Grid-Interop™

January 9, 2013 Presentation to INCOSE

Identifying Architectural Modularity in the Smart Grid

An Application of the Design Structure Matrix Methodology

Architecture Track – Innovative Architectural Models Session

Brad Rogers (Session Chair)
& Erik Gilbert
Navigant Consulting
www.navigant.com

NAVIGANT

#GridInterop

What is Smart Grid?

Simple Answer:

An **umbrella term** for the enhancement of the traditional electricity infrastructure that uses computer technology and **two-way digital communications** networking to improve and expand the capabilities of the grid.

Why a Smart Grid?

Smart grid promises to transform the electric industry yielding many benefits, such as:

- A more stable and **reliable** electric supply
- Increased utilization of the immense investment in our electric infrastructure
- Increased capability to integrate **renewable** resources
- More **customer choice** and improved cost structures

This isn't incremental change.

- But smart grid is currently a vision that can only be realized if the diverse elements of the grid can work together as a **system**.

- **Interoperability** is the lynchpin of smart grid success.

  Interoperability refers to the ability of diverse systems and organizations to work together (inter-operate). In the context of the electric system, interoperability refers to the seamless, end-to-end connectivity of hardware and software from end-use devices through the T&D system to the power source, enhancing the coordination of energy flows with real-time information and analysis.

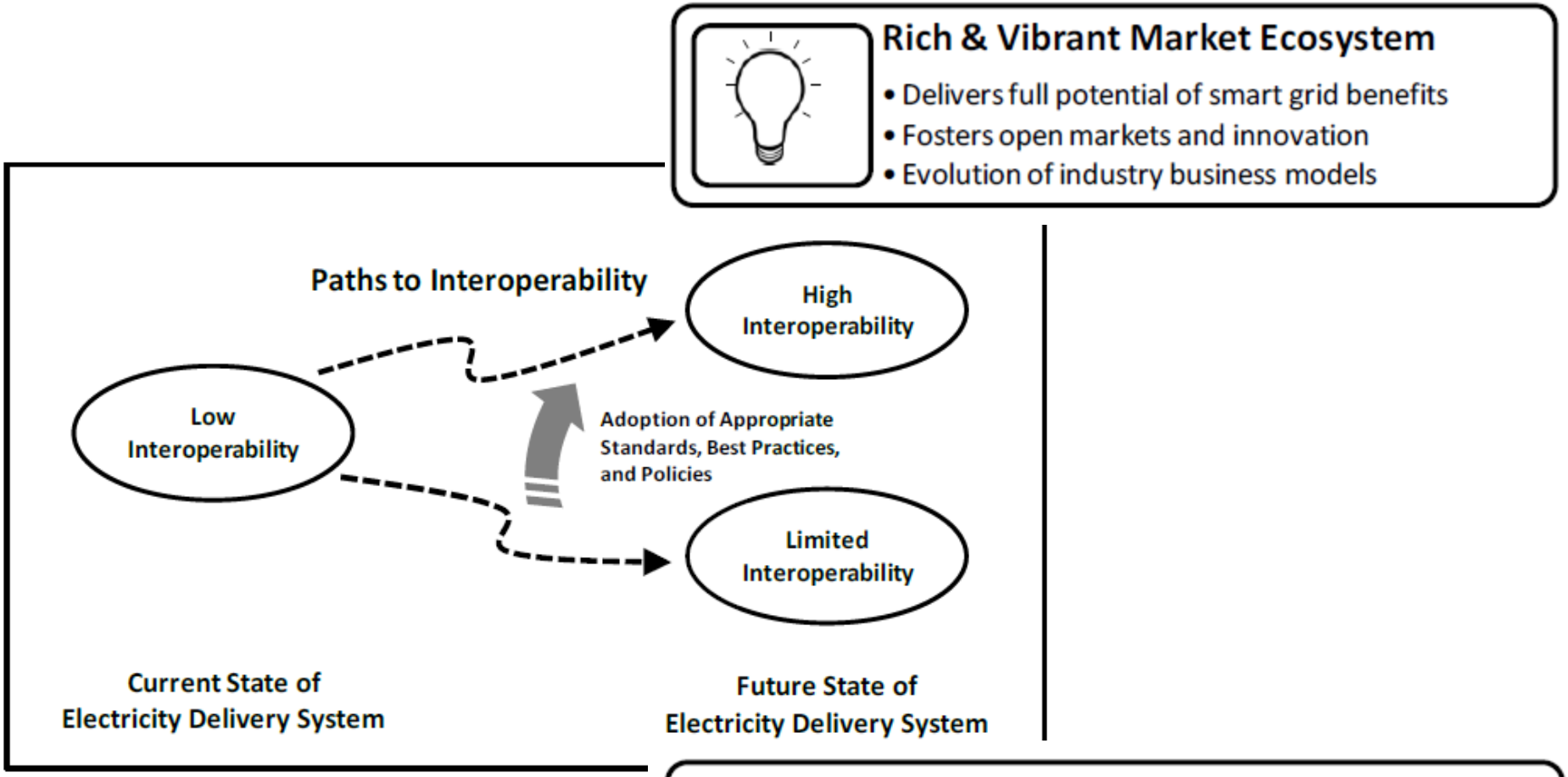
Today interoperability is dismal.

US 'smart' grid more Flintstones than Jetsons

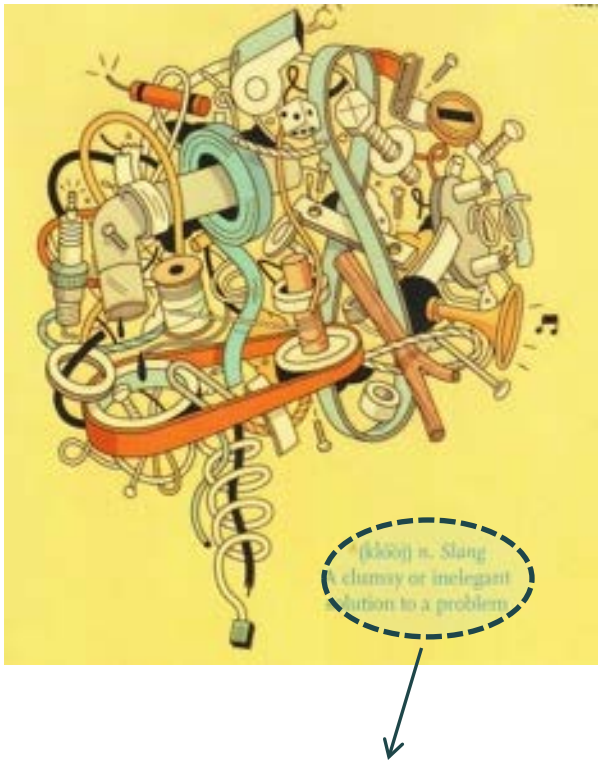
- Smart Grid Today Headline (8/8/2011)

?

Realizing the vision requires interoperability.



The grid has an 'Accidental Architecture'



*(klo͞oj) n. Slang
A clumsy or inelegant solution

An *accidental architecture*[1] is the organization of a system resulting from numerous **point-to-point** integrations between various applications to achieve **near-term** objectives.

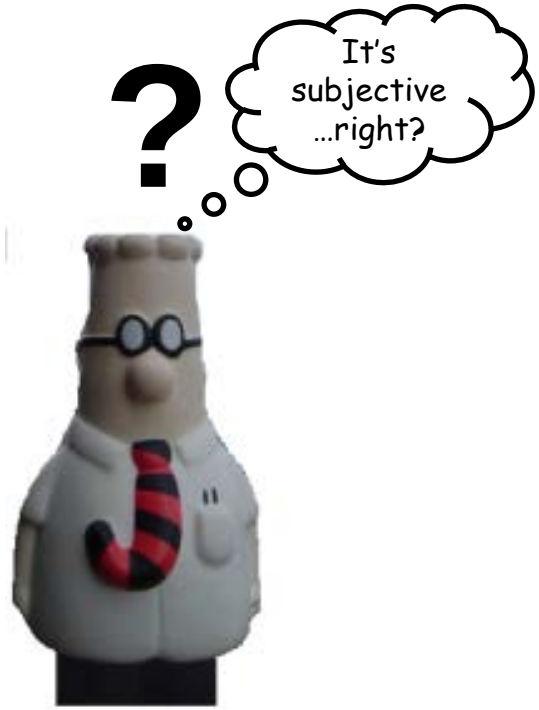
Point-to-point integrations are **not scalable** and often create unintended *ripple effects* on downstream applications.

The result is a unique and customized system that becomes increasingly **difficult** to maintain and update.

1. Giroti, Tony. "Integration Roadmap for Smart Grid: From Accidental Architecture to Smart Grid Architecture." 2009.

If the grid is a patchwork quilt, which quilt do we want?

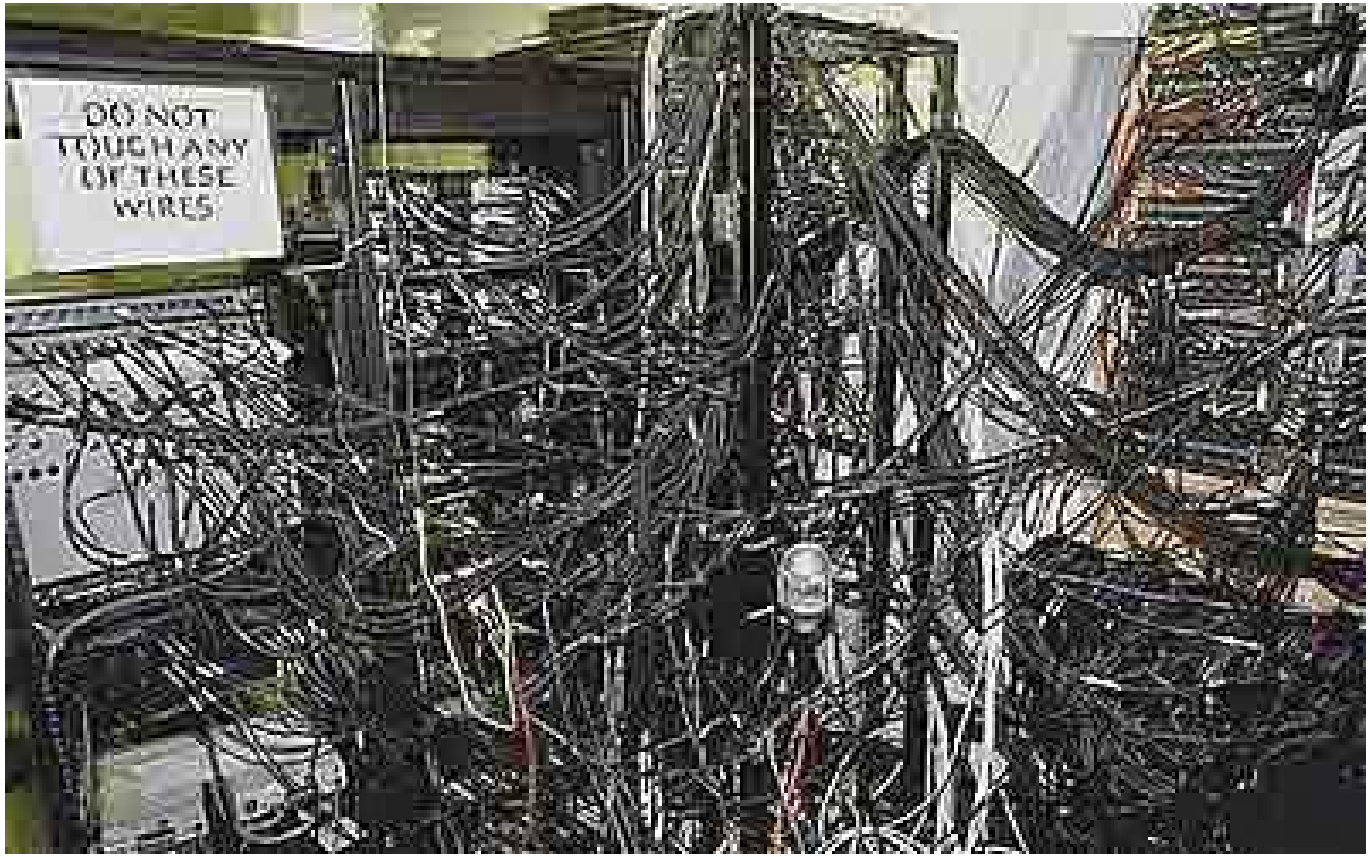
Fiberfantasies.wordpress.com



TheStitchersCupboard.com

Why do we need architecture?

Well architected systems integrate easily, evolve flexibly, and operate simply and reliably.[1]



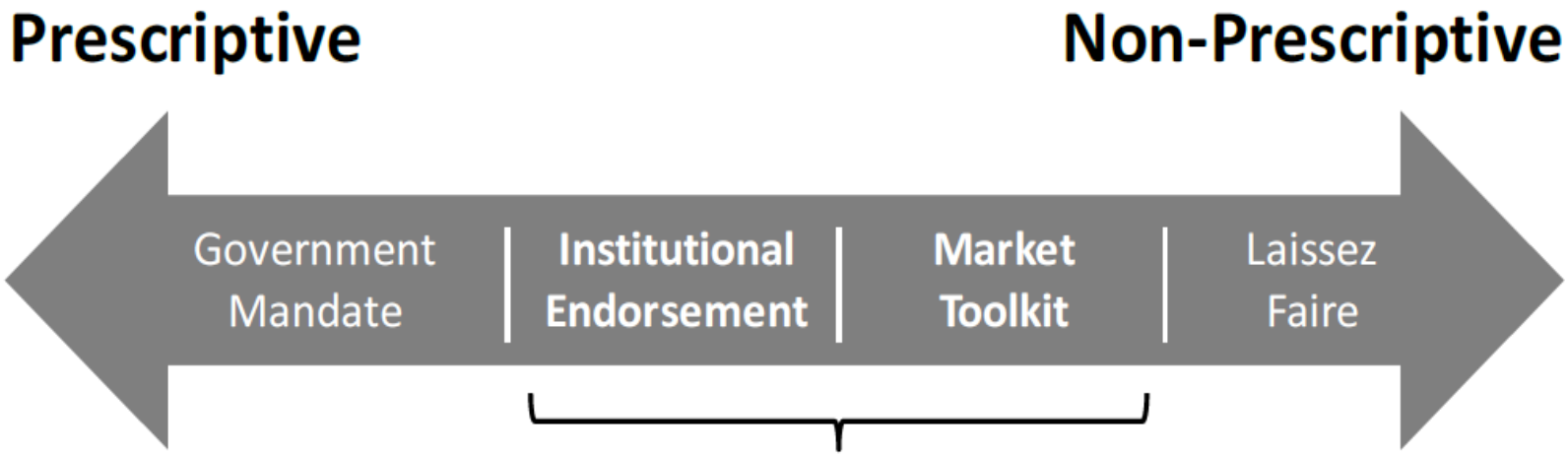
1. Massachusetts Institute of Technology © Ed Crawley 2007

How to approach architecture?

More Specificity

More Degrees of Freedom

How do we get interoperability?



Generally accepted as the **sweet spot** to addressing interoperability

SGIP was established, run by NIST.

In the **Energy Independence and Security Act** of 2007 (EISA), the U.S. Congress established the development of a "smart" electric power grid as a national policy goal.

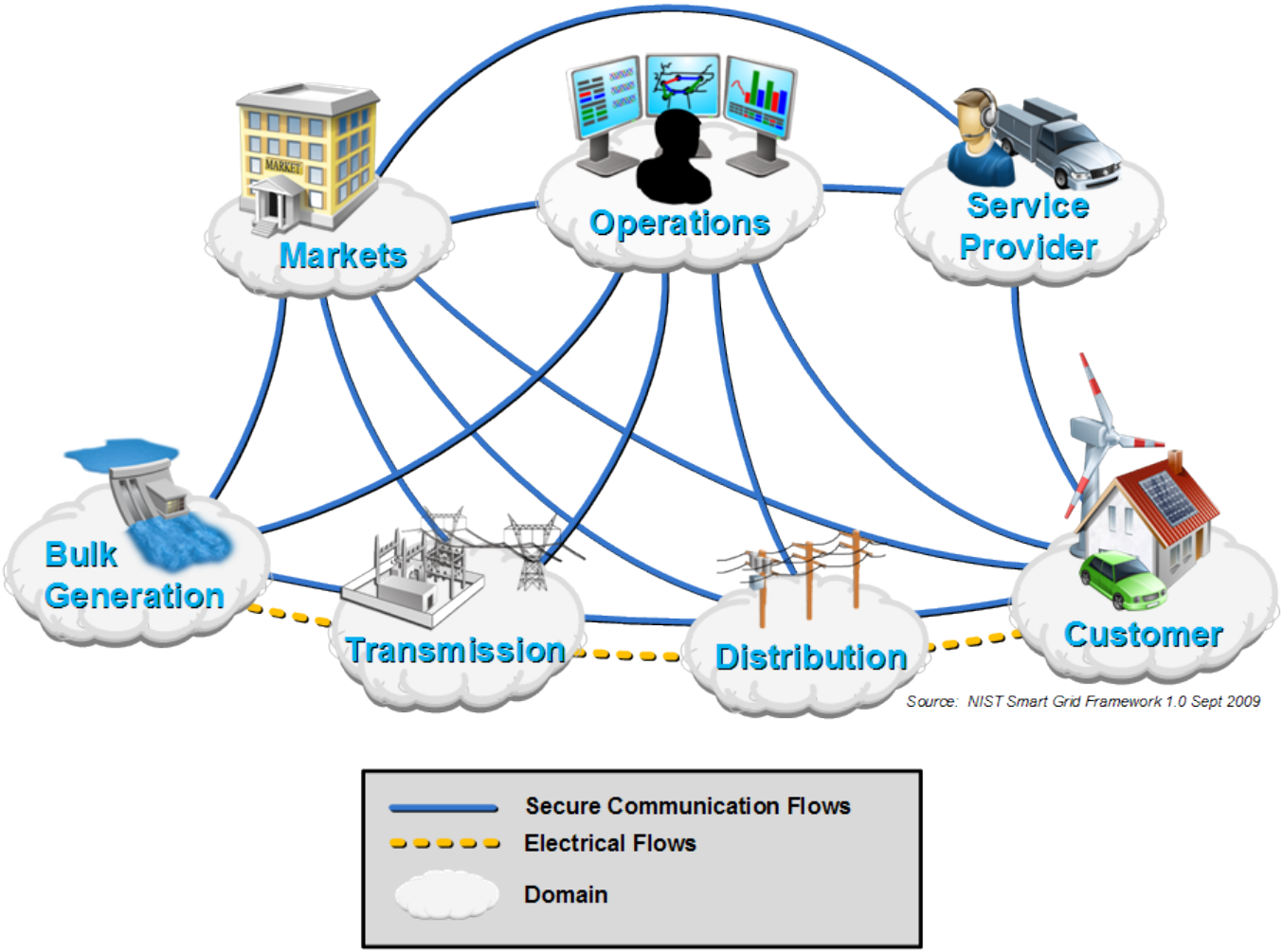
Essential components of the Smart Grid, as conceived in the EISA legislation, include:

- standards
- an information architecture
- a cyber-security strategy
- a framework for testing and certification

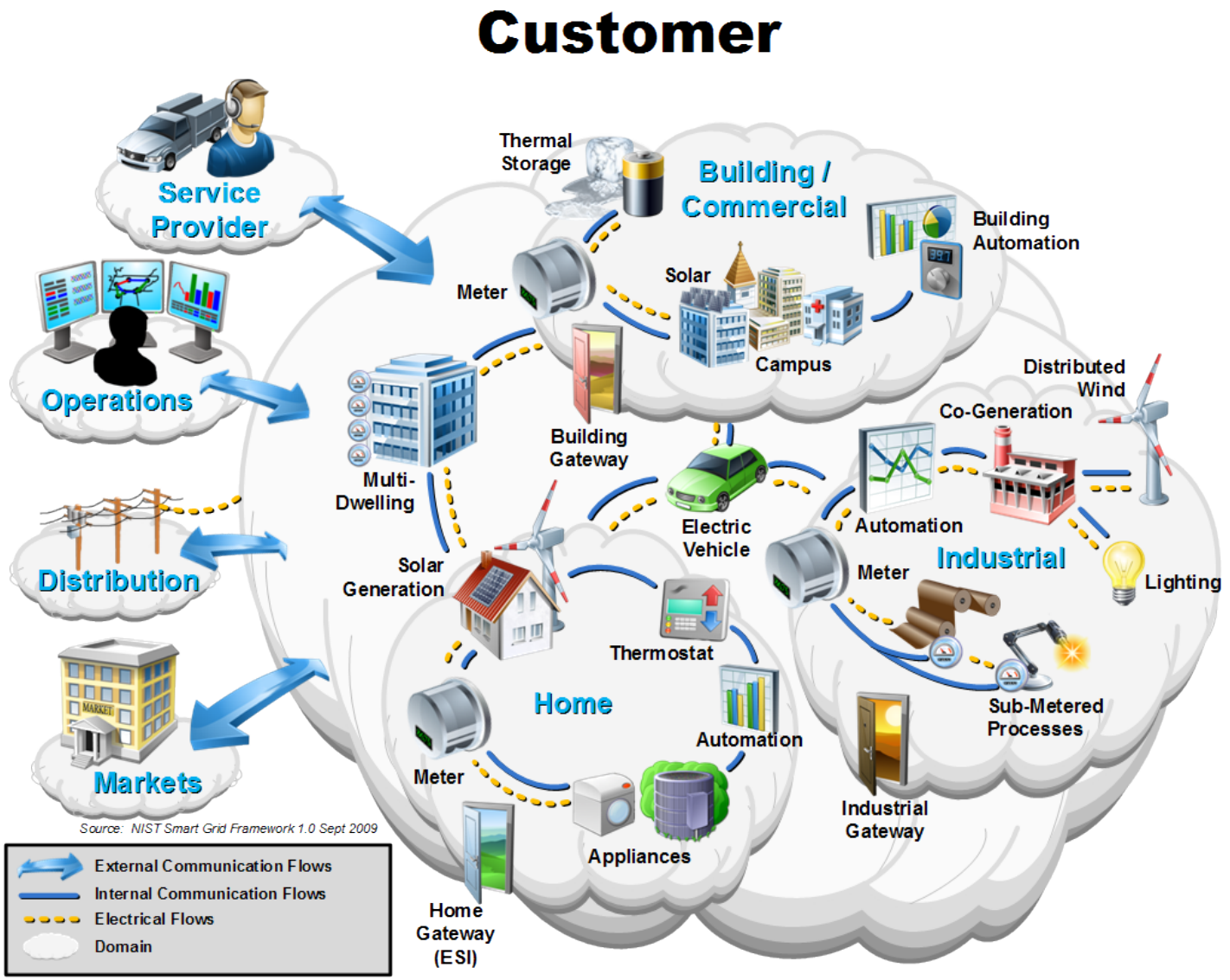
NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Initiated by the National Institute of Standards and Technology (**NIST**), the **Smart Grid Interoperability Panel** (SGIP) plays a leadership role in facilitating and developing these components and in realizing the national policy for the transformation of the power system to the Smart Grid.

SGIP created the Conceptual Model



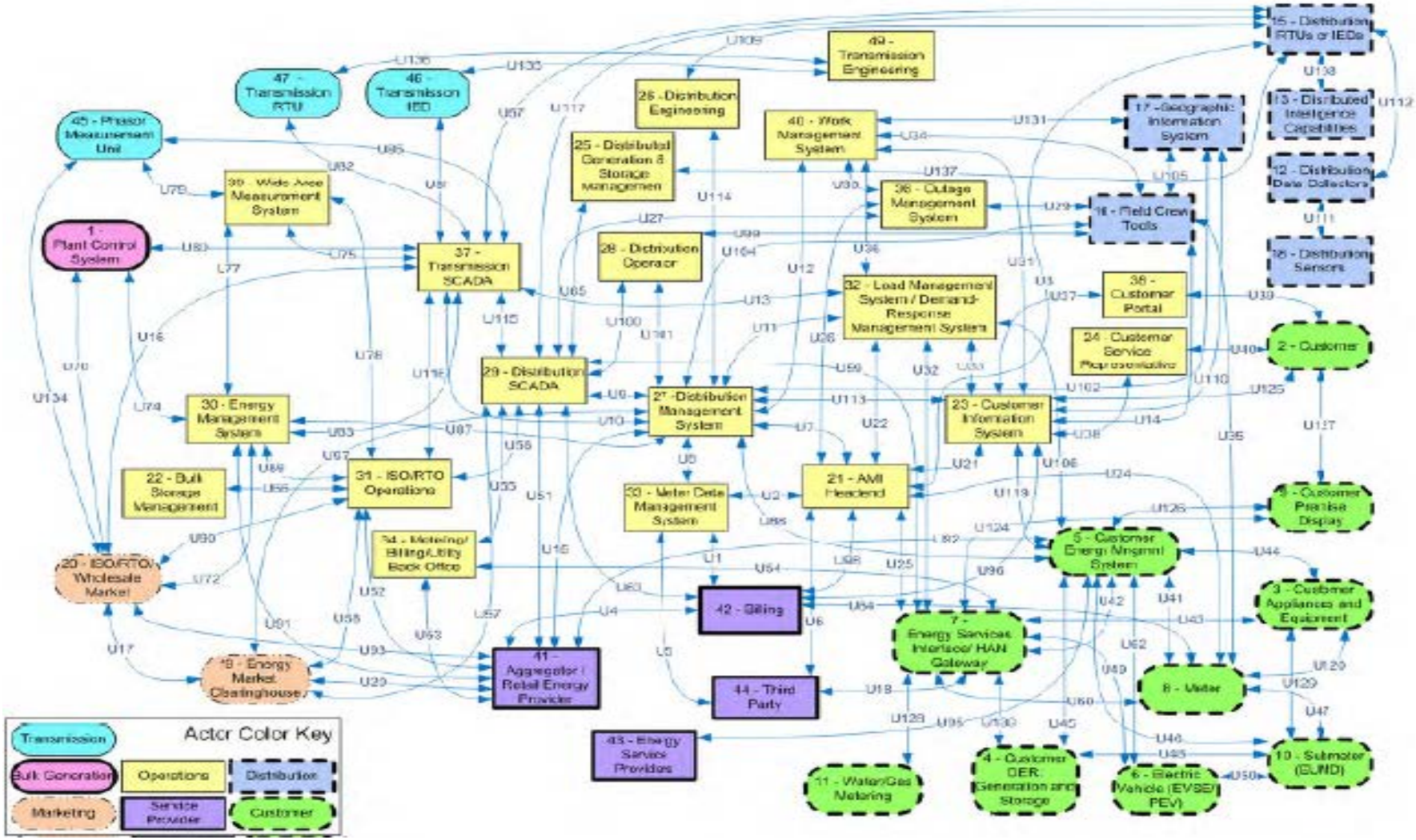
…and added some detail.



A Brief Moment of Zen.

…and it became a standard organizing principle.

NISTIR Logical Reference Model[1]



1. NISTIR 7628. "Guidelines for Smart Grid Cyber Security." v1.0, Volume 1, p. 17. Aug 2010.

What is modularity?

Lego Einstein

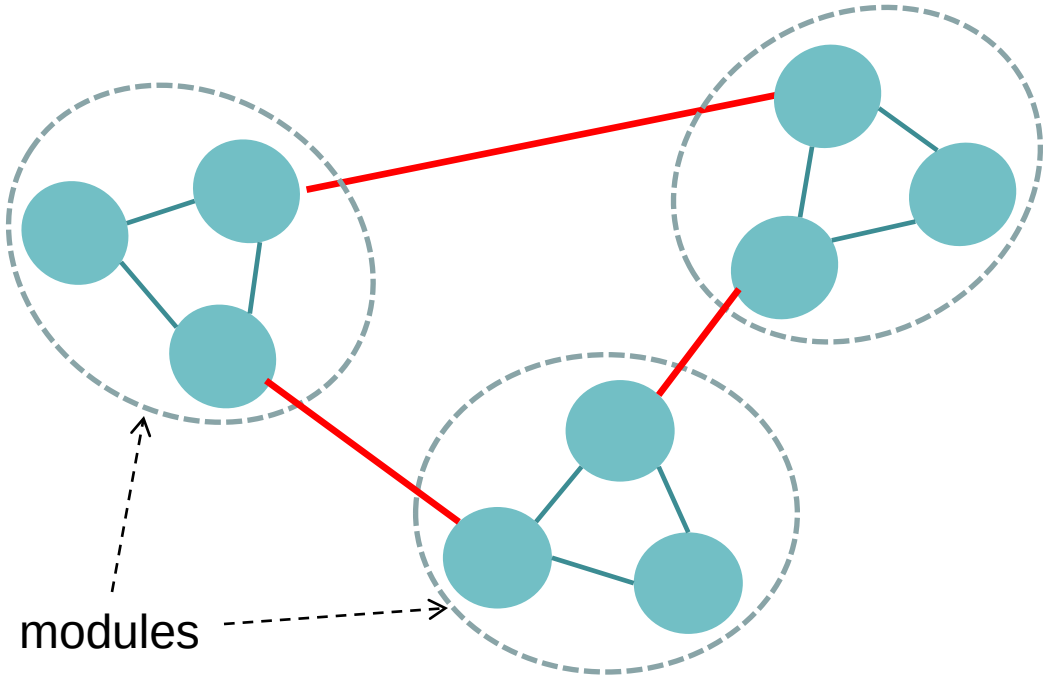
Modularity is a general systems concept, typically defined as a continuum describing the degree to which a system's components may be separated and recombined.[1] It refers to both the tightness of **coupling** between components, and the degree to which the "rules" of the system architecture enable the **mixing and matching** of components.

- Wikipedia article on modularity 12/5/2011

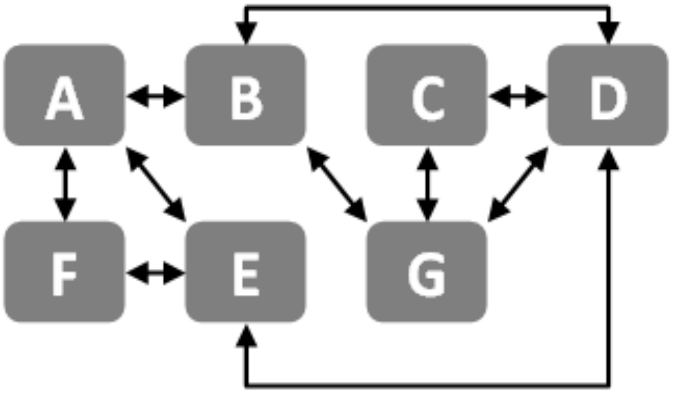
1. Schilling, M.A. 2000. Towards a general modular systems theory and its application to inter-firm product modularity. Academy of Management Review, Vol 25:312–334.

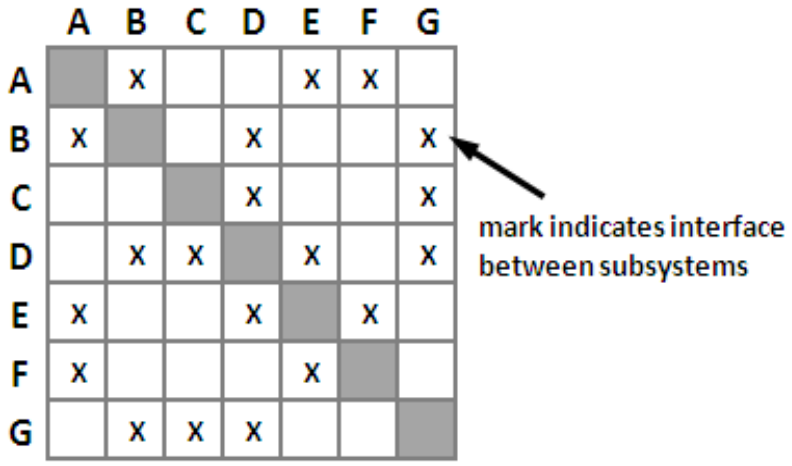
What is modularity?

Modularity in systems architecture is the degree to which elements of a system can be **grouped** with minimal dependency across groups.



What is Design Structure Matrix?



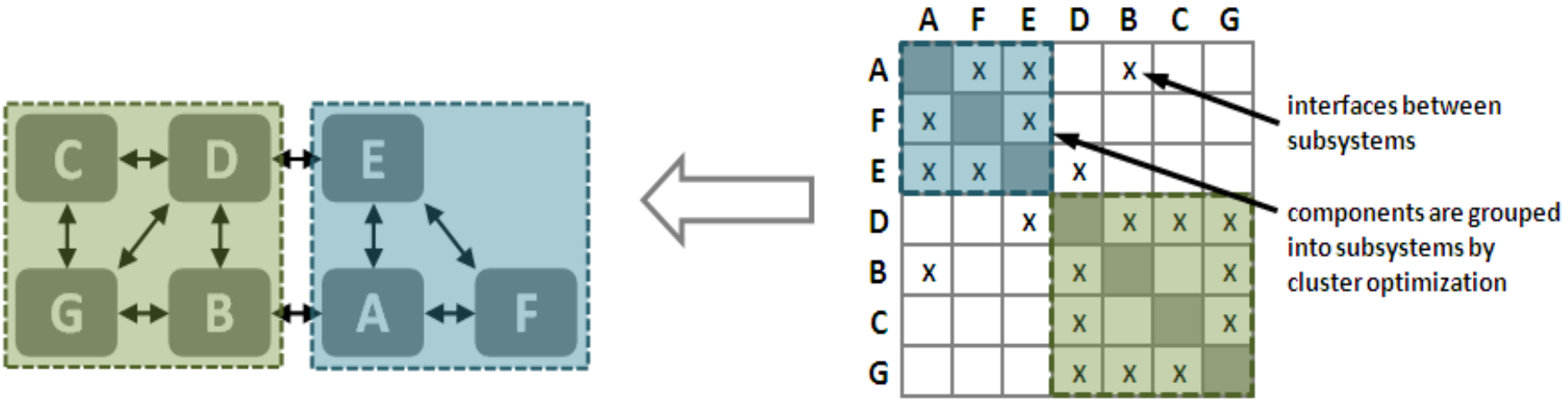


The **design structure matrix** (DSM) is a modeling tool that represents the relationships and dependencies between components of a system, product, or process. The DSM captures **coupling and dependency** relationships between the components of a system in a graphical matrix.

[1] Steward, Donald V., "Systems Analysis and Management: Structure, Strategy and Design," Petrocelli Books, Princeton, NJ, 1981.

How can DSM help identify modularity?

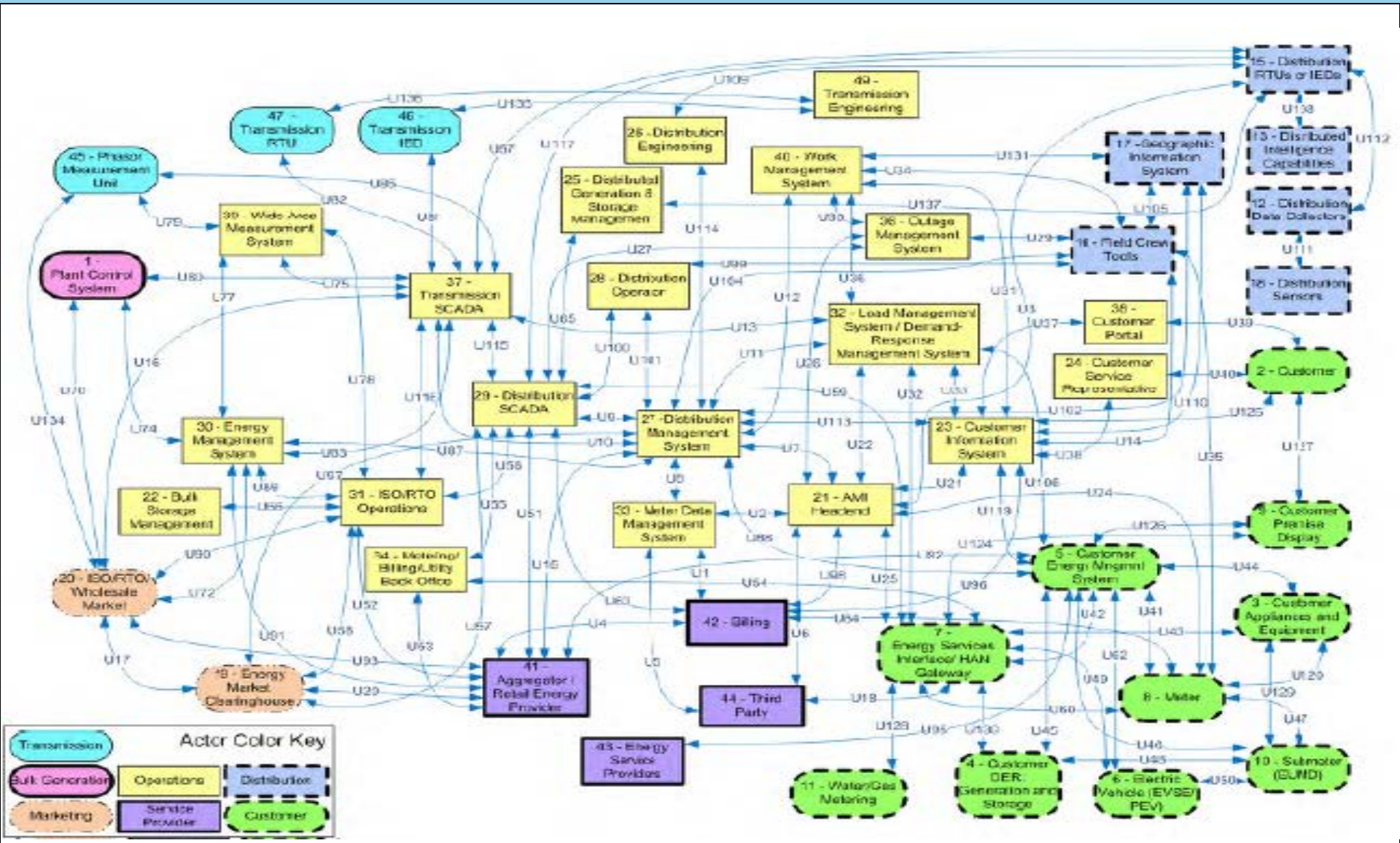
Clustering is a process applied to a DSM by which elements of a system are arranged and grouped in order to **minimize interdependency** across groups.



"Technical skill is mastery of complexity, while creativity is mastery of simplicity."

- Sir Erik Christopher Zeeman, Mathematician

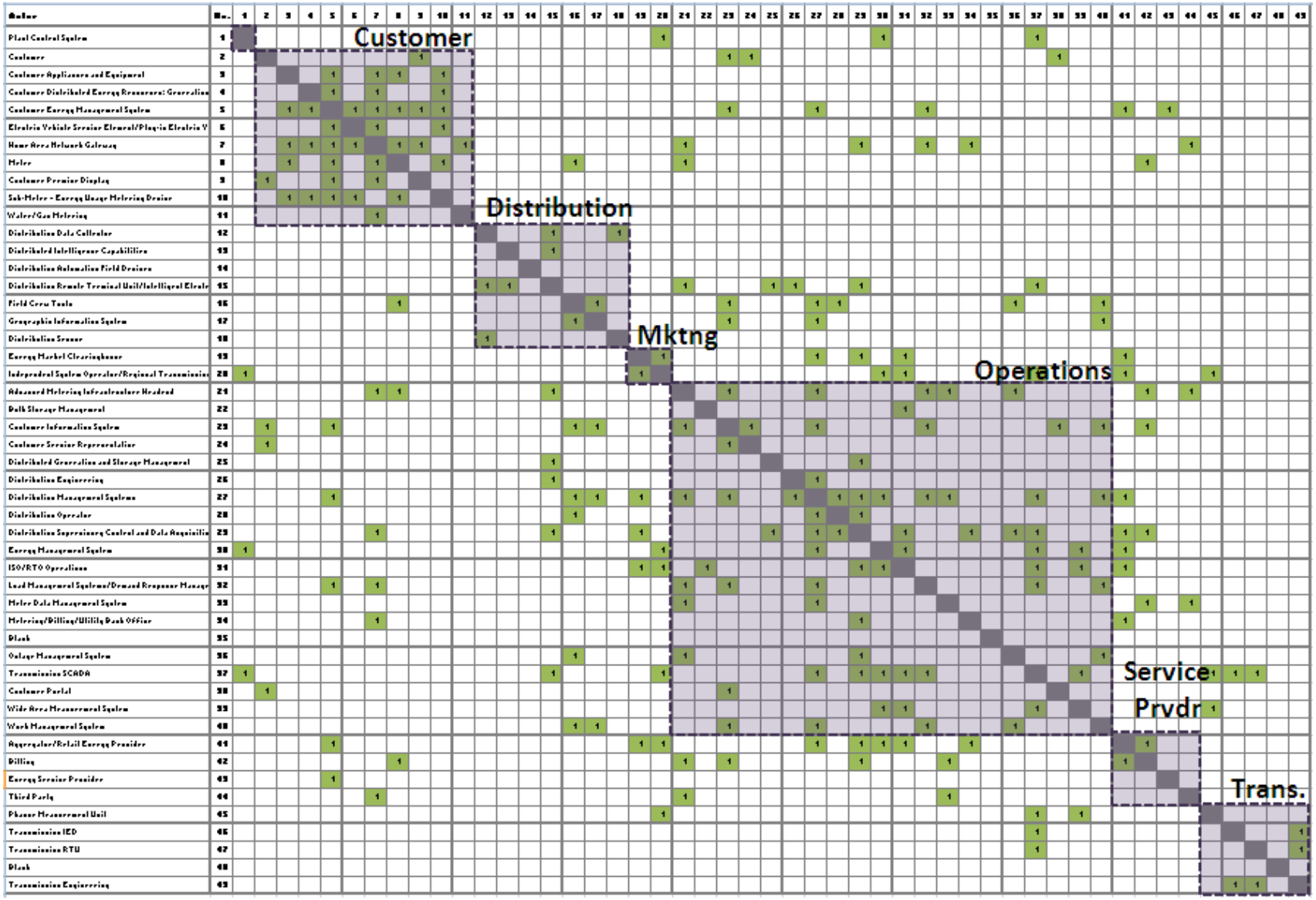
Let's take the NISTIR Logical Reference Model



1. NISTIR 7628. "Guidelines for Smart Grid Cyber Security." v1.0, Volume 1, p. 17. Aug 2010.

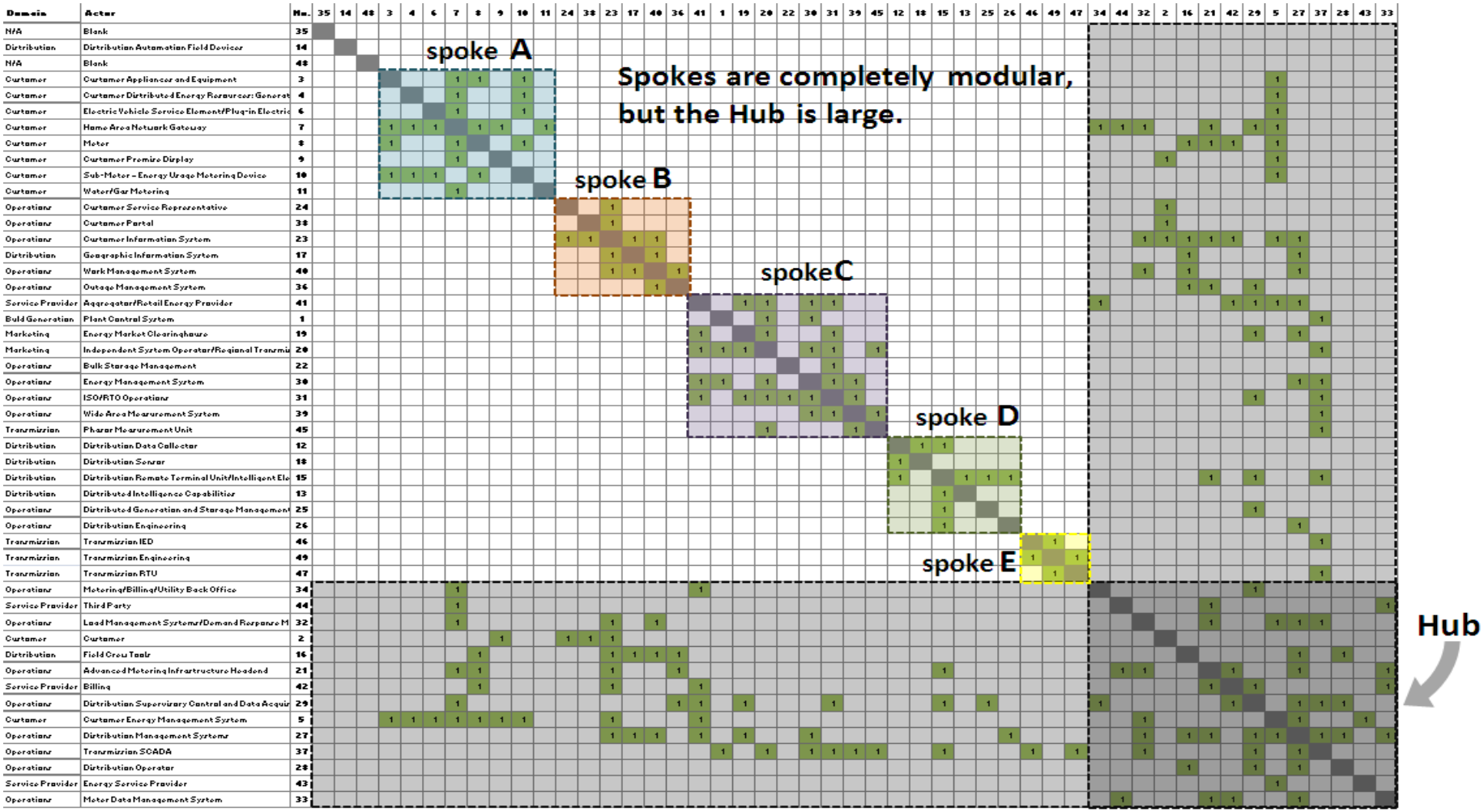
Translate dependencies into a DSM matrix

DSM Representation of the NISTIR Logical Reference Model



Clustering can be more an art than a science.

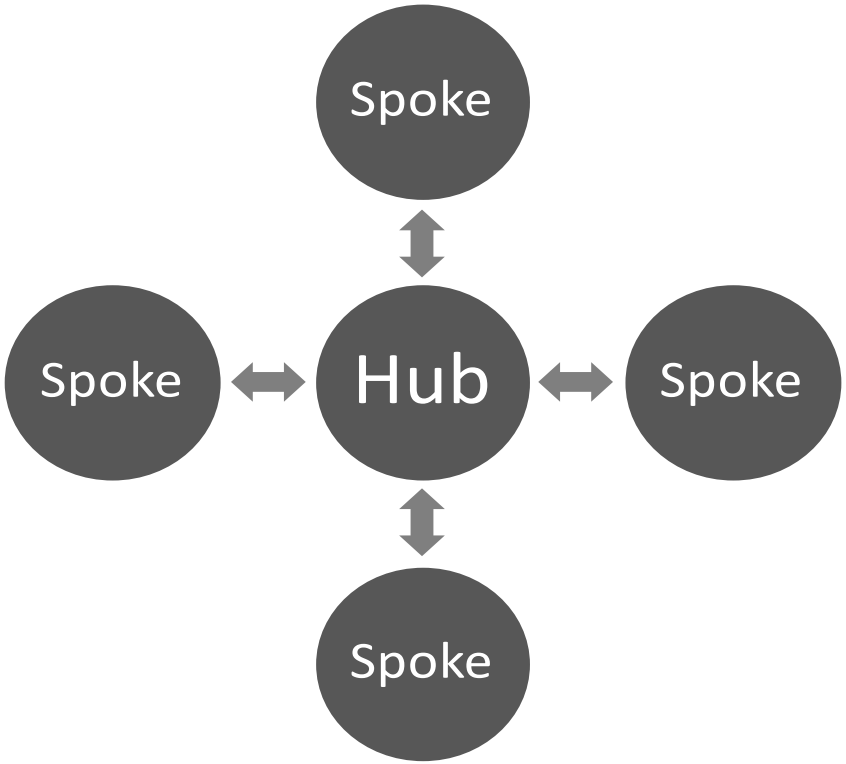
A clustering algorithm can give a good starting point, but "manual" organization is typically needed.



Domain	Actor	No.
N/A	Blank	35
Distribution	Distribution Automation Field Devices	14
N/A	Blank	48
Customer	Customer Appliances and Equipment	3
Customer	Customer Distributed Energy Resources: Generat	4
Customer	Electric Vehicle Service Element/Plug-in Electric	6
Customer	Home Area Network Gateway	7
Customer	Meter	8
Customer	Customer Premise Display	9
Customer	Sub-Meter – Energy Usage Metering Device	10
Customer	Water/Gas Metering	11
Operations	Customer Service Representative	24
Operations	Customer Portal	38
Operations	Customer Information System	23
Distribution	Geographic Information System	17
Operations	Work Management System	40
Operations	Outage Management System	36
Service Provider	Aggregator/Retail Energy Provider	41
Bulk Generation	Plant Control System	1
Marketing	Energy Market Clearinghouse	19
Marketing	Independent System Operator/Regional Transmi	20
Operations	Bulk Storage Management	22
Operations	Energy Management System	30
Operations	ISO/RTO Operations	31
Operations	Wide Area Measurement System	39
Transmission	Phasor Measurement Unit	45
Distribution	Distribution Data Collector	12
Distribution	Distribution Sensor	18
Distribution	Distribution Remote Terminal Unit/Intelligent Ele	15
Distribution	Distributed Intelligence Capabilities	13
Operations	Distributed Generation and Storage Management	25
Operations	Distribution Engineering	26
Transmission	Transmission IED	46
Transmission	Transmission Engineering	49
Transmission	Transmission RTU	47
Operations	Metering/Billing/Utility Back Office	34
Service Provider	Third Party	44
Operations	Load Management System/Demand Response M	32
Customer	Customer	2
Distribution	Field Crew Tools	16
Operations	Advanced Metering Infrastructure Headend	21
Service Provider	Billing	42
Operations	Distribution Supervisory Control and Data Acquis	29
Customer	Customer Energy Management System	5
Operations	Distribution Management Systems	27
Operations	Transmission SCADA	37
Operations	Distribution Operator	28
Service Provider	Energy Service Provider	43
Operations	Meter Data Management System	33

A pattern emerges in complex systems.

Clustering complex systems frequently results in a **Hub & Spoke** configuration

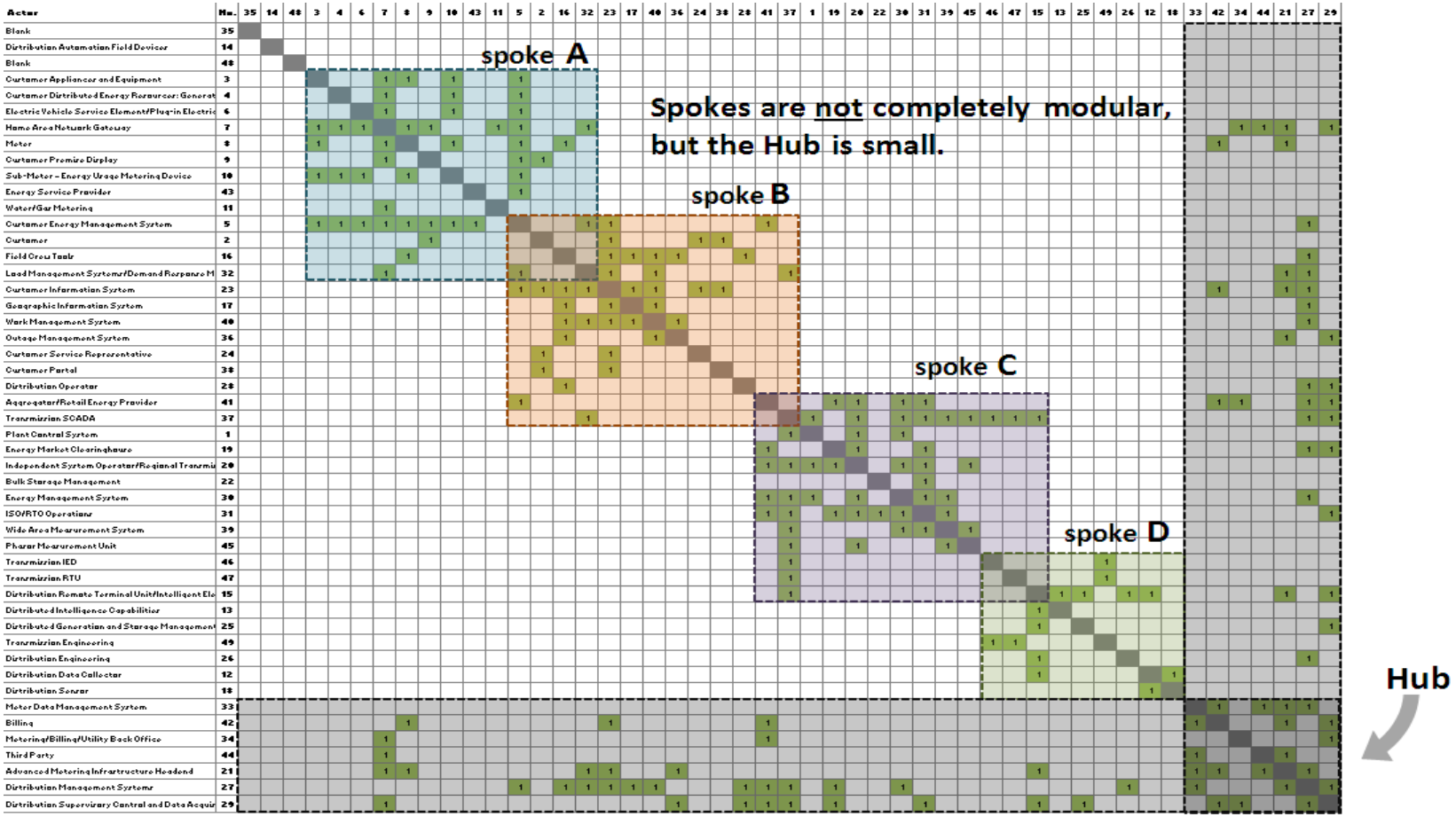


Identifying the appropriate hub elements allows for the creation of **modular spokes**.

Without indentifying and grouping the most central, cross-cutting elements…high levels of dependency would exist across the spokes, and little modularization can be achieved.

Varying levels of dependency may be allowed.

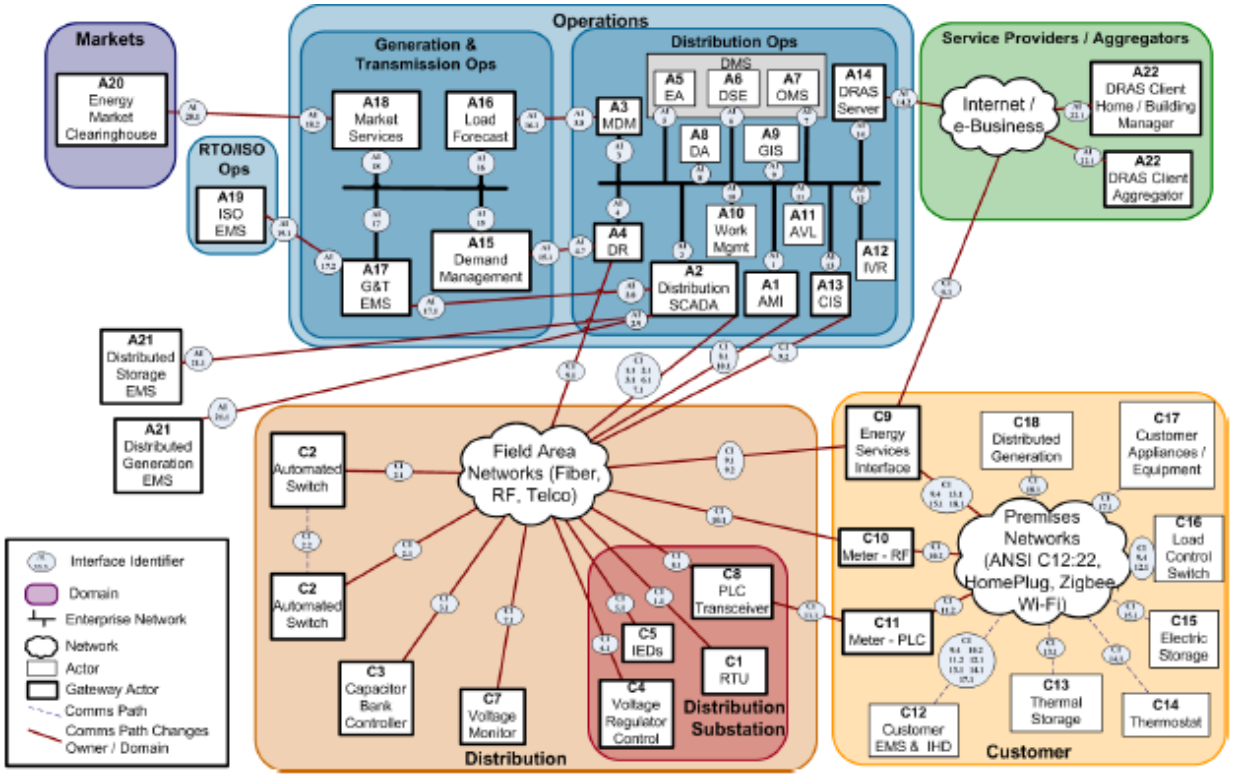
It's up to the architect to determine the most **appropriate configuration**.



DSM can be applied for specific implementations.

This is the planned architecture for a federally funded smart grid **demonstration project**.

NRECA's Demonstration Architecture: Physical and Logical Architecture for Enterprise Application Integration[1]

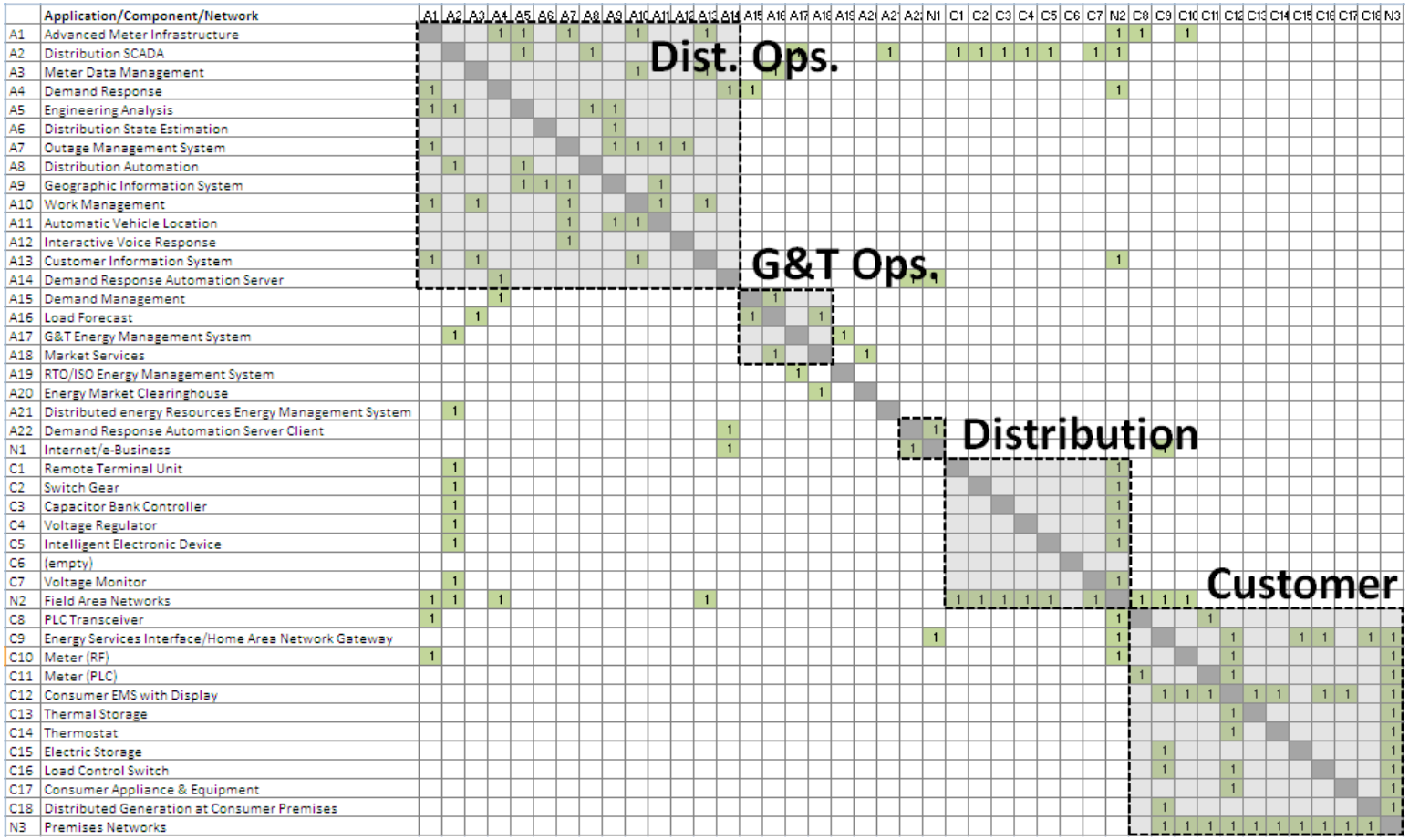


1. “Interoperability and Cyber Security Plan, NRECA CRN Smart Grid Regional Demonstration.” May 2010.

DSM can be applied for specific implementations.

High densities of dependencies and of whitespace generally indicate a **more modular** organization.

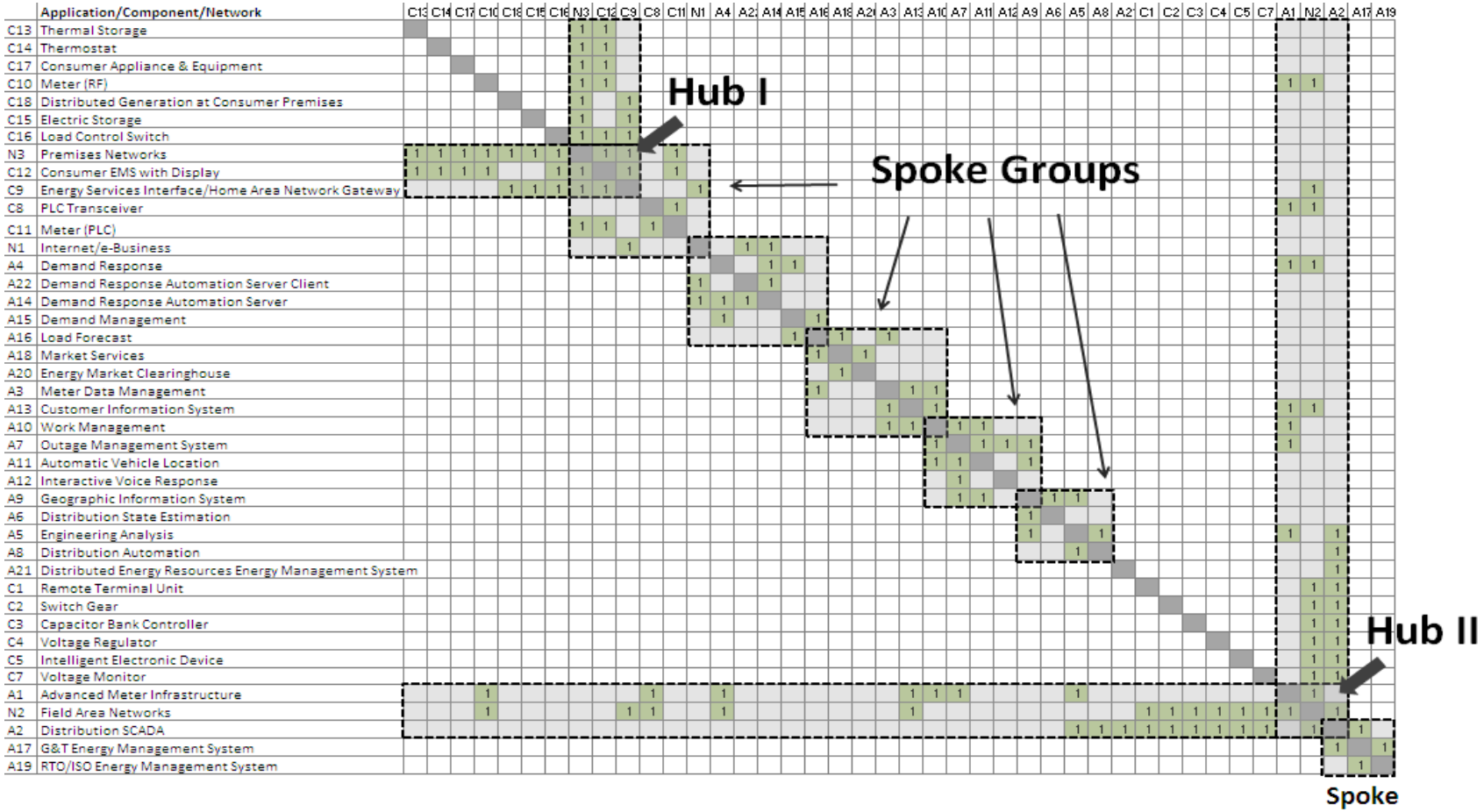
DSM Representation of NRECA's Demonstration Architecture



	Application/Component/Network	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	N1	C1	C2	C3	C4	C5	C6	C7	N2	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	N3
A1	Advanced Meter Infrastructure				1	1		1			1			1																		1	1		1										
A2	Distribution SCADA					1			1																1		1	1	1	1		1	1											
A3	Meter Data Management										1																																	
A4	Demand Response	1												1		1															1													
A5	Engineering Analysis	1	1						1	1																																		
A6	Distribution State Estimation									1																																		
A7	Outage Management System	1								1	1	1	1																															
A8	Distribution Automation		1			1																																						
A9	Geographic Information System					1	1	1				1																																
A10	Work Management	1		1				1				1		1																														
A11	Automatic Vehicle Location							1		1	1																																	
A12	Interactive Voice Response							1																																				
A13	Customer Information System	1		1							1																																	
A14	Demand Response Automation Server				1																																							
A15	Demand Management				1												1																												
A16	Load Forecast			1												1		1																											
A17	G&T Energy Management System		1														1			1																									
A18	Market Services															1					1																								
A19	RTO/ISO Energy Management System																1																												
A20	Energy Market Clearinghouse																	1																											
A21	Distributed energy Resources Energy Management System		1																																									
A22	Demand Response Automation Server Client													1										1																					
N1	Internet/e-Business													1										1																					
C1	Remote Terminal Unit		1																													1												
C2	Switch Gear		1																													1												
C3	Capacitor Bank Controller		1																													1												
C4	Voltage Regulator		1																													1												
C5	Intelligent Electronic Device		1																													1												
C6	(empty)																																											
C7	Voltage Monitor		1																													1												
N2	Field Area Networks	1	1		1									1											1	1	1	1	1		1		1	1	1								
C8	PLC Transceiver	1																														1			1									
C9	Energy Services Interface/Home Area Network Gateway																							1								1				1			1	1		1	1	
C10	Meter (RF)	1																														1				1								1
C11	Meter (PLC)																																1			1								1
C12	Consumer EMS with Display																																	1	1	1		1	1		1	1		1
C13	Thermal Storage																																			1								1
C14	Thermostat																																			1								1
C15	Electric Storage																																	1										1
C16	Load Control Switch																																	1		1								1
C17	Consumer Appliance & Equipment																																			1								1
C18	Distributed Generation at Consumer Premises																																	1										1
N3	Premises Networks																																	1	1	1	1	1	1	1	1	1	1	

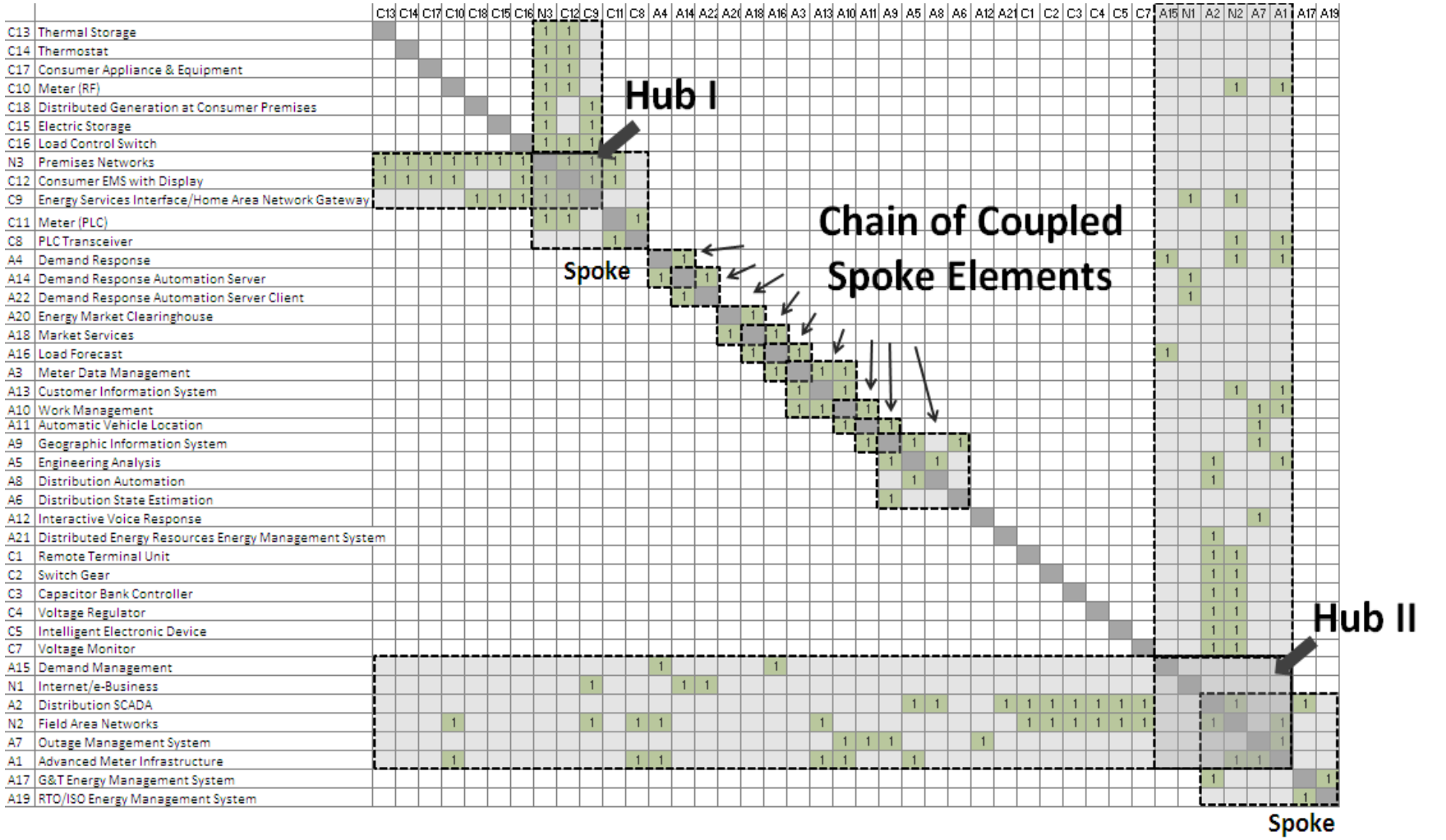
Different organizations may emerge.

But you never know what might emerge…such as **two** independent **hubs** in this case.



Different organizations may emerge.

Or a **daisy chain** of dependency in an alternate configuration.

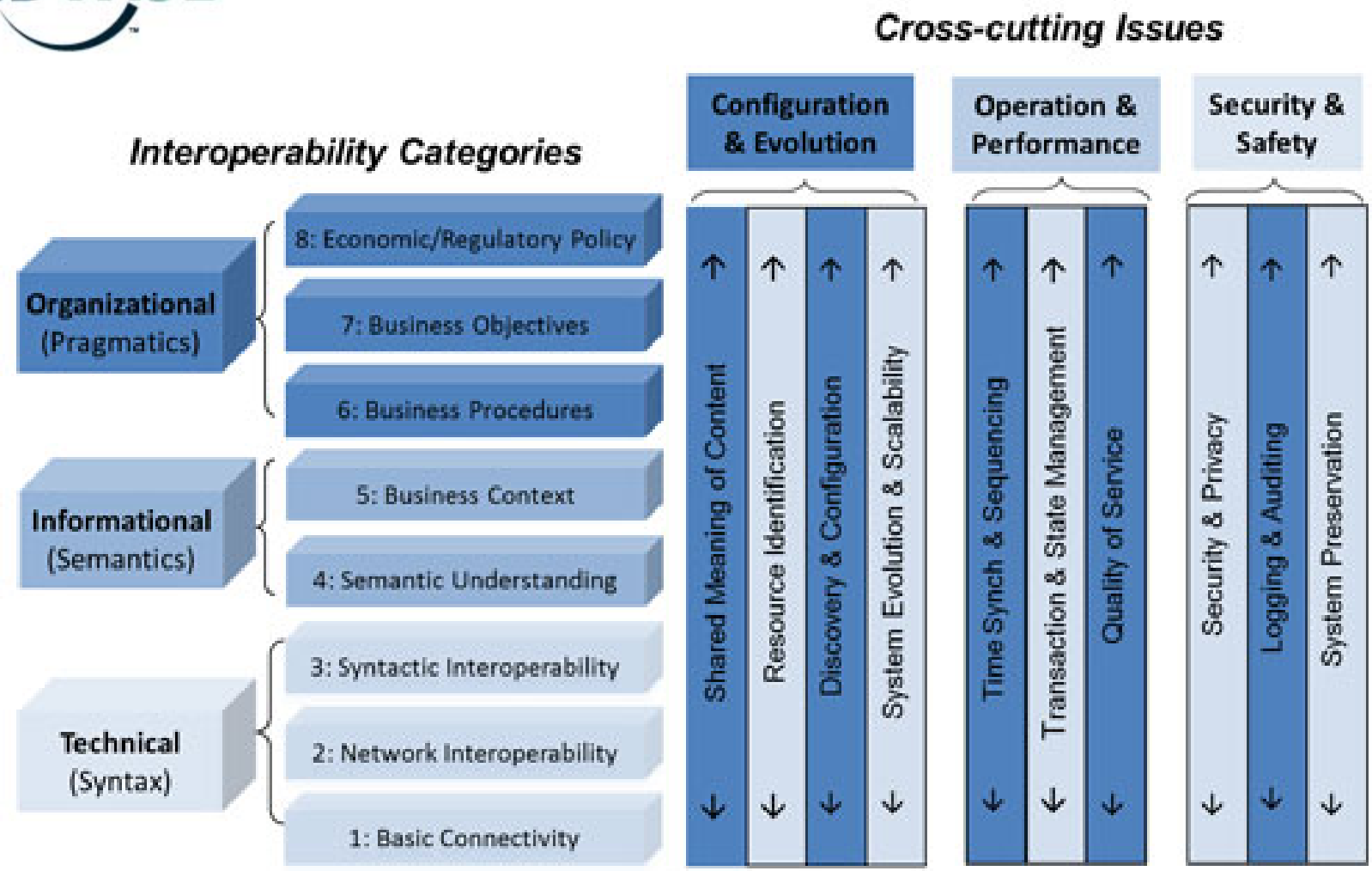


Conclusions

- Modularization can help **combat accidental architectures** by isolating groups of dependency allowing them to be treated as an independent sub-system. Modular systems can **evolve more elegantly** because modular organization is more easily respected.
- Hubs identify the most cross-cutting elements of a system. Prioritizing these elements and **acknowledging their centricity** will reduce the complexity of the system.
- DSM is a useful approach to visualizing and structuring complex systems, such as those in a smart grid.

Shout-Out to the GWAC Stack

GRIDWISE



Just Published: the First DSM Text

If you work with complex systems, products, processes, or other giant hairballs…
…this is a **MUST READ**!

Design Structure Matrix Methods and Applications

Steven D. Eppinger and Tyson R. Browning

An introduction to a powerful and flexible network modeling tool for developing and understanding complex systems, with many examples from a range of industries.

- 334 pages
- >175 color illustrations
- 44 detailed examples from industry
- 80 contributors
- 12 reviewers

Finally… a comprehensive introduction to DSM methods… all in one place.

Now available from **MIT Press** and other sellers (e.g., **Amazon**).

Brad Rogers (LGO/ESD)
Managing Consultant
Boulder, CO
(303) 728-2500
brad.rogers@navigant.com

Erik Gilbert (Course 6)
Associate Director
Boulder, CO
(303) 728-2500
erik.gilbert@navigant.com

For more DSM resources, see:
DSMweb.org

For DSM training, see:
executive.mit.edu
Managing Complex Product Development Projects