larger operational demands." There is a definition from Investopedia: [Quantum Financier, 2011].

Model scalability is the ability to refactor a base model, by adding or replicating the base model elements, connections or substructures, in order to build a larger and more complex model to satisfy new design requirements. Although a number of modelling tools have been developed to create and edit models for different purposes, mechanisms to scale models have not been well-supported." [Sun at al, 2011].

The understanding of term "scalability" expressed above reflects scalability in the case of "scale up". For designing and managing telecommunication systems we need scalable models in the full meaning: "scale down: make smaller in proportion; reduce in size"; "scale up: make larger in proportion; increase in size"; "to scale: with a uniform reduction or enlargement" [COD 11].

The most close to our understanding is the following opinion: “Scalability is very important to computers and communications systems. The advantage of scalability of networks is the ease and low cost of adjusting them to the size required. This scalability has been a major factor in the success of the Internet” [LINFO, 2006].

Models scalability includes: temporal, spatial, structural, parametric, conceptual, functional and other scalabilities.

Open Issue 2: Development of General methodology of building scalable models. The most of scalabilities, mention above, are found only in several documents in Internet.

In this paper, we’ll discuss some ITU-T recommendations, existing scalable models of telecommunication systems and open issues in telecom models scalability.

Overall QoS in the telecommunication system is an aggregative result of several systems’ interaction, including network performance in every network point. Estimating and designing overall telecommunication systems, we need models on many levels, allowing parameters’ and values’ aggregation and decomposition.

Scalable reference models of Overall Telecommunication Systems

At the one extreme, the Telecommunication System is the biggest Global machine, made by humans. It comprises billions terminals all over the World, works continuously, gives about 10% of the Gross Domestic Product (GDP) of the developed countries and is the basis of the information society evolvement.

At the other extreme, each call attempt in the Telecommunication System engages concrete telecommunication equipment and may finish by many causes (see Causal Classification below). Describing network performance, we have to associate several virtual devices (“almost or nearly as described, but not completely or according to strict definition.” [COD 11]) to one real pool of recourses, reflecting causes considered. The software, realizing the intelligence in the modern telecommunication systems, is often considered as consists of virtual devices (Note: resource is “Any set of physically or conceptually identifiable entities within a telecommunications network, the use of which can be unambiguously determined.” – term 1.3 in [ITU-T E.600, 1993]). For each of the virtual devices, traffic is describing by means of incoming rate of requests and holding time. This approach is unavoidable in pool of recourses’ dimensioning. Hence, on the most detailed level, the number of performance parameters, in the Global Telecommunication System is immense.

Therefore, we need scalable reference models on many (at least 5) levels: virtual devices level; telecommunication system level; telecommunication systems’ interaction level; National telecommunications; Global Telecommunication System.

Open Issue 3: Only several scalable reference models were found, but not in telecommunications. Creation of scalable modelling methodology is an open issue.

2.1. Reference Models on the Virtual Devices Level

On the virtual devices level, there is a very usable reference model and correspondent classification of a pool of recourses with a queue – the Kendal's classification [Kendall, 1951] and its extensions, This classification considers mainly number of recourses and parameters' distributions' types. The notation of parameters and scalability are not discussed.

2.2. Reference Models on the Telecommunication System Level

On the telecommunication system level there is reference model of Ericson [Ericsson, 2001], Page 37. It contains five types of parts: Terminals; Access; Transport; Network Management; Network Intelligence.

We propose more complete reference model of a telecommunication system (Fig.1.1.), reflecting the present ITU-T terminology and making a difference between telecommunication system and telecommunication network. It contains seven types of subsystems:

- Network Environment (Nature, Technological and Socio-Economic);
- Users;
- Customers;
- Terminals;
- Telecommunication Network;
- Network's Information Servers;
- Telecommunication Administration.

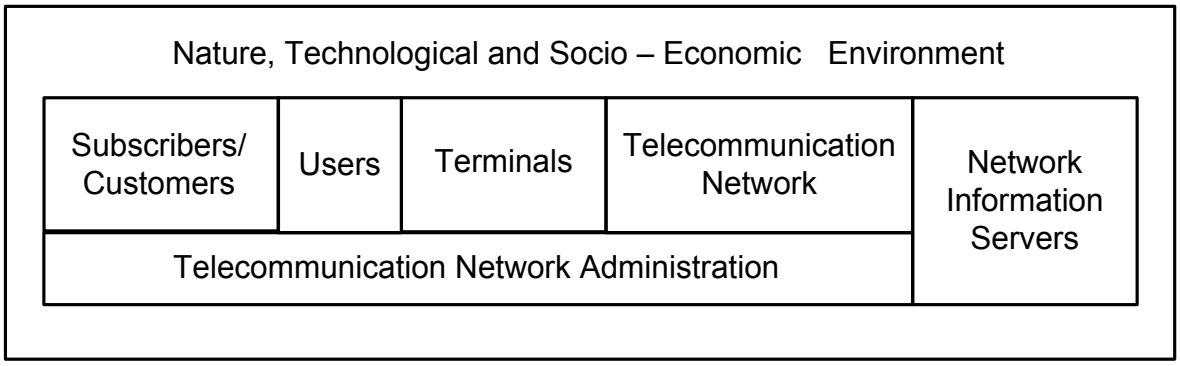

Figure 1. Overall Telecommunication System Reference Model. The subsystems are presented as rectangles. The considered possible interactions between two subsystems are presented by a common border between their presenting rectangles.

Explanations of the subsystems, and other involved terms are following:

Network Environment Subsystem (Nature, Technological and Socio-Economic) includes:

- Nature characteristics, important for cables' distribution and radio wave propagation and functioning. For example: seismic and ionosphere' geographical (position, relief, weather, flora, fauna), etc.;
- sociological (population's distribution and behaviour),
- economical (e.g. means of livelihood, GDP, competitors in the market);
- technological (availability and prices, of design, building and maintenance of the premises, hardware and software equipment) and so on.

The all parties types of telecommunications service market are: user, service provider, manufacturer, regulator [ITU-T E.800, 2008] and "academic experts who want to become inventors of new technological approaches" [Anttalainen, 2003]. In a more general view: The Information Communication Architecture (future development of information communication networks and services) accommodates the needs of different roles such as user, subscriber, network provider, service provider, network designer, service designer, developer, deployer/withdrawer, network manager, service manager, and service broker [ITU-T Y.130 2000].

The proposed general reference model, includes users, customers and Network Administration of roles described, because some quantitative models, connecting them to the existing network traffic models are known. All other players are considered as parts of the Network Environment.

Open issue 4: To develop qualitative and quantitative models allowing separating the network Environment into parts, interacting among themselves and with others subsystems of the telecommunication system.

Users' Subsystem

For users – see definitions in Section 1.

Customers' Subsystem

Customer is "a user who is responsible for payment for the services" (term 2.18 in [ITU-T E.800, 2008]). The similar term is "subscriber":

Subscriber [ITU-T M.3050.1, 2007]: The subscriber is responsible for concluding contracts for the services subscribed to and for paying for these services [ITU-T Y.1910, 2008].

Service provider A general reference to an operator that provides telecommunication services to customers and other users either on a tariff or contract basis. A service provider can optionally operate a network **[**ITU-T M.1400, 2006]. A service provider can optionally be a customer of another service provider. NOTE – Typically, the service provider acquires or licenses content from content providers and packages this into a service that is consumed by the end-user [ITU-T Y.1910, 2008]. Another definition is:

Service provider: An organization that provides services to users and customers [ITU-T E.800, 2008].

Content provider: The entity that owns or is licensed to sell content or content assets [ITU-T Y.1910, 2008].

"The Information Communication Architecture is aimed at both user and network operators. In this context "user" covers both "end-user" as well as "user" as a client in any client server situation. In addition, content providers and service providers may also be considered to be users" [ITU-T Y.130, 2000].

Open Issue 5: Obviously, user, end-user, customer/subscriber, content provider, network provider, service provider, network designer, service designer, developer, deployer/withdrawer, network manager, service manager, service broker etc. are not entities, there are roles. Two or more roles may belong to an entity simultaneously. The roles' modelling of one entity is an open issue in telecommunication systems.

Terminals' Subsystem

Terminal (terminal equipment) is a communication entity between user and communication network (see Fig. 1 in [ITU-T E.800, 2008]). Particularly, a terminal may be voice terminal, video terminal, data terminal (A device to allow a user to communicate with a computer [ITU-T Q.1300, 1995]), multimedia terminal, etc. Related term is Customer premises equipment: Telecommunications equipment located at the customer installation on the customer side of the network interface [ITU-T E.800, 2008].

Telecommunication Network Subsystem

Network is: A set of nodes and links that provide connections between two or more defined points to facilitate telecommunication between them [ITU-T Y.101 2000]. Telecommunication Network consists of Communication Entities – nodes (terminal and distribution entities) and links (lines).

Communication entity (CE) is an entity (e.g. telephone) that originates, terminates or becomes visible in a call.(term 3.1.10 in [ITU-T Q.1300, 1995]).

Telecommunication Device is abstracted as a Communication Entity (CE). Communication entities include lines and distribution entities [ITU-T Q.1300, 1995]. Distribution entities are switches and routers, for example.

Connection is "bearer path, label switched path, virtual circuit, and/or virtual path established by call routing and connection routing". ([ITU-T E.360.1, 2002] and [ITU-T E.361, 2003]). See also [ITU-T E.600, 1993]: Connection is "an association of resources providing means for communication between two or more devices in, or attached to, a telecommunication network.'

At functional view point, telecommunication network consists of "traffic network" (at "user plane" in [ITU-T Y.1711 2004]), 'transmission network" [ITU-T E.737, 2001] (caring target users' traffic), and "signalling network" [ITU-T Y Suppl. 11, 2010] (caring network control traffic). The both networks are strongly interconnected and often use common equipment (see ITU-T Recommendations M.760-M.799: "Common channel signalling systems)", but in the more cases "bearer and signalling circuits" are considered separately [ITU-T E.755, 1996] and are

dimensioning differently – see for example [ITU-T E.733, 1998] and [ITU-T E.734, 1996]. "The transport plane should be separated from the control plane for efficient mobility management and scalability. Such separation of control and transport planes provides the architectural flexibility that facilitates the introduction of new technologies and services. Open interfaces between the control plane functions and the transport plane functions are necessary to implement their separation" [ITU-T Q.1706/Y.2801, 2006].

Note: The terminology here is an open issue – from one hand, "traffic network", "transmission network", "bearer circuits", "transport plane", "Content delivery functional architecture in NGN" ([ITU-T Y.2019, 2010]) are used in similar meaning, and from the other hand: "signalling network", "control traffic", "control plane", "Telecommunications Management Network" (see below). More terminology co-ordination looks necessary.

Network's Information Servers' Subsystem

Network's Information Servers are intelligent network nodes [ITU-T E.415, 1991] and other network entities, providing subscribers' identification, terminals' location, billing and other network control and management functions. Examples are bandwidth-broker processors and other automatic/manual work centres [ITU-T E.360.7, 2002].

Note: Network's Information Servers are part of the telecommunication network and are different from external information servers and services providers, ensuring tele-shopping or tele-medicine for example. These external service providers are users and/or customers of the telecommunication network.

Telecommunication Administration's Subsystem

In ITU-T recommendations, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency [ITU-T G.1000, 2011].

A connected term is Network provider: An organization that owns a telecommunications network for the purpose of transporting bearers of telecommunication services [ITU-T E.800, 2008].

A function of the Telecommunication Administration is:

Customer relationship management (CRM): Identification and resolution of the issues in the contractual relationship between the service provider and the user in the provision and consumption of a service. NOTE – Examples of issues are customization of bills, tariff options, variants of service, negotiated repair arrangements, etc. [ITU-T E.800, 2008].

Other functions of the Telecommunication Administration are: network control, management, dimensioning, re-dimensioning, design, planning and interconnection:

'Interconnection' shall mean the physical and logical linking of public communications networks used by the same or a different service provider in order to allow the users of one service provider to communicate with users of another service provider, or to access services provided by another service provider [ITU-T E.800, 2008].

Open Issue 6: The Overall Telecommunication System Reference Model proposed does not explain interconnections and interactions among subsystems. There are many papers on parts of these interactions, but overall approach is missing. May be the best paper (yet !) is [ITU-CCITT, 1987], and for Bulgaria – [Todorov et al, 1981]

2.3. National Telecommunications Level Reference Models

Models on National Telecommunications Level are more complicated than reference models of a single telecommunication system, because one user may have and use several terminals and each terminal may request connections from several possible Network Providers [Andrianov et al 2009].

Open Issue 7: Complete enough Reference Telecommunication systems' models on National Level are not known.

Consideration on national (United States) level are presented in ITU-T 360.X series, e.g., a full-scale national 135-nodes network model is used, together with a multiservice traffic demand model, to study various TE scenarios and tradeoffs in [ITU-T E.360.2, 2002], but the interaction with other national networks is not considered.

2.4. Global Telecommunication System level Reference Models

On the Global Telecommunication System level we have statistical data and econometric dependencies only [ITU-D Database, 2010].

Example of end-to-end communication across different national ETS (emergency telecommunications services) is given in [ITU-T Y.2701, 2007]. This is far from a model of Global Telecommunication System level, but shows its necessity.

Open Issue 8: Creating the methodology and scalable reference models, allowing scalability in telecommunication systems' considerations, in case of global, national and local emergency situations. Such approach may help in econometric and other interactions modelling.

2.5. Inter-Conceptual Interactions and Models' Scalability

An example of Inter-Conceptual Interactions necessity is the concept of "telecommunications management network", including different, but strongly interconnected sub-concepts [ITU-T M.3050.1, 2007]:

Telecommunications Management Network (TMN): The telecommunications management network model was developed to support the management requirements of PTOs (public telecommunication operators) to plan, provision, install, maintain, operate and administer telecommunication networks and services. As the

communications industry has evolved, use of TMN also evolved and it has influenced the way to think logically about how the business of a service provider is managed. The TMN layered model comprises horizontal business, service, and network management layers over network hardware and software resources, and vertical overlapping layers of fault, configuration, accounting, performance and security (FCAPS) management functional areas. The latter should not be considered as strictly divided "silos" of management functions, but interrelated areas of functionality needed to manage networks and services. Indeed, [ITU-T M.3200, 1997] and [ITU-T M.3400, 2000] define a matrix of management services and management function sets (groups of management functions), which in turn are used to define more detailed Recommendations on specific management functions

The Enhanced Telecom Operations Map (or eTOM for short) is a business process model or framework for use by service providers and their suppliers and partners within the telecommunication industry. It describes all the enterprise processes required by a service provider and analyses them to different levels of detail according to their significance and priority for the business [ITU-T M.3050.1, 2007].

Open Issue 9: In telecommunication we need scalable models with multi-conceptual interactions, by reasons explained above.

Inter-Conceptual Interactions are known in physics and engineering as “multiphysics” and is already subject of baccalaureate engineering degree programs [Eppes et al 2011].

3. The Overall Versus End-to-End Approach to Telecommunication Network Performance

The expression “overall network” is often used, but a clear definition was not fined. In an attempt to propose definitions, we’ll consider different points in telecommunication networks and their functional architecture, defined in ITU-T recommendations as follows:

Functional Architecture: A set of functional entities and the reference points between them used to describe the structure of an NGN (New Generation Networks). These functional entities are separated by reference points, and thus, they define the distribution of functions. NOTE 1 – The functional entities can be used to describe a set of reference configurations. These reference configurations identify which reference points are visible at the boundaries of equipment implementations and between administrative domains. NOTE 2 – This definition is relates to NGN. However, it is also valid for other networks, e.g., networks supporting IPTV [ITU-T Y.2012, 2010].

Functional Entity: An entity that comprises an indivisible set of specific functions. Functional entities are logical concepts, while groupings of functional entities are used to describe practical, physical implementations [ITU-T Y.2012, 2010].

Reference Point: A conceptual point at the conjunction of two non-overlapping functional entities that can be used to identify the type of information passing between these functional entities. NOTE – A reference point corresponds to one or more physical interfaces between pieces of equipment [ITU-T Y.2012, 2010].

Network head-point: A network head-point refers to a terminal at the sending user's side which is connected to the measurement system either electrically or acoustically [ITU-T P.10/G.100 Amendment 2, 2008].

Network end-point: A network end-point refers to a terminal at the receiving user's side which is connected to the measurement system either electrically or acoustically [ITU-T P.10/G.100 Amendment 2, 2008].

Network mid-point: A network mid-point refers to any point in the network that is not the head point or the end-point which is connected to the measurement system either electrically or acoustically [ITU-T P.10/G.100 Amendment 2, 2008].

3.1. End-to-end Network Approach

In the end-to-end approach, call/connections from a network head-point to a network end-point are considered usually. For example, in [ITU-T E.737, 2001]: “End-to-end call/connection blocking probability is defined here as the probability that an arriving call/connection is not successfully established due to lack of sufficient resources for the call/connection in the user-plane of the network”.

In Figure 1 in [ITU-T E.800, 2008] a “Schematic contributions to end-to-end QoS” is presented. It includes: Users, Terminal Equipment and Access networks. Users are not connected to the terminals.

In [ITU-T Y.2173, 2008] a General Reference Network Model is described: “Along the end-to-end path, there are two CPNs (Customer Premises Network), two access networks, one or multiple core networks, zero or multiple transit networks, and one or multiple service provider networks. The access networks, core networks, transit networks and service provider networks may belong to the same or different network or service providers.” In the same Recommendation, there is a more detailed “terminal equipment-to-terminal equipment” model, including Measurement points. Users are not mentioned as a part of the network in both reference models.

The understanding of end-to-end QoS definitely considers connections of one user/customer:

“End-to-End QoS consider the case when a SLA (Service Level Agreement) between an end user and a provider, for a connection passing through several SP (Service Provider) domains, is agreed. Thanks to the one stop responsibility, the end user will require the agreed QoS exclusively from the service provider with whom he agreed upon the SLA, while the latter will have to guarantee that QoS by signing, in its turn, suitable SLAs with its subproviders” [ITU-T E.860, 2002].

In accordance with this ”customizable end-to-end QoS services” are discussed in [ITU-T Y.1292, 2008] and “the fundamental challenges to achieving end-to-end QoS are present”, considering users, in [ITU-T Y.1542, 2010]. For end-to-end view of key assumptions in QoS-enabled mobile VoIP service, see [ITU-T Y.2237, 2010].

Based on these concepts, accepted in ITU-T, we propose a General reference model of contributions to end-to-end QoS (Fig. 2.). In our understanding users are indivisible part of end-to-end QoS concept (see QoSE in Section 1). NOTE – The phrase "End-to-End" has a different meaning in Recommendations concerning user QoS classes, where end-to-end means, for example, from mouth to ear in voice quality Recommendations. Within the context of this Recommendation, end-to-end is to be understood as from UNI-to-UNI (UNI = User-Network-Interface) [ITU-T Y.1541, 2006].

On Figure 2: User A is calling user. User B is called user.

Network Terminal: See Terminals' Subsystem above

Customer Premises Network: A network administered by the users [ITU-T Y – Supplement 7, 2008]; Customer premises network includes business premises network, where some kinds of information appliances such as telephone, TV and PC are interconnected via wired or wireless LAN, and residential premises network, where such information appliances are interconnected via access unit. Various kinds of network services would be provided by means of such network segments. Some other components such as video servers, head ends, and routers might be necessary for specific services [ITU-T Y.110 1998]; A Mobile Customer Premises Network (MCPN) is a subnetwork in a mobile vehicle (e.g. train, ship, car, etc.). Thus MCPNs involve radio interfaces at both the terminal and the network side ITU-T E.751 1996].

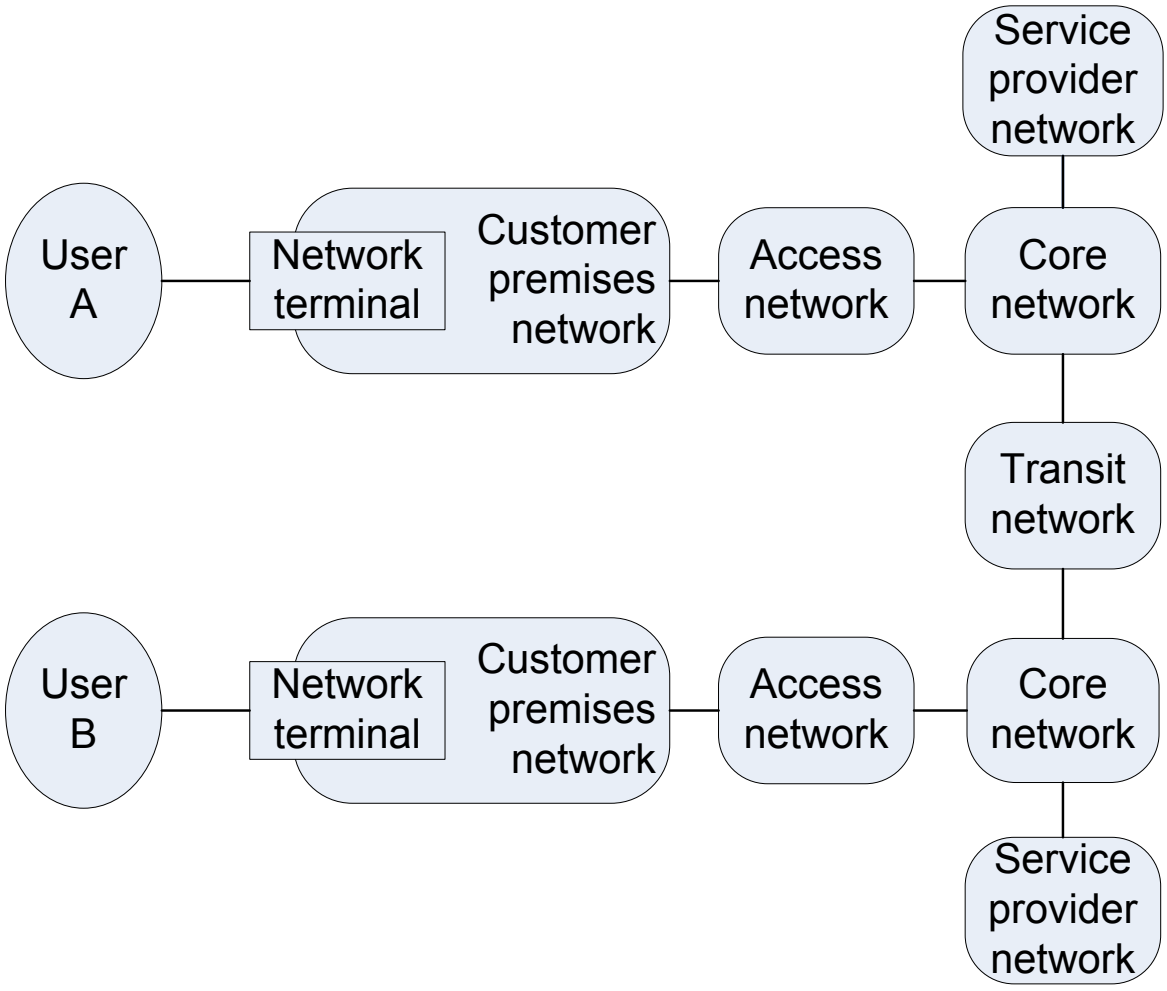

Figure 2. General reference model of contributions to end-to-end QoS.

On telecommunication systems interaction level we have–originating, transit, and terminating network [ITU-T E.755, 1996], respecting origination and destination of the calls. These networks are not necessary fixed –see "Multiple ingress/egress interdomain routing" [ITU-T E.360.2, 2002]. In this classification, Customer Premises Networks of A and B-users are originating and terminating, respectively.

Access Network: An implementation comprising those entities (such as cable plant, transmission facilities, etc.) which provide the required transport bearer capabilities for the provision of telecommunications services between a Service Node Interface (SNI) and each of the associated User-Network Interfaces (UNIs) Service Node is "A network element that contains one or several of the service control functions, service data functions, specialized resource functions and service switching/control function to provide a service in the context of GII (Global Information Infrastructure); Service Node Interface (SNI) is not described in this Recommendation; User-Network Interface (UNI): The interface between the terminal equipment and a network termination at which interface the access protocols apply [ITU-T, Y.101 2000].

Core Network: A portion of the delivery system composed of networks, systems equipment and infrastructures, connecting the service providers to the access network [ITU-T, Y.101 2000].

Core Network: An architectural term related to the part of an NGN (New Generation Networks) network, which is independent of a specific access technology [ITU-T Q.1707/Y.2804, 2008].

Service Provider Network: A network administered by a Service Provider.

3.2. Overall Telecommunication System Approach

Our Overall Telecommunication System Approach is in conformance with the general quality definition:

Quality: The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs – (ISO 8402: 1986, 3.1), remains in (ISO 8402, 1994) and [ISO 9000, 2005].

The ITU-T quality definition is similar, which shows the stability of the concept:

Quality - The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs. NOTE – The characteristics should be observable and/or measurable. When the characteristics are defined, they become parameters and are expressed by metrics [ITU-T E.800, 2008].

Based on the expression in [ITU-T E.202, 1992]:"In principle, the design of future mobile systems should take into account, the overall end-to-end transmission performance on all realistic connections", and overall blocking definition in [ITU-T E.737, 2001]. we propose the following overall telecommunication network approach definition:

Definition 3: Overall telecommunication network performance includes network performance of all connections' attempts in an overall telecom network, from all access-network-head-points to all access-network-end-points, in the time interval considered.

Note 1: For connection definition see “Telecommunication Network Subsystem” in Section 2.2;

Note 2: For connection attempt definition (call attempt, call demand and repeated call attempt) see [ITU-T E.600, 1993]:

- call attempt: An attempt to achieve a connection to one or more devices attached to a telecommunications network. At a given point in the network a call attempt is manifested by a single unsuccessful bid, or a successful bid and all subsequent activity related to the establishment of the connection;
- call demand: A call intent that results in a first call attempt;
- repeated call attempt; reattempt: Any of the call attempts subsequent to a first call attempt related to a given call demand. Repeated call attempts may be manual, i.e. generated by humans, or automatic, i.e. generated by machines.

Note 3: For network performance definition see [ITU-T E.800, 2008] (Section 1). For Network performance objectives for IP-based services see [ITU-T Y.1541, 2006].

Note 4: Overall telecommunication network may consists of several telecommunication networks, operated by different operators (see end-to-end QoS approach above).

An end-to-end approach to QoS parameters, in a multi-provider environment, mentioning overall QoS parameters, is described in [ITU-T E.860, 2002].

In our approach, the overall QoS parameters are aggregation of all end-to-end QoS parameters of all connections in the telecom system, in the considered time interval.

Based on the Definition 3 above and our understanding of telecommunication system described in Open Issue 1, we propose the following overall telecommunication system performance definition:

Definition 4: Overall telecommunication system performance, in the time interval considered, includes:

- all intended, suppressed and attempted connections, among all users/subscribers through the overall telecommunication network
- all intended, suppressed and attempted connections (not necessary telecommunication connections) between users/subscribers, from one side and network information servers, Network Service Providers and/or Network Administrations, from other side.

Note 1: For intended and suppressed connection definition, see [ITU-T E.600, 1993] – Call intent: The desire to establish a connection to a user. Note – This would normally be manifested by a call demand. However, demands may be suppressed or delayed by the calling user's expectation of poor Quality of Service performance at a particular time.

Open Issue 10: Some providers are now beginning to interconnect with each other via "QoS-enabled peering" in an attempt to offer QoS that spans the networks of multiple providers. However, in the absence of appropriate standards and established procedures for management, trouble-shooting, monitoring, etc., such interconnections are likely to be challenging and labour-intensive. Note however that large amounts of Provider Edge – Provider Edge or Customer Edge – Customer Edge probing raises scalability issues. [ITU-T E.800 Suppl. 8, 2009].

4. States' Models Scalability

States: An indication of an object's current condition that permits prediction of the object's future behaviour [ITU-T Q.1300, 1995].

Object: An intrinsic representation of an entity that is described at an appropriate level of abstraction in terms of its attributes and functions [ITU-T Q.1300, 1995].

The Network State expression is used often in ITU-T Recommendations, without explicit definition, for example: "State-Dependent Routing (SDR) path selection methods use the principle of routing connections on the best available path on the basis of network state information" [ITU-T E.360.2, 2002].

4.1. Network's Call/Connection Streams State

In ITU-T Recommendations state space analysis is used in the meaning of "call/connection streams" state:

State space analysis: Computation of end-to-end call/connection blocking probabilities could be based on a state space analysis of the network. For the purpose of computing the blocking probabilities, a vector, each of whose elements represents the number of calls/connections in progress of one of the call/connection streams in the network, is usually taken as the state of the network. In general, there are various ways of specifying network states and state space depending on the purpose of applications. Usually, it may be possible to specify a state space and state transitions in the space by considering the characteristics of call demand types and the call and connection level traffic controls employed. By analysing the steady-state probabilities of the network, the call/connection blocking probabilities of individual traffic streams may be computed. In some cases, the state probabilities have the product-form [ITU-T E.737, 2001].

The "call/connection streams" are requests. The term "request" is in the general meaning of "an act of asking politely or formally for something" [COED11] It is used as at least 18 451 times in ITU-T Recommendations in associations like: "request for service"; "call request"; "request associated with the original message"; "A request is a message that results in action by the…"; "request packet"; "connection request"; "handover request"; "request of transmission"; "channel request"; "facility request" etc.

We will use, in this paper, term "request" as a generalization of all these and following cases:

A call attempts and a call (explained above) are requests;

A session is a request:

Session: A temporary telecommunications relationship among a group of objects in the service stratum that are assigned to collectively fulfil a task for a period of time. A session has a state that may change during its lifetime. Session-based telecommunications may, but need not be, assisted by intermediaries. Session-based telecommunications can be one-to-one, one-to-many, many-to-one, or many-to-many [ITU-T Y.2807 2009].

Upper levels requests are thinkable also, because they may be paid separately: work, task, sup-packed, packed, project etc. Telecommunication models including request scalability are not known.

Every network state concept is facing a parameter's scalability problem by reason of real networks' complexity. For example in "call/connection streams" approach the micro-states number of an end-to-end telephone call model is from 10^8 to 10^{14} [Endaltsev et al, 1988].

Open Issue 11: Development of an appropriate approach to requests' definitions, requests, states description and requests' models scalability is an open issue.

4.2. Network's Aggregative Device State

In [Poryazov, 1991] other approach to the network state is proposed: The overall network model is considered comprising (nested) virtual devices on several service levels: (base virtual device, phase, stage, switching subsystem, terminals subsystem). The network state is considered as aggregation of the macro-states (e.g. mean traffic intensity) of these virtual devices. This allows states scalability in the model.

The "call/connection streams state" and "aggregative device state" approaches are not alternative. They are supplementary, because requests' and devices' states are interconnected.

This "aggregative device state" approach is advanced in [Poryazov, Saranova, 2006], where tuple concept for networks state is proposed. It is presented here in developed and abstracted, from the concrete model, edition applicable not only to a network, but to a telecommunication system's state also:

System Tuple Set

Full system's parameter set: consists of all parameters of the virtual devices (communication entities) composing the telecom network model.

A system tuple is a finite set of distinguishable (by name and/or position) parameters and their values, which fulfils simultaneously the three following requirements:

1. All parameters (parameters' set), of the system tuple, correspond to one considered (observed, modelled) system;
2. All the values of a system tuple parameters correspondent to the one and the same time interval of measurements or considerations;
3. The instant of beginning and duration of this time interval are elements of the system tuple set.

Remarks: 1. Our definition of system tuple is based on the tuple definitions in Computer Science (Relational Data Bases) and Mathematics. It is adjusted for real systems' measurements, modelling and simulation; 2. Every subset of a system tuple, we call "sub-tuple".

Static and Dynamic Parameters' Classification

The duration of the observed or/and modelled time interval may vary from:

- Years – see annual reports of Telecom Administrations and [ITU-D Database, 2010];
- Season or month ("A month is chosen because it is short enough that seasonal variations and growth will not significantly affect load behaviour during the time interval considered, and it is long enough to get adequate statistical significance" [ITU-T E.500, 1998]);
- week, day ("The three daily groups to be considered are: working days, week-end days (including most holidays), and yearly exceptional days (e.g. Christmas, Mother's Day, extraordinary events, etc".) [ITU-T E.500, 1998]);
- hours, minutes ("In fact, the daily peak traffic intensity for different traffic systems can occur during different read-out periods" [ITU-T E.500, 1998]), "Use of an hour or possibly 15-minute interval of time would facilitate support by existing operations systems" [ITU-T I.358, 2003].
- minutes, seconds ("In all sections where the evaluation of events is described, the measurement technique is based on a sliding-window with a 1 second (and x second for FFD OAM option) granularity of advance" [ITU-T Y.1711 2004].);
- instant of time (see traffic intensity definition in [ITU-T E.600, 1993]),

[ITU-T E.360.1, 2002]: "Capacity management must provide sufficient capacity to carry the expected traffic variations so to meet end-to-end blocking/delay objective levels. Traffic load variations lead in direct measure to capacity increments and can be categorized as:

1) minute-to-minute instantaneous variations and associated busy-hour traffic load capacity;

2) hour-to-hour variations and associated multihour capacity;

3) day-to-day variations and associated day-to-day capacity; and

4) week-to-week variations and associated reserve capacity."

In each non-zero time interval above, the values of the system's tuple parameters may be classified as static (constant, independent of time), stationary (in a steady state, e.g. variable but with near to constant mean) or dynamic (dependent of the time). The classification depends on time scale, parameter's values dynamic and system's model objectives.

A telecommunication system's state is presented and modelled with a system tuple, if the model considers a stationary state of the system (the predominant practice). In dynamic models, more system tuples are needed, as well as functions, describing transitions dynamic between system tuples.

Telecom system may consists of many networks. This gives rise to problems in observation co-ordinations: "Different measurement periods and principles for collecting traffic data may have been used in different networks and services, depending on the operator. This solution leads, however, to overlapping data collecting and processing, and increases the possibility of inconsistencies. This Recommendation presents some principles which facilitate collecting and handling of data for different purposes, in different networks and services, run by several operators" [ITU-T E.492, 1996].

Base Parameters' Set (Base Tuple)

There are many obvious dependencies in a System Tuple (the Full System's Parameter Set). For example, the sum of probabilities of outgoing transitions in every virtual switch devices has value one; in stationary state Little's formula (Y = F T) [Little, 1961] is in force for every virtual device; we assume most of devices with infinite capacity. As a result, there are sets of parameters (sub-tuples of 'base parameters'), with the following property: If we knew the values of the base parameters, we may calculate the values of all other parameters of the overset System Tuple. Several different base parameters' sets may exist. We call base parameters' set and correspondent values of these parameters "*Base Tuple".* Obviously, a Base Tuple is a sub-tuple of the System Tuple.

Open Issue 12: To find minimal Base Tuple, among all base tuples of a System Tuple. This is important, because a telecommunication system is modelled with a big number of parameters, making measurements, modelling and simulation, visualization and understanding too hard.

Open Issue 13: To find minimal Easy-to-Measure Base Tuple, among all base tuples of a System Tuple.

Values of many important parameters in telecommunication system is Hard-to-reach data [ITU-T E.360.1, 2002] and "The functions of a network management operations system include the following:…– calculating hard-to-reach status of destinations and providing this information (hard-to-reach information) to exchanges" [ITU-T E.411, 2000]; "one of the early things traffic managers should look at is the hard-to-reach data" [ITU-T E.360.7, 2002].

5. Parameters' Classification Based on Their Values' Establishing Method

In many Teletraffic Engineering (TE) tasks, especially in Telecommunication System Design, we have to use more than one different values of a parameter, in one consideration, even in a mathematical expression. For example: empirical, target and design values of the blocking probability parameter. This shows necessity of values classification and correspondent notation.

The parameters of the System Tuple and chosen base parameters' subset (Base Tuples) may be classified, according their values Establishing Method, in at the least seven groups:

Empirical values

Empirical values are results of measurements, observation, surveys in real systems. They are two types: Primary (direct) and derived (indirect, second level):

Primary performance parameter: A parameter or a measure of a parameter determined on the basis of direct observations of events at services access points or connection element boundaries [ITU-T I.350, 1993].

More generally, measurements for a primary QoS parameter are taken at specific measurement points. Such points are simply interaction points, where reference events or their outcomes can be observed, and may be located or not in the technical interface (e.g., when measurements are obtained from a sub-provider) [ITU-T E.860, 2002].

Derived performance parameter: A parameter or a measure of a parameter determined on the basis of observed values of one or more relevant primary performance parameters and decision thresholds for each relevant primary performance parameter [ITU-T I.350, 1993].

Once primary QoS parameters are obtained, parameters of second level can be derived as functions of these values…Indirect Parameters are defined as functions either of values of primary QoS parameters or of decisions taken on the basis of the latter [ITU-T E.860, 2002].

Forecasted values

Telecom system's design includes network performance modelling in a future environment, so of vital importance is forecasting not only of traffic and call data but also economic, social and demographic data. Forecasting methods and econometric models are given in [ITU-T E.506, 1992]. There are many papers on forecasting methods, but in ITU recommendations aspects of value forecasting are described in [ITU-T E.507, 1988], [ITU-T E.508, 1992] and [ITU-CCITT 1987].

Assumed values

In the complicated telecommunication systems' modelling, structures', business relationships', processes' and parameters' simplifying assumptions are unavoidable:

- "Independence assumption among components" [ITU-T E.737, 2001];
- "In the context of this Supplement, it is a reasonable basic assumption that a receiving provider, promising to deliver IP traffic with a defined quality of service, performs a service to the sending provider" [ITU-T E.800 – Suppl. 8, 2009];
- "Traffic models adopt simplifying assumptions concerning the complicated traffic processes. These assumptions are directly explained in the Recommendations on dimensioning". (pp.9) [ITU-T E.490.1, 2003];

- "The objective of this Recommendation is to provide possible methods which are useful for dimensioning the network for a given set of traffic demand assumptions and GoS objectives, particularly, call/connection blocking probability objectives" [ITU-T E.737, 2001];

Sometimes assumptions are "for further study": "Assumptions for establishing objectives… The exact conditions or assumptions under which these worst-case objectives may apply are for further study" [ITU-T I.358, 2003].

Assumptions may be hypothetical: "In order to evaluate the performance of a component, it is assumed that a hypothetical traffic is offered to the component. The hypothetical traffic variables such as arrival rate are derived from the traffic characteristics of the original traffic assumption, the performance of the other components and traffic routing among the components" [ITU-T E.737, 2001].

Assumptions are always important, but sometimes are "no longer realistic": "The specific proposal for a throughput probe that appeared in previous versions of this Recommendation has been deleted, since some of the assumptions about maximum TCP window size settings and packet sizes are no longer realistic" [ITU-T Y.1540, 2007].

Target values

QoS objectives may be expressed by target values, thresholds and ranges set to QoS parameters [ITU-T E.860, 2002]. "The target values in this table are to be interpreted as design objectives" [ITU-T E.721, 1999].

"Network operators are using Grade of Service (GoS) parameters and their associated target values:

- as internal design objectives;
- to meet Quality of Service (QoS) objectives to customers; and
- to meet commitments to other network operators" [ITU-T E.726, 2000].

(GoS (grade of service) is one of the few ITU-T concepts not easy for grasping and using. It is: "a number of network design variables used to provide a measure of adequacy of a group of resources under specified conditions (e.g., GoS variables may be probability of loss, dial tone delay, etc.)" [ITU-T E.361, 2003]. . "NOTES: 1. The parameter values assigned as objectives for grade of service variables are called grade of service standards. 2 The values of grade of service parameters achieved under actual conditions are called grade of service results" [ITU-T E.600, 1993]. "The key point to solve in the determination of the GoS standards is to apportion individual values to each network element in such a way that the target end-to-end QoS is obtained". [Iversen, 2010]. Term "GoS" is not mentioned in [ITU-T E.800, 2008])

Defining target values: "Target values are determined in order to improve the quality of a service within a specified period of time. Depending on the service aspect that is subject for improvement, target values are fixed for specific QoS parameters" [ITU-T E.802, 2007]. Many key performance parameters and their target values are described in [ITU-T E.671, 2000], [ITU-T E.802, 2007], [ITU-T G.1010, 2001] and other ITU-T Recommendations.

Threshold Values

"Derived performance parameters describe performance based on events which are defined as occurring when the value of a function of a primary performance parameter(s) crosses a particular threshold. These derived threshold events identify the transitions between the available and the unavailable states" [ITU-T I.350, 1993].

"Depending on the QoS parameter under consideration, the reference value can consist of a threshold value (e.g., the performance should be better than a minimum threshold) or of an acceptable performance range. The final determination of a specific reference value depends on the kind of parameter (e.g., whether it is based on network performance parameters or subjective aspects), the technology involved and the kind of verification methodology used" [ITU-T E.802, 2007].

Threshold values occur in many theoretical considerations. In Terminal Teletraffic Theory and Overall Teletraffic Theory thresholds are introduced in [Poryazov, 1991], [Poryazov, 2004], used in [Poryazov, Saranova, 2006] and extended to more parameters in [Saranova, 2008].

Administrative values

Some parameters' values are determined or coordinated administratively. For example:

- The durations of busy and ringing tones are usually limited administratively.
- "The QoS parameter values administratively coordinated at the network-to-network interface include: committed information rate, transit delay, and frame loss ratio. Additional parameters including Bc, Be, frame size, and DLCI should also be administratively coordinated at the network-to-network interface" [ITU-T I.372, 1993].

Design values

Design values are values of design variables, e.g. in [ITU-T E.529, 1997]: "The objective of network dimensioning in this Recommendation is to determine the design variables for a given traffic load assumption to meet a given end-to-end GoS requirement in the most economical way".

Design values are output of the design model, with input consists of empirical, forecasted, assumed, target, threshold and administrative values.

Sometimes design values may correct design model's input values. For example, the design value of blocking probability may be lower than the target one.

Test values

Test values are values of design variables ("test parameters" [ITU-T Q.542 1993]), in the processes of a communication entity or its model testing (model verification and validation [?]). "Routine tests, statistical tests,

manual activities and/or other means may be used to verify proper operation of these functions...Testing may be manual or automatic" [ITU-T Q.542 1993].

In a summary, designing a telecommunication system we need at least one base system tuple of parameters, with several qualifiers for parameters characterization and at least seven qualifiers for parameters' values classification based on values' establishing method. Each parameter may be base or aggregative.

6. Causal Classification of Values

In [ITU-T E.425 2002] Network Effectiveness depends of three parts: Network Failures; User Failures (ineffective calls associated with the calling and called subscribers) and Completed Seizures. There is a note in the "Cause value categorization" section: "It is important to note that this classification is theoretical and that in practice, some cause values categorized as a user failure can be in reality a network problem". "Cause value" field in [ITU-T E.425 2002] contents 99 items. In [ITU-T Q.850 1998] there are 127 cause value numbers and other failures' sources, for example Network Service Provider.

Causal values' classification is necessary not only for network control and management. It is important for network modelling and design also. In models we have other sources causing values – the modellers. Some model variables have not corresponding objects in the modelled system, but may sometimes improve the adequateness of the models' behaviours. For example, see the parameter in the Bernoulli-Poisson-Pascal model ([Iversen, 2010]).

Open Issue 14: Causal qualifiers and causal scalability are necessary for performance modelling and presentation on different causal levels: from hundreds causes, in the system control and management plane, to several main causes in the Annual Reports Level.

7. Overall Telecommunication System's Parameters' Notation System

Open Issue 15: Developing of a telecommunication system's parameters' notation system, allowing parameters' and their values naming according to at least eight requirements:

- Multi-conceptual dynamic modelling of the system. In the traffic modelling concept there are virtual devices and their parameters (see "Full system's parameter set" above). For other concepts, used for telecommunication system description (see "Overall Telecommunication System Reference Model" above) there are other entities, processes and parameters, which need appropriate notation, but are outside the scope of this paper. Notation means for Inter-conceptual interactions are mandatory. Overall telecommunication system is an entire entity, so conceptual scalability of its models is very welcome.
- Functional Role of the characterized virtual device or participating entity (for communication entity, see above) in the functional structure of the model. For telecommunication network such functional roles are, for example: transmission, switching, storage, computing, decision, management and billing. Now, practically, only graphic notation of these entity's functions is used. In electronics there is letter notation, e.g. R is standing for "resistor", C – for "capacitor", T – for "transistor" etc.

- Parameters' Characterization. In almost every model of a complex system, a parameter's name is not enough and qualifiers are used. For some qualifiers in Teletraffic models see [ITU-T E.600, 1993].
- Service Position in the model, of the characterized virtual device or participating entity. For telecom network, for example, one may divide the following service levels: base virtual device, phase, stage, switching and other subsystems, terminals subsystem and network state (considered as aggregation of the macro-states of included virtual devices.).
- Space Position in the model, of the characterized virtual device or participating entity. Telecommunication systems are distributed all over the World, but every their entity influences their performance, so space position notation and space scalability are advantages.
- Parameters' Values' Establishing Classification
- Parameters' Values' Causal Classification
- Name Design Criteria. "Names with which human beings deal directly should be user-friendly. A user-friendly name is one that takes the human user's point of view, not the computer's. It is one that is easy for people to deduce, remember and understand, rather than one that is easy for computers to interpret." - This is the only one criterion addressed in [ITU-T, X.501, 2005], Annex J: "Name Design Criteria".

Development of such telecommunication system's parameters' notation system looks pretty but impossible. Our experience in overall telecommunication networks' (including terminals and users' behaviour) modelling shows a big usefulness and even unavoidability of a general notation system, when the modelled system tuple includes hundreds parameters, in the simplest homogeneous case.

The problem was realized in the preparation of an overall network simulation model [Todorov, Poryazov 1985]. An initial decision was used in [Poryazov, 1991] and tested in a model with heterogeneous terminals in [Poryazov 1992]. The notation system refers overall terminal traffic and overall network traffic modelling and is extended in [Poryazov, 2004] and [Poryazov, Saranova 2006]. Its main approaches are:

1. A set of Base Virtual Devices, each with a unique Functional Role is chosen (see "Functional Entity" in Section 3). Only graphic notation of functions is used for presentation in the conceptual reference models. The minimal set of used functions consists of: Generator (creates or copy requests); Terminator of requests; Modifier (combination of Generator and Terminator); Server (serves requests); Pointer or Director (shows the next virtual device); Switch (switches to the one of outgoing pointers). Every Server device has at least six parameters: Probability for direction the requests to it (P); Frequency (rate) of requests (F); Time for service (holding time) of a request in the device considered (T); Traffic intensity (Y); Traffic volume (V); Capacity of the device (N = number of servers).

2. The real devices are presented as a connected, by means of pointers, set of virtual devices. The overall network model is considered comprising (nested) virtual devices on five service levels: (base virtual device, phase, stage, switching subsystem, terminals subsystem).

3. Parameters' qualifiers as a part of the parameter's name are used for parameters characterization. The meaning of used qualifiers (e.g.: demand, offered, carried, blocked) is described in [ITU-T E.6001993].

4. Causal values classification is presented by reference model structures and causal qualifiers. Each service phase consists of:

- Successful branch of consecutive base virtual devices, corresponded to the successful (carried, completed) branch of the requests' way (correspondent to the "Normal" cause value 31 in [ITU-T E.425 2002]; and
- Failure branches, correspondent to the modelled failures. Each failure is presented as a base virtual device with its parameters.

Causal qualifiers participate in the device name with the first letter of modelled failure. Now "enter", "carried" (correspondent to the begin and the end of successful branch in the phase modelled), "abandoned", "blocked", "interrupted" and "not available" qualifiers are used. For example, "*Prad*" stands for "Probability for repeating the attempts after abandoned dialling cases).

5. Values' Establishing Method Classification is used for determination of second set of qualifiers in Network Dimensioning Task [Saranova, 2007] and [Saranova, 2008]. For example, *emp.crr.Ys* and *dsn.crr.Ys* means empirical and design values of the carried traffic intensity in the switching subsystem.

The used notation system has some advantages and disadvantages:

- It reflects current ITU-T terminology and enable:
- Semiautomatic virtual devices', their parameters' and values' naming;
- Working with big numbers (e.g. thousands) of names;
- More precise parameters and their values qualification and notation, allowing simultaneous usage of different values of a parameter in one consideration and mathematical expression;
- Easy for people deducing, remembering and understanding the names;
- Using the same names in administration's reports, mathematical expressions and computer programs;
- The names are longer than usually used ones.

The described notation system is only a development step of a general telecommunication system notation, fulfilling requirements stated in Open Issue 15.

Conclusion

1. The main current concepts in overall Quality of Service (QoS) considerations in telecommunication systems, in documents of the leading standardization organizations, are found and put together.
2. The current definition of Telecommunication does not correspondent to the: concept of QoSE – QoS experienced/perceived by customer/user; to the general concept of QoS; and to the current works of Human-Computer Interface Personalization. New definitions of Communication and Telecommunication are proposed.
3. The necessity of Scalable Models of Overall Telecommunication Systems is argued. The scalability of real systems is much better than the one of their models. The lack of methodology and useful models is described in several Open Issues formulated.
4. A Reference Model of a Telecommunication System, comprising seven subsystems, is proposed. ("Telecommunication System" is in European, not in a US understanding as "Telecommunication Network").
5. The necessity of Inter-Conceptual Interactions and Scalability in Overall Telecommunication Systems Models is argued.

6. The Overall and End-to-End Approaches to Telecommunication Network Performance are described. A General reference model of contributions to end-to-end QoS is proposed and described.
7. A definition of Overall telecommunication network performance is proposed.
8. A definition of Overall telecommunication system performance is proposed. It defers from Overall telecommunication network performance, because: 1. includes the all user-to-user connections in the overall network; 2. includes users' and subscribers connections (not necessary telecommunication connections) to Network and Service Providers.
9. Two Telecommunication System States' modelling supplementary approaches are described: the "call/connection streams state" and "aggregative device state".
10. The Network's Aggregative Device State approach, developed by authors, is presented in more details. It is influenced from Informatics and Mathematics and includes concepts as System Tuple Set, Base Tuple, and Minimal Base Tuple. Static and Dynamic Parameters' Classification is described, along with the duration of the observation intervals
11. Parameters' Classification Based on Their Values' Establishing Method is proposed, for the needs of design models, based on practice described in ITU-T Recommendations.
12. The necessity of Causal Classification of Values in Telecommunication Systems' Models is argued, based on "Cause value" field in Network Signalization.
13. The necessity of Overall Telecommunication System's Parameters' Notation System is argued and a set of requirements is listed. An initial step of such notation system, proposed and used by authors is described.
14. At least fifteen Open Issues for further study are formulated.

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SEARCH ALGORITHM FOR SHORTEST SYNCHRONIZING SEQUENCES USING BOOLEAN SATISFIABILITY

Liudmila Cheremisinova

***Abstract**: The problem under consideration is to find a synchronizing sequence for a logic network with memory. A novel method is proposed that is based on formulation of the task as the Boolean satisfiability problem solved with any standard SAT solver. The developed method allows creating a Boolean equation presenting the problem in conjunctive normal form.*

***Keywords**: design automation, verification, testing.*

***ACM Classification Keywords**: B.6.2 [Logic Design]: Reliability and Testing; B.6.2 [Reliability and Testing]: Error-checking.*

Introduction

Advances in manufacturing process technology leads to very complex designs. But with the increasing complexity of integrated circuits the problem of ensuring that no faults exist which can cause the device to malfunction is on the rise. The problem of testing VLSI circuits with great design complexity is the dominating validation activity in industry today, its cost is quickly increasing. The necessity to improve the process of testing is urgent today.

The traditional method for testability verification is based, as a rule, on gatelevel simulation. A subset of the functional test patterns (sequences of input vectors) is applied to integrated circuits on the manufacturing testers. Those design parts that yield the expected values for the applied vectors are said to pass and are decided as good ones; those that do not pass, are said to be bad.

Purely combinational logic can be modeled with two states (0 and 1). The sequential circuit having memory can have internal states that make sequential circuit testing more complex than that of the combinational logic. That is because in typical case the state of internal memory is not known at the beginning of the simulation to test. This assumption is also a good representation of the reality, because when a circuit is powered up, its flip-flops can be in any of the two possible states. In order to begin execution of any test sequence it is necessary to bring a sequential circuit under test to some identified state from which it is known how to proceed. So we must to initialize the internal memory to some identified state. And only after the initialization it is possible to activate the faults and to test circuit. As input sequences that solve the problem of initialization homing and synchronizing sequences are used.

Test sequence (the sequence of input vectors) that brings a sequential circuit to some known state regardless of its initial state is the synchronizing sequence. A homing sequence is such an input sequence that the corresponding output sequence uniquely determines its final state regardless of its initial state. After applying a synchronizing sequence, the final state of the circuit is known without observing the outputs. So, every synchronizing sequence is also a homing sequence, but not conversely.

These two sequences play an important role in the testing of finite state systems and have been used in a number of applications such as hardware fault detection, protocol verification, learning algorithms, etc. In the past and existing literature the problem of homing and synchronizing sequences generation is usually considered for the case of finite state machines (FSM). Motivated mainly by automata theory, the problem was heavily studied many years ago [Kohavi, 1978], [Gill, 1962]. In most applications the underlying FSM is an automaton with abstract state, whose functionality is described by a transition and an output tables (or by state transition graph). Several approaches are used to obtain a synchronizing and homing sequences for a FSM. A survey of the main methods can be found in [Lee, 1996]. It should note that finding a shortest homing or synchronizing sequence (with minimum legth) is an NP-hard problem [Eppstein, 1990]. Further we will consider the problem of obtaining synchronizing sequence for sequential logic circuits.

Recent advances in solving Boolean satisfiability problems caused a significant resurgence of the application of satisfiability solvers (SAT-solvers) in different electronic design automation domains. In the last years, great improvements were achieved in both the speed and capacity of SAT-solvers [Eén], [Mahajan, 2005], [Goldberg, 2002], which are now very fast and can handle huge problems. The new efficient SAT-solvers open new possibilities for applying this technology by translating hard design problems to equivalent SAT problems. So the existence of effective SAT solvers makes it attractive to translate looking-for synchronizing sequence problem into Boolean problem solvable by SAT solvers. SAT solvers normally operate on Boolean formulas in Conjunctive Normal Form (CNF), so the method is proposed that allows to create a Boolean function presenting problem of search for synchronizing sequence in CNF form.

The case considered here concerns to synchronous logical circuits having flip-flop primitives of type D as memory elements. For such a case a method of finding synchronizing sequence is proposed, the method allows creating a Boolean equation presenting the problem of search for synchronizing sequence in form of CNF.

The problem statement

The proposed method works on a synchronous circuit that consists of combinational logic and flip-flops, and is often represented in the form of two blocks. The first block is purely combinational, some its outputs feed a set of flip-flops, which in turn control some inputs of the combinational block. So the combinational block has two types of inputs: external inputs known as primary inputs and internal inputs, they present the internal state of the circuit and are supplied by the flip-flops. Similarly, the combinational block has two types of outputs: externally observable and known as primary outputs, and internal outputs, they present excitation functions for flip-flops.

The combinational block is modeled as an interconnect of primitive gates such as AND, OR, NOT, NAND, NOR, XOR, and in addition to them sometimes complex gates such as blocks implementing combinational circuits are also allowed.

The second block consists of register of the frequently used data flip-flops – D flip-flops. The example of such a logic circuit is shown in Figure 1.

The task is to be initialize memory elements to some reset states, that is, to find out the synchronizing sequence. Informally, a synchronizing sequence is a sequence of input sets that, when fed the sequential circuit, is guaranteed to bring it to some specified final state.

Let we have a circuit with n primary inputs and m D flip-flops. An input sequence, $\boldsymbol{X} = (\boldsymbol{x}^1, \boldsymbol{x}^2, \ldots, \boldsymbol{x}^k)$ (where $\boldsymbol{x}^i = (x_1^i, x_2^i, \ldots, x_n^i)$ is a vector of input signals that is fed the circuit in the time moment i) is said to be a synchronizing sequence of a sequential circuit, if the final circuit internal state after feeding it on the sequence can be determined uniquely regardless of the circuit initial state.

In general case there exists more than one synchronizing sequence for a finite state machine. We classify a synchronizing sequence $\boldsymbol{X}$ for a circuit as optimal if it is the shortest for all synchronizing sequences accepted by the circuit, that is $\boldsymbol{X}$ is of the shortest length k. It can be not alone too. The task is to find one of the shortest synchronizing sequences.

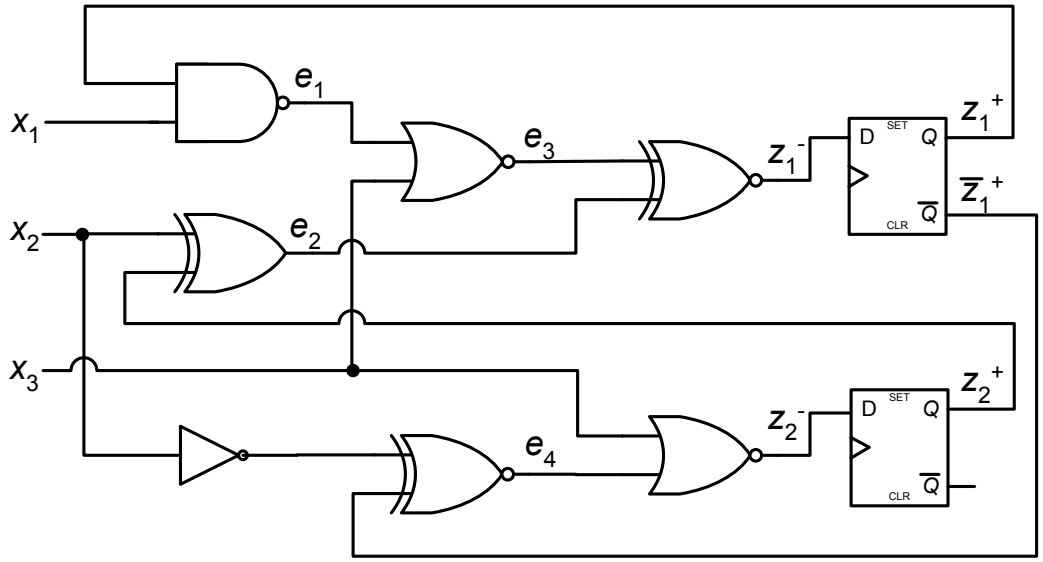

Figure 1. The example circuit under test

The behavior of the D flip-flop is described as the behavior of Moore's automaton with two states: 0 and 1. The symbol at its output coincides with the symbol of the state, in which the flip-flop is at the current time instant. Usually, the structure of an output symbol is given as two Boolean variables: Q and $\overline{Q}$ (Figure 1). The D flip-flop acts as a delay, i.e. at the next instant after the excitation signal has come it comes to the state corresponding to this signal. The search for known D flip-flop states is reduced to search for predefined values of excitation functions of the flip-flops. So further we are allowed to consider only combinational block having $n + m$ primary inputs $x_1, x_2, \ldots, x_n, x_{n+1}, x_{n+2}, \ldots, x_{n+k}$ corresponding n primary inputs and k flip-flop outputs, and k primary outputs $y_1, y_2, \ldots, y_k$ corresponding to flip-flop inputs defining their excitation functions. The circuit part defining primary outputs of ancestor sequential circuit is deleted as it is shown in Figure 2.

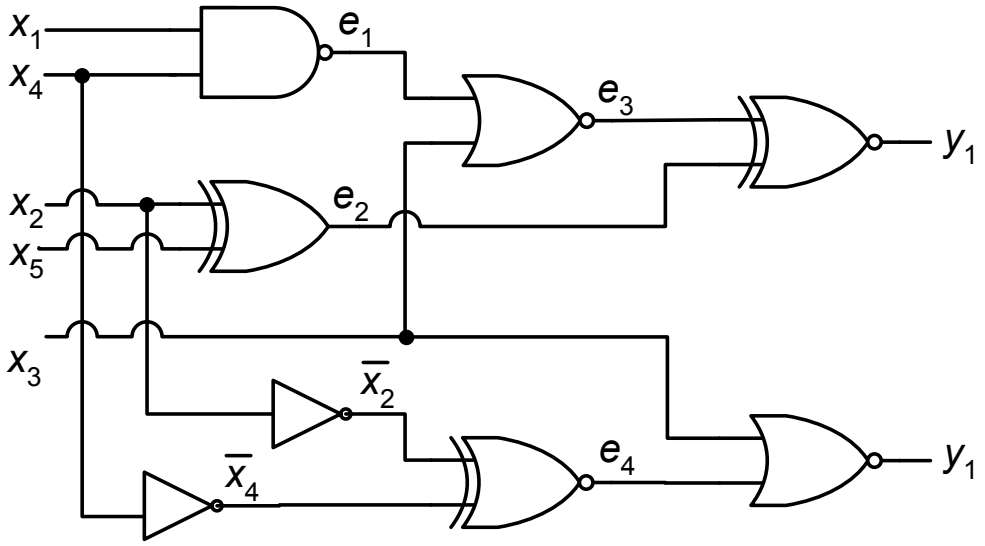

Figure 2. Combinational part of the sequential circuit shown in Figure 1

SAT-based approach to solving the problem of synchronizing sequence search

A CNF represents a Boolean function as conjunction of one or more clauses, each being in its turn a disjunction of literals (from now on literal is a Boolean variable or its inversion). A CNF denotes a unique completely specified Boolean function. Matrix representation of CNF formula *C* containing *k* clauses and *n* distinct variables is a ternary matrix ***C*** having a row for each clause and a column for each variable. The entry c_{ij} of the matrix in the *i*-th row and the *j*-th column is 1, 0 or "–" depending on in what a form (x_j or $\bar{x}_j$) the variable x_j appears or does not appear in *i*-th clause of *C*.

CNF representation is popular among SAT algorithms because each clause must be satisfied (evaluate to 1) for the overall CNF to be satisfied. The SAT problem is concerned with finding a truth assignment of literals which simultaneously satisfies each of CNF clauses. If such an assignment exists the CNF is referred to as satisfiable, and the assignment is known as a satisfying assignment.

A variable value assignment ***a*** (a set of *n* equalities of type $a_i = \sigma_i$, where $\sigma_i \in \{0, 1\}$) for the vector ***x*** can be complete if all x_i are assigned or partial otherwise. A complete variable value assignment represents a minterm and a partial assignment represents a cube that could be thought as a product of literals.

The topological description of a combinational circuit can be represented using a directed acyclic graph, where nodes correspond to the mentioned gates, primary inputs and outputs; edges correspond to circuit wires connecting the nodes. Incoming edges of a circuit node are called its fanins and outgoing edges are called fanouts. A node in the circuit is multiple fan-out if its output is a fan-in to different gates. The node and its output signal are named the same. Let us call the functionality of a circuit node in terms of its immediate fanins as the local function of the node. The functionality of the circuit in terms of its primary inputs is the system of global functions implemented on primary outputs.

Majority of SAT applications derived from circuit representation produce so called conventional CNF describing all combinations of signal values on all circuit terminals. The conventional CNF of a combinational circuit specifies all combinations of signal values of its terminals that can take place when it functions.

A circuit-to-CNF conversion uses as many variables as there are primary inputs and gates in the circuit. When the conventional transformation is applied to a combinational circuit, for output of each gate (except output ones) its own internal Boolean variable is introduced and only local functions of the gates are considered. The procedure of derivation of conventional CNF is known, it associates a CNF formula with each circuit gate that captures the consistent assignments between gate primary inputs and output. All such gate local CNFs are joined then in the overall circuit conventional CNF by using the conjunction operation. CNF for a gate representing a local function $y = f(z_1, z_2, \ldots, z_k)$ is based on defining and representing in a CNF form a new Boolean function $\varphi(y, f) = y \sim f(z_1, z_2, \ldots, z_k)$ [Kunz, 2002] that is true in the only case when both functions y and $f(z_1, z_2, \ldots, z_k)$ assume the same value.

Here are the conventional CNF representations of NOT, 2EXOR, *n*AND, *n*OR functions and their inversions:

$$y = \bar{z} \rightarrow (z \vee y)(\bar{z} \vee \bar{y});$$

$$y = z_1 \oplus z_2 \rightarrow (z_1 \vee z_2 \vee \bar{y})(\bar{z}_1 \vee \bar{z}_2 \vee \bar{y})(z_1 \vee \bar{z}_2 \vee y)(\bar{z}_1 \vee z_2 \vee y);$$

$$y = z_1 \wedge z_2 \wedge \ldots \wedge z_n \rightarrow (z_1 \vee \bar{y})(z_2 \vee \bar{y}) \ldots (z_n \vee \bar{y})(\bar{z}_1 \vee \bar{z}_2 \vee \ldots \vee \bar{z}_n \vee y);$$

$$y = z_1 \vee z_2 \vee \ldots \vee z_n \rightarrow (\bar{z}_1 \vee y)(\bar{z}_2 \vee y) \ldots (\bar{z}_n \vee y)(z_1 \vee z_2 \vee \ldots \vee z_n \vee \bar{y});$$

$$y = \overline{z_1 \oplus z_2} \rightarrow (z_1 \vee z_2 \vee y)(\bar{z}_1 \vee \bar{z}_2 \vee y)(z_1 \vee \bar{z}_2 \vee \bar{y})(\bar{z}_1 \vee z_2 \vee \bar{y});$$

$$y = \overline{z_1 z_2 \ldots z_n} \rightarrow (z_1 \vee y)(z_2 \vee y) \ldots (z_n \vee y)(\bar{z}_1 \vee \bar{z}_2 \vee \ldots \vee \bar{z}_n \vee \bar{y});$$

$$y = \overline{z_1 \vee z_2 \vee \ldots \vee z_n} \rightarrow (\bar{z}_1 \vee \bar{y})(\bar{z}_2 \vee \bar{y}) \ldots (\bar{z}_n \vee \bar{y})(z_1 \vee z_2 \vee \ldots \vee z_n \vee y).$$

It is possible to eliminate the output variable y of NOT gate and two appropriate clauses if to subsume it in its fan-out gates replacing all instances of y with the negated input variable x of this gate.

The obtained gate local CNFs are joined then in the overall circuit CNF by using the conjunction operation. Both the size of the resulting CNF and the complexity of the conventional translation procedure are linear in the gate number of the original combinational circuit.

For example, four additional variables e_1, e_2, e_3 and e_4 were supplemented the circuit shown in Figure 2. The corresponding conventional CNF is shown at the second column in Table 1.

Given a conventional CNF formula the SAT problem may be restated as the problem of finding a variable value assignment that satisfies every clause, taking into account that a clause is satisfied if at least one its literal is equal to 1. Recall, a CNF formula is satisfiable if and only if there is a satisfying assignment of its literals which simultaneously satisfies each of its member clauses.

The method of searching for synchronizing sequence for a logic circuit via Boolean satisfiability

Boolean SAT formulations are binary in essence. Introduced Boolean variables represent solution alternatives, and Boolean formulas represent constraints imposes by the solved problem. All variable assignments satisfying Boolean formulas are equivalent when solving the satisfiability problem. During the search for SAT solution of the synchronizing sequence problem there is no cost mechanisms to favor one solution over another. Thus formulating SAT problem of searching the shortest synchronizing sequence, we are able only to get the answer whether some solution (of the predefined length) of our problem exists. That is why the problem of optimal synchronizing sequence finding is solved regarding a priori assigned synchronizing sequence length. The

problem is formulated as a problem of Boolean satisfiability, deriving a Boolean function such that an assignment of variables that satisfy it (if it exists) defines a synchronizing sequence of the predefined size.

Thus, we are forced to reformate continuously the folding problem with increasing values of synchronizing sequence length until a satisfiable problem formulation arises. Such a reformulation of the problem based on enumeration of sequence length values seems cumbersome for logic circuits of great size, but below it will be shown that the process of alternate CNF building for increasing synchronizing sequence length is iterative.

At the beginning we search for a synchronizing sequence $\boldsymbol{X}^1 = (\boldsymbol{x}^1)$ of the length 1 and form conventional CNF C^1 for the combinational circuit under test assuming that its primary inputs corresponding to primary inputs of ancestor sequential circuit are $(x_1^1, x_2^1, \ldots, x_n^1)$ and primary inputs correspond to flip-flop outputs of ancestor sequential circuit are $(x_{n+1}^1, x_{n+2}^1, \ldots, x_{n+k}^1)$. The values of the last variables are accepted to be don't-care: x_{n+1}^1 = "–", x_{n+2}^1 = "–", …, x_{n+k}^1 = "–" because we don't know their initial values.

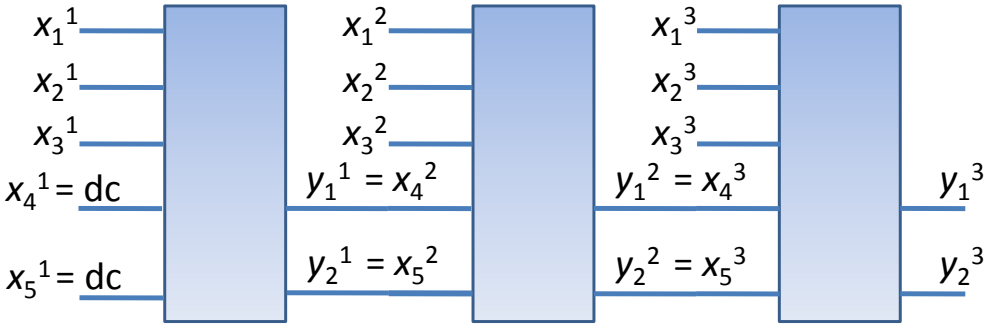

Figure 3. The process of augmentation of the number of blocks for the circuit of Figure 2

If such a manner formed CNF C^1 is satisfiable we will obtain synchronizing sequence $\boldsymbol{X}^1 = (x_1^1, x_2^1, \ldots, x_n^1)$ of unit length and the corresponding values of the circuit primary outputs $y_1^1, y_2^1, \ldots, y_k^1$ – defining values of excitation functions. Otherwise we should augment the experiment length and form the conventional CNF C^2 to search for a two cycle synchronizing sequence $\boldsymbol{X}^2 = (\boldsymbol{x}^1, \boldsymbol{x}^2)$. So two block combinational circuit will be considered: the first block is the circuit considered on the first step and the second one is a circuit identical to the first one but having primary inputs $(x_1^2, x_2^2, \ldots, x_n^2)$ and $x_{n+1}^2 = y_1^1$, $x_{n+2}^2 = y_2^1$, …, $x_{n+k}^2 = y_k^1$. Its k primary inputs $x_{n+1}^2, x_{n+2}^2, \ldots, x_{n+k}^2$ are connected with primary outputs $y_1^1, y_2^1, \ldots, y_k^1$ of the first block circuit, identifying the variables $y_1^1, y_2^1, \ldots, y_k^1$ and $x_{n+1}^2, x_{n+2}^2, \ldots, x_{n+k}^2$, so we use $x_{n+1}^2, x_{n+2}^2, \ldots, x_{n+k}^2$ instead of $y_1^1, y_2^1, \ldots, y_k^1$ have been introduced earlier. Then we again verify whether such a formed CNF C^2 is satisfiable to test whether there exists synchronizing sequence $\boldsymbol{X}^2 = (\boldsymbol{x}^1, \boldsymbol{x}^2)$ of the length 2 and so on as long (Figure 3) as we will obtain satisfiable CNF or the number of iterations exceeds the limit of iterations predefined in advance. In the last case our search fails and we don't find out any synchronizing sequence.

The peculiarities of search for synchronizing sequence via Boolean satisfiability

Here for illustration we consider the mentioned above example circuit (Figures 1 and 2) and find a synchronizing sequence for it. Taking in mind the proposed method we construct one-block circuit (Figure 4) and the conventional CNF C^1 corresponding to it (the second column of Table 1). For the convenience of its future augmentation (in the case if CNF C^1 will be unsatisfiable) we place the inner variables x_4^1, x_5^1 forward of the primary input variables x_1^1, x_2^1, x_3^1. CNF C^1 has 21 clauses. Before testing its satisfiability let substitute don't-care values for inner variables x_4^1, x_5^1 because their values are unknown and we don't entitled to assign them as distinct from values of primary input variables x_1^1, x_2^1, x_3^1. Replacement of the values will simplify the conventional

CNF C^1. For example, three clauses of CNF – $(x_1^1 \vee e_1^1)(x_4^1 \vee e_1^1)(\bar{x}_4^1 \vee \bar{x}_1^1 \vee \bar{e}_1^1)$ for NAND gate e_1^1 are replaced with $(x_1^1 \vee e_1^1)\, e_1^1 (\bar{x}_1^1 \vee \bar{e}_1^1)$ or after simplification with only two simple clauses – e_1^1 and $\bar{x}_4^1$.

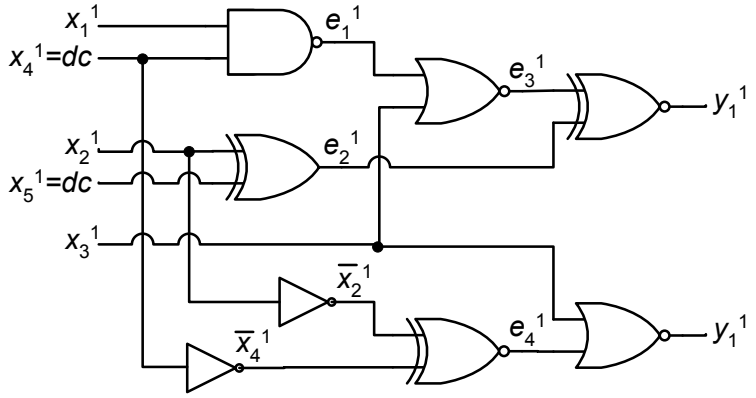

Figure 4. One-block combinational circuit for searching part of the sequential circuit shown in Figure 1

It should note that there exist some primitive gates that always have don't-care on its outputs when they have don't-care at least in one input. Gates realizing XOR and equivalency functions are such ones. For example, four clauses CNF for NXOR gate e_2^1 – $(x_5^1 \vee x_2^1 \vee e_2^1)(\bar{x}_5^1 \vee \bar{x}_2^1 \vee e_2^1)(x_5^1 \vee \bar{x}_2^1 \vee \bar{e}_1^1)(\bar{x}_5^1 \vee x_2^1 \vee \bar{e}_1^1)$ is replaced with CNF $(x_2^1 \vee e_2^1)(\bar{x}_2^1 \vee e_2^1)(\bar{x}_2^1 \vee \bar{e}_1^1)(x_2^1 \vee \bar{e}_1^1)$ that is always unsatisfiable. So, we may delete fragments associated with such gates from CNF C^1 taking the values of their output variables to be don't-care.

Simplified conventional CNF C^1_{sim} for our example circuit (Figure 4) is shown in the second column of the second row in Table 1. The CNF is unsatisfiable, so we have no synchronizing sequence of the unit length. More precisely in the case in question we cannot initialize the first D flip-flop in the only cycle, while the synchronizing sequence of the unit length for the second D flip-flop exists.

Table 1

Conventional conjunctive normal forms for example combinational circuits

	CNF C^1 for one-block circuit					CNF C^2 for two-block circuit						
	x_4^1	x_5^1	x_1^1	x_2^1		x_4^1	x_5^1	x_1^1	x_2^1	x_3^1	e_1^1	e_2^1
1		x_3^1	e_1^1	e_2^1			e_3^1	e_4^1	x_4^2	x_5^2	x_1^2	x_2^2
2		e_3^1	e_4^1	y_1^1			x_3^2	e_1^2	e_2^2	e_3^2	e_4^2	y_1^2
3		y_2^1					y_2^2					
4	–	–	1	–	–	–	–	–	–	–	1	–
5		1	–	–	–		–	–	–	–	–	–
6		–	–				–	–	–	–	–	–
7		e_1^1					–		e_1^1			
8	1	–	–	–	–	–	–	0	–	–	–	–
9		1	–	–	–		–	–	–	–	–	–
10		–	–				–	–	–	–	–	–
11	0	–	0	–	–		–					
12		0	–	–	–	–	–	–	–	–	0	–
13		–	–				0	–	–	–	–	–
14	–	1	–	1	–		–	–	–	–	–	–
15		–	1	–	–		–		e_3^1			
16		–	–			–	–	–	–	0	–	–
17		e_2^1					0	–	–	–	–	–
18	–	0	–	0	–		–	–	–	–	–	–
19		–	1	–	–		–					
20		–	–			–	–	–	–	1	1	–
21	–	1	–	0	–		1	–	–	–	–	–
		–	0	–	–		–	–	–	–	–	–

22		–	–				–						
23	–	0	–	1	–	–	–	–	–	–	–	–	
24		–	0	–	–		–	–	–	0	–	–	
25		–	–				–	–	–	–	–	–	
26	–	–	–	–	–		–		y_2^1				
27		0	–	0	–	–	–	–	–	1	–	–	
28		–	–				–	–	–	–	–	–	
		e_3^1					–	–	–	–	–	–	
	–	–	–	–	0		–						
		–	–	0	–	–	–	–	–	–	–	–	
		–	–				–	–	–	–	1	–	
	–	–	–	–	1		–	1	–	–	–	–	
		1	–	1	–		–		e_1^2				
		–	–			–	–	–	–	–	–	–	
	0	–	–	0	–		–	–	1	–	–	–	
		–	–	–	1		–	1	–	–	–	–	
		–	–				–						
		e_4^1				–	–	–	–	–	–	–	
	1	–	–	1	–		–	–	0	–	0	–	
		–	–	–	1		–	0	–	–	–	–	
		–	–				–						
	0	–	–	1	–	–	–	–	–	–	–	–	
		–	–	–	0		–	–	–	1	–	1	
		–	–				–	–	1	–	–	–	
	1	–	–	0	–		–		e_2^2				
		–	–	–	0	–	–	–	–	–	–	–	
		–	–				–	–	–	0	–	0	
	–	–	–	–	–		–	–	1	–	–	–	
		–	1	1	–		–						
		1	–			–	–	–	–	–	–	–	
		y_1^1					–	–	–	1	–	0	
	–	–	–	–	–		–	–	0	–	–	–	
		–	0	0	–		–						
		1	–			–	–	–	–	–	–	–	
	–	–	–	–	–		–	–	–	0	–	1	
		–	1	0	–		–	–	0	–	–	–	
		0	–				–						
	–	–	–	–	–	–	–	–	–	–	–	–	
		–	0	1	–		–	–	–	–	–	–	
		0	–				–	0	–	0	–	–	
	–	–	–	–	0		–		e_3^2				
		–	–	–	–	–	–	–	–	–	–	–	
		–	0				–	–	–	–	–	–	
		y_2^1					0	–	–	0	–	–	
	–	–	–	–	–		–						
		–	–	–	0	–	–	–	–	–	–	–	
		–	0				–	–	–	–	–	–	
	–	–	–	–	1		1	1	–	1	–	–	
		–	–	–	1		–						
		–	1			–	–	–	–	–	–	–	
							–	–	0	–	–	0	
							–	–	–	–	1	–	
							–		e_4^2				
						–	–	–	–	–	–	–	
							–	–	1	–	–	1	
							–	–	–	–	1	–	
							–						
						–	–	–	–	–	–	–	
							–	–	0	–	–	1	
							–	–	–	–	0	–	
							–						
						–	–	–	–	–	–	–	
							–	–	1	–	–	0	

						–	–	–	–	0	–		
						–							
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						–	–	1	1	–	1		
						–		y_1^2					
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						–	–	0	0	–	1		
						–							
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						–	–	1	0	–	0		
						–							
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						–	–	0	1	–	0		
						–							
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						0	–	–	–	–	–		
						0		y_2^2					
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						–	–	–	–	0	–		
						0							
					–	–	–	–	–	–	–		
						–	–	–	–	–	–		
						1	–	–	–	1	–		
						1							
	CNF C^1_{sim} after C^1 simplification												
	x_4^1	x_5^1	x_1^1	x_2^1		x_4^1	x_5^1	x_1^1	x_2^1	x_3^1	e_1^1	e_2^1	
1		x_3^1	e_1^1	e_2^1			e$_3^1$	e_4^1	x_4^2	x_5^2	x_1^2	x_2^2	
2		e_3^1	e_4^1	y_1^1			x_3^2	e_1^2	e_2^2	e_3^2	e_4^2	y_1^2	
3		y_2^1					y_2^2						
4	–	–	–	–	–	–	–	–	–	–	1	–	
5		1	–	–	–		–	–	–	–	–	–	
6		–	–				–	–	–	–	–	–	
7		e_1^1					–		e_1^1				
8	–	–	0	–	–	–	–	0	–	–	–	–	
9		–	–	–	–		–	–	–	–	–	–	
10		–	–				–	–	–	–	–	–	
11	–	–	–	–	–		–						
12		0	–	0	–	–	–	–	–	–	0	–	
13		–	–				0	–	–	–	–	–	
14		e_3^1					–	–	–	–	–	–	
15	–	–	–	–	0		–		e_3^1				
16		–	–	0	–	–	–	–	–	0	–	–	
17		–	–				0	–	–	–	–	–	
18	–	–	–	–	1		–	–	–	–	–	–	
19		1	–	1	–		–						
20		–	–			–	–	–	–	1	1	–	
21	–	–	–	–	–		1	–	–	–	–	–	
22		–	–	–	–		–	–	–	–	–	–	
		–	–				–						
		y_1^1				–	–	–	–	–	–	–	
	–	–	–	–	–		–	–	–	0	–	–	
		–	–	–	–		–	–	–	–	–	–	
		–	0				–		y_2^1				
		y_2^1				–	–	–	–	1	–	–	
	–	–	–	–	1		–	–	–	–	–	–	
		–	–	–	–		–	–	–	–	–	–	
		–	–				–						

		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	1	–	–	–	–
			–		e_1^2			
		–	–	–	–	–	–	–
			–	–	–	–	0	–
			–	–	–	–	–	–
			–					
		–	–	–	–	–	–	–
			–	–	–	1	–	1
			–	–	1	–	–	–
			–		e_2^2			
		–	–	–	–	–	–	–
			–	–	–	0	–	0
			–	–	1	–	–	–
			–					
		–	–	–	–	–	–	–
			–	–	–	1	–	0
			–	–	0	–	–	–
			–					
		–	–	–	–	–	–	–
			–	–	–	0	–	1
			–	–	0	–	–	–
			–					
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	0	–	0	–	–
			–		e_3^2			
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			0	–	–	0	–	–
			–					
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			1	1	–	1	–	–
			–					
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	–	1	1	–	1
			–		y_1^2			
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	–	0	0	–	1
			–					
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	–	1	0	–	0
			–					
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	–	0	1	–	0
			–					
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			–	–	–	–	–	–
			0		y_2^2			
		–	–	–	–	–	–	–
			–	–	–	–	–	–
			1	–	–	–	–	–
			–					

Further we construct two-block circuit (Figure 5). Its conventional CNF C^2 (the third column of Table 1) turns out simple enough: CNF C^1 after renumbering its variable labels (the superscripts 2 are replaced for 1) is attached to CNF C^1_{sim}. At that, the columns labeled y_1^1, y_2^1 of CNF C^1_{sim} and the columns x_4^2, x_5^2 of CNF C^2 are merged. So CNF C^2 has 20 columns (instead of 11 columns of CNF C^1 and C^1_{sim}) and 28 rows. Instead of including the sixth row of CNF C^1_{sim} in CNF C^2 we substitute x_4^2 with don't-care everywhere in C^2. After that we obtain the simplified form of CNF C^2 – CNF C^2_{sim} (the third column of Table 1). After testing CNF C^2_{sim} we discover that there exists its satisfying assignment:

x_4^1	x_5^1	x_1^1	x_2^1	x_3^1	$e_1^1e_2^1e_3^1e_4^1x_4^2$		x_5^2	x_1^2	x_2^2
	x_3^2	$e_1^2e_2^2e_3^2e_4^2y_1^2$		y_2^2					
–	–	0	–	1	1	–	0	–	–
	0	0	0	1	1	1	0	–	0
	0 .								

That is $\bar{x}_1^1 x_3^1 e_1^1 \bar{e}_3^1 \bar{x}_5^2 \bar{x}_1^2 \bar{x}_2^2 x_3^2 e_1^2 e_2^2 \bar{e}_3^2 \bar{y}_1^2 \bar{y}_2^2$ in the form of conjunction. So we obtain the following synchronizing sequence of the length 2:

$$\boldsymbol{X}^2 = ((0–1, 001).$$

Thus to initialize the sequential circuit (Figure 1) we should feed it at the first cycle with input signals $x_1 = 0$, $x_2 = 0$, $x_3 = 1$ or $x_1 = 0$, $x_2 = 1$, $x_3 = 1$, then at the next cycle with input signals $x_1 = 0$, $x_2 = 0$, $x_3 = 1$. After that both D flip-flops pass into the state 0.

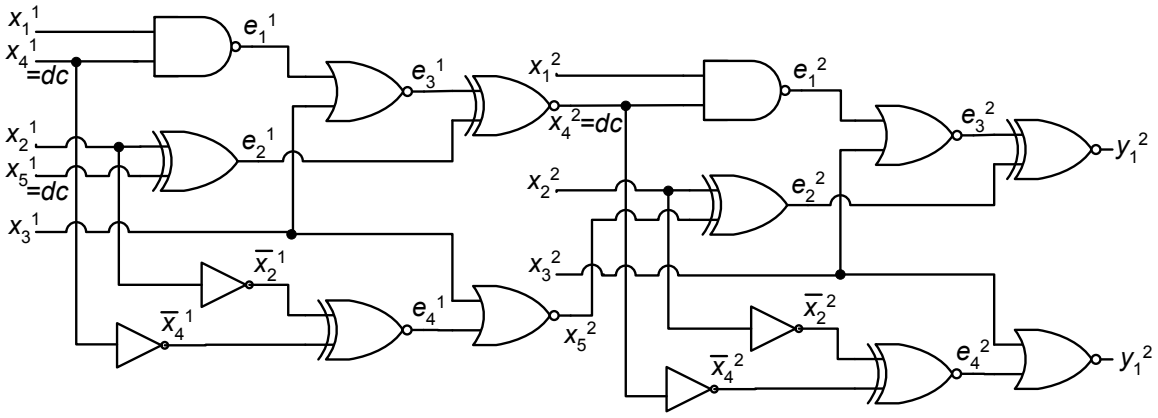

Figure 5. Two-block combinational circuit for searching part of the sequential circuit shown in Figure 1

Here one should draw attention that there are some peculiarities of searching for synchronizing sequence via Boolean satisfiability. They result from existence of don't-care signals in tested circuit that can cause local fragments of conventional CNF to be unsatisfiable though the tested circuit has a synchronizing sequence. That is because don't-care signal run through this circuit fragment from input to output. The characteristic example of such a case is some gate, such as XOR, or some subcircuit realizing such a function. To don't miss a synchronizing sequence for a circuit having such fragments, when testing CNF satisfiability it should use SAT solvers (for instance, SAT solver PicoSAT [Biere, 2008]) that permit to give proof traces from which it is possible to extract a reason why the tested CNF is erroneous. In that case we can substitute the unsatisfiable fragment

with assigning don't-care value to the variable corresponding to the appropriate fragment output signal, just as we have substituted CNF fragments concerned with XOR gate.

Conclusion

In this paper the problem of search for synchronizing sequence for logic circuits with memory elements is considered. A novel reformulation of the problem as the Boolean satisfiability problem solved with any existing SAT-solver was developed. The proposed method is used when testing a memory block whether D flip-flops are good or faulty.

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Major Fields of Scientific Research: Logic Design, CAD systems, optimization

COMPARATIVE ANALYSIS FOR ESTIMATING OF THE HURST EXPONET FOR STATIONARY AND NONSTATIONARY TIME SERIES

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Abstract: *Estimating of the Hurst exponent for experimental data plays a very important role in the research of processes which show properties of self-similarity. There are many methods for estimating the Hurst exponent using time series. The aim of this research is to carry out the comparative analysis of the statistical properties of the Hurst exponent estimators obtained by different methods using model stationary and nonstationary fractal time series. In this paper the most commonly used methods for estimating the Hurst exponents are examined. There are: R/S-analysis, variance-time analysis, detrended fluctuation analysis (DFA) and wavelet-based estimation. The fractal Brownian motion that is constructed using biorthogonal wavelets have been chosen as a model random process which exhibit fractal properties.*

In this paper, the results of a numerical experiment are represented where the fractal Brown motion was modelled for the specified values of the exponent H. The values of the Hurst exponent for the model realizations were varied within the whole interval of possible values $0 < H < 1$.The lengths of the realizations were defined as 500, 1000, 2000 and 4000 values. For the nonstationary case model time series are presented by the sum of fractional noise and the trend component, which are a polynomial in varying degrees, irrational, transcendental and periodic functions. The estimates of H were calculated for each generated time series using the methods mentioned above. Samples of the exponent H estimates were obtained for each value of H and their statistical characteristics were researched.

The results of the analysis have shown that the estimates of the Hurst exponent, which were obtained for the stationary realisations using the considered methods, are biased normal random variables. For each method the bias depends on the true value of the degrees self-similarity of the process and length of time series. Those estimates which are obtained by the DFA method and the wavelet transformation have the minimal bias. Standard deviations of the estimates depending on the estimation method and decrease, while the length of the series increases. Those estimates which are obtained by using the wavelet analysis have the minimal standard deviation.

In the case of a nonstationary time series, represented by a trend and additive fractal noise, more accurate evaluation is obtained using the DFA method. This method allows estimating the Hurst exponent for experimental data with trend components of virtually any kind. The greatest difficulty in estimating, presents a series with a periodic trend component. It is desirable in addition to investigate the spectrum of the wavelet energy, which is demonstrated in the structure of the time series. In the presence of a slight trend, the wavelet-estimation is quite effective.

Keywords: *Hurst exponent, estimate of the Hurst exponent, self-similar stochastic process, nonstationary time series, methods for estimating the Hurst exponent.*

ACM Classification Keywords: *G.3 Probability and statistics - Time series analysis, Stochastic processes, G.1 Numerical analysis, G.1.2 Approximation - Wavelets and fractals.*

Introduction

Nowadays problems of nonlinear physics, radio electronics, control theory and image processing require the development and employment of new mathematical models, methods and algorithms for data analysis. At present it has been generally accepted, that many stochastic processes in nature and in engineering exhibit a long-range dependence and fractal structure. The most suitable mathematical method for research of the dynamics and structure of such processes is fractal analysis.

The Stochastic process $X(t)$ is statistically self-similar if the process $a^{-H}X(at)$ shows the same second-order statistical properties as $X(t)$. Long-range dependence means slow (hyperbolic) decay in the time of the autocorrelation function of a process. The parameter H $(0 < H < 1)$ is called the Hurst exponent and is a measure of self-similarity or a measure of duration of long-range dependence of a stochastic process.

Let us consider the most well-known examples of the self-similar processes. One of the first real stochastic processes, that have been found with self-similar properties is informational data traffic in telecommunication networks. For self-similar traffic methods for calculating the characteristics of a computer network (channel capacity, buffer size, etc.), that is based on classical models, don't meet the necessary requirements and don't allow to estimate adequately, the load of the network. There are a large number of publications, which are devoted to the fractal properties analysis and their influence on the functioning and quality of service in the telecommunication network. Another example of fractal stochastic structures is the modern financial market. The modern fractality hypothesis of a financial time series supposes that the market is a self-regulating macro-economic system with feedback which uses information about past events to affect decisions in the present, and contains long-term correlations and trends. The market remains stable, as long as it retains its fractal structure. Analyzing the dynamics of occurrence of time section with various fractal structures, we can diagnose and predict unstable states (crises) of a market. It has become generally accepted in the recent years that a lot of bioelectric signals have fractal structure, so in researches of cerebral and cardio processes are increasingly important roles played by fractal analysis. Distinct changes in fractal characteristics of cardiograms and encephalograms manifest in various diseases, in changes of mental and physical load on the body. Fractal analysis of bioelectrical signals can be the basis for statistical researches, which will allow to formulate a methodology that will be significant for clinical practice.

It is obvious that Hursts' exponent estimation for experimental data plays an important role in the study of processes which exhibit properties of self-similarity. There are many methods for the Hurst exponent evaluation for a time series. Sufficient review of these methods is represented in [Willinger, 1996; Clegg, 2005]. However, most methods of the Hurst exponent estimation is applied only to stationary time series, while a lot of natural, technical and information processes are nonstationary. The main type of nonstationarity, which occurs in practice, is the existence of trend and cyclical components.

Nevertheless, at the present time there is no proper summary research where the results of the Hurst exponent estimation Í using stationary and nonstationary fractal time series with different methods would be generalized and the comparative analysis of statistical properties of estimations obtained for a small amount of sample data would be. The given research is an attempt to carry out such analysis for the most commonly used methods of estimation of self-similarity.

The aim of this research is to carry out the comparative analysis of the statistical properties of the Hurst exponent estimates obtained by different methods, using a short length model fractal time series (the number of values being less than 4000). In this paper the most commonly used methods for estimating the Hurst exponent are researched. There are: R/S-analysis (rescaled range method) (see, for instance [Feder, 1988; Peters, 1996; Stollings, 2003; Sheluhin, 2007], variation in time of variance of an aggregate time series (variance-time analysis), see [Stollings, 2003; Sheluhin, 2007], detrended fluctuation analysis (see [Kantelhardt, 2001; Chen, 2002; Gu, 2006; Kantelhardt, 2008]) and estimation using the wavelet analysis (see [Mallat, 1998; Abry, 1998; Abry, 2003]) The fractal Brownian motion has been chosen as a model random process which exhibit fractal properties.

Methods of estimating the Hurst exponent

Rescaled range method. This empirical method suggested by G. Hurst is still one of the most popular methods of research of fractal series of different nature. According to this method for the time series $x(t)$ of the length τ the rate $\frac{R(\tau)}{S(\tau)}$ is defined, where $R(\tau)$ is the range of the cumulative deviate series $x^{cum}(t,\tau)$, $S(\tau)$ is standard deviation of the initial series:

$$R/S = \frac{\max(x^{cum}(t,\tau)) - \min(x^{cum}(t,\tau))}{\sqrt{\frac{1}{\tau - 1}\sum_{t=1}^{\tau}\left(x(t) - \overline{x}\right)^2}},\ t = \overline{1,\tau}, \tag{1}$$

where $\overline{x}(\tau) = \frac{1}{\tau}\sum_{t=1}^{\tau} x(t)$, $x^{cum}(t,\tau) = \sum_{i=1}^{t} x(i) - \overline{x}(\tau)$.

For a self-similar process and big values of τ this ratio has the following characteristics:

$$M\left[\frac{R}{S}\right] \sim (c \cdot \tau)^H, \tag{2}$$

where c is a constant.

The log-log diagram dependence of $\frac{R(\tau)}{S(\tau)}$ on τ represents a line approximated by the least square method. Then the estimate of the exponent H is a tangent of the angle of slope of the line which represents the dependence $\log\frac{R(\tau)}{S(\tau)}$ on $\log(\tau)$ (see Fig. 1, where theoretical values of $H = 0.8$).

Variance-time analysis is most often used to processes researches in telecommunication networks. When someone mentions the aggregation of a time series $x(t)$ of the length τ on the time scale with the parameter m, they mean the transition to the process $x^{(m)}$, where $x_k^{(m)} = \frac{1}{m}\sum_{t=km-m+1}^{km} x(t)$, $k = \overline{1,\tau/m}$. For self-similar process the variance of the aggregated time series $x^{(m)}$ for big values of m follows the formula:

$$Var(x^{(m)}) \sim \frac{Var(x)}{m^{\beta}}. \tag{3}$$

In this case, the parameter of self-similarity $H = 1 - \frac{\beta}{2}$ can be obtained if we generate an aggregated process on different levels of aggregation m and calculate the variance for each level. The dependence diagram of $\log(Var(x^{(m)}))$ on $\log(m)$ will represent a line with a slope equal to $-\beta$. Fig. 2 shows log-log diagram of $Var(x^{(m)})$ on m (dependence (3)), where theoretical values of $H = 0.8$.

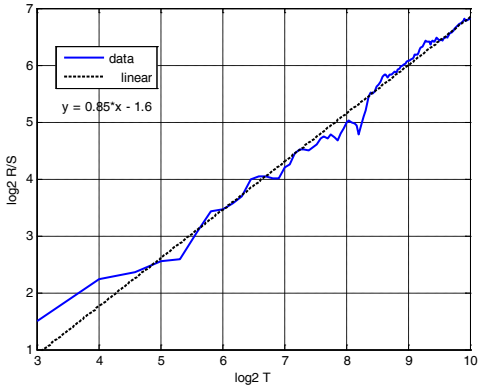


Figure 1. log-log diagram of $\frac{R(\tau)}{S(\tau)}$ on τ

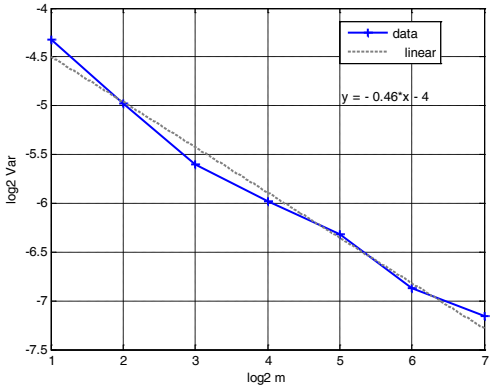


Figure 2. log-log diagram of $Var(x^{(m)})$ on m

Detrended fluctuation analysis (DFA). DFA originally suggested by [Peng, 1994], is the main method of determining self-similarity for nonstationary time series nowadays. This method is based on the ideology of one-dimensional random walks. Assume that the autocorrelation function (ACF) of the process shows the power dependence for the values of time argument $\tau > \tau_1$.

When τ is large, the ACF receives small values (near zero), that leads to the increase of statistical errors. The main idea of the fluctuation analysis consists in transformation of decay of the ACF which will be less sensitive to statistical errors. This analysis is applied for the purpose of detection effects of the long-term correlations in researched process. There are many variations of fluctuation analysis methods. From the very beginning the DFA method has used in biological and medical researches, but recently is being applied more often in analysis of financial time series [Kantelhardt, 2001, Kantelhardt, 2008].

According to the DFA(m) method, for the initial time series $x(t)$ the cumulative time series $y(t) = \sum_{i=1}^{t} x(i)$ is constructed which is then divided into N segments of length τ, and for each segment $y(t)$ the following fluctuation function is calculated:

$$F^2(\tau) = \frac{1}{\tau}\sum_{t=1}^{\tau}(y(t) - Y_m(t))^2, \qquad (4)$$

where $Y_m(t)$ is a local *m*-polynomial trend within the given segment. The averaged on the whole of the time series $y(t)$ function $F(\tau)$ depends on the length of the segment: $F(\tau) \propto \tau^H$.

In some interval the diagram of dependence of $\log F(\tau)$ on $\log \tau$ represents a line approximated by the least square method. Estimate of the exponent $\acute{I}$ is a tangent of the angle of slope of the line which represents the dependence of $\log F(\tau)$ on $\log(\tau)$ (see Fig. 3, where theoretical values of $H = 0.7$).

Wavelet-based estimation. Of recent, the effective tool for a time series analysis is the multiresolution wavelet-analysis, which's main idea consists in the expansion of a time series on an orthogonal base, formed by shifts and the multiresolution copies of the wavelet function. Base functions $\psi(t)$ are named wavelets, if they satisfy a number of conditions, in particular they should be defined in place of complex-valued functions with restricted energy, which oscillate around an abscissa axis, converging rapidly to zero and having a vanishing moment of the first order. Discrete wavelet-transform (DWT) is a continuous and discrete form of wavelet-transformation consisting of a two decomposition researched series : approximating and detailing, with their successive separation for the purpose of increasing the decomposition level.

Discrete wavelets are used, as a rule, together with scaling-functions connected to them. Scaling-functions with wavelets have the general definitional domain and a determined relation between values. At a given mother wavelet ψ and corresponding scaling-function φ with approximate coefficients $a(j,k)$ and detailing coefficients $d(j,k)$ are defined as follows:

$$a(j,k) = \int_{-\infty}^{\infty} X(t)\varphi_{j,k}(t)dt, \quad d(j,k) = \int_{-\infty}^{\infty} X(t)\psi_{j,k}(t)dt,,$$

where

$$\varphi_{j,k} = 2^{-j/2}\varphi\left(2^{-j}t - k\right);$$
$$\psi_{j,k} = 2^{-j/2}\psi\left(2^{-j}t - k\right).$$

According to the DWT the time series is represented as the sum of detailing and approximating components:

$$X(t)=\text{approx}_J(t)+\sum_{j=1}^{j=J}\text{detail}_j(t) = \\ = \sum_k a(j,k)\phi_{J,k}(t) + \sum_{j=1}^{J}\sum_k d(j,k)\psi_{j,k}(t) \quad . \tag{5}$$

For estimation of the Hurst exponent in applied research, the method described in [Abry, 1998] is the commonly used. The mentioned method is based on the statement that the averaged squared values of the wavelet coefficients $E_j = \frac{1}{n_j}\sum_{k=1}^{n_j}\left|d_x(j,k)\right|^2$ obey the scaling law:

$$E_j \sim 2^{(2H-1)j}, \tag{6}$$

where *H* is the Hurst exponent. The following equation represents the practicable method of the estimation of the Hurst exponent:

$$\log_2 E_j = \log_2 \left(\frac{1}{n_j} \sum_{k=1}^{n_j} |d(j,k)|^2 \right) \sim (2H-1)j + const\,. \qquad (7)$$

From this formula it can be concluded that if there is the long-range dependence of the time series $x(t)$ then the Hurst exponent H can be obtained by estimating the slope of the graph of the function $\log_2(E_j)$ from j. Fig. 4 shows dependence $\log_2(E_j)$ on j (dependence 7), where theoretical values of $H = 0.7$.

Modelling of fractal Brownian motion

One of the well known and simple models of stochastic dynamics which exhibits fractal properties is fractal Brownian motion (fBm). It is widely used in physics, chemistry, biology, economics and theory of network traffic.

Gaussian process $X(t)$ is called fractal Brownian motion with the parameter H, $0 < H < 1$, if the increments of the random process $\Delta X(\tau) = X(t+\tau) - X(t)$ are distributed in the following way

$$P(\Delta X < x) = \frac{1}{\sqrt{2\pi}\sigma_0 \tau^H} \cdot \int_{-\infty}^{x} \mathrm{Exp}\left[-\frac{z^2}{2\sigma_0^{\,2}\tau^{2H}} \right] dz\,, \qquad (8)$$

where σ_0 is diffusion coefficient.

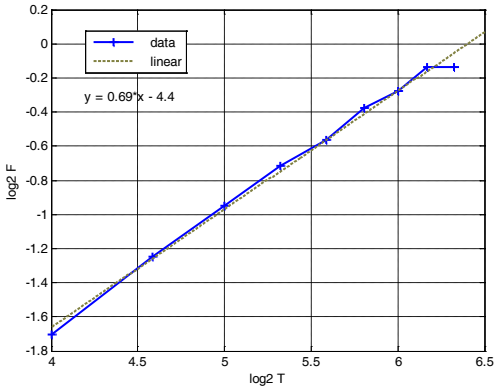


Figure 3. log-log diagram of $F(\tau)$ on τ

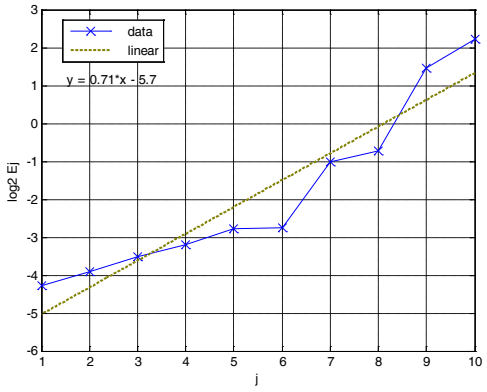


Figure 4. Dependence $\log_2(E_j)$ on j

fBm with the parameter $H = 0.5$ coincides with the classic Brownian motion. Increments of fBm are called fractal Gaussian noise and its dispersion can be described by the formula $D[X(t+\tau) - X(t)] = \sigma_0^{\,2}\tau^{2H}$.

There are many methods of construction of fBm for the case of discrete time, which have been considered in [Mandelbrot, 1983; Feder, 1988; Voss, 1988; Cronover, 2000]. These models have some weak sides. One of them is underestimating/overestimating of the degree of self-similarity of a process for small and big theoretical values of the Hurst exponent and the short length of a model realisation [Jeongy, 1998; Cronover, 2000; Sheluhin, 2007].

One of the methods which can help to resolve the mentioned problems is the construction of fBm using biorthogonal wavelets [Sellan, 1995; Abry, 1996; Sellan, 1995; Meyer, 1999; Bardet, 2003]. In this case the fBm

realization is constructed using discrete wavelet transform where the detail wavelet coefficients on each level are independent normal random values and approximation wavelet coefficients are obtained using fractal autoregression and moving average process FARIMA:

$$B_H(t) = \sum_{k=-\infty}^{\infty} \Phi_H(t-k) S_k^{(H)} + \sum_{j=0}^{\infty} \sum_{k=-\infty}^{\infty} 2^{-jH} \Psi_H(2^j t - k) \varepsilon_{j,k} - b_0 \,, \tag{9}$$

where Ψ_H is biorthogonal base wavelet function, Φ_H is corresponding Ψ_H scaling function, $S_k^{(H)}$ is stationary Gaussian process FARIMA with the fractal differentiation parameter $d = H - 0.5$, $\varepsilon_{j,k}$ – independent standard Gaussian random values, b_0 – constant where $B_H(0) = 0$.

The program implementation of the given algorithm is accessible in the mathematical packet MatLab, from version 7 onwards. Fig. 5 shows a time series fBm with different Hurst exponents ($H = 0.3,\ 0.5,\ 0.8$). In fig. 6 we can see corresponding realizations of fGn.

Investigation Results: Stationary time series.

In this paper the results of a numerical experiment are represented where a fractal Brownian motion with the specified value of exponent $\acute{I}$ have been simulated. The values of $\acute{I}$ for the model realisation were varied within the interval $0 < H < 1$. The length of realizations was accepted equal to 500, 1000, 2000 and 4000. For each received realization, estimates $\acute{I}$ have been obtained using the methods described above: R/S-analysis $\left(\hat{H}rs\right)$, variance-time analysis $\left(\hat{H}d\right)$, DFA method $\left(\hat{H}fa\right)$ and discrete wavelet transform $\left(\hat{H}w\right)$. For each value of H samples of its estimates have been computed, and their statistical characteristics have been investigated.

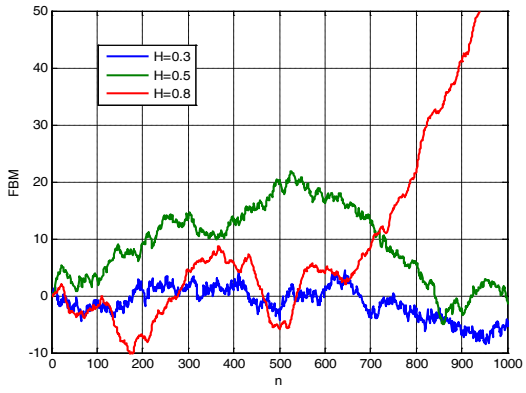


Figure 5. Realizations of fBm

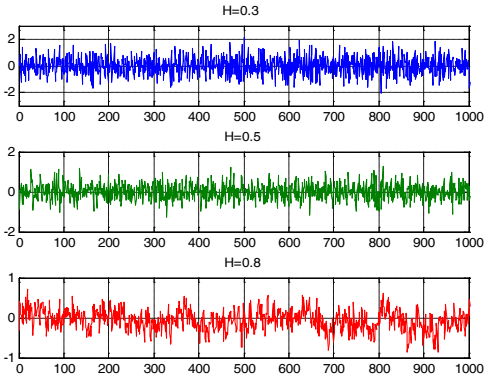


Figure 6. Realizations of fGn

Investigation of bias of estimates

Fig. 7 shows dependence of average values of estimates of the Hurst exponent on its theoretical value. The model realizations contained 1000 values. The Solid line refers to the theoretical values of H. Obviously, the average values of the estimates are biased, where the bias depends on the theoretical values of the Hurst exponent.

Obviously, the estimates of the Hurst exponent are biased in a region of persistence as well as in an antipersistence one. Since most of the fractal processes have a long-range dependence, we will be considering results only for the interval $0,5 < H < 1$. From Fig. 7 we can see that the estimates obtained by the methods of R/S - analysis and variance-time analysis are the most biased.

Let us consider the results of estimation of the exponent H by the method of R/S-analysis. The method of the rescaled range proposed by Hurst is, perhaps, the most popular one and is used in all fields of scientific research. Its main merit is its robustness. Actually, this method works even on non-stationary data. But also, as it was noticed by Hurst, the estimates of H below $H \approx 0,75$ obtained by the R/S-method are overestimated, and the estimate of H over $H \approx 0,75$ are understate.

Fig. 8 represents a dependence of average values of estimates $\hat{H}rs$ on theoretical values of H for model series of different length. Obviously, the average values of estimates can be approximates quite well with lines $\hat{H}_N = k_N H + b_N$, where coefficients k_N and b_N depend on the realization N where the estimation is done. This lines cross the line of the theoretical values of H at around $H \approx 0,75$; and are overestimated below this values and are underestimated above this value. The results of the performed research confirm the results obtained by analysing the estimation of other models [Feder, 1988; Jeongy, 1998; Кириченко, 2005; Sheluhin, 2007]. With the increase of the realisation length N the angle of slope k_N of the approximated line increases slowly and approaches the theoretical value $\pi/4$.

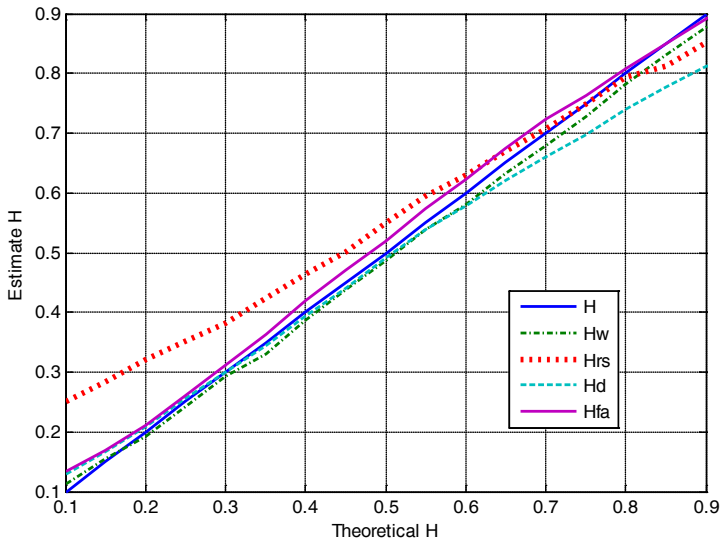


Figure 7. Dependence of the average values of estimates obtained by various methods on the theoretical H

Due to its simplicity and easy understanding of its results the method of variance-time analysis is the most commonly used for assessment of self-similarity of the information network traffic. Nevertheless, for processes with a long-range dependence, this method gives undervalued estimates. [Jeongy, 1998; Кириченко, 2005; Sheluhin, 2007]. This can be unacceptable, for instance, in the case of assessment of the network load during the transmission of the self-similar traffic. [Stollings, 2003].

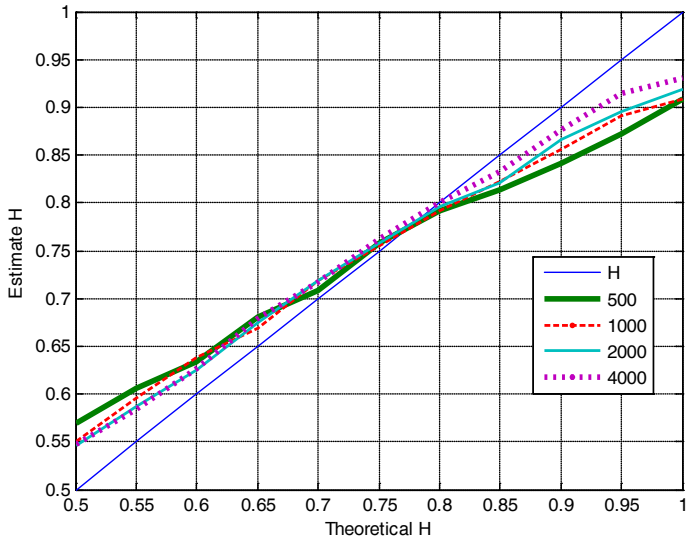


Figure 8. Dependence of average values of estimates $\hat{H}rs$ on the theoretical value of H

Fig. 9 shows the dependence of the average values of estimates $\hat{H}d$ obtained by the method of variance-time analysis. These dependence can also be approximated by the lines $\hat{H}_N = k_N H + b_N$ where coefficients k_N and b_N depend on the length of realization N. In this case the approximating lines cross the line of theoretical values at around $H \approx 0,5$ (see Fig. 7) and actually the estimates of the exponent H are undervalued within the whole interval of persistence. The bias increases with the growth of the Hurst exponent, particularly for $H > 0,9$. It can be noted that the bias of the estimates $\hat{H}d$ are greater that the appropriate bias of $\hat{H}rs$. With the increase of the realization length N, the bias slowly decreases.

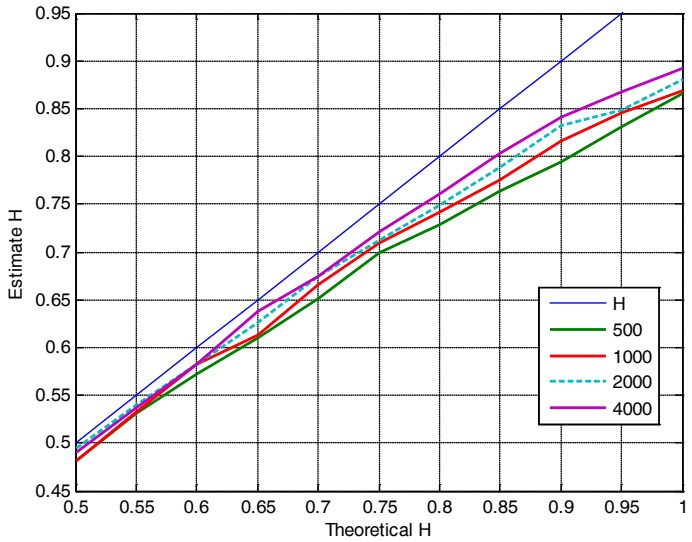


Figure 9. Dependence of average values of estimates $\hat{H}d$ on the theoretical value of H

The DFA method is based on the ideology of one-dimensional random walk and is widely used in the analysis of bioelectric signals. The estimates $\hat{H}fa$ obtained by the DFA method can be characterised by a small bias within the interval $0,5 < H < 0,9$ (see Fig. 10) even for realizations of short length. The sign of this bias reverses and increases for $H > 0,9$. It should be brought into focus that most of the natural and information fractal processes have a degree of self-similarity less than 0,9.

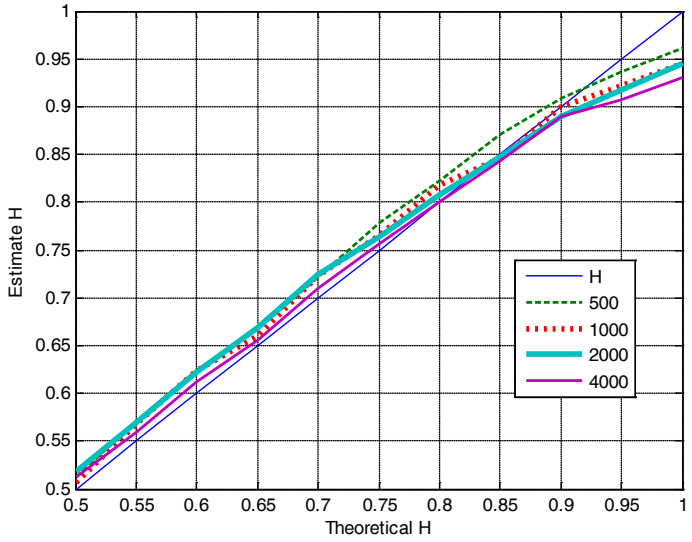


Figure 10. Dependence of the average values of the estimates $\hat{H}fa$ on the theoretical value of H

The methods of estimation of the Hurst exponent by the use of wavelet analysis are the most recent and still have not been commonly used. Nevertheless, their merits are obvious. In the paper [Abry, 1998] it has been shown that the estimates are asymptotically unbiased if base wavelets are chosen in a proper way. Fig 11 represents the dependence of the average values of $\hat{H}w$ obtained by the method of discrete wavelet expansion with the base wavelet function of Daubechies D4. It is obvious that with the increase of the time series length N the bias decreases and is actually equal to 0 for $N \approx 4000$.

Research of the standard deviations of the estimates

In this paper, the dependence of standard deviations of estimates of the Hurst exponent on the values of H and length of the model fractal series has been investigated for each method. In Table 1 the values of the standard deviations of the estimates of the Hurst exponent which have been received for the series of length for 1000 values are represented.

Table 1. Standard deviations of the estimates of the Hurst exponent

Estimation method	Range $S_{\hat{H}}$	Dependence on H
R/S-analysis	$0.03 \le S_{\hat{H}} \le 0.08$	Increases along with H
Variation of dispersion	$S_{\hat{H}} \approx 0.06$	No obvious trend
DFA	$S_{\hat{H}} \approx 0.07$	No obvious trend
Wavelet analysis	$S_{\hat{H}} \approx 0.045$	No obvious trend

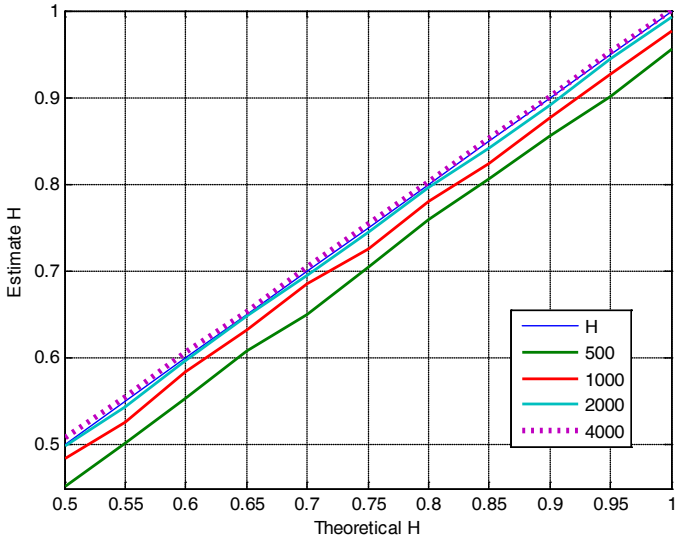


Figure 11. Dependence of the average values of the estimates $\hat{H}w$ on the theoretical values of H

Table 2 demonstrates how standard deviations obtained during the estimation of $\hat{H}$ (rounded value) decrease with the increase of the length of time series. In this specific case the Hurst model exponent $H = 0.8$.

The problem of distribution law of the estimates of $\acute{I}$ was considered in a number of works where it was shown, numerically and analytically, that the estimates are normal for a specific method or specific values of the Hurst exponent (see, for instance [Feder, 1988, Peters, 1996; Abry, 1998]). In this paper the distribution of the estimates $\hat{H}$ have been researched for each method and different values of the parameter. For all considered methods, the hypothesis of normal distribution of sample values of the estimates with parameters $N(\bar{H}, S_{\hat{H}})$ have been suggested. For nearly all sample data, the hypothesis has been accepted with the confidence level $\alpha = 0.05$ by a narrow criterion.

Table 2. Standard deviations of the estimates depending on length of time series

$S_{\tilde{H}}$	500	1000	2000	4000
S_{Hrs}	0.08	0.06	0.05	0.04
S_{Hd}	0.07	0.06	0.05	0.045
S_{Hfa}	0.085	0.07	0.055	0.045
S_{Hw}	0.065	0.045	0.03	0.02

Thus, the estimates of the Hurst exponent which are obtained by the methods considered above are biased normal random variables. For each method, the bias depends on a true value of degree of self-similarity and the length of a time series. Standard deviations of the estimates depend on the estimation method and decrease with the growth of the series length.

Research results: nonstationary time series

We investigated different model time series, presented by the sum of fractional Brownian noise the specified value of the Hurst exponent and the trend component, which is a polynomial in varying degrees, irrational, transcendental and periodic functions (see Fig. 12). The total signal can be written as

$Y(t) = k * T(t) + fgn(t)$,

where $T(t)$ is a trend, $fgn(t)$ is a fractal Gaussian noise, and k a is a factor that regulates the ratio of trend to the noise.

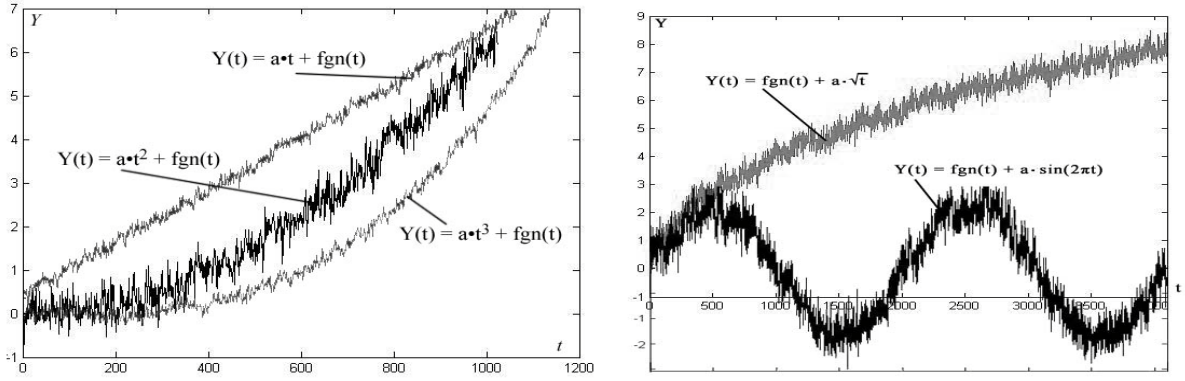
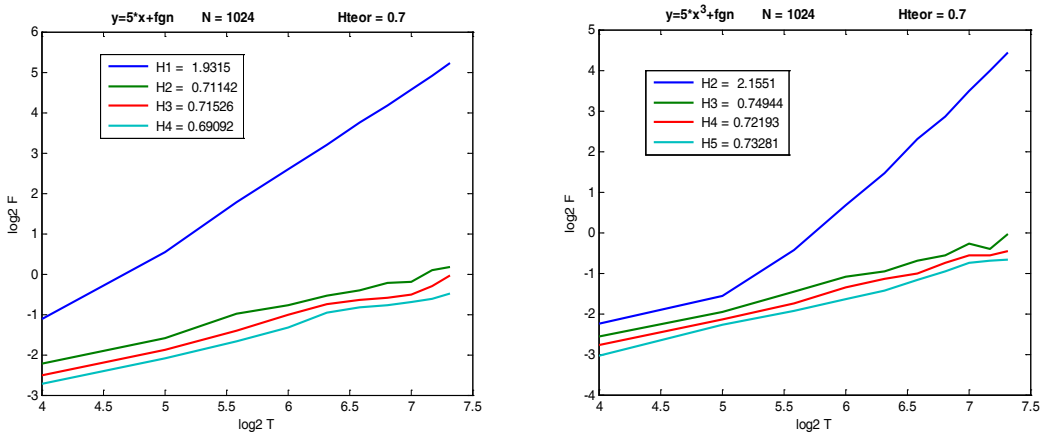


Figure 12. Model nonstationary time series

Detrended fluctuation analysis. The DFA(m) method is traditionally used in analyzing the fractal structure and estimating the degree of self-similarity of a time series with trends (for example, the implementation of encephalograms) or cumulative series with nonstationary increments (for example, financial series).

In this paper, in each case in the construction of the fluctuation functions, a local polynomial trend of increasing orders was considered [Kirichenko, 2010].The numerical study of a fractal series with a polynomial trend

component of the order p showed that an adequate valuation of the Hurst parameter is achieved by using a local polynomial trend order $m > p$. Fig. 13 presents the fluctuation function $F(\tau)$ constructed of the different order polynomials for the fractal series (the theoretical value of the Hurst exponent equals 0.7) with linear (a) and cubic (b) trends. In the first case, the adequate valuation H is achieved for the local trend of the order $p = 2$, i.e. it is sufficient DFA(2), and in the second case adequate valuation is started with order $p = 4$, i.e. we need to use DFA(4).



a) b)

Figure 13. Fluctuation functions for time series with linear (a) and cubic (b) trend

The estimation of Hursts exponent have been analyzed for time realizations with different trend–to–fractal noise ratio. Analysis of results showed that with local polynomial trend $m > p$, the value of the trend–to–noise ratio does not matter. An investigation conducted for the fractal noise with rational polynomials and transcendental trends showed an adequate estimation using the local polynomial trend order $m > 2$.

The greatest difficulty in estimating the degree of self-similarity presents a series with a periodic trend component. Fig. 14 presents a fluctuation function for a series including sinusoidal components with the number of periods equal to two and four. A numerical analysis showed that the greater the numbers of periods, the greater the degree of local polynomial should be used.

Summarizing the numerical results we can conclude that the DFA method is a convenient and reliable method for determining the degree of self-similar stochastic processes with trending components of different types.

Wavelet-based estimation. It is shown, that the influential parameter in the selection of the mother wavelet for estimating the Hurst parameter of a time series with a polynomial trend order m is the existence of its vanishing moments of order $p > m$ [Flandrin, 2009]. However, numerical studies have shown that the above method of wavelet estimation gives an adequate valuation in the case where the trend–to–fractal noise ratio is not great [Кириченко, 2010]. The estimator of the Hurst parameter H is calculated correctly or not, depending on value of the ratio of trend and noise $\text{Ratio} = \frac{S_{trend}}{S_{noise}}$, where S_{trend} is the standard deviation of the trend component, S_{noise} is the standard deviation fractal noise.

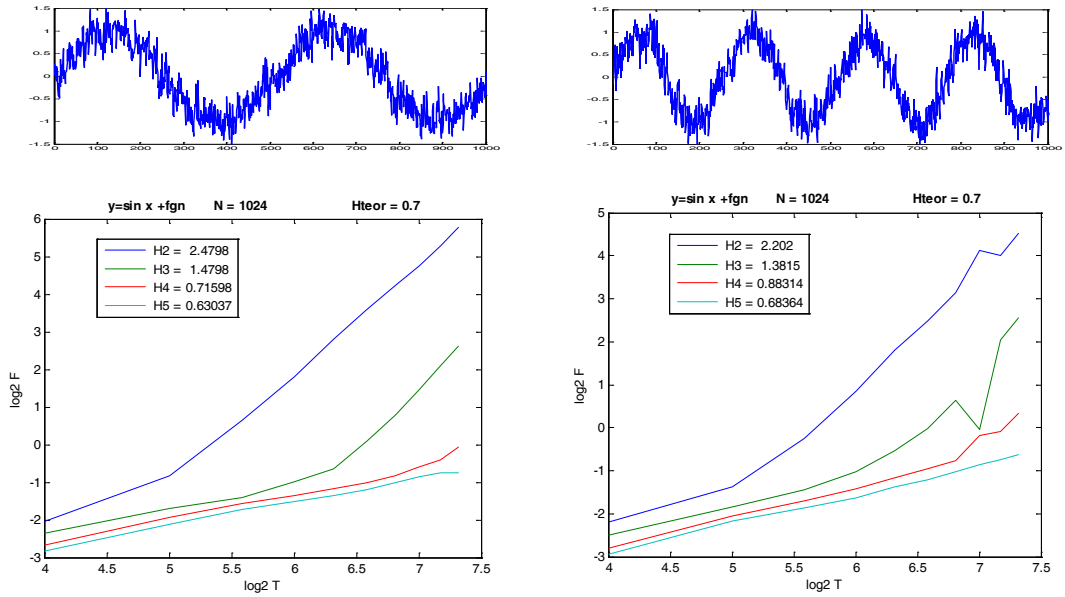


Figure 14. Model time series with sinusoidal trends and corresponding fluctuation functions for DFA(2)- DFA(5)

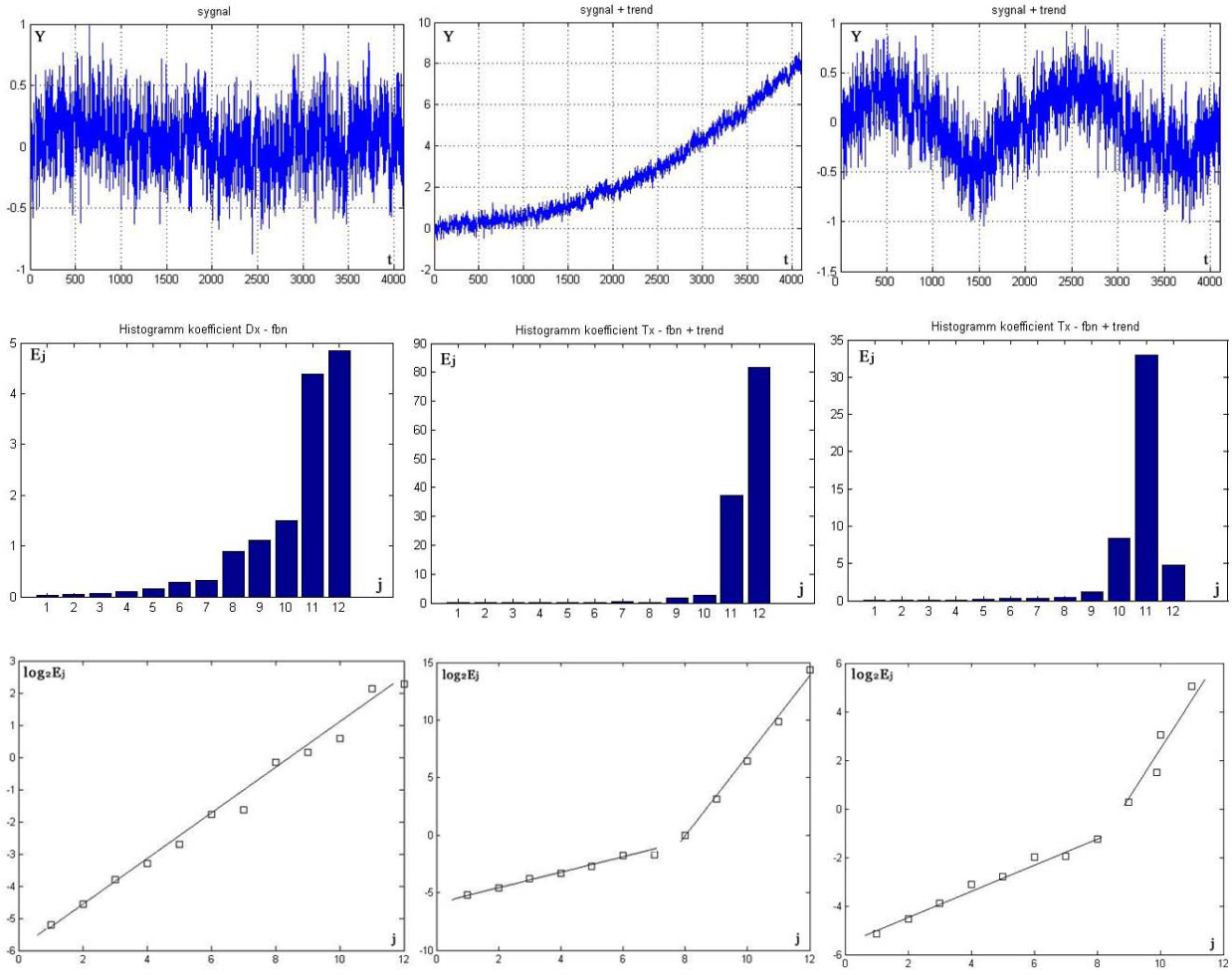
The numerical investigation have shown that the value Ratio^*, from which the effect of trend becomes significant, does not depend on the length of the model realization, but only on the standard deviation of the fractal process and factor k in the expression $k * T(t)$. The table 3 shows the experimental results for various model signals and the value of Ratio^*.

Table 3. Model trends and the value of Ratio^*

Trend	Value of Ratio*	Trend	Value of Ratio*
T(t) = k·t	9	$T(t) = k \cdot t^{\frac{3}{4}}$	0,45
$T(t) = k \cdot t^2$	7	T(t) = k·ln(t)	0,30
$T(t) = k \cdot t^3$	5	T(t) = k sin(2πt), 1 period	0,18
$T(t) = k \cdot \sqrt{t}$	2	T(t) = k·sin(2πt), 2 periods	0,08

To understand why the trend component leads to a deterioration of estimation, let us consider in more detail the spectrum of the wavelet energy of the signal E_j, which obeys the scaling law $E_j \sim 2^{(2H-1)j}$. The wavelet energy is equal to the amount of energy at a given level of wavelet decomposition $E_j = \frac{1}{N_j}\sum_{k=1}^{N_j} d(j,k)^2$. The Fig. 15

shows a spectrum of the wavelet energy fractal noise (a), noise with a polynomial trend (b) and noise with a periodic component (c). The lower figures show the graphs of wavelet energy in a logarithmic scale, in which the slope gives an estimate of the Hurst exponent.



a) b) c)

Figure 15. Model time series and corresponding spectrum of wavelet energy and dependence $\log_2(E_j)$ on j

Obviously, the high value of energy at levels determined by the trend components overstates the estimator of the Hurst parameter. In cases where these levels are low frequency components (which is typical), they can be discarded, and carry out evaluation of high-frequency levels.

Examples of real time series

In the Fig.16 below are three time realizations of processes that possess self-similar properties: site traffic protocol TCP, finance index S&P 500 for 2005 and the encephalogram of a laboratory animal in the awaking state.

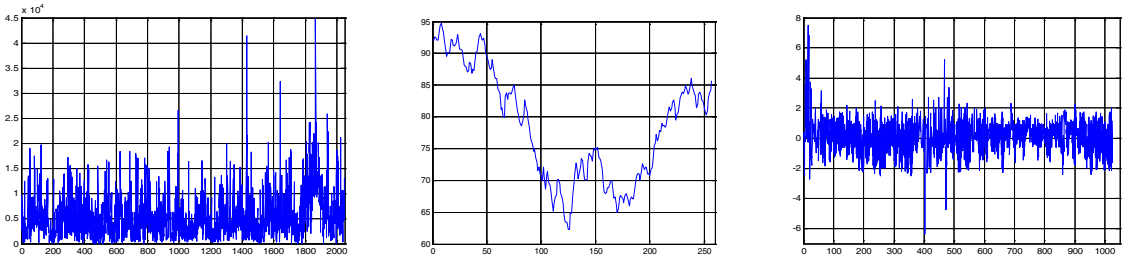
The table 4 below shows the values of estimator of the Hurst parameter, obtained by the methods discussed in this paper. It should be noted that the financial series is cumulative, so in this case it was considered a series of increments.

Conclusion

Thus, the estimates of the Hurst exponent which are obtained for the stationary realisations by the methods considered above are biased normal random variables. For each method the bias depends on a true value of the degree of self-similarity and the length of a time series. Standard deviations of the estimates depend on the estimation method and decrease with the growth of the series length.

Table 4. Estimates of the Hurst exponent

Method	R/S-analysis	Variance-analysis	DFA(1)	Wavelet- estimation
Traffic (N=2000)	$\hat{H}=0.69;\ S=0.05$	$\hat{H}=0.81;\ S=0.05$	$\hat{H}=0.75;\ S=0.055$	$\hat{H}=0.78;\ S=0.03$
Index S&P 500 (N=250)	$\hat{H}=0.65;\ S=0.09$	$\hat{H}=0.51;\ S=0.08$	$\hat{H}=0.57;\ S=0.09$	$\hat{H}=0.6;\ S=0.07$
Encephalogram (N=1000)	$\hat{H}=0.72;\ S=0.06$	$\hat{H}=0.63;\ S=0.06$	$\hat{H}=0.68;\ S=0.07$	$\hat{H}=0.65;\ S=0.04$



a) b) c)

Figure 16. Time series of traffic protocol TCP, finance index and encephalogram

Summarizing the results of the numerical research we can make a conclusion that the estimates with the least bias and standard deviation can be given by the method which uses wavelet analysis. Also, other methods have some merits which can be significant in relation to some aims and ways of the research. For instance, R/S-analysis allows to estimate the degree of self- similarity of a time series for which the wavelet estimation nearly cannot be applied, The DFA method gives the best results for short series. Thus, in most cases for the estimation of the Hurst exponent it makes sense to use various methods and comparison of the results provides extra information.

In the case of a nonstationary time series represented, a trend and additive fractal noise, more accurate evaluation is obtained using the DFA method. This method allows estimation of the Hurst exponent for experimental data with trend components of virtually any kind. The greatest difficulty in estimating presents a series with a periodic trend component. It is desirable in addition to investigate the spectrum of the wavelet energy, which is demonstrates the structure of the time series. It should be noted that in the presence of a slight trend, the wavelet-estimation is quite effective.

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INFORMATIONAL-PARAMETRIC MODEL OF SIGN LANGUAGE FINGERSPELLING UNITS

Iurii Krak, Bogdan Trotsenko, Julia Barchukova

Résumé: An approach for researching fingers' movement with an aim to create a formal notion of sign language fingerspelling units (dactyls) is considered. Then an informational parametric model of a human arm is suggested that describes possible movements during fingerspelling process. 10 fingerspelling alphabets are analyzed mutually compared for exact and partial similarity as well as notable distinctions. The example of a .Net-based software application is then provided that teaches proper Ukrainian fingerspelling.

***Keywords**: fingerspelling alphabet, specification, model of human movements.*

***ACM Classification Keywords**: I.2.8 Problem Solving, Control Methods, and Search H.1.1 Systems and Information*

Introduction and problem statement

The rapid development of computing and creation of new methods for data representation, storage and organization makes it possible to innovate and create new technologies in the field of analysis of communication in sign language and modeling thereof. [1]. From the practical point of view, teaching systems of sign language that use 3D human model are very promising. Since the information is transmitted by the mean of arms movements, mimics and articulation it is necessary to research the process of construction of a sign language sentence as well as the synthesis of the elements in order to get a good understanding of the subject. The problem of description of human movements is complex enough with a high percentage of fuzzy knowledge about human body and its physiology. From the linguistic viewpoint, the problem is considered in a vast amount of research works, e.g, [2], [3] et al. Among language specification systems, *Hamburg Notation System* [4] stands apart, as it includes various graphical signs and therefore allows to describe a large set of gestures. The system *SignWriter* [5] got a wide range of applications as it uses textual signs alongside graphical ones. This kind of signs is not always suitable for modeling purposes since the information requires equivalent counterparts in data structures. Therefore it is important to conduct a research of the process of how the gestures are formed from the viewpoint of formalization for the problem of modeling using 3D model and for the problems of gestures analysis and synthesis.

This work pays the primary attention to research of fingers movement since they play primary role in the fingerspelling process. The essence of the problem is to reconstruct the information about a gesture for the visual reproduction on a 3D model of human palm based on the textual description. The complexity of the problem is that the verbal description of a dactyl (fingerspelling unit) combined with photo and video materials do not fully define the special positions of the dactyl and therefore the question of how the fingers are positioned may be hard to answer. It is therefore necessary to create such a notion of a dactyl that would unambiguously define the position of every finger and the dactyl. The other problem no sign language speaker learns the exact dactyls, but

introduces his or her tiny variations. Therefore, there is not "right" etalon of a dactyl. Therefore it is necessary that created hand models and corresponding animation would satisfy the standard of fingerspelling. The creation of informational parametric model of a hand should take into account the standard but ignore the variations that do not change the meaning. For example, the degree of a finger's curvature would vary with speakers, but this does not involve that there are as many ways of showing the same dactyl. Conclusively, the problem is to denote the formal description of a dactyl and create its visual animated representation on a 3D human's hand model. The purpose of this work is to analyze fingerspelling alphabets and a formal notion of a dactyl for the problem of modeling the human movements using informational 3D model and further synthesis of dactyl information and for the creation of computer-based fingerspelling teaching technologies.

Analysis and formalization of fingerspelling alphabet based on natural parameters

Parameters of a dactyl's structure. W.Stokoe determined three parameters that describe the structure of a gesture: the position of a gesture, the hand shape (its configuration and orientation) and the movement [2]. Based on the classification, three main parameters were determined and were used to analyze dactyls:

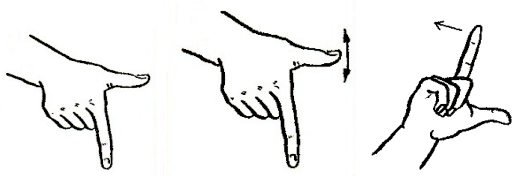
1. Fingers configuration,
2. Orientation of a hand in space,
3. Type of the movement.

Special attention is paid to the study of a hand configuration because in the process of constructing three-dimensional model of the human hand, the key moment is to determine the correct configuration of the fingers and then to determine a location of the hand in space and the kind of motion. At this stage, hand position in space relatively to the speaker is not taken into account, it is believed that the hand is an object in a space. To build the specifications of fingerspelling units of a sing language the following parameters were used: fingers configuration, hand orientation, and hand movement.

Fingers configuration is a set of the following parameters: a set of fingers involved in the letter construction; fingers configuration (the degree of the slope, curvature); mutual disposition.

Preserving generosity, let's demonstrate the process of building of informational-parametric model of dactyls visualization Ukrainian fingerspelling alphabet. Ukrainian fingerspelling alphabet consists of 33 letters and 24 of them have a distinct corresponding fingers' configuration (А, Б, В, Г, Е, Є, Ж, З, И, І, Л, М, Н, О, П, Р, С, Т, У, Ф, Х, Ч, Ю, Я). For the other 9 letters, the corresponding fingers' configuration is similar and differ from the previous by a hand orientation (e.g. Ш) and/or by the movement (e.g. Ь, Ї, К). Other fingerspelling alphabets have a similar structure. The example is shown in the Table 1.

Table 1. Dactyls that share fingers' configuration but differ in hand orientation and movement.

Letters	Hand configurations
Г – Ґ – Ь	

Informational-parametric model of fingerspelling units

Informational-parametric model of fingerspelling units is an ordered triple {*K, O, M*}, where parameter *K* describes fingers' configuration, *O* describes hand's orientation in space, *M* describes the movement.

Parameter *K* is an ordered sextuple {f_1, f_2, f_3, f_4, f_5, *c*}, where parameters f_i, $i = \overline{1,5}$ describe a configuration of each finger separately, specifically configurations of: f_1 – thumb, f_2 – pointing finger, f_3 – middle finger, f_4 – ring finger, f_5 – little finger, *c* is a relation between fingers except thumb, which are used for building dactyl.

Meaning of the parameter f_1 (thumb finger) is shown in the Table 2.

Table 2. Meaning of the parameter f_1

Meaning	Description	Example
1	Straight	А (Ukrainian)
2-α	Deflects in a plane of the palm on α degrees	Г (Ukrainian)
3-1	Over fist (or over a few fingers)	Я, І (Ukrainian)
3-2	Over pointing finger	
3-3	Over middle finger	Р (Ukrainian)
3-4	Over ring finger	Н (Ukrainian)
3-5	Over little finger	Т (Ukrainian)
4	In the middle of a fist (or on a palm)	В, Х (Ukrainian)
5-0	Forms an arc with other fingers (not closed arc)	С (Ukrainian)
5-1	Forms an arc with other fingers (closed arc)	О (Ukrainian)
5-2	Forms crossing with a finger	T (Polish)
6	Horizontally, props fingers	E (American)
7-3	Abuts on a middle finger by finger-pad	T (American)
7-4	Abuts on a ring finger by finger-pad	N (American)
7-5	Abuts on a little finger by finger-pad	M (American)
8	Parallel to the palm plane	K (American)

Other parameters vary as follows: $f_i = x[y]$, $i = \overline{2,5}$, where $x \in [0,1]$, $y \in [0,1]$. Here x denote the degree of the slope of the *i-th* finger relatively to the flat state ($x = 1$), y – the degree of curvature of a finger (parameter y can be skipped in description).

Flat state ($x=1$) is equivalent to the letter «В»'s hand configuration (all fingers are straight and in the plane of the palm). Close state ($x=0$) is equivalent to the letter «А»'s hand configuration (fingers are bent into a fist).

Parameter *c* is defined as follows:

$$c=\begin{cases}0, \text{ if only 1 or 0 fingers involved,}\\ 1, \text{ if fingers (2 or more) raised up and touch to each other,}\\ 2, \text{ if fingers don't touch each other,}\\ 3, \text{ if fingers are one above the other (letter «Я»),}\\ 4, \text{ if fingers are shifted in diffferent planes (letter «Б»).}\end{cases}$$

An example of defining the specifications for fingers' configuration is listed in the Table 3.

Parameter *O* is an ordered triple *{α, β, γ}*, where *α, β, γ* denote angles of a hand rotation in space relatively to the initial state.

Initial state is defined as hand orientation *O {0,0,0}*  . When fingerspelling letter «В», hand rotates with angle $\alpha=180^{\circ}$ i.e. with palm facing the viewer.

Table 3. Specification of fingers' configuration.

Letter	F_1	f_2	f_3	f_4	f_5	c	Configuration
Х	4	0	0	0	0,2 [0,2]	0	
К	3-1	0	0	1	1	2	
Е	5-1	0,5 [0,5]	0,5 [0,5]	0,5 [0,5]	0,5 [0,5]	1	
Я	3-1	0	0	1	1	3	

Parameter *M* describes the type of a movement. At this stage of the making specification, parameter of movement is described as follows:

$$M=\begin{cases}0, \text{ no movement,}\\ 1, \text{ movement is made by some part of a hand (e.g. «Г»),}\\ 2, \text{ movement is descriptive(e.g. «З», «Д»),}\\ 3, \text{ shift in a spacec, rotation, slope (e.g. «К», «Щ»),}\\ 4, \text{ transition from one fingers' configuration to another one.}\end{cases}$$

Based on these parameters, the table of specifications with 12 parameters is built (see Table 4).

Table 4. An example of specifications.

Language	Letter	f_5	f_4	f_3	f_2	f_1	c	α	β	γ	M
Ukrainian	У	1	0	0	0	2-45	2	180	0	0	0

Given formal notion is informative and easy enough for perception in the context of movement modeling. It is quite easy to build specifications for other manual alphabets using the notion.

Analyses of fingerspelling units with the help of specification system

Similarly to the analysis of Ukrainian fingerspelling alphabet, analyses of other fingerspelling alphabets have been made and the tables of specifications for American, German, French, Polish, Russian, Greek, Japanese, Spanish, Swedish fingerspelling alphabets have been built. The general analysis of abovementioned fingerspelling alphabets makes it possible to build such a formal specification that allows to describe not only Ukrainian fingerspelling alphabet, but also other one-handed manual alphabets. For instance, the result of similarity analysis of each fingerspelling alphabet is shown in Table 5.

Table 5. Results of research on similarity of the fingerspelling alphabets

Fingerspelling alphabet	Number of letters	Number of configurations	Fingerspelling alphabet	Number of letters	Number of configurations
Ukrainian	33	24	French	26	21
American	26	23	Swedish	29	20
Polish	32	19	Japanese	46	27
Russian	33	24	Spanish	30	20
German	30	23	Greek	24	20

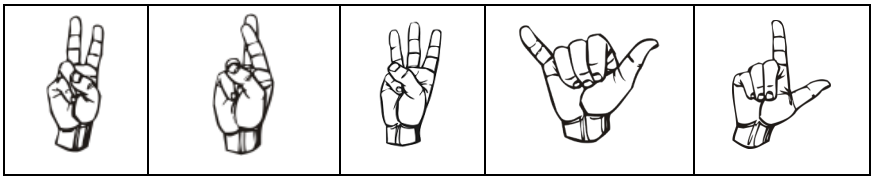
Based on the obtained specifications a comparative analysis of the Ukrainian manual alphabet with other sign languages manual alphabets was performed. Parameters of fingers configurations defined earlier in this paper were used for the comparison. Herewith we ignored hand orientation and movement since any letter can be obtained by constructing fingers' configuration, determine hand orientation in a space and movement. The results of analysis that show equal dactyls are listed in Table 6.

Table 6. Results of the comparison of the fingers' configurations fingerspelling alphabets. Legend: 1 – number of unique configurations for particular fingerspelling alphabet; 2 – number of configurations that coincide with set of 24 distinct configurations of Ukrainian fingerspelling alphabet.

Alphabet	1	2	Alphabet	1	2
American	23	12	French	21	10
Polish	19	11	Swedish	20	11
Russian	24	21	Japanese	27	13
German	23	13	Spanish	20	12
Greek	20	10			

Also the comparative analysis of each alphabet with another one was made. Can be determined that three configurations (Л, М, Я) are common for all ten fingerspelling alphabets. Such configurations as Л, Я, М, У, Г are common for 10 alphabets (see Table 7).

Table 7. Fingers' configurations that are common for 10 manual alphabets.

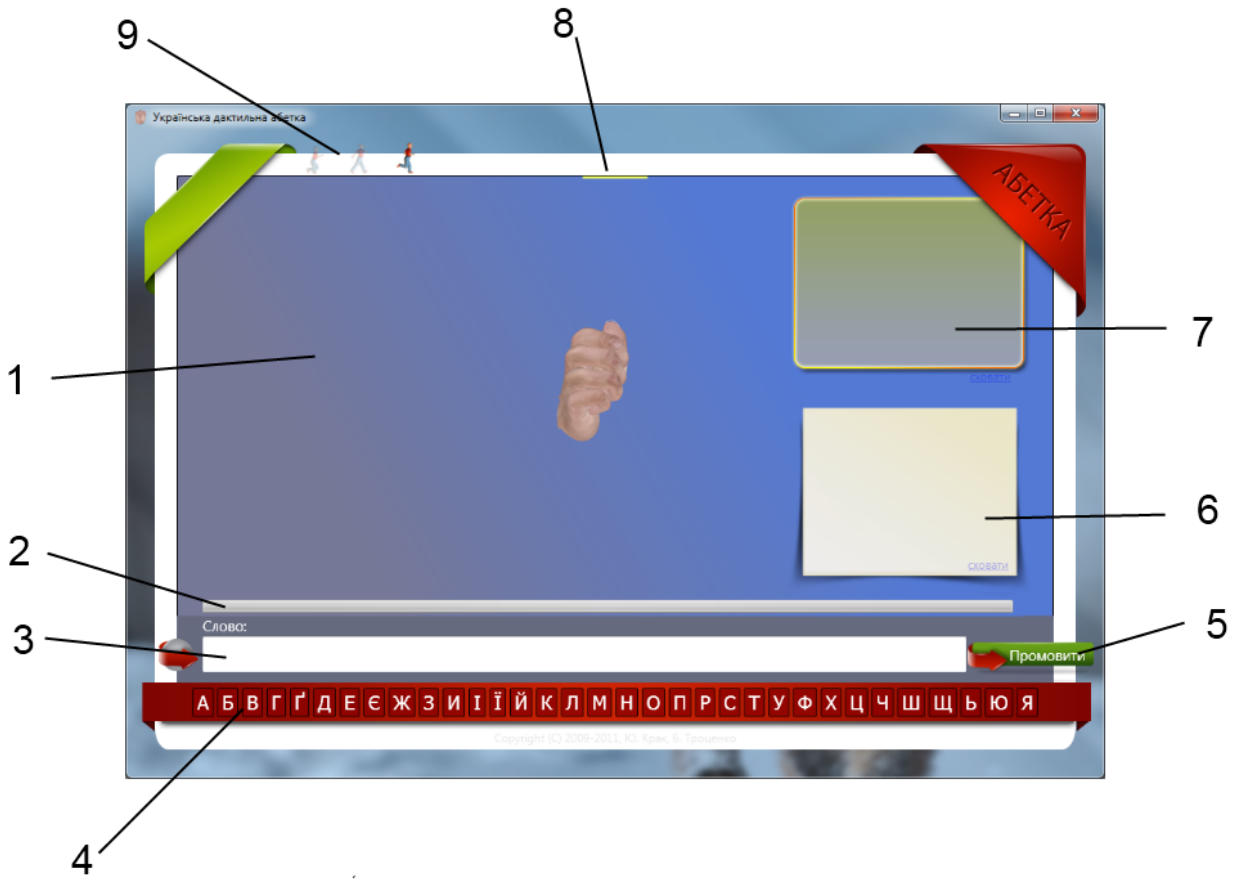


An analysis of ten fingerspelling alphabets were performed. 309 letters (dactyls) of 10 sign languages fingerspelling alphabets were analyzed. 221 is the sum of number of unique configurations for each fingerspelling alphabet. From the set of 221 configurations only 59 are unique configurations. Denote this set by U. It follows that any letter from the 10 fingerspelling alphabets analyzed can be uniquely obtained from the set U, changing the orientation of the hand in a space and/or adding movement.

Thus, we can conclude that it is possible to build set of models of human hand, which will identify precisely the fingers' configurations for manual alphabets of Ukrainian, Russian, Polish, Greek, American, German, French, Spanish, Swedish, Japanese sign languages.

Software implementation of modeling of a three-dimensional model of a hand and animation of fingerspelling process

To teach fingerspelling, technology that uses a three-dimensional model of a hand based on a informational-parametric model has been developed. The technology allows to observe hand from different viewpoint during the learning process, show sequence of letters etc. The main window is shown on a Picture 1.



Picture 1. The main window of a program «Ukrainian fingerspelling alphabet».

At this point the numbers mean: 1 – area of displaying fingerspelling alphabet; 2 – panel of displaying playback progress of letters or words; 3 – input panel for words; 4 – list of letters; 5 – button «spell», the process of fingerspelling of input word begins when the button is clicked; 6 – panel to display the verbal description of a hand configuration that correspond to the current displayed letter; 7 – panel to display written letter and a picture that correspond to the current displayed letter; 8 – indicator of a location of a hand rotation; 9 – define the pace of fingerspelling.

The main features of the program:

1. Changing of a view angel. The use of a three-dimensional modeling enables the possibility to examine hand model from different viewpoints. That would be impossible using video materials. The range of changing an angle of viewpoint vary to 80° right/left.

2. Presence of pictures which are associated with particular letter for whole alphabet (see Picture 2) (this panel can be hidden and shown back).

Picture 2. Working examples of fingerspelling letters “O” and “X”, respectively.

3. Verbal description of hand configuration which is shown.

4. Presentation of dactyls is performed by selecting a particular letter from a list using mouse or by pressing letter-button on a keyboard. If user wants to repeat, press space. This feature allows to implement interactive learning process, when thee right arm (trained) is in the free position and the left realize interactions with the program.

5. Changing the pace of the animation. Three pace modes (slow, medium, fast) are implemented in the program for the different needs of the learning process (repetition after the model, recognition of the foregoing, etc.).

6. Fingerspelling of a word. This feature allows entering words into input panel and observing process of fingerspelling of a word. That allows not only learn separate letters but also learn how to spell whole words.

7. Verification mode. The program has a feature to “hide” the panel of the verbal description of a hand configuration and the panel with written letter and a picture. That allows conducting examination of knowledge displayed letter (hand configuration).

Based on this technology, training programs for any one-handed fingerspelling alphabet can be created. There are currently developed programs for Ukrainian, Russian, Polish and American fingerspelling alphabets.

Conclusion

The resulting information-parametric model allows to effectively build specifications for different fingerspelling alphabets. Investigation of Ukrainian fingerspelling alphabet in this work contributes to the development of technologies for the building of computer technologies of training Ukrainian fingerspelling alphabet. Construction of specifications of fingerspelling alphabets of different sign languages and their comparative analysis are the basis for the development of training systems of fingerspelling alphabet for different sign languages. Developed technologies in the field of three-dimensional modeling and animation of human gestures have shown their efficiency in training Ukrainian fingerspelling alphabet. The universality of this technology allows creating various training programs of fingerspelling alphabets.

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