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Prospects for Information Economy in Ukraine Using Grid-computations Based on Nbic-technologies

Igor Matyushenko[1*]

[1]Department of Foreign Economic Relations and Touristic Business, V. N. Karazin Kharkiv National University, Kharkiv, Ukraine (app.379, 6 Svobody Sq., 61022 Kharkiv, Ukraine.

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Aims: In the conditions of advanced countries industrial markets' competition escalation the issue of creating new economy on the basis of global technologies is becoming more and more important. New global technologies have appeared due to convergence of Nano-bio-info and cogno(NBIC)-technologies. Large scale shaping of information economy in the conditions of information volume explosion occurs in the majority of world countries and involves the majority of industrial branches together with social life. That process requires Grid-computations for inter-disciplinary research to provide for modern NBIC-civilization emergence.
The main aim of the research is to analyze the modern prospects of creating Grid-technologies for information economics in the World and in Ukraine basing on NBIC-technologies.
Study Design: The reviews were carried out in the period 2009–14 on the basis of studying the world countries Grid-technologies development trends as well as on the basis of the research results obtained by Ukrainian academic institutions.
Place and Duration of Study: Scientific research center for industrial development problems of the National academy of sciences of Ukraine, Department of Foreign Economic Relations and

**Corresponding author: E-mail: igormatyushenko@mail.ru;*

Touristic Business of V.N. Karazin Kharkiv National University between September 2015 and December 2015.
Methodology: Content analysis has been used as the main method of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the modern prospects of creating Grid-technologies for information economics in the World and Ukraine with using of NBIC-technologies.
Results: The article demonstrates that in the result of implementing comprehensive scientific-technical programs to develop Grid-technologies during 2009–2014 in Ukraine will create a multi-national grid network elements that will allow to take into account sectoral and regional interests and ensure its integration into European and global Grid-infrastructure. The article analyses the modern prospects of creating Grid-computations based on NBIC-technologies for information economics in the World and Ukraine.
Conclusion: We can conclude that in order to establish an information economy in Ukraine during 2009-2014 should make efforts to develop and implement Grid-technology in the calculations for interdisciplinary research and the formation of modern NBIC-society.

Keywords: Information economics; grid-technologies; NBIC-technologies; interdisciplinary research; economic growth of Ukraine.

1. INTRODUCTION

In the conditions of advanced countries external and domestic industrial markets' competition escalation the issue of implementing scientific projects is becoming more and more important. The projects are directed to investigate prospective directions in enhancing business entities innovative performance on the basis of the so-called "global technologies".

NBIC-technologies convergence is the foundation to create 21st century "break-through" innovative technologies that provide for considerable development of social sphere to treach a qualitatively new level. Exactly information and communication technologies (ICT) laid the foundation to develop global technologies, which similarly to NBIC-technologies, are of huge scale. They involve the majority of world countries and the majority of economic branches together with social life. Global technologies are spread not only in economies of separate countries and continents, but also in the life of an individual and in the life of many nations. At the same time global technologies, which are by their origin and content innovative technologies, stimulate world economy and globalization processes, and can lead to mankind's cognitive potential unification and its mentality standardization.

The named problem was tackled by many renown scientists, including also M. Roco, W. Bainbridge, B. Tonn, G. Whitesides [1,2], R. Campano [3]; R. Silberglitt, P. S. Anton, D. R. Howell [4]; R. Voyer, N. Makhija [5]; L. Stenberg, H. Nagano [6], who studied the issues of knowledge, technologies and society convergence; many renown organizations, for example European Commission [7]; European Parliament [8]; Organization for Economic Co-operation and Development [9]; National Intelligence Council [10] and also Russian scientists A. Kazantsev, V. Kisilev, D. Rubvalter, O. Rudenskiy [11], together with Ukrainian scientists M. Kyzym, I. Matyushenko, I. Buntov, Yu. Moiseienko, O Khanova [12-23] et al. dealt with the development and prospects for NBIC-civilization.

At the same time the growing implementation of NBIC-technologies into developed countries information economics requires review of the prospects for their use to develop Grid-technologies in Ukraine.

The article aims at analyzing the prospects of creating information economics in Ukraine on the grounds of Grid-technologies utilizing NBIC-technologies.

2. METHODOLOGY

Content analysis has been used as the main research method, which allowed making a meaningful analysis of classic papers and researches of modern economists-practicians devoted to studying modern trends in creating Grid-technologies on the basis of NBIC-technologies to implement in the world information economy.

General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way.

We also apply the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards the investigated topic.

Official statistical data of the state institutions and international organizations, referencial publications, analytical monographs, annual statistical bulletins, Ukrainian National Academy of Science reports as well as annual Ukrainian State Statistical Bureau reports serve as an information ground for our research.

3. RESULTS AND DISCUSSION

3.1 Modern Global Trends in Grid-networks Development

Informatization of different social life spheres accelerates world economy development providing for a society social transformation. Transfer from post-industrial society to information society requires implementing advanced information technologies in all social life spheres. Creation of global open scientific and educational systems and Grid-technologies implementation lead to emergence of principally new methods to organize and perform scientific research.

During the latest decade the implementation of cutting-edge information technologies, including the Grid-technologies, into science, industry, financial, social and humanitarian spheres in the EU has considerably outstripped internet development. Advanced countries have been allocating considerable funds to carry out Grid-technologies research, set up national grid-infrastructures, and maintain international cooperation in the mentioned spheres. Grid-technologies provide for performing highly voluminous computations and for creating a system which could be conditionally called computerized internet.

The advanced countries experience proves that Grid-technologies provide for complicated and bulky computations cost reduction by 25-30%. Implementation of Grid-technologies in science, industry, financial, social and humanitarian sphere in all EU countries considerably impacts society rate of development, provides for new scientific and industrial branches emergence as well as for the development of new trends in cultural and social spheres [13,23].

Modern trends in global communication grids development demonstrate that in the coming decades the quite habitual for the modern specialists PCs, servers and local computer networks would disappear from day-to-day life because information services would be transformed into ordinary municipal amenities like power or water supply. Separate computers with multicore processors would dissolve in global information grid infrastructure.

Initially Grid-technologies were designed to solve complex scientific and engineering tasks which could never be solved during reasonable period of time with the help of separate computation installations (e.g., general meteorological forecasting, any natural calamities' forecasting, simulation or analysis of nuclear physics experiments, research in nanotechnologies sphere, designing aero-space vehicles and motor cars, DNA decoding, proteins identification, etc.). However, Grid-technologies implementation today is not limited only by such type tasks. As Grid technologies develop they penetrate into industry and business, begin to claim the role of a universal infrastructure to process data, where a big number of services (Grid Services) exist providing for solving not only specific application tasks but also proposing services in searching the necessary resources, or in gathering information on the resources status, or in data storage and delivery [24].

There are several reasons why scientists have to use Grid-technologies: First, there is a need to process a big volume of data stored at different organizations (in different world countries – e.g., Earth satellite photographs); second, there is a need to perform big computation volumes (e.g., when simulating impact of thousands of molecules (potential medical drug) on proteins when searching for drugs against definite diseases); third, scientific team members, working in different world countries, have the need to use jointly great data volumes, perform their quick and efficient comprehensive analysis, visualize and discuss research results online.

Supercomputers and their centers are major resource elements of Grid-networks, while high-speed networks for data-transfer are the major

infrastructural components. Super-computers, which are not combined into territorial distribution network, have three considerable drawbacks: they are very expensive and become out of date very quickly (in 2-3 years); computation hardware can't be considerably upgraded quickly that may hamper prompt computation of the new more complicated tasks; super-computers have low efficience due to unbalanced processors load.

Those drawbacks could be rectified through combining super-computers into Grid-networks, but initially the services, interfaces, databases, etc. must be standardized. Middleware "Globus" has become de-facto one of the first standards to build up Grid-networks (access to resources is provided on the basis of creating virtual organization consisting of separate services, enterprises and individual specialists that jointly use the corresponding resources).

The following Grid-projects are very well known in the world [24]:

1) TeraGrid was started in 2001 in the USA and was financed by the National Science Foundation; its main task was to create distributed infrastructure for highly productive computations. Since 2004 strategic Grid-program "Strategic Grid Computing Initiative" has been officially announced to function under the patronage of the US president. Its main objective is "to set up uniform national space for high-productive computations". As of today 4 national Grid-networks has been functioning in the USA: National Science Foundation computer network; information network for NASA support; global information network of the US Ministry of Defense; super-computer Initiative network for the US Department of Energy. Moreover, the USA also has Grid-networks within Ministry of Health and Information Services consumer sector. For example, National Mammography Digital Center with general data volume of 5.6 petabytes was set up under the leadership of Pennsylvania University. It provides opportunities to have quick access to the available records on millions of patients.
   Google corporation project is one more example of building up Grid-network, which will turn computing into customer service. That project stipulates that within the project frames all computerized appliances (PCs, TV-sets, mobile phones, etc.) would be connected as ordinary terminals to the server Grid Google with the services of information supply to any appliance in any location of the world.
2) In May 2004 European Union started an analogue to the US project – DEISA consortium, which was partially financed within the frames of the 6th Framework Agreement to combine leading EU national supercomputers' centers into a Grid network. At the end of March 2004 a three-year project "DataGrid" was finished. Within its frameworks a testing infrastructure for data computing and exchange was built up for the European scientific community needs. Basing on those research results a new international project was launched to create high-productive scientific Grid-network EGEE (Enabling Grids for E-sciencE), which was performed under the leadership of Swiss CERN (European Center for Nuclear Research) and was financed by EU and participating countries governments. The project enveloped 70 scientific institutions from 27 world countries. Within the frames of that project the biggest in the world Grid with total computing capacity of 20 thousand powerful processors was built up. The CERN leading role was manifested in the fact that at the end of 2007 – beginning of 2008 the first test launches of the Large Hadron Collider (LHC) were performed. It would become a source of the great information volume (approximately 10 PBytes (1PByte = 10^{15} bytes). EGEE task was to implement the Grid potential for many scientific-technological branches. E.g., a separate bio-informational "Grid-block" was planned to be set.
3) Pan-European data network for the research and education community GEANT had been developing in close interaction with EGEE project. In the middle of 2006 inter-governmental organization DANTE announced the launch of the new generation scientific-educational network GEANT 2 to involve 3 mln. users from 3.5 thousand academic institutions located in 34 European countries. The new network provided for qualitative change in radio-astronomic systems data processing by registering systems located at a considerable distance from one another. It also serviced CERN needs in data transmitting after LHC

launching. In 2005 the European Commission prepared a special program with total cost of 13 bln.Euro, where Grid-computing would act as a stimulus and the most important resource to transform the European Union into "the most competitive knowledge economy in the world";

4) In the middle of 2006 China finished "The China Education Grid Project" (CEGP), which combined computer networks of the dozens of the biggest national universities providing the students and users with the direct access to databases, online educational resources, server applications in different directions and disciplines. Implementation of the joint Chinese and European project EUChinaGRID financed by Euro commission has already been started to combine European and Chinese Grid-infrastructures (as a counterbalance to the US claims on the world leadership in that large scale technologic competition) to enhance efficiency of the different scientific applications working in the Grid-environment. Moreover, India is also ready to connect to that alliance: it announced launching of its own national Grid-project GARUDA, which stipulates combining of 17 largest national scientific-research centers into a Grid-network.
5) The Northern hemisphere finishes setting the world computer network GLORIAD, that combines computing resources of different scientific-research establishments of the USA, Canada, Europe, Russia, China and South Korea (physics centers).

3.2 Status of Research in Developing Grid-networks in Ukraine

In 2002 Ukraine created the first Grid-cluster on the basis of the National Academy of Science of Ukraine (NASU) by a group of physics from the National Science Center "Kharkov Institute of Physics and Technology" (NSC KIPT), but still now (due to the weakness of internet-channels) it is connected with Russian Joint Institute of Nuclear Research (JINR), Dubna, Russia. In autumn 2004 specialists of the Institute for Theoretical Physics (ITP) of the NASU together with the specialists of Shevchenko Kiev National University (KNU) Computer Center built up experimental Grid-platform out of two servers. During 2005 ITP built up Grid-cluster out of 20 two-processor servers. In April 2006 ITP received quick internet access with the help of fiber optic channel (2 Mbit/s, now, it's 8 Mbit/s). CERN conducted a full-scale testing of both clusters (ITP and KNU), and both of them were included into official computing resources of AliEn-Grid and WLCG committee. In 2005 the meeting of NASU Coordination Council on informatization was held to discuss the project "The Program to implement Grid-technologies and create clusters at NASU" [25].

Moreover, NASU became a full-fledged member of CERN the same year. At the end of 2006 the following actions were performed by the same program [26]: New Grid-clusters were built up at the Institute of Cell Biology and Genetic Engineering (ICBGE), Institute of Molecular Biology and Genetics (IMBG) and Main Astronomical Observatory (MAO) of NASU; clusters at ITP, NSC KIPT and at Lviv Institute for Condensed Matter Physics (ICMP) were also built; 50 tasks requested by CERN and AliEn-Grid member-states were computed or are under computation using the ITP cluster. In addition, a laboratory for Grid-computations in physics was set at ITP. On its basis the first NASU Grid-segment was created to combine ITP, ICBGE, IMBG, MAO, KNU as well as Cybernetics Institute, Institute for Space Research and ICMP.

In 2007 financial resources were committed to implement the next stage of the Program "Grid-technologies implementation in creating clusters in the National Academy of Science of Ukraine" (NASU), particularly for creating new Grid-clusters in academic institutes of Kyiv, Kharkiv, Dnipropetrovsk.

The development of the second Grid-infrastructure component – high-speed fiber-optical channels – is implemented by the Ukrainian internet provider UARNET, which not only creates and runs backbone fiber-optical channels (e.g., Kyiv – Lviv with the entry to Poland; Kyiv-Kharkiv with the throughput of 2.5 Gb/s), but also lays fiber-optical lines to the specific institutions. In 2007 a number of Kharkiv academic institutions like KPTI, Radio-astronomic institute, Institute for Institute of Scintillation materials were connected to the NASU grid network.

Therefore, availability of the academic Grid-infrastructure in Ukraine helps activate international relations of NASU institutions: the relations with CERN; implementation of the agreement between Main Astronomic Observatory (MAO) and AstroGrid-D (Germany); implementation of the project of virtual astrophysical laboratory "Integral" (Institute for

Theoretical Physics (ITP) – Kiev National University (KNU) – Geneva University (Switzerland), as well as a number of projects in biology.

In January 2007 The Ministry of Education and Science (MES) announced the start of the project to set up a national UGRID in Ukraine – the infrastructure to ensure scientific research within the frameworks of the State Target Program "Information and Communication Technologies in Education and Science for the period 2006 – 2010". The Project UGRID, prepared by the National Technical University of Ukraine (NTUU) "Kyiv Polytechnic Institute" (KPI) set a task: complete and combine scientific-educational computation and communication infrastructure into a national Grid-infrastructure and integrate it with the European Grid-network; spread the knowledge on Grid-technologies in the society; ensure joint utilization of unique supercomputers, experimentation installations and appliances by separate scientists; actively participate in forming up new concept of European Grid-infrastructure; develop new original Grid applications in the sphere of tele-medicine for Chornobyl NPP employees, for distant learning in the Central-Eastern-European university (CEEVU), for servicing the Ukrainian Branch of the World Data Center (UB WDC).

The mentioned Grid-project was based on using the most powerful (for that period of time) in Ukraine supercomputer of cluster architecture (built up on 168 LAPACK processors with the general productivity of 1.4 Teraflops and commissioned in NTUU KPI at the end of 2006) with the participation of Grid-clusters of Kharkiv National University for Radio-electronics (NURE), Lviv, Donetsk and Zaporizzhia National Technical Universities, Institute for Modelling in Energy Engineering (IMEE) of NASU, state enterprise (SE) "Lviv Radio-Engineering Research Institute" (LRERI), etc. [24].

As of today the NTU "KPI" provides free distant access for Ukrainian users to that supercomputer capacities via scientific-educational network "URAN" created in 1998 at the initiative of NTUU "KPI", technical universities of Kyiv, Kharkiv, Dnipropetrovsk, Donetsk, Odesa with participation of NASU. URAN connected 18 Ukrainian regions via fiber-optic cables. At the end of June 2007 London witnessed signing of the agreement on connecting the network URAN with pan-European scientific-educational network GEANT2, which connected more than 30 scientific-educational European networks [27].

In other words, beginning from 2008 academic year nearly 100 universities and research institutes in 18 Ukrainian regions as well as other scientific-educational establishments, which had joined the network later, had the opportunity to use information resources of GEANT2 (e-libraries, databases, information search engines, distant learning resources, etc.).

URAN network – is a joint ideology, joint channels, a system of e-libraries, a system to train system administrators, "Education" system, a system to inform on the issues of education etc. Basing on that network, regional centers for distant learning were set up. Via that network the supercomputer is accessible for all academic establishments. Basing on it in 2006 a data storage was arranged for Ukrainian branch of World Data Center (a System of World Data Centers is located now in 12 countries; it is coordinated by the International Council for Scientific Unions (ICSU) and is a world renown source for versatile and unique data in different branches of modern science. E.g., Ukrainian branch of WDC is called to maintain data sections on solid body physics; solar-earth physics; economic geography; oceanography; energy security and technologies of the information society in cooperation with the leading local scientific organizations of the corresponding profiles). A very important thing to mention: the agreement was achieved to combine URAN Grid-clusters with the Ukrainian Institute of Theoretical Physics and Cyber-Center of NASU.

The directions of Grid-networks development in Ukraine are as follows: Support at the governmental level and implement the National project to set up and develop Grid-networks (on the basis of academic Grid-infrastructure and UGRID); connect all computation clusters in Ukraine (more than 30) to the national grid with the help of high-speed fiber-optical channels; connect the national Grid-network to the general European Grid-infrastructure and ensure its continuous functioning as its robust operational and functional component; catch-up in near future with European countries and enter European research area (ERA) as an eligible qualified partner.

To solve complex tasks with the help of the already built supercomputers NASU has set up Academic network data exchange (AMOD), which enhanced efficiency and quality of scientific research. It is an assembly of

distributed hardware and software, the corresponding organizational and staffing means directed to provide telecommunication services in data accessing and transfer to NASU and other users with the speed of up to 10 Gb/s. The network envelops 7 regional networks in Ukrainian scientific centers, to which nearly 160 NASU institutions are connected; it has access to European scientific network GEANT and direct access to Polish academic network PIONER as well as Ukrainian scientific-educational network URAN; it has acquired the status of the autonomous system with the registration in European internet-register; it is the major network to implement VoIP and develop national Grid-infrastructure [28].

Before 2011 the academic Grid-infrastructure had grown considerably having combined more than 30 Grid-clusters not only among academic institutes, but also the clusters of universities and Ukrainian Ministry of Уducation and Icience institutions. Ukrainian academic grid had transformed into *Ukrainian National Grid (UNG).* In May 2011 UNG became a full-fledged NorduGrid collaboration participant thanks to which the Ukrainian specialists could influence the development of European grid-technologies and participate in joint international projects in that sphere [29].

The distributed computations as a method to obtain digital scientific results had attracted scientists' interest since emergence of powerful workstations on the basis of UNIX type systems. However, exactly the restricted data transfer speed hampered wide implementation of such technologies. Scientists from European Center for Nuclear Research (CERN) were the first to see the alternative to very expensive supercomputers: Processing of the experimental data obtained at Large Hadron Collider (LHC) required not only to accomplish resource-intensive algorithms in the shortest possible time period, but also high speed of great data volumes transfer during many years of the collider operation. After a number of years spent for developing and testing different approaches the computation Grid-technologies had become a day-to-day reality. Suffice to say, that the whole processing and analysis system to compute LHC experiments in CERN is based exactly on Grid-technologies.

To store and analyze in real time mode the unprecedented data volume (more than 15 Petabyte/year in four major experiments) a special Grid-infrastructure "Worldwide LHC Computing Grid" (WLCG) was created to combine the world computer centers of all the universities, institutes, laboratories that perform research in the sphere of high energy physics.

From a user point of view Grid is a great resource to make computations of any complexity and store data of any volume. Not a single organization could afford having such combined computation resource. However, Grid, possibly, is not optimal for all types of computations (e.g., it does not fully meet the requirements of parallel computations). In Ukraine due to unfavorable financial situation Grid could be treated as temporary alternative to super powerful supercomputers, which are very expensive in servicing.

As in any computation Grid-infrastructure it is necessary to set up the so-called *middleware* to integrate all the computation resources and organize their coordinated work. The segment creators selected the package Nordugrid ARC (Advanced Resource Connector), developed in collaboration with north-European countries NorduGrid (http://www.nordugrid.org). It was the simplest middleware to support all the necessary functions of the Grid-infrastructure work; it worked very stably and was supported (and still is supported) by the fullest set of complete and understandable documentation.

It's worth stressing, however, that the initiators of Grid-technologies implementation in Ukraine did not limit themselves by their narrow profile interests (e.g., high energy physics, participation in CERN infra-structure, etc.). Grid-infrastructure build-up was performed by the different profile agencies: e.g., Institute for Molecular Biology and Genetics, Institute for Cell Biology and Genetic Engineering (as of now that cluster has been transferred to the State Facility "Institute for Food Biotechnology and Genomics"), Institute for Scintillating Materials, Main Astronomical Observatory (all of them are integral to NASU), Ukrainian Space Research Institute, State Space Agency of Ukraine, etc.

3.3 The Results of the Academic Program to Implement Grid-technologies and Clusters Development in Ukraine and Further Development of Grid-infrastructure and Grid-community

Exactly such a multi-disciplinary approach had been formulated in the Academic Program to Implement Grid-technologies and Clusters

Development prepared by NASU and implemented till 2009. At the same time, the State Target Program to Implement and Use Grid-technologies in Ukraine in the period 2009–2013 stipulated data transfer speed increase between the most powerful Ukrainian National Grid clusters up to 10 Gb/s, which would provide for considerable increase of Grid-calculations efficiency. According to the strategy of Grid building up in Ukraine, selected in 2005, the Ukrainian national grid would function on middleware "ARC". At the same time, the middleware "gLite" was installed and certified at three clusters (Institute of Theoretical Physics (ITP), Shevchenko Kyiv National University (KNU) and Kharkiv Institute of Physics and Technics (KIPT), which are working within the CERN infrastructure. Exactly thanks to ARC middleware utilization there had appeared mutual interest between Ukrainian National Grid and NorduGrid to start collaboration.

NorduGrid amendment practically coincided with a new European initiative to develop unified middleware – the project "European Middleware Initiative" (EMI). It combines leading European middleware developers: ARC, gLite, UNICORE, dCache. Till recent time the named packages had been incompatible, because they had used different technological approaches to implement the systems of grid-type. It created numerous difficulties both for scientists and computer centers, which had to maintain several systems simultaneously, trying to meet the requirements of different research groups.

The EMI project task was to create general approaches and use standard means to combine different middleware. E.g., grid middleware elements were planned to locate in standard repositories of Linux operational system making the grid accessible for practically anyone. It would make the work of the scientists and computer centers' operators easier, and in the consequence it would increase resources utilization efficiency and research quality. Moreover, the new unique middleware would be more attractive for users, who treated Grid-technologies as too complicated for practical use.

NorduGrid collaboration expanding at the expense of Ukrainian National Grid (UNG) was very timely: UNG specialists with their experience in using grid-technologies for absolutely different applications proved to be very useful. Moreover, having joined the collaboration, the Ukrainian Grid-specialists could influence the development of European grid-technologies even without being the participants of EMI project. Collaboration with NorduGrid had started a good tradition to perform working meetings on technical issues to develop the infrastructure, improve and develop software, etc. Such meetings were mandatory for developers' teams, the offices of whom were located all over Europe. In routine work modern information technologies reduce distances, but nothing could replace live discussions vis-à-vis. It's also important that the meetings were held in different countries to attract a bigger number of specialists.

In 2009 The State Target Scientific-Technical Program (STSTP) to Implement and Apply Grid-technologies in Ukraine for the period 2009-2013 was approved. Within the frameworks of that program *The Ukrainian Grid-infrastructure* had been actively built up on the basis of Academic network data exchange (AMOD). The Program financing had started since 2010 (though not in full volume) [30].

The aim of the program was to set up national Grid-infrastructure and conditions for its wide application on the basis of Grid-technologies including also increase the throughput capacity of fiber-optic communication channels; develop specialized Grid-software and adapt the available software for grid-application; train specialists in the spheres of Grid-technologies development and application.

There were three ways to achieve the task results:

1) The first one stipulated step-by-step computation resources capacity building within the scientific institutions which had already been experienced in using Grid-technologies with their further application in other spheres and sharing the obtained experience with the interested parties; it would provide for slow-rate application of Grid-technologies and thus increasing the gap between Ukraine and advanced countries in that sphere;
2) The second one stipulated creation of multi-level inter-departmental grid-network with the account of Grid-technologies profile application in different industrial branches and in different regions; it would cause creation of grid-segments with different specifics and would become an

obstacle for their unification into a national Grid-infrastructure;

3) The third one, the optimal one, stipulated creation of multilevel inter-departmental Grid-network with the centralized management elements, which would provide for integrating departmental and regional interests during national Grid-infrastructure setting and it would also provide for its integration into the European and all-world Grid-infrastructure.

To set up the national Grid-infrastructure and ensure its development it was planned to set up: a kernel grid-center at the National Academy of Science; resource and regional grid-centers, the work of which would be coordinated by the NASU institutions and Ministry of Education and Science; grid-nods with the interested establishments; inter-departmental coordination council to determine the major corner stones for setting and ensuring development of the national Grid-infrastructure; coordination committee as an executive body that would represent the national grid-infrastructure in Ukraine and in foreign countries; monitoring centers to follow functioning of the Grid-networks; a center with its branches to certify and register virtual organizations, grid-nods and individual users according to the international standards.

To achieve the Program goal it was necessary to do the following: Ensure development of powerful computation resources by way of setting new computation nods and processors as well as telecommunication infrastructure and enhance the throughput capacity of the fiber-optical communication channels; develop specialized software and adjust the available software for implementing grid-technologies; set up a system of specialists' training and skills upgrading in the issues of Grid-technologies development.

The Program priorities were as follows: create and provide system integration of the national Grid-infrastructure elements (kernel resource centers, grid-nods, fiber-optical communication channels with high throughput capacities, specialized grid software and information resources) with the European and all-world Grid-infrastructure adhering to the information security requirements; implement Grid-technologies in local multi-processor computation systems; implement Grid-technologies for scientific research; integrate local scientific institutions with the world scientific community; attract Ukrainian scientists to participate in modern unique experiments, in computing their results and in virtual scientific forums; implement new methods for the population medical servicing; create distributed diagnostic databases; provide consultations and conciliums with using telecommunication means, including also large-scale computer analysis of medical data; ensure operational processing of geophysical, meteorological and space research results in real-time mode; create conditions to implement grid-technologies in science, industry, financial, social and humanitarian spheres; create a system to train specialists and upgrade their skills in the issues of Grid-technologies development.

The Program implementation provided for: creating the national Grid-infrastructure with the account of the world advanced countries experience; activating international scientific and scientific-technical cooperation via attracting the national Grid-infrastructure users to participate in international virtual communities; satisfying the needs of science, industry, financial sector, social and humanitarian spheres in computation resources; strengthening scientific-technical and social integration of Ukraine into the European Union; ensuring access of the local users to the international projects and computation resources; creating conditions to determine theoretical and practical aspects of Grid-technologies use; developing specialized grid-type software and adapt the available software for grid-technologies application; setting up training centers and developing curricula to train specialists in the issues of developing and implementing grid-technologies; organizing seminars and workshops in Grid-computation techniques.

Table 1 provides the most prominent results of the mentioned program implementation in the period 2010-2013 [31-34].

Accomplishment of the State Target Scientific-Technical Program for Developing and Implementing Grid-Technologies in 2010-2013 yielded *positive results:* Ukrainian National grid was built-up, the main part of which included NASU computation clusters; many topical scientific research projects were performed in many directions, which were traditional for numerous academic institutions integral to NASU; grid-computations were included into applied scientific research projects and also proposed for practical use in medical and

engineering projects; interdisciplinary research had grown up considerably, close scientific relations had been maintained between different profile academic institutions; international scientific collaboration of Ukrainian scientists had grown up in such spheres as high-energy physics and astrophysics, molecular and cell biology, geo-science, etc., as well as in the sphere of global integration of national computation resources to create unified European and all-world research-information area.

Therefore, the program main achievement was creation of the Ukrainian national grid-infrastructure of the production type and its integration into the world biggest e-infrastructure that combined more than 22 thousand researchers from all over the world. It helped provide Ukrainian scientists with the necessary services to perform digital research of the global level both individually and in collaboration with other countries scientists regardless of their place of stay.

Ukrainian national grid today is a research e-infrastructure of the national level, which combines 39 resource centers of the Ukrainian scientific organizations (29 of them belongs to NASU). 12 resource centers make up a foundation of the UNG coordinated by the national operational center (NGI_UA). They are integrated into the European network as a grid-infrastructure. Generally, the setting of the communication-resource network of fiber-optical communication channels between academic institutions and grid-clusters have been completed. The majority of the clusters have been connected via data exchange fiber-optical channels with a throughput capacity ranging from 300 Mb/s to 1000 Mb/s; 7 the most powerful clusters have the channels with the speed of 10 Gb/s. Utilization of the built grid-infrastructure and distributed computation potential at NASU institutions helped achieve a number of important scientific results in high-energy physics, astrophysics and life science including also practical medicine, geo-since, Nano-physics and Nano-electronics, as wel as in materials science, etc.

The results of the State Program to implement Grid-technologies in Ukraine demonstrate the necessity of further grid- and cloud-technologies development in Ukraine as well as availability of wide opportunities for their implementation by Ukrainian scientists to solve complex problems requiring big and super big computation resources.

NASU Presidium considers *the following development directions that use grid- and cloud-technologies as well as high-productive computation means to be of top priority*: formation of the modern electronic infrastructure that stipulates creation and implementation of Grid-clusters, hardware-software complexes, telecommunication networks and systems of grid- & cloud- technologies together with other prospective technologies; enhancing capacity and quality of Grid-infrastructure with the help of strengthening the available computation Grid-clusters, creating national services' catalogue; creating flexible virtual research environment with the simplified access to the resources of Ukrainian and global information-computation environment; creating conditions and mechanisms for collaboration between research and IT-partners and between different countries' projects; formation and support for the virtual National Center of Competence and its cooperation with EGI Competence Center; spreading the application domain for grid- & cloud- technologies and other modern computation technologies to perform scientific research.

To achieve all those objectives and widen Grid-technologies application in scientific research the Target Comprehensive Program for NASU scientific research "Grid-infrastructure and Grid-technologies for scientific and applied scientific applications" for the period 2014-2018 was developed in 2013 [35].

Implementation of the new program is essential both for developing fundamental & applied science and for achieving the strategic goal of the Ukrainian state policy as regards Euro integration, especially in the conditions of signing the Association Agreement between Ukraine and EU. Euro Commission in its program "Horizon 2020" set a task to combine all the European available research infrastructures and scientists with the help of e-infrastructure to create a single digital research environment that requires continuing and strengthening integration of Ukrainian and European information-research environments.

Table 1. The most prominent results of implementing STSTP of NASU "Developing and implementing grid-technologies" in the period 2010–2013

Year	Program direction	Most prominent results	Practical value
1	**2**	**3**	**4**
2010	Develop grid-technologies' facilities and resources	26 computation clusters of different NASU and Ukrainian Ministry of Education & Science establishments got united	Modern powerful computation platform of the state significance was created to solve super complicated different profiles tasks
2011	Develop grid-technologies' facilities and resources	Logistic and functional support for the kernel and regional resource centers of the Ukrainian National Grid (UNG) was strengthened together with strengthening of computation resources for 10 grid-clusters	Modern powerful computation platform of the state significance was created to solve super complicated different profiles tasks
		A new cluster plus 4 grid-platforms to access grid-network were set up	
		Potential computation resource was increased to reach 31 grid-clusters having more than 3000 processor cores and more than 400 Terabytes for data storage	
	Use grid-technologies for fundamental research	With the help of cluster and grid-computations projects in the spheres of high-energy physics, astronomy and astrophysics, molecular and cell biology and medicine, solid and soft matters' physics, Nano-technologies and new materials, geophysics and environment protection, simulation of economic processes was implemented	Fundamental research projects implemented
		Relations with European and world grid-projects were adjusted to process experimental data from Large Hadron Collider (LHC)	LHC data processed
		Considerable success was achieved in the work of the virtual grid-organization "Moldyngrid", when molecular dynamics methods and grid-technologies were used to research complex biologic molecules	Grid-technologies to research complex biologic molecules developed
	Use grid-technologies for applied research	The 1st stage of strengthening throughput capacity of data transfer channels between grid-clusters was completed; connection to the European grid-infrastructure was performed	The UNG and connection to the European grid-infrastructure improved
	Train specialists in grid-technologies	Two display classes for theoretic and practical training of specialists in grid-technologies were set up; four Ukrainian grid-clusters were connected to the international education grid-network	Classes to train specialists in grid-technologies set
2012	Develop grid-technologies' facilities and resources	To implement the agreement on collaboration between European Grid Infrastructure and UNG 11 Ukrainian grid-clusters that work in accordance with high European standards were tested.	Certification of 11 Ukrainian grid-clusters completed
		General computation resource was increased up to 39 grid-clusters having 4000 processor cores and more than 500 Terabytes for data storage.	Computation resources increased
		The channels throughput capacity to exchange data between the most powerful grid-clusters was increased up to 10 Gb/s	Data exchange throughput capacity increased
	Use grid-technologies	Program packages to use grid-technologies in different scientific and scientific-	Specialized program packages started

Year	Program direction	Most prominent results	Practical value
1	2	3	4
	for fundamental research	technical research were developed and started to be widely used	to be used in research
		In the area of high energy physics research at LHC, Ukrainian scientists became co-authors in discovering new boson – candidate on the role of Higgs boson	Co-authorship in discovering new boson (Higgs boson) achieved
		Considerable success was achieved in the biological profile projects, where grid-technologies were used to research complex biologic molecules	The complex biologic molecules researched
	Use grid-technologies for applied research	The number of topical projects directed to solve important practical tasks got increased. Pilot projects in medical sphere as well as in material science, environmental condition analysis, forecast and protection from natural calamities, like inundation, for example, were performed	Pilot projects in applied research performed
	Train specialists in grid-technologies	The work with the international educational grid-network was continued	Specialists in grid-technologies trained
2013	Develop grid-technologies' facilities and resources	Integration at the technical level of UNG into the European Grid Infrastructure (EGI) was continued and deepened; collaboration of Ukrainian grid-clusters, including also academic grid-clusters, with European national grid-infrastructures and with separate international virtual organizations (in Poland, Germany, France) was strengthened	UNG integration at the technical level both inside the grid-clusters and with the international organizations deepened
	Use grid-technologies for fundamental research	Agencies-performers of the research programs in high energy physics sphere actively participated in the research at LHC at CERN (ALICE & CMS experiments). Project performers from NSC KIPT, participants of CMS experiment, became co-authors in discovering Higgs boson.	Participation in the high energy physics research programs
		Considerable success was achieved in the astrophysics and cosmology projects	Research in astrophysics and cosmology projects performed
		Success in the biological profile projects, where grid-technologies were used to research complex biologic molecules	Prospects for computer designing of new drugs; new agents to protect plants developed
	Use grid-technologies for applied research	Grid-technologies were implemented in practical medicine (jointly with the Institute of Nuclear Medicine & Radio diagnostics and M. Amosov Institute of Cardiovascular Surgery)	Grid-technologies in practical medicine implemented
	Train specialists in grid-technologies	The work with international grid-network was continued	Specialists in grid-technologies trained

Composed by: [31-34]

The further development of Grid-infrastructure and Grid-community requires comprehensive approach and efforts concentration on solving the following *problems:*

1) Enhancing capacity and quality of Grid-infrastructure through developing computation Grid-clusters, creating a national services' catalogue, satisfying the users' needs;
2) Increasing data exchange channels throughput capacity, increasing computation capacity of resource centers and Grid-infrastructure distributed data storage resources; developing national resources list and implementing the model of resources distribution provided by the resource centers. Development of "cloud" technologies and creation of comprehensive UNG "cloud" would provide for conducting distributed new technologies tests to be promoted by the national and European grid-community;
3) Arranging a flexible research environment with simplified access to UNG resources. Ensuring functional compatibility of platforms and working processes in such environment space with the European platforms for the joint utilization of the distributed databases. Conducting topical research in collaboration with other countries' scientists, who use the developed platforms, working processes and applications. Adaptation of the developed and accepted by the European community e-infrastructure standards must be one of the development directions;
4) Ensuring specialists training and creating conditions and mechanisms for cooperation between researchers and IT-collaborators within projects in different countries. Forming and supporting Virtual Competence Center, its interaction with EGI Competence Center.

The program aim is to provide further development of Grid-technologies and spread up the sphere of their application in scientific and applied science research at NASU; develop and implement new hardware/software methods and means of high productive computations; ensure participation of NASU scientists in international Grid-projects and organizations.

The main directions and priorities of the Program for 2014-2018 period are as follows:

1) Develop facilities and resources for Grid-technologies and high-productive computations to be used in scientific and applied science projects, including also the following: develop and promote kernel coordination center as UNG consolidating and coordinating body; develop resource centers (grid-sites) and data storage capacity; support and develop data exchange resource center; build-up the unified infrastructure for distributed computations, which is composed of the traditional Grid-infrastructure and cloud infrastructure with the opportunity to provide user access convenient interface to different information-computation resources and enhance productivity of their utilization; develop UNG universal services catalogue and implement service-oriented computations to create application software via combining and orchestrating separate services; ensure throughput capacity of communication fiber-optic channels between the resource centers not less than 1Gb/s and increase communication fiber-optic channels throughput capacity to communicate between local and foreign grid-nods in accordance with the European network GEANT-3 capabilities; develop and follow-up comprehensive system for UNG information protection; UNG system integration into the European infrastructure including also supercomputers' network PRACE, repository EUDIT, consolidated European cloud for scientific and innovative research;
2) Apply Grid-technologies in fundamental research and support virtual organizations working by the topics: physics and high energy astrophysics, astronomy; molecular and cell biology and genetics, neuro-physiology, life science; physical foundations of materials science, Nano-physics and Nano-materials; geo-physics, meteorology, climatology, geo-science; social-economic science. Other scientific directions;
3) Implement Grid-technologies and support the corresponding virtual organizations in application spheres, including also: practical medicine (in collaboration with the National Academy of Medical Science of Ukraine (NAMSU); develop and implement European systems of pictures processing and simulate neuro-degenerative diseases for diagnostic systems; combine distributed

medical diagnostic databases into a comprehensive system for scientific and clinical research; perform engineering computations, including also developing and implementing inter-disciplinary platform for collective engineer designing in grid/cloud-area; carry out Eco-monitoring, distant probing, forecasting of natural phenomena;

4) Train specialists in Grid-technologies and cloud computations; launch courses in digital science in the national higher educational establishments, develop theoretical minimum of digital science and a discipline quality standard; develop the system of distant learning and qualification upgrading for digital science learning process; create virtual Competence Center integrated into EGI Competence Center to transfer and exchange knowledge and skills of using grid- and cloud-infrastructure to process big data volumes.

Table 2 gives the most prominent results of accomplishing the State Target Scientific-Technical Program of Ukraine (STDTPU) "Grid-infrastructure and Grid-technologies for scientific and applied scientific projects" for 2014 [36].

The Program expected results would be as follows: Support for the Ukrainian Grid-infrastructure work would be ensured; continuous increase of its computation capacity and data storage capacity would be guaranteed; powerful computation resource-centers would be created; advanced technologies for efficient and effective resources utilization would be initiated (upgrading of middleware, virtualization of resources and cloud-technologies, advance to the international platforms of resources

Table 2. The most prominent results of accomplishing STDTPU "Grid-infrastructure and grid-technologies for scientific and applied scientific projects" for 2014

Year	Program direction	Most prominent result	Practical value
1	**2**	**3**	**4**
2014	Develop faci-lities and resources for grid-technologies and high productive computations	Technical and service improvement of north-east (in Kharkiv) and west (in Lviv) regional resource centers was performed; the functions to support virtual organizations and users were enforced	More advanced methods to manage clusters were implemented to ensure reliable faultless work; data storage in repositories guaranteed
	Implement grid-technologies in fundamental research	Clusters that participate in processing and analyzing LHC experimental data were prepared for intensive loading. Research and computations of theoretical models of strongly interacting matter were continued; data on the distribution of the born Z-bosons and j-mesons at the protons energies 7 & 8 TBytes were processed and researched	Working algorithms of clusters that participate in LHC data processing improved
		With the help of grid-technologies new weak energy line in x-ray spectra of Andromeda galaxy and Perseus galaxies cluster was researched.	Properties of that line totally agree with the line of dark matter particles disintegration
		Computer simulation of multi-molecular systems properties in the physics of solid and soft matters was continued	New effects in multimolecular systems behavior found
	Implement grid-technologies in application sphere	Instrumental means to simulate and analyze neurosystems 3D models were created; animation and 3D printing software means were developed. Results of 3D "fancy conditions" simulation were placed in the databank in grid-network, accessible via web-interface http://chimera.biomed.kiev.ua/video	Databank in grid-network with the opportunity to scan, visualize, search and aggregate 3D "fancy conditions" created
	Train specialists in grid-technologies	The work with the international educational grid-network was continued	Specialists in grid-technologies trained

Composed by: [36]

provision); stable and qualitative work of kernel Coordination. Center that manages the work of the national grid-infrastructure, provides services and technical support for a wide circle of users, spreads information on advanced Grid-technologies and opportunities for their implementation would be ensured; efficient coordination of scientific fundamental and applied research that require high-productive computations and huge data arrays processing would be guaranteed; collaboration with international grid- & cloud-platforms would be spread; conditions for integrating into the global research area would be created; participation in the global and European projects would be increased; virtual national Competence Center in digital science would be set up; information & computation services to the national and international researchers and their collaborators would be provided; training and skills upgrading for the Grid-technologies specialists and users would be ensured.

After the programs accomplishment the new intellectual IT to analyze and substantiate management decisions for economy and social sphere needs with using knowledge bases and data bases would be developed and created. IT for the needs of space and biologic research, efficient utilization of energy resources, medical diagnostics and development of medical drugs, telecommunication and information-analytical systems, etc., are planned to be developed with using the basic methods of solving trans-computational complex tasks. The work in solving the tasks connected with environmental control would be continued. They involve the problematics of monitoring and data analysis as well as simulation problems to include atmospheric simulations, models of water basins and soil grounds. Basing on the experience and achieved results in 2007–2012 the generic solutions to protect information in virtual data processing centers would be developed and tested [35].

Successful accomplishment of the mentioned programs would enable a wide circle of scientists and practitioners to use Grid-technologies to create information economy in Ukraine, perform scientific research and development of high level, increase National Academy of Science of Ukraine (NASU) participation in implementing competitive projects ordered by public administration, improve conditions for attracting and implementing international grants projects.

4. CONCLUSIONS

Ukraine has already exhausted itself as a country producing cheap labor force with predominantly low-technological and energy-inefficient industry. At the same time it has a chance to make a break-through on information technologies market thanks to the accumulated intellectual potential.

Grid-technologies implementation today is not limited to solving complex scientific and engineering tasks which could never be solved during reasonable period of time using separate computation installations (e.g., general meteorological forecasting, any natural calamities' forecasting, simulation or analysis of nuclear physics experiments, research in nanotechnologies sphere, designing aero-space vehicles and motor cars, DNA decoding, proteins identification, etc.). As Grid-technologies develop they penetrate into industry and business, begin to claim the role of a universal infrastructure to process data, where a big number of services (Grid Services) exist providing for solving not only specific application tasks but also propose services in searching the necessary resources, information gathering on the resources status, data storage and delivery.

In accordance with the Sate Target Program to implement and apply Grid-technologies in Ukraine for the period 2009-2013 the process of creating and developing Grid-networks was continued (on the basis of academic Grid-infrastructure and UGRID); connection to the national network with the help of high-speed fiber-optical channels of all computation clusters in Ukraine (more than 30) contiues; connecting the national Grid-network to the general European Grid-network and providing for its constant functioning as a full-fledged operational and functional component of that structure was ensured; catching up in near future with EU countries and entering the European research area (ERA) as a full-fledged and qualified partner would also continue.

Implementation of the Target comprehensive program for NASU scientific research "Grid-infrastructure and Grid-technologies for scientific and applied scientific applications" for the period 2014-2018 became very important for fundamental and applied research development in Ukraine as well as for achieving the state policy strategic goal of Ukraine's Euro integration, especially in the conditions of signing

Association Agreement between Ukraine and EU.

Further development of Grid-infrastructure and Grid-community requires comprehensive approach and efforts concentration on solving such problems:

Enhance capacity and quality of grid-infrastructure with the help of strengthening of the available computation grid-clusters; satisfy the users' needs;

Increase the data exchange channels throughput capacity, enhance grid-infrastructure resource centers computation capacity and distributed data storage resources capacity; create a national catalogue of resources and implement a model of resources distribution provided by resource centers. Development of "cloud" technologies and creation of combined UNG "cloud" would provide for conducting distributed testing of new technologies to be developed by the national and European grid-community;

Create flexible virtual research area with the simplified access to UNG resources; ensure functional compatibility of platforms and working processes in such environment with European platforms for joint utilization of distributed databases. Adaptation of the developed and used by the European community e-infrastructure standards should be one of the development directions;

Ensure training of specialists and create conditions and collaboration mechanisms between researchers, IT-collaborators and projects in different countries; form up and support virtual national competence center, its cooperation with EGI competence center.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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