

# Original Research Article

# PROSPECTS FOR INFORMATION ECONOMY IN UKRAINE USING GRID-TECHNOLOGIES & SUPERCOMPUTERS BASED OF NBIC- TECHNOLOGIES

## 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 super-powerful 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 and supercomputers 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 and supercomputers 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 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 and supercomputers 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 and supercomputers during 2009–2014 in Ukraine will create a multi-national grid network elements from a centralized management based supercomputers with cluster CKIT-structure 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-technologies and supercomputers 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 and supercomputers in the calculations for interdisciplinary research and the formation of modern NBIC-society.

**Key words:** information economics, Grid-technologies, supercomputers, 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

19 enhancing business entities innovative performance on the basis of the so-called “global  
20 technologies”.

21 As of today, practically all advanced world countries (USA, European Union, Japan,  
22 South Korea, China, India and Russia) consider Nano-technologies (N), biotechnologies  
23 (B), information technologies (I) and cognitive technologies (C) (NBIC-technologies) to be  
24 one of the main tools for solving the mankind global problems, like, for example:  
25 depopulation and population ageing; food shortage; environmental problems; natural  
26 resources exhaustion and new power engineering; transfer to a new techno-economic  
27 paradigm.

28 NBIC-technologies convergence is the foundation to create 21<sup>st</sup> century “break-through”  
29 innovative technologies that provide for considerable development of social sphere to  
30 reach a qualitatively new level. Scientific research in that sphere concerns development  
31 of super computers, quantum- and bio-computers, which in future are called to replace  
32 the existing technological platforms based on silicon technologies. Revolution in NBIC-  
33 technologies sphere as well as global challenges and crises also contribute to modifying  
34 traditional innovation policies and strategies of the industrially developed countries.  
35 Exactly information and communication technologies (ICT) laid the foundation to develop  
36 global technologies, which similarly to NBIC-technologies, are of huge scale. They  
37 involve the majority of world countries and the majority of economic branches together  
38 with social life. Global technologies are spread not only in economies of separate  
39 countries and continents, but also in the life of an individual and in the life of many  
40 nations. At the same time global technologies, which are by their origin and content  
41 innovative technologies, stimulate world economy and globalization processes, and can  
42 lead to mankind's cognitive potential unification and its mentality standardization.

43 The named problem was tackled by many renown scientists, including also M. Roco, W.  
44 Bainbridge, B. Tonn, G. Whitesides [1; 2], R. Campano [3]; R. Silberglitt, P. S. Anton, D.  
45 R. Howell [4]; R. Voyer, N. Makhija [5]; L. Stenberg, H. Nagano [6], who studied the  
46 issues of knowledge, technologies and society convergence; many renown organizations,  
47 for example European Commission [7]; European Parliament [8]; Organization for  
48 Economic Co-operation and Development [9]; National Intelligence Council [10] and also  
49 Russian scientists A. Kazantsev, V. Kisilev, D. Rubvalter, O. Rudenskiy [11], together  
50 with Ukrainian scientists M. Kyzym, I. Matyushenko, I. Buntov, Yu. Moiseienko, O  
51 Khanova [12; 13; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23] et.al. dealt with the development  
52 and prospects for NBIC-civilization.

53 Such the 21<sup>st</sup> century innovative economy, or as some key opinion leaders (KOL) say,  
54 NBIC-civilization, requires comprehensive research to understand scientific-technological  
55 changes and intellectual- spiritual consequences for every single country. Ukraine also  
56 performs fundamental and applied research in the sphere of information-communication  
57 technologies being one of the NBIC-technologies major components. At the same time  
58 shaping of “information economy” since 2008, when Ukrainian economy started to  
59 function according to World Trade Organization requirements, and also after signing in  
60 2014 Association Agreement between Ukraine as one party and The European Union &  
61 The European Atomic Energy Community and its member states as the other party,  
62 requires definition of the prioritized directions of cooperation in scientific-technical sphere  
63 (including also information-communication technologies (ICT), which experience more  
64 beneficial relations when implementing joint international projects in which Ukraine and  
65 EU countries jointly participate.

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

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

## 72 2. METODOLOGY

74 Content analysis has been used as the main method of research, which allowed making  
75 a meaningful analysis of classic papers and researches of modern economists-  
76 practitioners devoted to the peculiarities of the modern prospects of creating Grid-

77 technologies and supercomputers for information economics in the World and Ukraine  
 78 with using of NBIC-technologies.  
 79 General scientific methods make up a methodological foundation of the research. They  
 80 include: description, comparison, statistics review, system analysis and others, which  
 81 help characterize this phenomenon development in a more comprehensive way. We also  
 82 apply the methods of dialectic cognition, structural analysis and logic principles that  
 83 provide for making authentic conclusions as regards the investigated topic.  
 84 Official statistical data of the state institutions and international organizations, publications  
 85 of reference character, analytical monographs, annual statistical bulletins, Ukrainian  
 86 National Academy of Science reports as well as annual Ukrainian State Statistical Bureau  
 87 reports serve as an information grounds for our research.  
 88

## 89 3. RESULTS AND DISCUSSION

90

### 91 3.1. Modern trends in developing grid-networks in the world countries and in 92 Ukraine 93

94 Informatization of different social life spheres accelerates world economy development  
 95 providing for the society social transformation. Transfer from post-industrial to information  
 96 society requires implementing advanced information technologies in all social life  
 97 spheres. Creation of global open scientific and educational systems and grid technologies  
 98 implementation lead to emergence of principally new methods to organize and perform  
 99 scientific research.  
 100 Implementation of cutting-edge information technologies, including the grid-technologies,  
 101 into science, industry, financial, social and humanitarian sphere in the EU in the latest  
 102 decade has considerably outstripped internet development. Advanced countries have  
 103 been allocating considerable funds to carry out grid-technologies research, set up  
 104 national grid-infrastructure, and maintain international cooperation in the mentioned  
 105 branch. Grid-technologies provide for performing highly voluminous computations and for  
 106 creating a system which could be conditionally called computerized internet.  
 107 The advanced countries experience proves that grid-technologies provide for decreasing  
 108 cost of complicated and bulky computations by 25 – 30%. Implementation of grid-  
 109 technologies in science, industry, financial, social and humanitarian sphere in all EU  
 110 countries considerably impacts society rate of development, provides for new scientific  
 111 and industrial branches emergence as well as for the development of new trends in  
 112 cultural and social spheres [13; 23].  
 113 Modern trends in global communication grids development demonstrate that in the  
 114 coming decades quite habitual for the modern specialists PCs, servers, local grids could  
 115 disappear from day-to-day life because information services would be transformed into  
 116 ordinary municipal amenities as power or water supply; separate computers with  
 117 multicore processors would dissolve in global information grid infrastructure. Initially grid-  
 118 technologies were designed to solve complex scientific and engineering tasks which  
 119 could never be solved during reasonable period of time with the help of separate  
 120 computation installations (e.g., general meteorological forecasting, any natural calamities'  
 121 forecasting, simulation or analysis of nuclear physics experiments, research in  
 122 nanotechnologies sphere, designing aero-space vehicles and motor cars, DNA decoding,  
 123 proteins identification, etc.). However, grid-technologies implementation today is not  
 124 limited only by such type of tasks. As grid technologies develop they penetrate into  
 125 industry and business, begin to claim the role of a universal infrastructure to process  
 126 data, where a big number of services (Grid Services) exist providing for solving not only  
 127 specific application tasks but also proposing services in searching the necessary  
 128 resources, information gathering on the resources status, data storage and delivery [24].  
 129 There are several reasons why scientists have to use Grid-technologies: first, the need to  
 130 process a big volume of data stored at different organizations (in different world countries  
 131 – e.g., Earth photographs made from satellite); second, the need to perform a big  
 132 computation volume (e.g., when simulating impact of thousands of molecules (potential  
 133 medical drug) on proteins when searching for medications for definite diseases); third, the  
 134 desire of scientific team members, who work in different world countries, to use jointly

135 great data volumes, perform their quick and efficient comprehensive analysis, visualize  
 136 and discuss research results online.

137 Supercomputers and their centers are major resource elements of Grid-networks, and  
 138 high-speed networks for data-transfer are the major infrastructural components. Super-  
 139 computers, which are not combined into territorial distribution network, have three  
 140 considerable drawbacks: they are very expensive and become out of date very quickly (in  
 141 2-3 years); computation hardware can't be considerably upgraded, that may provide for  
 142 using it to solve new more complicated tasks; low efficiency of super-computers  
 143 utilization due to unbalanced processors load. Those drawbacks could be rectified  
 144 through combining super-computers into a Grid-network, but initially the standardization  
 145 of services, interfaces, databases, etc. must be agreed. Middleware "Globus" has  
 146 become de-facto one of the first standards to build up Grid-networks (access to resources  
 147 is provided on the basis of creating virtual organization consisting of separate services,  
 148 enterprises and individual specialists that jointly use the corresponding resources).

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

150 1) TeraGrid was started in 2001 in the USA and was financed by the National Science  
 151 Foundation; its main task was to create distributed infrastructure for highly productive  
 152 computations. Since 2004 strategic Grid-program "Strategic Grid Computing Initiative"  
 153 has been officially announced to function under the patronage of the US president. Its  
 154 main objective is "to set up uniform national space for high-productive computations". As  
 155 of today 4 national Grid-networks has been functioning in the USA: National Science  
 156 Foundation computer network; information network for NASA support; global information  
 157 network of the US Ministry of Defense; super-computer Initiative network for the US  
 158 Department of Energy. Moreover, USA also has Grid-networks within Ministry of  
 159 Health and Information Services consumer sector. For example, National Mammography  
 160 Digital Center with general data volume of 5.6 petabytes was set up under the leadership  
 161 of Pennsylvania University. It provides opportunities to have quick access to the available  
 162 records on millions of patients. Google corporation project is one more example of  
 163 building up Grid-network, which will turn computing into customer service. That project  
 164 stipulates that within the project frames all computerized appliances (PCs, TV-sets,  
 165 mobile phones, etc.) would be connected as ordinary terminals to the server Grid Google  
 166 with the services of information supply to any appliance in any location of the world.

167 2) In May 2004 European Union started an analogue to US project – DEISA consortium,  
 168 which was partially financed within the frames of the 6<sup>th</sup> Framework Agreement to  
 169 combine leading EU national supercomputers' centers into a Grid network. At the end of  
 170 March 2004 a three-year project "DataGrid" was finished. Within its frameworks a testing  
 171 infrastructure for data computing and exchange was built up for the European scientific  
 172 community needs. Basing on those research results a new international project was  
 173 launched to create high-productive scientific Grid-network EGEE (Enabling Grids for E-  
 174 scienceE), which was performed under the leadership of Swiss CERN (European Center  
 175 for Nuclear Research) and was financed by EU and participating countries governments.  
 176 The project enveloped 70 scientific institutions from 27 world countries. Within the frames  
 177 of that project the biggest in the world Grid with total computing capacity of 20 thousand  
 178 powerful processors was built up. CERN leading role was manifested in the fact that at  
 179 the end of 2007 – beginning of 2008 the first test launches of the Large Hadron Collider  
 180 (LHC) were performed. It would become a source of the great information volume  
 181 (approximately 10 PBytes (1PByte =  $10^{15}$  bytes). EGEE task was to implement the Grid  
 182 potential for many scientific-technological branches. E.g., a separate bio-informational  
 183 "Grid-block" was planned to be set.

184 3) Pan-European data network for the research and education community GEANT had  
 185 been developing in close interaction with EGEE project. In the middle of 2006 inter-  
 186 governmental organization DANTE announced the launch of the new generation  
 187 scientific-educational network GEANT 2 to involve 3 mln. users from 3.5 thousand  
 188 academic institutions located in 34 European countries. The new network provided for  
 189 qualitative change in radio-astronomic systems data processing by registering systems  
 190 located at a considerable distance from one another. It also serviced CERN needs in data  
 191 transmitting after LHC launching. In 2005 the European Commission prepared a special  
 192 program with total cost of 13 bln.Euro, where Grid-computing would act as a stimulus and  
 193 the most important resource to transform the European Union into "the most competitive  
 194 knowledge economy in the world";

195 4) In the middle of 2006 China finished "The China Education Grid Project" (CEGP),  
 196 which combined computer networks of the dozens of the biggest national universities  
 197 providing the students and users with the direct access to databases, online educational  
 198 resources, server applications in different directions and disciplines. Implementation of  
 199 the joint Chinese and European project EUChinaGRID financed by Euro commission has  
 200 already been started to combine European and Chinese Grid-infrastructures (as a  
 201 counterbalance to the US claims on the world leadership in that large scale technologic  
 202 competition) to enhance efficiency of the different scientific applications working in the  
 203 Grid-environment. Moreover, India is also ready to connect to that alliance: it announced  
 204 launching of its own national Grid-project GARUDA, which stipulates combining of 17  
 205 largest national scientific-research centers into a Grid-network.

206 5) The Northern hemisphere finishes setting the world computer network GLORIAD, that  
 207 combines computing resources of different scientific-research establishments of the USA,  
 208 Canada, Europe, Russia, China and South Korea (physics centers).

209 At the same time insufficient volume of computing resources considerably hampers  
 210 Ukrainian scientific-technological development. As of today the National Academy of  
 211 Science of Ukraine (NASU) institutions, Ukrainian Ministry of Education and Science and  
 212 Ministry of Health Care have acute need in computing resources the access to which is  
 213 ensured with the help of Grid-technologies. Implementation of the Grid-technologies  
 214 would provide for computer resources more efficient utilization and ensure scientific  
 215 technical and social integration to the world and European environment.

216 In 2002 Ukraine created the first Grid-cluster on the basis of the National Academy of  
 217 Science of Ukraine (NASU) by a group of physics from the National Science Center  
 218 "Kharkov Institute of Physics and Technology" (NSC KIPT), but still now (due to the  
 219 weakness of internet-channels) it is connected with Russian Joint Institute of Nuclear  
 220 Research (JINR), Dubna, Russia. In autumn 2004 specialists of the Institute for  
 221 Theoretical Physics (ITP) of the NASU together with the specialists of Shevchenko Kiev  
 222 National University (KNU) Computer Center built up experimental Grid-platform out of two  
 223 servers. During 2005 ITP built up Grid-cluster out of 20 two-processor servers. In April  
 224 2006 ITP received quick internet access with the help of fiber optic channel (2 Mbit/s,  
 225 now, it's 8 Mbit/s). CERN conducted a full-scale testing of both clusters (ITP and KNU),  
 226 and both of them were included into official computing resources of AliEn-Grid and  
 227 WLCG committee. In 2005 the Coordination Council on informatization at NASU was held  
 228 to discuss the project "The Program to implement Grid-technologies and create clusters  
 229 at NASU" [25].

230 Moreover, NASU became a full-fledged member of CERN the same year. At the end of  
 231 2006 the following actions were performed by the same program [26]: new Grid-clusters  
 232 were built up at the Institute of Cell Biology and Genetic Engineering (ICBGE), Institute of  
 233 Molecular Biology and Genetics (IMBG) and Main Astronomical Observatory (MAO) of  
 234 NASU; clusters at ITP, NSC KIPT and at Lviv Institute for Condensed Matter Physics  
 235 (ICMP) were also built; 50 tasks requested by CERN and AliEn-Grid member-states have  
 236 been computed or are under computation using the ITP cluster. Moreover, at ITP a  
 237 laboratory for Grid-computations in physics was set. On its basis the first NASU Grid-  
 238 segment was created to combine ITP, ICBGE, IMBG, MAO, KNU as well as Cybernetics  
 239 Institute, Institute for Space Research and ICMP.

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

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

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

255 (Institute for Theoretical Physics (ITP) – Kiev National University (KNU) – Geneva  
 256 University (Switzerland), as well as a number of projects in biology.  
 257 In January 2007 The Ministry of Education and Science (MES) announced the start of the  
 258 project to set up a national UGRID in Ukraine – the infrastructure to ensure scientific  
 259 research within the frameworks of the State Target Program “Information and  
 260 Communication Technologies in Education and Science for the period 2006 – 2010”. The  
 261 Project UGRID, prepared by the National Technical University of Ukraine (NTUU) “Kyiv  
 262 Polytechnic Institute” (KPI) set a task: complete and combine scientific-educational  
 263 computation and communication infrastructure into a national Grid-infrastructure and  
 264 integrate it with the European Grid-network; spread the knowledge on Grid-technologies  
 265 in the society; ensure joint utilization of unique supercomputers, experimentation  
 266 installations and appliances by separate scientists; actively participate in forming up new  
 267 concept of European Grid-infrastructure; develop new original Grid applications in the  
 268 sphere of tele-medicine for Chornobyl NPP employees, for distant learning in the Central-  
 269 Eastern-European university (CEEVU), for servicing the Ukrainian Branch of the World  
 270 Data Center (UB WDC).  
 271 The mentioned Grid-project was based on using the most powerful (for that period of  
 272 time) in Ukraine supercomputer of cluster architecture (built up on 168 LAPACK  
 273 processors with the general productivity of 1.4 Teraflops and commissioned in NTUU KPI  
 274 at the end of 2006) as well as with the participation of Grid-clusters of Kharkiv National  
 275 University for Radio-electronics (NURE), Lviv, Donetsk and Zaporizhia National  
 276 Technical Universities, Institute for Modelling in Energy Engineering (IMEE) of NASU,  
 277 state enterprise (SE) “Lviv Radio-Engineering Research Institute” (LRERI), etc. [24].  
 278 As of today the NTU “KPI” provides free distant access for Ukrainian users to that  
 279 supercomputer computation capacities via scientific-educational network “URAN” created  
 280 in 1998 at the initiative of NTUU “KPI”, technical universities of Kyiv, Kharkiv,  
 281 Dnipropetrovsk, Donetsk, Odesa with participation of NASU; it connected 18 Ukrainian  
 282 regions via fiber-optic cables. At the end of June 2007 London witnessed signing of the  
 283 agreement on connecting the network URAN with pan-European scientific-educational  
 284 network GEANT2, which connected more than 30 scientific-educational European  
 285 networks [27]. In other words, beginning from 2008 academic year nearly 100 universities  
 286 and research institutes in 18 Ukrainian regions as well as other scientific-educational  
 287 establishments, which had joined the network later, had the opportunity to use  
 288 information resources of GEANT2 (e-libraries, databases, information search engines,  
 289 distant learning resources, etc.).  
 290 URAN network – is a joint ideology, joint channels, a system of e-libraries, a system to  
 291 train system administrators, “Education” system, a system to inform on the issues of  
 292 education etc. Basing on that network, regional centers for distant learning were set up.  
 293 Via that network the supercomputer is accessible for all academic establishments; in  
 294 2006 on its foundation a data storage was arranged for Ukrainian branch of World Data  
 295 Center (a System of World Data Centers is located now in 12 countries; it is coordinated  
 296 by the International Council for Scientific Unions (ICSU) and is a world renown source for  
 297 versatile and unique data in different branches of modern science. E.g., Ukrainian branch  
 298 of WDC is called to maintain data sections on solid body physics; solar-earth physics;  
 299 economic geography; oceanography; energy security and technologies of the information  
 300 society in cooperation with the leading local scientific organizations of the corresponding  
 301 profiles). A very important thing to mention: the agreement was achieved to combine  
 302 URAN Grid-clusters with the Ukrainian Institute of Theoretical Physics and Cyber-Center  
 303 of NASU.  
 304 The directions of Grid-networks development in Ukraine are as follows: support at the  
 305 governmental level and implement the National project to set up and develop Grid-  
 306 networks (on the basis of academic Grid-infrastructure and UGRID); connect all  
 307 computation clusters in Ukraine (more than 30) to the national grid with the help of high-  
 308 speed fiber-optical channels; connect the national Grid-network to the general European  
 309 Grid-infrastructure and ensure its continuous functioning as its robust operational and  
 310 functional component; catch-up in near future with European countries and enter  
 311 European research area (ERA) as an eligible qualified partner.  
 312 To solve complex tasks with the help of the already built supercomputers NASU has set  
 313 up an Academic network data exchange (AMOD), which enhanced efficiency and quality  
 314 of scientific research. It is an assembly of distributed hardware and software, the

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

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

330 The distributed computations as a method to obtain digital scientific results had attracted  
331 scientists' interest since emergence of powerful workstations on the basis of UNIX type  
332 systems. However, exactly the restricted data transfer speed hampered wide  
333 implementation of such technologies.

334 Scientists from European Center for Nuclear Research (CERN) were the first to see the  
335 alternative to very expensive supercomputers: processing of the experimental data  
336 obtained at Large Hadron Collider (LHC) required not only to accomplish resource-  
337 intensive algorithms in the shortest possible time period, but also high speed of great  
338 data volumes transfer during many years of the collider operation. After a number of  
339 years spent for developing and testing different approaches the computation Grid-  
340 technologies had become a day-to-day reality. Suffice to say, that the whole processing  
341 and analysis system to compute LHC experiments in CERN is based exactly on the Grid-  
342 technologies.

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

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

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

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

369 Exactly such multi-disciplinary approach had been formulated in the Academic Program  
370 to Implement Grid-technologies and Clusters Development prepared by NASU and  
371 implemented till 2009. At the same time, the State Target Program to Implement and Use  
372 Grid-technologies in Ukraine in the period 2009–2013 stipulated data transfer speed  
373 increase between the most powerful Ukrainian National Grid clusters up to 10 Gb/s,  
374 which would provide for considerable increase of Grid-calculations efficiency. According

375 to the strategy of Grid building up in Ukraine, selected in 2005, the Ukrainian national grid  
 376 would function on middleware "ARC". At the same time, the middleware "gLite" was  
 377 installed and certified at three clusters (Institute of Theoretical Physics (ITP), Shevchenko  
 378 Kyiv National University (KNU) and Kharkiv Institute of Physics and Technics (KIPT),  
 379 which are working within the CERN infrastructure. Exactly thanks to ARC middleware  
 380 utilization there had appeared mutual interest between Ukrainian National Grid and  
 381 NorduGrid to start collaboration.

382 NorduGrid amendment practically coincided with a new European initiative to develop  
 383 unified middleware – the project "European Middleware Initiative" (EMI). It combines  
 384 leading European middleware developers: ARC, gLite, UNICORE, dCache. Till recent  
 385 time the named packages had been incompatible, because they had used different  
 386 technological approaches to implement the systems of grid-type. It created numerous  
 387 difficulties both for scientists and computer centers, which had to maintain several  
 388 systems simultaneously, trying to meet the requirements of different research groups.  
 389 The EMI project task was to create general approaches and use standard means to  
 390 combine different middleware. E.g., grid middleware elements were planned to locate in  
 391 standard repositories of Linux operational system making the grid accessible for  
 392 practically anyone. It would make the work of the scientists and computer centers'  
 393 operators easier, and in the consequence it would increase resources utilization  
 394 efficiency and research quality. Moreover, the new unique middleware would be more  
 395 attractive for users, who treated Grid-technologies as too complicated for practical use.

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

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

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

417 There were three ways to achieve the task results:

418 1) The first one stipulated step-by-step computation resources capacity building within the  
 419 scientific institutions which had already been experienced in using Grid-technologies with  
 420 their further application in other spheres and sharing the obtained experience with the  
 421 interested parties; it would provide for slow-rate application of grid-technologies and  
 422 increasing the gap between Ukraine and advanced countries in that sphere;

423 2) The second one stipulated creation of multi-level inter-departmental grid-network with  
 424 the account of Grid-technologies profile application in different industrial branches and in  
 425 different regions; it would cause creation of grid-segments with different specifics and  
 426 would become an obstacle for their unification into a national Grid-infrastructure;

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

431 To set up the national Grid-infrastructure and ensure its development it was planned to  
 432 set up: a kernel grid-center at the National Academy of Science; resource and regional  
 433 grid-centers, the work of which would be coordinated by the NASU institutions and  
 434 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 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 developing and implementing grid-technologies.

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 with 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 developing and implementing grid-technologies.

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;32;33;34].

**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           | Logistic and functional support for the kernel and regional resource centers of the Ukrainian National Grid (UNG) was | Modern powerful computation platform of the state                                                                              |

|      |                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                 |
|------|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
|      | resources                                           | strengthened together with strengthening of computation resources for 10 grid-clusters<br>A new cluster plus 4 grid-platforms to access grid-network were set up<br>Potential computation resource was increased to reach 31 grid-clusters having more than 3000 processor cores and more than 400 Terabytes for data storage                                                                                                                                                                                                                                                                                                                                           | significance was created to solve super complicated different profiles tasks                                                                    |
|      | 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<br>Relations with European and world grid-projects were adjusted to process experimental data from Large Hadron Collider (LHC)<br>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 | Fundamental research projects implemented<br><br>LHC data processed<br><br>Grid-technologies to research complex biologic molecules developed   |
|      | Use grid-technologies for applied research          | The 1 <sup>st</sup> 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.<br>General computation resource was increased up to 39 grid-clusters having 4000 processor cores and more than 500 Terabytes for data storage.<br>The channels throughput capacity to exchange data between the most powerful grid-clusters was increased up to 10 Gb/s                                                                                                                                                                                                           | Certification of 11 Ukrainian grid-clusters completed<br><br>Computation resources increased<br><br>Data exchange throughput capacity increased |
|      | Use grid-technologies for fundamental research      | Program packages to use grid-technologies in different scientific and scientific-technical research were developed and started to be widely used<br>In the area of high energy physics research at LHC, Ukrainian scientists                                                                                                                                                                                                                                                                                                                                                                                                                                            | Specialized program packages started to be used in research<br><br>Co-authorship in discovering new                                             |

|      |                                                     |                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                        |
|------|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| 2013 |                                                     | became co-authors in discovering new boson – candidate on the role of Higgs boson                                                                                                                                                                                                                                                                  | 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                                                                               |
|      | 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                                                                               |

481 Composed by: [31; 32; 33; 34].

482  
 483 Accomplishment of the State Target Scientific-Technical Program of Developing and  
 484 Implementing Grid-Technologies in 2010-2013 yielded *positive results*: Ukrainian National  
 485 grid was built-up, the main part of which included NASU computation clusters; many  
 486 topical scientific research projects were performed in many directions, which were

487 traditional for numerous academic institutions integral to NASU; grid-computations were  
 488 included into applied scientific research projects and also proposed for practical use in  
 489 medical and engineering projects; interdisciplinary research had grown up considerably,  
 490 close scientific relations had been maintained between different profile academic  
 491 institutions; international scientific collaboration of Ukrainian scientists had grown up in  
 492 such spheres as high-energy physics and astrophysics, molecular and cell biology, geo-  
 493 science, etc., as well as in the sphere of global integration of national computation  
 494 resources to create unified European and all-world research-information area.  
 495 Therefore, the program main achievement was creation of the Ukrainian national grid-  
 496 infrastructure of the production type and its integration into the world biggest e-  
 497 infrastructure that combined more than 22 thousand researchers from all over the world.  
 498 It helped provide Ukrainian scientists with the necessary services to perform digital  
 499 research of the global level both individually and in collaboration with other countries  
 500 scientists regardless of their place of stay.

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

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

518 NASU Presidium considers *the following development directions with using grid- and*  
 519 *cloud-technologies as well as high-productive computation means to be of top priority:*  
 520 formation of the modern electronic infrastructure that stipulates creation and  
 521 implementation of grid-clusters, hardware-software complexes, telecommunication  
 522 networks and systems of grid- & cloud- and other prospective technologies; enhancing  
 523 capacity and quality of grid-infrastructure with the help of strengthening the available  
 524 computation grid-clusters, creating a national service' catalogue; creating flexible virtual  
 525 research space with the simplified access to the resources of Ukrainian and global  
 526 information-computation space; creating conditions and mechanisms for collaboration  
 527 between research and IT-partners and different countries projects; formation and support  
 528 for the virtual national center of competence and its cooperation with EGI competence  
 529 center; spreading the application domain for grid- & cloud- and other modern computation  
 530 technologies for scientific research.

531 To implement all those directions and widen grid-technologies application in scientific  
 532 research the Target Comprehensive Program for NASU scientific research "Grid-  
 533 infrastructure and grid-technologies for scientific and applied scientific applications" for  
 534 the period 2014-2018 was developed in 2013 [36].

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

542 The further development of grid-infrastructure and grid-community requires  
 543 comprehensive approach and efforts concentration on solving the following *problems*:  
 544 1) Enhancing capacity and quality of grid-infrastructure through developing computation  
 545 grid-clusters, creating a national services' catalogue, satisfying the users' needs;

546 2) Increasing data exchange channels throughput capacity, increasing computation  
547 capacity of resource centers and grid-infrastructure distributed data storage resources;  
548 developing national resources list and implementing the model of resources distribution  
549 provided by the resource centers. Development of "cloud" technologies and creation of  
550 comprehensive UNG "cloud" would provide for conducting distributed new technologies  
551 tests to be promoted by the national and European grid-community;  
552 3) Arranging a flexible research space with simplified access to UNG resources. Ensuring  
553 functional compatibility of platforms and working processes in such a space with the  
554 European platforms for the joint utilization of the distributed databases. Conducting  
555 topical research in collaboration with other countries' scientists, who use the developed  
556 platforms, working processes and applications. Adaptation of the developed and  
557 accepted by the European community e-infrastructure standards must be one of the  
558 development directions;  
559 4) Ensuring specialists training and creating conditions and mechanisms for cooperation  
560 between researchers and IT-collaborations within projects in different countries. Forming  
561 and supporting virtual competence center, its interaction with EGI competence center.  
562 *The program aim* is to provide further development of grid-technologies and spread up  
563 the sphere of their application in scientific and applied science research in NASU;  
564 develop and implement new hardware/software methods and means of high productive  
565 computations; ensure participation of NASU scientists in international grid-projects and  
566 organizations.  
567 *The main directions and priorities* of the Program for 2014-2018 period are as follows:  
568 1) Develop facilities and resources for grid-technologies and high-productive  
569 computations to be used in scientific and applied science projects, including also the  
570 following: develop and promote kernel coordination center as UNG consolidating and  
571 coordinating body; develop resource centers (grid-sites), data storage capacity building,  
572 support and develop data exchange resource center; build-up the unified infrastructure  
573 for distributed computations, which is composed of the traditional grid-infrastructure and  
574 cloud infrastructure with the opportunity to provide user access convenient interface to  
575 different information-computation resources and enhance productivity of their utilization;  
576 develop UNG universal services catalogue and implement service-oriented computations  
577 to create application software via combining and orchestrating separate services;  
578 ensure throughput capacity of communication fiber-optic channels between the resource  
579 centers not less than 1Gb/s and increase communication fiber-optic channels throughput  
580 capacity to communicate between local and foreign grid-nods in accordance to the  
581 European network GEANT-3 capabilities; develop and follow-up comprehensive system  
582 for UNG information protection; UNG system integration into the European infrastructure  
583 including also supercomputers' network PRACE, repository EUDIT, consolidated  
584 European cloud for scientific and innovative research;  
585 2) Apply grid-technologies in fundamental research and support virtual organizations  
586 working by the topics: physics and high energy astrophysics, astronomy; molecular and  
587 cell biology and genetics, neuro-physiology, life science; physical foundations of materials  
588 science, Nano-physics and Nano-materials; geo-physics, meteorology, climatology, geo-  
589 science; social-economic science. Other scientific directions;  
590 3) Implement grid-technologies and support the corresponding virtual organizations in  
591 application sphere, including also: practical medicine (in collaboration with the National  
592 Academy of Medical Science of Ukraine (NAMSU); develop and implement European  
593 systems of pictures processing and simulate neuro-degenerative diseases for diagnostic  
594 systems; combine distributed medical diagnostic databases into a comprehensive system  
595 for scientific and clinical research); engineering computations, including also developing  
596 and implementing inter-disciplinary platform for collective engineer designing in  
597 grid/cloud-area; Eco monitoring, distant probing, forecasting natural phenomena;  
598 4) Train specialists in grid-technologies and cloud computations; launch courses in digital  
599 science in the national higher educational establishments, develop theoretical minimum  
600 of digital science and a discipline quality standard; develop the system of distant learning  
601 and qualification upgrading for digital science learning process; create virtual competence  
602 center integrated into EGI competence center to transfer and exchange knowledge and  
603 skills of using grid- and cloud-infrastructure to process big data volumes.

604 Table 2 gives the most prominent results of accomplishing the State Target Scientific-  
605 Technical Program of Ukraine (STDTPU) "Grid-infrastructure and grid-technologies for  
606 scientific and applied scientific projects" for 2014 [35].

607  
608 **Table 2.** The most prominent results of accomplishing STDTPU "Grid-infrastructure and  
609 grid-technologies for scientific and applied scientific projects" for 2014.

| Year | Program direction                                                                       | Most prominent result                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Practical value                                                                                                                                                                                                                                                             |
|------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | 2                                                                                       | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 4                                                                                                                                                                                                                                                                           |
| 2014 | Develop facilities 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<br>With the help of grid-technologies new weak energy line in x-ray spectra of Andromeda galaxy and Perseus galaxies cluster was researched. | Working algorithms of clusters that participate in LHC data processing improved                                                                                                                                                                                             |
|      | Implement grid-technologies in application sphere                                       | Computer simulation of multi-molecular systems properties in the physics of solid and soft matters was continued<br>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<br><a href="http://chimera.biomed.kiev.ua/video">http://chimera.biomed.kiev.ua/video</a>                | Properties of that line totally agree with the line of dark matter particles disintegration<br>New effects in multimolecular systems behavior found<br>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                                                                                                                                                                                                                                    |

610  
611 Composed by: [35].

612 *The Program expected results* would be as follows: support for the Ukrainian grid-  
613 infrastructure work would be ensured; continuous increase of its computation capacity  
614 and data storage capacity would be guaranteed; powerful computation resource-centers  
615 would be created; advanced technologies for efficient and effective resources utilization  
616 would be initiated (upgrading of middleware, virtualization of resources and cloud-  
617 technologies, advance to the international platforms of resources provision); stable and  
618 qualitative work of kernel coordination center that manages the work of the national grid-  
619 infrastructure, provides services and technical support for a wide circle of users, spreads  
620 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 researches and their collaborators would be provided; training and skills upgrading for the grid-technologies specialists and users would be ensured.

### 3.2. Creating and improving Ukrainian supercomputers of CKIT family

In the latest 15 years the volume of the stored and processed information has become million times more than it had been during the whole previous period of information technologies development. The capacity of the world computation resources has been growing very quickly, but the need in this capacity growth is even more. That need is not only limited by the necessity of information processing. Due to the development of interdisciplinary research (and with implementation of the concept of NBIC technologies converging we are approaching to the consolidation of these four areas into a single scientific-technological knowledge domain), scientific industries that require supercomputer resources to solve different tasks of simulation, forecasting, optimization, etc., have started to boom. In other words, the need in super powerful computation has been growing faster than the need in processing the accumulated data [37, pp.346–347]. Therefore, the improvement of the available supercomputers and development of principally new schemes of supercomputers (e.g., with cluster structure) – is one of the most prospective directions for ICT development in any country that considers itself to be technologically developed [13, pp. 110–112].

The advanced world countries consider development of this industry to be one of their national priorities. For example, in the USA the petaflops range (computer processing speed) – 10<sup>15</sup> operations/sec. – has already been reached and they are moving to the exaflops range – 10<sup>18</sup> operations/sec. Russia has the program of high-productive computations development “Skith-Grid” and several federal programs with annual budget financing of more than 5 bln. Rubles. Aggregate processing capacity of Russian supercomputers is planned to bring to 20 000 teraflops (20x10<sup>15</sup>) (teraflops is the speed of computer's performing 10<sup>12</sup> operations/sec.). At the end of 2010 the clusters “Lomonosov” (Moscow State University named after Lomonosov) with the productivity of more than 500 teraflops and K-100 (Keldysh Institute of Applied Mathematics, Russian Academy of Science) – 100 teraflops. As a reference: in 2011 the aggregate peak productivity of Ukrainian National Grid clusters did not exceed 27 teraflops [28].

According to the world TOP-500 supercomputers rating 50 the most powerful computers work in China, USA, Japan, France, Germany, Russia, South Korea, Brazil, Saudi Arabia, Switzerland, Canada, India. The first place in that rating belongs to Chinese computer Tianhe-1A, the second one belongs to the US computer Cray XT5 Jaguar and Blue Gene/L (installed at the Lawrence Livermore National Laboratory, USA). It performs 479.2 trillion operations with floating point per second [38]). Russian computer “Lomonosov” ranks 17<sup>th</sup> in that rating list.

In 2008 the research center in the town Julich (Germany) witnessed an official ceremony of commissioning a powerful supercomputer JUGENE belonging to Blue Gene/P family, IBM corporation. The new supercomputer has about 65 thousand PowerPC 450 processors and its productivity is 167 teraflops (trillion operations with floating point per second) [38]. Computation capacities of JUGENE, JUMP and JUBL systems are accessible to about two hundred research groups. Supercomputers resources are also used during projects computing connected with new materials development, search for the next generation medical drugs as well as when simulating climate change, elementary particles behavior, complex chemical reactions, etc. A group of independent experts distributes computing capacities between different projects.

In 2004 in the Ukrainian National Academy of Science (NASU) institutions created two high efficient computation cluster systems CKIT-1 and CKIT-2 on the basis of Intel Xeon and Intel Itanium 2 microprocessors, the characteristics of which go in line with the world analogues. Exactly the intellectual component of the developed clusters in combination with the distributed databases provide for efficient intellectual processing of big data

681 volumes and also ensures considerable competitive advantages in comparison with other  
682 world analogues [37, p.347].

683 Since 2007 in CIS countries' similar rating (TOP-50) Ukraine was represented by CKIT-3  
684 and by the NTUU "KPI" cluster, which initially were among the first 5 of the rating.  
685 However, Ukraine may stop being the part of the rating in the result of which the  
686 Ukrainian research institutions and universities would lose the chances to win tenders by  
687 international scientific-technical programs and would have limited capabilities to solve  
688 complex tasks. The reason for that is insufficient budget financing. E.g., to improve the  
689 CKIT-3 system it was necessary to bring its capacity to 400-500 teraflops (specialists of  
690 the Cybernetics institutes of NASU could accomplish that in 1 year). The aggregate cost  
691 of the project was UAH 50 mln., while the expected runtime period of the upgraded  
692 computer was 5 years [28].

693 Moreover, supercomputers' daily running and improvement are also very costly. In the  
694 result, the scientists are more interested in middle-range supercomputers, like, for  
695 example, the supercomputer INPARCOM designed by Kyiv Cybernetics institute and  
696 produced by Kyiv "Electronmash" factory. That supercomputer capacity (which is 1.5-2  
697 teraflops) is lower than the capacity of big supercomputers of CKIT type, but it is much  
698 cheaper and it does not required huge volumes of electric power during its running. At the  
699 same time it can solve rather complicated tasks on the basis of computation process  
700 parallelization. In other words, such supercomputers can ensure preparation of software  
701 and complex computer technologies while their implementation, if required, could be  
702 transferred to more powerful computers. According to the specialists, exactly INPARCOM  
703 computers should be supplied to the institutes, universities and government agencies.  
704 Moreover, in case of the government order availability "Electronmash" is ready to start  
705 serial production of that computer [28].

706 Though Ukraine is lagging behind in developing supercomputers, it is one of the leading  
707 countries in developing modern software for computers and computer systems. Modern  
708 mathematic methods of optimization and system analysis, mathematical simulation  
709 methods and complex objects and processes research, programming theory and  
710 methods to protect information when forming up knowledge bases (KB) and databases  
711 (DB), transfer of that data via communication channels to different computers and  
712 systems make up the foundation of those developments. Exactly in those science  
713 industries Ukraine is rather strong. Globally known scientific schools in those spheres  
714 function at the NASU institutions (including also the NASU Cybernetics center institutes)  
715 and in the profile universities, like Shevchenko Kyiv National University, STUU "KPI",  
716 Kharkiv National Radio Electronics University (KNRU), etc. At the same time, if the  
717 hardware component of ICT is not efficiently developed in parallel, the achievements of  
718 the Ukrainian mathematicians, system programmers and generally ICT specialists would  
719 be downgraded.

720 Thanks to supercomputers utilization NASU scientific-research institutions obtained very  
721 important fundamental and applied results in biophysics, biochemistry, physical  
722 chemistry, theoretical physics, materials science, medicine, geology/geophysics,  
723 nanotechnologies, etc. Within the frameworks of accomplishing research topical plans,  
724 government orders' programs, participation in the national and international scientific  
725 projects Ukrainian scientists constantly use CKIT supercomputer system of the NASU  
726 Glushkov Cybernetics Institute to solve the tasks of simulating molecular dynamics,  
727 quantum-chemical computations, simulating thermo-physical, hydrodynamic and  
728 geophysics processes. Supercomputers compute the properties of chemical compounds,  
729 alloys, biologically active substances and Nano-objects, processing of satellite pictures  
730 and seismological research results, medical populations and genome research,  
731 simulation of physical and social-economic processes.

732 Supercomputer computations agree with grid-computations, though they do not replace  
733 one another. Grid is an infrastructure of distributed computations, when the objective is  
734 subdivided by several separate sub-objectives, which are solved independently, even not  
735 simultaneously, and their results are copied into files, and only after that they are  
736 combined. Supercomputer is designed to perform parallel computations, i.e., sub-  
737 objectives are computed simultaneously and interact via data messages transfer.  
738 Generally speaking, Grid may use and actually is using supercomputers as nodes. But for  
739 many tasks of huge volumes there are no algorithms of subdividing a huge task by  
740 independent sub-tasks, and stability conditions limit sizes of atoms, ergo, the size of the

required memory. Generally speaking, such tasks could not be solved without a supercomputer.

Capacity of the modern supercomputers provide for creating information technologies, which from the perspectives of system (comprehensive) analysis and optimization reveal the essence of the naturally interconnected researched phenomena. Due to supercomputer technologies development the cost and time of digital simulation have decreased in comparison with the experimental testing of the real objects. Modern IT and supercomputers, as tooling in solving classes of super complex tasks, have become one of the determining factors in economic competitive advantage, and directly impact the national capacity to satisfy the population and business entities in information society.

Creation of supercomputer IT requires development of mathematic models, efficient methods for their analysis, algorithms and reliable programs. Complex character of the relations within the subject domain and growing requirements to the parallel implementation efficiency provide for the success of intellectual IT, capable to adjust independently to the task properties and to computation environment. Fundamental scientific component of this topic is in conducting research and development of efficient mathematic methods and algorithms to solve the jobs classes, which by the requirements to memory size and computation productivity exceed the capacities of the accessible computers, even to solve the jobs of trans-computation complexity.

The cluster system CKIT being the biggest computation resource of NASU and the foundation of the Ukrainian National Grid (UNG) resource center, since 2005 has been ensuring on a free basis highly productive computations for NASU agencies and institutions, Ministry of Education and Science establishments and Ukrainian National Space Agency units. Three generations of supercomputers CKIT (CKIT-1, CKIT-2 and CKIT-3) had been created and successfully used in the research conducted by "Intellect" program in 2007-2009. During the period 2010–2011 a hybrid segment CKIT-GPU was implemented for experimental research of new approaches to jobs parallelization. On its basis in 2012 in supercomputer CKIT-4 a new comprehensive architectural project to build cluster computation systems was developed and implemented to provide for reaching two times more productivity than the previous supercomputer generation CKIT-3 productivity - nearly 12 Tflops. Moreover, it also helped considerably increase its energy efficiency, power consumption of which (15 KWh) is 4 times less than the power consumption of SKIT-3. Thus, CKIT-4 by energy efficiency ranks the 99<sup>th</sup> in the world rating of the most environmentally friendly computers (Green 500), and further increase of its capacity is stipulated.

As of today supercomputer CKIT-4 is the most powerful Ukrainian computation means. It is connected to the SKIT system as a component, and the SKIT system is a foundation of the Ukrainian National Grid resource center. It has already passed certification by the European Grid-initiative (EGI). Thus, we may say that the further progress of computations implementation for NASU fundamental and applied science purposes requires development of the supercomputer capacities.

Consequently, NASU Presidium decree #785 dated 26.12.2012 approved the NASU scientific research program concept "Development of intellectual supercomputer systems of SKIT family, ensuring their efficient functioning and creating information technologies, modern mathematic, software/hardware support to solve complex and super complex scientific-practical tasks ("Intellect") for the period 2013-2015" [39].

The Program had two sections:

1. Further capacity increase, implementation area spread-up and providing for efficient functioning of intellectual supercomputer systems and intellectualization means to solve super complex profile tasks;
2. Developing the available IT, creating new and implementing information technologies, modern mathematic support and software to solve complex and supercomplex scientific-practical tasks, with the first priority given to public administration, economics, medicine, biology, science, space exploration, environmental protection, information protection, etc.

The work planned in Section 1, was needed due to the fact that the retardation of the Ukrainian supercomputers from the similar computers in the developed countries had been growing very rapidly. The world trends review shows that USA, EU, China, Japan, Russia etc., consider computers development to be their priorities. EU, for example, allocates dozens of billion Euros; USA – nearly 8 bln.USD/year, Russia in 2009-2012 period had commissioned several powerful supercomputer centers, and before 2014

801 Russia had spent 7.3 bln.Rub. for developing high productive computation industry. If in  
 802 2008 Ukrainian supercomputers competed with the Russian supercomputers and were in  
 803 the first 10 of the CIS rating Top50, at the beginning of 2013 the capacity of the Russian  
 804 computer "Lomonosov" was 75 times higher than the best Ukrainian supercomputer  
 805 capacity, and retardation from the fastest in the world US computer "Titan" is 1500 times.  
 806 Such a gap slows down Ukraine's scientific-technical and innovation development,  
 807 because thanks to the accelerated supercomputers development the computation  
 808 experiments have become both cheaper and faster than the natural testing almost in all  
 809 science and technology branches.  
 810 With regard to the prospects for CKIT system development at the beginning of 2013 the  
 811 lowest teraflops cost, the best ratio productivity/electric power consumption for work and  
 812 cooling had been provided by hybrid assemblies on the basis of general purpose graphic  
 813 accelerators. CKIT-4 architecture and technical project were developed in the result of  
 814 detailed experimental research of modern hardware different configurations. In the result  
 815 CKIT-4 demonstrates now not only high real productivity and energy efficiency, but also  
 816 adaptability to different class tasks. For example, the algorithms that are specifically  
 817 adjusted for graphic accelerators could reach peak productivity of more than 25 teraflops.  
 818 The usual programs, not adapted for graphic accelerators, receive advantage of using  
 819 192 central processors cores Intel Xeon E5-2600 2.6 GHz (up to 32 flows per nod) and a  
 820 big volume of RAM (64 Gb per nod). Speed of processor access to the nod RAM is 0.7-  
 821 0.8 ms that provides to work with all 768 Gb memory in program emulation mode with  
 822 supercomputer unified memory array.  
 823 Research of the SKIT system usage history shows that the biggest part of resources  
 824 (more than 90%) is consumed for solving tasks of molecular dynamics, quantum  
 825 chemistry, hydro- and aero-dynamics as well as for developing customized software. To  
 826 use SKIT-4 efficiently for those purposes the supercomputer has the installed software  
 827 with supporting graphic accelerators: packages GROMACS, NAMD and Abalone for  
 828 molecular dynamics, NWChem and Quantum ESPRESSO for computational chemistry,  
 829 OpenFOAM with plugin Vratiss for the tasks in hydro-dynamics, mathematic library of  
 830 foreign and domestic production, programs for astronomy and geo-physics developed by  
 831 Ukrainian scientists – UNG users. At the same time, the issue of efficient computations in  
 832 heterogeneous environment remains unsolved, i.e., it is necessary to develop algorithms  
 833 and programs that could have simultaneously solved and used different by technology  
 834 and characteristics appliances, like, for example, graphic accelerators and multi-core  
 835 processors of different types and manufacturers. The theory of flow computations and  
 836 standard language of flow computations OpenCL could become a technological  
 837 foundation for such problem solving.  
 838 The jobs mentioned in Section 2 are required to be done because according to the  
 839 statistical analysis of the CKIT supercomputers usage about 80% of the tasks could be  
 840 accelerated dozens of times if using graphic accelerators. These are the tasks of  
 841 quantum chemistry, molecular dynamics, space photos processing, geophysics  
 842 simulation, crypto-analysis, etc. Information search in internet and popular magazines on  
 843 supercomputer computations proved the topicality of developing and implementing  
 844 versatile software for clusters with graphic accelerators and availability of numerous  
 845 projects in developing scientific and application programs.  
 846 According to the corresponding sections of the Program its aims are as follows: further  
 847 considerable development of CKIT cluster system, decrease of the computation  
 848 resources deficit and decrease of the gap with the modern computation capacity level  
 849 available in CIS and in the world; development of the initiated and creation of new  
 850 specific intellectual IT, modern mathematic support and hardware/software means  
 851 directed to solve topical tasks in the spheres of public administration, economy, medicine,  
 852 biology, analysis of complex scientific research databases, developing methods of  
 853 parallel solving of trans-computation complexity tasks using supercomputers with  
 854 applying graphic accelerators.  
 855 The Program stipulates for the period 2013–2018 to develop analogues of major methods  
 856 of intellectual libraries on computation mathematics and data processing to be performed  
 857 at graphic accelerators. We mean the development of qualitatively new algorithms, other  
 858 means for data exchange and load balancing, considerable improvement of the  
 859 "intellectual" part of the library, connected with the algorithm selection and selection of the  
 860 accomplishment parameters depending on the hardware specifics. Algorithms and

861 programs, directed to work in hetero-geneous environment and capable to maximally use  
862 all the available hardware means to solve the biggest tasks – is a special direction of this  
863 work.

864 As to the Section 2, the following is stipulated: continue working in developing new  
865 intellectual IT for new important tasks classes – both for the hybrid ones and for usual  
866 clusters; use CKIT supercomputers as “cloud” foundation for national information-  
867 analytical systems and data processing centers (as it is done in the USA, EU member  
868 countries, Russia, China); conduct informatization of the Ukrainian economy public  
869 administration sphere (the Ministries and Agencies really received computer equipment  
870 and communication systems, internet access has increased, national information  
871 resources have been developing with the priority for several registers of state significance  
872 and information-analytical systems); create and implement IT-grounding for management  
873 decisions on the level of the government, Verhovna Rada (Parliament), local self-  
874 governance bodies; arrange electronic documents circulation; create new information-  
875 analytical systems and systems to analyze distributed databases for different branches of  
876 economic and social performance in the constantly changing conditions and situations.

877 Table 3 shows the most prominent results of the Program accomplishment in the period  
878 2013–2014 [34; 35].  
879

880 **Table 3.** The most prominent results of accomplishing STSP of NASU “Developing  
881 intellectual supercomputer systems of CKIT family, ensuring their efficient functioning and  
882 creating information technologies, modern mathematic support and hardware/software  
883 support to solve complex and super complex scientific-practical tasks (“Intellect) in the  
884 period 2013-2014.  
885

| Year | Program direction                                                                         | Most prominent result                                                                                                                                                                                                                            | Practical value                                                                   |
|------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| 1    | 2                                                                                         | 3                                                                                                                                                                                                                                                | 4                                                                                 |
| 2013 | Further development of CKIT cluster system                                                | Data repository for CKIT supercomputer system was upgraded; its usable volume was increased up to 120 Tb; its speed was increased up to 1 Gbyte/s (in 8 times)                                                                                   | CKIT system characteristics improved                                              |
|      |                                                                                           | Usage of supercomputer CKIT-4 interconnection was adjusted                                                                                                                                                                                       | CKIT-4 adjusted                                                                   |
|      |                                                                                           | Topology of CKIT system data transfer network was upgraded, which provided for additional increase of data exchange speed between parallel file system and CKIT-3 and CKIT-4 cluster nodes by 5%                                                 | Data exchange speed increased                                                     |
|      |                                                                                           | Data repository of CKIT system is used by scientific agencies to process and store super-big data volumes                                                                                                                                        | CKIT system data repository used                                                  |
|      | Development of intellectual IT, modern mathematical support and hardware/software support | Methods to solve vector discreet big size optimization tasks in the conditions of uncertainty and risks, connected with parallelization of optimization process were developed                                                                   | Cost and time of taking decisions in complex situations decreased                 |
|      |                                                                                           | Gradient methods to identify parameters were built up for: layered media in the frameworks of the established and unestablished diffusive processes; layered cylindrical bodies within the frames of the established and unestablished diffusion | Methods to identify parameters for layered media and cylindrical bodies developed |
|      |                                                                                           | Customized program tooling was developed for NADRA-3D system to create and edit digital models of multi-component layered 3D media                                                                                                               | Program tooling to create and edit digital models provided                        |
|      |                                                                                           | Methods to identify different parameters                                                                                                                                                                                                         | Solving the problems                                                              |

|      |                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                      |
|------|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      |                                                                                           | of mathematic models of diffusion in layered bodies and layered revolved solids were developed. They provide for identifying characteristics of the mentioned bodies' separate components with nondestructive method with the aim of solving the problem of extending service life of complex modern objects of various designation, solve the problem of environment conservation, determining characteristics of new materials, etc. Approaches to building mathematical models of economic and production processes optimization were proposed together with the models of energy saving & computation biology which are formed in the terms of computer optimization. CKIT supercomputer system was upgraded to increase data imaging system to 150 Tb | of heat-power engineering, machine engineering, environmental problems research, nature conservation and drinking water and oil products purification, etc.                                                                                                                                          |
| 2014 | Further development of CKIT cluster system                                                | Research computation nod with hybrid architecture of 1.17 TFlops was developed and commissioned into the CKIT system composition. It matches productivity of CKIT-3 cluster 25 nods All SKIT system grid-services transferred to virtual machines which provided for energy efficiency triple increase                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Possibility to obtain scientifically grounded applied results to take decisions in different application spheres provided SKIT computer imaging system characteristics improved Productivity of SKIT-3 computations increased                                                                        |
|      | Development of intellectual IT, modern mathematical support and hardware/software support | New efficient parallel algorithms to research and solve basic tasks of computation mathematics with crude data at the computers of hybrid architecture (with multi-core and graphic processors) were developed A series of stochastic algorithms for global equilibrium search were developed and researched                                                                                                                                                                                                                                                                                                                                                                                                                                               | CKIT system energy efficiency increased Algorithms of solving tasks with crude data at the computers with hybrid architecture developed Algorithms of designing communication networks, super-big integrate circuits, phased antenna arrays, drawing of neuron networks, image recognition developed |
|      |                                                                                           | Mathematical models and software for high-productive computations on the basis of video-graphic accelerators were proposed                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Models and software for efficient solving of the tasks to forecast meteorological processes on Ukrainian territory created                                                                                                                                                                           |

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Composed by: [34; 35].

After the Program accomplishment the following results would be achieved:  
Many times growth of SKIT supercomputers productivity would be ensured to solve typical scientific-technical tasks and public administration tasks;  
Qualitatively new level of applications parallel development for graphic accelerators and dataflow architecture processors would be supported; tooling would be developed to

be tested in the adaptation to hybrid clusters of the available intellectual IT and in developing the new intellectual IT;

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.

Successful accomplishment of the mentioned programs would enable a wide circle of scientists and practitioners to use supercomputer and 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.

Due to the need in the accumulated information processing under the conditions of explosive-type growth of information volumes and due to the need in super powerful computations for interdisciplinary research (especially in the conditions of implementing the concept of NBIC-technologies convergence and the processes of those areas merging into a unique scientific-technological knowledge domain) improvement of the available supercomputers functional diagrams and development of new ones (e.g., to include cluster structure) – is one of the most prospective directions to develop information communication technologies (ICT) in any technologically developed country.

Review of the world trends shows that supercomputer development direction is accepted as top priority in the USA, EU, China, Japan, Russia, etc. Ukraine also has created high-efficient computation cluster systems CKIT-1, CKIT-2 and CKIT-3, where at the expense of the intellectual component of the developed clusters in combination with distributed databases there have appeared a chance to perform efficient intellectual processing of big knowledge bases and databases as well as to receive considerable competitive advantage in comparison with the supercomputers produced in the world. Moreover, in 2012 Ukraine developed and implemented in supercomputer CKIT-4 a new comprehensive architectural project of cluster computation systems build-up, which provided for achieving a two times more productivity in comparison with the previous generation supercomputer CKIT-3 – nearly 12 Tflops. Moreover, it helped considerably increase its energy efficiency, power consumption of which (15 KWh) is 4 times less than the power consumption of CKIT-3.

In the result of accomplishing the NASU scientific research program “Development of intellectual supercomputer systems of SKIT family, ensuring their efficient functioning and creating information technologies, modern mathematic, software/hardware support to solve complex and super complex scientific-practical tasks (“Intellect”) for the period 2013-2015” general many times growth of SKIT supercomputers productivity increase would ensure solving benchmark scientific-technical problems and public administration problems; qualitatively new level of parallel development of applications for graphic accelerators and flow-data architecture processors would be supported; tooling would be developed to be tested in the adaptation to hybrid clusters of the available intellectual IT and in developing the new intellectual IT; 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.

952 Supercomputers, which are not combined into territorial distribution network, have three  
 953 considerable drawbacks: they are very expensive and become out of date very quickly (in  
 954 2-3 years); computation hardware can't be considerably upgraded, that may provide  
 955 using it for solving new more complicated tasks; low efficiency of super-computers  
 956 utilization due to unbalanced processors load. Those drawbacks could be rectified  
 957 through combining supercomputers into a Grid-network. Supercomputers and their  
 958 centers are main resource elements of grid networks, and high-speed data transfer  
 959 networks are the most important infrastructural component.

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

970 Ukraine has created a number of Grid-clusters in academic institutes of Kyiv, Kharkiv,  
 971 Dnipropetrovsk, and also an academic Grid-infrastructure have been developed and is  
 972 working to provide for activating international relations of NASU and for integrating into  
 973 European Grid-network. Moreover, scientific-educational network "URAN" was set at the  
 974 initiative of NTUU "KPI", technical universities of Kyiv, Kharkiv, Dnipropetrovsk, Donetsk,  
 975 Odesa together with NASU. It connects practically all Ukrainian regions with fiber-optical  
 976 communication and has been connected to pan-European scientific-educational network  
 977 GEANT2, which combines more than 30 scientific-educational networks of EU countries.

978 In accordance with the State Target Program to implement and apply Grid-technologies in  
 979 Ukraine for the period 2009–2013, as well as thanks to creating and implementing new  
 980 national projects (e.g., the national project "Open world" – setting an information-  
 981 communication (4G) educational network of the national level) the process of creating  
 982 and developing Grid-networks was continued (on the basis of academic Grid-  
 983 infrastructure and UGRID); connection to the national network with the help of high-speed  
 984 fiber-optical channels of all computation clusters in Ukraine (more than 30) continues;  
 985 connecting the national Grid-network to the general European Grid-network and providing  
 986 for its constant functioning as a full-fledged operational and functional component of that  
 987 structure was ensured; catching up in near future with EU countries and entering the  
 988 European research area (ERA) as a full-fledged and qualified partner would also continue  
 989 Implementation of the Target comprehensive program for NASU scientific research "Grid-  
 990 infrastructure and grid-technologies for scientific and applied scientific applications" for  
 991 the period 2014-2018 became very important for fundamental and applied research  
 992 development in Ukraine as well as for achieving the state policy strategic goal of  
 993 Ukraine's Euro integration, especially in the conditions of signing Association Agreement  
 994 between Ukraine and EU. Euro Commission in its program "Horizon 2020" set a task to  
 995 combine all the European available research infrastructures and scientists with the help  
 996 of e-infrastructure into a single digital research space that requires continuing and  
 997 strengthening integration of Ukrainian and European information-research areas. Further  
 998 development of Grid-infrastructure and Grid-community requires comprehensive  
 999 approach and efforts concentration on solving such problems:

1000 Enhance capacity and quality of grid-infrastructure with the help of strengthening of  
 1001 the available computation grid-clusters; satisfy the users' needs;

1002 Increase the data exchange channels throughput capacity, enhance grid-  
 1003 infrastructure resource centers computation capacity and distributed data storage  
 1004 resources capacity; create a national catalogue of resources and implement a model of  
 1005 resources distribution provided by resource centers. Development of "cloud"  
 1006 technologies and creation of combined UNG "cloud" would provide for conducting  
 1007 distributed testing of new technologies to be developed by the national and European  
 1008 grid-community;

1009 Create flexible virtual research area with the simplified access to UNG resources;  
 1010 ensure functional compatibility of platforms and working processes in such environment  
 1011 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.

## REFERENCES

- [1] Roco, M., Bainbridge, W., Tonn, B., Whitesides, G., eds. (2013). Converging knowledge, technology and society beyond convergence of Nano-bio-info-cognitive technologies. Dordrecht, Heidelberg, New York, London.
- [2] Roco, M., Bainbridge, W., eds. (2006). Managing Nano-Bio-Info-Cogno Innovations. Converging Technologies in Society. Heidelberg; New York.
- [3] Campano R., eds. (2006). Converging Application enabling the Information Society – Trends and Prospects of the Convergence of ICT with Cognitive Science, Biotechnology, Nanotechnology and Material Sciences. – Future Technologies Division of VDI Technologiezentrum GmbH, Düsseldorf. – 252 p. Available: [http://www.vditz.de/fileadmin/media/publications/pdf/band\\_69\\_screen.pdf](http://www.vditz.de/fileadmin/media/publications/pdf/band_69_screen.pdf).
- [4] Silbergliitt R. (2006). The Global Technology Revolution, In-Depth Analyses. Bio/Nano/ Materials/Information Trends, Drives, Barriers, and Social Implications (Prepared for the National Intelligence Council) / R. Silbergliitt, P. S. Anton, D. R. Howell etc. – Rand Corp. – 316 p. Available: [http://www.rand.org/content/dam/rand/pubs/technical\\_reports/2006/RAND\\_TR303.pdf](http://www.rand.org/content/dam/rand/pubs/technical_reports/2006/RAND_TR303.pdf).
- [5] Voyer R. (2004). ICT/Life science Converging Technologies Cluster Study: A Comparative Study of the Information and Communications, Life Science, and Converging Next Generation Technology Clusters in Vancouver, Toronto, Montreal and Ottawa / R. Voyer, N. Makhija. – Government of Canada, Ottawa. Available: <http://strategis.ic.gc.ca/epic/internet/inict-tic.nsf/en/it07730e.html>.
- [6] Stenberg L., Nagano H. (2009). Priority-Setting in Japanese Research and Innovation Policy / L. Stenberg, H. Nagano; VINNOVA and University of Tokyo; National Graduate Institute for Policy Studies (GRIPS) and Japan Science and Technology Agency (JST). – VINNOVA – Verket för Innovationssystem; Swedish Governmental Agency for Innovation System. – 118 p. Available: [http://www.grips.ac.jp/jp/faculty/profiles/nagano2\\_Priority\\_setting\\_in\\_Japanese\\_Research\\_and\\_Innovation\\_Policy\\_VINNOVA.pdf](http://www.grips.ac.jp/jp/faculty/profiles/nagano2_Priority_setting_in_Japanese_Research_and_Innovation_Policy_VINNOVA.pdf).
- [7] Emerging Science and Technology priorities in public research policies in the EU, the USA and Japan. (2006). Foresight, Unit K2 – Scientific and technological foresight. – European Commission, Directorate General for Research; Directorate K-social sciences and humanities. – P. 14-15. Available: [ftp://ftp.cordis.europa.eu/pub/foresight/docs/ntw\\_emerging\\_report\\_en.pdf](ftp://ftp.cordis.europa.eu/pub/foresight/docs/ntw_emerging_report_en.pdf).
- [8] Workshop "Converging Technologies in the 21st Century: Heaven, Hell or Down to Earth?" (2007). European Parliament, Scientific Technology Options Assessment (STOA) Annual Report 2006. – European Parliament, Brussels. – P. 20. – 36 p. Available: [http://www.europarl.europa.eu/stoa/webdav/site/cms/shared/4\\_publications/annual\\_reports/2006\\_en.pdf](http://www.europarl.europa.eu/stoa/webdav/site/cms/shared/4_publications/annual_reports/2006_en.pdf).
- [9] Challenges and Opportunities for Innovation through Technology: The Convergence of Technologies. (2014). Directorate for science, technology and innovation of the Committee for scientific and technological policy of the Organization for Economic Co-operation and Development. – 39 p. Available: [http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=dsti/stp\(2013\)15/final&doclanguage=en](http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=dsti/stp(2013)15/final&doclanguage=en).
- [10] Global Trends 2030: Alternative Worlds. (2012). National Intelligence Council. – December. – 166 p. Available: <http://globaltrends2030.files.wordpress.com/2012/11/global-trends-2030-november2012.pdf>.
- [11] Kazantsev, A., Kisilev, V., Rubvalter, D. & Rudenskiy, O. (2012). NBIC-technologies: Innovative civilization of the XXI century: monograph. Moscow.
- [12] Kyzym, M. & Matyushenko, I. (2011). Prospects for nanotechnologies development and commercialization in world countries and in Ukraine: monograph. Kharkiv.

- 1070 [13] Kyzym, M. & Matyushenko, I. (2012). Perspectives of development of information  
1071 and communication technology and artificial intelligence in the economies of  
1072 countries of the world and Ukraine: monograph. Kharkiv.
- 1073 [14] Matyushenko, I. & Buntov, I. (2012). Prospects for NBIC-technologies convergence  
1074 to create a technological platform for new economy. *Business inform*, 409(2): 66–71.
- 1075 [15] Matyushenko, I. & Buntov, I. (2011). The synergetic effect of development of NBIC-  
1076 technologies for solution of global human problems. *The Problems of Economy*, 4:  
1077 3-13.
- 1078 [16] Matyushenko, I. & Khanova, O. (2014). Convergence of NBIC-Technologies as a  
1079 Key Factor in the Sixth Technological Order' Development of the World Economy.  
1080 Social Educational Project of Improving Knowledge in Economics. *Journal*  
1081 *L'Association 1901 «SEPIKE»*. Ausgabe 6. Osthofen, Deutschland, Poitiers, France,  
1082 Los Angles, USA: 118-123.
- 1083 [17] Matyushenko, I. & Moiseenko, Yu. (2015). Outlook on bio economy development in  
1084 Ukraine: introduction of molecular and cell biotechnologies in 2010-2013.  
1085 *International Journal of Economics, Commerce and Management*. Rochester, UK,  
1086 III (5): 764-772. Available: <http://ijecm.co.uk/wp-content/uploads/2015/05/3545.pdf>.
- 1087 [18] Matyushenko, I. & Khaustova, V. (2015). Modern trends on bio economy  
1088 development in the world: the introduction of NBIC-technologies in biomedicine.  
1089 *Integrated Journal of British, Navi Mumbai, India*, Vol. 2 (2): 103-118. Available:  
1090 <http://www.ijbritish.com/Downloads.aspx?PA=IJBRTISH-279-PA.pdf>.
- 1091 [19] Matyushenko, I., Buntov I., & Khanova, O. (2015). The next economy in Ukraine:  
1092 developing alternative energy with the help of NBIC-technologies. *British Journal of*  
1093 *Economics, Management & Trade*, London, UK, Wilmington, USA, Gurgaon, India,  
1094 9 (2): 1-19. Available: <http://sciencedomain.org/issue/1223>.
- 1095 [20] Matyushenko, I., Moiseenko, Yu., & Khanova, O. (2015). Prospects for creating  
1096 material grounds for information economics on the basis of micro-electronic  
1097 technologies and sensor enginery utilizing NBIC-technologies in Ukraine. *British*  
1098 *Journal of Economics, Management & Trade*, London, UK, Wilmington, USA,  
1099 Gurgaon, India, 9 (3): 1-16. Available: <http://sciencedomain.org/issue/1224>.
- 1100 [21] Matyushenko, I., Goncharenko, N., & Michaylova, D. (2015). Future Considerations  
1101 For Developing Energy Efficient Economy In Ukraine Using Light Emitting Diode  
1102 (LED) Enginery On The Basis Of NBIC-Technologies. *Global Journal of*  
1103 *Management and Business Research*, Cambridge (Massachusetts), USA, London,  
1104 UK, Indore, India, 15 (5): 7-16. Available:  
1105 [https://globaljournals.org/GJMBR\\_Volume15/2-Future-Considerations.pdf](https://globaljournals.org/GJMBR_Volume15/2-Future-Considerations.pdf).
- 1106 [22] Matyushenko, I., Moiseenko, Yu., & Khanova, O. (2015). Prospects for constructing  
1107 Nano-bio-economics in Ukraine: using sensor systems on the basis of NBIC-  
1108 technologies for medico-environmental and industrial needs. *American Research*  
1109 *Journal of Business and Management (An Academic Publishing House)*, Chicago,  
1110 USA, 1 (2): 37-43. Available: <https://www.arjonline.org/papers/arjbm/v1-i2/4.pdf>.
- 1111 [23] Kyzym, M. & Matyushenko, I. (2015). NBIC-technology as a key factor in the  
1112 development of information and communication technologies and microelectronics in  
1113 the world and Ukraine: monograph. Kharkiv.
- 1114 [24] Petrenko, A. (2007) Grid as the 4<sup>th</sup> stage of informatization development // *Zerkalo*  
1115 *Nedeli*. – #8. – P.13.
- 1116 [25] On approving the list of projects of the Program to implement Grid-technologies and  
1117 create clusters within The National Academy of Science of Ukraine (NASU) /  
1118 Resolution of the NASU Presidium #211 dated 30.03.2007 Available:  
1119 [http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2007/directions/OpenDocs/07](http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2007/directions/OpenDocs/070330_211.pdf)  
1120 [0330\\_211.pdf](http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2007/directions/OpenDocs/070330_211.pdf).
- 1121 [26] Martynov, E., Svistunov, S. (2007). So, is there any Grid in Ukraine? / *Zerkalo*  
1122 *Nedeli*. – #10. – P.14.
- 1123 [27] Rozhen, A. (2007). GEANT2, or “attempt number two” to connect Ukrainian science  
1124 to Europe / *Zerkalo Nedeli*. – #27. – P.13.
- 1125 [28] Sergienko, I. (2011). Information society in Ukraine: problems of development and  
1126 functioning / *Zerkalo Nedeli*. – #26. Available:  
1127 [http://dt.ua/TECHNOLOGIES/informatsiynе\\_suspilstvo\\_v\\_ukrayini\\_problemi\\_rozvitk](http://dt.ua/TECHNOLOGIES/informatsiynе_suspilstvo_v_ukrayini_problemi_rozvitku_i_funktsionuvannya-84519.html)  
1128 [u\\_i\\_funktsionuvannya-84519.html](http://dt.ua/TECHNOLOGIES/informatsiynе_suspilstvo_v_ukrayini_problemi_rozvitku_i_funktsionuvannya-84519.html)

- 1129 [29] Martynov, E., Smirnova, O. (2011). Ukrainian National Grid – participant of  
1130 international association NorduGrid / Bulletin of NASU. – #12 Available:  
1131 [http://supercomputer.com.ua/ua/40-ukrajinskii-natsionalnii-grid-uchasnik-](http://supercomputer.com.ua/ua/40-ukrajinskii-natsionalnii-grid-uchasnik-mizhnarodnogo-obdnannya-nordugrid.html)  
1132 [mizhnarodnogo-obdnannya-nordugrid.html](http://supercomputer.com.ua/ua/40-ukrajinskii-natsionalnii-grid-uchasnik-mizhnarodnogo-obdnannya-nordugrid.html)  
1133 [30] State Target Scientific-Technical Program to Implement and Use Grid-technologies  
1134 in Ukraine in the period 2009–2013 / Cabinet of Ministers of Ukraine No.1020, dated  
1135 23.09.2009. Available: <http://zakon2.rada.gov.ua/laws/show/1020-2009-%D0%BF>.  
1136 [31] National Academy of Science of Ukraine Progress Report for 2010. (2011). Kyiv.  
1137 [32] National Academy of Science of Ukraine Progress Report for 2011. (2012). Kyiv.  
1138 [33] National Academy of Science of Ukraine Progress Report for 2012. (2013). Kyiv.  
1139 [34] National Academy of Science of Ukraine Progress Report for 2013. (2014). Kyiv.  
1140 [35] National Academy of Science of Ukraine Progress Report for 2014. (2015). Kyiv.  
1141 [36] On the Target Comprehensive Program for NASU scientific research “Grid-  
1142 infrastructure and grid-technologies for scientific and applied scientific applications”  
1143 for the period 2014-2018/ NASU Presidium Resolution #164-a dated 11.12.2013.  
1144 Available:  
1145 [http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2013/regulations/OpenDocs/1](http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2013/regulations/OpenDocs/131211_164a.pdf)  
1146 [31211\\_164a.pdf](http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2013/regulations/OpenDocs/131211_164a.pdf).  
1147 [37] Innovation-technological economic development. (2007). / under the editorship of  
1148 Geits, V., Seminozhenko, V., Kvasniyuk. B. – K. – P. 564  
1149 [38] The most powerful in Europe. (2008). / Zerkalo Nedeli.. – # 8. – P.17.  
1150 [39] On the program of the National Academy of Science of Ukraine (NASU)  
1151 “Development of intellectual supercomputer systems of SKIT family, ensuring their  
1152 efficient functioning and creating information technologies, modern mathematic,  
1153 software/hardware support to solve complex and super complex scientific-practical  
1154 tasks (“Intellect”) for the period 2013-205”/ NASU Presidium Resolution #785 dated  
1155 26.12.2012  
1156 Available: [http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2012/directions](http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2012/directions/Pages/default.aspx)  
1157 [/Pages/default.aspx](http://www1.nas.gov.ua/infrastructures/Legaltexts/nas/2012/directions/Pages/default.aspx)