Distributed graph models and transformations – slashed graph representation in design and control problems

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Outline

- Research background
- Graphs distribution
- Real-life drivers
- Lighting design & control
- Results

Research background

- Graphs – Flexible representation of systems – both static and dynamic ones
- System changes modeled by graph transformations

Graphs transformations

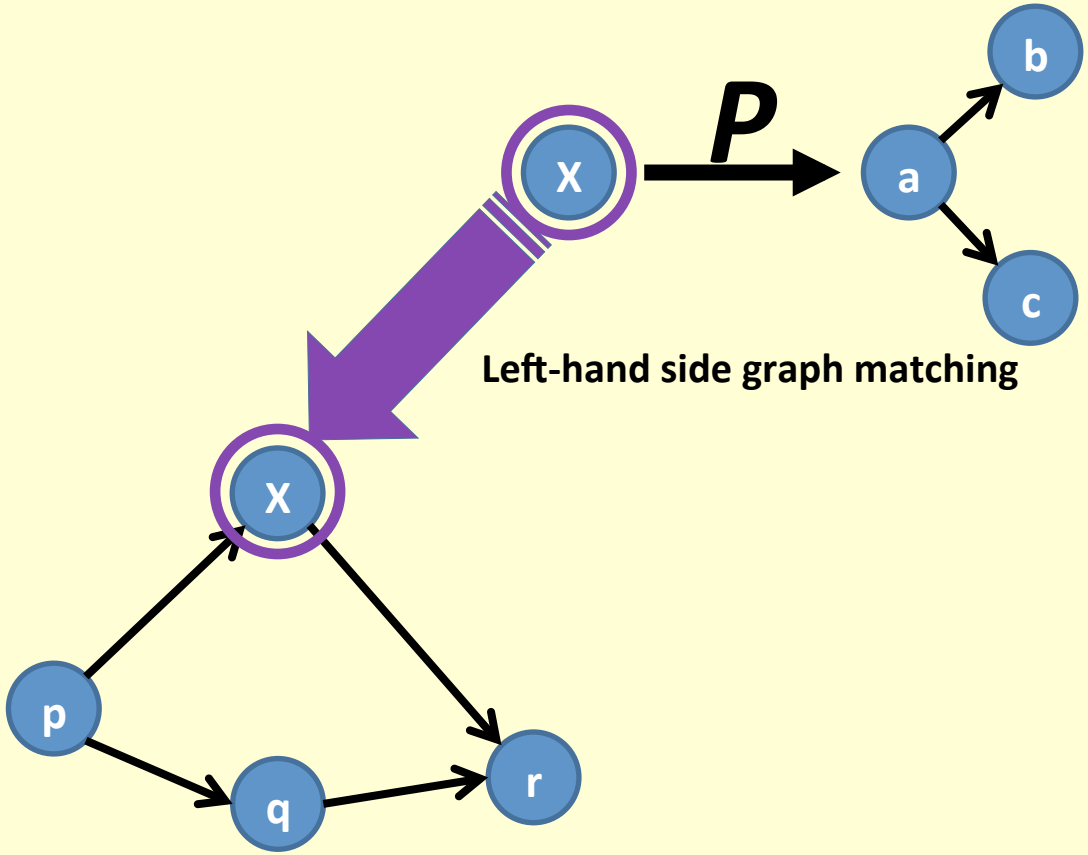
- Structural and semantic changes are modeled by graph transformations
- **Graph grammars** – generalization of string grammars

Graph grammar – formal definition (algorithmic approach)

A **graph grammar** is a system $G = (\Sigma, \Delta, P, Z)$ where:

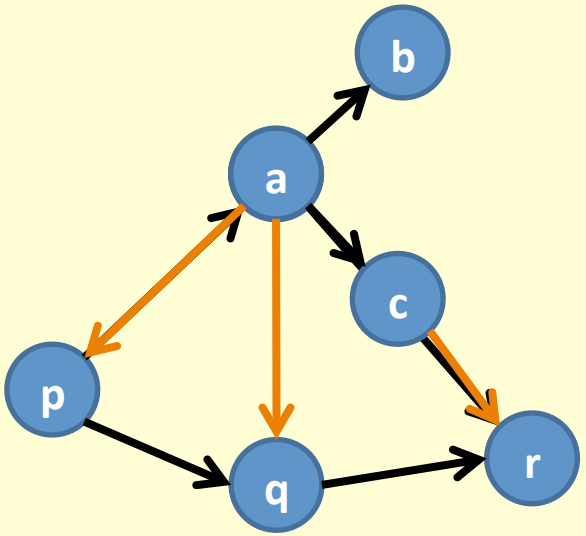
- Σ is a finite nonempty set, called the total alphabet,
- $\Delta \subset \Sigma$ is a terminal alphabet,
- P is a finite set of productions of the form (α, β, ψ) where α is a connected graph, β is a graph and $\psi: V_\alpha \times V_\beta \times \Sigma \rightarrow \{0,1\}$ is an embedding function of the production, and
- Z is a graph over Σ, called the axiom

Graph grammar production – intuitive approach



Left-hand side graph matching

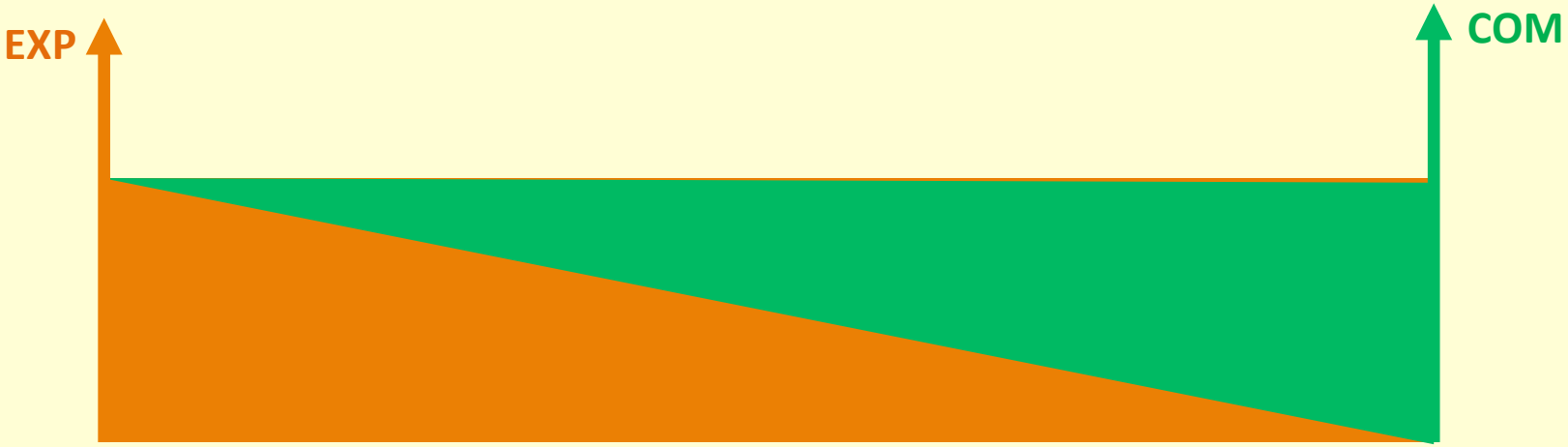
Replacing X with right-hand side graph



Embedding right-hand side graph

Graphs transformations (cont.)

- Two contradictory approaches: **expressiveness** **vs** **low computational complexity**



- **Is a polynomial complexity, say $\mathcal{O}(N^3)$, satisfactory?**

Complexity issue – workaround

- Using grammars of a polynomial (quadratic) complexity – **not sufficient!**
- Graph distribution – ***Replicated Complementary Graphs*** (RCG) representation

  [*Ref:* Kotulski, A. Sędziwy, ***GRADIS -- the multiagent environment supported by graph transformations***, Simulation Modelling Practice and Theory : International Journal of the Federation of European Simulation Societies, 2010]

- Distributed graph transformations are proven to have the polynomial complexity

  [*Ref*: L. Kotulski, A. Sędziwy, ***Parallel graph transformations supported by replicated complementary graphs***, Lecture Notes in Computer Science, vol. 6594, 2011, Springer]

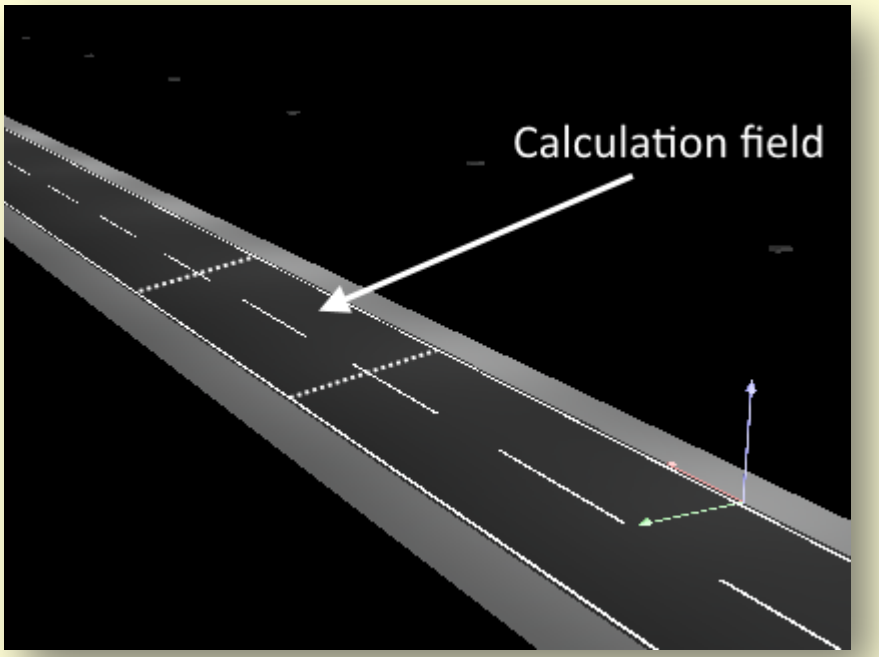
Real-life drivers

- The global number streetlights is estimated to increase by 60 millions and reach nearly 340 million by 2025 [Northeast Group] → Expected annual electric power energy costs: **$23.9B** to **$42.5B** by 2025
- Even small unit power efficiency improvement can yield significant savings
- Objective: **improving energy efficiency of public lighting**

Real-life drivers (cont.)

- Large-scale retrofit of roadway lighting
- Wide-area street lighting control systems
- Energy efficient outdoor lighting systems
- R&D Projects:
  - **Products and Services of a Living Smart Energy City Lab**, the city of Geel, Belgium (settings for 5,500 HPS fixtures)
  - **SOWA Project** (5,500 HPS → LEDs fixtures)
  - **ISE Project** (3,700 HPS → LEDs fixtures)
  - Public lighting retrofit in the city of **Pabianice**, Poland (700 HPS → LEDs fixtures)

Photometric Computations



- Luminance related requirements have to be met on each calculation field
- Full uniformity is imposed for calculations made by industry-standard software

Real-life drivers (cont.) – new approach to lighting design

- Actual coordinates of poles and a road layout instead of averaged values
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[*Ref:* A. Sęd
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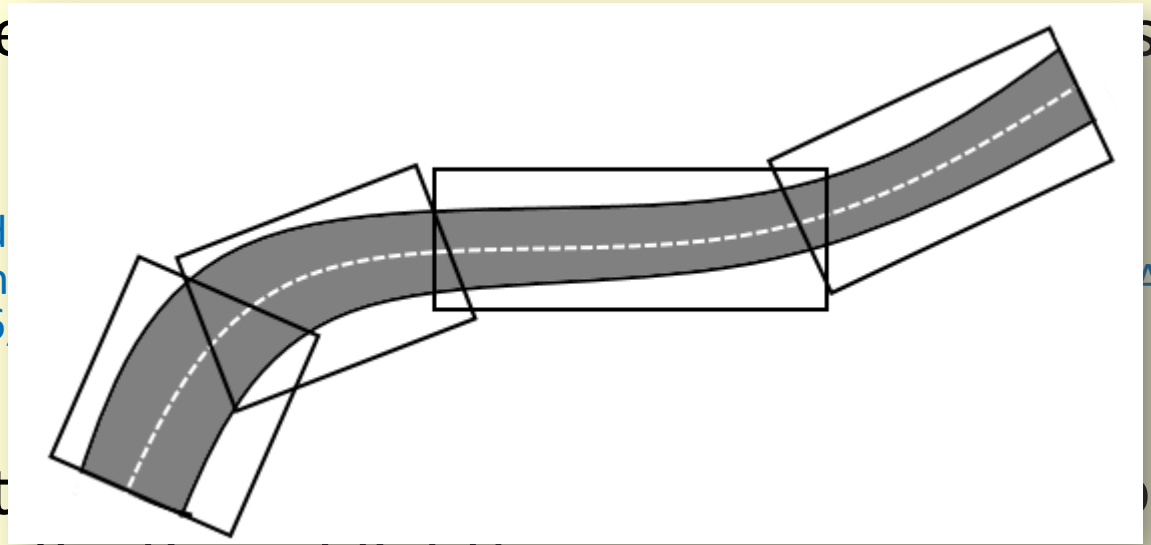


- Impact
rtant as well (reflection of light)
- **The cost paid is the significant growth of computational complexity**

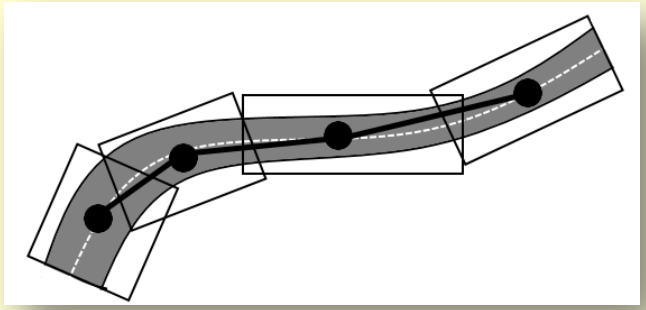
Problem formulation

- Large-scale computations performed during lighting design/optimization are not doable in a reasonable time, even when supported by industry-standard software (e.g., DIALux)

- Achieving additional power savings in public lighting requires applying another, scalable computational method capable of bearing the new lighting design methodology

Problem solution – hierarchical hypergraph distributed model

- **Hypergraph representation is a necessity!**
- **Covers**
  - Massive objects (buildings)
  - Dimensionless entities (sensors, lamps)
  - Areas (streets)
  - Any relations among them



[*Ref*: A. Sędziwy, ***Representation of Objects in Agent-Based Lighting Design Problem***, Advances in Intelligent and Soft Computing, 2012, Springer (WoS indexed, 10 pts.)]

Test cases – hypergraph sizes, the scale of a problem

Rome

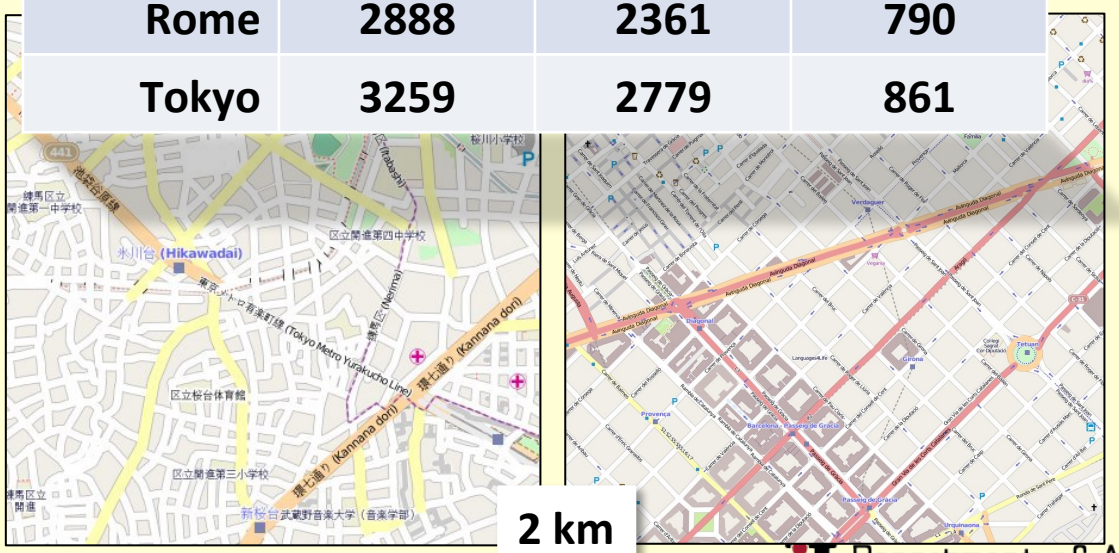
Chicago

Data source:
OpenStreetMap

City	Nodes	Edges (tot.)	Hyperedges
Barcelona	2918	2205	897
Chicago	1989	1552	631
Rome	2888	2361	790
Tokyo	3259	2779	861

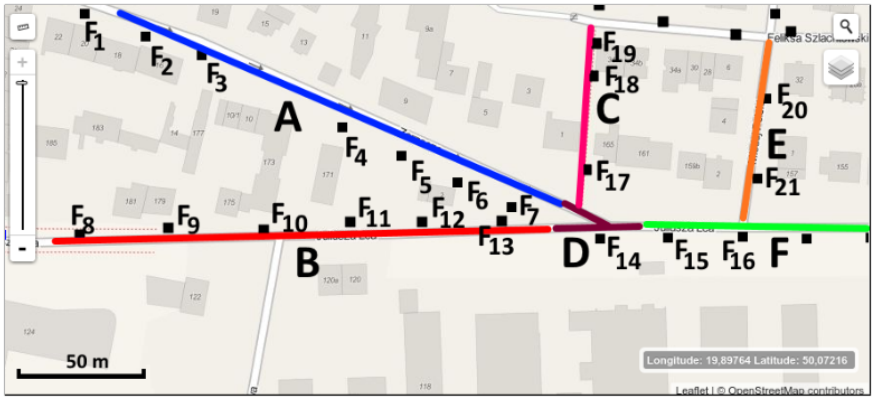
Tokyo

Barcelona

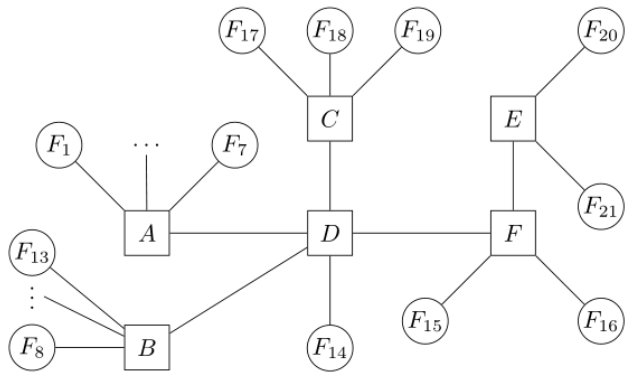


Hierarchical hypergraph model

- An upper level graph (ULG) – the coarse grain representation – **subject to decomposition**
- A lower level hypergraph – nodes of an ULG are expanded **locally** into hypergraphs representing physical objects

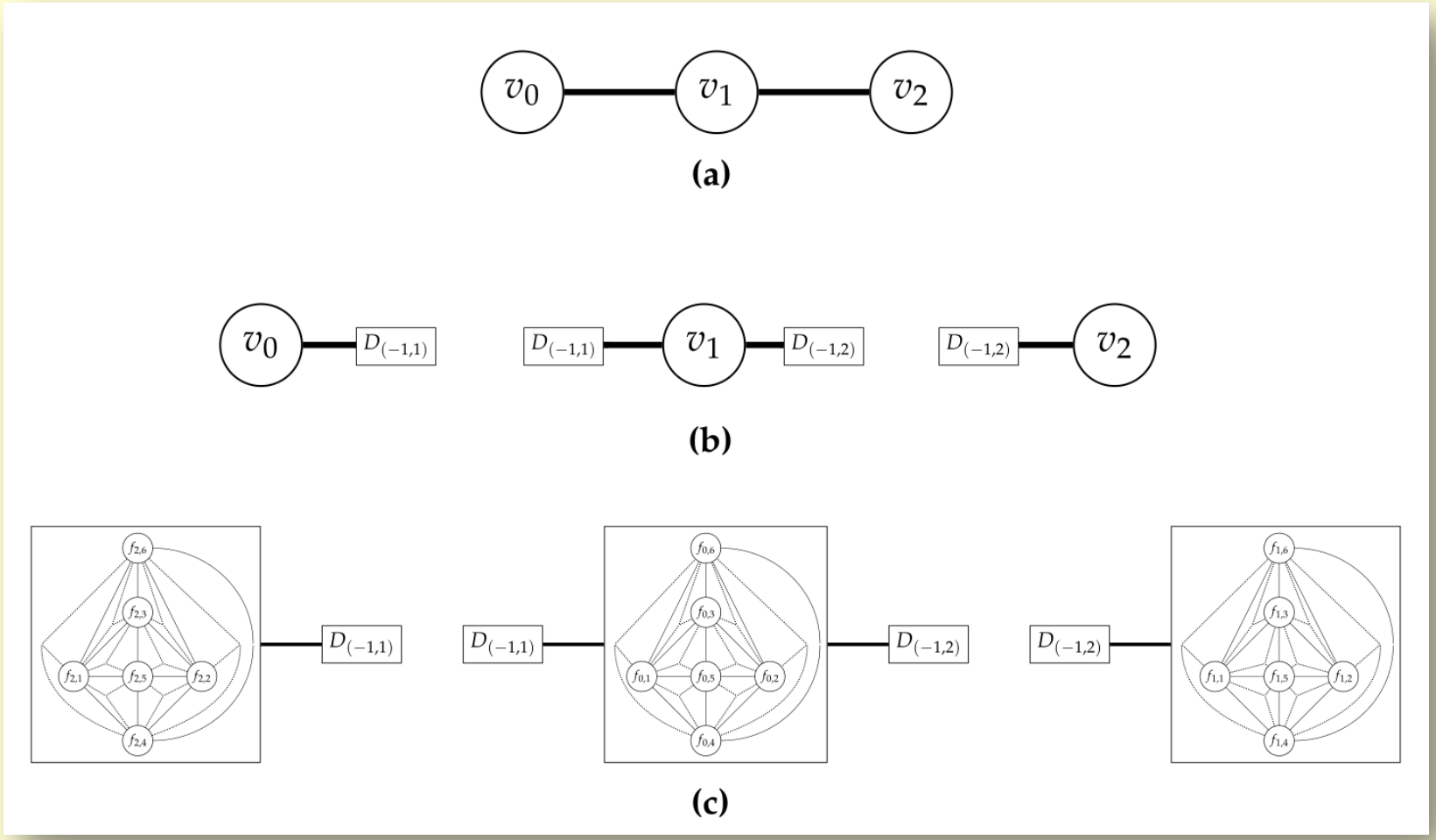


(a) The sample map showing distribution of luminaires. A, B, C, D, E, F denote selected calculation fields and $F_1, F_2, \ldots F_{21}$ represent luminaires



(b) The graph representing the scene shown in Fig. 2a. Square nodes correspond to calculation fields and the round ones the luminaires

Hierarchical hypergraph model (cont.)



Distributed graph model application

- The new design method remains useless unless some efficient calculation approach is applied
- The new paradigm of a roadway lighting design/ optimization requires new computational environment expressive enough to model:
  - Lighting infrastructure
  - Areas
  - Buildings
- Hierarchical hypergraph model + mult-agent computations

[*Ref*: A. Sędziwy, L. Kotulski, ***Towards highly energy-efficient roadway lighting***, Energies, 9(4), 263, 2016, MDPI]

Distributing graphs (cont.)

- ***Slashed graphs*** respresentation
  - **More suitable than RCG (no replication is required)**
  - **Limited numbers of synchronizing parties, locked nodes/edges and messages being exchanged among agents are proven**

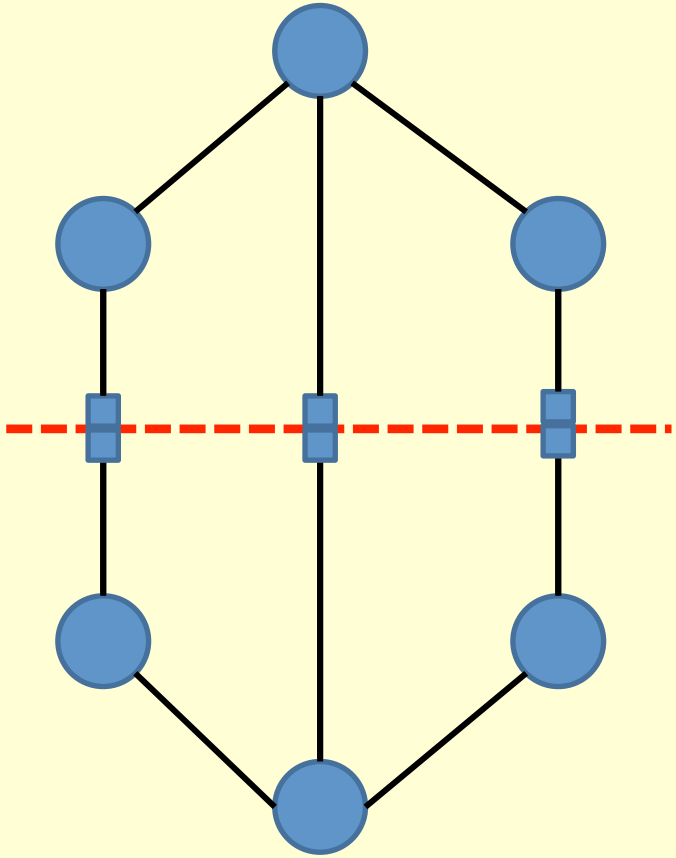
Comparison of the *Incorporate* procedure for RCG and slashed graphs

Parameter	RCG representation	Slashed representation
Number of coordinating agents	$\mathcal{O}(N)$	$\mathcal{O}(2)$
Number of locked nodes/edges	$\mathcal{O}(d \cdot N)$	$\mathcal{O}(d)$
Number of updating messages	$\mathcal{O}(d \cdot N^2)$	$\mathcal{O}(d)$

d – maximum node degree in a centralized graph, N – number of subgraphs

[*Ref:* Adam SĘDZIWY, ***Effective Graph Representation for Agent-Based Distributed Computing***, Lecture Notes in Computer Science, vol. 7327, 2012, Springer]

Graph slashing



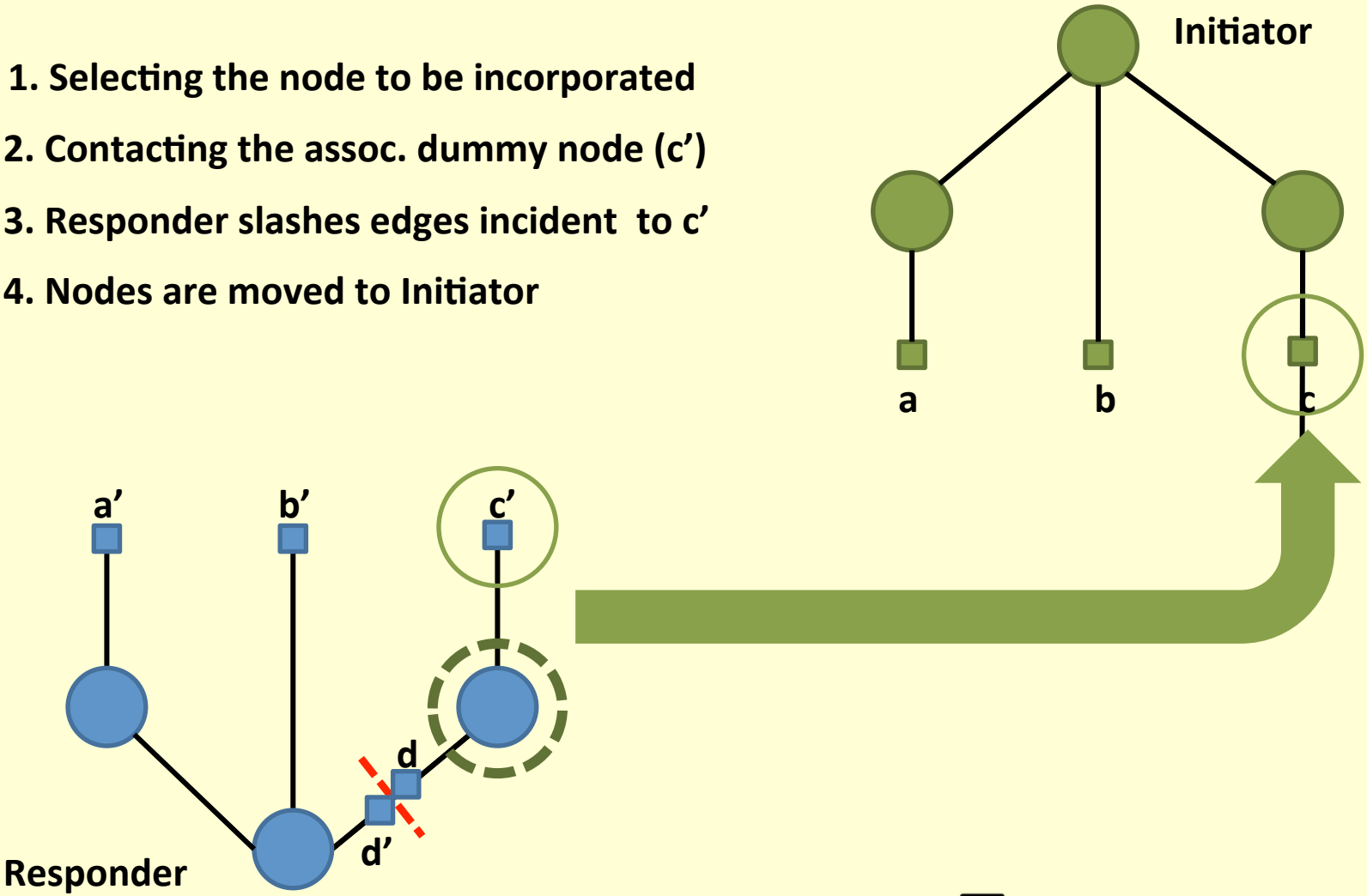
Slashed graphs are ready to use

Setting slashing line(s)

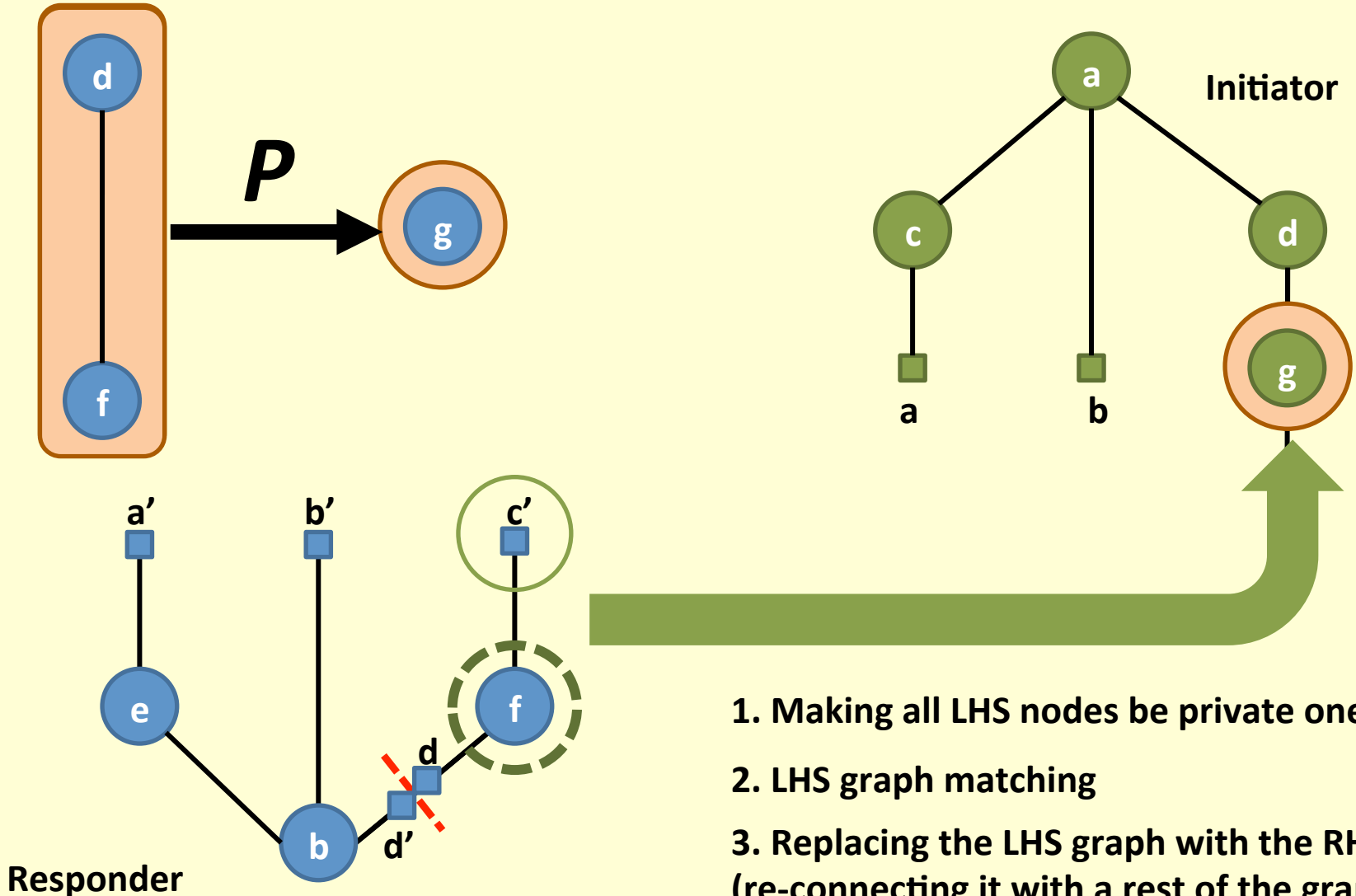
Establishing slashed edges

Node incorporation

1. Selecting the node to be incorporated
2. Contacting the assoc. dummy node (c')
3. Responder slashes edges incident to c'
4. Nodes are moved to Initiator



Graph transformation in distributed environment



1. Making all LHS nodes be private ones
2. LHS graph matching
3. Replacing the LHS graph with the RHS one (re-connecting it with a rest of the graph)

Additional heuristics

- DRY (Don't repeat yourself) methodology: no input pattern is processed twice

Optimization of lighting installations on the area decomposable into 2886 calculation fields

Area of application

- Lighting design

  [*Ref*: A. Sędziwy, L. Kotulski, ***Multi-agent system supporting automated large-scale photometric computations***, Entropy 18(3), 76, 2016, MDPI]

- Optimizing existing lighting installations

  [*Ref*: A. Sędziwy, ***Sustainable Street Lighting Design Supported By Hypergraph-Based Computational Model***, Sustainability , 8(1), 13, 2016, MDPI]

- Preparing adaptive lighting control systems

  [*Refs*:
  • I. Wojnicki, S. Ernst, L. Kotulski, A. Sędziwy, ***Advanced Street Lighting Control***, Expert Systems with Applications, 2014, Elsevier,
  • I. Wojnicki, L. Kotulski, S.Ernst, A. Sędziwy, B. Strug, ***A Two-Level Agent Environment for Intelligent Lighting Control***, International Journal of Materials and Product Technology, vol. 53, 2016, Inderscience Enterprises Ltd.]

- Support for architectural design tools

  [*Ref*: Kotulski, A. Sędziwy, B. Strug, ***Heterogeneous Graph Grammars Synchronization in Computer Aided Design***, Expert Systems with Applications, 2014, Elsevier]

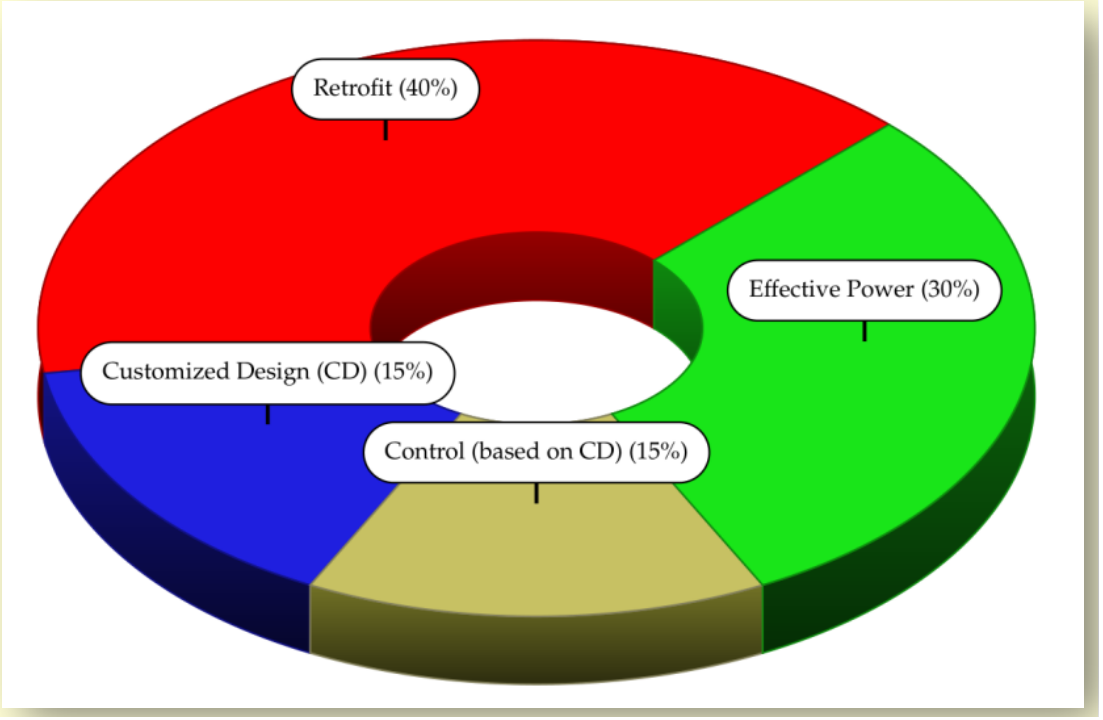
Practical applications & results

ISE Project

Public lighting is an important part of a smart city

- **3748** HPS fixtures → LEDs
- **622** calculation fields (**239** streets)
- **73** control cabinets

Impact on energy efficiency




"That's all Folks!"
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