IBM Research

Cyber-Physical-*Business* Systems: A Possible Framework

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Smart Grids as Cyber-Physical-Business Systems

- Intelligent Utility Networks (IUN) are about optimization …
  - of physical asset life-cycle management
  - of capital investment
  - of grid performance – asset utilization, demand mgt, reliability, …
  - of energy resources – carbon intensity, renewables integration, …
- IUN's must be viewed as extremely large-scale, distributed control systems
  - Because of the transient nature of the commodity the manage, they present challenges not found in many other industry segments
  - Complex system theory, high-performance computing, and many other information technology domains will all have a significant role to play
- Cyber-Physical-Business Systems must be designed for ***interoperability*** in the context of business *and* regulatory processes
  - Solutions must bridge the operational, business, and regulatory domains
  - There are real technical challenges in linking the time-dependent cyber-physical *operations domain* with the more transactional *business and regulatory domains*
- In most solution areas, cyber-physical-business systems will need to integrate highly heterogeneous environments
  - Large capital infrastructures turn over very slowly, so we must address that heterogeneity as a primary design requirement, to support evolution of the infrastructures over appropriate timeframes

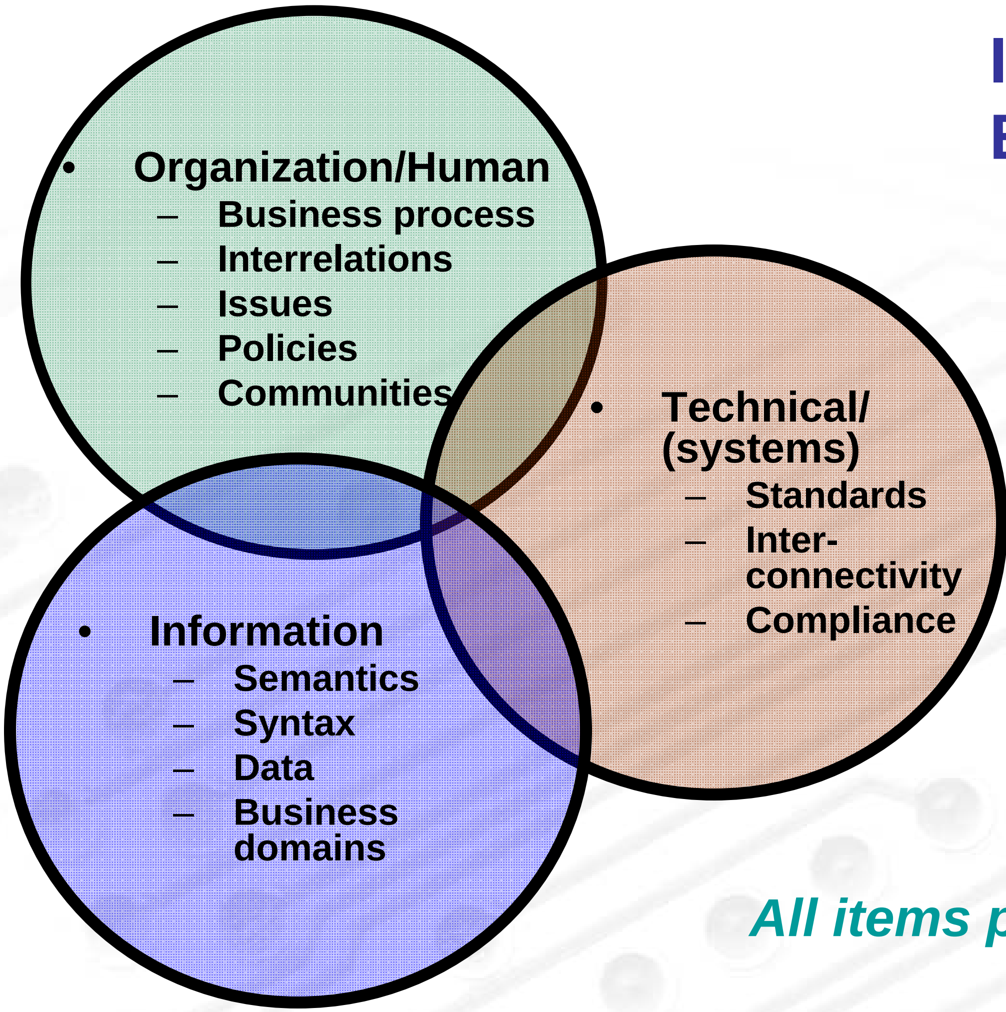
GridWise

"Bringing the Electricity System into the Information Age"

- Multiple, related government and industry activities
  - DoE GridWise Initiative
    - Under Office of Electricity Delivery and Energy Reliability (OE)
  - DoE GridWise Architecture Council (GWAC)
    - 13 member DoE advisory panel of experts from various industry segments
  - GridWise Alliance industry consortium (GWA)
    - IBM was a charter member and currently holds Chairman of the Board seat
    - Over 60 members as of 1Q2008

- In December 2007, the Architecture Council and the Alliance signed a Memo of Understanding to formalize the collaboration that was already taking place

GWAC focus is on Interoperability



Interoperable Software - Expected Impact:

- **Reduces integration cost**
- **Reduces cost to operate**
- **Reduces capital IT cost**
- **Reduces installation cost**
- **Reduces upgrade cost**
- **Better security management**
- **More choice in products**
- **More price points & features**

All items provide compounding benefits

Interoperability – Integration at Arm's Length

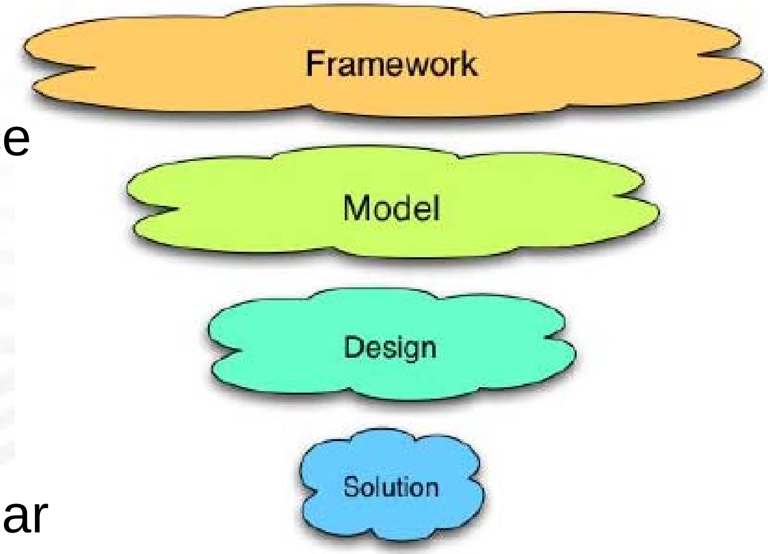
- Exchange of actionable information
  - between two or more systems
  - across organizational boundaries
- Shared meaning of the exchanged information
- Agreed expectation with consequences for the response to the information exchange
- Requisite quality of service in information exchange
  - reliability, fidelity, security

An Interoperability Framework

- Organizing concepts
  - Taxonomy, definitions, levels, tenets
- Attempts to simplify the complex
  - *Warning – it's still complex*
- Aids communication between community members
  - *Careful – semantics remain a stumbling block*
- Provides perspective from selected viewpoints
- Reveals points where agreement simplifies integration
- Focuses on plight of integrator, not component developer
- EISA 2007 calls on NIST to define an Interoperability Framework
  - Directed to work with the GridWise Architecture Council among others

What do we mean by "Framework"?

- *Framework* organizes concepts and provides context for discussion of detailed technical aspects of interoperability
- *Model* identifies a particular problem space and defines a technology independent analysis of requirements
- *Design* maps model requirements into a particular family of solutions
  - Uses standards and technical approaches
- *Solution* manifests a design into a particular developer software technology
  - Ensures adherence to designs, models, and frameworks.



Borrowed from NEHTA: Australian National E-Health Transition Authority

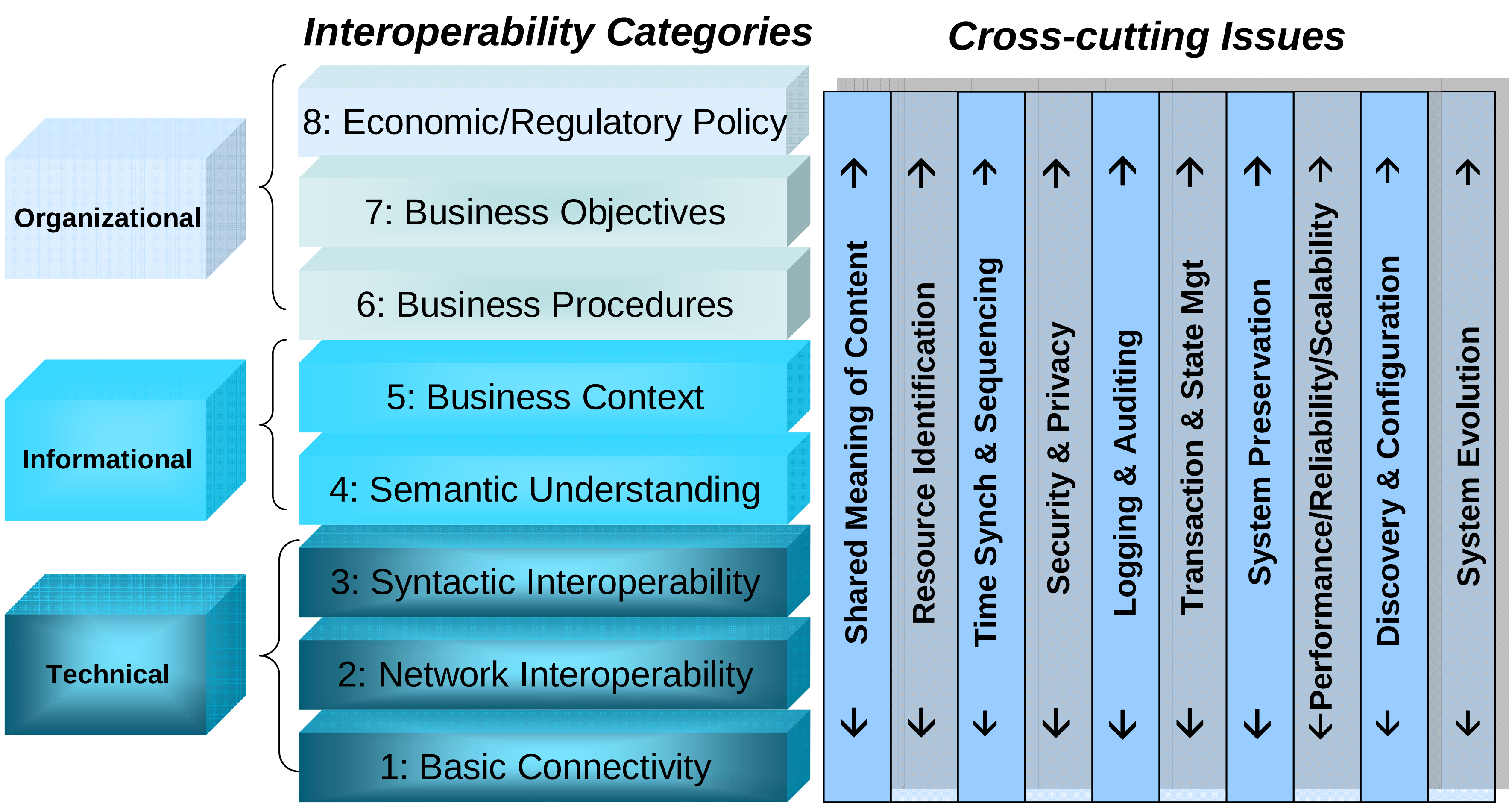
System Integration Philosophy

- Agreement at the interface
  - Create an interaction contract
  - Terms and conditions, consequences for failure to perform…
- Boundary of authority
  - Respect privacy of internal aspects on either side of the interface (technology choice and processes)
- Decision making in very large networks
  - Decentralized/autonomous decision-making
  - Multi-agent v. hierarchical approach
  - Addresses scalability, evolutionary change, eases integration
- Role of standards in the framework
  - Encourages standards for improving interoperation
  - Agnostic to specific standards and technologies

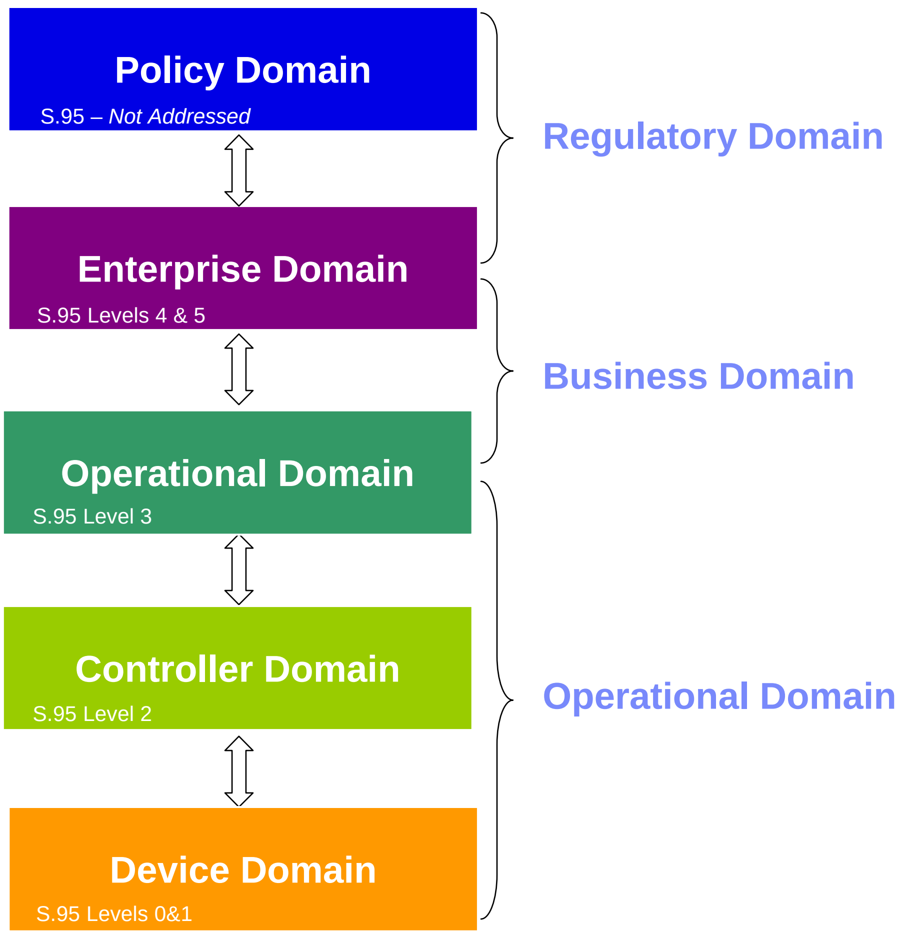
Interoperability Categories

Category	Layer	Description
Organizational (pragmatic)	8: Economic/Regulatory Policy	Political and Economic Objectives as Embodied in Policy and Regulation
	7: Business Objectives	Strategic and Tactical Objectives Shared between Businesses
	6: Business Procedures	Alignment between Operational Business Processes and Procedures
Informational (symantic)	5: Business Context	Awareness of the Business Knowledge Related to a Specific Interaction
	4: Semantic Understanding	Understanding of the Concepts Contained in the Message Data Structures
Technical (syntactic)	3: Syntactic Interoperability	Understanding of Data Structure in Messages Exchanged between Systems
	2: Network Interoperability	Mechanism to Exchange Messages between Multiple Systems across a Variety of Networks
	1: Basic Connectivity	Mechanism to Establish Physical and Logical Connections between Systems

Framework Areas of Investigation



Multiple Domains of Integration



- *Policy Domain*
  - National and local legislative constructs within which cyber-physical-business systems operate
- *Enterprise Domain*
  - Markets, customer accounts, billing, work and asset management, etc.
- *Operational Domain*
  - Bridges the device and business worlds – understands the relationship between them (e.g., can create market bids based on HVAC state, home-owner goals, and market conditions)
- *Controller Domain*
  - Implements goals of the owner based on control settings; is influenced by the higher-levels in the system (e.g., the market prices)
- *Device Domain*
  - Sensor and actuator space; physical world interface – HVAC, Water Heater, Revenue Meter, etc.

Internet-scale Control Systems (iCS) project at IBM Research

prototype implementation of an event-based integration framework

- Model, at both the design and programming levels, the operational, business, and regulatory domain components of cyber-physical-business system solutions as control elements
  - *Sensing: Information collection, data acquisition*
  - *Controlling: Information/data analysis and decision making*
  - *Actuating: Action/command output and execution*

- Apply loosely-coupled distributed computing technology and event-based programming models to the challenge of integration across the domains: *runtime middleware/services, event-based signaling, declarative programming, component/service oriented design, etc.*

- Address the issues arising from that integration related to the critical requirements of the operational domain: time-sensitive behavior, secure-signaling, resilient communication
  - Part of our broader Event and Stream Computing Strategy in the area of Cyber-Physical-Business Systems

Guiding Architectural Principles of iCS

- Two communities of developers being supported:
  - Object/device/service developers (“building the widgets”)
  - Solution builders/integrators (“composing the widgets into solutions”)
- Maintain separation of:
  - Solution object abstraction from solution object implementation
  - Logical solution topology from physical device/network topology
- *Treat time as a fundamental primitive in the programming model*
- Must be designed for relatively small footprint systems
  - Easy to scale up – hard to scale down
- Enable higher-level abstraction and integration of Operational Domain systems and components through encapsulation
  - *Accommodate heterogeneity rather than eliminate it*
  - Minimize impact on existing Operational Domain systems and skills

Conclusion

- *Interoperability* is an important organizing and design theme for Cyber-Physical-Business Systems
  - EISA 2007 directive to define and Interoperability Framework
- Heterogeneity is here to stay – we must design for it to be successful
  - We are pulling together very diverse systems in multiple domains that weren't designed to interoperate originally
  - Even when standards exist, they can evolve at a different rate than the deployment of those standards, so we'll always be faced with integration of heterogeneous components
- Within the Smart Grid space, the DoE GridWise Architecture Council is working with all parts of the *eco-system* (commercial, academic, and policy) to foster a common organizational framework for interoperability (www.gridwiseac.org, www.grid-interop.com)
- At IBM we are using event-based programming frameworks to extend traditional Service Oriented Architecture business systems to enable Cyber-Physical-Business Systems in many industry solutions – this has grown out of our Smart Grid (a.k.a IUN) work