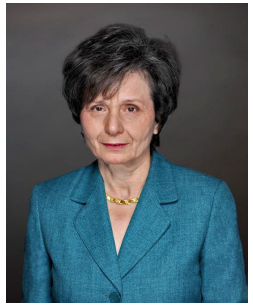
InfoSymbiotics/DDDAS
for Systems-Analytics and Autonomic Capabilities

DDDAS2022 Conference

October 6-10, 2022



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DDDAS - enabling New Capabilities and addressing Challenges

- For systems of today and more so in future, there is a confluence of needs and technological advances:
  - Increasingly we deal with systems-of-systems & systems/environments that are
    complex | heterogeneous | multimodal | multiscale | dynamic
- Need to understand characteristics/behaviors: design - operation – evolution – interoperability – maintenance - *lifecycle*
- Support end-to-end/Systems-of-Systems adaptive coordination of multiple, heterogeneous, dynamic resources
- Need cognizant decision-making - situational awareness and real-time decision-support
- Ad-hoc methods are not enough – need (*comprehensive*) modeling not only for design but the entire life-cycle

Data alone is not enough

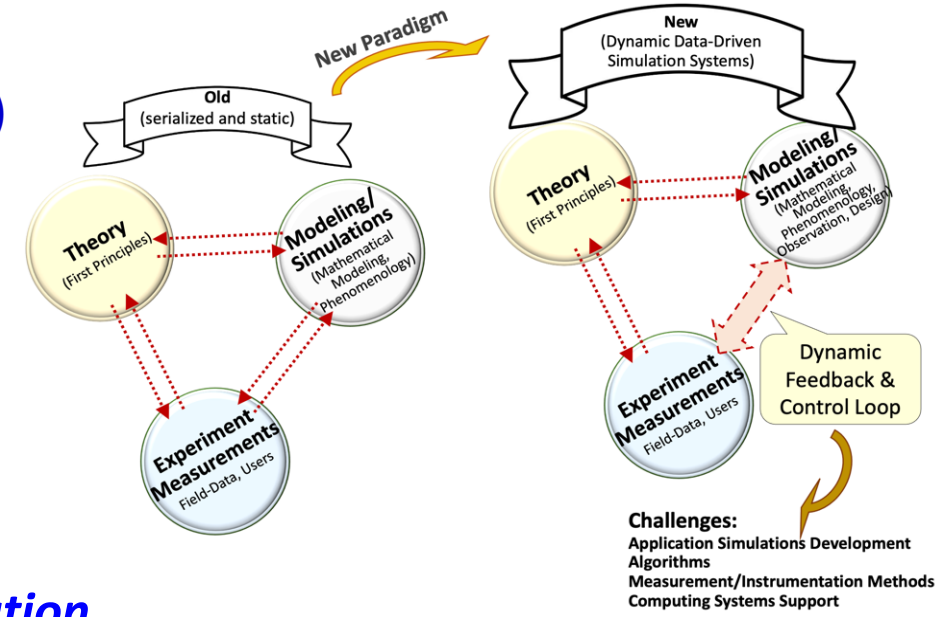
Data is not the 4th paradigm… - Data is the primordial paradigm

Data Analytics is not enough - We need Systems Analytics

ML alone is not enough - *we need "context-driven" approaches, not only "data fitting"*

-> …. Models ∮ Data ….

DDDAS – *Dynamic Data Driven Applications Systems (InfoSymbiotic Systems)*



Enabling/Exploiting new S&T directions

- DDDAS/InfoSymbiotics – Dynamic Data Driven Applications Systems (www.1dddas.org)
  - *an effective methodology for advanced capabilities in a wide range of applications areas & infrastructures*
- Timely confluence:
  - High-end computing with the real-time, Edge computing and IoT
  - 5G & B5G – supporting DDDAS-based applications;
  - 5G & B5G infrastructures optimized design and operation - enabled by DDDAS
- Autonomy – AI/ML and DDDAS
- Ubiquitous Instrumentation - Test&Evaluation (T&E becomes part of the system's lifecycle)

Landscape: applications/systems-of-systems

and powerful/ubiquitous computing/interconnects/instrumentation

AI - ML – Automation – Autonomy - DDDAS

- AI (What is and what are its methods)
  - machines with human-like intelligence that can learn, reason, plan, perceive, and/or process natural language
  - Narrow-AI; general-AI; super-AI; AI completely without human-in-the-loop not in the foreseeable future
  - AI far from what human-brain can accomplish <-> human brain lacks ability of number-processing by computers
  - Achieve AI by synergistic exploitation of "complementary capabilities" of the "human brain" & the "computer brain"
- ML (Machine-Learning) models/algorithms
  - parameter fitting method – "learns" by updating its parameters with "additional" data -> generates "new algorithm/model"
  - Issues/Shortcomings (the ML-model/algorithm may not be fully understood as it evolves - "can go rogue"):
    - issue of "transparency" – not well understood how does the MLmodel changes itself based on new training data
    - issue of "interpretability" - not understood how accurately/adequately the changed MLmodel represents the system
    - quality/appropriateness of the (training) data – skewed data - (adverse) data bias
    - safety and security implications due to such pitfalls
- Learning Model in DDDAS
  - DDDAS also includes the notion of a "Learning Model"
    - incorporating dynamically selected data into an executing model &executing model controls instrumentation
    - but the DDDAS-learning model embodies the conceptual aspects (e.g., the physics) of the system it represents
    - thus the DDDAS-based learning is safeguarded from going rogue
  - Concomitant benefits of DDDAS-based approaches:
    - DDDAS-based methods enable real-time decision-support with the accuracy of full-scale modeling
    - such methods being comprehensive/cognizant of systems they represent – they are key for autonomy
- Overcome Challenges encountered with ML - avoid ML-based algorithm/model going "rogue"
  - devise "safety bounds"; one way would be to make Test&Evaluation part of the lifecycle of the ML model
  - In DDDAS, ML has been used as tool together with DDDAS-based models (e.g., aerospace applications)

Examples of Areas of DDDAS Impact

from the nano-scale, to the tera-scale, to the extraterra-scale

- Materials – Fundaments & Design
- Structural Health Monitoring
- Advanced Manufacturing
- Medical & NeurobioInfomatics
- Smart Civil Infrastructures
  - Transportation
  - Power-grids
  - Water Distribution
- Smart Cities
- Ecological Systems
- Smart Agriculture
- Atmospheric Weather
- Adverse events / Environmental Disasters
  - Hurricanes
  - Tornadoes
  - Floods
  - Earthquakes
  - Wildfires
  - Oil Spills
- Space Weather
- Land, Air, Space
- Emergency Response
- CyberSecurity
- Resource Planning
- Supply-Chain Logistics
- Social Systems Analytics
- Financial Systems
- Model-based Real-time Decision Support
- 5G and Beyond5G, and more ...

->*Autonomic Systems*

Figure from AFOSR-NSF 2010 Report
Research Work(Projects) supported 2000 - present

This Conference covers:

Aerospace Systems; Space Systems; Network Systems;
Distributed Computational Systems and Energy Grids;
Systems Support Methods; Deep Learning Methods;
Tracking and Security Methods
Healthcare
&
Environmental areas:
Wildfires Panel
Earth, Planets, Climate and Life Workshop

DDDAS/InfoSymbiotics drives:

- **Foundational methods**
- Filtering, Estimation,
- Machine Learning
- Uncertainty Quantification(gPC, PCQ)
- **Applications approaches**
- systems-of-systems
- representation models
- network control
- sensor management

DDDAS has influenced extensions:

- Data Assimilation
- Digital Twin (-> Dynamic Digital Twin)

Recent/emerging ML algorithms apply &/or adopt the essence of DDDAS

- Informative Sensing, Estimation, Planning
- Targeted Observation, Active Learning
- Reinforcement Learning RelevanceFeedback
- Stochastic Modeling, Feature Selection
- Recommender Systems, etc

Other initiatives, such as:
Cyber-physical Systems (NSF 2006)
can benefit from the more comprehensive approaches of the DDDAS paradigm

www.1dddas.org & Springer DDDAS Book Series