

Introduction to the ICCS 2007 Workshop on Dynamic Data Driven Applications Systems

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Abstract. This is the 5th International Workshop on Dynamic Data Driven Applications Systems (DDDAS), organized in conjunction with ICCS. The DDDAS concept entails the ability to dynamically incorporate data into an executing application simulation, and in reverse, the ability of applications to dynamically steer measurement processes. Such dynamic data inputs can be acquired in real-time on-line or they can be archival data. DDDAS is leading to new capabilities by improving applications modeling and systems management methods, augmenting the analysis and prediction capabilities of simulations, improving the efficiency of simulations and the effectiveness of measurement systems. The scope of the present workshop provides examples of research and technology advances enabled through DDDAS and driven by DDDAS. The papers presented in this workshop represent ongoing multidisciplinary research efforts by an international set of researchers from academe, industry, national and research laboratories.

Keywords: applications, measurements, dynamic runtime, sensors, grids.

1 Introduction

The Dynamic Data Driven Applications Systems (DDDAS) [1,6] concept entails the ability to dynamically incorporate data into an executing application simulation, and in reverse, the ability of applications to dynamically steer measurement processes. Such dynamic data inputs can be acquired in real-time on-line or they can be data retrieved from archival storage. The DDDAS concept offers the promise of improving modeling methods, augmenting the analysis and prediction capabilities of application simulations, improving the efficiency of simulations and the effectiveness of measurement systems. The kind of multidisciplinary advances that can be enabled through the DDDAS concept, as well as technology capabilities required to support DDDAS environments, have been discussed in [1-8, 10-11]; papers presented in the DDDAS/ICCS Workshops Series provide examples of advances enabled through an increasing number of projects. The DDDAS Program [5] announced in 2005, with seeding efforts on DDDAS having started previously (2000 – 2005) through the NSF ITR Program [6], have provided some initial funding support for these efforts. In particular, the DDDAS Program was co-sponsored by multiple NSF Directorates and Offices, and by NOAA and NIH, and in cooperation with Programs in the European

Community and the United Kingdom [5]. The value of DDDAS has been increasingly recognized by the broader community and has been discussed in the reports of “blue ribbon” studies [7, 8] and community driven workshops [10, 11]. DDDAS is a “revolutionary and important” direction [7]. This impact of DDDAS to scientific, engineering, and societal areas is increasingly becoming widely and internationally recognized: the 2006 NSF sponsored DDDAS Workshop [4], drew participation from multiple US agencies, and there is an established cooperation of European programs with the US on DDDAS. Furthermore, at the same time there is an increasing interest by industry on DDDAS, and this is manifested through the participation of industry in a number of the DDDAS research projects.

The need for synergistic multidisciplinary research in enabling DDDAS capabilities has been articulated from the outset and consistently thereafter [1-8]; and specifically, there is need for synergistic multidisciplinary research advances in applications modeling, in mathematical and statistical algorithms, in measurement methods and data management, and in computer systems software, targeted towards creating DDDAS capabilities and environments. Furthermore, in [2] the case is made that the DDDAS concept leads to an infrastructure that goes beyond the traditional notions of computational grids, and provides an impetus for new directions and capabilities in CyberInfrastructure environments [9]. Presently an increasing number of multidisciplinary research efforts on DDDAS is being pursued by an international set of researchers from academe, industry, national and research laboratories, leading to new capabilities in application modeling and measurement capabilities, computer sciences methods, and development of enhanced software systems architectural frameworks supporting DDDAS environments, and driving new directions in CyberInfrastructure [4].

The efforts presented in this workshop provide examples of technologies and new capabilities that are being developed based on the DDDAS concept and in supporting DDDAS environments. The www.cise.nsf.gov/dddas and www.dddas.org sites are source of information on a multitude of projects and other efforts encompassed under the DDDAS rubric. The present workshop is the fifth of a series of international workshops on the DDDAS topic that have been organized as part of ICCS, starting with ICCS'03. The Workshop provides a forum where project investigators update the broader community on the progress in their project. In addition, the discussions that take place, provide an opportunity for leveraging advances made in related projects, and facilitating objectives for creating collaborations and liaisons among complimentary projects, thus leading “systems of systems” through horizontal integration across projects, and creation of “software architectural frameworks” through vertical integration leveraging across projects. In addition to DDDAS/ICCS and the NSF sponsored workshops [1, 6], other workshops and community building activities are organized by the research community [e.g. 10, 11] further broadening the outreach to other researchers and application areas. The papers presented in the present workshop represent a sample of the scope of technical efforts pursued. This introduction serves as an overview to place in context the work presented in the workshop.

2 Overview of Work Presented in This Workshop

The papers presented in this workshop represent a sample of the ongoing research efforts to enable DDDAS capabilities, in a wide set of areas, such as: enhanced civil and mechanical systems; health systems; critical infrastructure systems, such as electrical power grids, transportation and urban water distribution systems, emergency detection, response and disaster mitigation; enhanced methods for severe weather analysis and prediction; air, water, and subsurface chemical contaminant propagation and mitigation of damage; human and social systems; and enhanced computer systems software methods and environments. The papers represent ongoing efforts synergistic, multidisciplinary research advances in applications modeling, applications algorithms, measurement methods, and in systems software. These efforts contribute and build the layers of software architectural frameworks that are being developed to enable and support DDDAS capabilities and requirements. A number of projects have interactions and collaborations with relevant industrial partners, and with regional and other governmental organizations, to utilize existing infrastructure resources and to demonstrate in realistic situations the new capabilities developed. Each paper, together with an overview of the respective project, discusses at depth recent technical advances made in the project.

Papers [12-15] discuss applications related to human health: from personalized pharmaceuticals, to advanced medical intervention and customized medical treatment. In [12] is discussed the onset of a paradigm shift in pharmaceutical and biotechnology research methods, leading towards a future world of personalized medicines, which will be enabled through a foundational framework that will be based on the DDDAS concept. In [13] new frameworks and architectures for brain-machine interface communication and control capabilities are developed, using mixture models to enhance rehabilitation of disabled patients. In [14] and [15] are presented new modeling methods and distributed computational frameworks for advanced medical procedures. Paper [14] discusses an image-guided neurosurgery and grid-enabled software environment by integrating real-time acquisition of intra-operative Magnetic Resonance Imaging (I-MRI) with the preoperative MRI, fMRI, and DT-MRI data. Paper [15] discusses work on novel advances for cancer tumor treatment by utilizing real-time imaging data to provide dynamic control of a laser heat source targeted to ablate only the tumor-tissue, and at the same time imparting minimal damage to the tumor surrounding area.

In papers [16-22], new applications and methods are enabled in the areas of environmental and natural resource management. Dynamic streaming of data into the application models and architecture and adaptive control of sensor networks, is a common aspect of the work discussed here. Papers [16] and [17] discuss new capabilities on DDDAS methods for application models driving and establishing system architecture, enabling adaptive management and control of stationary and mobile sensors for monitoring ecosystems such as forests [16] and aqueous environments [17], and addressing issues such reducing errors and uncertainty, dynamic control of the sensor network for power management, and adaptive placement of mobile sensors. Papers [18-21] address advances through DDDAS in contaminant tracking in subsurface and aqueous environments (e.g. oil spills in [18]), or in the atmosphere ([19-21]). In [19] DDDAS methods are used to perform analysis

and accurately predict the path of the contaminant, by effectively solving the forward problem, as well as the inverse problem, so that the location of the contaminant source can be identified. Furthermore the project is developing enhanced reduced-order-modeling approaches to enable such predictions and analysis to be done in near-real time. Papers [20] and [21] use the DDDAS concept to develop enhanced Kalman Filtering methods and an integrated framework for analysis of transport of atmospheric chemical pollutants (like sulfur) in wide geographical regions. In the context of a research effort addressing the development of DDDAS environments for coastal and environmental applications, paper [22] focuses on discussing the advances in a software framework for providing accurate and timely analysis for hurricane events. Paper [23] uses DDDAS approaches for improving analysis and the accuracy of predicting the path of wildfires, through dynamic incorporation, into executing simulations, measurement data dynamically acquired through aerial survey, thermal sensors on the ground, winds and humidity measurements, together with archival data on the terrain and vegetation.

Papers [24-28] discuss work that is aimed to create DDDAS-based enhanced critical infrastructure systems, where simulation models use dynamic data inputs and control the data acquisition process in real-time evolving conditions to provide optimized planning, operation and response and mitigation of the impact of adverse unexpected conditions. Advances made include work reported in [24] on ad-hoc simulation modeling and monitoring data for adaptive management of transportation systems to optimize conditions in urban traffic and to provide decision support for responding to adverse and disruptive events such as needs emergency evacuation of a city area. Work reported in [25] on adaptive monitoring and detection of water contamination in a city system, and determining the source of the contaminant; this work can lead to more safe urban water systems and provide response capabilities in cases of adverse events affecting a city's water system. Papers [26-28] discuss the development of DDDAS environments for optimized management of electrical power-grid systems, to predict, respond, and mitigate, failures such as power demand surge, or disruptive events such as failure of transformers and thus avoid extensive blackouts. The methods include streaming monitoring data in to continually running simulation models, and through simulation control determine adaptively the kinds of further monitoring needed, as well as develop robust methods in the presence of measurement uncertainties.

Papers [29-32] deal with behavioral and situational awareness management systems, which, through DDDAS approaches, seek to develop advanced analysis, prediction, and response capabilities. Paper [29] discusses work where data from continually monitored cell-phone activity is streamed into agent-based simulations, to detect potentially disruptive events, like traffic congestion or an adverse event in a large crowd gathering, or evacuation situations. Work discussed in [30] is aimed at developing methods and frameworks to support large DDDAS "mixed reality" environments of agent-based simulations together with full scale preparedness exercise, by modeling individual and group dynamics, and using on-line monitoring for analyzing and predicting the onset of behaviors and actions, in situations such as the effects and impact of an epidemic disease, or a chemical or radiological release, and guiding responders actions as such events evolve. Paper [31] discusses DDDAS methods to track facial expressions and body movement to detect human behaviors

such as deception and predict intent. In [32] is the use of DDDAS approaches to enhance fidelity of simulations for social sciences studies environments, through adaptive data collection processes, to minimize the impact of input data uncertainties.

Papers [33-38] discuss novel methods of weather analysis and forecast, including for situations of severe or extreme weather events. In [33] and [34] are discussed DDDAS-based simulation and measurement methods and software frameworks, for supporting the required cyber-infrastructure for tornadic events, and for improving the accuracy of predicting the tornado path. Paper [33] presents software infrastructure advances needed to support real-time, dynamic and adaptive feed-back loop between dynamic incorporation of monitoring data into the executing simulation models, and in return continuous and simulation-based adaptive control of multiple and heterogeneous on-line measurements, such as radar measurements, winds, atmospheric pressure, temperature, humidity, etc. Work in [34] is developing new algorithmic methods, by applying active learning with support vector machines approaches, to improve the methods for discriminating between conditions that lead to onset of tornados versus those that do not. In [35] are discussed new advances in adaptive observation strategies through integration of non-linear adaptive weather prediction models, as well as algorithms that learn from past-experience, for adaptive planning and control of the best discrete locations and times for additional measurements under time-varying conditions, in order to minimize the forecast errors for “high-impact” weather in the Pacific. Paper [36] uses DDDAS to enhance and overcome limitations of traditional data-assimilation approaches; the new methods reported here treat jointly position and amplitude data assimilation, and extend the methodology to multivariate fields, as a generalized solution applicable to meteorological, oceanographic and hydrological applications. While measurements in ambient environments are very important and used extensively in many modeling efforts (including many of the ones presented in this workshop), there is value also derived from more controlled measurement environments; this is the approach in the efforts discussed in [37] and [38] which use DDDAS-based adaptive modeling and measurement methods for weather forecasting. Paper [37] discusses the experimental infrastructure as a testing observatory for laboratory simulations of planetary flows that functions in real-time. Paper [38] discusses the software methods for more efficient execution of the weather model simulator, including fluids modeling, algorithms and performance.

Papers [39-43] address DDDAS-based methods on structural monitoring, fault-tolerance, and optimized management of systems like buildings, aircraft, wind-turbines, fluid thermal systems, optimized performance in materials. In [39] are presented advances through DDDAS for prediction of “near real-time” structural dynamics and impact, in a structure like an aircraft, through reduced-order modeling methods integrated with on-line sensor data, together with the development of a novel sensor-data compression algorithm and its application to fast detection of structural damage. The research pursued in [40] applies DDDAS to materials characterization by enabling new methods for determining a priori and as the experiment proceeds the collection of data needed to characterize the material. Paper [41] is employing DDDAS for evaluation of fluid-thermal systems for conditions such of a heated jet injected into a laminar boundary layer. Paper [42] is applying DDDAS to novel capabilities for more effective fault diagnosis in wind turbines, and more efficient

operation of such systems. The efforts in [43] are developing new systems methods for supporting DDDAS environments for analysis of structural aspects of sensor instrumented buildings, and specifically new methods for managing distributed communication and coordination of over large self-organized networks of heterogeneous devices, under critical conditions with resource constraints and needs for prioritization of resource allocation.

Papers [44-48] discuss algorithmic and software advances for supporting DDDAS environments. The focus of paper [44] is on novel algorithms to support parallel multi-block numerical models coupled with global stochastic optimization algorithms, dynamic multi-dimensional, scientific datasets, and adaptive runtime management strategies, resulting into a software architectural framework for developing large-scale and complex decision-making DDDAS systems. In [45] methods are developed for dynamic intrusion detection and a software framework to support the requirements of such applications. Work in [46] uses DDDAS to improve on the precision and robustness of signal and speech recognition process. In [47] are discussed methods and a framework to enable verification of dynamically composable and configurable simulations, such as those required in DDDAS environments. Paper [48] discusses the challenges of propagation and compounding of uncertainties and novel methods on increasing confidence in evolving complex simulations in DDDAS environments.

3 Summary

DDDAS has been gaining recognition as an important and revolutionary concept that creates new capabilities in applications and measurement methods and systems. Through efforts that are developing DDDAS environments, we are in a strong path towards accomplishing such objectives and realize the DDDAS promise.

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