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

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
- 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

Technical (syntactic)
Framework Areas of Investigation

**Interoperability Categories**

- 1: Basic Connectivity
- 2: Network Interoperability
- 3: Syntactic Interoperability
- 4: Semantic Understanding
- 5: Business Context
- 6: Business Procedures
- 7: Business Objectives
- 8: Economic/Regulatory Policy

**Cross-cutting Issues**

- Shared Meaning of Content
- Resource Identification
- Time Synch & Sequencing
- Security & Privacy
- Logging & Auditing
- Transaction & State Mgt
- System Preservation
- Performance/Reliability/Scalability
- Discovery & Configuration
- System Evolution
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, homeowner 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](http://www.gridwiseac.org), [www.grid-interop.com](http://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