Large-Scale System Integration with DDS for SCADA, C2, and Finance

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What do I mean by “large system”?

- **Systems of systems**
  - Modular, hierarchical design
  - Legacy components, subsystems
  - Multiple technologies
  - Global scale
- **Decoupled subsystem lifecycles**
  - Independent development
  - Independent deployment and use
  - Independent management
  - Independent revision and retirement
- **Multiple communities of interest**
  - Different data interest, entitlements
  - Non-uniform levels of trust

What matters to integrators of large systems?

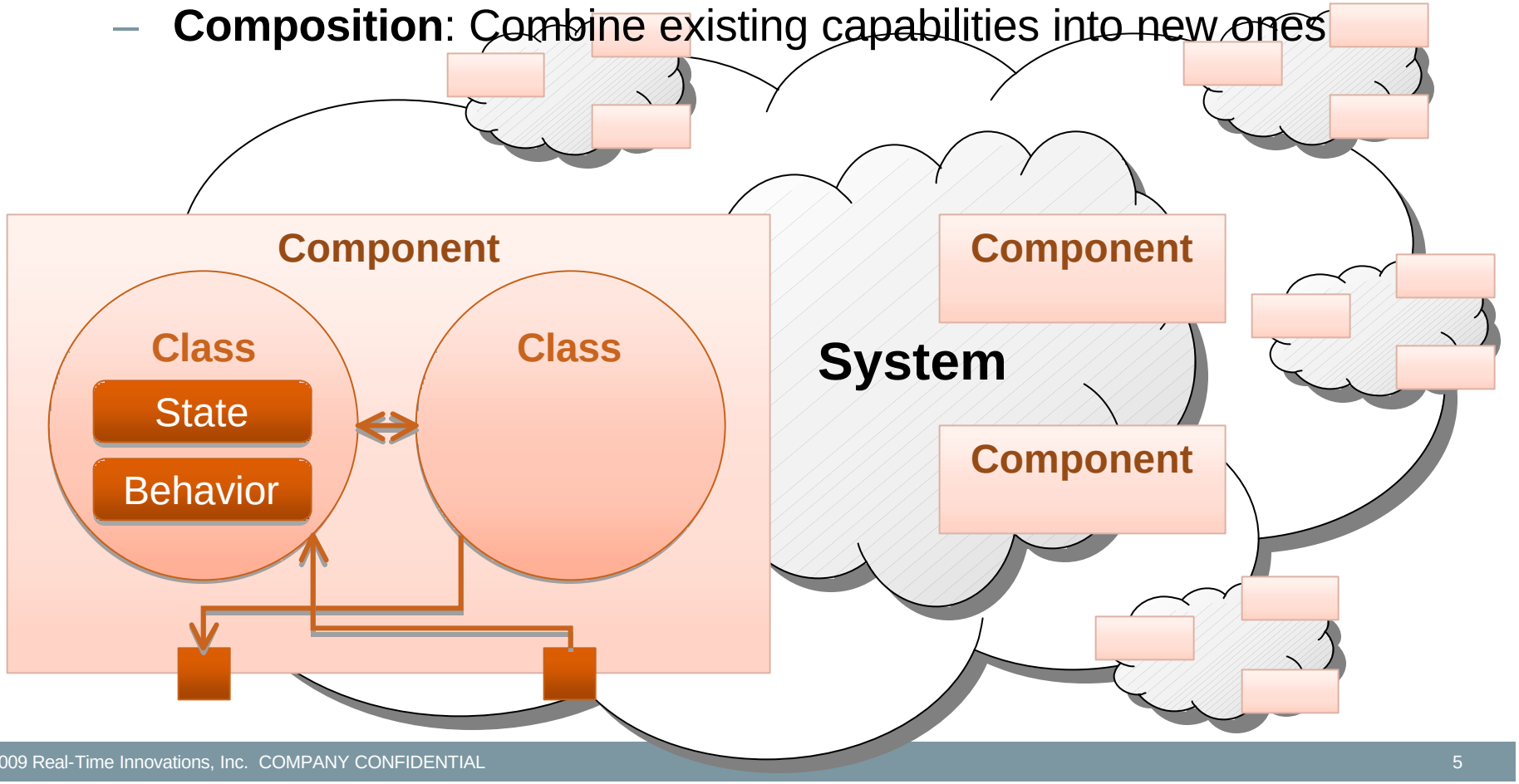
- **Governance**
  - **What** information will be exchanged?
  - **Under what conditions** will it be exchanged?
  - **Who** is allowed to exchange this information?
  - **If these SLAs are violated**, can the exchange be prevented? Can I be notified?
  - **In the past**, what has occurred wrt these SLAs?
- **Isolation**
  - When I connect A and B, ensure they don't break (each other)
  - When I disconnect A, ensure B doesn't break
  - When I connect C, don't change A or B
- **Scalability** *(like in any system,*
- **Fault Tolerance** *but stakes are higher)*

Part 1: Architecture

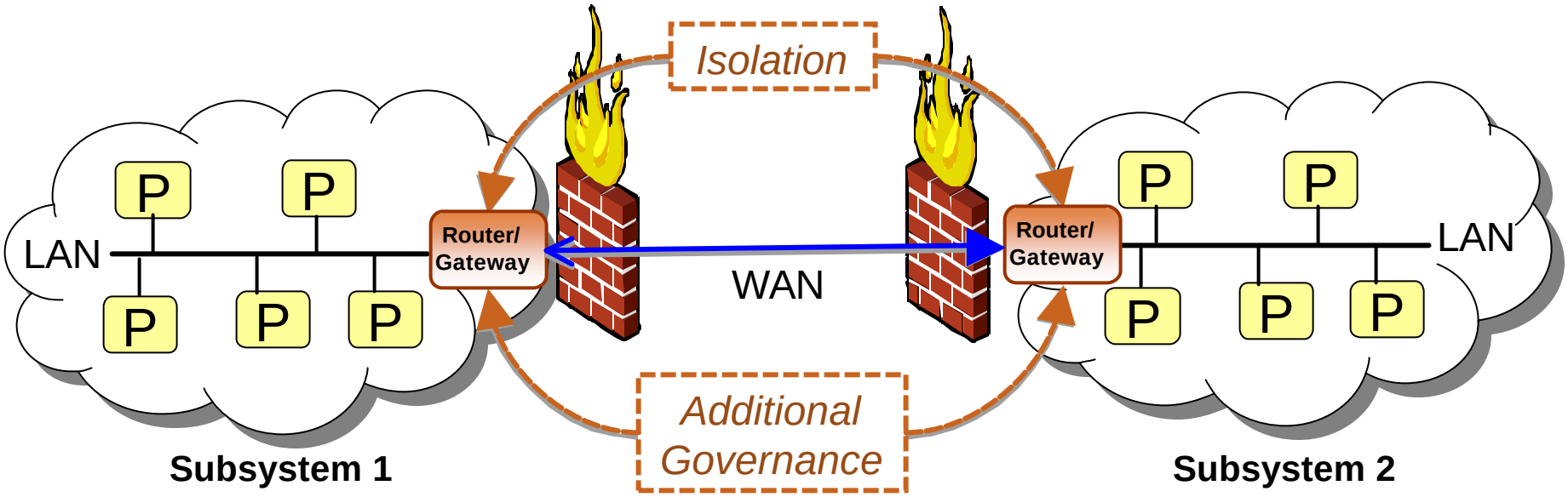
(we'll get to technology later)

A Modest Proposal

- ***Fundamental design principles scale***
  - **Abstraction**: Provide interface based on relevant concepts
  - **Encapsulation**: Hide internal implementation, communication
  - **Composition**: Combine existing capabilities into new ones

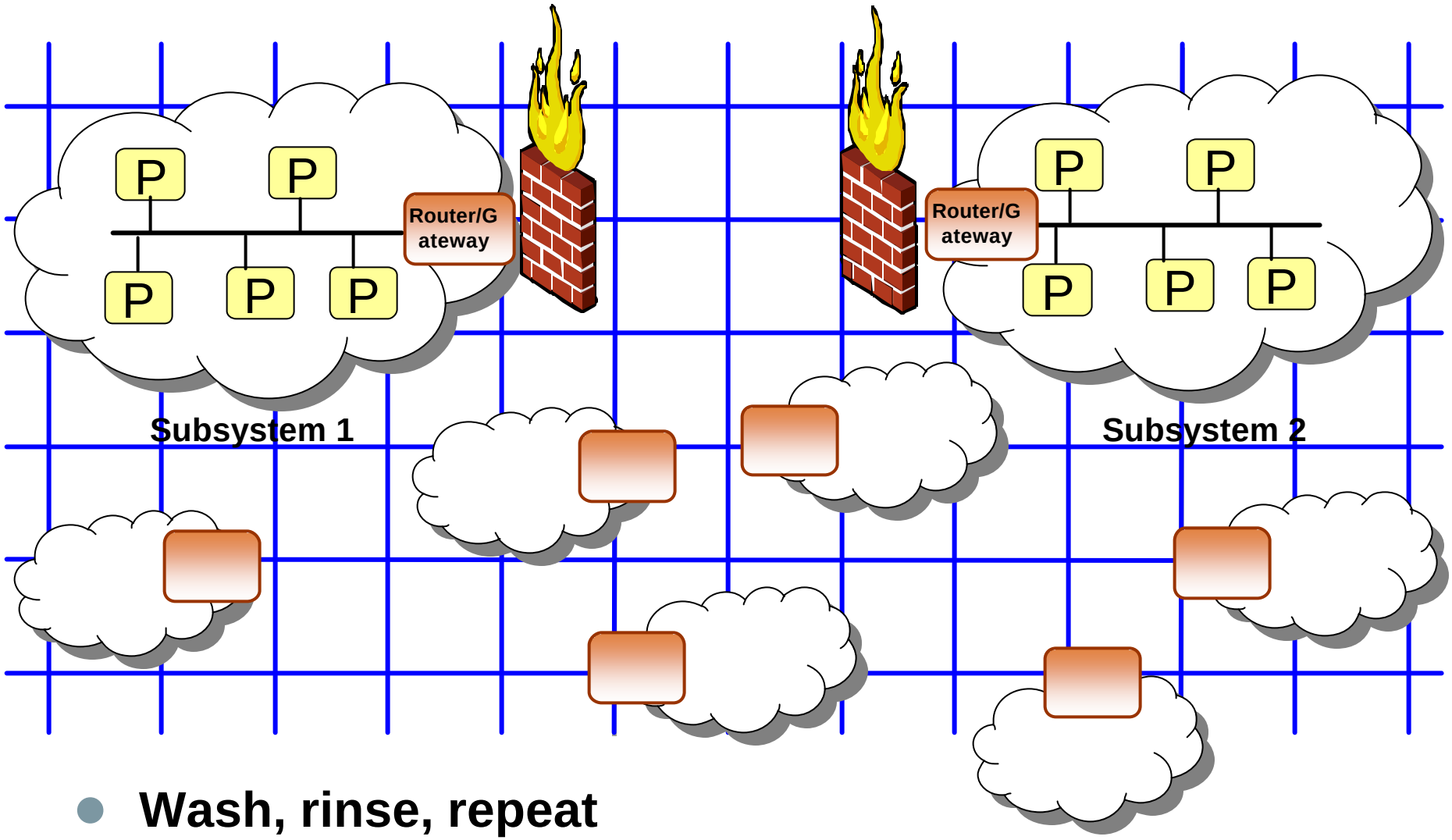


Schematic of a Composed System



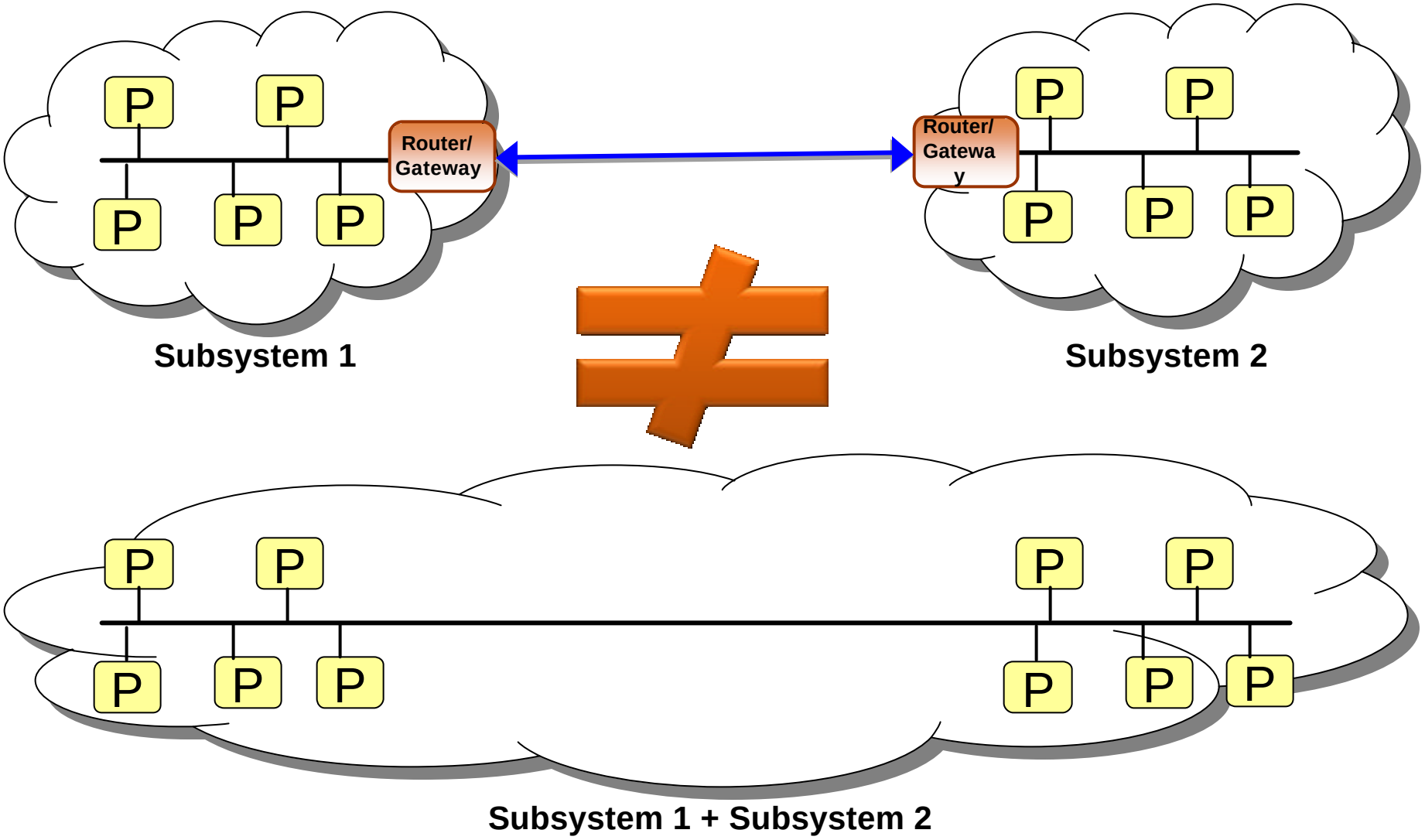
- Subsystems may have different network environments
- Integration may have different network environment than subsystems themselves
- Data may need to be transformed/cleansed as it moves among subsystems
- *Routing/gateway services will adapt data types / formats / protocols*

Schematic of a Composed System

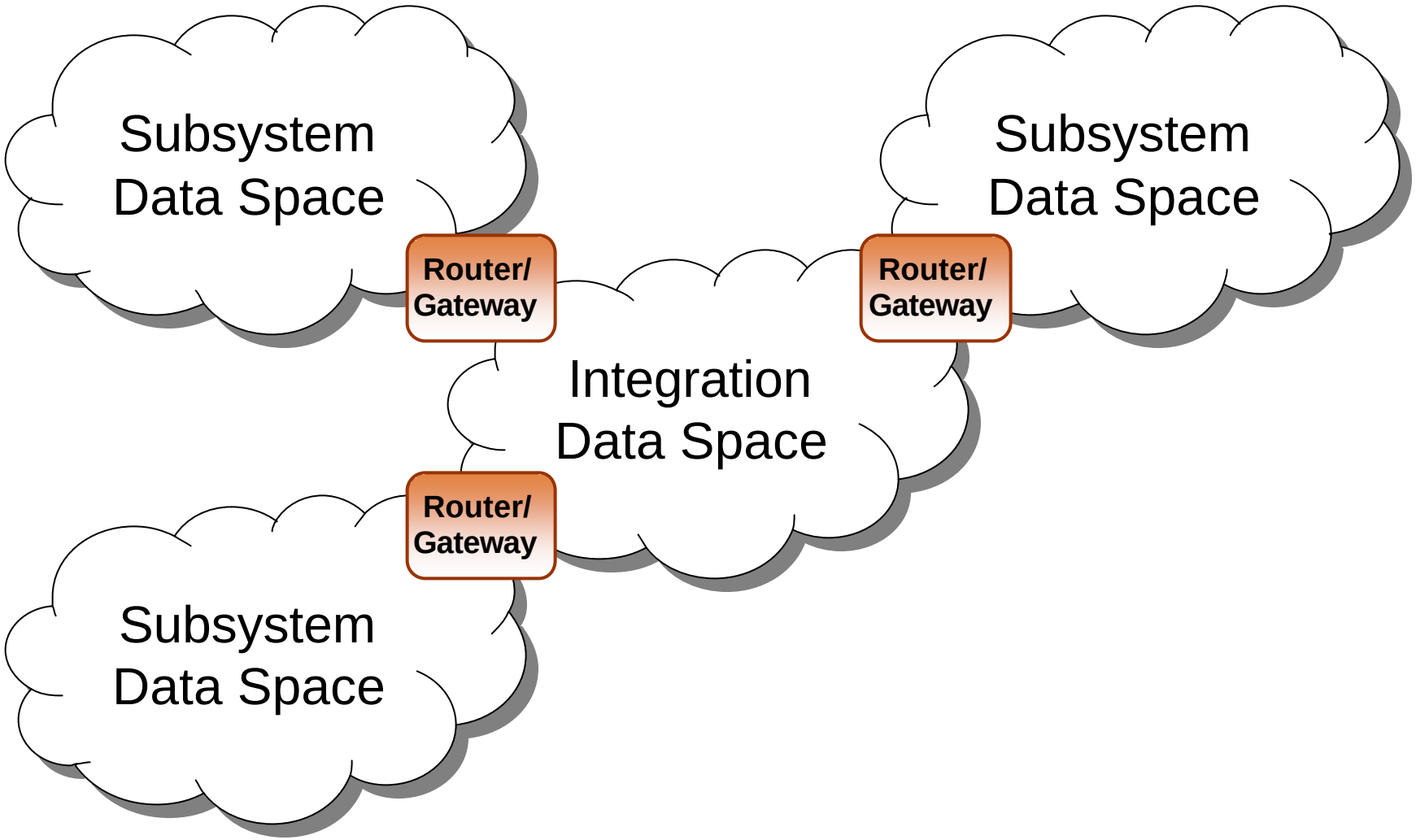


- **Wash, rinse, repeat**

Apples and Oranges



Nothing New Under the Sun



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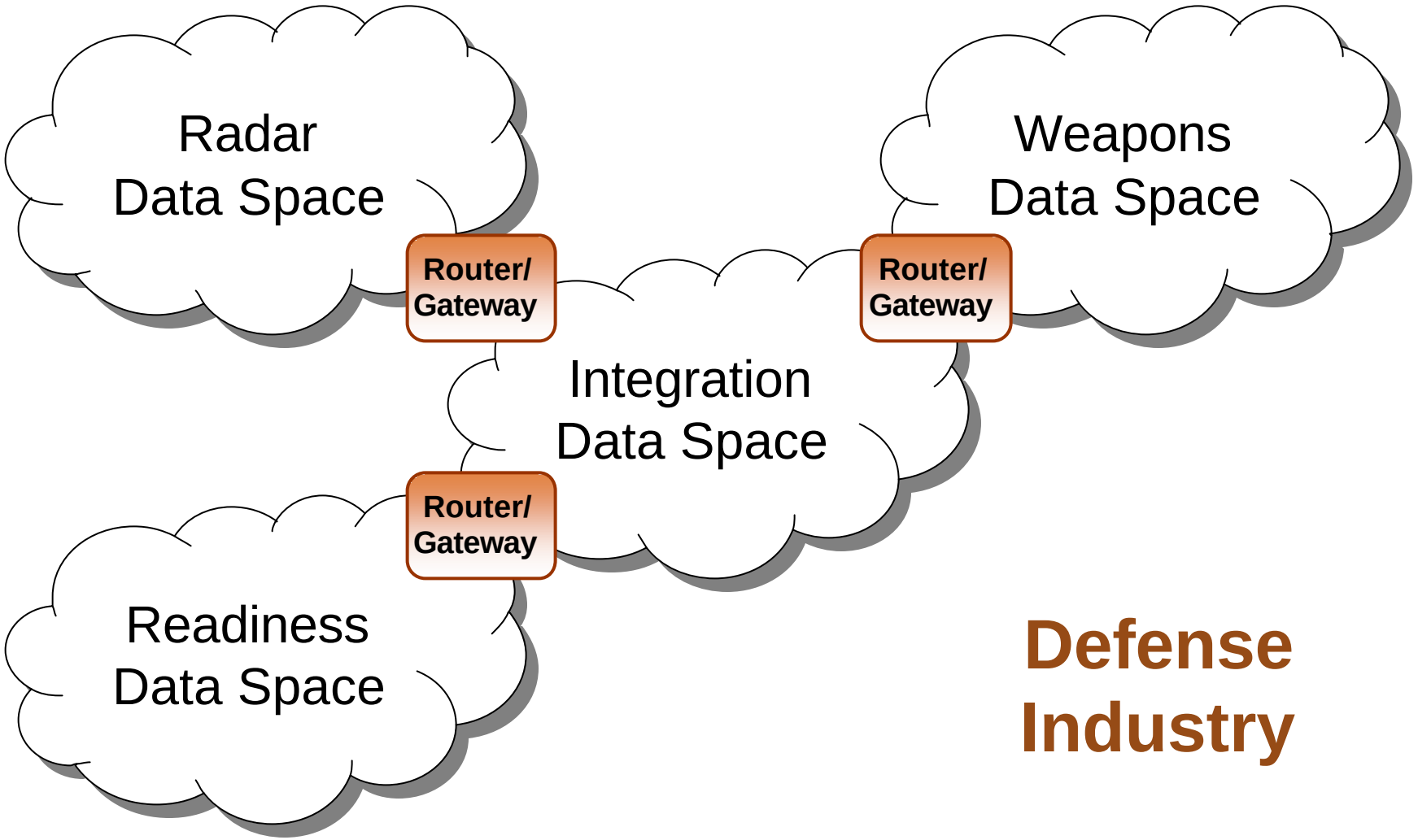
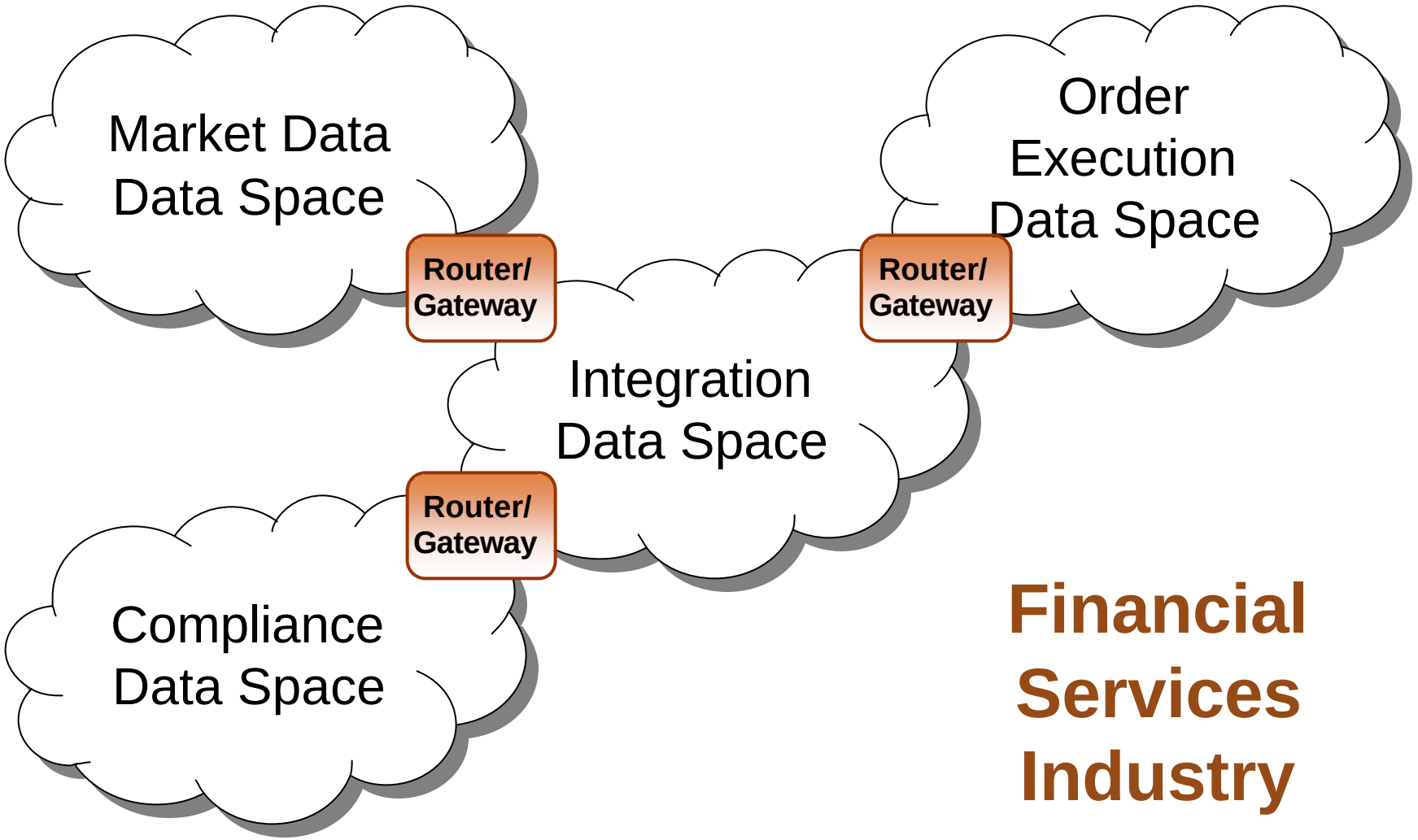


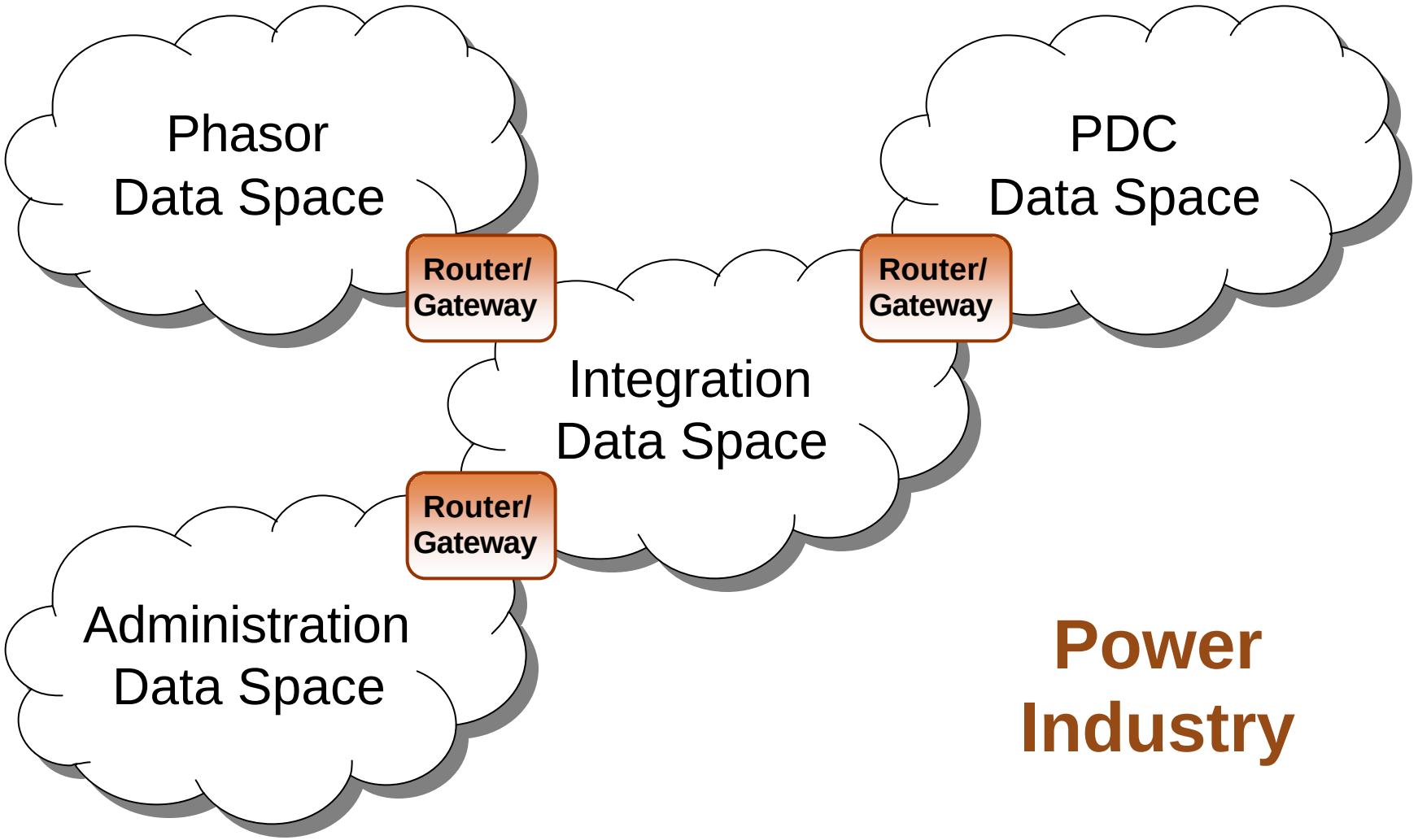
Defense Industry

Nothing New Under the Sun



Financial Services Industry

Nothing New Under the Sun



Power Industry

Architecture Recap

- Solve big problems like you solve small ones
  - Break them into pieces
  - Define interfaces between pieces
  - Implement each piece
  - Integrate along the interfaces
- Translation
  - Define subsystems
  - Implement them how you like
    - May have different requirements, therefore technology
  - Router/gateway defines/enforces interfaces

Remaining Problems to Address

- **Fault tolerance**: Router can't be single point of failure
  3 answers:
  - Persistent data survives system failures
  - Segmented/load-balanced configuration limits scope of failures
  - Redundancy allows continued service during failure

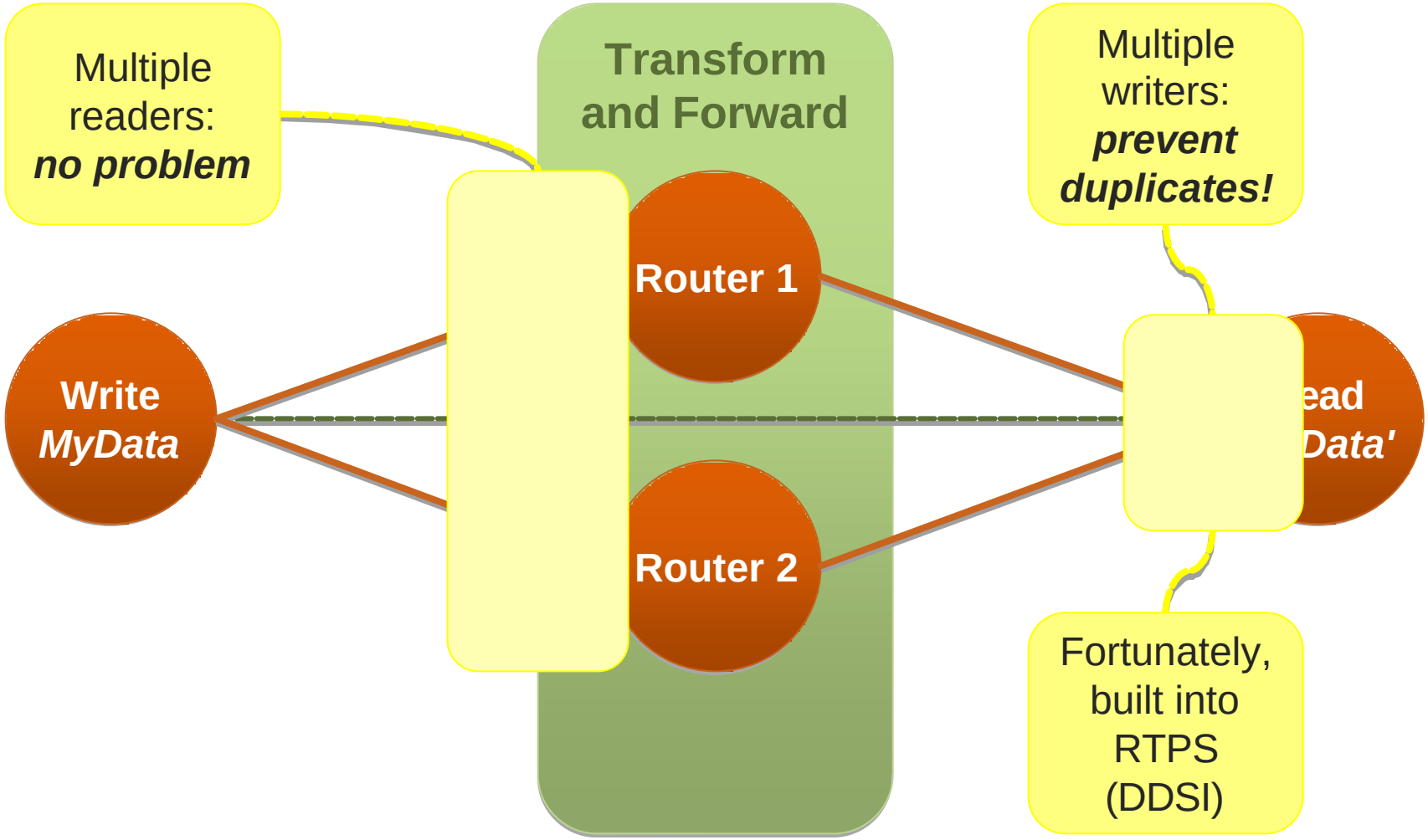
- **Scalability**: How big can a subsystem be?
  1. How big a subsystem can you understand, test, and debug?
  2. How well does infrastructure scale?

Part 2: DDS

How Does DDS Stack Up?

- Governance
  - Structural SLA: data type — Built in
  - Behavioral SLA: delivery QoS — Built in
  - Security — Products available; future standards
  - Problem detection/prevention/notification — Built in
  - System monitoring and recording — Products available
- Isolation
  - Prevent data “leaks” and side effects — Built in: domains, partitions
  - Allow dynamic (dis-|re-)connection — Built in
  - Support independent integration and evolution — Built in, esp. w/ DDS-Xtypes
- Fault tolerance
  - Data persistence — Built in
  - Segmented/load-balanced routing — Built in if router uses DDS
  - Redundant routing — Built in if router uses DDS
- Scalability
  - WAN connectivity — Products available; future standards
  - Peer-to-peer communication — Highly scalable
  - Brokered/managed communication — Protocol support if necessary

Redundant Data Routing



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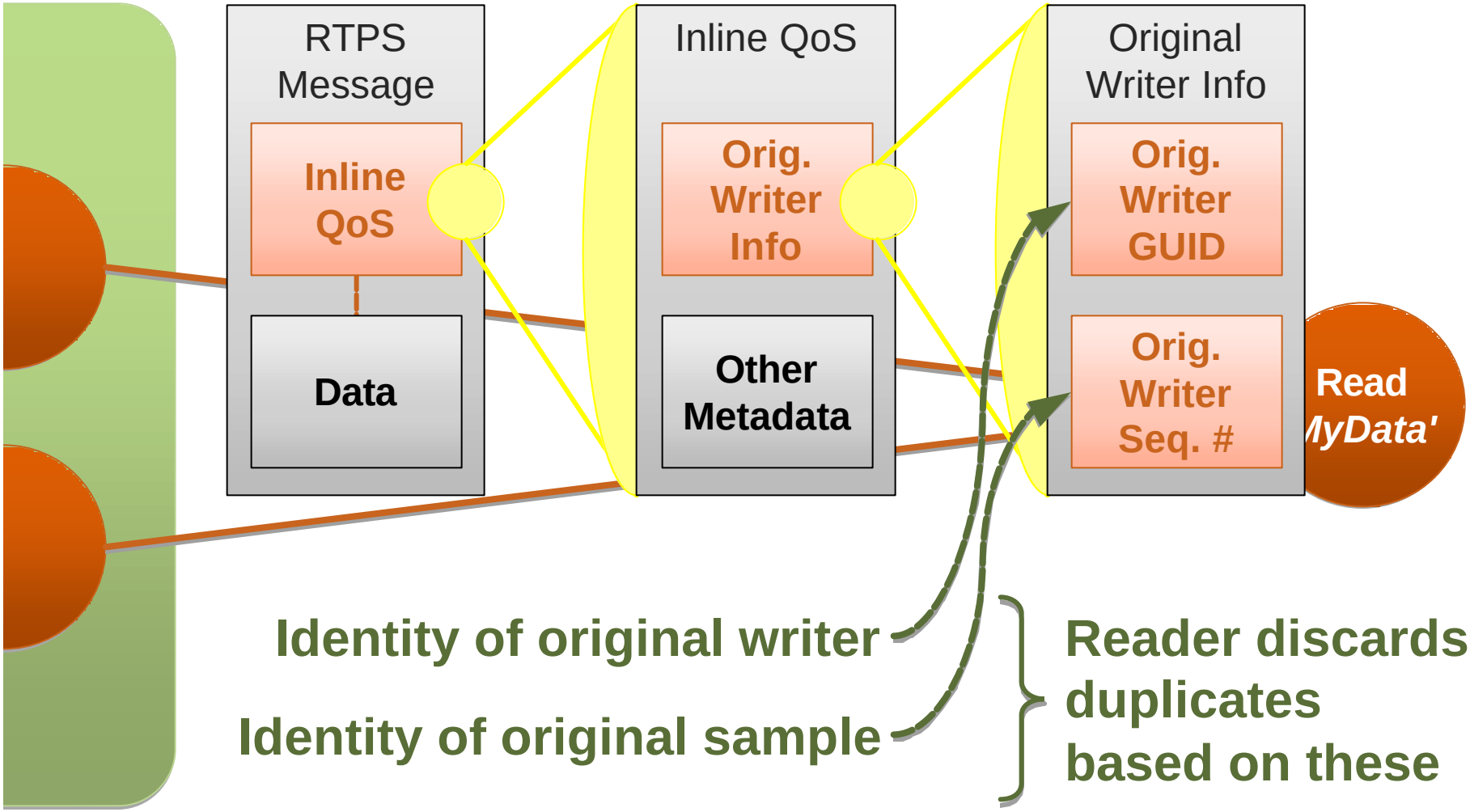
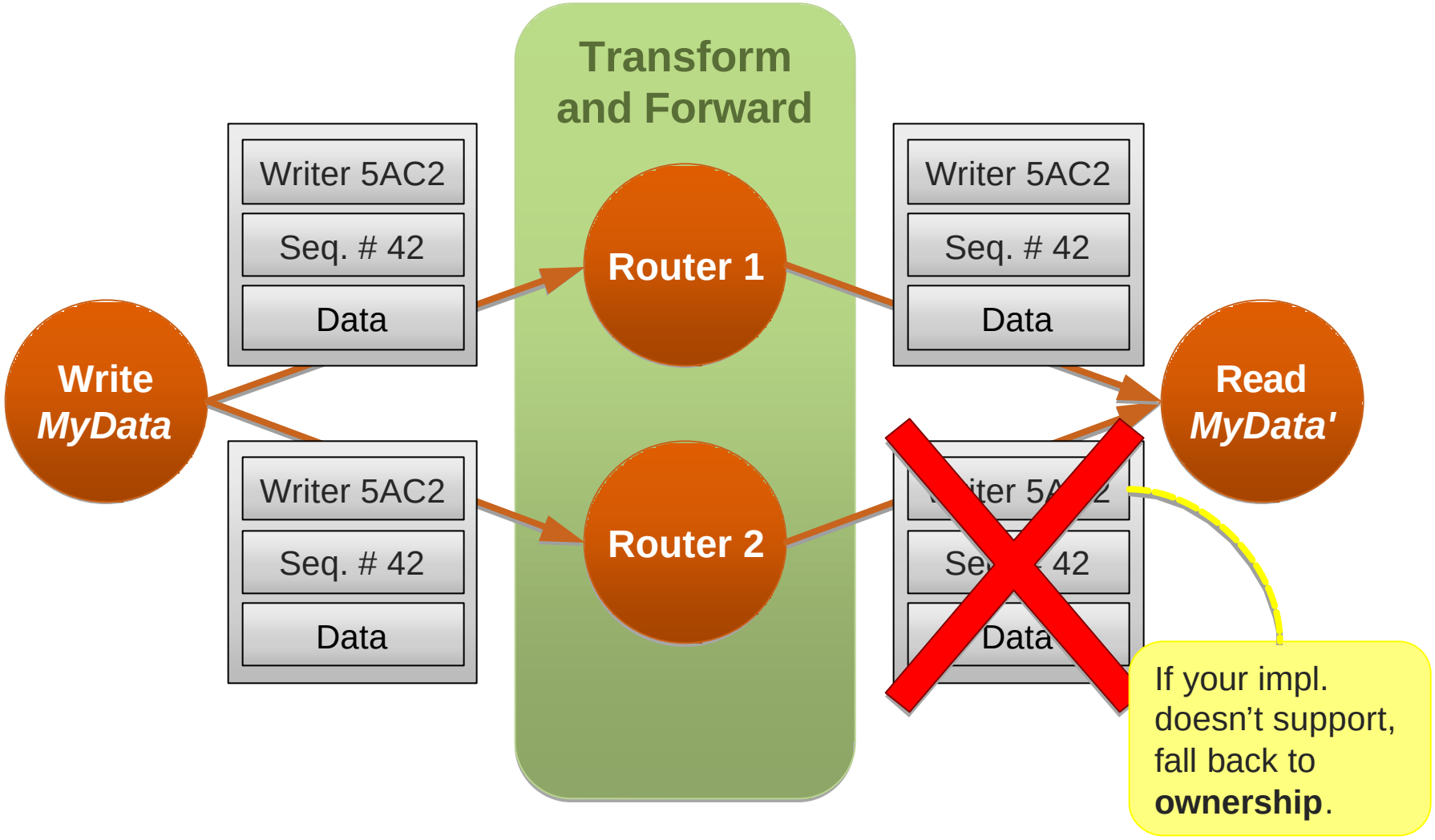


Redundant Data Routing

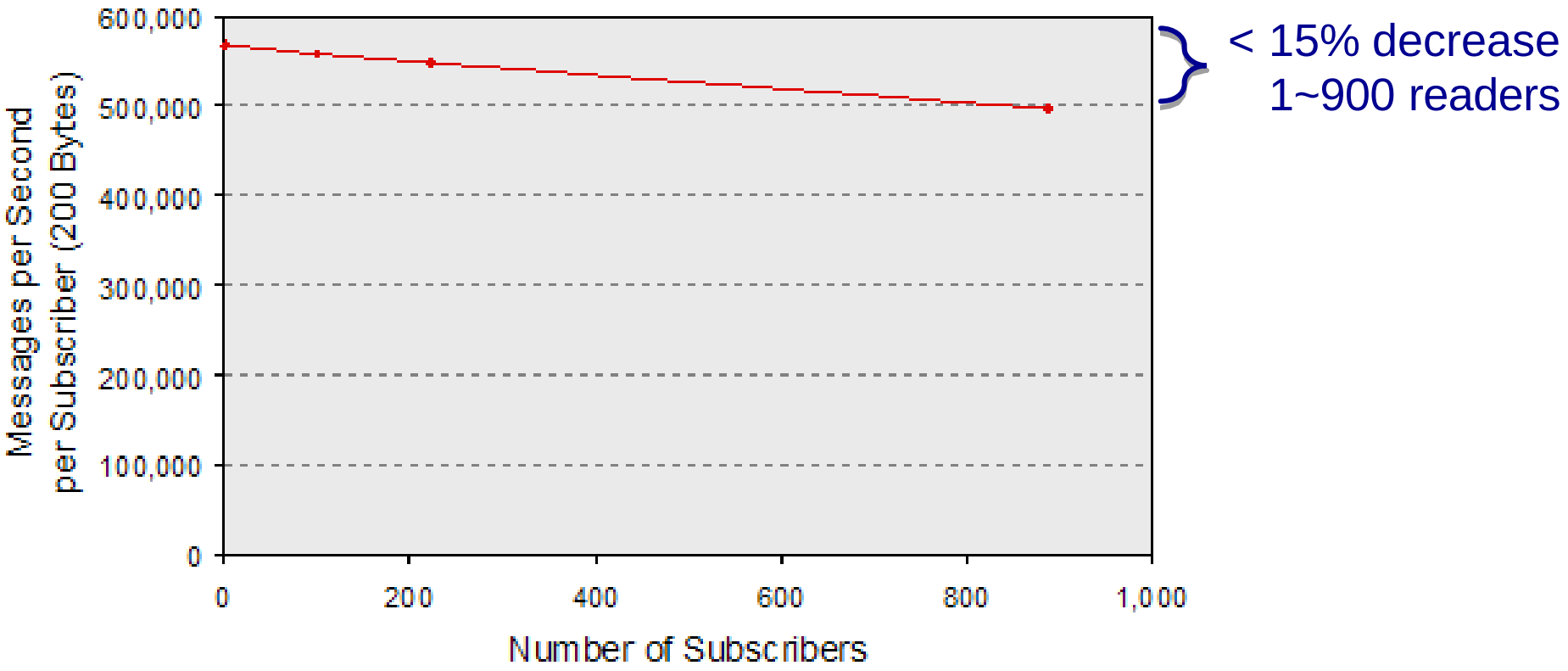


DDS Scalability: Two Aspects

- **Application data**
  - How does performance fall off as # participants, writers, readers increase?
  - Any single writer/reader pair can saturate gig-E: aggregate throughput is not main issue
  - *Interesting issue*: Fan-out – number of readers per writer
- **Discovery**
  - How many DDS applications can discover one another?
  - *Interesting issue*: How many applications *need* to discover one another?
- *Hard limits, if any, very dependent on DDS implementation, machine configuration, network, etc.*

DDS Scalability: Application Data

- RTPS reliable multicast scales *at least*:
  - …to hundreds of readers per writer
  - …with very little degradation in throughput.
  - Larger testing facilities welcomed. ☺



DDS Scalability: P2P Discovery Scenarios

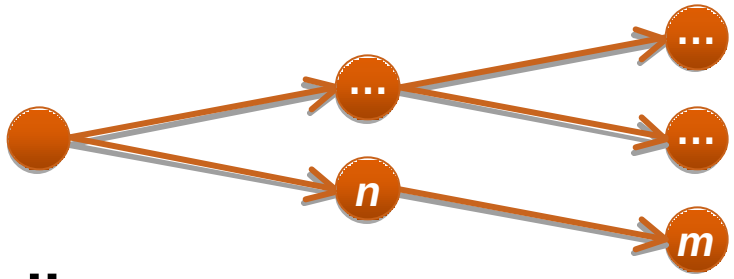
- **Single domain, symmetric discovery**
  - Everyone discovers everyone else
  - Easiest to configure; most challenging wrt scalability
  - *RTI test results*: **1,800 participants**; **3.2M endpoint matches**
- **Single domain, asymmetric discovery**
  - Each participant only knows of certain others in its domain
  - Good for partitioning domains in which not everyone talks

- **Multiple domains**
  - Greatest separation for subsystems that rarely exchange data
    - RTPS maps to different IP ports

DDS Scalability: Stronger Measures

- P2P RTPS allows participant to talk to at least 1-2K others (*based on current experimental data*)
  - My system is properly decomposed. Discovery is optimized. *But I still need to scale bigger.*

1. **Brokered application data**



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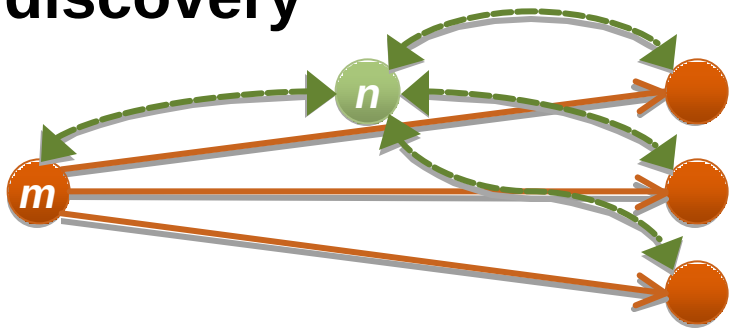
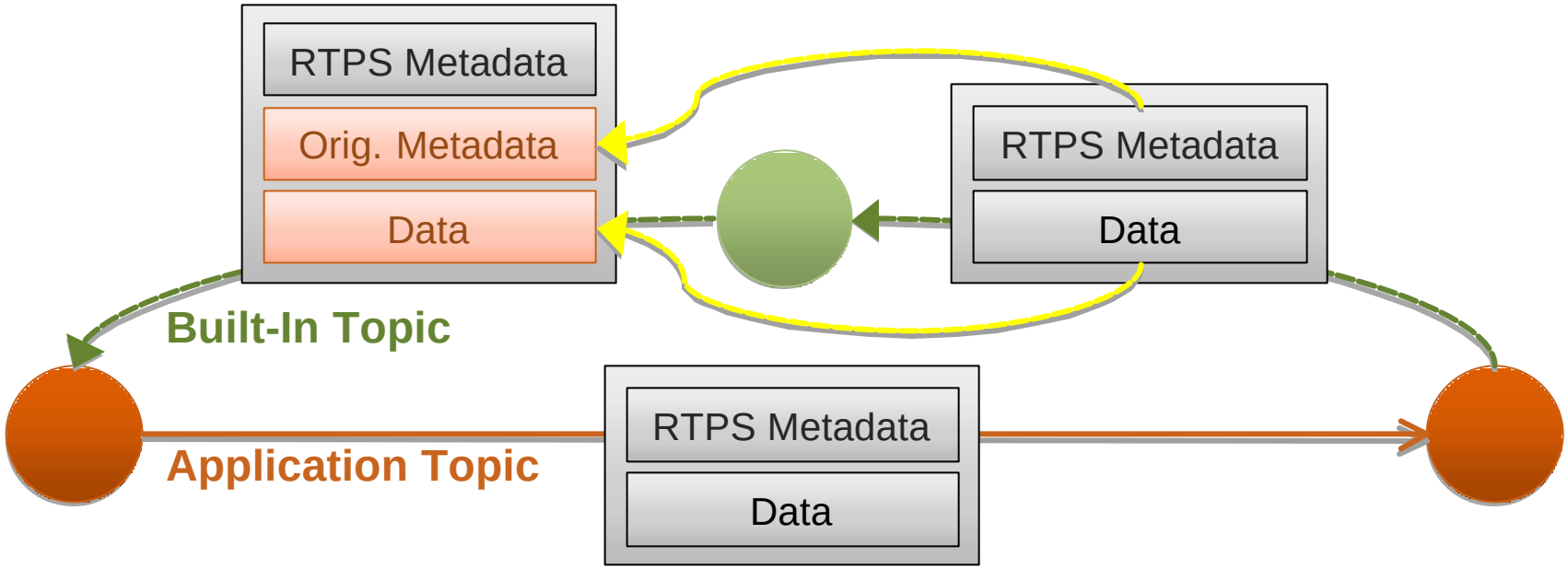
1. **Brokered discovery**



DDS Scalability: Brokered Discovery

- Can be built with RTPS-standard building blocks



RTPS `InfoSource` submessage provides data forwarding capability:
"Treat the following as if it came from that guy instead of from me."

Future Direction: Enhanced Built-in Security

- **System of systems may have non-uniform trust**
  - Multiple communities of interest w/ different entitlements/authorization
  - Infrastructure components may (not) be trusted (e.g. brokers, daemons, persistence, recording/playback, etc.)
  - *There is no "system high"*
- **Desirable new specifications**:
  - Topic-level access control
  - Sample-level tagging and labeling
  - Sample-level signing and/or encryption
- *More on security concerns in other talks this week*

Future Direction: Standardized WAN Support

- **Site-to-site comms need DDS across WAN(s)**
  - Including untrusted networks
  - Including firewall, NAT traversal
- **RTPS (DDSI) protocol designed for layering** atop diverse lower-level protocols
  - *Proven*: UDP, TCP, serial, switched fabric, Infiniband, VME, shared memory…
  - *Blessed for interop by OMG*: UDP
  - *Challenge*: UDP may not be routable, especially if multicast
- **Additional protocol mappings (PSMs)** could provide improved site-to-site interop
  - TCP for WAN routing
  - (D)TLS for transport-level security (a clarification, not a new PSM)
  - *Could be standardized quickly*

Recap

- **Large systems frequently composed** of smaller subsystems
  - Developed independently
  - …With different network environments
  - …And different data interest/entitlements

- **Best expressed in hierarchical system design**
  - Subsystems "gated" by DDS router/gateway
    - Broker internal ←→ external protocols (may be different)
    - Transform/cleanse internal ←→ external data types
    - Impose governance: enforce policy, attach monitoring
  - Inter-router integration space is itself a "subsystem" for purposes of hierarchical composition

Recap

- **DDS already provides** much of what's needed
  - Strong SLAs for governance
  - Multiple topologies for fault-tolerant subsystem isolation
  - Flexible, scalable interoperability protocol

- **Promising future directions:**
  - RTPS/TCP protocol layering for WAN traversal
  - Enhanced security model
    - Topic-level access control
    - Sample-level tagging, signing, and encrypting