Computation of Things for Human Protection and Fulfillment

Justyna Zander
Fraunhofer Institute FOKUS, MOTION
Harvard University, HHI
Berlin, Germany; Cambridge, MA, USA
justyna.zander@gmail.com

Pieter J. Mosterman
MathWorks
McGill University, SOCS
Natick, MA, USA; Montréal, Canada
pieter.mosterman@mathworks.com

John S. Kinnebrew, Gautam Biswas
Vanderbilt University, ISIS
Nashville, TN, USA
john.s.kinnebrew@vanderbilt.edu
gautam.biswas@vanderbilt.edu

***Abstract*—Computer science and computational engineering have enabled great advances in modeling and simulation to analyze various scenarios. Still, facilitating and enhancing situational awareness for a single human is rarely considered. Poor decisions by an individual encountering everyday challenges or public threat situations can have dramatic effects, both for the individual and others. In the presented research, a Computation of Things (CoTh) framework is proposed to provide individual decision support during crises and prevent long-term deviations from safe and secure conditions. The target of CoTh is to enable a profound understanding of the situation from the viewpoint of individual persons in order to permanently reduce their fear, while simultaneously increasing awareness of appropriate responses. CoTh allows for a quick forecasting of action (or non-action) alternatives based on an individual human context, including geographic position (e.g., pollution level and energy usage), activity patterns (e.g., personal nutrition habits, lifestyle, traveling load, family status, circle of friends, social network, and virtual life), and state patterns (e.g., the DNA, current health conditions, and musculature of a human), depending on the considered situation. Insights into CoTh's motivation, requirements, and challenges are provided and the architecture proposal is depicted.**

Computation, Modeling, Simulation, Model-based Design, Software, Humanity, Digital Earth, Life Mirror

I. VISION INTRODUCTION

Life has it that there is never enough preparation for a crisis, uncertainty about the appropriate actions to recover from a traumatic experience, and insufficient awareness of proper responses to bothering situations. Human beings and the problems that they encounter around the globe are so different from each other, in so many aspects, that research into appropriate sets of solutions is paramount.

The convergence of recent technological advances and concepts, such as the cloud and high performance computing, information access/sharing, and Internet of Things enable the design of a Computation of Things (CoTh) framework with effective human-computer interaction for crisis situations. This paper illustrates how these advances could be employed and presents remaining challenges in its design and integration.

An initial architectural design for CoTh is proposed, integrating (1) participatory sensing and remote sensing platforms, (2) a computational analysis engine, and (3) visually-spectacular interfaces that support making the decisions [30]. The overall architecture borrows from multiple, heterogeneous designs to provide an efficient, generic CoTh platform. It includes studies of selected existing components for data integration [3][10][15] and the insights into the computation engine itself.

CoTh is an approach to understanding the individual self and its surrounding based on the micro-scale information that combines with macro-scale data to enable prediction [1] of different life scenarios. It serves to deliver guidance towards sustainable development for an individual, but if projected and combined with behavioral patterns of groups, communities, and nations, it provides knowledge about the world-wide changes and their possible global effects. A more technical definition of CoTh is provided in the proceedings.

The outlined vision of CoTh requires an analysis breaking the system down to its main objectives, requirements, and components. Section II provides selected individual-related scientific trends that constitute a basis for development of a more comprehensive definition for CoTh. This definition is then discussed in Section III. Here, the technological challenges are described and are then compared with the state of the art. In Section IV, the architecture proposal for CoTh is provided and the uniqueness of the computational paradigm shift is highlighted. Section V constitutes a preliminary achievability assessment of merging CoTh with the objectives of Digital-Earth vision. Also, risk factors and concept illustrations are briefly investigated. Conclusions complete the paper with a short summary and future plans.

[1] According to [5] there is a distinction between a prediction and a forecast. Prediction attempts to accurately say what will happen before it happens. A forecast is an if/then contingency statement. Thus, a forecast does not describe what will happen, but rather what may happen given certain assumptions. By this definition, forecasting is the main driver of this research, although both terms are used interchangeably in this work.

978-1-4244-6048-9/10/$26.00 ©2010 IEEE

II. SELECTED HUMAN-ORIENTED SCIENTIFIC TRENDS

Engineered systems are nowadays realized by increasingly extensive use of software components in such fields as embedded systems, cyber-physical systems, and ultra-large systems [22]. Thus, software is expected to have a far reaching impact on the industry, market, innovations, and everyday life in the near future.

A scientific understanding combined with appropriate methods and technologies for effectively developing software-intensive systems on the scale of entire ecosystems is still missing, though [21]. The corresponding gaps in knowledge and capability are strategic challenges and roadblocks for continuous progress of applying technology. These gaps are unlikely to be addressed adequately by incremental research within isolated fields. Instead, a novel theory and methodological framework for dealing with the software intensity, quality, and functionality demands in a more comprehensive manner is necessary [22].

In the research presented in this paper the main drivers are computational modeling, simulation, and analysis as well as their application for advancing human fulfillment level. This is then linked to the sustainability theory to enable engineering of a better, more aware, and more empowered quality of life. Sustainable development is defined as the development that ”meets the needs of the present without compromising the ability of future generations to meet their own needs” [27]. The main objective of CoTh relates to the analysis of sustainability in human life, with a particular attention to the role of social activities and their geospatial dimension by application of novel computational methods to forecast future scenarios. In doing so, the Human-in-the-Loop simulation is considered as early as the design stage of the system.

III. DEFINING COMPUTATION OF THINGS

Definition of CoTh starts with an outline of its objectives and is followed by non exhaustive list of technical requirements and challenges to which will be added in ongoing research. Next, the technological state of the art on selected aspects related to CoTh is provided.

A. Objectives

CoTh serves as a means to introduce computational science in a manner that is accessible to society and makes an individual the key beneficiary of the technological progress. Computation is increasingly proliferating in our life. Rapid technological evolution is supposed to provide a more fulfilled and happier life where technology serves human beings instead of making us compulsive slaves to progress. Hence, the ultimate goal of CoTh is to employ technology to help guide an individual in finding the best balance and adapting to the evolving rules of change in any situation.

Novel attitudes to leveraging the existing datasets about humans and the surrounding physical and biological phenomena together with modern prediction algorithms allow for transformative thinking about a new kind of computational reasoning [29]. CoTh enhances the corresponding transformation by delivering a set of tools to take a conscious, scientifically-founded action as a response to computational thinking.

Thus, CoTh is a novel predictive approach that ultimately increases the awareness of society in various contexts. It requires a deep technological understanding of the current state of the art in many disciplines (e.g., social computation, human computing, knowledge-based computation, human-based computation, human-centered computing, citizen science, human-computer interaction, nature-inspired computation, etc.) and establishes a broad application expertise for every human using CoTh’s ultimate results. Cross-cutting concerns (horizontal and vertical) between different domains within the specific field and across the fields and new analysis methods with a potential to reason on the level of an individual with the potential to explore impact on a global scale [12]. A person is becoming a realistic and reasonable source and recipient of knowledge (and wisdom) on forecasting their own walk-of-life alternatives.

The intent of CoTh is to provide a methodology and toolset to predict diverse turns of life on different levels. This is, for example, a set of predictions on the influence of carbon dioxide or particulate matter on the health of an individual; given that the person chooses a selected means of transportation and route for, say a year. Further, the manner, in which this correlates with the DNA of the individual or nutritional habit allows for estimation of health status, including various possible dangers or failures. From here, the approach can be scaled up to families, communities, and nations. Clearly, further criteria can be added to those examples. Depending on the considered group these criteria may include further risk exposures, such as likelihood of terrorist attacks in case of organizing the defense logistics, people’s migration paths in case of severe weather conditions, effects of any resource scarcity crisis, or violence likelihood, to name a few. The applications of CoTh are manifold. Examples include selection of the safest and healthiest way for sending your children to school, choosing the best place to live in accordance with your preferences, but also specific personal conditions or diseases, up to individual evacuation plans during natural disasters.

Moreover, CoTh opens up a completely new awareness level of seeing things that matter or that should matter to develop sustainability in every person’s life. It also addresses the issues relevant at a large scale. Using a platform that integrates, for example, mobile data collection, real-time weather data sources, and prediction models that take time and location as primary inputs provides an opportunity to explore the effects of decisions that are of a critical nature to humans [22].

B. Technical Requirements and Challenges

The main goal of CoTh is to be accessible for everybody. It should be built oriented towards responding to the particular problems of an individual, for example, health, social behavior, pollution exposure, but more importantly addressing cross-domain problems, such as the impact of certain behavior on another behavior given selected states from other disciplines. Thus, components responsible for solving domain- and cross-domain issues should be anticipated.

One challenge to achieving this goal is to enable an access to data, knowledge, services, and predictions, ideally equal to everybody. Another even more demanding challenge is to allow for a proper) analysis of data that can be acquired in this age of information technology. That is, the combination of domain-related forecasts, their impact on the life of an individual, and vice-versa.

The forecasting of scenarios should be possible by analysis of the data of an individual through time and space based on patterns to find similar situations and comprehensive sets of possible answers. Real-time data from sensors, such as devices and humans (e.g., those belonging to individual's social network) should be acquired to establish a current situational awareness. Further on, alert information about any sudden changes or anomalies that could significantly impact the life of a person should be supported (e.g., civilian guidance in environmental crisis [1][5]).

Clearly, the multimedia and visualization interfaces for both the problem input and output scenarios constitute one of the factors determining the success of the user-acceptance level, hence, the breadth of the system application.

Revisiting the further long-term aim of CoTh to target selected groups of people, its application- and user-oriented conceptualization is similar to the Geographic Information Systems. It should support different views for different stakeholders with limited access to the processing units and temporarily irrelevant data.

C. *Advancement of the State of the Art*

Considering CoTh it is imperative to study software development practices because they ultimately allow for an artificial observance of rules in the natural sciences. Further, as CoTh is an advanced type of simulation, topics such as modeling, analysis, and synthesis are its integral components and model-based design techniques are a means to address them.

Computational modeling as such is an important element in the design of engineered systems. For example, computational models, because of their predictive power, are an essential part in designing efficient control strategies, decision-making, and early-warning systems. Given that a good model is one that helps solve the particular task at hand, a physical system may be represented by many different models. Each of these models is then most efficient for solving the particular issue under study, and, therefore, ideally only those phenomena observed in the system that are considered of importance are embodied by the model. All other phenomena are best abstracted away [3].

On the other hand, the complexity of desired functionality and the difficulty of software design have proven to be a magnificent challenge for the design of reliable systems. This has brought about a need to raise the level of abstraction and to remove any 'accidental complexity' from the separate design activities. Model-Based Design has demonstrated its success in tackling these issues by supporting requirements traceability, executable specifications, automatic code generation, and facilitating continuous test and verification [17][18].

Furthermore, CoTh is related to such terms as ubiquitous computing, pervasive computing, and everyware [8] but distinguishes itself in two main dimensions. It is leveraging the existence of connected computing devices and sensors embedded in the environment at the nexus of advanced electronics, wireless technologies, and the internet. It aims for a predictive evaluation of the activities of a human, though, and for that it is based on a new paradigm of computation, which will be outlined in Section 4. Clearly, CoTh is the response to the Internet of Things [7][28] where all objects around us are envisioned to be in a near invisible network of radio frequency identification tags (RFID) deployed on them. These tiny, traceable chips are then connected to the internet in a plug 'n' play fashion, and, therefore, instantly create a global network of physical objects. Similarly, CoTh builds up on the concept of the Web of Things [26] defined as an alternative vision of how the Web of tomorrow could be expressed. Web of Things is then an extension towards a virtual mechanism emulating the sensing capabilities located worldwide. It is a type of connection between the physical and the virtual world.

Finally, the CoTh vision includes an abundant supply of computational capabilities for individual scenario prediction and decision-support that would be economically viable for every person on the planet. In this paper, the analysis and prediction core is given additional attention. The main obstacle in increasing the forecasting power of computational models is their still poor understanding and lack of accuracy that ultimately leads to extremely high verification and validation costs. Therefore, it is proposed to formally define the computational approximation (i.e., error) as a development artifact. This allows refinement of the semantics of a computational model by adding necessary modeling constraints and enforcing relevant domain characteristics of a dynamic system during development.

IV. TECHNICAL INSIGHTS INTO COMPUTATION OF THINGS

In this Section, a proposal for a CoTh architecture is discussed. It has been designed by mainly taking the perspective of scenario prediction. Following, a relation to previous work [19][30] is discussed and the uniqueness of the solution is explained.

A. *Architecture Proposal*

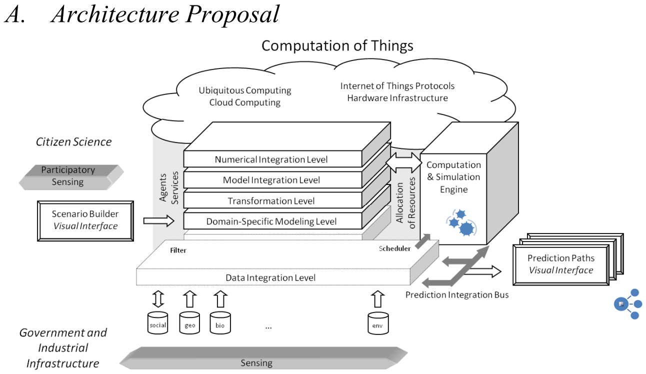

Figure 1. Architecture proposal for Computation of Things.

CoTh architecture comprises three main components, the sensing, analysis (i.e., the actual computation), and decision-making part (i.e., synthesis). They all can be identified in Figure 1. The *sensing component* (on the bottom left-hand side) includes both the government- and industry-enabled elements (e.g., satellites, sensors, cyber infrastructure) and participatory sensing [24] contributed by the so-called citizen scientists [4] [23].The former part can be based on such systems as a Multi-agent Architecture for Coordinated, Responsive Observations (MACRO) [15][23] that provides a natural computational infrastructure for enabling the deployment and operation of a sensor web, primarily designed to support the needs of future Earth Science Missions. The participatory sensing, on the other hand, could be based on the Platform for Participatory Sensing Systems (PSS) developed in [20]. It is an online tool that is based on the current geo-location and human activity patterns that allows for a continuous use of a mobile phone to explore and share how an individual impacts the environment and vice versa.

Then, the *scenario builder* complements the user-oriented part of the system by letting the user input the queries of her/his interest. They are represented by text that is analyzed based on keywords, graphics analyzed based on key-objects, or domain-specific models (DSMs) analyzed based on key-elements (e.g., geo-elements, geo-parcels, etc). The *agents and services* translate the input using the functionality of *DSMs* and applying the *transformation level* capabilities. Also, the data coming from the underlying databases are fed to the engine. Here, the *data integration level* functionality is leveraged. Next, such concepts as semantics and ontologies find their application to create patterns and scenarios from the acquired data. Semantically-adjusted models of computation are then created, integrated, and matched with the *numerical integration schemes* (represented by the upper level of the system). This allows for executing the simulations and ultimately for production of the predictions. Additionally, the unit controlling the allocation of computation resources links the resulting *models of computation* with the *computation and simulation engine*. In this so-called next-generation prediction engine the actual forecasting of the scenarios takes place. The insights of this mechanism are provided in the proceedings. The forecasts are then sent back to the *user visual interface* indicating options to choose or to follow and to further explore.

B. Relation to Previous Work

In this work aspects relevant for Human-in-the-Loop converge to a common purpose, that is, focus on an individual person and its surrounding [30]. The merging of such fields as, for example, early-warning disaster systems, crisis crowd sourcing, or digital infrastructure plans exist, though, there is no common understanding in terms of combining them into one ubiquitous platform yet. Therefore the goal of this architecture is to provide conditions for an efficient integration of data, similarly as it is to some extent achieved in the area of disaster response [14][25].

This multi-disciplinary thinking should then allow for an in-depth analysis of the cross-cutting concerns existing in human life. For example, nowadays, it is not extensively researched how the possible health problems of a single individual being who is part of a selected social network relates to the change of climate. CoTh is going to change this trend and raise interest in a human being to automatically identifya set of existing conditions that otherwise could have been missed.

C. The Uniqueness of the Solution

As introduced before, the CoTh system architecture includes a computational analysis engine of which the unique details are highlighted below.

In the approach presented here, the accidental complexity of the code normally used for computation implementation is removed by application of a representation on a higher level abstraction. The reliability and verity of predictions is then increased by capturing the dynamics of the computation in an abstract notation, such as, for example, block diagrams provided in Figure 2 (right bottom). This declarative and purely functional, side-effect free approach makes solver dynamics explicit and allows a computational framework that enforces inherent dynamic systems semantics. As a result, correctness and consistency of the computations as representations of dynamic systems is guaranteed by construction at this level.

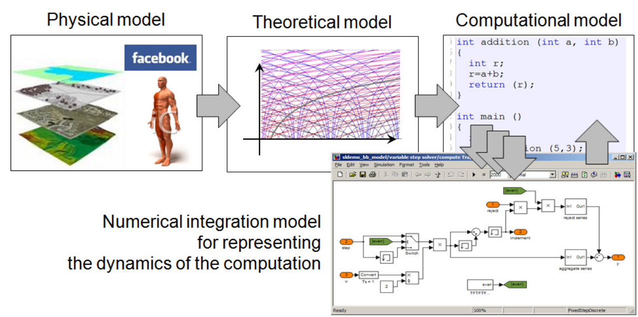

Figure 2. Modeling a computational model as an explicit dynamic system

The dynamic system representation can be directly derived from the physical and theoretical model parts and solvers, or it may be based on particular parts of the code. From here, through several lowering stages an implementation is derived that ultimately relies on code again for its execution. However, these computations are restricted to being correct in a dynamic systems sense.

V. Reality Check

The vision of CoTh is grand and challenging. It piques interest, but clearly, it also introduces a lot of controversy. In this Section, CoTh is related to the even bigger picture. The risks of the initiative are listed and a couple of application examples are highlighted.

A. Embedding Computation of Things in the 'Big Picture'

The concept called Digital Earth (DE) has been recalled investigated for over a decade as a result of Gore's activities [8]. DE is envisioned as a multi-resolution, three-dimensional representation of the planet that would make it possible to find, visualize, and analyze vast amounts of geo-referenced information on the physical and social environment. It should allow users to navigate through space and time, access historical data and future predictions, and support scientists, policy-makers, and the society.

Although major progress has been made (see Google Earth service or NASA systems [15][23]), the vision has still not been achieved. It is mainly because in parallel to the increased availability and access to information, human collective awareness of the need to understand interdependencies of environmental and social phenomena on a global scale has also increased [3].

Globally-oriented initiatives, such as, for example, the Global Earth Observation System of Systems (GEOSS) [10] aim at linking existing monitoring systems and networks to achieve comprehensive, controllable, and sustained observations of the planet Earth. GEOSS is directed by the Group on Earth Observations [10][11], an intergovernmental organization at the ministerial level comprising seventy three nations, the European Commission, and fifty two international organizations. A major role of GEOSS is to promote scientific connections between the observation systems that constitute the Earth system of systems, and promote applications across nine societal benefit areas as given on the left-hand side in Figure 3.

Relating the objectives of CoTh to this vision of DE, CoTh represents a complementary element, akin to a metaphoric Digitalized Mirror of Human Life on Earth as given on the right-hand side in Figure 3. Here, the objective is to promote the benefits for an individual across at least ten areas.

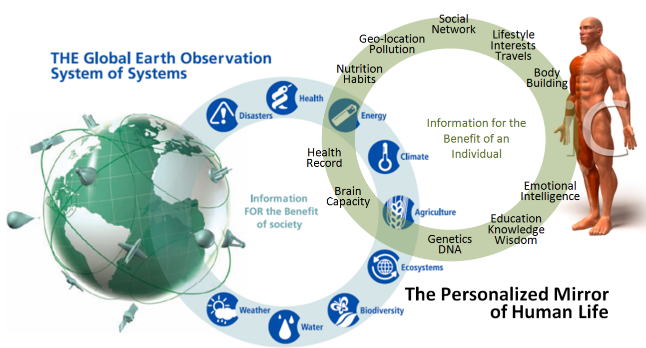

Figure 3. Convergence of two visions into one: 'Digital Earth' and 'Digitalized Mirror of Human Life on Earth'.

Whereas CoTh holds similar promise for the society advancement, the challenges and limitations are corresponding to those related to DE. Research and new solutions are required in such areas as information interoperability, integration, space- and time-based analysis, handling the heterogeneity of methodologies and domain semantics, prediction methods, quality measures, feasible visualization methods, proper architectural designs, infrastructure, open data sharing, and system impact analysis (e.g., privacy violence).

Clearly, CoTh is going intends to leverage the development of DE. It will be embedded in the similar infrastructure. In parallel, it is going to be enhanced with CoTh-related elements and follow the next-generation DE recommendations highlighted, for example, in [3].

B. Risk Factors

The risk factors comprise at least two types of failure. Firstly, the challenges resulting from the integration and heterogeneity as well as the futuristic and multidisciplinary views may be too difficult to be solved within the next few years. Thus, the timeline for the realization of the vision is not well established. As a mitigating factor, however, considering the exponential growth and convergence of the underlying technologies, the solutions may emerge quicker than one anticipates [16]. From the industrial perspective, CoTh represents a candidate for the customer-oriented market. Here, similarly as in the case of DE, the competitive environment may direct its development into not quite urgently intended directions. Further, privacy and policy represent the issues already now. Technological game-changes developments, such as parallel computing, novel computational algorithms, and next-generation computation and prediction capabilities require strong abilities to adopt the CoTh system to emerging architectures and infrastructures. Inclusion of certain components in CoTh, for example, capturing human emotions in the correct fashion and their intersection with other domains can be misleading as much as they are in the real life.

In spite of these risks, computational progress can be of paramount importance for the society in developing human skills, applying computation results, and using these results to improve the quality of life. The thesis holds even more value if this progress enables a more sustainable and more environment-conscious living.

C. Illustration

To illustrate, the prediction scenarios enabled by CoTh can include, for instance, the geo-tracking of an ever-changing virus that can ultimately develop into a pandemic. This tracking can be correlated with how the migration of the virus relates to climate disturbances and, furthermore, this can be connected with the data on the past and future traveling plans of an individual. This information can then be leveraged in planning location changes and directing traffic better to help prevent the virus from spreading and help a single person adjust to the rapidly changing situation.

Another example is the mobility pattern investigation to guide a civilian in natural disasters as intended by [5]. The assessment of local behavior of civilians at a given point in time can be leveraged to predict their further movements and help them out as quickly and efficiently as possible.

VI. Conclusions

Conclusions comprise a brief summary of the paper and future plans on building the CoTh system.

A. Summary

An interesting question arises when a person analyzes the development of different scenarios based on our decisions. *What if we had decided differently? What would be the implications?* This paper presents a thought model that may be controversial but in turn holds promise of a breakthrough in applying technology for human everyday needs, with a particular emphasis on an individual and her/his meaning in the society of knowledge [21]. To illustrate a technological innovation for leveraging the best possible predictive conclusions from omnipresent information, a novel method of computation from previous work was recalled and embedded into the vision.

The aim of CoTh is to provide an accurate, precise, and well-understood manner for enabling the forecast of events that in turn trigger decisions shaping our own lives. In this regard, the further attempt of this research is to deliver a system that influences human generations with the agreement on the common vision of sustainable development. Here, another question arises. *So what?* CoTh is able to educate and increase the awareness on choice in life, the effects for the alternatives. This knowledge enables one to act wiser, live happier and purposeful, and contribute more to the society.

The technological contribution of this paper comprises the following issues. This sustainability drive intended with CoTh enables a shift of people's attention to things that matter to them and their future as well as that of future generations. Clearly, numerous challenges exist to realize this mission. The fundamentals of computational semantics should be revised and extensively researched to allow for providing highly reliable and at best self-verified predictions. Also, the approach presented in [15][23] to incorporate seamless dynamic connectivity between different sensors, employs reactive and proactive strategies for improved analysis, and uses enhanced dynamic decision-making for rapid responses to changing situations will be further investigated. The architecture of the system is dependent on the above mentioned research, other existing trends (cf. DE vision), and the quickly transforming technological advances.

To that end, CoTh application holds market-related values. Its underlying analysis engine and thus the anticipated computational framework are the backgrounds of the system. If successful, they represent catalytic technological innovation and uniqueness distinguishing it from similar other attempts.

Finally, there is a distinct potential for a global impact of CoTh applications. Taking the challenges of climate change as an example, the developing countries are widely recognized as most vulnerable to its severe effects [1]. In Africa, the impact is exacerbated by its geographic location, but also lack of adaptive capacity in terms of developing economy, health, education, infrastructure, and governance. At the same time, the mobile phone is becoming the main technological device that is available to many [1]. Hence, if the trend persists, a cell-phone-based interface of CoTh can bring its advantages to most all parts of the world. This implicates a global awareness revolution and so enables substantial progress towards sustainability.

Some religions or independent thinkers emphasize that the level of fulfillment and happiness in individual's life is a mirror of its life activities and soul states [13]. The message of CoTh application is to improve the quality of life with thoughts on scenarios that otherwise would not be so obvious and by that enriching the soul with a conscious and brave empowerment to lead a better existence. All that is based on the principle that we are *one humanity* or at least we can be regarded as such. Hence, whatever we do, it is contagious and impacts those around us [1][13].

B. *Future Plans*

Future plans include founding of a research laboratory oriented towards multiple countries that is to realize CoTh objectives with a number of international industrial, government, and research partners. The first orientation step is to conduct a set of interviews of citizens and experts on their most urgent domain-oriented needs related to predictions so as to enable a quick anchoring of the case studies. In parallel, the computation engine is being developed and selected algorithms are being studied [19]. Visual user interfaces and simplicity is targeted. The currently investigated case study comprises the implications of climate change on human health for a given region relating to the individual members of a selected social network and will be further developed.

The desire of people to know more about their future opportunities and impact will be, to some extent, fulfilled with CoTh and will allow for creating a better life based on scientifically-proven scenarios, not the stereotypes, prejudices, or lack of information.

References

[1] Christakis, N.A. and Fowler, J.H., *"Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives"*, New York: Little, Brown and Company, ISBN-10: 0316036145, 352 pages, 2009.

[2] Coyle, D. and Meier, P.: *"New Technologies in Emergencies and Conflicts: The Role of Information and Social Networks"*, Washington, D.C. and London, UK: UN Foundation-Vodafone Foundation Partnership, 2009.

[3] Craglia, M., Goodchild, M. F., Annoni, A., Camara, G., Gould, M., Kuhn, W., Mark, D., Masser, I., Maguire D., Liang, S., Parsons, S.: "*Next-Generation Digital Earth, A position paper from the Vespucci Initiative for the Advancement of Geographic Information Science*", International Journal of Spatial Data Infrastructures Research, Vol. 3, 146-167, 2008.

[4] Climate Collaboratorium, Harnessing the world's intelligence to save the planet, MIT Composite model, http://www.climatecollaboratorium.org/.

[5] Civilian Guidance, CiviGuard, Inc. 2010, http://civiguard.com/.

[6] Dator, J.: "Forecasts useful, morally right", In Honolulu *Advertiser*, December 18, 2000. http://www.futures.hawaii.edu/dator/futures/Forecastsuseful.pdf.

[7] Dodson, S.: *"The internet of things"*. The Guardian. 2003.

[8] Gore, A.:"*The Digital Earth: Understanding our planet in the 21st Century*", California Science Center, Los Angeles, California, on January 31, 1998. http://www.digitalearth.gov/VP19980131.html.

[9] Greenfield, A.: *"Everyware: The Dawning Age of Ubiquitous Computing"*, ISBN-10: 0321384016, 272 pages, New Riders Publishing, March 20, 2006.

[10] Group on Earth Observaton (GEO) Secretariat (Ed.) 2007b. "*The First 100 Steps to GEOSS: Annex of Early Achievements to the Report on Progress 2007*", Cape Town Ministerial Summit. Geneva: GEO. http://earthobservations.org/documents/2007_%20Annex%20of%20Early%20Achievements%20to%20the%20Report%20on%20Progress.pdf.

[11] Group on Earth Observations, http://earthobservations.org/.

[12] Hey, T., Tansley, S., Tolle, K.: *"The Fourth Paradigm: Data-Intensive Scientific Discovery"*, 284 pages, ISBN-10: 0982544200, ISBN-13: 978-0982544204, Microsoft Research, October 16, 2009.

[13] Lama, Dalai, Cutler, H.C.: *"The Art of Happiness"*, 352 pages, ISBN-10: 1594488894, 2009.

[14] InSTEDD Riff, Innovative Support to Emergencies, Diseases and Disasters, http://instedd.org/evolve.

[15] Kinnebrew, J., Biswas, G.: "Efficient Allocation of Hierarchically-Decomposable Tasks in a Sensor Web Contract Net", Proceedings of the 2009 IEEE/WIC/ACM International Joint Conference on Web Intelligence and Intelligent Agent Technology - Volume 02, Pages: 225-232, 2009.

[16] Kurzweil, R.: *"The Singularity Is Near: When Humans Transcend Biology"*, 672 pages, ISBN-10: 0670033847, Viking Adult, September 22, 2005.

[17] Mosterman, P.J., Vangheluwe, H.: "Computer Automated Multi-Paradigm Modeling: An Introduction", in *SIMULATION: Transactions of The Society for Modeling and Simulation International*, Vol. 80, Nr. 9, pp.: 433–450, *Editor Choice Article*, 2004.

[18] Mosterman, P.J., Vangheluwe, H.: "Computer Automated Multi-Paradigm Modeling in Control System Design", in Proceedings of the IEEE International Symposium on Computer-Aided Control Systems Design (CACSD00), pp.: 65–70, Anchorage Hilton, Anchorage, Alaska, USA, September 25-27, 2000.

[19] Mosterman, P.J., Zander, J., Hamon, G., Denckla, B.: "Towards Computational Hybrid System Semantics for Time-Based Block Diagrams", *In proceedings of the 3rd IFAC Conference on Analysis and Design of Hybrid Systems (ADHS'09),* A. Giua, C. Mahulea, M. Silva, J. Zaytoon (editors), pp.: 376–385, plenary paper, Zaragoza, Spain, September 16-18, 2009.

[20] Mun, M., Reddy, S., Shilton, K., Yau, N., Burke, J., Estrin, D., Hansen, M., Howard, E., West, R., Boda, P.: "PEIR, the personal environmental impact report, as a platform for participatory sensing systems research", In *Proceedings of the 7th International Conference on Mobile Systems, Applications, and Services*, Kraków, Poland, pp.: 55–68, ISBN:978-1-60558-566-6, 2009.

[21] National Science Foundation, *Program Solicitation, NSF 09-559,* Social-Computational Systems, http://www.nsf.gov/pubs/2009/nsf09559/nsf09559.htm.

[22] Pollak, B. (Ed.): *Ultra-Large-Scale Systems*, 150 pages, ISBN:0-9786956-0-7, June 2006.

[23] Suri, D., Howell, A., Schmidt, D.C., Biswas, G., Kinnebrew, J., Otte, W., and Shankaran, N.: "A Multi-agent Architecture for Smart Sensing in the NASA Sensor Web", In *Proceedings of the 2007 IEEE Aerospace Conference*, Big Sky, Montana, Mar. 2007.

[24] Surowiecki, J.: "The Wisdom of Crowds: Why the Many Are Smarter Than the Few and How Collective Wisdom Shapes Business, Economies, Societies and Nations", 320 pages, ISBN-10: 0385503865, Doubleday, 2004.

[25] Taaffe, K., Johnson, M., Steinmann, D.: "Improving Hospital Evacuation Planning Using Simulation", In *Proceedings of the 2006 Winter Simulation Conference*, L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, eds, Monterey, California, ISBN: 1-4244-0501-7, pp.: 509–515, 2006.

[26] Trifa, V., Guinard, D., Web of Things, http://www.webofthings.com/about/.

[27] United Nations, *"Our Common Future"*, ISBN: 0-19-282080-X, Oxford: Oxford University Press, 1987.

[28] Van Kranenburg, R.: "*The Internet of Things*", Institute of Network Cultures, ISBN/EAN: 978-90-78146-06-3, Amsterdam, September 2008. http://www.networkcultures.org/_uploads/notebook2_theinternetofthings.pdf.

[29] *Report of a Workshop on The Scope and Nature of Computational Thinking*, Committee for the Workshops on Computational Thinking; National Research Council 126 pages, ISBN-10: 0-309-14957-6, 2010. http://books.nap.edu/openbook.php?record_id=12840&page=2.

[30] Zander, J., Mosterman, P.J.: "*Computation of Things for Sustainable Development*", Homeland Security Workshop on Grand Challenges in Modeling, Simulation, and Analysis, March 2010.