Complex Systems Engineering for the Global information Grid

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Overview of Talk

- Background
- NCOIC and the Global Information Grid
- Complex Systems Engineering Strategies
- Foundation Information Grid (NCOIC Demo)
- Conclusion

My Background

- Industrial system of systems architecture and implementation at Boeing and General Motors
- Military systems of systems architecture and standards as an SRI consultant to the DoD
- Author of “Great Global Grid: Emergency Technology Strategies” (2002)
- Director of Colorado State Grid Initiative
- Chair of Modeling, Simulation and Demonstration Working Group at Network Centric Operations Industry Consortium (NCOIC)
  - Foundation Information Grid Demonstration as a step towards the Global Information Grid

GREAT GLOBAL GRID

EMERGING TECHNOLOGY STRATEGIES

ROBERT MARCUS

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The NCOIC and
the Global Information Grid

Overview of the NCOIC

- The Network-Centric Operations Industry Consortium (NCOIC.org) membership includes all of the leading defense contractors
- The NCOIC's mission is to facilitate collaboration on creating standardized interoperability frameworks
- The Modeling, Simulation and Demonstration Working Group's goal is to initiate foundation demonstrations for future system of systems architectures
- One example of these future architectures is the DoD's Global Information Grid
- The initial demonstration is called the Foundation Information Grid

Information Grid

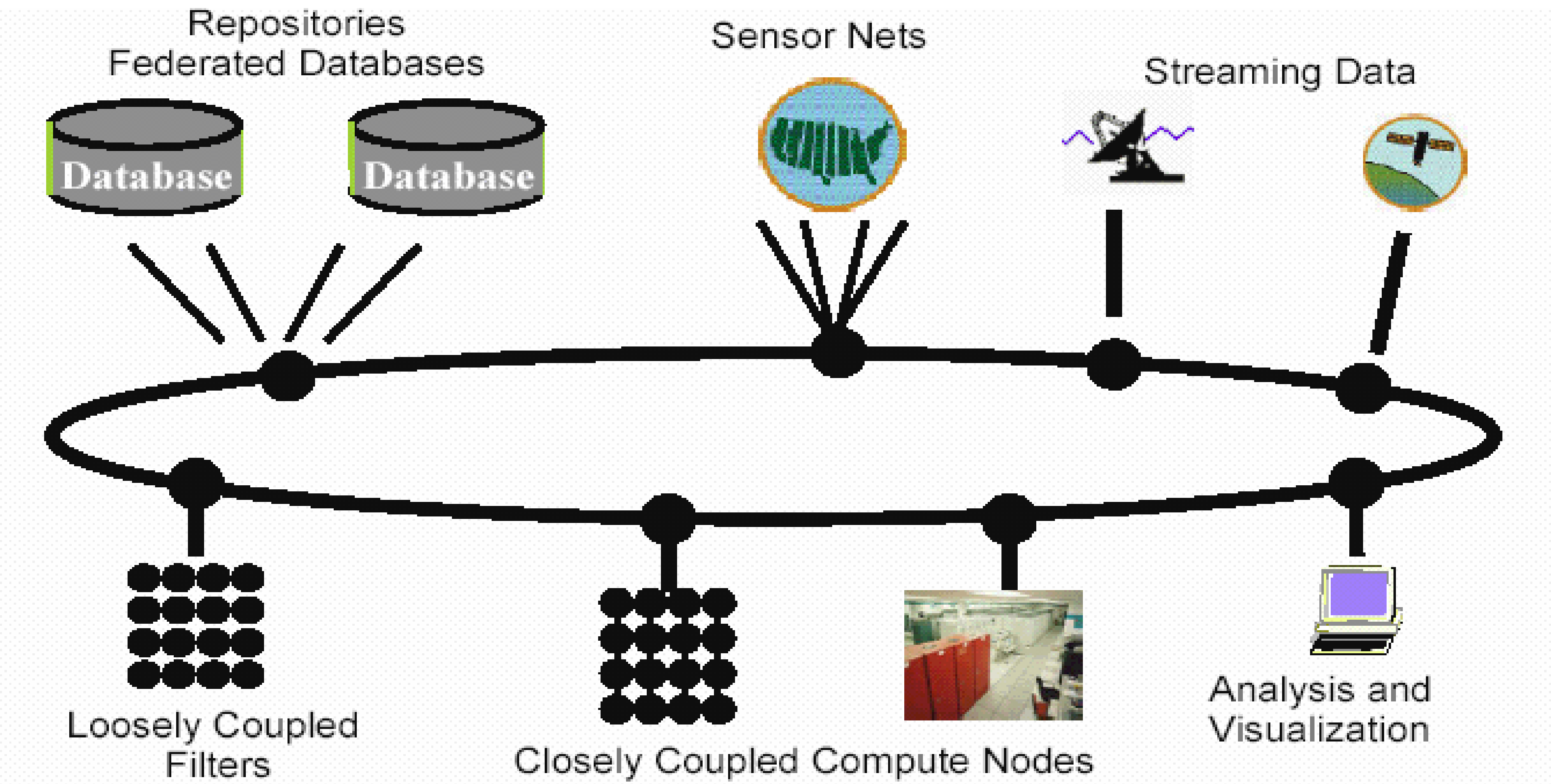
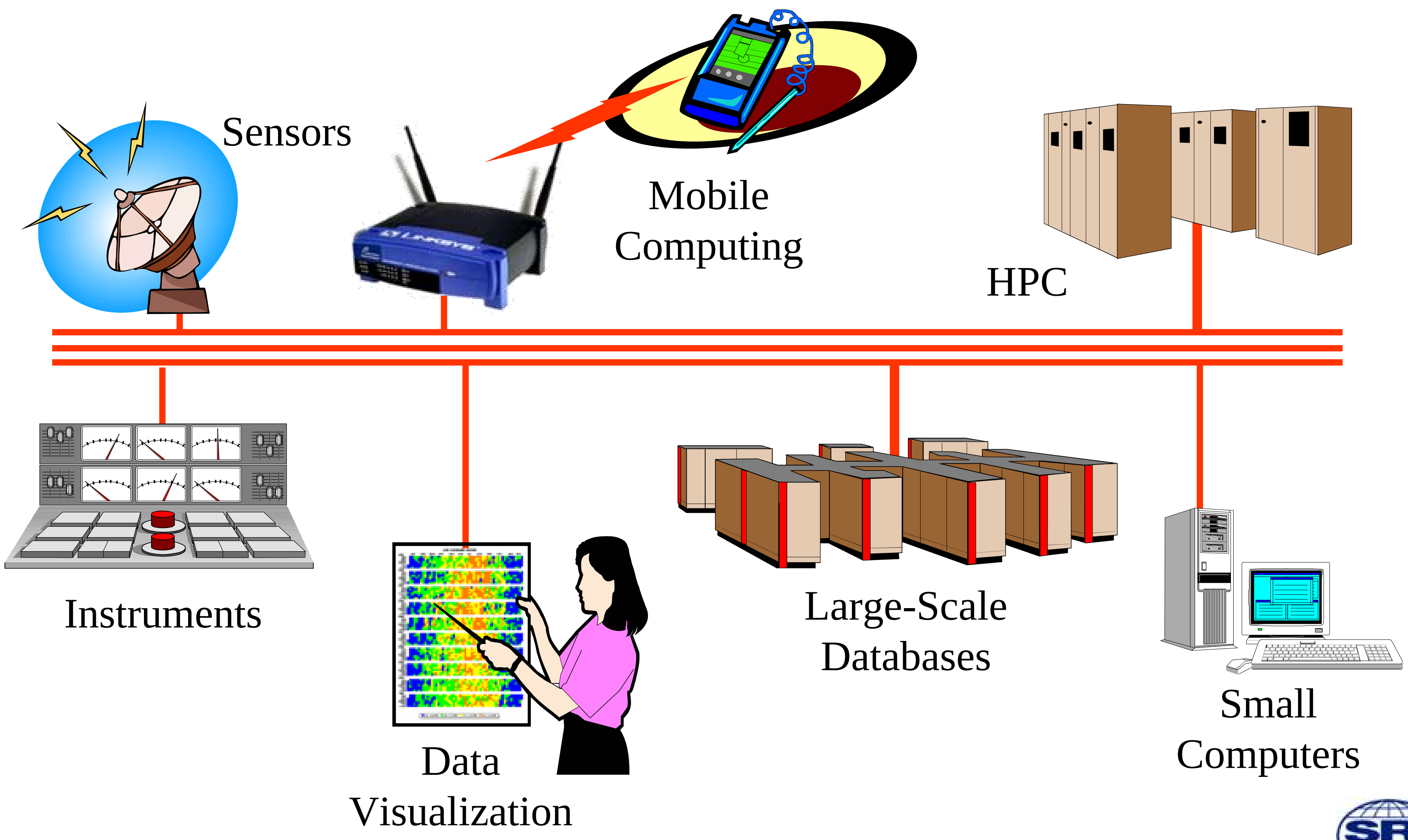
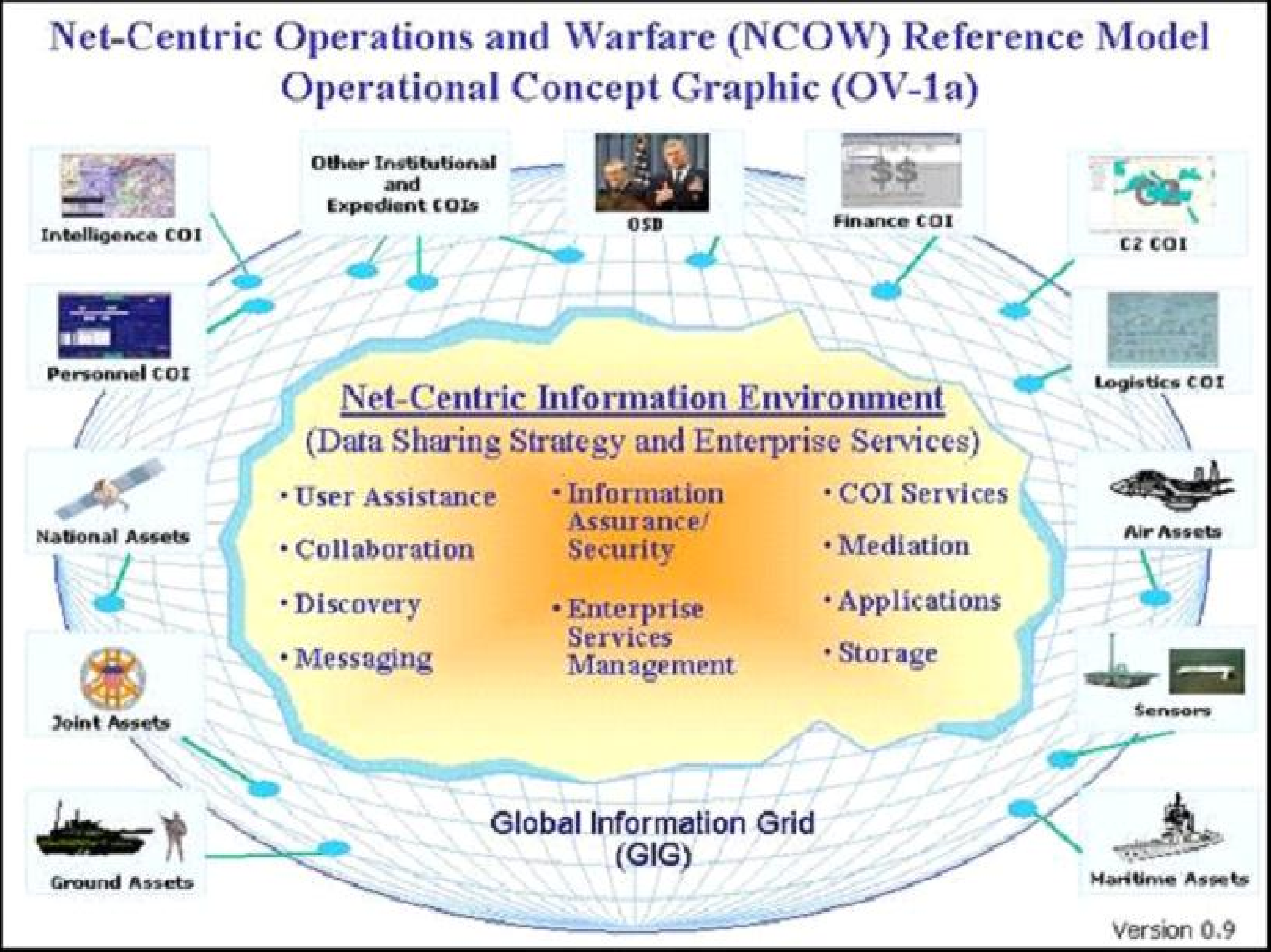


Fig. 1: Information Grid with Sensors, Satellites, databases, high performance computers, clusters and filters (independent machines)

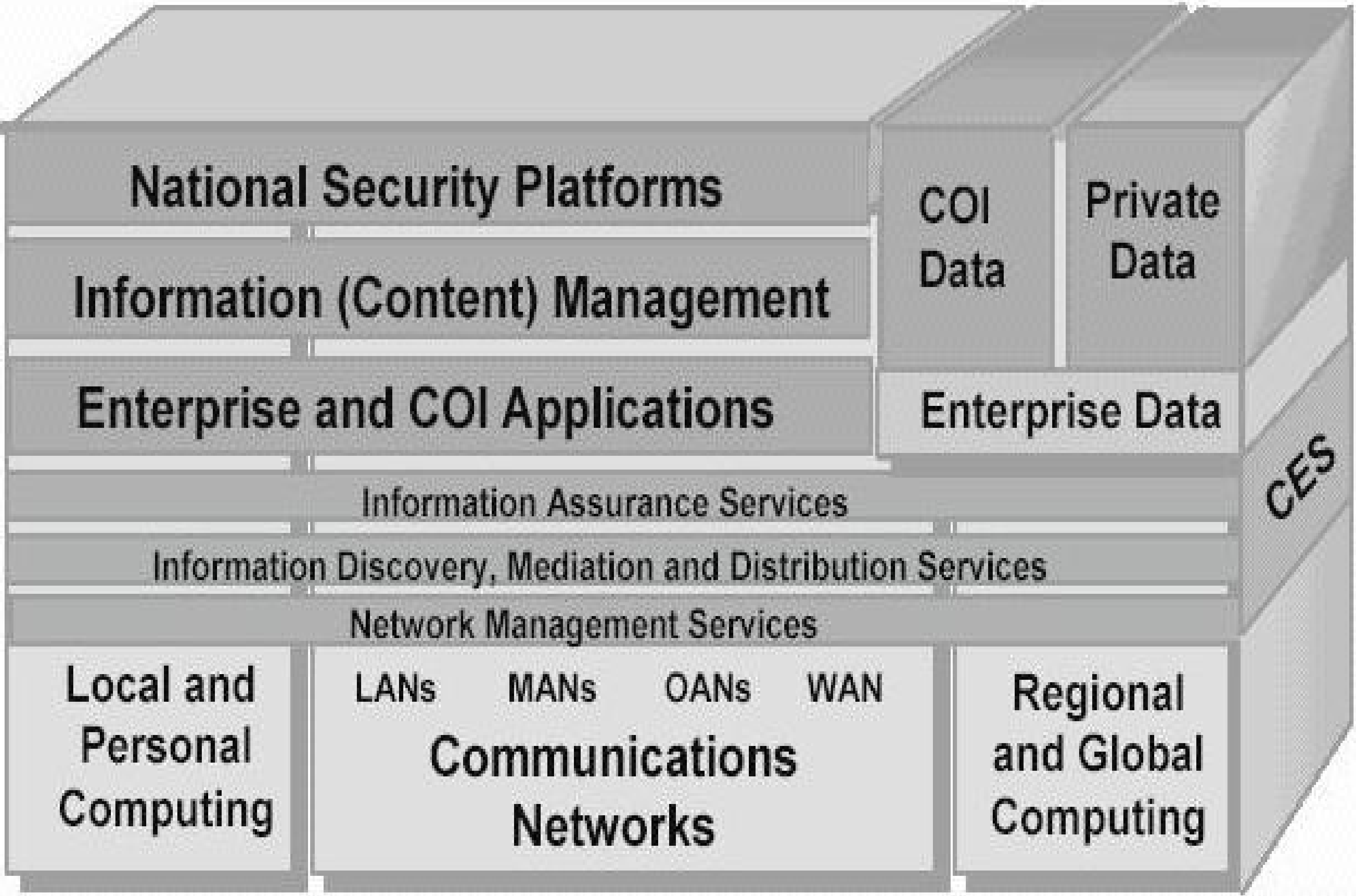
Colorado Information Grid Vision





Net-Centric Operations and Warfare (NCOW) Reference Model
Operational Concept Graphic (OV-1a)
Intelligence COI
Other Institutional and Expedient COIs
OSD
Finance COI
C2 COI
Personnel COI
Logistics COI
Net-Centric Information Environment
(Data Sharing Strategy and Enterprise Services)
• User Assistance
• Collaboration
• Discovery
• Messaging
• Information Assurance/ Security
• Enterprise Services Management
• COI Services
• Mediation
• Applications
• Storage
National Assets
Air Assets
Joint Assets
Sensors
Ground Assets
Maritime Assets
Global Information Grid (GIG)
Version 0.9

Global Information Grid (GES.DOD.MIL)



Standards Needed at Multiple Levels

Applications, Data Analysis and Data Mining
Interface Protocols and APIs
Data Processing, Transformation, and Fusion
Data, Metadata, and Semantic Representations
Non-functional Capabilities e.g. IA, QoS, Policies
Data Transport and Messaging Mechanisms
Network and Communication Protocols
Virtualized Databases
Virtualized Storage

Complex Systems Engineering Strategies

Complex Systems Properties

- **Emergent -** Macroscopic dynamics and variables occur in the system, which is not easily predictable from local dynamics
- **Multiscale Interactive** - The macroscopic and component-level behavior interact in a measurable way
- **Non-equilibrium Metastable** – Short term stability with large state changes possible under small perturbations
- **Evolutionary Adaption-** The system exhibits altered behavior in response to environmental changes
- **Self Organizing -** Coordinated behavior can take place among components without centralized guidance

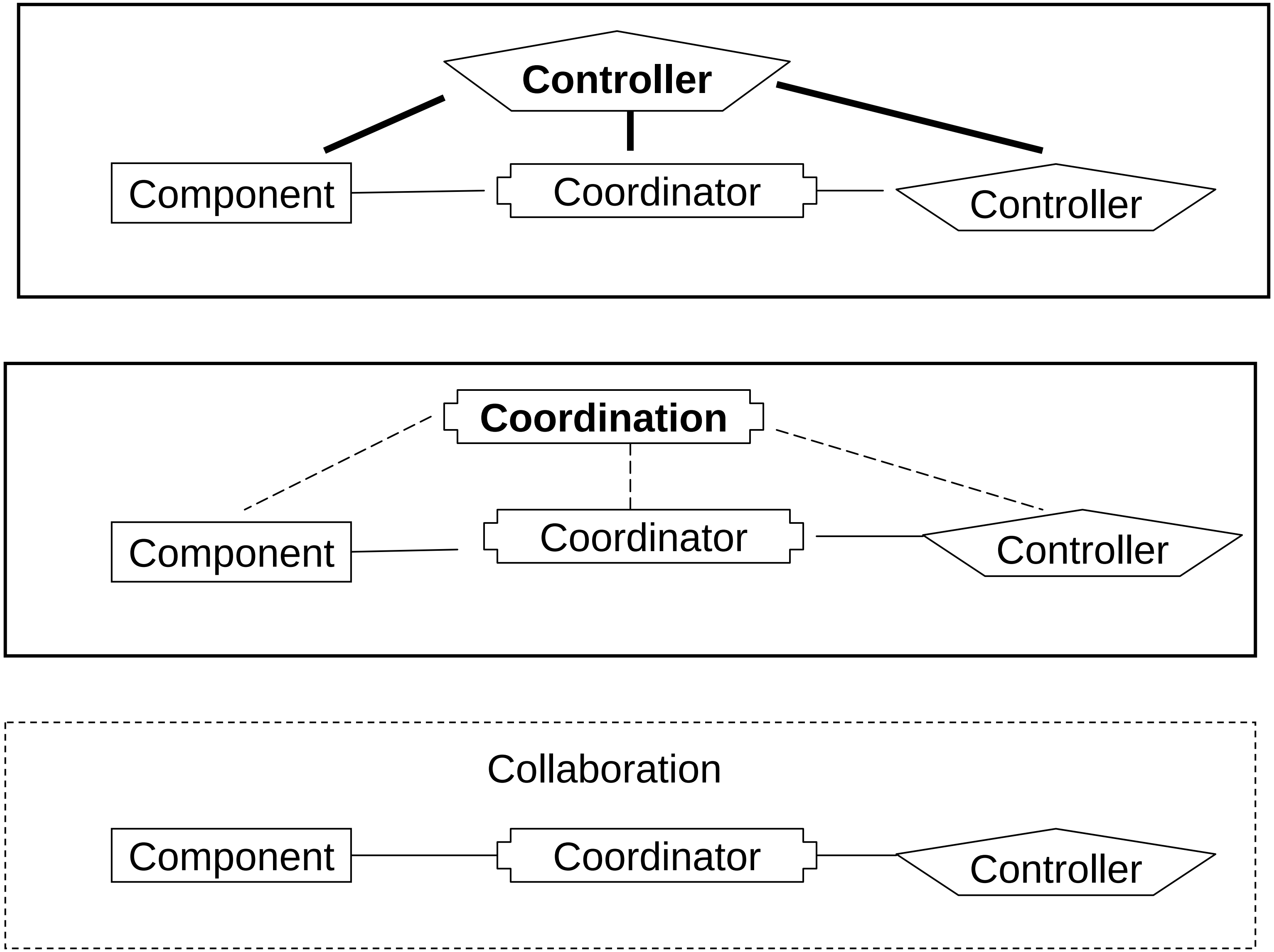
Structures in Complex Systems

- **Component** = Basic element of functionality in the system. Intrinsic behavior under environment influences.
- **Collaboration** = Interactions without macroscopic coordinators. Behavior influenced by peer-to-peer interactions.
- **Coordination** = Interaction possibly managed by coordinators to support group goals. Behavior influenced by group dynamics.
- **Control** = Interactions directed hierarchically to foster global goals. Behavior constrained by controller.
- All of these structures can be present in a system of systems and can be mixed and combined recursively

Complex Systems Properties

- **Emergent -** Collaboration**,** Coordination and Control dyanmics can arise that is not easily predictable from component dynamics
- **Multiscale Interactive** – Component behavior can influence coordinators
- **Non-equilibrium Metastable** – Collaborations and coordinations can undergo large changes in response to small inputs
- **Evolutionary Adaption-** Components, coordinators and controllers can adjust their behavior as environments change
- **Self Organizing -** Coordinated behavior can take place among components without centralized guidance

Complex System Structures



Structures in Complex Systems

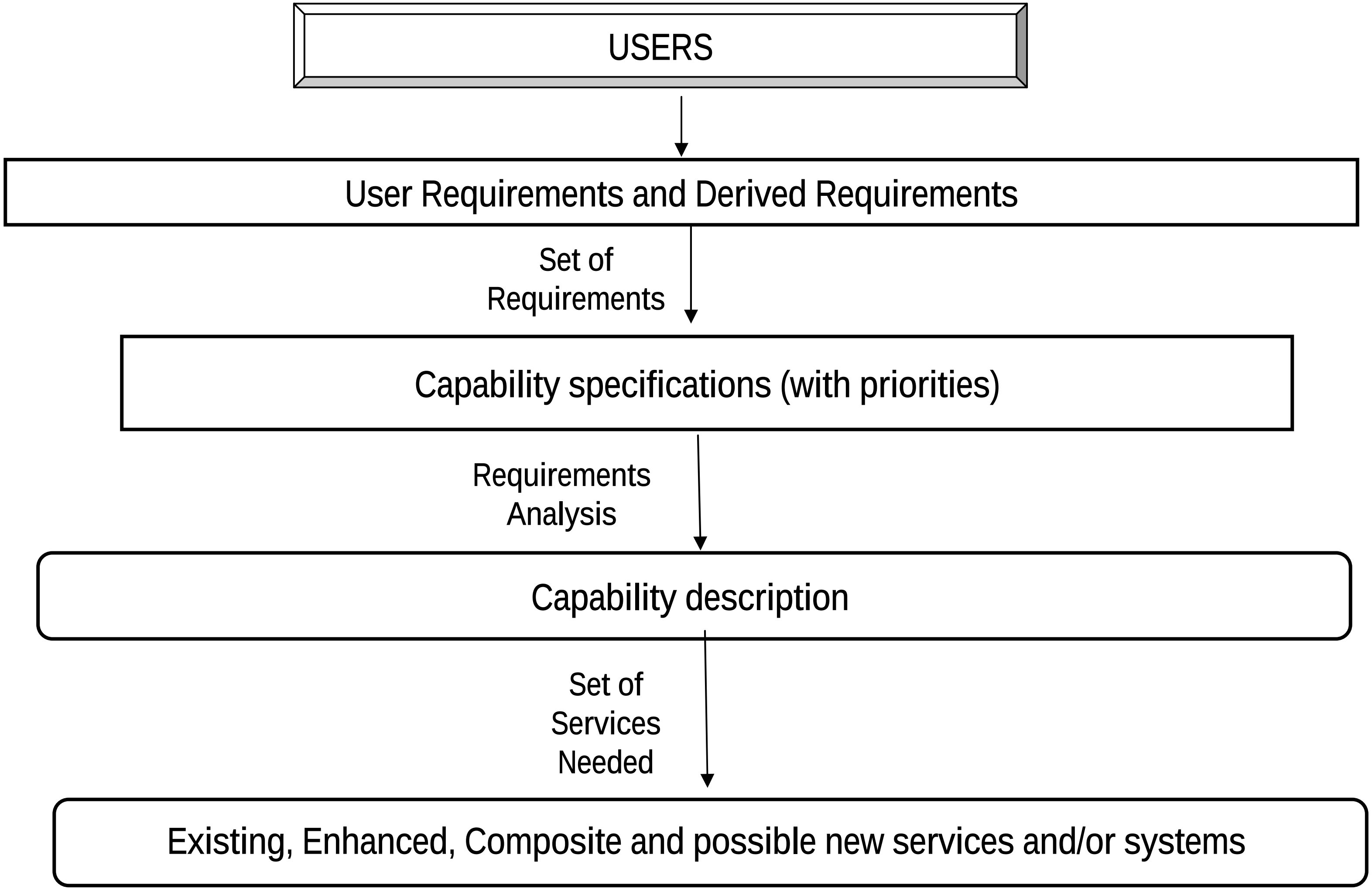
Components	**Collaboration**	**Coordination**	**Control**
Have dynamics and/or goals	Individual dynamics and/or goals	Shared dynamics and/or goals	Global dynamics and/or goals
Capable of adaptable behavior	Individuals adapt	Individuals and coordinators adapt	Controllers adapt
Individuals	Interaction	Communities of Interest	Enterprise
Molecules in Chemistry	Gas	Liquid	Solid
No coupling	Loose coupling	Cooperative processes	Tight coupled
Citizens in Government	Town Meetings	Representatives	Authoritarian
Computers in network	Internet	Extranet	Intranet
Neurons in Neurodynamics	Nervous System	Brain Cerebellum	Cognitive system

Complex Systems Engineering Strategies

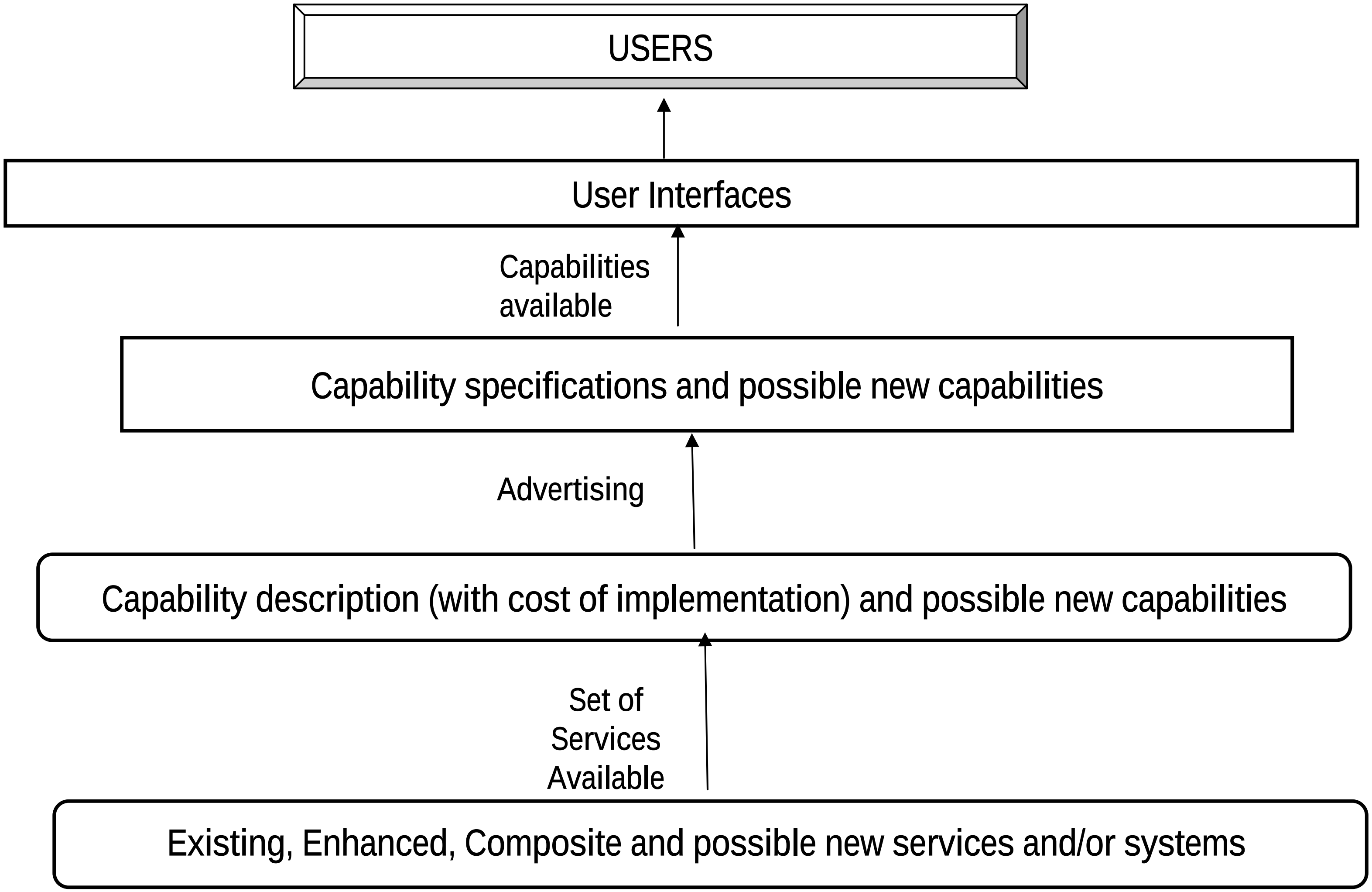
- Bottom up – Self-organizing, Emergent collaboration and coordination from interactions.
- Top down - Traditional systems engineering, Pre-defined coordination and interactions
- Matchmaking – Coordination is based on matching and combining existing components to meet requirements
- Middle Out – Coordination combines existing components and collaborations but also drives new requirements, collaborations and components

Note: Alternate strategies can be used in different stages of engineering

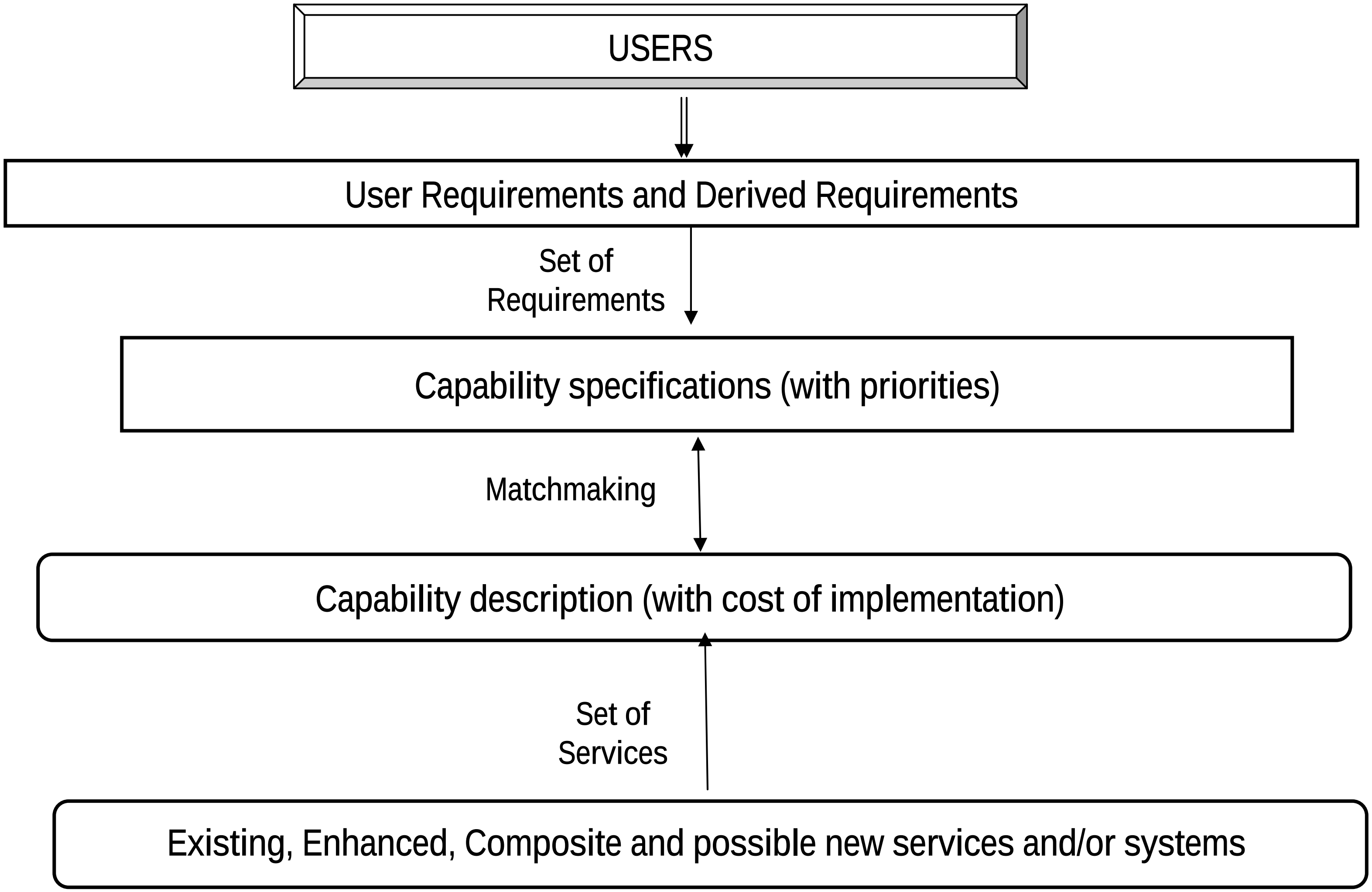
Top Down Design (Control-based)



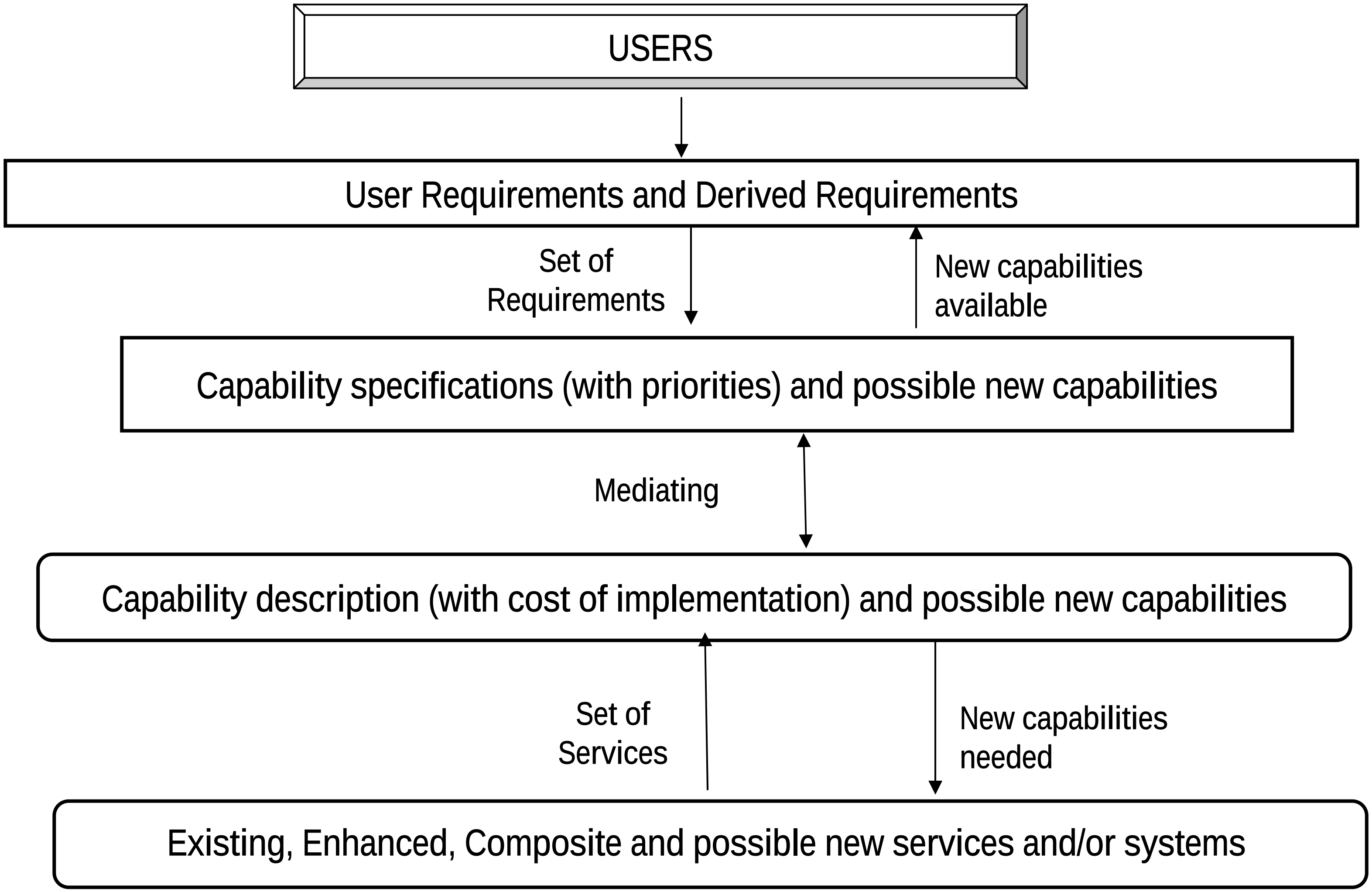
Bottom Up Design (Collaboration-based)



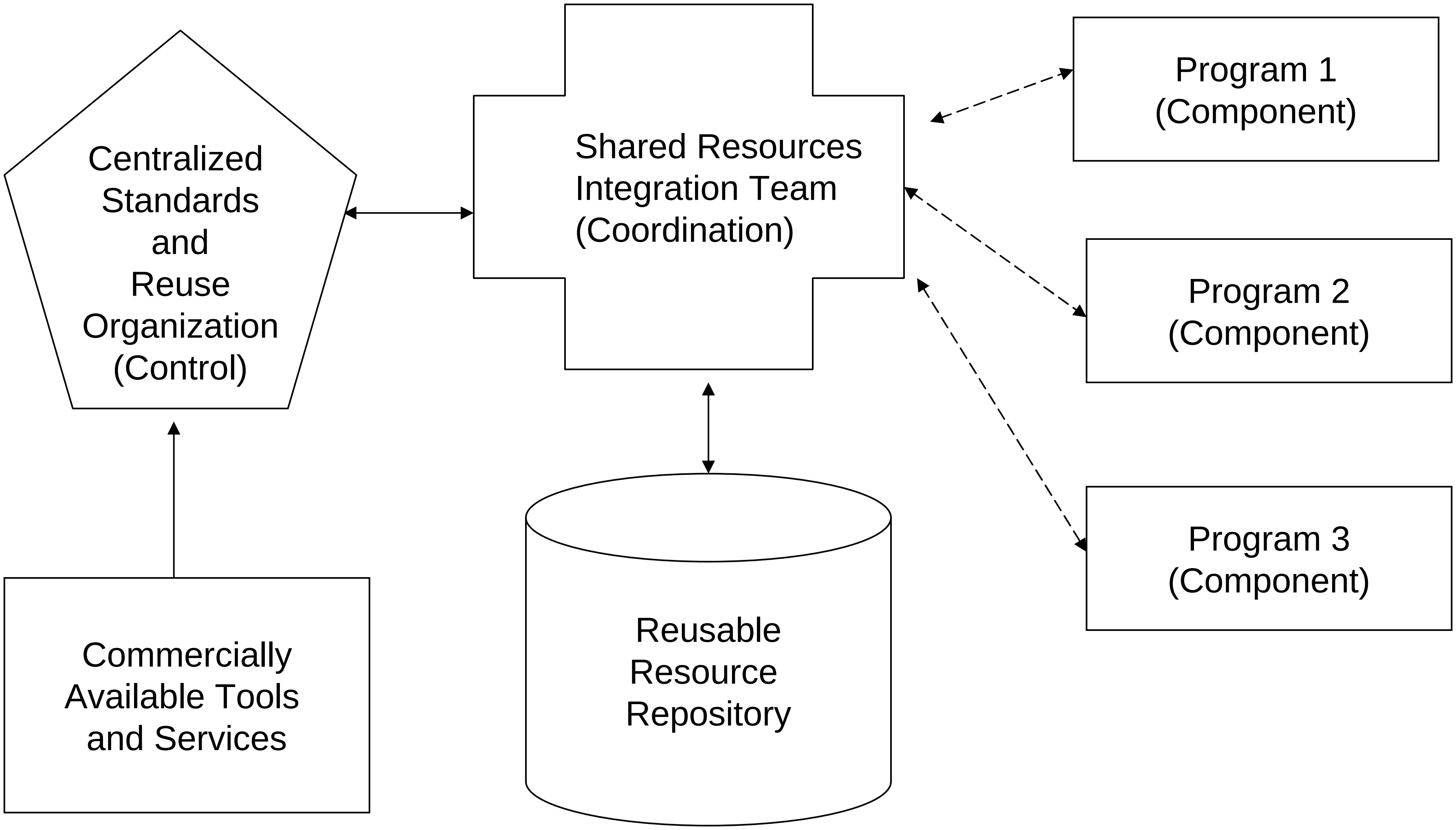
Matchmaking (SOA Orchestration)



Middle Out Design (Coordination-based)



Shared Resource Integration Process

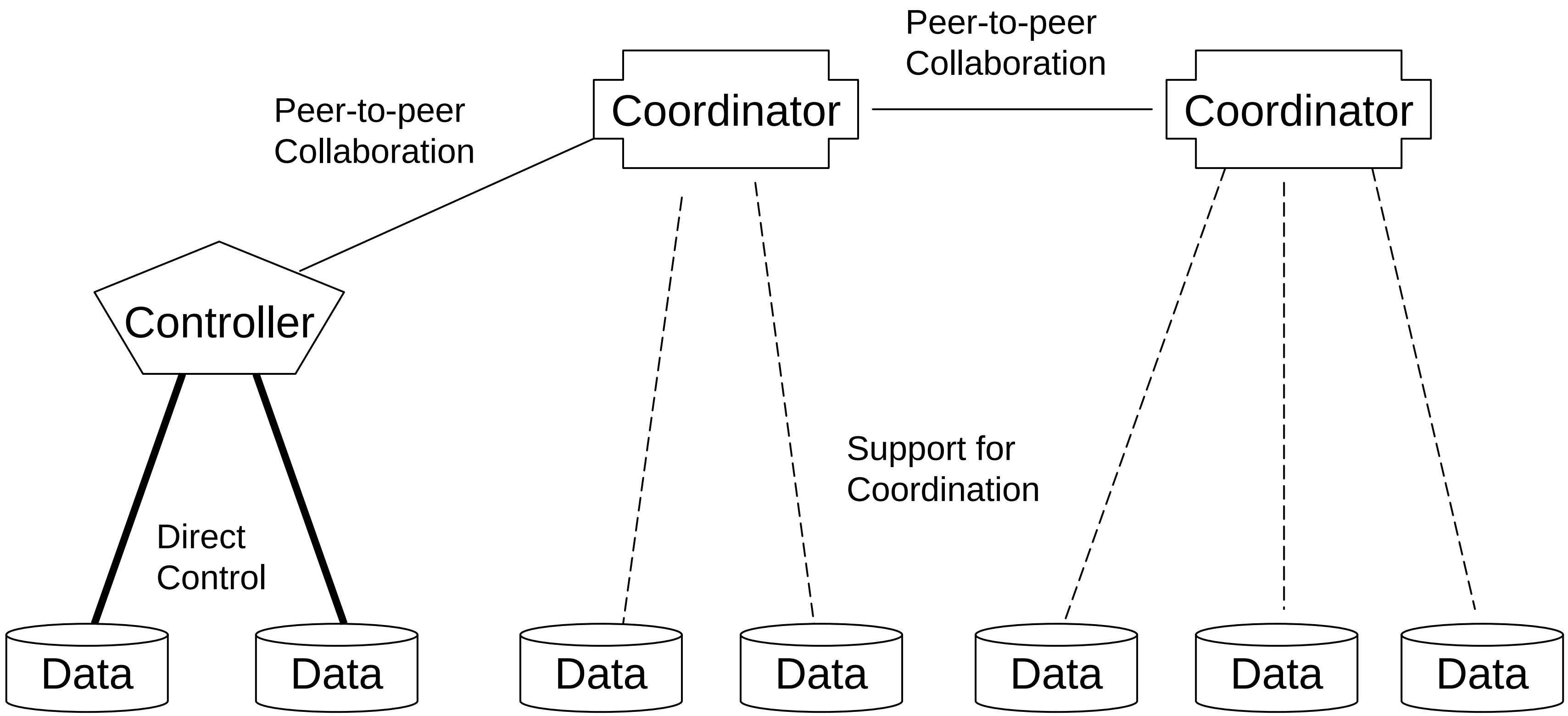


Foundation Information Grid (NCOIC Demo)

Foundation Information Grid

- Components – Diverse data bases and physical storage with application program interfaces.
- Control – Components under a single organization. Data access controlled by management. Can be viewed as a high level component.
- Coordination – Components under diverse management use shared metadata and data access through a Coordinator. (Storage Resource Broker (SRB) from UCSD).
- Collaboration – Data sharing across coordination zones using metadata mappings and middleware. Cooperation across communities based on need to share.

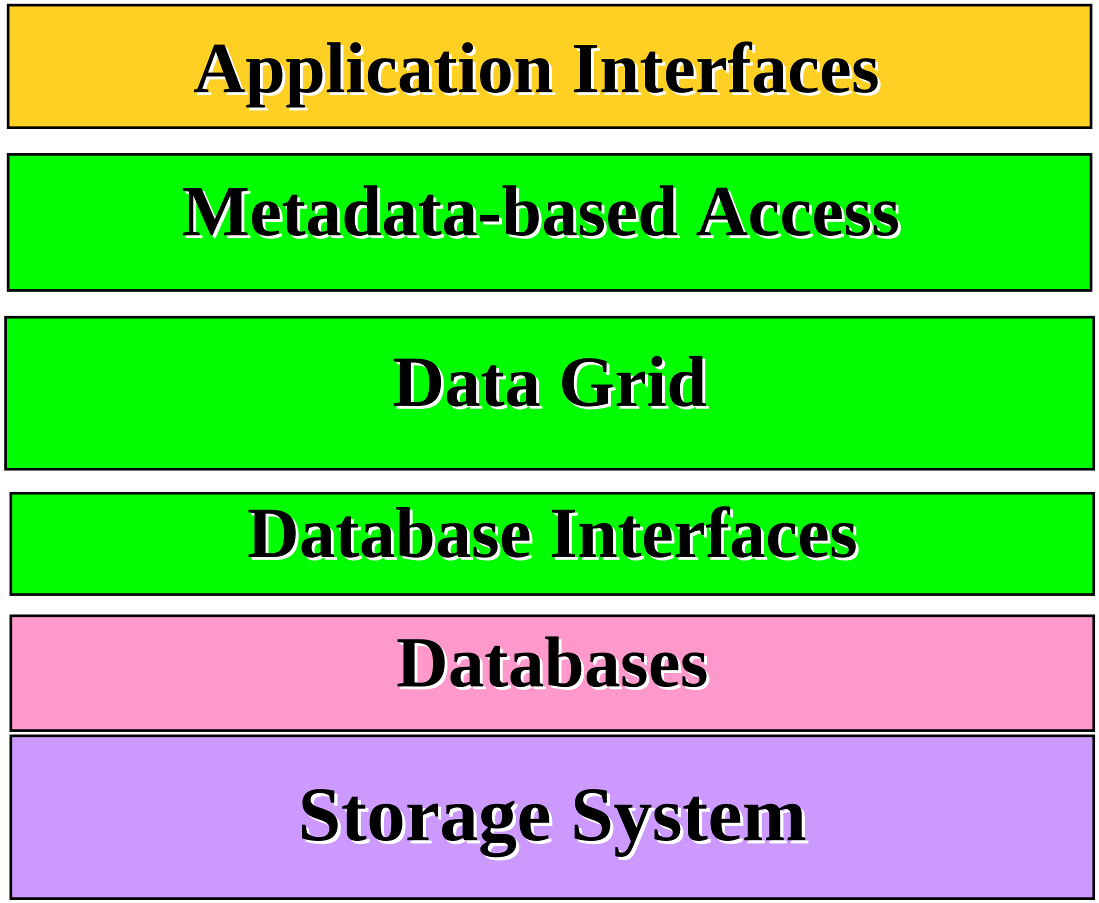
Foundation Information Grid



Foundation Information Grid Strategy

- A Community of Interest (COI) is a group of users who have agreed to collaborate and have a centralized process for defining shared capabilities
- COIs define an architectural framework for their components
- The components are placed in the framework to implement a COI coordination for users
- Multiple COIs can voluntarily collaborate to share a subset of their coordinated components
- Communities of Interest must agree on interoperability standards for the shared collaborative capabilities

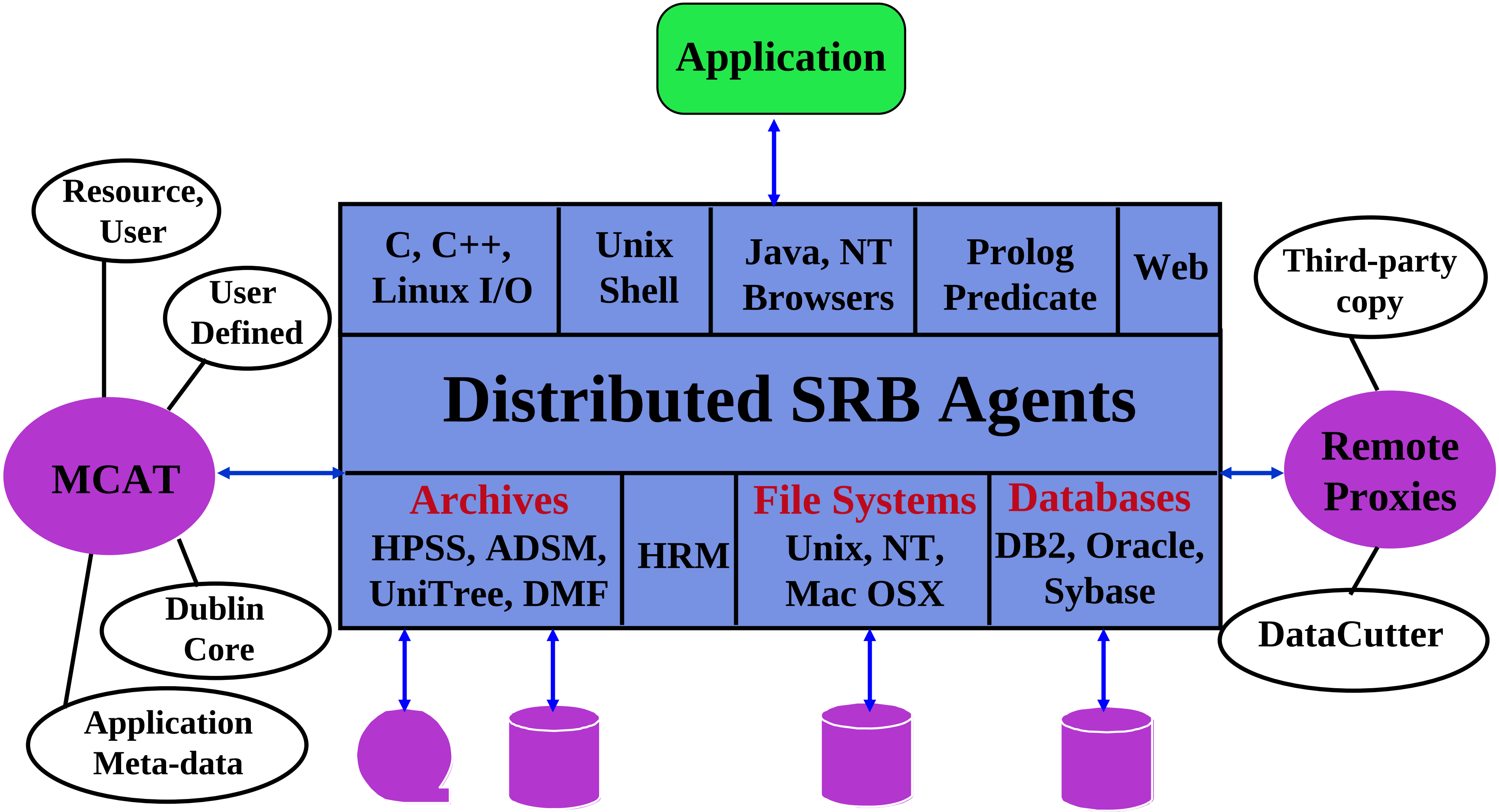
Application -> SRB -> Data



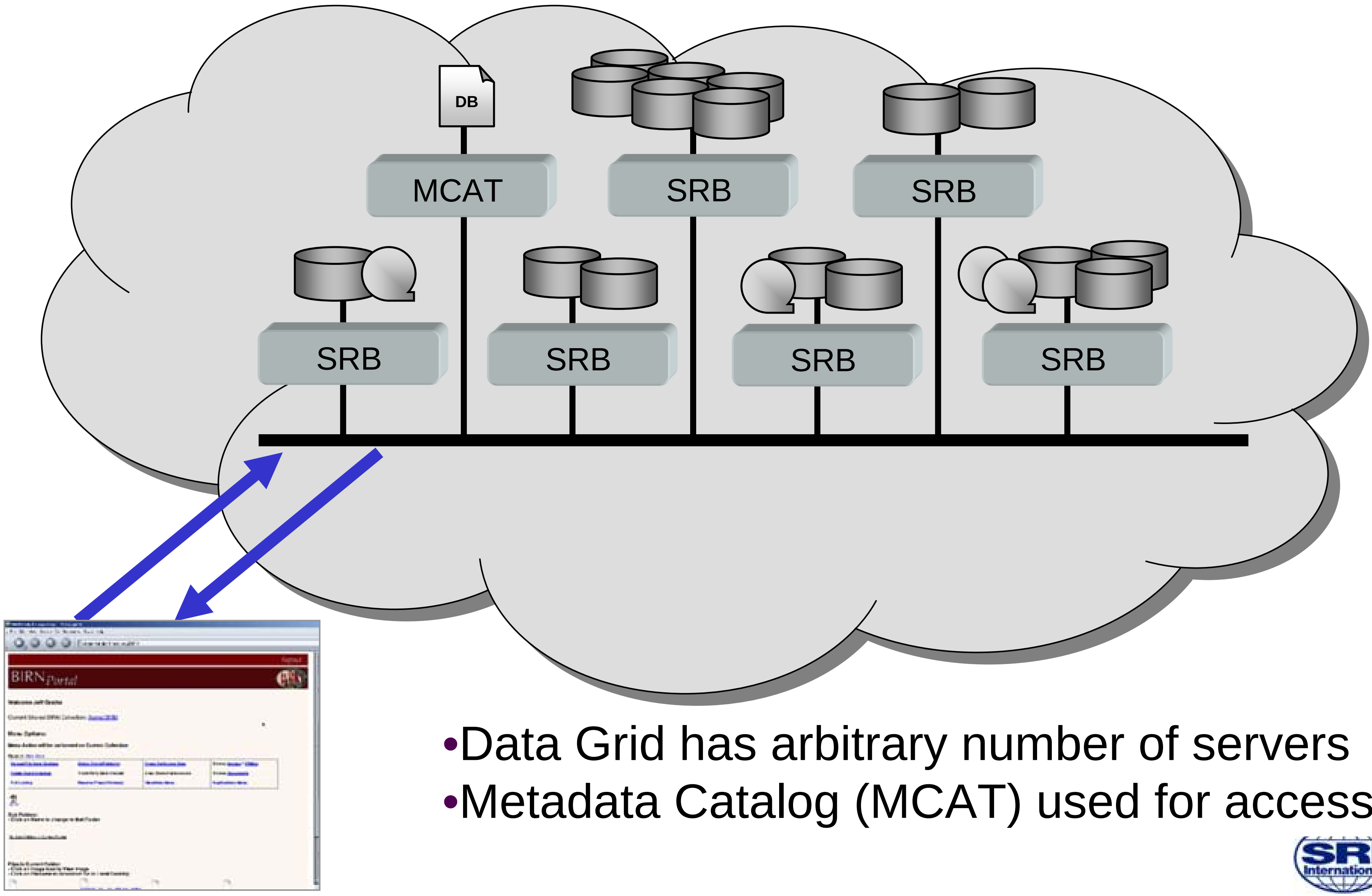
The SRB (Storage Resource Broker) is middleware that supports multiple application interfaces to diverse databases and storage systems

Next four slides produced by collaborators at UCSD SRB Group

Storage Resource Broker

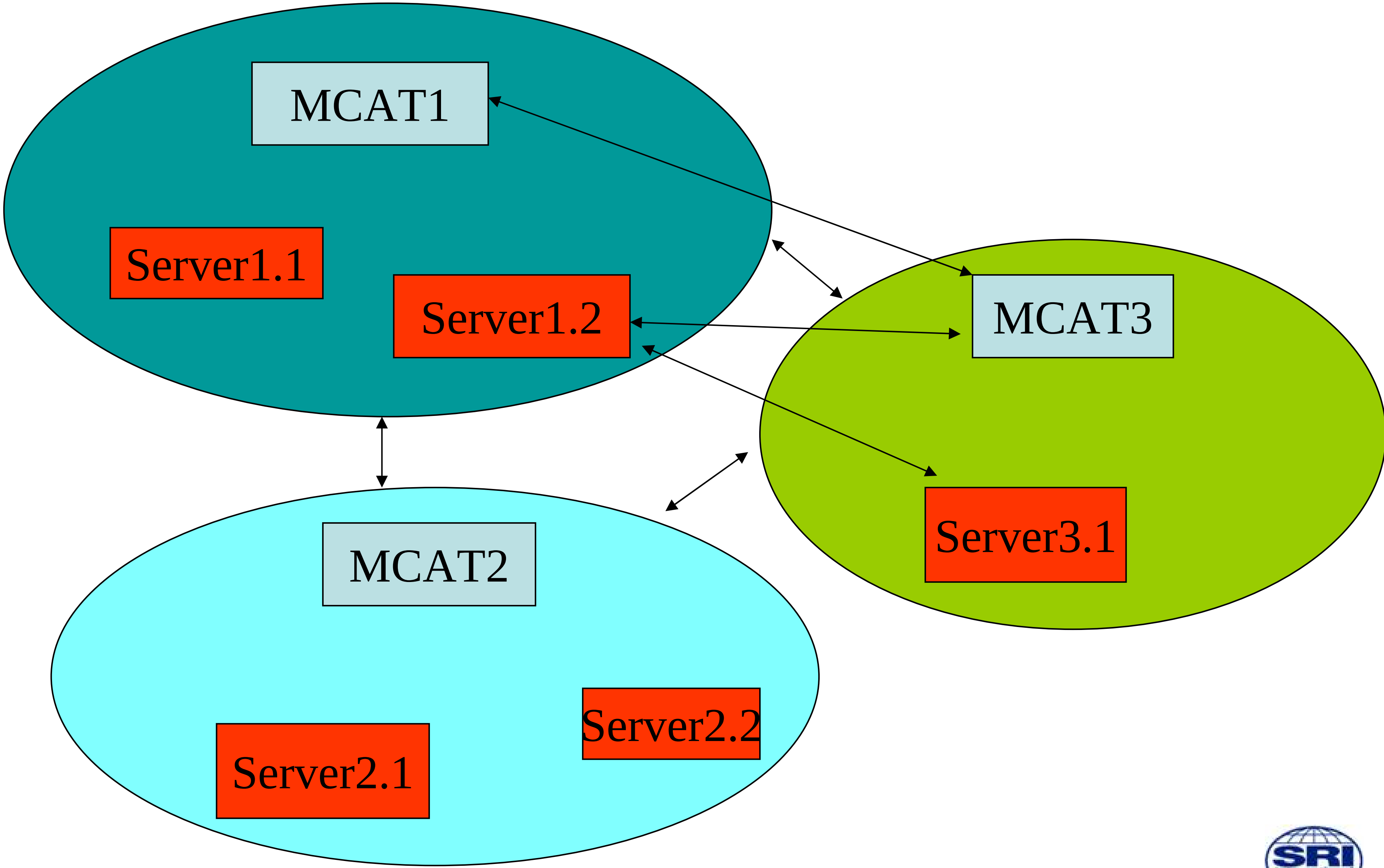


SRB Data Integration Zone (Coordination)



- Data Grid has arbitrary number of servers
- Metadata Catalog (MCAT) used for access

Collaboration Across Zones



Next Steps

- Determine user requirements for the Global Information Grid
- Work with groups responsible for standards and implementation of core services for Global Information Grid
- Develop a coordination strategy matching Foundation Information Grid capabilities and end-user requirements

Conclusions

Questions from 1995

- What are the basic laws of the scientific discipline of complex systems?
- What are the generic principles for complex systems engineering?
- Is it possible to build customizable generic tools for the modeling, simulation, and analysis of complex systems?
- How can we maintain systems with constantly changing requirements?
- Is there a management strategy for dealing with systems that are too complex for individuals or small groups to understand?
- Are there unique characteristics of complex systems that are composed primarily of multiple intelligent entities, both human and non-human?
- How can non-adaptable system elements be reengineered, and can adaptability be 'designed into' complex systems in the first place?

Final Thoughts

• The fundamental change that complex systems bring to systems engineering is the need to create federated coordination strategies in addition to control algorithms.

• Implementing this new paradigm will require extensive research in many disciplines during the next decade.

• Due to the broad fundamental impact of complex systems engineering, there should be a coordinated initiative to support research projects in this domain.