# A Reference Model for Managing Large-Scale Software-Defined Network (SDN) Infrastructures

**Klaus Wehmuth** and **Artur Ziviani**

National Laboratory for Scientific Computing (LNCC), Brazil

IRTF NMRG - Meeting 97 - Seoul - November 15, 2015

# SDNs getting complex

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

# SDNs are Multi-layered

- From its basic definition:
  SDNs have Application, Control, and Data layers
- A multi-layered 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 Multi-layer Networks

# MultiAspect Graphs (MAGs)

- MAGs can represent **Multi-layer Time-varying** networks, or even 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
    - 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,
  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

$E \subseteq V \times L \times V \times L$ $\quad e \in E,\ e = (v_1, L_a, v_2, L_b)$

$v_1, v_2 \in V$ - Vertices

$L_a, L_b \in L$ - Layers

An edge expresses a relation between two vertices at two layers

# Edges

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

$e \in E,\ e = (v_1, L_a, v_2, L_b)$

$v_1, v_2 \in V$ - Vertices

$L_a, L_b \in L$ - Layers

o d

Binary Relation

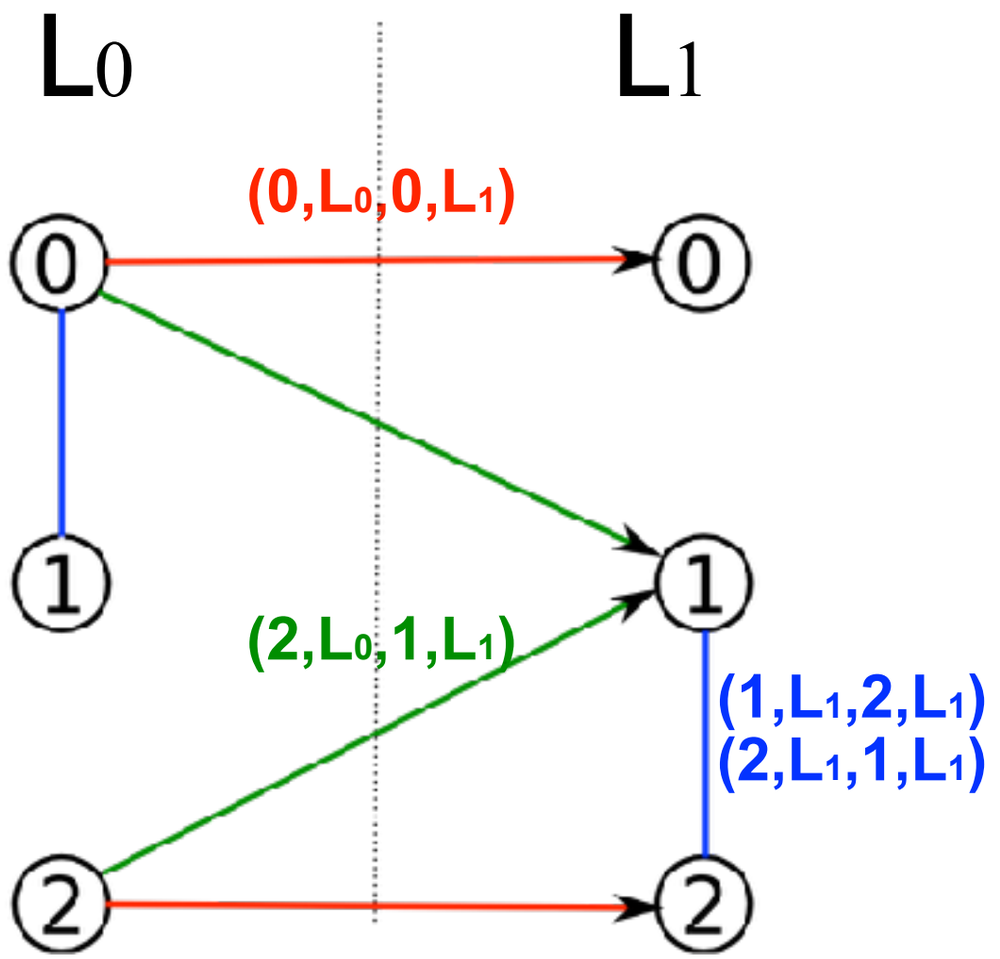
An edge expresses a relation between two vertices at two layers

# Edges Types

Inter-layer Edges

Intra-layer Edges

Mixed Edges



# Composite Vertices

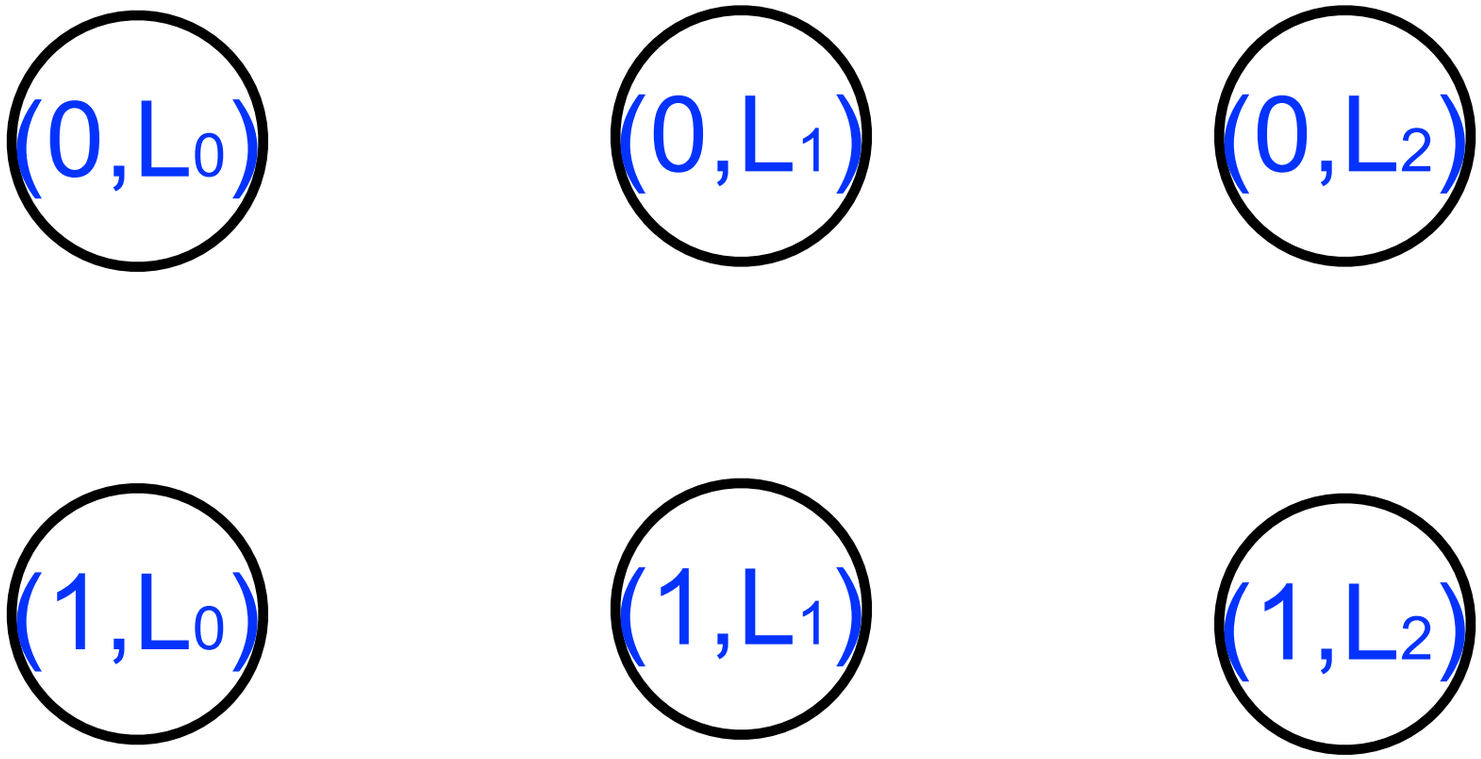
$G = (V,E,L)$

$e = (\underbrace{v_1, L_a}_{\mathbf{u}}, \underbrace{v_2, L_b}_{\mathbf{v}})$

$V = \{0, 1\}$

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

$\mathbf{u},\mathbf{v} \in V_s = V \times L$



# Composite Vertices Representation

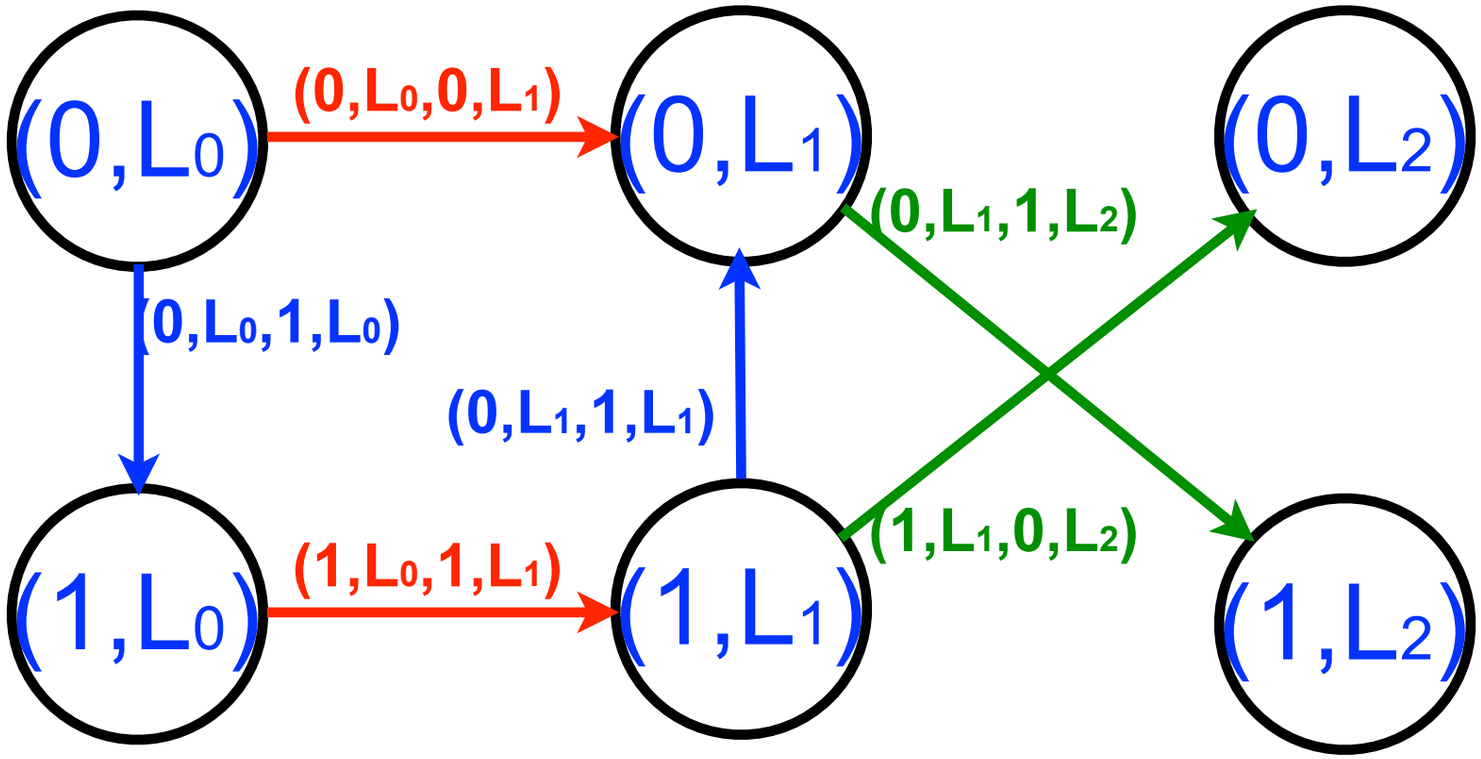
$G = (V,E,L)$

$e = (\underbrace{v_1, L_a}_{\mathbf{u}}, \underbrace{v_2, L_b}_{\mathbf{v}})$

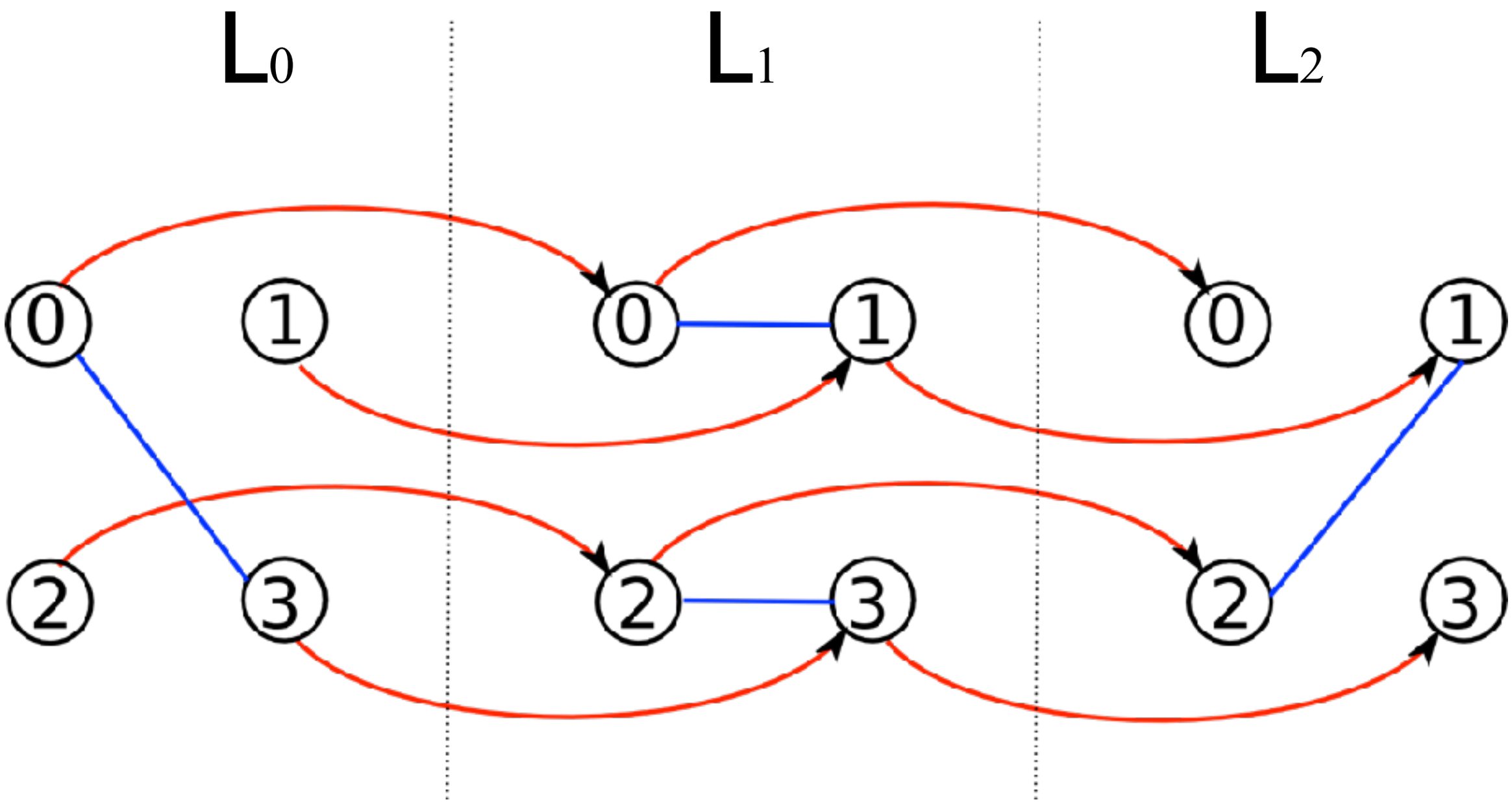
$V = \{0, 1\}$

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

$\mathbf{u},\mathbf{v} \in V_s = V \times L$

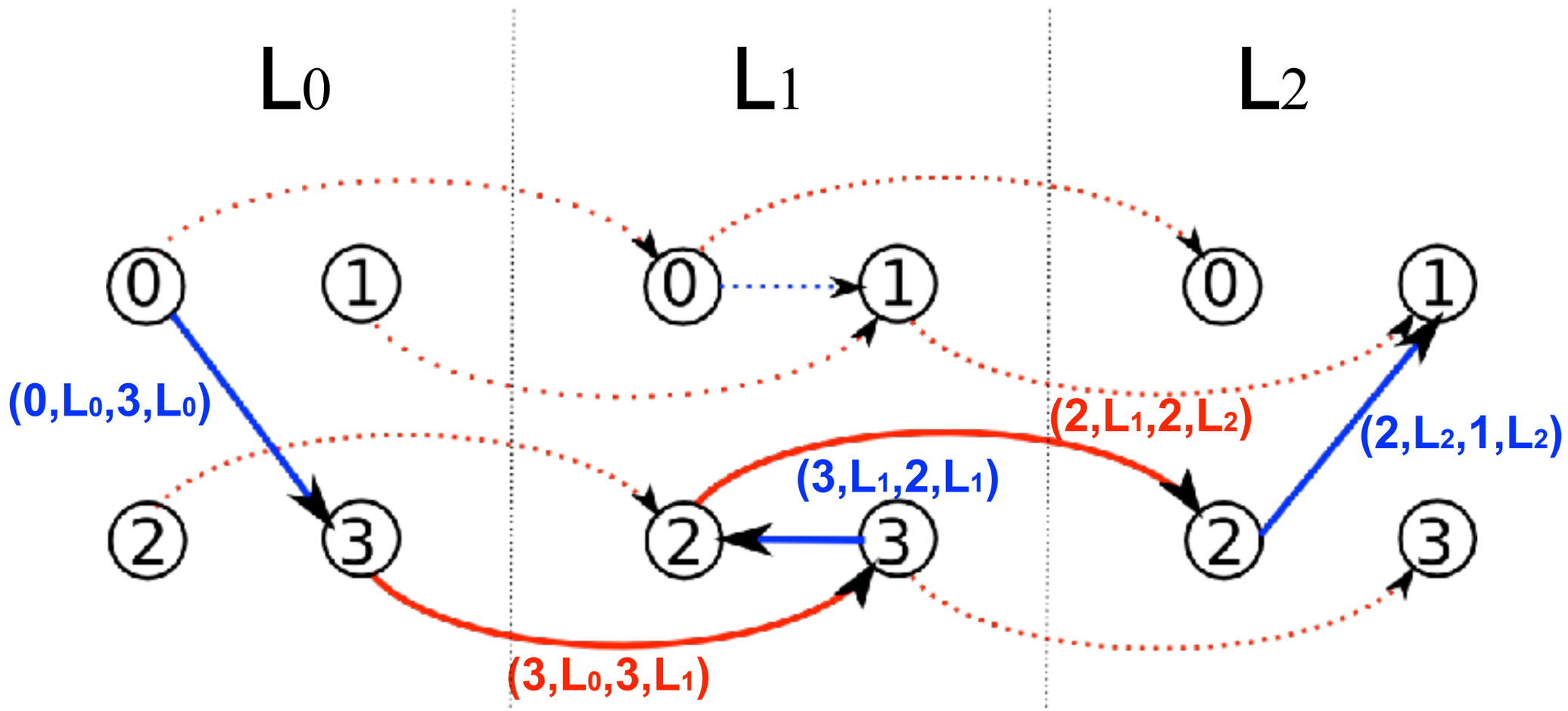


# MLG Example

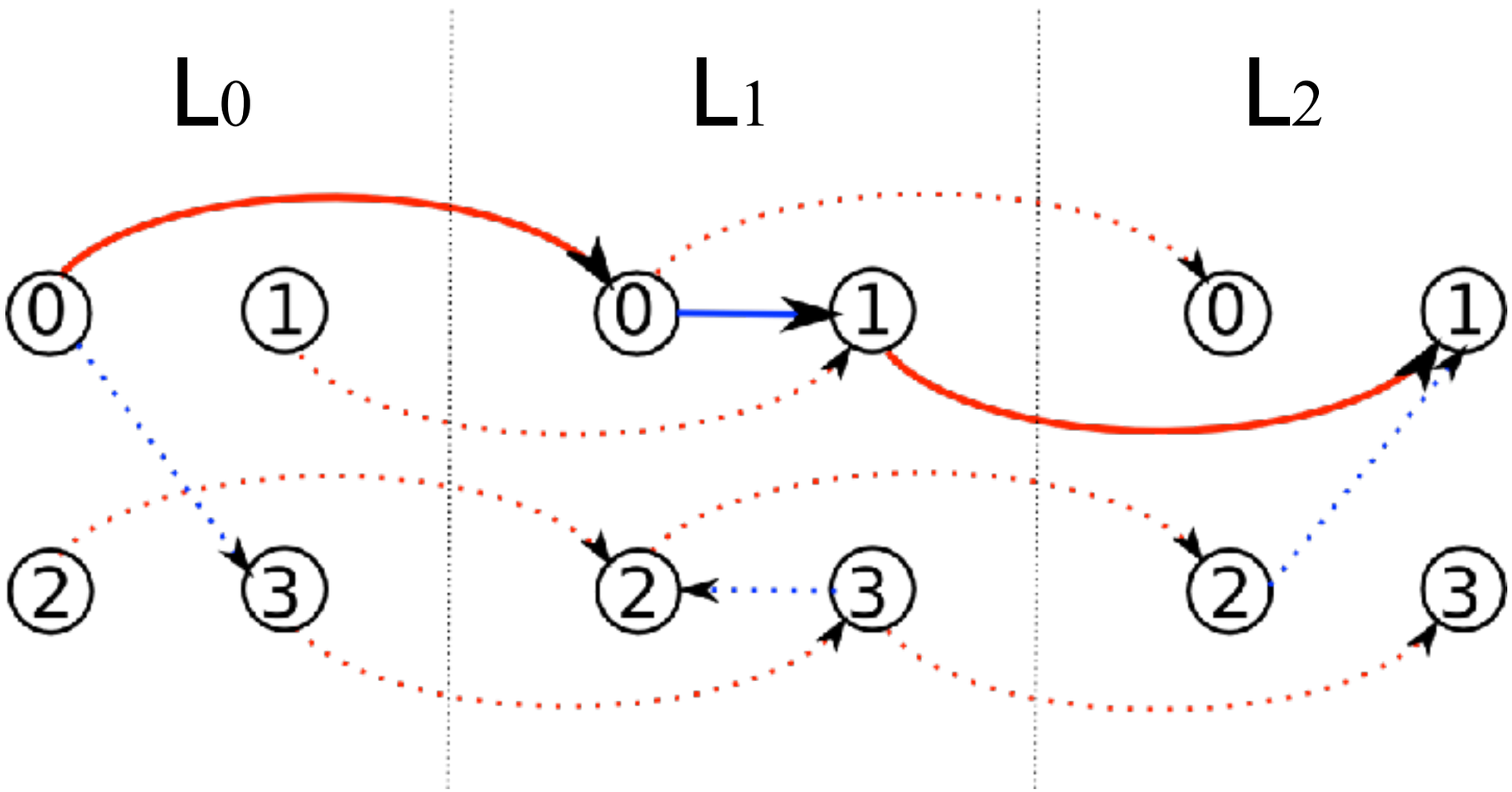


# MLG Paths

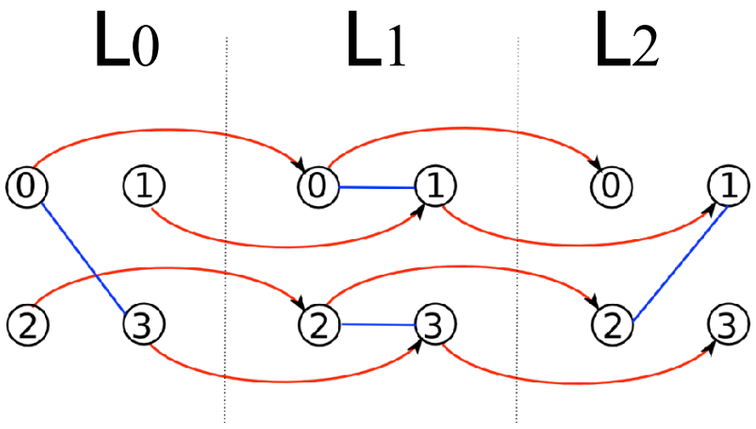
Paths are established by antecessor/successor relations

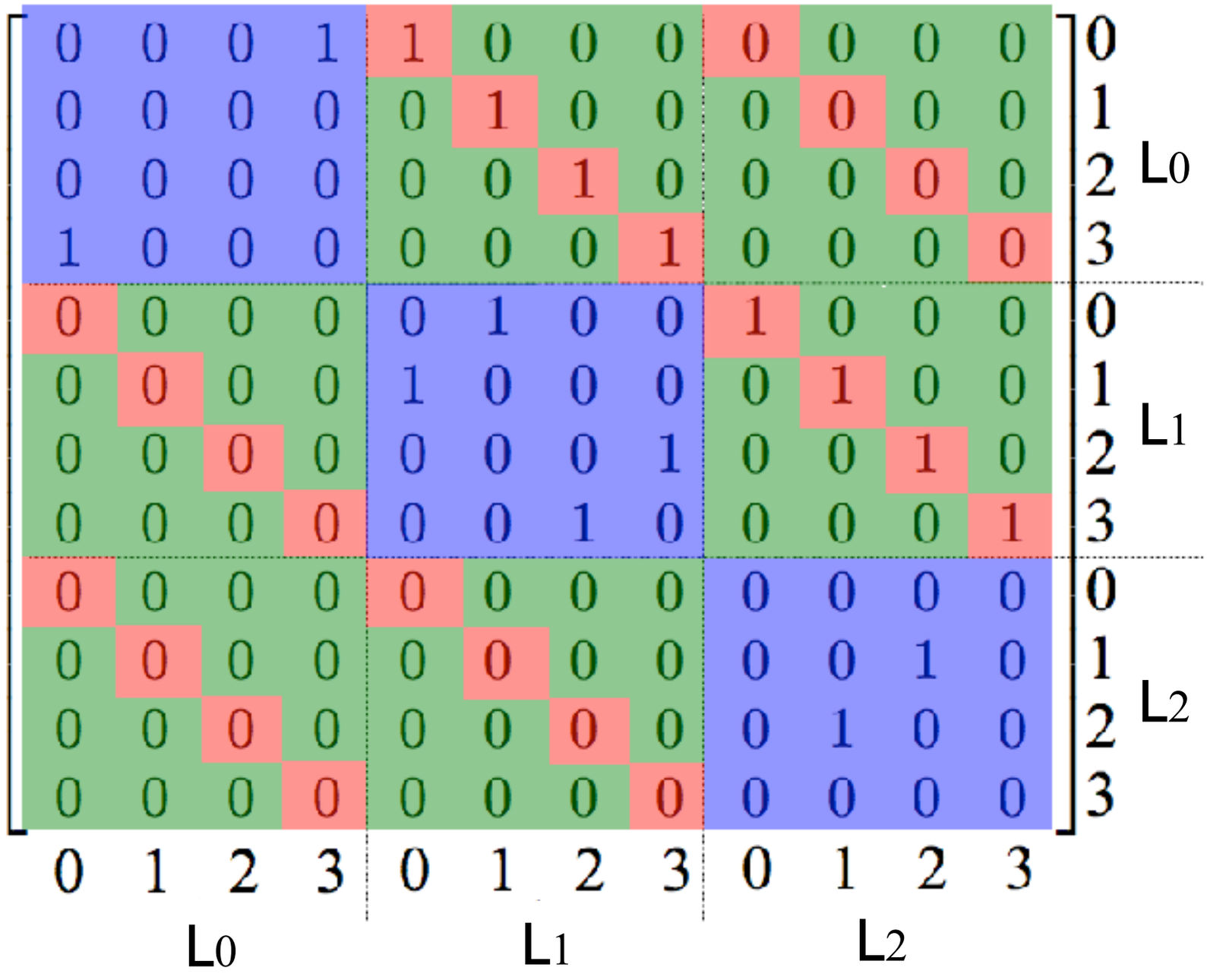


# MLG shortest paths



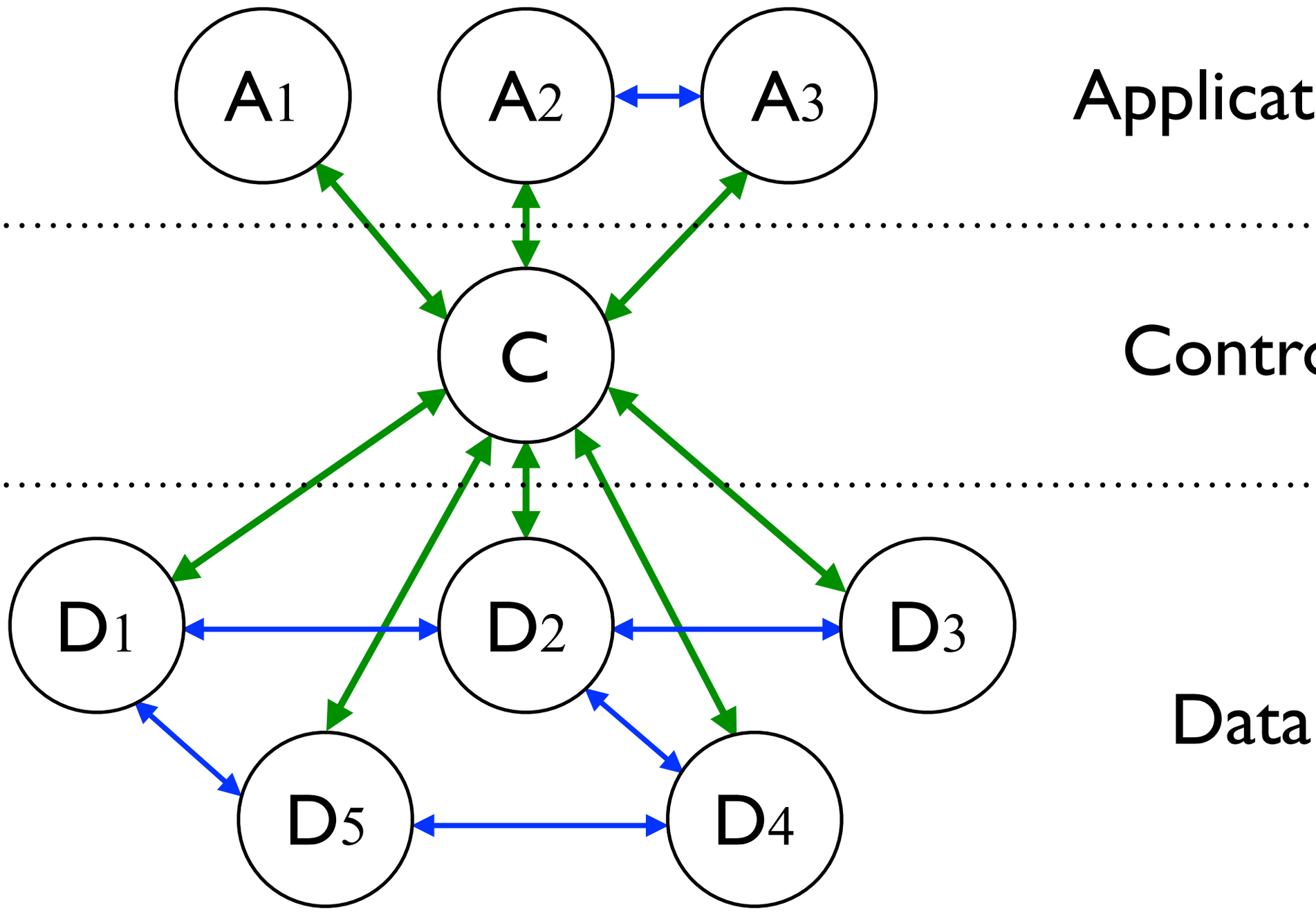
# Adjacency Matrix



# A reference model for SDNs based on MLGs

# SDN Example




Application layer

Control layer

Data 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!

Laboratório Nacional de Computação Científica


## Klaus Wehmuth & Artur Ziviani (LNCC)

{klaus,ziviani}@lncc.br



Acknowledgement:

cgi.br

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

FAPERJ
Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

Finep
INOVAÇÃO E PESQUISA

CAPES

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES