Your systems.
Working as one.

Lua Workshop 2016
San Francisco, CA

Connecting the Industrial Internet of Things

Working with strongly typed data models in Lua for building Industrial Internet of Things (IIoT) applications

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Principal Solution Architect, Real-Time Innovations, Inc.

Agenda

- Background
- Problem
- Solution
- Tutorial | Demo
- Applications
- Next Steps

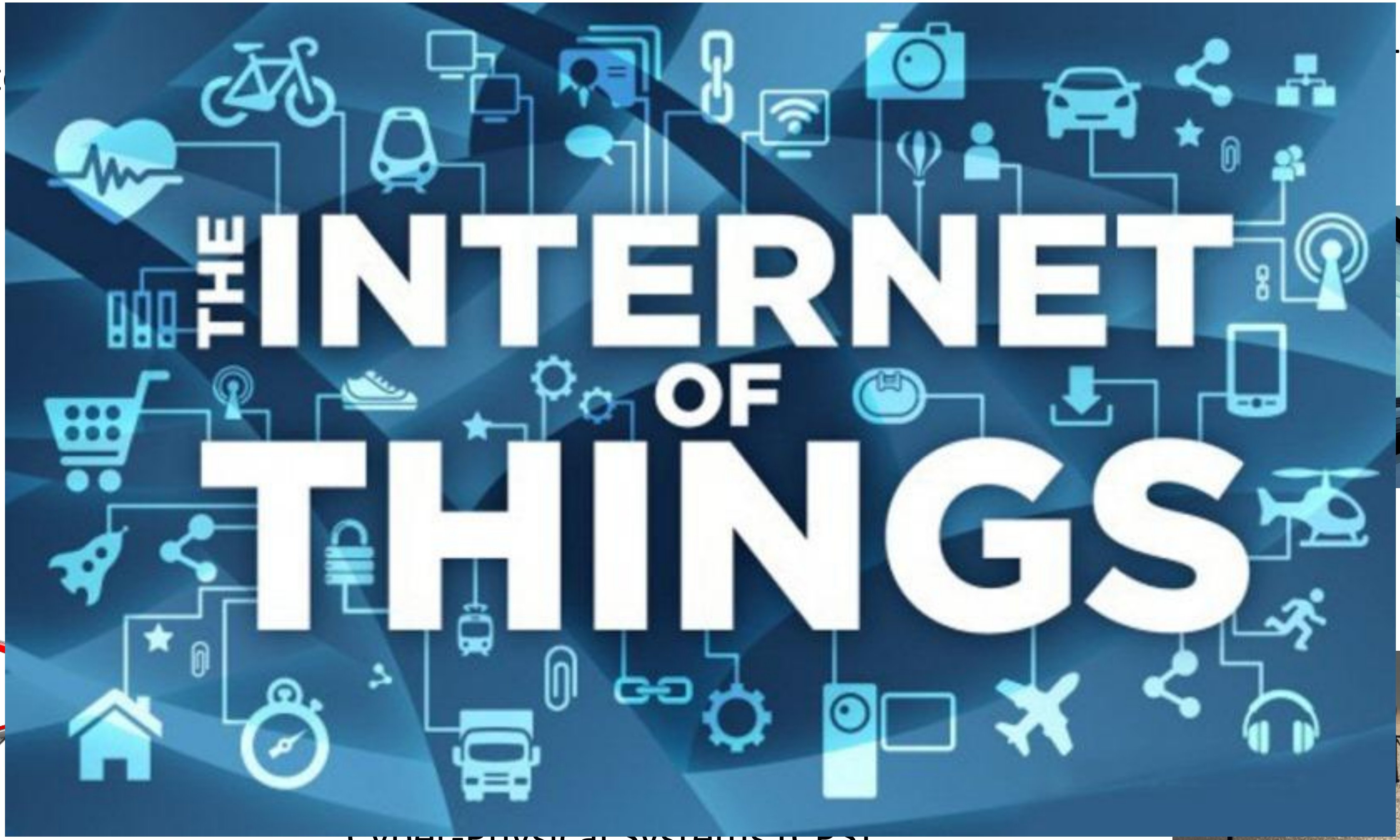
Background

What we do?

The Industrial Internet of Things

Consumer Int

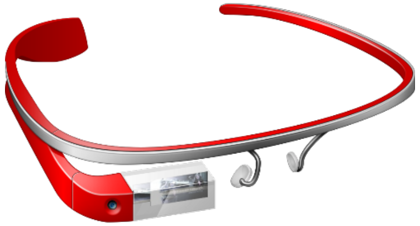
)



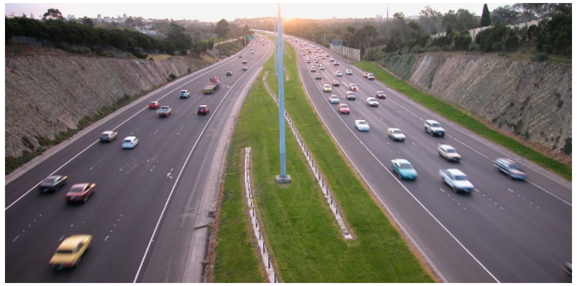
Cyber-Physical Systems (CPS)

The Industrial Internet of Things

Consumer Internet of Things (CIoT)



Industrial Internet of Things (IIoT)



Cyber-Physical Systems (CPS)

RTI Excels at Industrial IoT (IIoT)

rti

- ~1000 Projects
  - Healthcare
  - Transportation
  - Communications
  - Energy
  - Industrial
  - Defense
- 15+ Standards & Consortia Efforts
  - Interoperability
  - Multi-vendor ecosystems







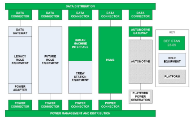



DDS

OMG
OBJECT MANAGEMENT GROUP

OSA

FACE
Future Airborne Capability Environment



OPEN INTERCONNECT CONSORTIUM

MD PnP
Getting connected for patient safety

SGIP
SMART GRID INTEROPERABILITY PANEL

ICE Alliance
Integrating Clinical Environments

OpenFog

industrial internet CONSORTIUM

OPC FOUNDATION

Connect Anything, Anywhere - Intelligently!

Seamless data sharing regardless of:

- Proximity
- Platform
- Language
- Physical network
- Transport protocol
- Network topology

✓ Reliable
✓ Real-Time
✓ Scalable
✓ Available
✓ Resilient
✓ Secure
✓ Safe
✓ Composable

RTI Connext Platform is built on the DDS Standard

DDS

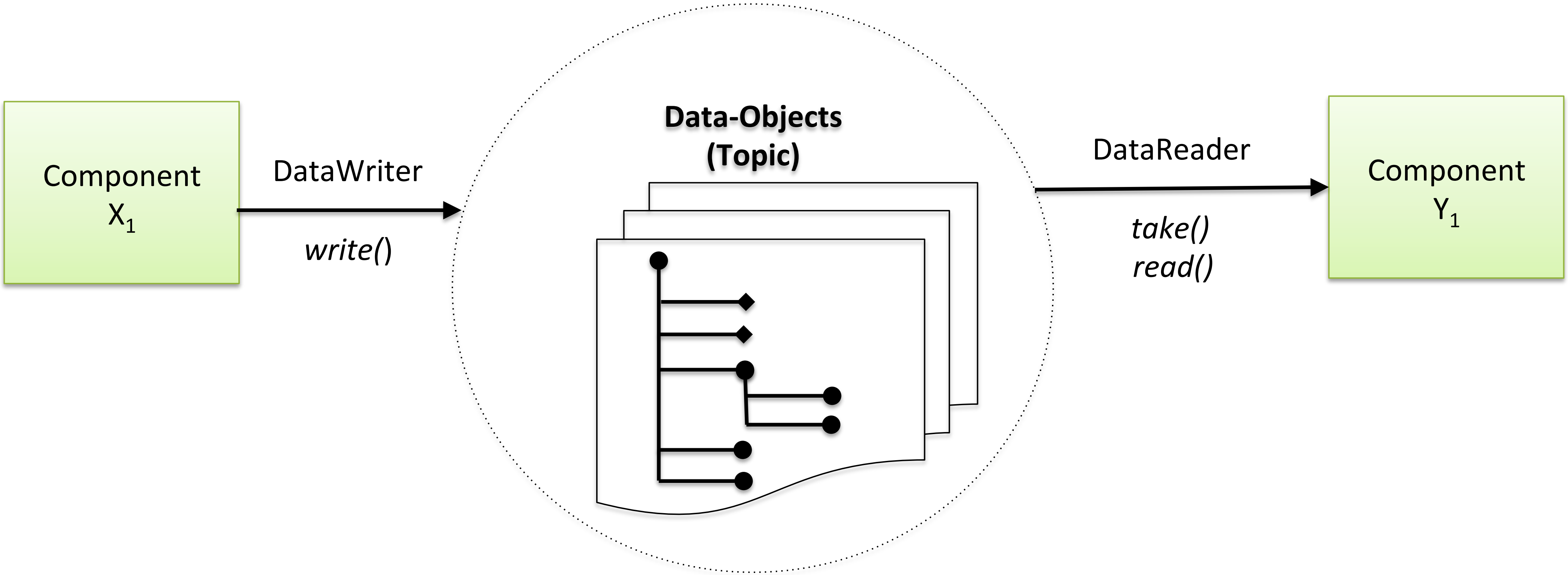
The Proven Data Connectivity Standard for the IoT

http://portals.omg.org/dds/

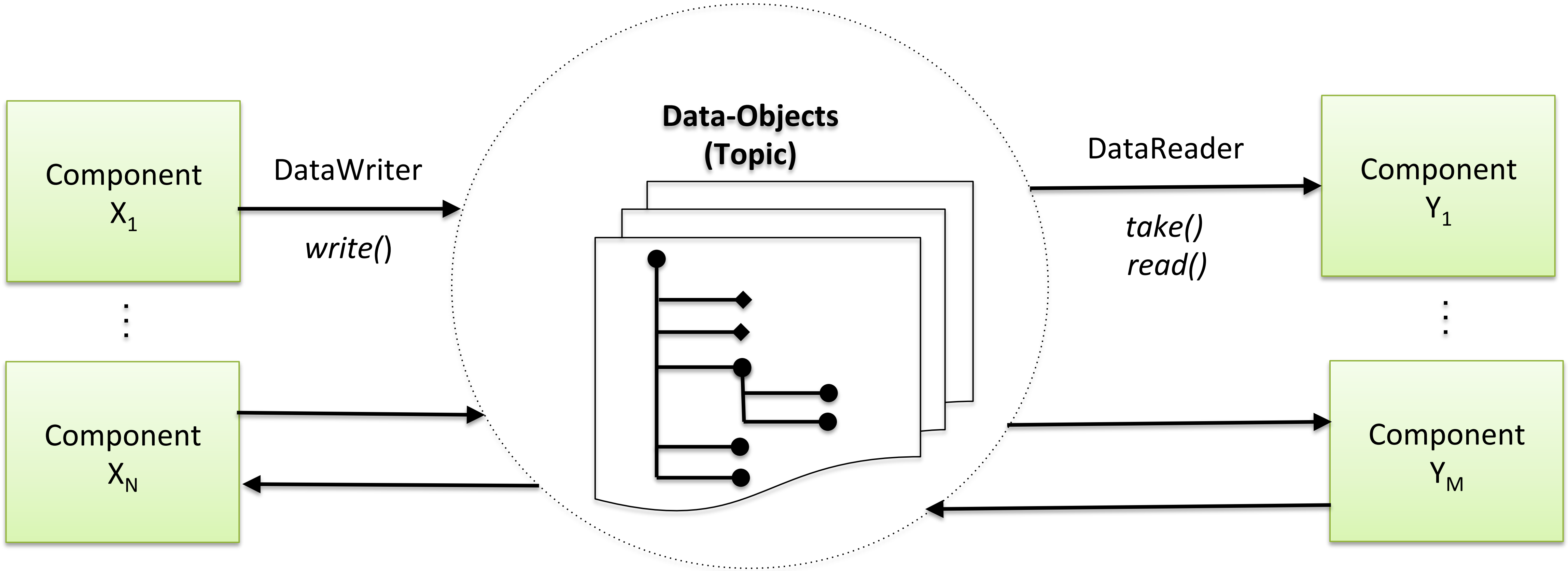
Problem Definition

“Data dominates. If you've chosen the right data structures and organized things well, the algorithms will almost always be self-evident. Data structures, not algorithms, are central to programming. (See Brooks p. 102.)”

Data-Centric Systems: Shared Data Space

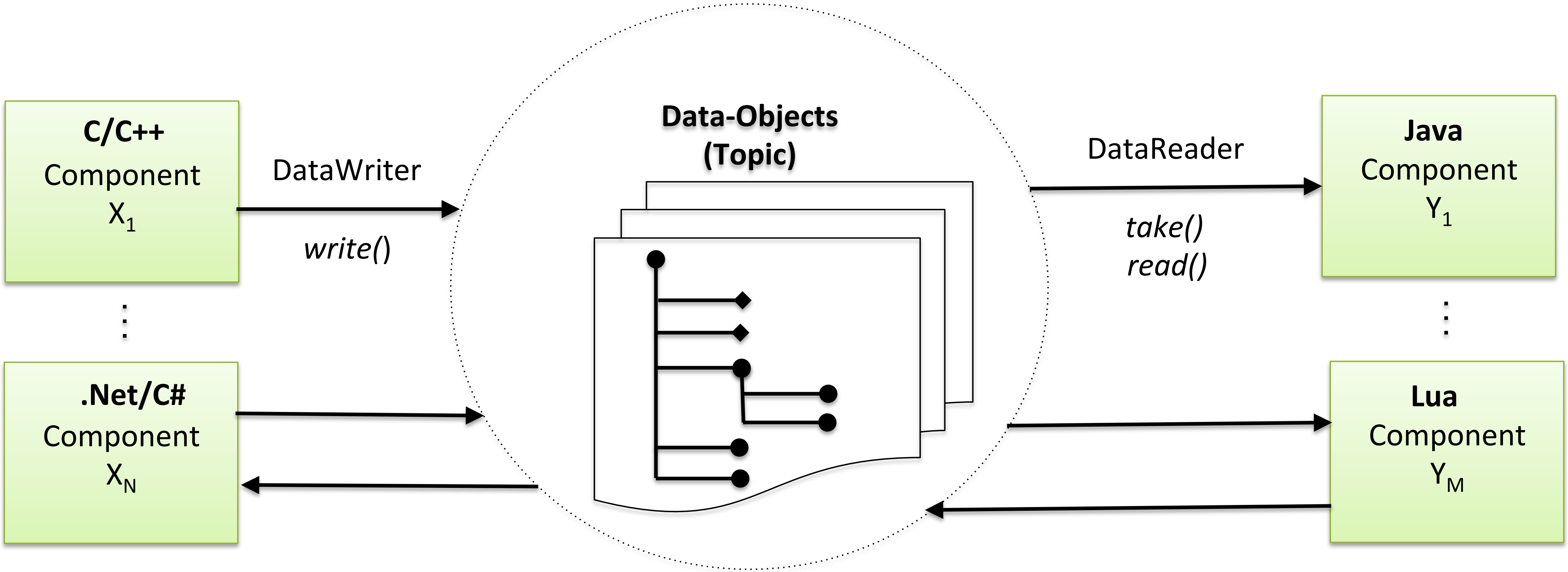


Data-Centric Systems: Shared Data Space



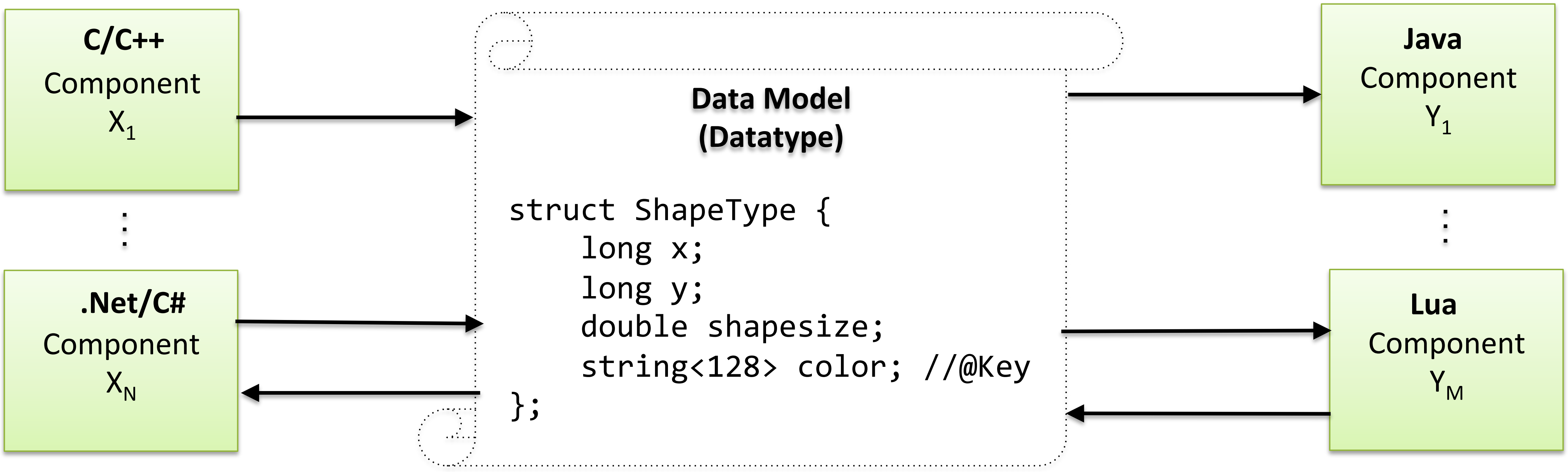
Data-Centric Systems: Shared Data Space

Multiple platforms, Multiple Languages

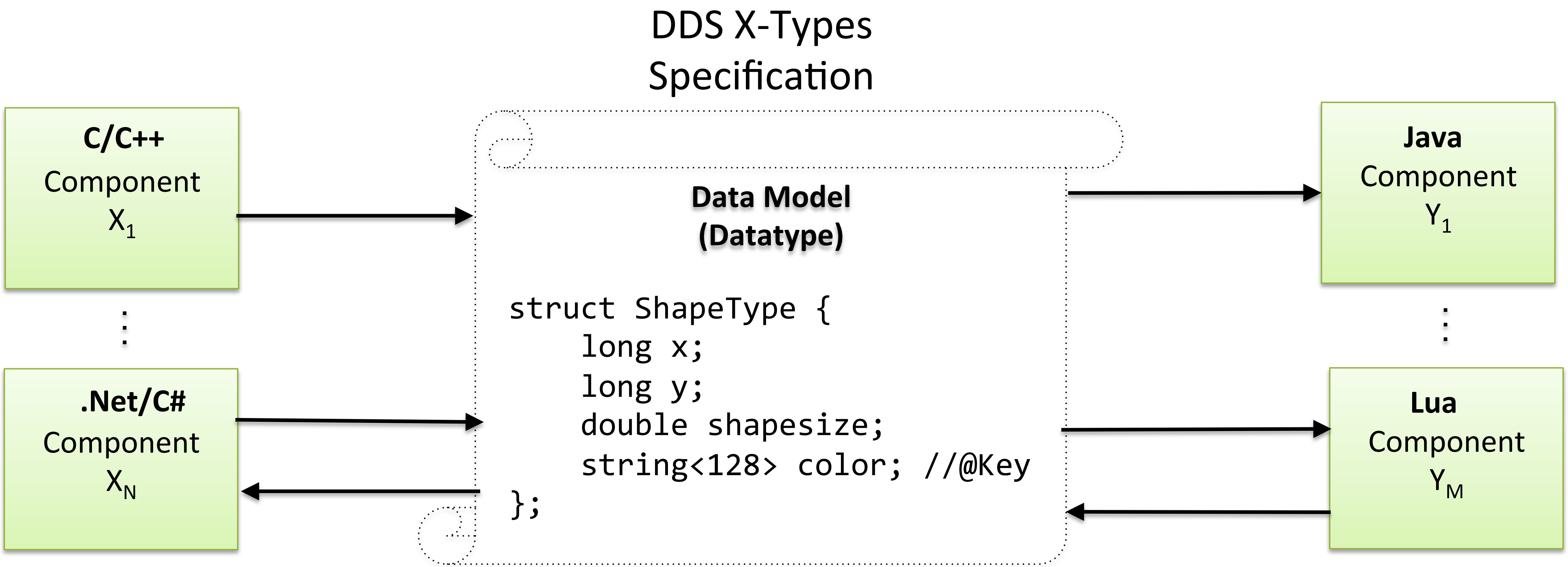


Pick the language most suitable to the requirements of a component

Data-Centric Systems: Data Models

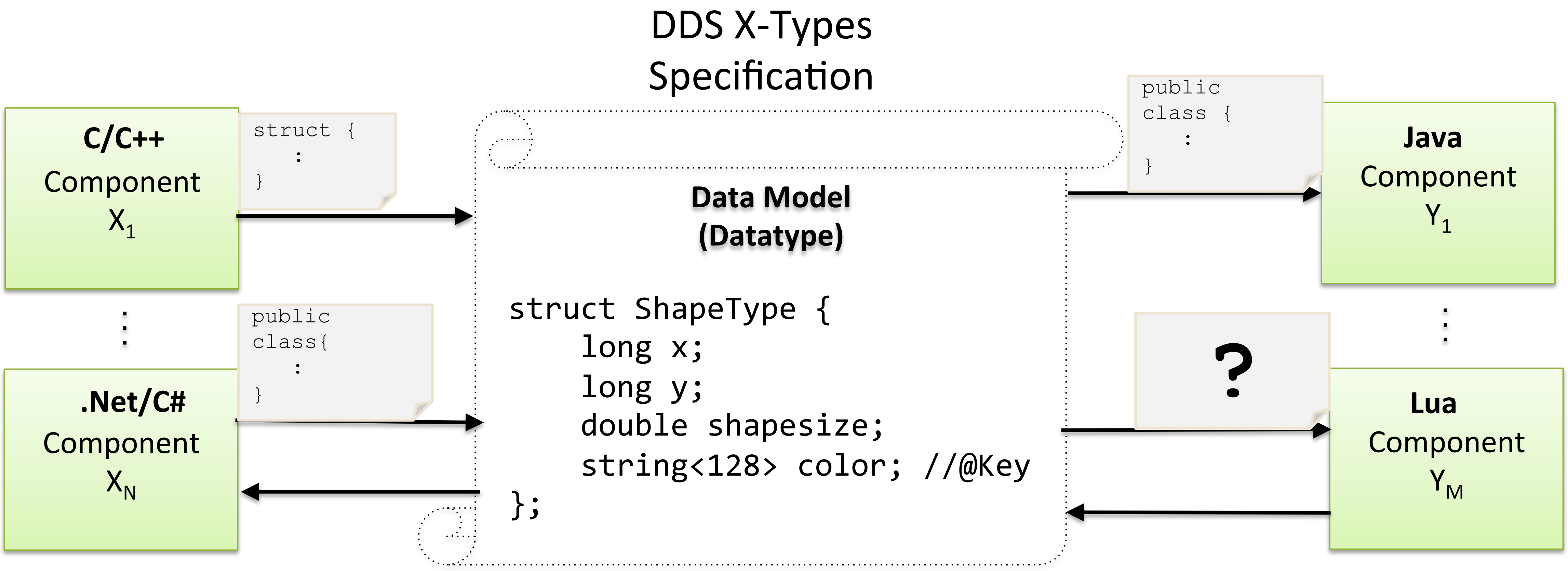


Data-Centric Systems: Data Models



Interface Definition Language (IDL)
XML with Equivalent Schema

Data-Centric Systems: Data Models

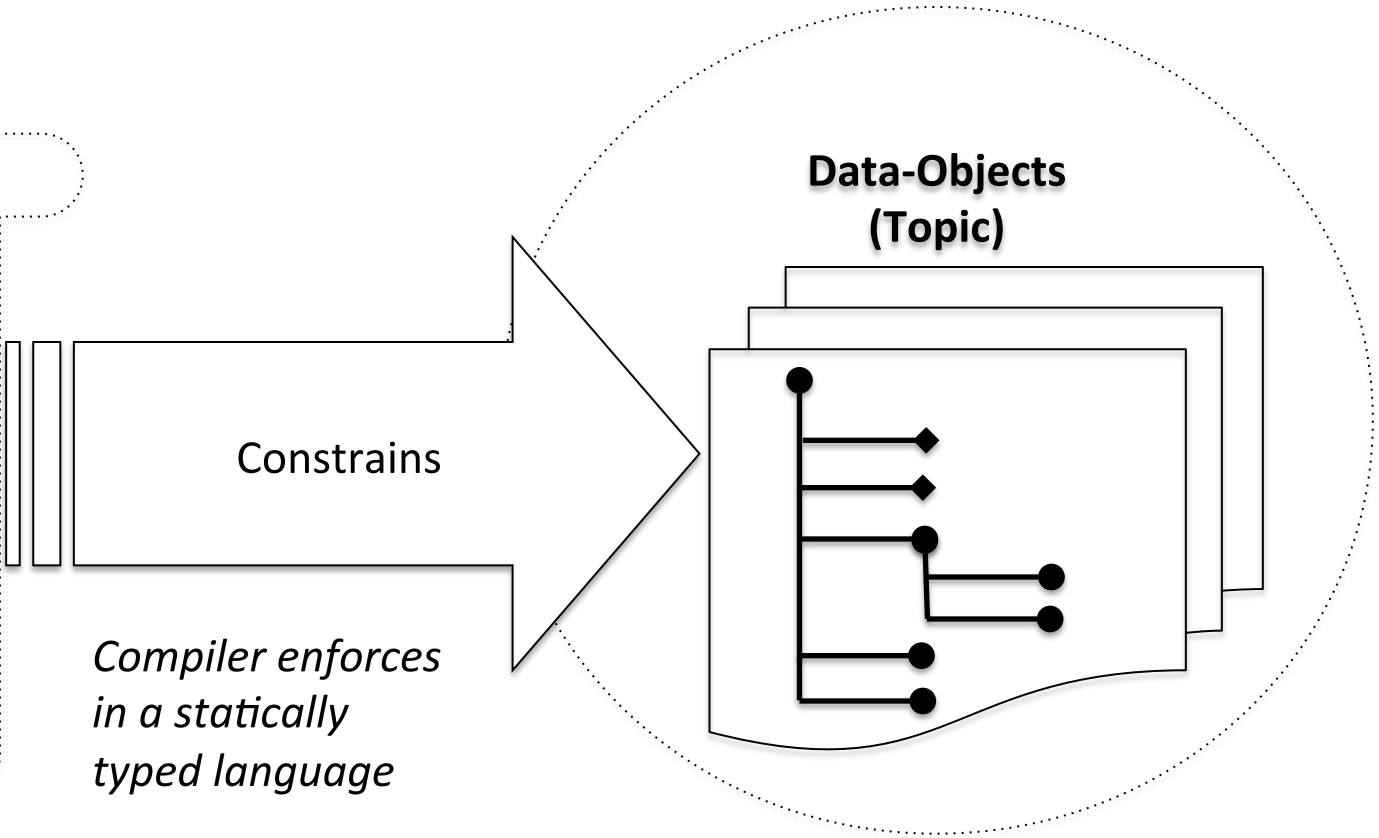


Interface Definition Language (IDL)
XML with Equivalent Schema

Data Model Constrains the Data-Objects

Data Model
(Datatype)

```
struct ShapeType {
    long x;
    long y;
    double shapesize;
    string<128> color; //@Key
};
```



Language Neutral

Language Specific
Static: C/C++, Java. .NET/C#, Ada. …
Dynamic: Lua, Python, Javascript, …

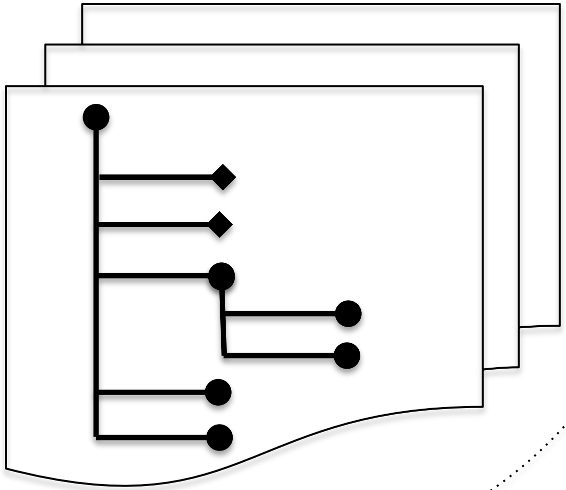
Data Model Constrains the Data-Objects

Data Model
(Datatype)

```
struct ShapeType {
    long x;
    long y;
    double shapesize;
    string<128> color; //@Key
};
```

Constrains

Data-Objects
(Topic)



How to enforce in dynamically typed languages?

How to enforce in Lua?

Language Neutral

Language Specific
Static: C/C++, Java. .NET/C#, Ada. …
Dynamic: Lua, Python, Javascript, …

Solution

DDSL: Data Domain Specific Language

DDSL: Data Domain Specific Language

An algebra for defining, using, and manipulating X-Types (in Lua)

Data Model
(Datatype)

```
struct ShapeType {
    long x;
    long y;
    double shapesize;
    string<128> color; //@Key
};
```

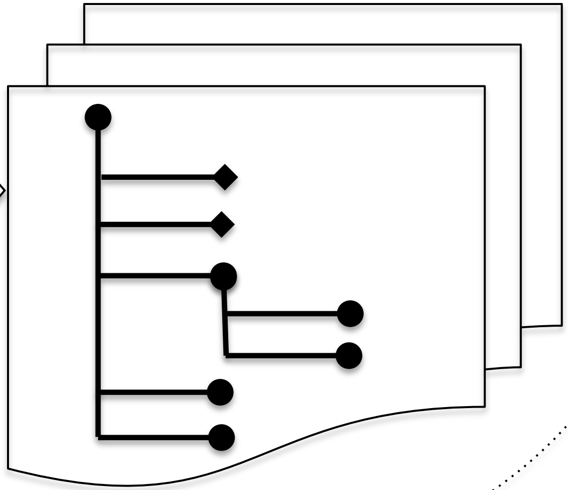
DDSL
Enforces Constraints
Keeps Synchronized

Create & Modify

- *Datatypes*
- *Instances*

Index data fields

Data-Objects
(Topic)



template
(Lua)

instances
(Lua)

Data models can be very complex….

Primitive

- Atomic (long, double, string, etc…)
- Const
- Enums

Structural

- Structs
- Unions
- Sequences (multidimensional)
- Arrays (multidimensional)

Organizational

- Typedefs
- Module
- Annotations

Without DDSL…

- The datatype must be maintained outside the scripting language environment
  - –not accessible to program (in the language)
- The datatype must be known to the programmer, and its structure hard-coded in the script
  - –error-prone due to duplication
  - –brittle to datatype evolution or large/complex types
- A script cannot use or introduce new topics or endpoints (not known to the programmer)
  - –impossible to build generic components

With DDSL…

- The datatype can be maintained inside the scripting environment
  - fully accessible to program
- The datatype need not be known to the programmer, and its structure need not be hard-coded in the script
  - safe, single version of truth (no datatype duplication)
  - robust to datatype evolution or large/complex types
- A script **can** use or introduce new topics or endpoints (not known to the programmer)
  - **possible** to build generic components

Quick Example…

Data Model - IDL

```
struct ShapeType {
    long x;
    long y;
    double shapesize;
    string<128> color; //@Key
};
```

Data-Object - Lua

```
shape = {
    x          = 50,
    y          = 30,
    shapesize  = 20,
    color      = ‘GREEN’
}
```

Quick Example…

Data Model - IDL

```
struct ShapeType {
    long x;
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```

Data-Object - Lua

```
shape = {
    x          = 50,
    y          = 30,
    shapesize  = 20,
    color      = ‘GREEN’
}
```

Data Model – DDSL (template)

```
local
 ShapeType = xtypes.struct{
   ShapeType = {
     { x = { xtypes.long } },
     { y = { xtypes.long } },
     { shapesize = { xtypes.long } },
     { color = { xtypes.string(128), xtypes.Key } },
   }
 }
```

Data-Object – DDSL (instance)

```
local
 shape = xtypes.new_instance(ShapeType)

 shape.x = 50
 shape.y = 30
 shape.shapesize = 20
 shape.color = 'GREEN'
```

DDSL opens up new possibilities...

- A DDSL datatype
  - Can be examined and traversed in the program
  - Can be defined and manipulated by the program
    - create|read|update|modify operations
  - Can be synthesized and manipulated by the program
  - Can be used to automate code or data generation

  while using the full power and flexibility of Lua

- Brings datatypes to every IoT platform
  - DDSL is platform independent
    - is written in **pure Lua** with no external dependencies (not even DDS!)
    - can be used on any platform on which Lua can be used (practically everywhere)
  - Even web-browsers (e.g. using lua.vm.js)

DDSL

An algebra for defining, using, and manipulating X-Types (in Lua)

So, what exactly is DDSL?

1. Replacement for IDL, by allowing datatypes definitions in Lua
2. Factory of data-objects (instances) that adhere to a datatype
3. An algebra to operate on datatypes and maintain the associated data-objects (instances)
4. Generator of accessor strings for indexing members in a data-object store
5. An extensible framework for data modeling

1. IDL Replacement in Lua

- OMG DDS X-Types Specification in Lua
  - –including features not yet supported in IDL
    - e.g. custom annotations
- XML → DDSL
  - –Import datatypes defined in XML
- DDSL → IDL (→ XML)
  - –Export datatypes to IDL
- Easy to define new kinds of datatypes
  - –Useful for experimenting with new X-Types features
    - e.g. choice

1. IDL Replacement in Lua

Declarative style (Datatype Constructor)

```
local MAX_COLOR_LEN = xtypes.const{ MAX_COLOR_LEN = { xtypes.long, 128 } }

local ShapeType = xtypes.struct{
  ShapeType = {
    { x = { xtypes.long } },
    { y = { xtypes.long } },
    { shapesize = { xtypes.long } },
    { color = { xtypes.string(MAX_COLOR_LEN), xtypes.Key } },
  }
}
```

Imperative Style (Datatype CRUD)

```
local MAX_COLOR_LEN = xtypes.const{ MAX_COLOR_LEN = { xtypes.long, 128 } }

local ShapeType = xtypes.struct{ShapeType=xtypes.EMPTY}
ShapeType[1] = { x = { xtypes.long } }
ShapeType[2] = { y = { xtypes.long } }
ShapeType[3] = { shapesize = { xtypes.long } }
ShapeType[4] = { color = { xtypes.string(MAX_COLOR_LEN), xtypes.Key } }
```

2. Factory of instances

- Instances are constrained by the datatype
  - arbitrary members cannot be added to instances
  - members may be assigned nil (e.g. optional); and later re-assigned a non-nil value
  - collection (array and sequence) bounds are enforced; now allowed to exceed the max capacity
- Yet, instance performance is on par with a manually defined instance
  - no overhead in setting/getting member values
    - it was an explicit design goal to not add any overhead over raw member field setters/getters
  - only structural constraints are enforced!
    - type-checking is not enforced for member value assignment (although an application could easily do so if desired)

2. Factory of instances

```
-- shape is equivalent to manually defining the following --
 local shape_manual = {
     x          = 50,
     y          = 30,
     shapesize  = 20,
     color      = 'GREEN',
 }

local shape = xtypes.new_instance(ShapeType)
print("--- Iterate through instance members : unordered ---")
  for role, _ in pairs(shape_manual) do
    shape[role] = shape_manual[role]
    print('\t', role, shape[role])
  end
```

⇒

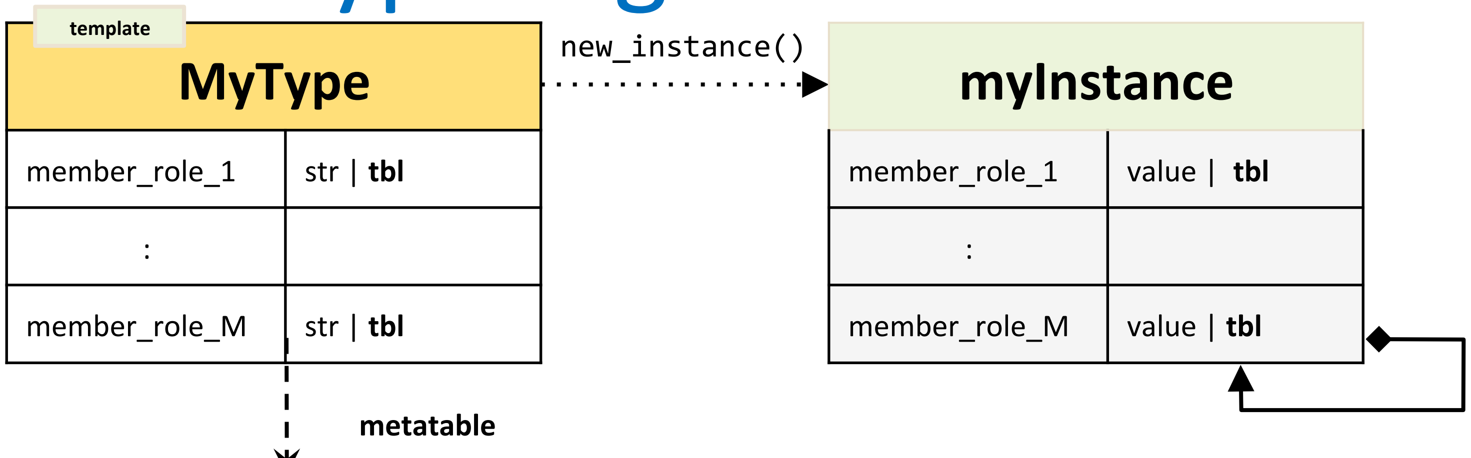
```
--- Iterate through instance members : unordered ---
          color   GREEN
          x               50
          shapesize       20
          y               30
```

3. Datatype Algebra

- Datatypes can be mutated (unlike IDL/XML)
  - the “kind” (meta-datatype) is immutable and defines the structure and constraints
  - all other aspects of a datatype can be changed, e.g.: name, members, annotations, inheritance, switch

- Datatype changes are propagated to instances (unlike IDL/XML)
  - adding a member to the datatype also adds it to all the instances (with a default value)
  - removing a member from a the datatype also removes it from all the instances
  - changing a member's datatype propagates the change to all the instances

3. Datatype Algebra



MyType Model Operators	
i-th member	MyType[i] = { role = { … } }
#members	#MyType
name	MyType[NAME]
namespace	MyType[NS]
kind	MyType[KIND]
()	capacity | const value | alias
qualifiers | base | switch	MyType[QUALIFIER | BASE | SWITCH]

Models and Instances

A DDSL instance has two faces (like a coin):

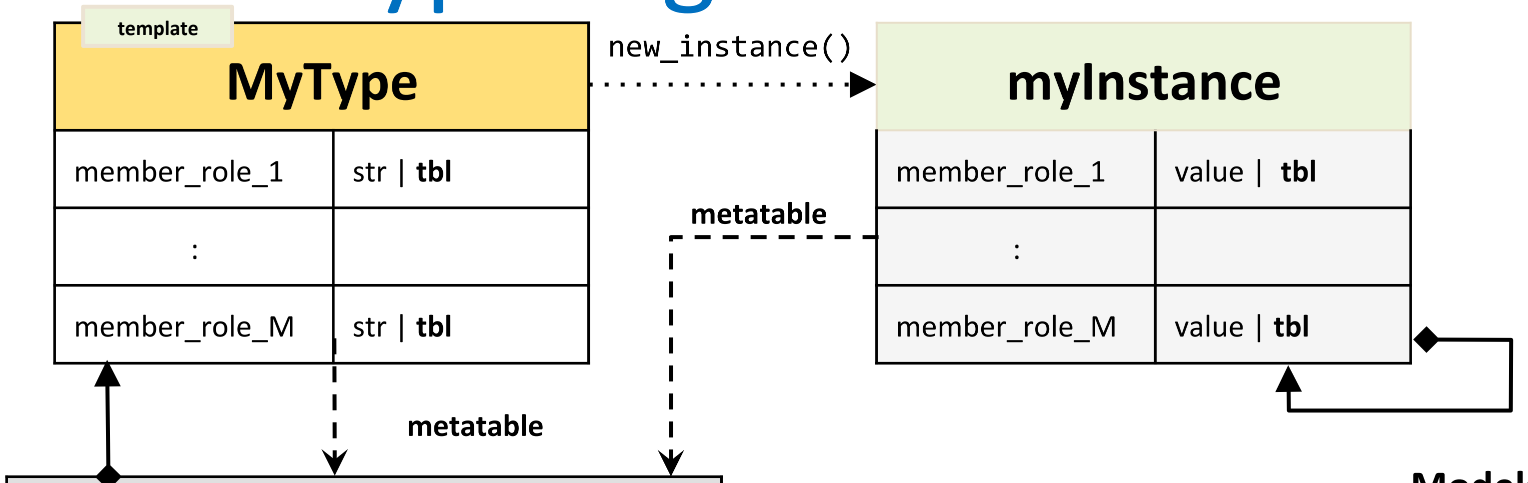
- an underlying datatype model (the blueprint)
- fields with role names dictated by the datatype

Constructors return a special “template” instance (e.g. MyType) as a handle to the underlying model.

Datatype models are manipulated using operators on instances. Any of the instances could be used, but its idiomatic to use the template instance.

Template instances link model elements to form a data model graph.

3. Datatype Algebra



MyType Model Operators

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#members	#MyType
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Models and Instances

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Datatype models are manipulated using operators on instances. Any of the instances could be used, but its idiomatic to use the template instance.

Template instances link model elements to form a data model graph.

3. Datatype Algebra: Model Operators

```
print('--- add member z ---')
 ShapeType[#ShapeType+1] = { z = { xtypes.string() , xtypes.Key } }
 print_datatype(ShapeType, 'ShapeType:')

 print('--- remove member x ---')
 ShapeType[1] = nil
 print_datatype(ShapeType, 'ShapeType:')

 print('--- redefine member y ---')
 ShapeType[1] = { y = { xtypes.double } }
 print_datatype(ShapeType, 'ShapeType:')

 print('--- add a base struct ---')
 local Property = xtypes.struct{
   Property = {
     { name  = { xtypes.string(MAX_COLOR_LEN) } },
     { value = { xtypes.string(MAX_COLOR_LEN) } },
   }
 }
 ShapeType[xtypes.BASE] = Property
 print_datatype(ShapeType, 'PropertyShapeType:')
 print_instance(ShapeType, 'PropertyShapeType accessors:')
```

4. Generator of Accessor Strings

- Datatype is a special ‘template’ instance
  - whose members are initialized to the accessor strings for a DDS DynamicData object
  - automatically maintained to confirm with the underlying data model
  - for efficiency, collection member elements are allocated (at most once) on demand (i.e. when accessed)

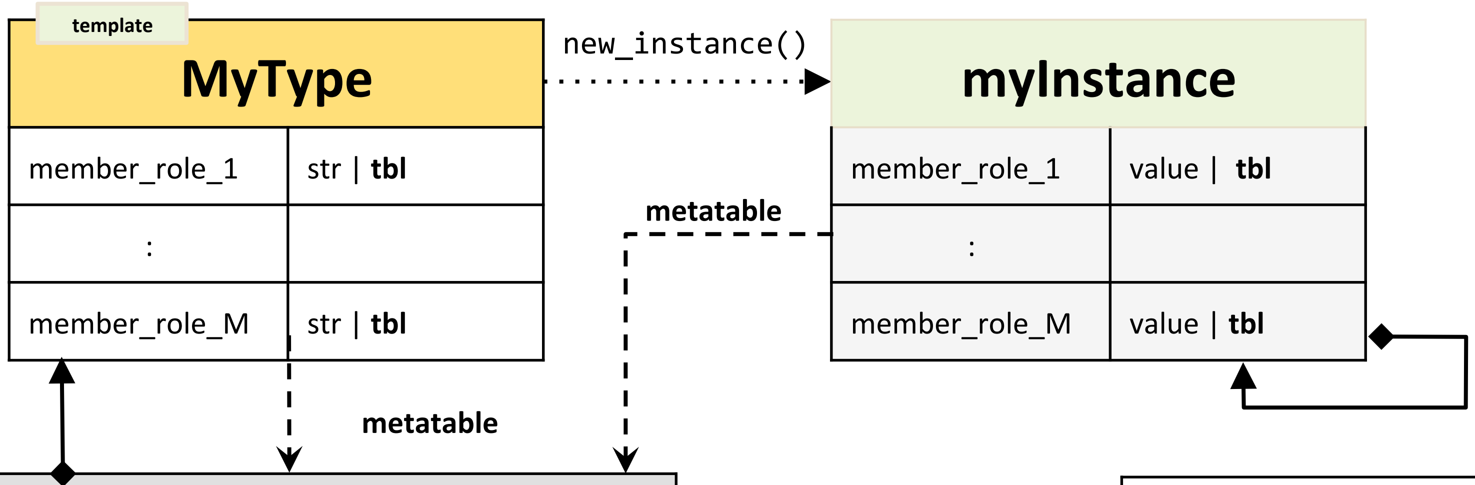
```
-- ShapeType can be accessed as if it was defined as --
ShapeType = {
     x          = ‘x’,
     y          = ‘y’,
     shapesize  = ‘shapesize’,
     color      = ‘color’
}
```

4. An extensible framework for data modeling

- Core engine supports a generic meta-model
  - Agnostic to specific data modeling language constrains
  - X-Types module extends the ddsl engine to support DDS X-Types (OMG IDL)
- Easy to extend the modeling language
  - New atomic data types, annotations, compositions, …
- Easy to add new constraints
  - Data ranges
  - Data units
  - Semantics

Datatype Algebra

DDSL Nomenclature



MyType API

i-th member	MyType[i] = { role = { … } }
#members	#MyType
name	MyType[NAME]
namespace	MyType[NS]
kind	MyType[KIND]
()	capacity | const value | alias
qualifiers | base | switch	MyType[QUALIFIER | BASE | SWITCH]

Nomenclature

General Concept	DDSL Terminology
instance (a.k.a. data-object)	instance
datatype	template
member	
member name	role
member definition	role definition (roledef)
annotation	qualifier

Datatype Algebra - Model Constructors

Create a datatype template:

```
MyType = xtypes.<kind>{...}
```

where, `<kind> is one of:`

```
    annotation,
const, enum,
    struct, union,
    module,
    typedef
```

and `{...}` depends on `<kind>`

e.g.

```
MyType = xtypes.struct{MyType=xtypes.EMPTY}
```

Common definition style:

```
{ <name> = { <definition> } }
```

Datatype Algebra - Model Operators

Create a member:

```
MyType[i] = { role = {template, [array|sequence,] [[annotation,]...] }
```

Delete a member:

```
MyType[i] = nil
```

Namespace, Qualifiers, Base (structs), Switch (unions):

```
MyType[xtypes.NS]         = AnotherType
MyType[xtypes.QUALIFIERS] = { annotation, ... }
MyType[xtypes.BASE]       = BaseType
MyType[xtypes.SWITCH]     = DiscriminatorType
```

Name:

```
MyType[xtypes.NAME]       = 'NewTypeName'
tostring(MyType)
```

Kind (immutable):

```
MyType[xtypes.KIND]
```

Datatype Algebra - Model Iterators

structs

Iterate over the members:

```
for i = 1, #MyType do
  local role, roledef = next(MyType[i])
  print(role, table.unpack(roledef))

end
```

unions

Iterate over the members:

```
for i = 1, #MyType do
  local case = MyType[i]

  -- case discriminators:
  print(table.unpack(case))

  -- member:
  local role, roledef = next(case, #case)
  print(role, table.unpack(roledef))
end
```

Datatype Algebra - Instance Constructors

Create an instance:

```
myInstance   = xtypes.new_instance(MyType)
```

Create a collection of instances:

```
myCollection = xtypes.new_collection(MyType,
                                    capacity)
```

NOTE: A sequence or array member in an instance is a collection

Datatype Algebra - Instance Collections

Is it a collection?

```
if xtypes.is_collection(myCollection)then
     print( 'capacity',    myCollection() )
     print( 'length',      #myCollection )
 end
```

Iterate over a collection's length:

```
    for i = 1, #myCollection do
       print( myCollection[i] )
    end
```

Iterate over a collection's capacity:

```
    for i = 1, myCollection() do
       print( myCollection[i] )
    end
```

Datatype Algebra - Instance Iterators

Iterate over instance members (unordered):

```
for role, value in pairs(myInstance) do
   print(role, value)
end
```

Iterate over instance members (ordered):

```
for i = 1, #MyType do
    local element_i, role = MyType[i]

   role = next(element_i)                  -- struct
 role = next(element_i, #element_i)-- union

   local value = myInstance[role]
   print(role, value, table.unpack(MyType(role)))
end
```

Datatype Algebra – Template Instance

Iterate over DDS DynamicData accessor strings (unordered):

```
for role, accessor in pairs(MyType) do
   print(role, accessor)
end
```

Iterate over DDS DynamicData accessor strings (ordered):

```
for i = 1, #MyType do
    local element_i, role = MyType[i]

   role = next(element_i)              -- struct
 role = next(element_i, #element_i)-- union

   local accessor = MyType[role]
   print(role, accessor)
end
```

*Field values are **accessor strings** for **indexing** members in a **data-object store***

Datatype Algebra – Misc Operators

Get the fully qualified name within the namespaces

```
print( xtypes.nsname(MyType) )
```

Resolve an alias (e.g. typedef) to its underlying datatype

```
print( xtypes.resolve(MyType) )
```

Get an instance's underlying datatype template

```
print( xtypes.template(myInstance) )
```

Datatype Algebra – Utilities

- ddsl.xtypes.utils
  - to_instance_string_table(instance)
  - to_idl_string_table(instance)
  - nslookup(name, ns)
- ddsl.xtypes.xml
  - filelist2xtypes(filename_array)
  - file2xtypes(filename)
  - string2xtypes(xmlstring)
- Command line
  - run xml2ddsl [-d] <xml-file> [<xml-files> ...]

Tutorial

Running the tutorial…

```
git clone github.com/rticommunity/rticonnextdds-ddsl/

export DDSL_HOME=$(pwd -P)
export LUA_PATH+="${DDSL_HOME}tutorial/?.lua;"

cd tutorial/
lua ddsl_tutorial.lua
```

Applications

Current Applications (that I am aware of)

- Data Emulator
  - RTI Experimental Product
    - Emulate data-centric interfaces
    - First drop to customer (2015 Jun 30)

- Data Generators for Reactive Programming
  - Contribued by Sumant Tambe
  - Useful for simulation and testing

Potential Applications

- Community of **open data models** for [Industrial] IoT
- Data serialization and deserialization
- Code generation
  - Integration with templating libraries
- Model mapping and generation
  - synthesize datatypes from **semantic** models
  - synthesize data-model mappings
- Synthesis of data models
  - machine learning
- Experimentation with New Data Modeling Ideas

Next Steps

- Getting Started Guide
  - README
    - https://github.com/rticommunity/rticonnextdds-ddsl
- Users Manual
  - API
    - http://rticommunity.github.io/rticonnextdds-ddsl/
- Unit Tests
  - test/ *(for more advanced examples)*
    - ddsl-xtypes-tester.lua

Apache 2.0

Thank You!

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