A Reference Model for Representing SDN Environments

draft-wehmuth-nmrg-sdn-model-00

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SDNs getting complex

- Possible use of multiple/hierarchical/distributed controllers
- Complex data planes
- Complex relations between applications
  - e.g. management applications based on info gathered from other applications

SDNs are Multilayered

- From its basic definition:
  SDNs have Application, Control, and Data layers
- A multilayered complex system can be extended to absorb the increasing complexity in the SDN landscape
  - Each of these layers may be sub-divided into sub-layers (e.g. hierarchical controllers)
  - Additional layers may be added in specific deployments (e.g. a layer for NFVs)

Representation of Multilayer Networks

MultiAspect Graphs (MAGs)

- **MAGs** can represent **Multilayer time-varying** networks, or more complex objects
  - Edges are even tuples, $e = (a_1,\ldots,a_n,b_1,\ldots,b_n)$
  - MAGs are proven to be equivalent to directed graphs
  - As a consequence, MAG algebraic representations and algorithms can be derived from well-known directed graph representations and algorithms

- On MultiAspect Graphs, *Theoretical Computer Science, 651, pp. 50-61, Oct 2016* K. Wehmuth, E. Fleury, A. Ziviani, pre-print available at arXiv 1408.0943
- MultiAspect Graphs: Algebraic Representation and Algorithms, *Algorithms (MDPI), vol. 10, no. 1, Mar 2017,* K. Wehmuth, E. Fleury, A. Ziviani, pre-print available at arXiv 1504.07893

Multilayer Graph (MLG)

MLG is a particular case of MAG

G = (V, E, L)

V - Vertice set

E - Edge set

L - Layer set

Edges

$E \subseteq V \times L \times V \times L$ $e \in E$, $e = (u, L_a, v, L_b)$

$u, v \in V$ - Vertices

$L_a, L_b \in L$ - Layers

An edge expresses a relation between two vertices at two layers

Edges

$E \subseteq V \times L \times V \times L$

$u, v \in V$ - Vertices

$L_a, L_b \in L$ - Layers

$$e \in E, \quad e = (\underbrace{\underbrace{u, L_a}_{o}, \underbrace{v, L_b}_{d}}_{\text{Binary Relation}})$$

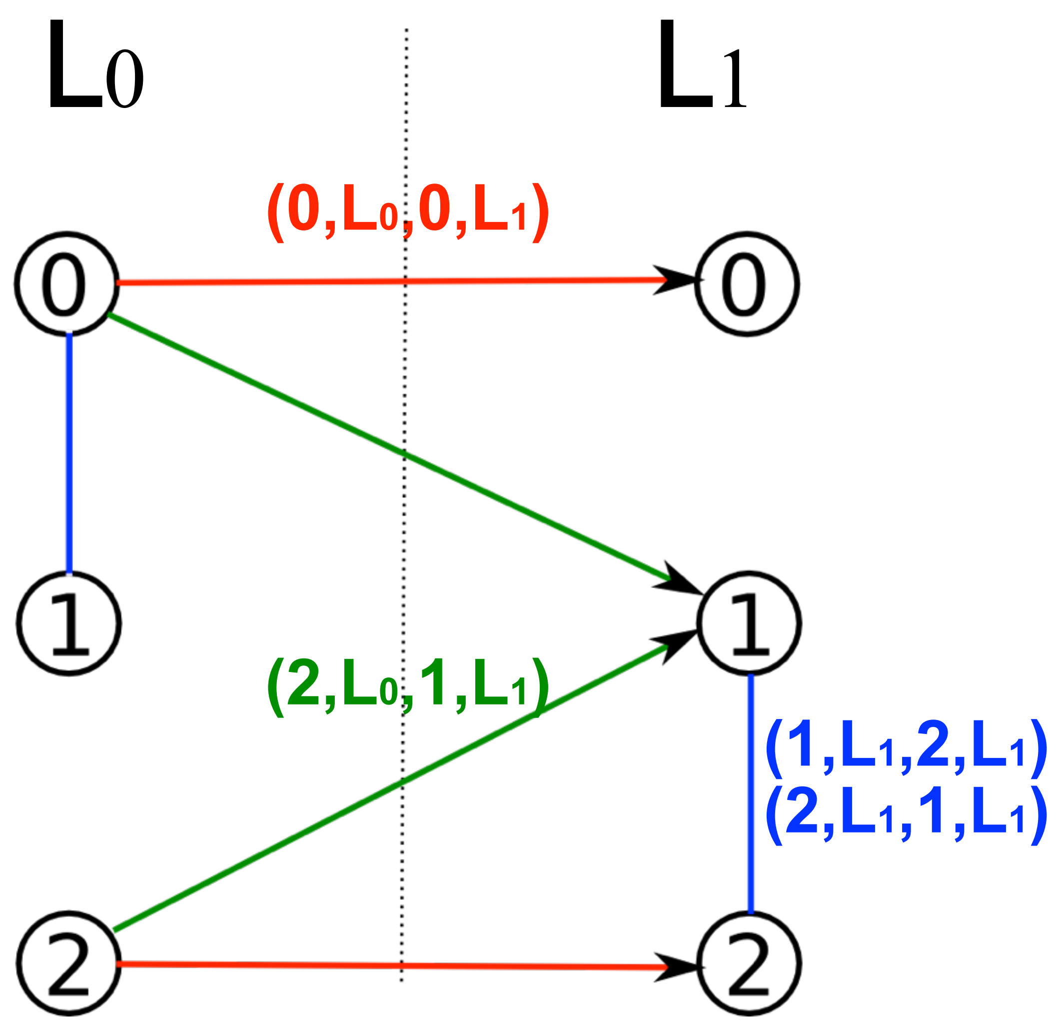
An edge expresses a relation between two vertices at two layers

Edges Types

Inter-layer Edges

Intra-layer Edges

Mixed Edges



Composite Vertices

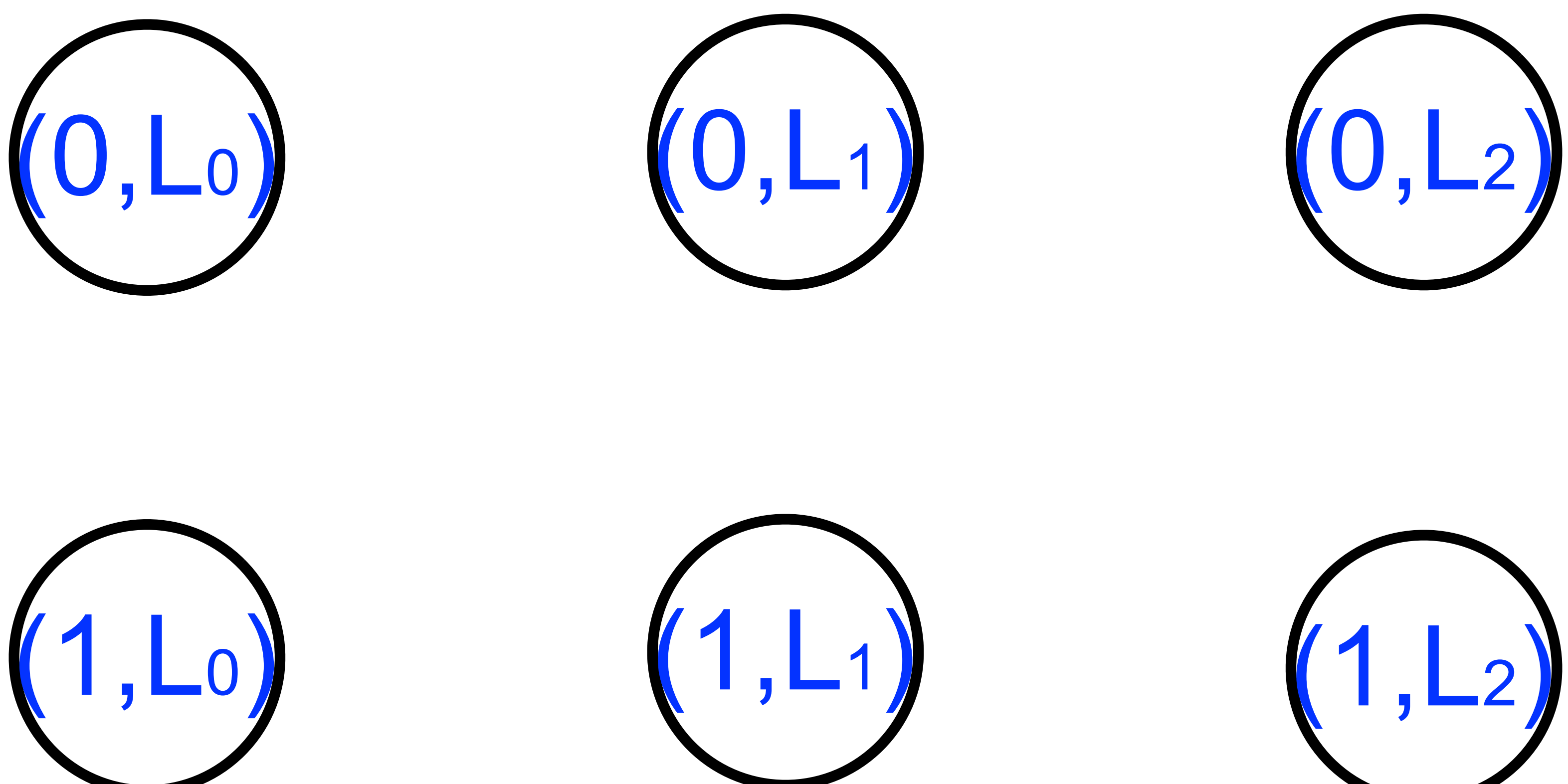
$G = (V, E, L)$

$e = (\underbrace{u, L_a}_{\mathbf{r}}, \underbrace{v, L_b}_{\mathbf{s}})$

$V = \{0, 1\}$

$L = \{L_0, L_1, L_2\}$

$\mathbf{r}, \mathbf{s} \in V_s = V \times L$



Representation based on Composite Vertices

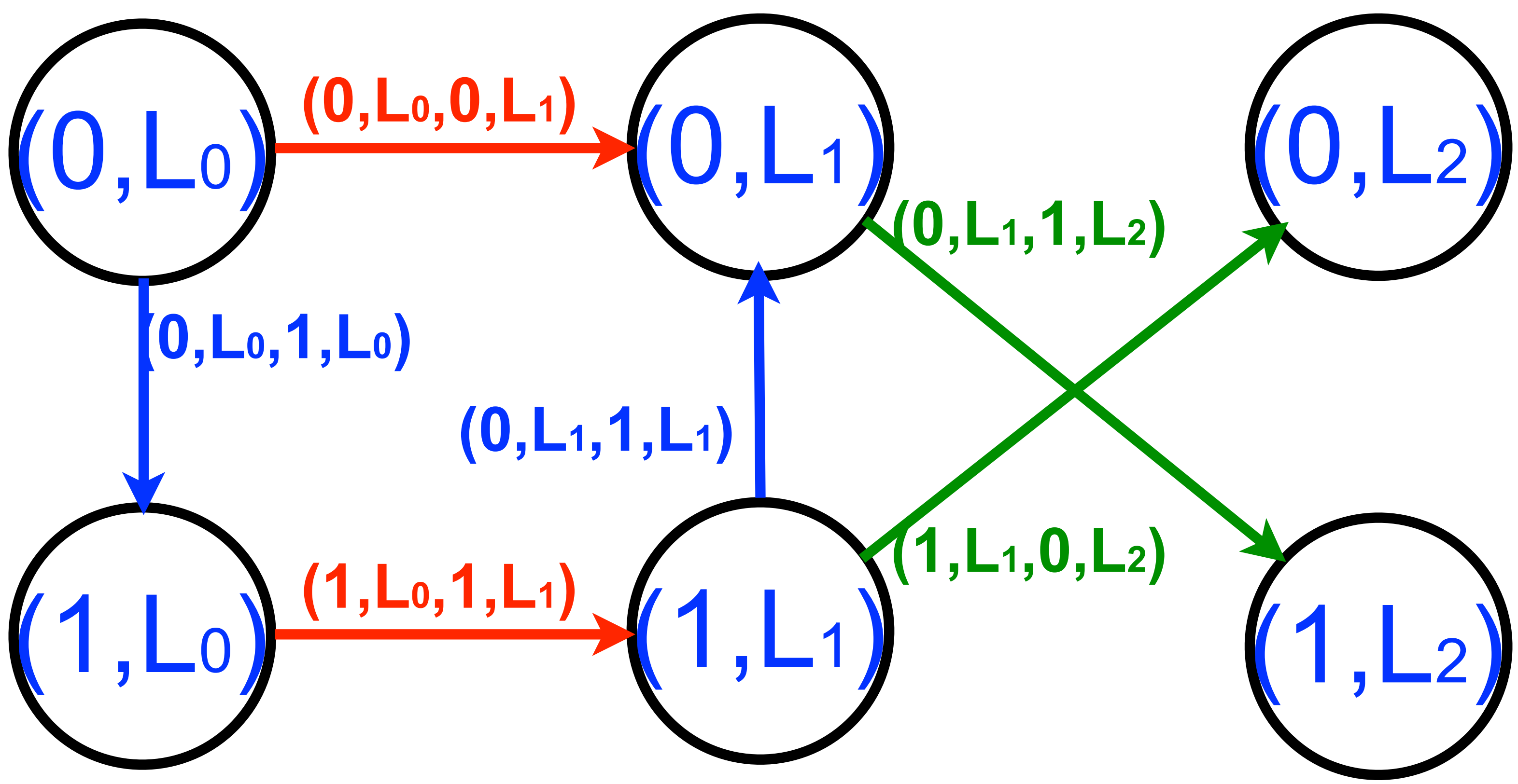
$G = (V,E,L)$

$e = (\underbrace{u, L_a}_{\mathbf{r}}, \underbrace{v, L_b}_{\mathbf{s}})$

$V = \{0, 1\}$

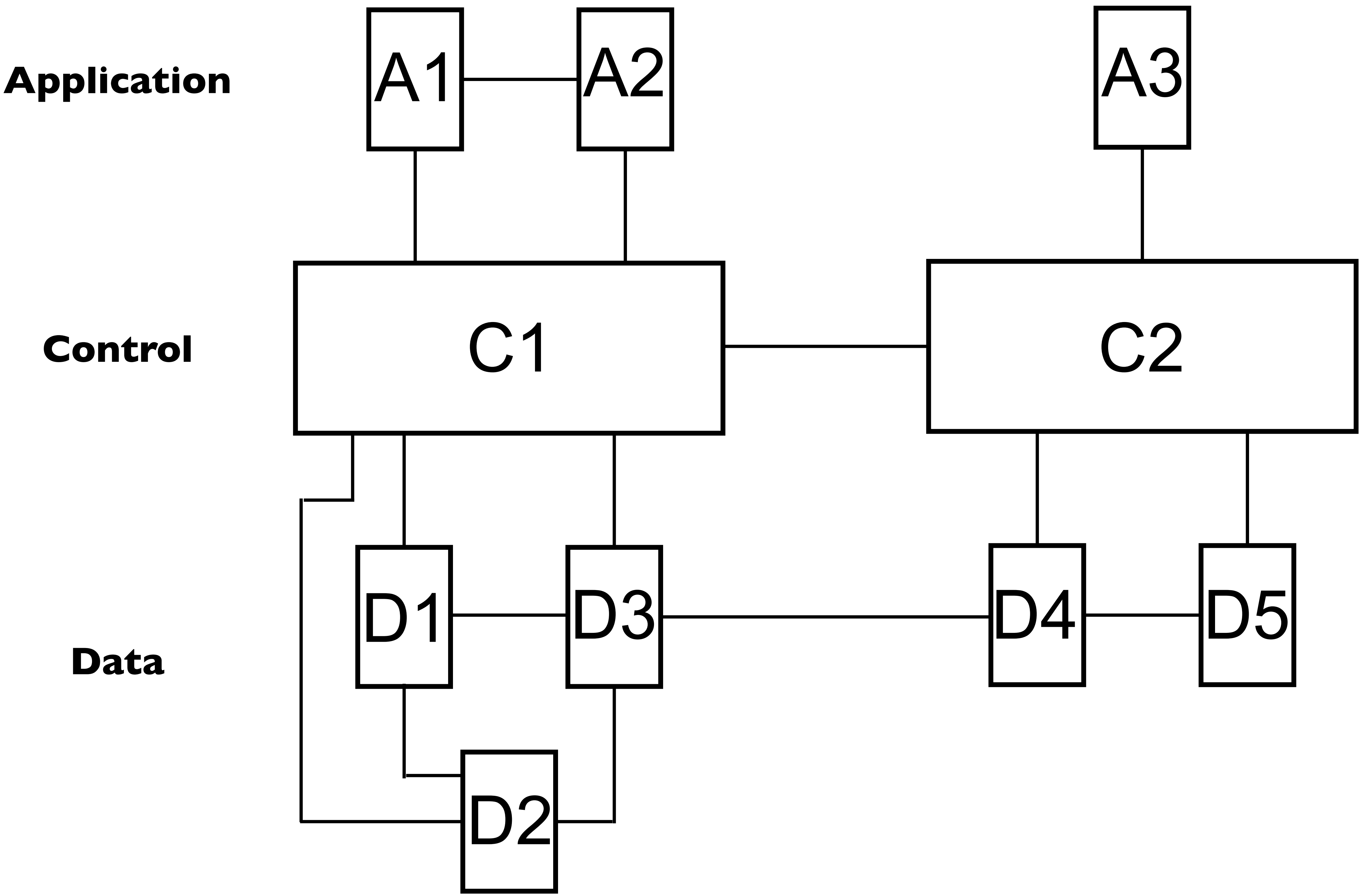
$L = \{L_0, L_1, L_2\}$

$\mathbf{r},\mathbf{s} \in V_s = V \times L$

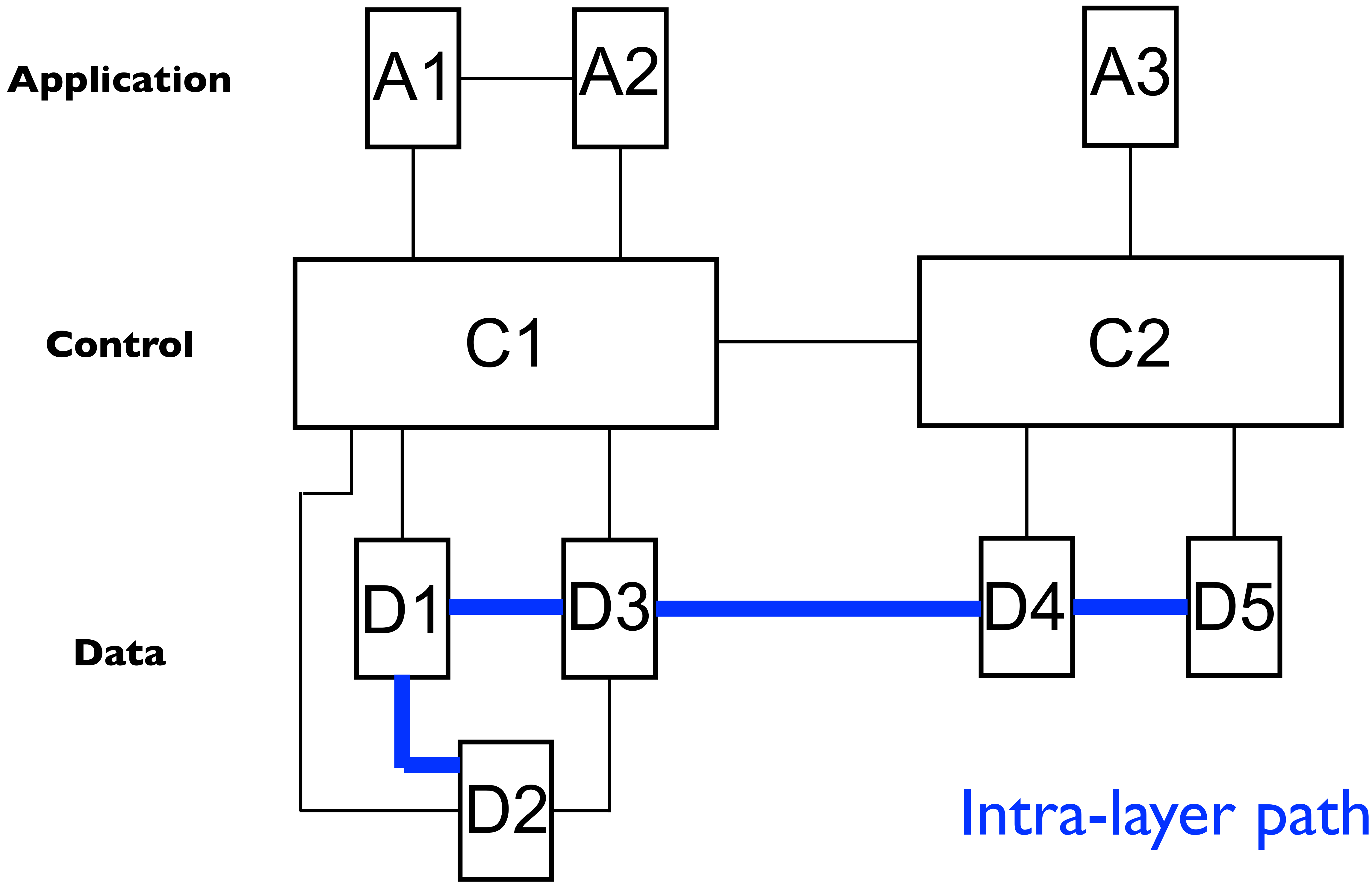


A reference model for SDN environments based on MLGs

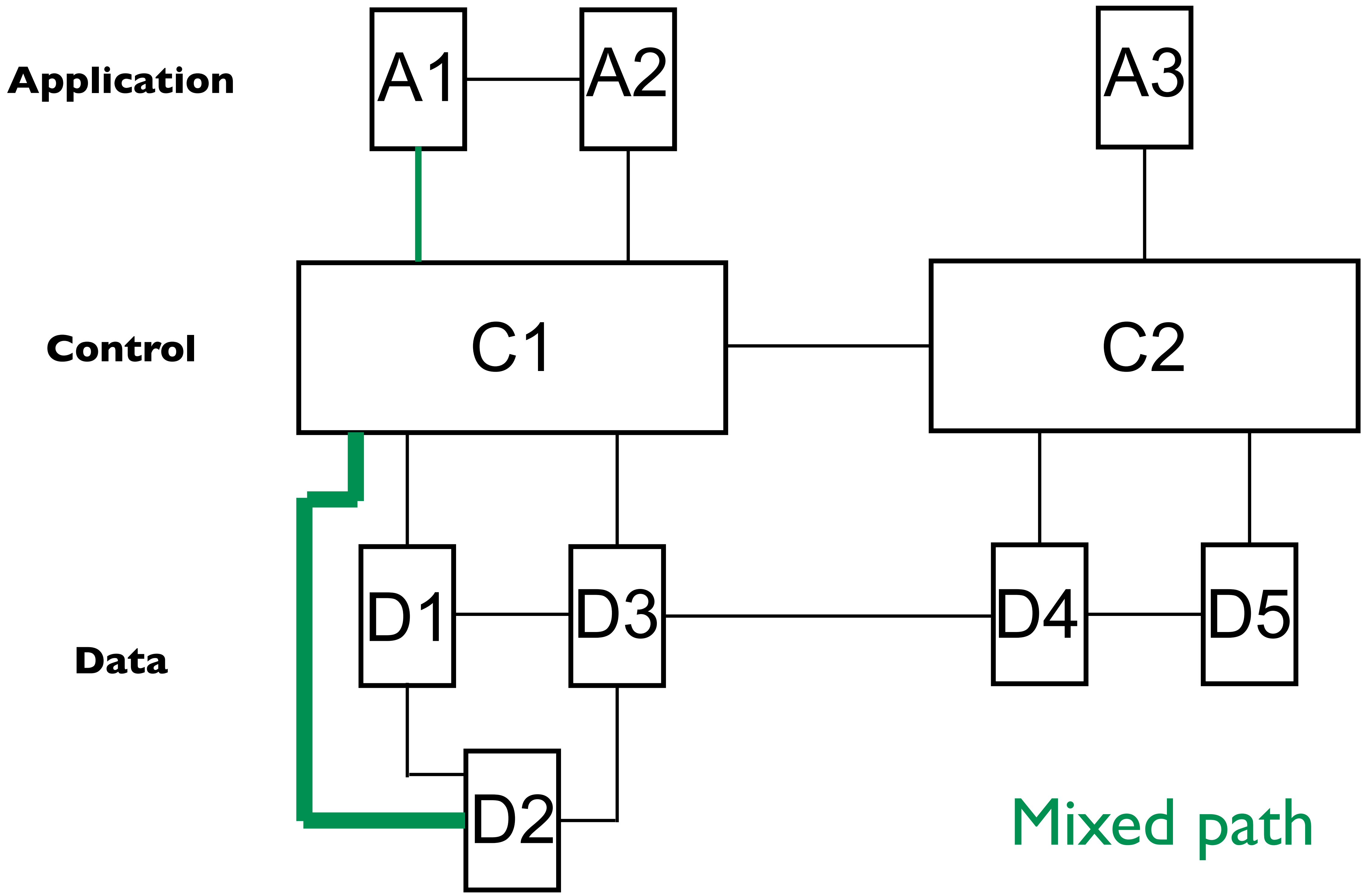
MLG Example



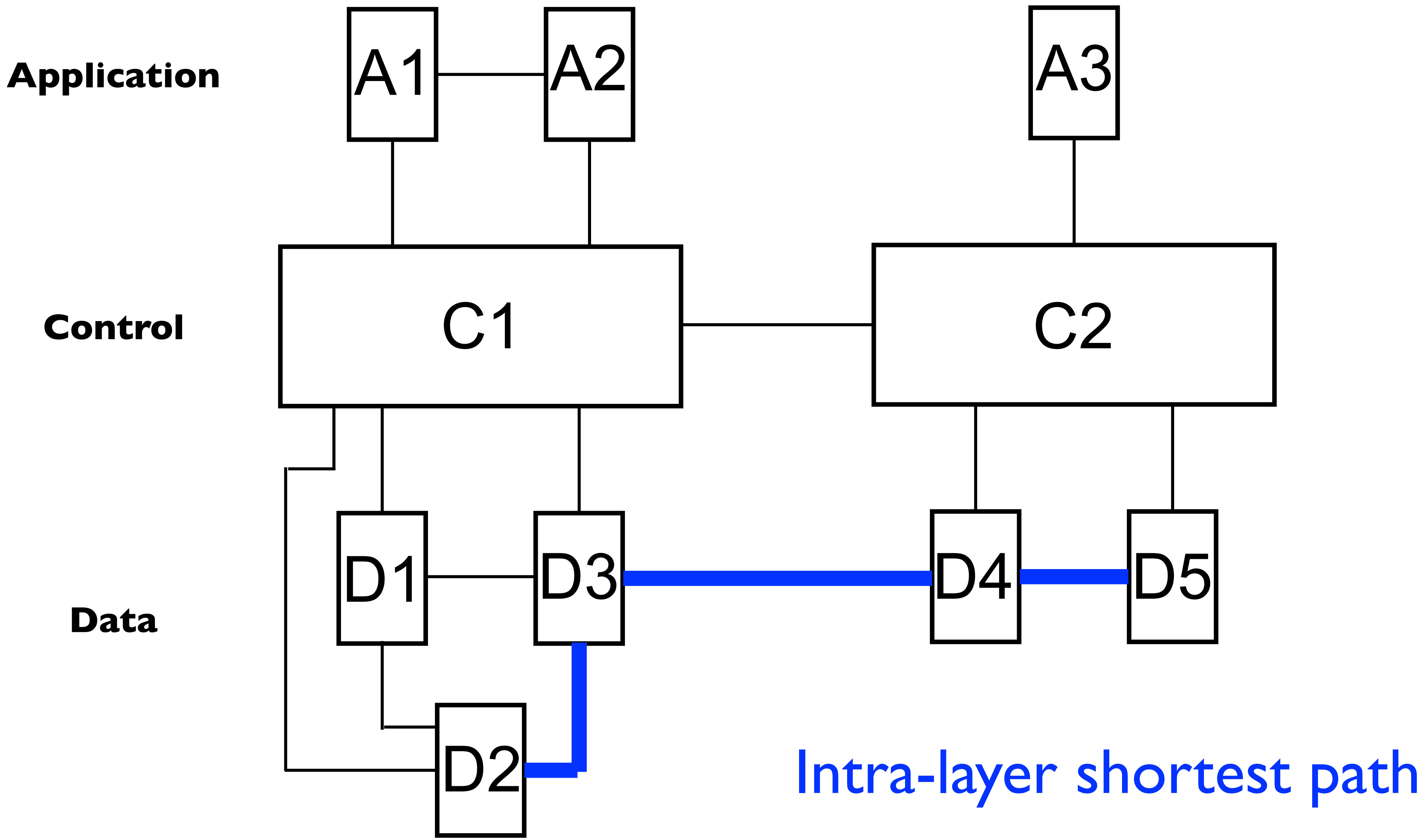
MLG Paths


Application
A1
A2
A3
Control
C1
C2
Data
D1
D3
D4
D5
D2
Intra-layer path

MLG Paths


Application
Control
Data
A1
A2
A3
C1
C2
D1
D3
D4
D5
D2
Mixed path

MLG Shortest Paths



Adjacency Matrix

```
+-                                                         -+
|0 1 1 0 0 0 0 0 0 0|0 0 0 0 0 1 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D1
|1 0 1 0 0 0 0 0 0 0|0 0 0 0 0 1 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D2
|1 1 0 1 0 0 0 0 0 0|0 0 0 0 0 1 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D3
|0 0 1 0 1 0 0 0 0 0|0 0 0 0 0 0 1 0 0 0|0 0 0 0 0 0 0 0 0 0|D4
|0 0 0 1 0 0 0 0 0 0|0 0 0 0 0 0 1 0 0 0|0 0 0 0 0 0 0 0 0 0|D5 Data
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|C1 Layer
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|C2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|A1
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|A2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|A3
|...................|...................|...................|
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D1
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D3
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D4
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D5 Ctrl
|1 1 1 0 0 0 0 0 0 0|0 0 0 0 0 0 1 0 0 0|0 0 0 0 0 0 0 1 1 0|C1 Layer
|0 0 0 1 1 0 0 0 0 0|0 0 0 0 0 1 0 0 0 0|0 0 0 0 0 0 0 0 0 1|C2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|A1
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|A2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|A3
|...................|...................|...................|
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D1
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D3
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D4
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|D5 Apps
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|C1 Layer
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 0 0 0 0|C2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 1 0 0 0 0|0 0 0 0 0 0 0 0 1 0|A1
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 1 0 0 0 0|0 0 0 0 0 0 0 1 0 0|A2
|0 0 0 0 0 0 0 0 0 0|0 0 0 0 0 0 1 0 0 0|0 0 0 0 0 0 0 0 0 0|A3
+-                                                         -+
 D D D D D C C A A A D D D D D C C A A A D D D D D C C A A A
 1 2 3 4 5 1 2 1 2 3 1 2 3 4 5 1 2 1 2 3 1 2 3 4 5 1 2 1 2 3

       Data                Control             Apps
       Layer               Layer               Layer
```

Adjacency Matrix

Intra-layer edges for the data layer

mixed edge (C1-D2) of the previous example

	D1	D2	D3	D4	D5	C1	C2	A1	A2	A3	D1	D2	D3	D4	D5	C1	C2	A1	A2	A3	D1	D2	D3	D4	D5	C1	C2	A1	A2	A3	
D1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D3	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D4	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
D5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	Data
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Layer
C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
A1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Ctrl
C1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	Layer
C2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
A1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
A2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
A3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Apps
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Layer
C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
A1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
A2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
A3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	

Data Layer | Control Layer | Apps Layer

Take Away Messages

A reference model for SDNs based on MLGs

- Can represent SDNs with arbitrary number of layers
- Is equivalent to a directed graph
- Can be represented by matrices or any other form of direct graph representation
- Can use well-known graph algorithms for the analysis of the SDN structure
  - e.g. controller location, management of distributed controllers, study of intra- and inter-layers flows, …

Thanks!

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