New Frontiers
Through Computer and Information Science

June 4, 2012
ICCS2012

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Air Force Office of Scientific Research

Integrity ★ Service ★ Excellence
Transformation Inducing Directions

• Multidisciplinary Research
  ▪ Fostering Transformative Innovations
  ▪ Expanding Fundamental Knowledge and Capabilities

• Unification Paradigms – Multidisciplinary Thematic Areas
  ➢ InfoSymbiotic Systems
    The Power of DDDAS – Dynamic Data Driven Applications Systems
  ➢ Multicore-based Systems
    Unification of HEC w RT Data Acquisition & Control Systems
  ➢ Systems Engineering
    Engineering Systems of Information (design-operation-maintenance-evolution)
  ➢ Network Systems Science (Network Science)
    Discover Foundational/Universal Principles across Networks
  ➢ Understanding the Brain and the Mind
    From Cellular Networks … to Human Networks

• Transformative Partnerships across Academe-Industry
• Summary
**Dynamic Data Driven Applications Systems (DDDAS)**

**InfoSymbiotic Systems**

**DDDAS**: ability to dynamically incorporate additional data into an executing application, and in reverse, ability of an application to dynamically steer the measurement process.

A “revolutionary” concept enabling to design, build, manage and understand complex systems.

Dynamic Integration of Computation & Measurements/Data (from the High-End, to the RT, to the PDA)

Unification of Computing Platforms & Sensors/Instruments

**DDDAS** - architect & adaptive-mngmnt sensor/cntrl systems

**Challenges**:
- Application Simulations Methods
- Algorithmic Stability
- Measurement/Instrumentation Methods
- Computing Systems Software Support

**Software Architecture Frameworks**

Synergistic, Multidisciplinary Research
Advances in Capabilities through DDDAS

• DDDAS: integration of application simulation/models with the application instrumentation components in a dynamic feed-back control loop

Advanced modeling methods

- speedup of the simulation, by replacing computation with data in specific parts of the phase-space of the application enable ~decision-support capabilities w simulation-modeling accuracy and/or

- augment model with actual data to improve accuracy of the model, improve analysis/prediction capabilities of application models

Advanced instrumentation methods

- dynamically targeted data collection (rather than ubiquitously )

- dynamically manage/schedule/architect heterogeneous resources of: networks of heterogeneous sensors, or networks of heterogeneous controllers

• unification from the high-end to the real-time data acquisition and control
• DDDAS: integration of application simulation/models with the application instrumentation components in a dynamic feed-back control loop

Advanced modeling methods
- speedup of the simulation, by replacing computation with data in specific parts of the phase-space of the application
- augment model with actual data to improve accuracy of the model, improve analysis/prediction capabilities
- decision support capabilities

Advanced instrumentation methods
- dynamically targeted data collection (rather than ubiquitously)
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• unification from the high-end to the real-time data acquisition and control

Computational Science - the 3rd paradigm

Data - the 4th paradigm

DDDAS /InfoSymbiotics is the unifying paradigm
• Current (NEXRAD) Doppler weather radars are high-power and long range – Earth’s curvature prevents them from sensing a key region of the atmosphere: ground to 3 km

• CASA Concept: Inexpensive, dual-polarization phased array Doppler radars on cellular towers and buildings
  – Easily view the lowest 3 km (most poorly observed region) of the atmosphere
  – Radars collaborate with their neighbors and dynamically adapt to the changing weather, sensing multiple phenomena to simultaneously and optimally meet multiple end user needs
  – End users (emergency managers, Weather Service, scientists) drive the system via policy mechanisms built into the optimal control functionality
LEAD: Users INTERACTING with Weather

“The LEAD Goal Restated - to incorporate DDDAS “ - Droegemeier

Interaction Level II: Tools and People Driving Observing Systems – Dynamic Adaptation

“Sensor Networks & Computer Networks”

Slide courtesy Droegemeier
March 2000 Fort Worth Tornadic Storm
Local TV Station Radar
Corrected Forecast with LEAD(DDDAS)
(Slide – Courtesy K. K. Droegemeier)

Xue et al. (2003)
Vortex2 Experiment with Trident

Vortex2 Workflow guided by Trident

Real-Time Public Data Sources

Data Search

Running inside Windows Box

WRF Pre-Processing

Running inside Linux Clusters

WRF

Running inside Windows Box

WRF Post-Processing

Visualizations Repository

Mobile Web-site

UCAR

LEADPORTAL

Mobile Web-site

Visualizations Repository

Running inside Linux Clusters

WRF

Running inside Windows Box

WRF Post-Processing

Mobile Web-site

Real-Time Public Data Sources

Data Search

Running inside Windows Box

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WRF

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WRF Post-Processing

Visualizations Repository

Mobile Web-site
Dynamic Workflow: THE Challenge

Automatically, non-deterministically, and getting the resources needed
Examples of Areas of DDDAS Impact

• Physical, Chemical, Biological, Engineering Systems
  – Chemical pollution transport (atmosphere, aquatic, subsurface), ecological systems, molecular bionetworks, protein folding..
• Medical and Health Systems
  – MRI imaging, cancer treatment, seizure control, …
• Environmental (prediction, prevention/mitigation of adverse effects, and response)
  – Earthquakes, hurricanes, tornados, wildfires, floods, landslides, tsunamis, …
• Critical Infrastructure systems
  – Electric power systems, water supply systems, transportation networks and vehicles (air, ground, water, space)

“revolutionary” concept enabling to design, build, manage and understand complex systems
NSF/ENG Blue Ribbon Panel (Report 2006 – Tinsley Oden)
“DDDAS … key concept in many of the objectives set in Technology Horizons”

• Robust and Dependable Large-Scale systems
• Large-Scale Computational Environments

+ (AFOSR-NSF joint) August 2010 MultiAgency InfoSymbiotics/DDDAS Workshop
The AirForce 10yr + 10 Yr Outlook: 
Technology Horizons Report
Top Key Technology Areas

- Autonomous systems
- Autonomous reasoning and learning
- Resilient autonomy
- Complex adaptive systems
- V&V for complex adaptive systems
- Collaborative/cooperative control
- Autonomous mission planning
- Cold-atom INS
- Chip-scale atomic clocks
- Ad hoc networks
- Polymorphic networks
- Agile networks
- Laser communications
- Frequency-agile RF systems

- Spectral mutability
- Dynamic spectrum access
- Quantum key distribution
- Multi-scale simulation technologies
- Coupled multi-physics simulations
- Embedded diagnostics
- Decision support tools
- Automated software generation
- Sensor-based processing
- Behavior prediction and anticipation
- Cognitive modeling
- Cognitive performance augmentation
- Human-machine interfaces

Dr. Werner Dahm: DDDAS … key concept in many of the objectives in Technology Horizons

Fundamental Science and Technology
Challenges for Enabling DDDAS Capabilities

• Application modeling (in the context of dynamic data inputs)
  ➢ interfacing applications with measurement systems
  ➢ dynamically invoke/select appropriate application components
    multi-modal, multi-scale – dynamically invoke multiple scales/modalities
  ➢ switching to different algorithms/components depending on streamed data
    dynamic hierarchical decomposition (computational platform - sensor) and partitioning

• Algorithms
  ➢ tolerant to perturbations of dynamic input data
  ➢ handling data uncertainties, uncertainty propagation, uncertainty quantification

• Measurements
  ➢ multiple modalities, space/time-distributed, heterogeneous data management

• Systems supporting such dynamic environments
  ➢ dynamic execution support on heterogeneous environments
    new fundamental advances in compilers (runtime-compiler)
    integrated architectural frameworks of cyberinfrastructure encompassing app-sw-hw layers
  ➢ extended spectrum of platforms (beyond traditional computational grids)
    grids of: sensor networks and computational platforms
  ➢ architect and manage heterogeneous/distributed sensor networks

DDDAS environments entail new capabilities but also new requirements and environments
... beyond GRID Computing -> SuperGrids
and... beyond the (traditional) Clouds
What makes DDDAS(*InfoSymbiotics*) TIMELY NOW MORE THAN EVER?

- **Emerging scientific and technological trends/advances**
  - *ever more complex applications – systems-of-systems* (Natural, Engineered, and Societal Systems)
  - increased emphasis in complex applications modeling (multi-scale/multi-modal modeling)
  - increased computational capabilities (*multicores*; *peta-, exa-scale*)
  - increased data volumes (*Big Data*) and increased bandwidths for streaming data, and…
  - …Sensors– Sensors EVERYWHERE… (*data intensive Wave #2*)
    - Swimming in sensors and drowning in data - LtGen Deptula (2010)
  
  **Analogous experience from the past:**
  - *“The attack of the killer micros*(*microprocessors*)” - Dr. Eugene Brooks, LLNL (early 90’s)
    - about microprocessor-based high-end parallel systems
    - then seen as a problem – have now become an opportunity for advanced capabilities
  
  **Back to the present and looking to the future:**
  - *“Ubiquitous Sensoring – the attack of the killer micros*(*sensors*) – wave # 2”
    - Dr. Frederica Darema, AFOSR (Aug 2011, LNCC)
    - *challenge*: how to deal with heterogeneity, dynamicity, large numbers of such resources
    - *opportunity*: “smarter systems” – *InfoSymbiotics DDDAS* provides methods for such capabilities

- **Need capabilities for adaptive management of such resources**
  - advances have been made, can be furthered in an accelerating way
Heterogeneity within and across Platforms
• Multiple levels of hierarchies of processing nodes, memories, interconnects, latencies

Grids: Adaptable Computing Systems Infrastructure

Fundamental Research Challenges & Needs in Applications and Systems Software
• Map the multilevel parallelism in applications to the platforms multilevel parallelism and for multi-level heterogeneity and dynamic resource availability
• New programming models and environments, new compiler/runtime technology
• Adaptively compositional software at all levels (applications/algorithms/sys-sw)
• Systematic “performance-engineering” methods – systems & their environments
Multicore-based Systems (InfoGrids) (Multicores everywhere!)

Multicores in High-End Platforms
• Multiple levels of hierarchies of processing nodes, memories, interconnects, latencies

Multicores in “measurement/data” Systems
• Instruments, Sensors, Controllers, Networks, ...

DDDAS - Integrated/Unified Application Platforms
Adaptable Computing and Data Systems Infrastructure
spanning the high-end to real-time data-acquisition & control systems
manifesting heterogeneous multilevel distributed parallelism
system architectures – software architectures

Fundamental Research Challenges in Applications- and Systems-Software
• Map the multilevel parallelism in applications to the platforms multilevel parallelism and for multi-level heterogeneity and dynamic resource availability
• Programming models and environments, new compiler/runtime technology for adaptive mapping
• Adaptively compositional software at all levels (applications/algorithms/ systems-software
• “performance-engineering” systems and their environments

SuperGrids: Dynamically Coupled Networks of Data and Computations
Dynamic Runtime Support needed for DDDAS environments

Runtime Compiling System (RCS) and Dynamic Application Composition (NSF/NGS Program)

Dynamic Analysis Situation

Launch Application (s)

Interacting with Data Systems (archival data and on-line instruments)

Dynamically Link & Execute

Distributed Computing Resources

Dynamically Link & Execute

Application Model

Application Program

Application Intermediate Representation

Dynamically Link & Execute

Distributed Programming Model

Compiler Front-End

Compiler Back-End

Application Components & Frameworks

Performance Measurements & Models

Adaptable Computing Systems Infrastructure

Distributed Platform

MPP

NOW

SP
Example of Runtime-Compiler effort I started in ~2000 (NSF/NGS Program)
Programming Heterogeneous Systems

**LLVM: Compiler Infrastructure for compile-, link-, run-time, iterative program optimization**

### Systems, Applications

- Collaboration middleware
- OS kernel
- Optional JIT Engine
- Kernel/hardware API
- Compiler back ends
- Language extensions, libraries
- High-level libs
  - Customized low-level libs
- Autotuners
- Compilers
- Vendor IP
- Device drivers
- Vendor IP
- OEMs, ISVs

### LLVM in the Real World Today

**Major companies using LLVM:** Adobe, AMD, Apple, ARM, Cray, Intel, Google, Nokia, nVidia, Qualcomm, Sony

- **MacOS X 10.7, iOS 5:** LLVM is the primary compiler on both platforms, *replacing GCC*
  
  Nearly all MacOS 10.7 application software compiled with LLVM

- **OpenCL:** *All* known commercial implementations based on LLVM
  
  AMD, Apple, ARM, Intel, nVidia, Qualcomm

- **HPC:** Cray using LLVM for Opteron back-ends, e.g., in Jaguar (ORNL)
  
  New Sandia Exascale project using LLVM as compiler system
Systems Engineering

• Methods to design, build, and manage the operation, maintenance, extensibility, and interoperability of complex systems
• in ways where the systems’ performance, fault-tolerance, adaptability, interoperability and extensibility is considered throughout this cycle.
• Such complex systems include:
  • heterogeneous and distributed sensor networks
  • large platforms & other complex instrumentation systems & collections thereof
    – need to exhibit:
      • adaptability and fault tolerance under evolving internal and external conditions
      • extensibility/interoperability with other systems in dynamic and adaptive ways
• Systems engineering requires novel methods that can:
  – model, monitor, & analyze all components of such systems
  – at multiple levels of abstraction
  – individually and composed as a system architectural framework
Systems Engineering

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Performance Models & Resource Monitoring

New Directions in Systems Engineering

Multidisciplinary Research & Technology Development
Systems Engineering

Example:

sw/hw Performance Modeling and Analysis Framework

Distributed Applications

Advanced Execution Systems

Progs. Models
Compilers
Libraries
Tools

Parallel and Distributed Operating Systems

Visualization
Collaboration Environments
Authentication
Authorization
Fault Recovery Services

Distributed Systems Management

Distributed, Heterogeneous, Dynamic, Adaptive Computing Platforms and Networks

Memory Technology
CPU Technology
Device Technology

System Modeling and Analysis

Application Models
Sys. Software Models (IO/File)
Sys. Software Models (OS scheduler)
Sys. Software Models (Nets Resources)
Hardware Models (Nets Architecture)
Hardware Models (CPU & Mem Arch)

Application Layer/Component Services
Application Support/Services Layer/Component Services
OS/Middleware Support/Services Layer/Component Services
Nets/Middleware Support/Services Layer/Component Services
CPU & Memory Support/Services Layer/Component Services
Platform/Nets Support/Services Layer/Component Services
Modeling Multiple views of the system
The Operating Systems’ view
Enabling DDDAS

Multidisciplinary Research

CS Research

Systems Software
(NGS: 1998-2004)
(CSR/AES&SMA: 2004-todate)

Dynamic Data-Driven Application Systems
-- Symbiotic Measurement&Simulation Systems

Dynamic Compilers & Application Composition

Performance Engineering

Applications Modeling & Measurements
Multidisciplinary Research
in
applications modeling
mathematical and statistical algorithms
measurement methods
dynamic, heterogeneous systems support
Some Examples of DDDAS/InfoSymbiotics Efforts

(more examples in Workshop W17/ICCS2012)
Critical Infrastructure Systems
Auto-Steered Information-Decision Processes for Electric System Asset Management

James McCalley, et al (Iowa State University)

Multi-disciplinary research and industry collaboration
- Electrical Engineering – Power Systems
- Computer Sciences – Data Integration, ML, Agents
- Statistics – Reliability, Decision
- Computer Engineering – Sensor Networks
- Aerospace Engineering – Nondestructive Evaluation
- Industrial Engineering – Stochastic Optimization

Layer 1: The power system
- Iowa/ISU Power System Model
  - Condition Histories Iowa Sub 1
  - Condition Histories Iowa Sub 2
  - Condition Histories Iowa Sub 3
  - Condition Histories ISU Sub 1
  - Condition Histories ISU Sub 2
  - Condition Histories ISU Sub 3

Layer 2: Condition sensors
- Operation policies
- Maintenance schedules
- Facility R&R plans

Layer 3: Data communication and integration
- Nameplate data
- Maintenance histories
- Condition histories

Layer 4: Data processing and transformation
- Current loading & 1-day forecast
- Short-term maintenance planning
- Probabilistic failure indices
- Long-term maintenance planning
- Stochastic maintenance & inspection model
- Long-term deterioration

Layer 5: Simulation & decision
- Time frame: Minutes - 1 week, 1 week-2 years, 1-10 years, 2-20 years
- Maintenance schedule
- Desired maintenance & inspection frequency
- Short-term facility plans
- Long-term facility plans

Sensor & communication box
- Transformer
- Power Grid
- Sensors?
- Expand?
- Maintain?
- Operate?

Equipment health
- Internet
- Fiber
- Wide Area Network

AREVA (Energy Company)

Layer 1: Long-term power system simulation
- Areva commercial grade simulator (DTS), Iowa/ISU grid

Layer 2: Sensing and communications
- One or two field installations on campus, wireless sensors

Layer 3: Data integration
- Ontology-based, query-centric, federated

Layer 4: Converting condition data into failure predictors
- Steady-state & transient failure probabilities

Layer 5: Integrated decision algorithms
- Interacting, rolling, multi-objective, stochastic optimization
- Two stage analysis for uncertainty reduction to decide new sensor measurements

Advances through the project are aimed to enable enhanced electrical power-systems management
Enable economic and efficient management of electrical power-grids, foresee and mitigate failures and widespread blackouts.
Enhance the nation’s electrical energy distribution health and preparedness in cases of natural and man-made disasters
Threat management in WDSs involves real-time characterization of any contaminant source and plume, design of control strategies, and design of incremental data sampling schedules. Requires dynamic integration of time-varying measurements along with analytical modules that include simulation models (evolutionary algorithms), adaptive sampling procedures, and optimization methods. A live demonstration of this preliminary cyberinfrastructure using Suragrid resources was carried out at the Internet2 meeting in Chicago in December 2006.
Delay in surface transportation systems today cost tens of billions of dollars annually in the U.S. in lost productivity, wasted fuel, and pollution. In times of crisis, delays can result in lost lives.

The project developing novel ad hoc distributed simulations that feature dynamic collections of autonomous in-vehicle simulations interacting with each other and real-time data in a continuously running distributed simulation environment. Each simulator models some portion of the transportation network, and exchange data with other simulators through a mobile, wireless network to predict future states of the overall system.

Ad hoc distributed simulations combine elements of conventional distributed simulations and replicated simulation runs, together with dynamic and continuous monitoring. Incorporating dynamically monitoring data poses challenges of data distribution and synchronization; a synchronization protocol based on rollback mechanisms has been designed for use in these systems.
Three Layer Architecture

- Data Source and Measurement
- Detection, Simulation, and Prediction
- Decision Support System (DSS)
Emergency Response Systems
MIPS:
A Real-Time Measurement-Inversion-Prediction-Steering Framework
for Hazardous Events

Slide Courtesy O. Ghattas (UT Austin)
Objective:
Development of methodology for achieving real time detection and prediction of Chemo/Bio-contaminant dispersion under various weather conditions, enabling the protection of warfighters and civilians in urban or industrial environments.

Benefit to warfighter: Information superiority, C4IR integration, rapid and accurate assessment of COP and CBRN, and automated decision support.
Forrest Fire Modeling

- Sensible and latent heat fluxes from ground and canopy fire -> heat fluxes in the atmospheric model.

- Fire’s heat fluxes are absorbed by air over a specified extinction depth.

- 56% fuel mass -> H₂O vapor

- 3% of sensible heat used to dry ground fuel.

- Ground heat flux used to dry and ignite the canopy.

Kirk Complex Fire. U.S.F.S. photo

Coen/NCAR; Jan Mandel, Craig Douglas, Tony Vodacek, et al
Dynamic Data Driven Application System: Wildfire Modeling

Weather model

Fire model

Dynamic Data Assimilation

Visualization

Weather data

Map sources (GIS)

Aerial photos, fuel

Sensors, telemetry

Communication

Supercomputing

Software engineering

Jan Mandel and Team
Measured Response (A Homeland Security Simulation)
Synthetic Environments for Analysis and Simulation (SEAS)

Shared Reality Engine

Alok Chaturvedi, Director
Shailendra Mehta, co-Director
Purdue Homeland Security Institute
Interaction between Fire, Structure, Agent-Based Models

Network of sensors coupled with computational network for fire modeling

Network of sensors coupled with computational network for structural analysis

Purdue University Projects
PI: Alok Chaturvedi and Team
PI: Ahmed Sameh and Team
Micro-future Simulation of Submarine Room fuel-leak fire

Location aware mobile or static distributed sensor network

Before Door Opening

After Door Opening

Red surface: 25 C
Green Surface: 55 C
DDEMA: Fire-Fighting Scenario (enclosed and ambient environments)

The Grid

Building with temperature sensors

Handheld device

Base Station

Fire-fighter

Streaming data

Results

Data

Install

Query

Results

Query

Results
Real-Time Support for supersonic/hypersonic multiphysics simulation-based platform management (Flutter, Temperature & Softening of Skin Material Degredation, ...)

Simulation Environment

1. Sensor Data Handler
2. Basis Solutions Database
3. Computational Model
4. Solution Composer
5. Computational Model/Behavior
6. Visualization Model/Behavior
7. Solution Composer
8. Visualization Model/Behavior
9. User Interface

Physical system

Simulated system

Slides Courtesy C. Farhat
Damping Coefficient (%) -- 1st Torsion

Mach Number

Flight Test
ROM
FOM
(1998 - ... precursor Next Generation Software Program)
SystemsSoftware - Runtime Compiler - Dynamic Composition - Performance Engineering

(2000 - Through NGS/ITR Program)
Pugali. Adaptive Software for Field-Driven Simulations

(2001 - Through ITR Program)
Biegler - Real-Time Optimization for Data Assimilation and Control of Large Scale Dynamic Simulations
Car - Novel Scalable Simulation Techniques for Chemistry, Materials Science and Biology
Knight - Data Driven design Optimization in Engineering Using Concurrent Integrated Experiment and Simulation
Lonsdale - The Low Frequency Array (LOFAR) - A Digital Radio Telescope
McLaughlin - An Ensemble Approach for Data Assimilation in the Earth Sciences
Patrikolakis - Poseidon - Rapid Real-Time Interdisciplinary Ocean Forecasting: Adaptive Sampling and Adaptive Modeling in a Distributed Environment
Pierrehumbert - Flexible Environments for Grand-Challenge Climate Simulation
Wheeler - Data Intense Challenge: The Instrumented Oil Field of the Future

(2002 - Through ITR Program)
Carmichael - Development of a general Computational Framework for the Optimal Integration of Atmospheric Chemical Transport Models and Measurements Using Adjoints
Douglas-Ewing - Predictive Contaminant Tracking Using Dynamic Data Driven Application Simulation (DDDAS) Techniques
Evans - A Framework for Environment-Aware Massively Distributed Computing
Farhat - A Data Driven Environment for Multi-physics Applications
Gulbis - Representations and Algorithms for Deformable Objects
Oden - Computational Infrastructure for Reliable Computer Simulations
Treflass - A Real Time Mining of Integrated Weather Data

(2003 - Through ITR Program)
Boden - Asynchronous Execution for Scalable Simulation in Cell Physiology
Chaturvedi - Synthetic Environment for Continuous Experimentation (Grisam Applications)
Dregermeier - Linked Environments for Atmospheric Discovery (LEAD)
Kumar - Data Mining and Exploration Middleware for Grid and Distributed Computing
Machinisp - A Framework for Discovery, Exploration and Analysis of Evolutionary Data (DEAS)
Mandel - DDDAS: Data Dynamic Simulation for Disaster Management (Fire Propagation)
Metaxas - Stochastic Multicue Tracking of Objects with Many Degrees of Freedom
Sameh - Building Structural Integrity (Sensors Program: Seltzer - Hourglass: An Infrastructure for Sensor Networks)

(2004 - Through ITR Program)
Brogan - Simulation Transformation for Dynamic, Data-Driven Application Systems (DDDAS)
Ballal - A Novel Grid Architecture Integrating Real-Time Data and Intervention During Image Guided Therapy
Bledag - In Silico De Novo Protein Design: A Dynamically Data Driven, (DDDAS), Computational and Experimental Framework
Grimeshow - Dependable Grids
Leal - Computational simulation, modeling, and visualization for understanding unsteady bioflows
Metaxas - DDDAS - Advances in recognition and interpretation of human motion: An Integrated Approach to ASL Recognition
Wheeler - Data Driven Simulation of the Subsurface: Optimization and Uncertainty Estimation

(2005 DDDAS Multi-Agency Program - NSF/NIH/NOAA/AFOSR)
Shottles - MPS: A Real-Time Measurement-Inversion-Prediction-Steering Framework for Hazardous Events
How - Coordinated Control of Multiple Mobile Observing Platforms for Weather Forecast Improvement
Bernstein - Targeted Data Assimilation for Disturbance-Driven Systems: Space weather Forecasting
McLaughlin - Data Assimilation by Field Alignment
Leiseron - Planet-in-a-Bottle: A Numerical Fluid-Laboratory
Chryssostomidis - Multiscale Data-Driven POD-Based Prediction of the Ocean
Ntimo - Dynamic Data Driven Integrated Simulation and Stochastic Optimization for Wildland Fire Containment
Allen - DynaCode: A General DDDAS Framework with Coast and Environment Modeling Applications
Douglas - Adaptive Data-Driven Sensor Configuration, Modeling, and Deployment for Oil Chemical, and Biological Contamination near Coastal Facilities
Clark - Dynamic Sensor Networks - Enabling the Measurement, Modeling, and Prediction of Biophysical Change in a Landscape
Golubchik - A Generic Multi-scale Modeling Framework for Reactive Observing Systems
Williams - Real-Time Astronomy with a Rapid-Response Telescope Grid
Gilbert - Optimizing Signal and Image Processing in a Dynamic, Data-Driven Application System
Liang - SEP: Integrating Multipath Measurements with Site Specific RF Propagation Simulations
Chen - SEP: Optimal interlaced distributed control and distributed measurement with networked mobile actuators and sensors
Oden - Dynamic Data-Driven System for Laser Treatment of Cancer
Babbitt - Development of a closed-loop identification machine for biomarkers (CIMM) and its application to nucleotide metabolism
Fortes - Dynamic Data-Driven Brain-Machine Interfaces
McCabe - Auto-Steered Information-Decision Processes for Electric System Asset Management
Down - Autonomous Interconnected Systems: The National Energy Infrastructure
Sauer - Data-Driven Power System Operations
Ball - Dynamic Real-Time Order Promising and Fulfillment for Global Make-to-Order Supply Chains
Thiele - Robustness and Performance in Data-Driven Revenue Management
San - Dynamically-Integrated Production Planning and Operational Control for the Distributed Enterprise

* . . .

* projects, funded through other sources and "retargeted by the researchers to incorporate DDDAS"

* ICCS/DDDAS Workshop Series, yearly 2003 - todate
  * other workshops organized by the community...


* www.dddas.org (maintained by Prof. Craig Douglas)
Where we are … & QUO VADIMUS

• DDDAS/InfoSymbiotics
  – high pay-off in terms of new capabilities
  – need fundamental and novel advances in several disciplines
  – well-articulated and well-structured research agenda from the outset

• Progress has been made – it’s a “multiple S-curves” process
  – experience/advances cumulative - accelerating pace of progress in the future
  – we have started to climb the upwards slope of each of these S-curves
  – need of sustained, concerted, synergistic support
  – timely, now more than ever – multicores, ubiquitous sensoring, BigData, …


• New projects launched through AFOSR BAA – www.afosr.af.mil
Multi-Agency Interest

- **DDDAS/InfoSymbiotics Multi-agency Workshop (August 2010)**
  - AFSOR – NSF co-sponsored
  - Report posted at [www.dddas.org](http://www.dddas.org) (academic community website)

**Cross-Agencies Committee**

**DOD/AFOSR:**
- F. Darema
- R. Bonneau
- F. Fahroo
- K. Reinhardt
- D. Stargel

**DOD/ONR:**
- Ralph Wachter

**DOD/ARL/CIS:**
- Ananthram Swami

**DOD/DTRA:**
- Kiki Ikossi

**NASA:**
- Michael Seablom

**NSF:**
- H. E. Seidel (MPS)
- J. Cherniavsky (EHR)
- T. Henderson (CISE)
- L. Jameson (MPS)
- G. Maracas (ENG)
- G. Allen (OCI)

**NIH:**
- Milt Corn (NLM), Peter Lyster (NIGMS)
Report Outline

Executive Summary
1. Introduction - InfoSymbiotics/DDDAS Systems
2. InfoSymbioticSystems/DDDAS Multidisciplinary Research
3. Timeliness for Fostering InfoSymbiotics/DDDAS Research
   3.1 Scale/Complexity of Natural, Engineered and Societal Systems
   3.2 Applications’ Modeling and Algorithmic Advances
   3.3 Ubiquitous Sensors
   3.4 Transformational Computational and Networking Capabilities
4. InfoSymbiotics/DDDAS and National/International Challenges
5. Science and Technology Challenges discussed in the Workshop
   5.1 Algorithms, Uncertainty Quantification, Multiscale Modeling
   5.2 Large, Complex, and Streaming Data
   5.3 Autonomic Runtime Support in InfoSymbiotics/DDDAS
   5.4 InfoSymbioticSystems/DDDAS CyberInfrastructure Testbeds
   5.5 InfoSymbioticSystems/DDDAS CyberInfrastructure Software Frameworks
6. Learning and Workforce Development
7. Multi-Sector, Multi-Agency Co-operation
8. Summary

Appendices
   Appendix-0 Workshop Agenda
   Appendix-1 Plenary Speakers Bios
   Appendix-2 List of Registered Participants
   Appendix-3 Working Groups Charges
Some recently funded AFOSR DDDAS projects … from the nano-scale to the “Terra”-scale

- Development of a Stochastic Dynamic Data-Driven System for Prediction of Materials Damage
- Dynamic Data-Driven Modeling of Uncertainties and 3D Effects of Porous Shape Memory Alloys
- DDDAS: Computational Steering of Large-Scale Structural Systems Through Advanced Simulation, Optimization, and Structural Health Monitoring
- Dynamic Data Driven Methods for Self-aware Aerospace Vehicles
- Bayesian Computational Sensor Networks for Aircraft Structural Health Monitoring
- DDDAS for Object Tracking in Complex and Dynamic Environments (DOTCODE)
- Dynamic Data Driven Machine Perception and Learning for Border Control
- Dynamic Predictive Simulations of Agent Swarms
- Fluid SLAM and the Robotic Reconstruction of Localized Atmospheric Phenomena
- Energy-Aware Aerial Systems for Persistent Sampling and Surveillance
- DDDAMS-based Urban Surveillance and Crowd Control via UAVs and UGVs
- A Framework for Quantifying and Reducing Uncertainty in InfoSymbiotic Systems Arising in Atmospheric Environments
- Application of DDDAS Ideas to the Computation of Volcanic Plume Transport
- Transformative Advances in DDDAS with Application to Space Weather Monitoring
- An Adaptive Property-Aware HW/SW Framework for DDDAS
- Active Data: Enabling Data-Driven Knowledge Discovery through Computational Reflection
- Adaptive Steam Mining: A Novel Dynamic Computing Paradigm for Knowledge Extraction
- DDDAS-based Resilient Cyberspace (DRCS)
- PREDICT: Privacy and Security Enhancing Dynamic Information Monitoring with Feedback Guidance

In the future expect to explore other AF important areas e.g. energy efficiency, combustion, …
Some recently funded AFOSR DDDAS projects
… from the nano-scale to the "Terra"-scale

• Development of a Stochastic Dynamic Data-Driven System for Prediction of Materials Damage
• Dynamic Data-Driven Modeling of Uncertainties and 3D Effects of Porous Shape Memory Alloys
• DDDAS: Computational Steering of Large-Scale Structural Systems Through Advanced Simulation, Optimization, and Structural Health Monitoring
• Dynamic Data Driven Methods for Self-aware Aerospace Vehicles
• Bayesian Computational Sensor Networks for Aircraft Structural Health Monitoring
• DDDAS for Object Tracking in Complex and Dynamic Environments (DOTCODE)
• Dynamic Data Driven Machine Perception and Learning for Border Control
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• DDDAS-based Resilient Cyberspace (CRCS)
• PREDICT: Privacy and Security Enhancing Dynamic Information Monitoring with Feedback Guidance

In the future expect to explore other AF important areas e.g. energy efficiency, combustion, …
• Understanding, architecting, building, managing, exploiting complex networks
• Foundational properties and unifying principles across classes of networks
  – biological, networks in materials & other physical systems, infrastructure systems, computer and other engineered networks, animal, and human networks
  – Examples of such networks: neural networks in the brain, neuronal pathways in living systems, ..., networks in collections of biological organisms, ecological systems; systems of molecules, granular systems and grain boundaries in solids, porous media networks in materials, ...; engineered and critical infrastructure networks - communication networks, electrical power-grids, water-distribution grids, transportation grids, ..., operations and components involved in production planning in manufacturing systems and plants; human social and business networks, ...
• Seemingly diverse networking systems
  – differ in their realization infrastructure and their function and behaviors
  – but also exhibit behaviors and patterns that are common among such systems
  – dynamic, interactive, mutually interdependent, self-organizing, self-configuring, self-healing; neither closed nor static; exhibit heterogeneity & dynamicity;
  – are not isolated systems, may be interrelated with other classes of networks, and in a hierarchical, multi-scale, multi-level, or multi-modal fashion
• Is there a universality, complementarity, uncertainty principle for networks?
• Design/performance tradeoffs in engineered systems
  – Exploit or discover new properties in networks through understanding of characteristics and behaviors observed in other classes of networks
Understanding the Brain and the Mind (from cellular networks ... to human networks)

• Neural and Brain models, processes and functions
  – architecture/macroscopic models, neural pathways, chemical mechanisms, ...

• Neural, perceptual, learning and decision processes
  – organization, categorization, classification, aggregation, ...

• Connection of brain processing with sensory systems and their actions
  – memory, vision, auditory, olfactory, speech, ..., eco-location, ...

• Cognition, inference, reasoning, decision making
  – learning processes and algorithms, planning/control, reinforced learning, ...

• Human (individual and collective) behavior – Socio-Cultural dynamics
  – alertness, learning, deception, influence, competition, collaboration, ...

• Enhancing Human ability
  – human-machine interaction, individual capabilities, humans in extremes

• Enhancing Engineered Systems
  – new computer architectures/algorithms/software, engineered sensory systems, ...
Transformative Partnerships between Academe and Industry/Business

What will drive these U-I/B partnerships?
Address and Solve Hard Problems, that
Industry alone cannot do
Universities alone cannot do

Methods and Tools to enable Advanced Research in Academe
Methods and Tools for New Capabilities for Industry

Combine broad expertise in Academe
With Industry/Business know-how for building robust systems(prototypes)

Examples: CyberInfrastructures for Complex Applications Systems
(Need comprehensive systems frameworks – not just system components)

Models exist for long-term viability of such partnerships in self-sustaining ways
(and where government funding contribution becomes minimized)

New Capabilities - New Directions through Advanced CyberInfrastructures (★)
“Innovation through CyberInfrastructure Excellence” (ICIE) (★)

(★) Darema, Report on: Industrial Partnerships in Cyberinfrastructure, October 2009
New discoveries and research and technology advances at the interface and confluence of multiple science and engineering areas through multidisciplinary approaches and multidisciplinary efforts

Computer Sciences and Information Technologies have become key for advances in any other Scientific, Engineering, Societal fields

Transformative Innovations through University-Industry/Business partnerships catalyzed by Government

International component is important!
New discoveries and research and technology advances at the interface and confluence of multiple science and engineering areas through multidisciplinary approaches and multidisciplinary efforts have led to transformative innovations.

Computer and Information Technologies have become key for advances in any other scientific, engineering, societal field. New opportunities and new capabilities are being created through University-Industry/Business partnerships catalyzed by Government.

The international component is important!

Unification – High-End to RT/DA&Control

Systems Engineering

Network Science

InfoSymbiotics/DDDAS

Understanding the Brain and the Mind
Back-up slides