Energy-aware mappings of series-parallel workflows onto chip multiprocessors

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Scheduling in Aussois

Motivation and introduction

- Energy saving: crucial problem
- Chip MultiProcessor (CMP): present and future of the processor
- Streaming applications: ubiquitous in many domains, like image processing
- Most task graphs are Series-Parallel Graphs (SPGs)

Outline of the talk

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Series-parallel graph

- G is a SPG if G is a composition of two SPGs
-  is a SPG
- Compositions

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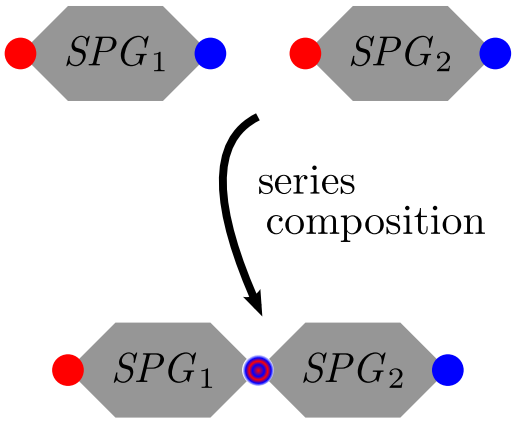

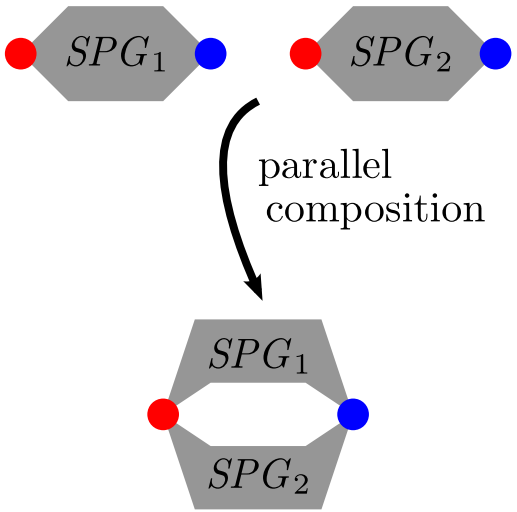

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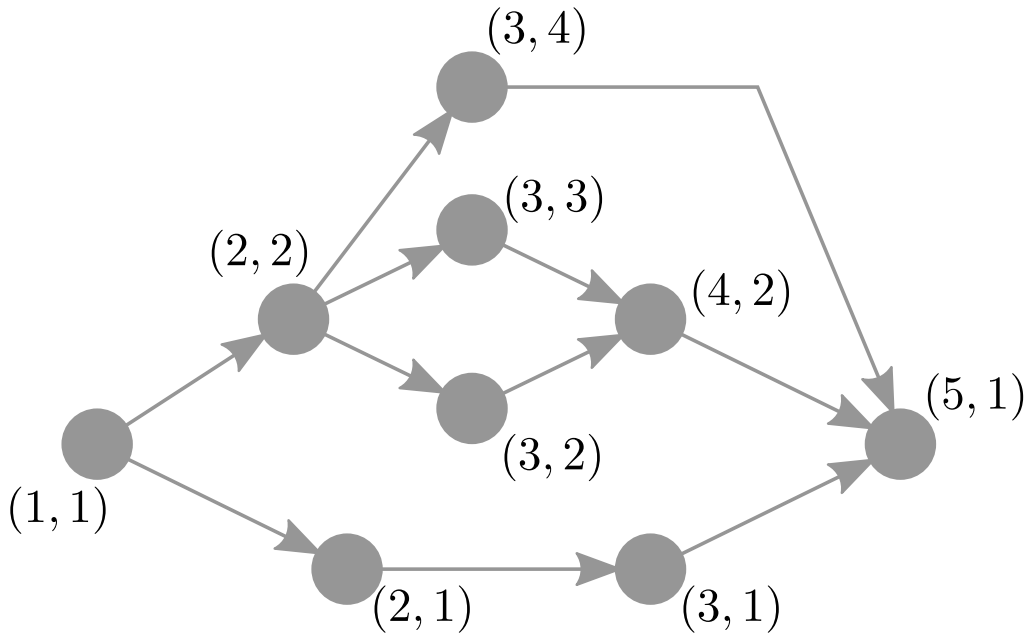

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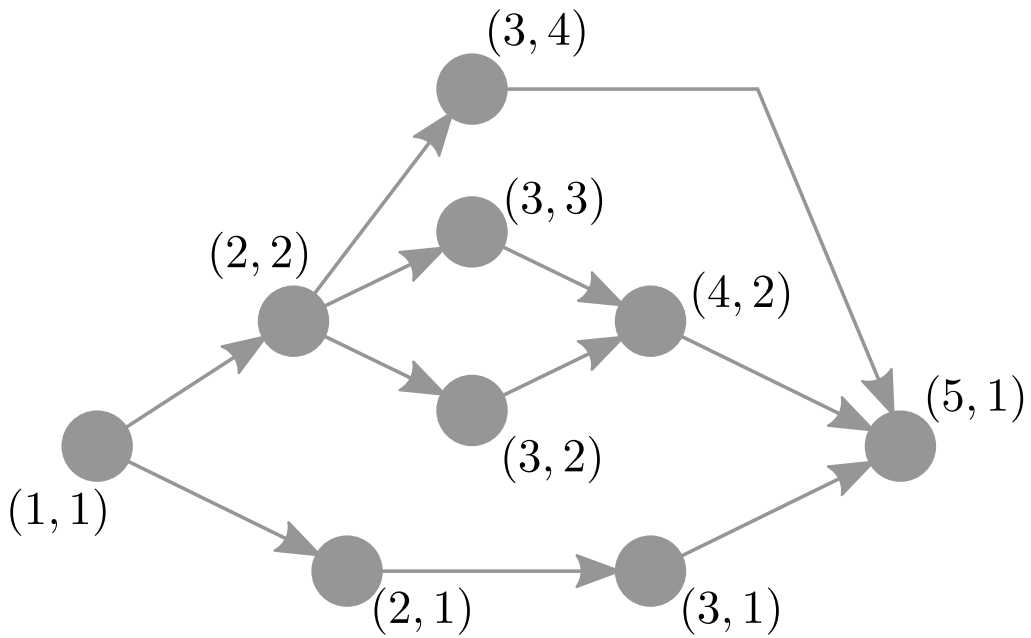
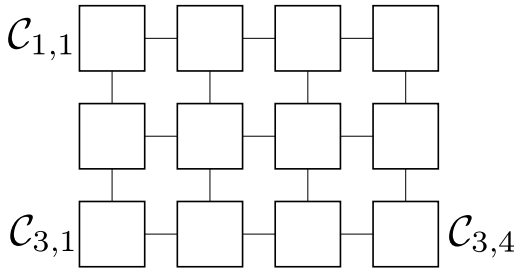


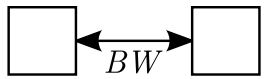
$\Rightarrow$ bounded elevation

Target platform

- Cores $\mathcal{C}_{u,v}$ on a $p \times q$ grid

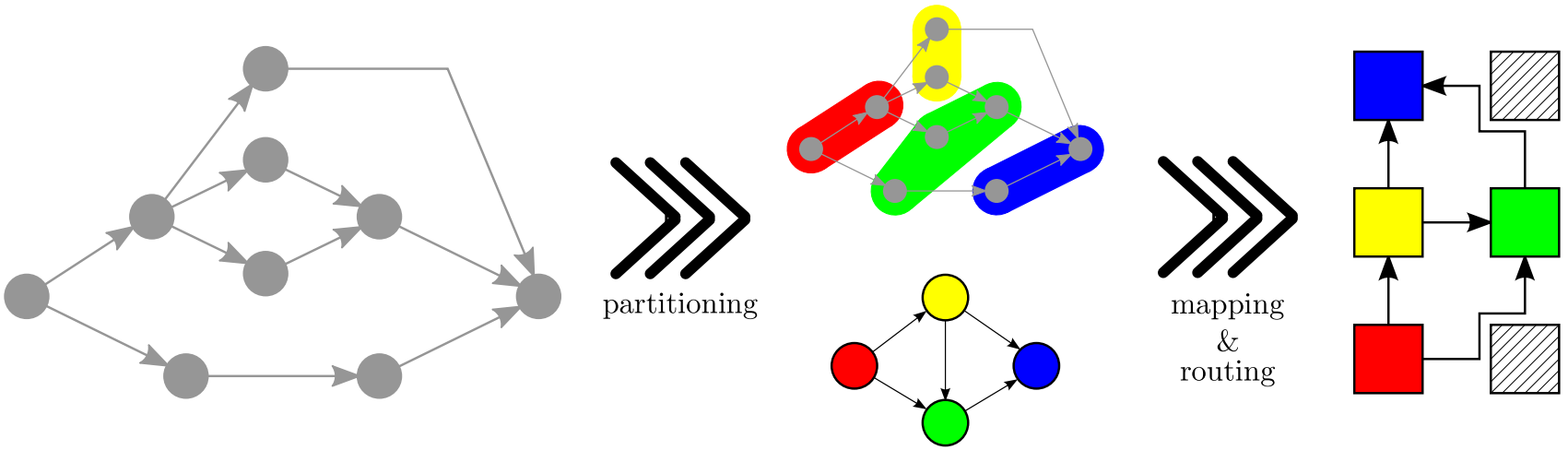


- Bidirectional links of bandwidth BW



- $\mathcal{C}_{u,v}$ running at speed $s_{u,v} \in \{s^{(1)}, \ldots, s^{(M)}\}$

Mapping strategy

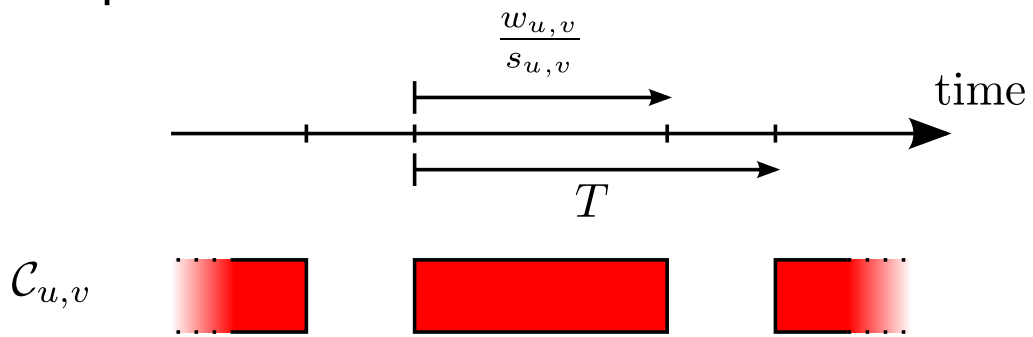


- Partitioning: if S_i and S_j mapped onto $\mathcal{C}_{u,v}$ and $S_i \rightarrow S_k \rightarrow S_j$, then S_k mapped onto $\mathcal{C}_{u,v}$
- Mapping:
  - One-to-one
  - Routing free, but single-path

$\Rightarrow$ $w_{u,v}$: work computed by $\mathcal{C}_{u,v}$
$b_{(u,v)\rightarrow(u',v')}$: communication from $\mathcal{C}_{u,v}$ to $\mathcal{C}_{u',v'}$

Objective functions

- Given period T
- Energy of computations



$$E^{(\text{comp})} = |\mathcal{A}| \times P_{\text{leak}}^{(\text{comp})} \times T + \sum_{\mathcal{C}_{u,v} \in \mathcal{A}} \frac{w_{u,v}}{s_{u,v}} \times P_{s_{u,v}}^{(\text{comp})},$$

where $\mathcal{A}$ is the set of active cores

- Energy of communications

$$E^{(\text{comm})} = P_{\text{leak}}^{(\text{comm})} \times T + \left(\sum_{u,v} \sum_{u',v'} b_{(u,v)\to(u',v')} \right) \times E^{(\text{bit})}$$

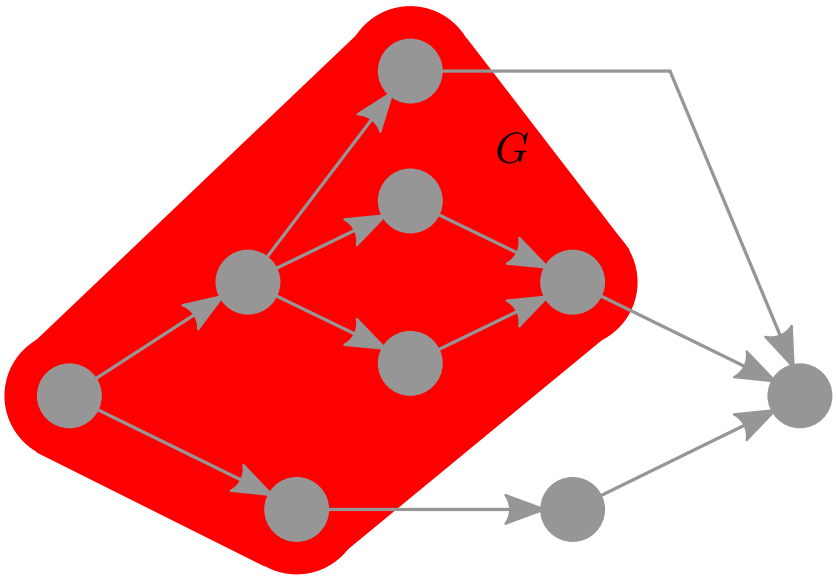
Outline of the talk

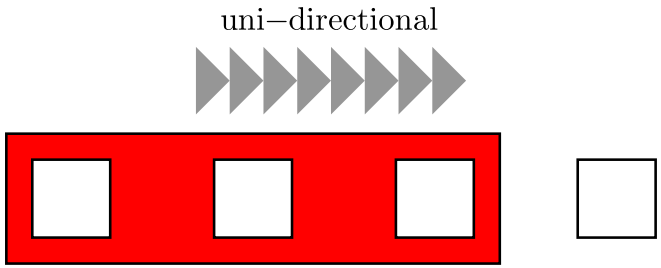
Uni-directional uni-line CMP

Polynomial with bounded elevation:
dynamic programming algorithm

$$\mathcal{E}(G,k) = \min_{G' \subseteq G} \left(\mathcal{E}(G', k-1) + \mathcal{E}^{\text{cal}}(G \setminus G') \right) ,$$

where
- G' is admissible
- outgoing communications of G' do not exceed BW





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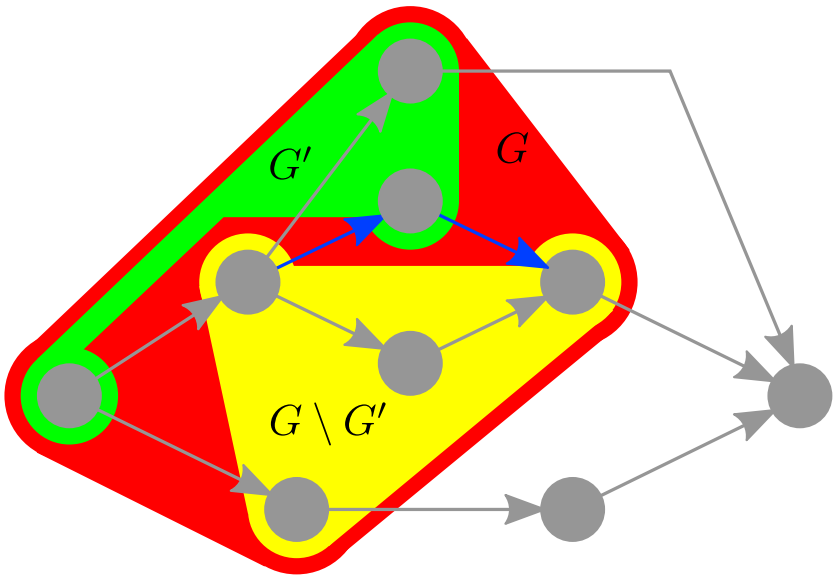

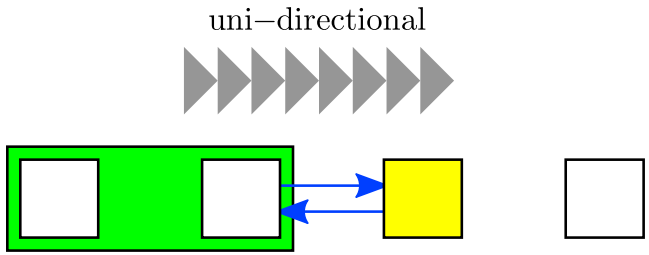

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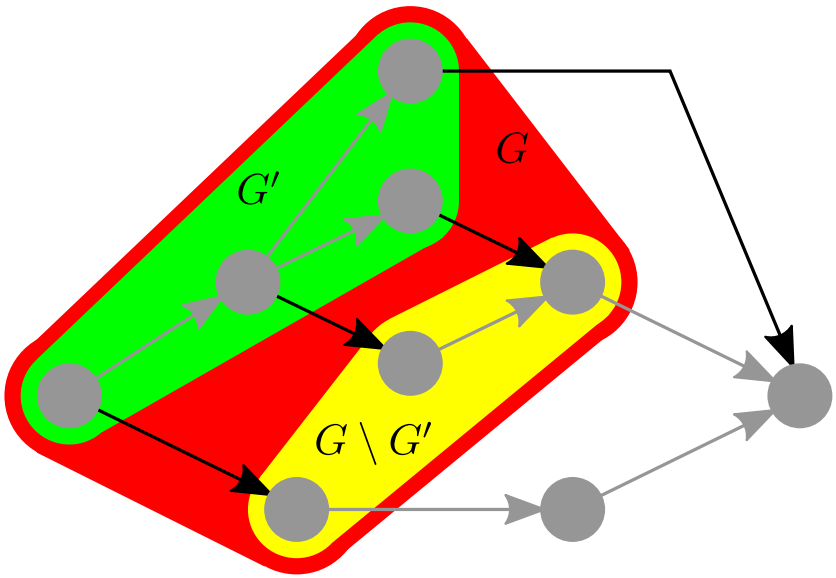

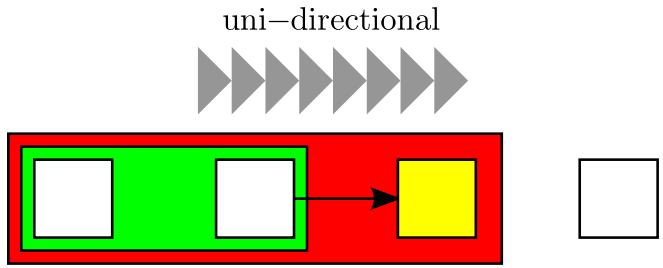

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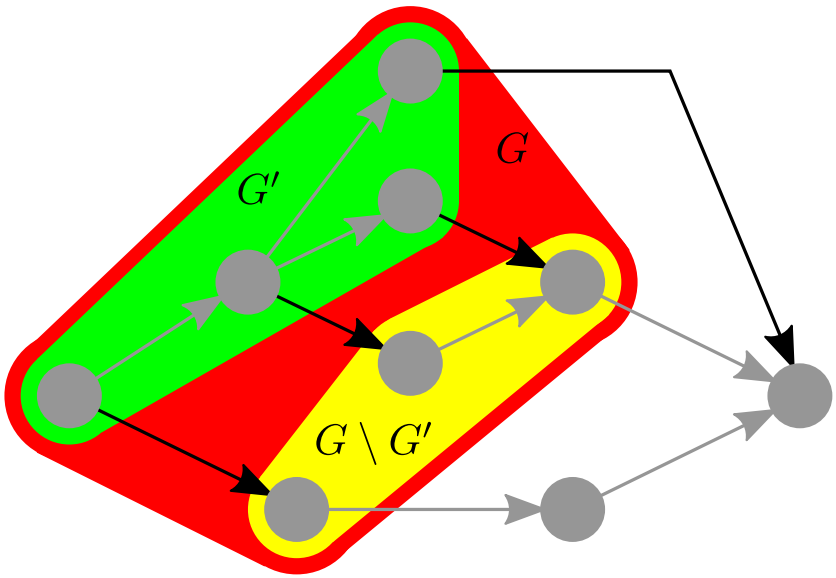
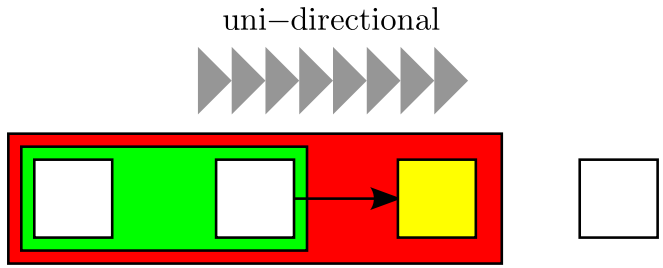
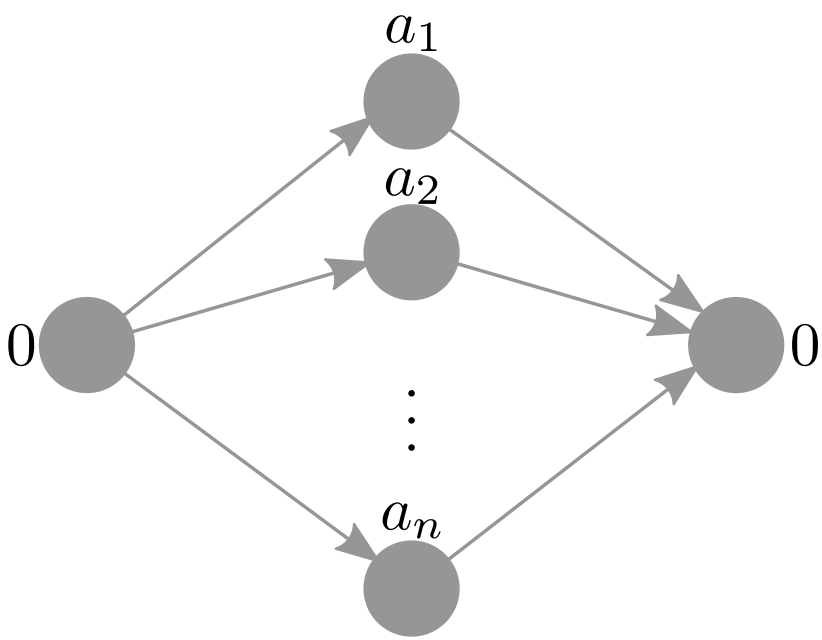


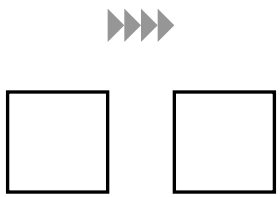


Polynomial
$O(q \times n^{y_{\max}+1})$

Uni-directional uni-line CMP

NP-complete with unbounded elevation:
reduction from 2-PARTITION

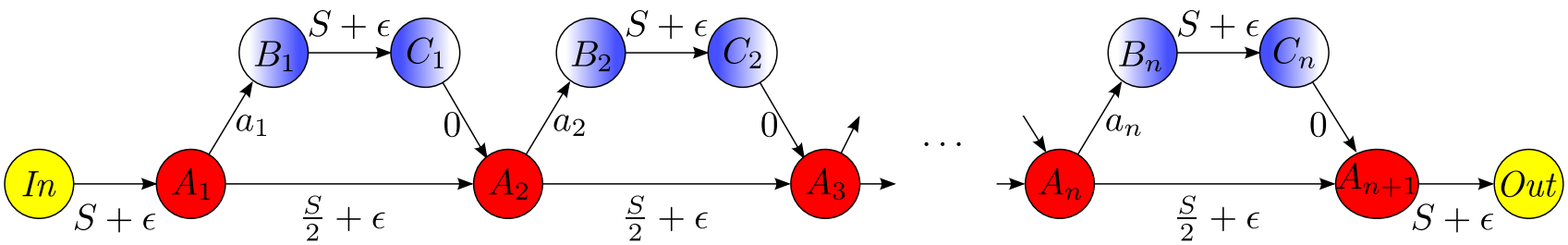




Single speed $\frac{\sum_{i=1}^{n} a_i}{2}$

Bi-directional uni-line CMP

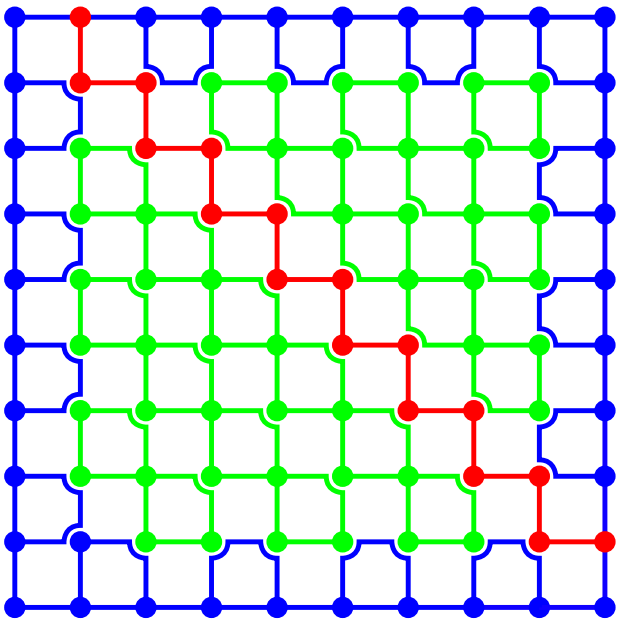
NP-complete with bounded elevation:
reduction from 2-PARTITION

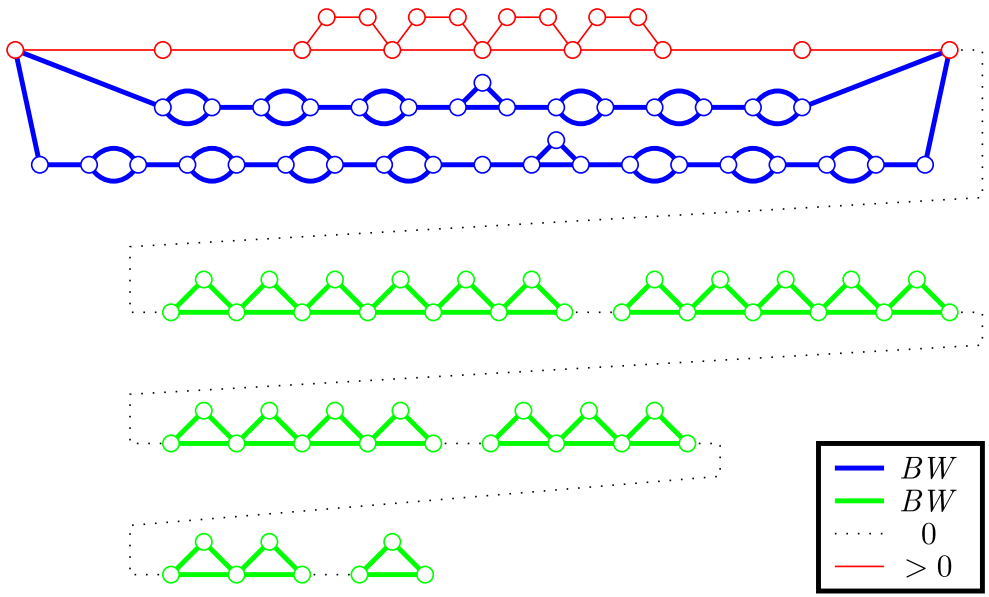


$$BW = \frac{3S}{2} + \epsilon$$

Bi-directional square CMP

NP-complete with bounded elevation:
reutilization of previous proof



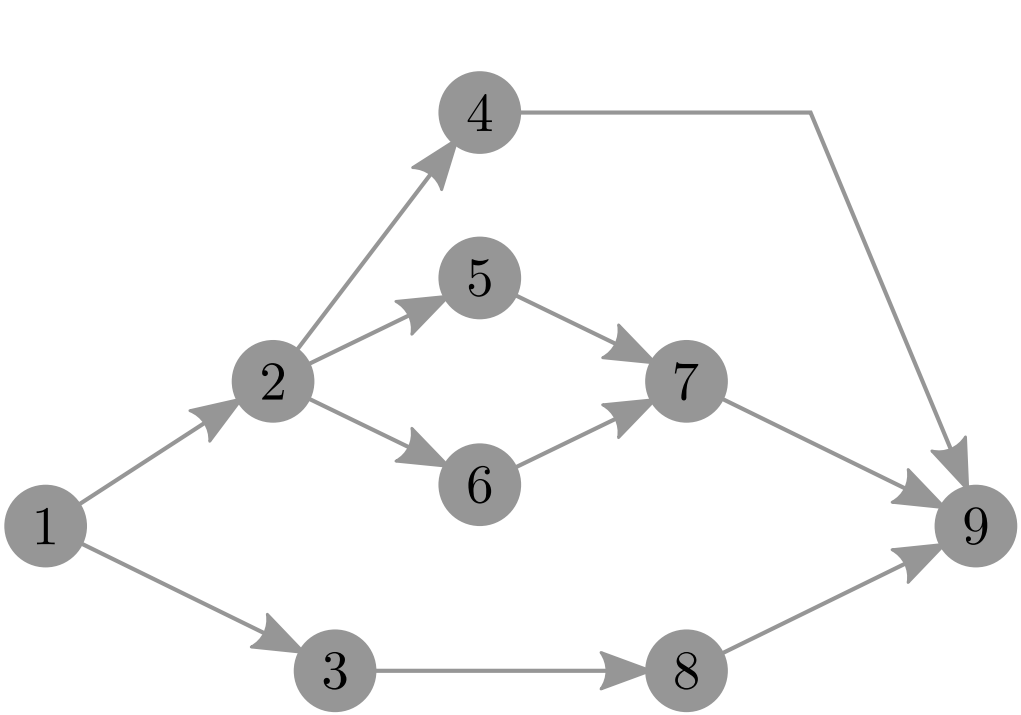


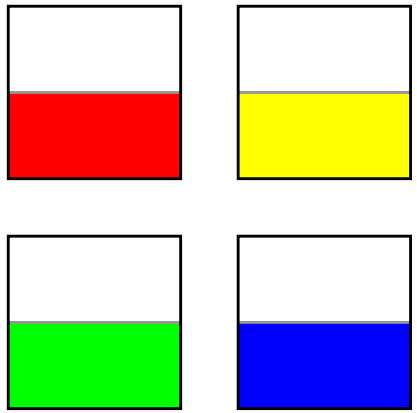
Outline of the talk

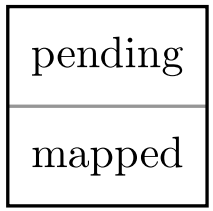
Heuristic summary

- Random heuristic: random speeds, random assignments, XY routing
- Greedy heuristic: starting from $\mathcal{C}_{1,1}$, process as many nodes as possible, give following nodes to right and down cores; iterate on those cores
- 2D dynamic programming algorithm
- 1D heuristics (2D CMP configured as a snake):
  - Optimal solution on 1D uni-directional CMP
  - Previous 2D dynamic programming algorithm onto snake

Greedy







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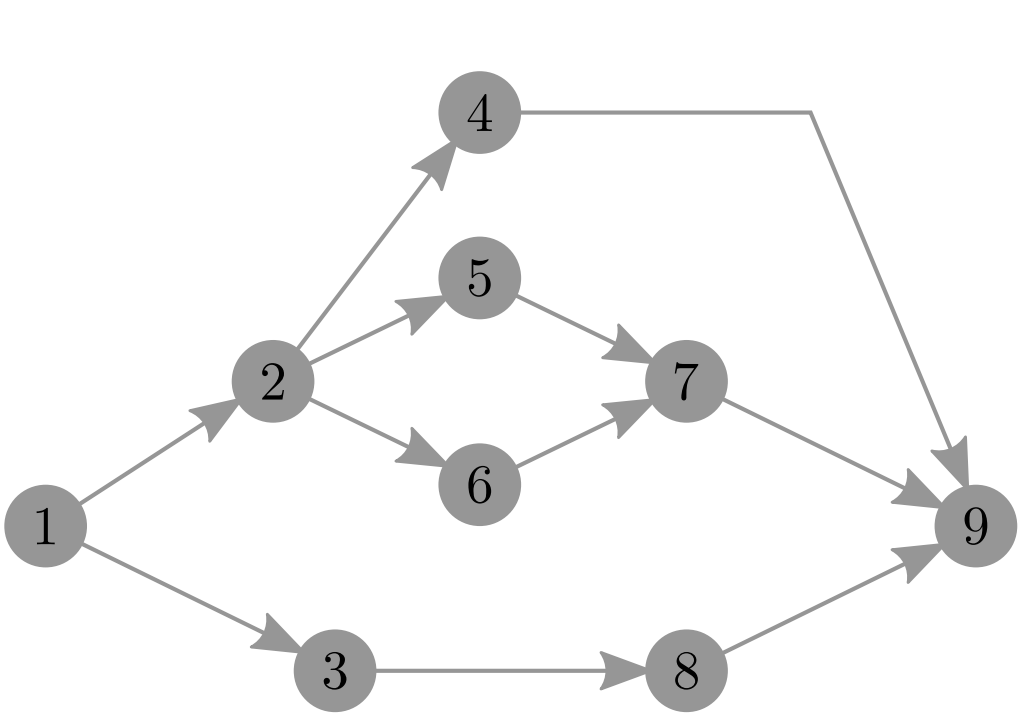

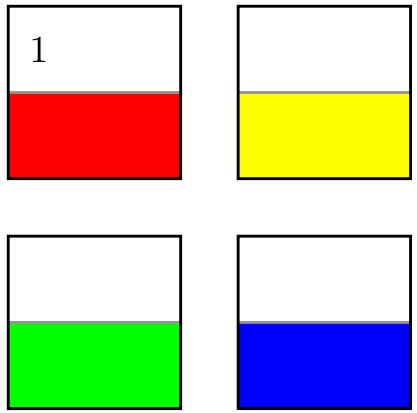

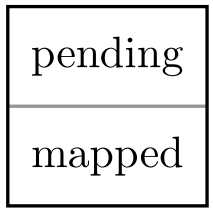

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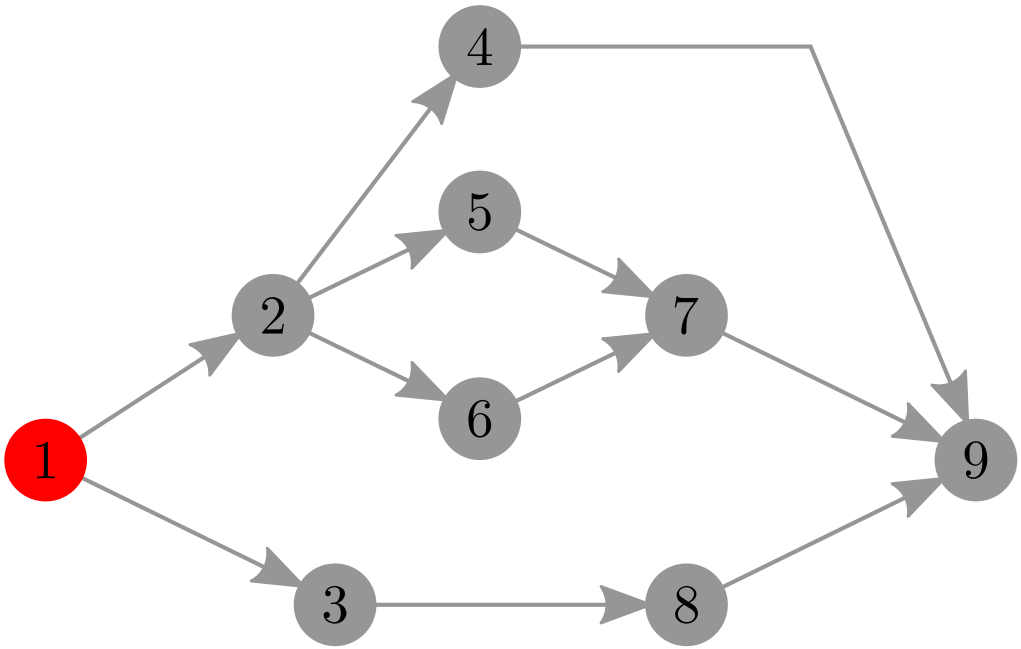

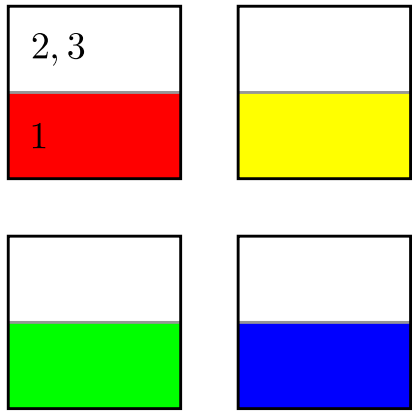

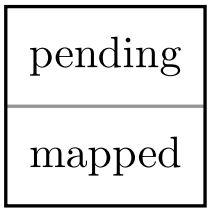

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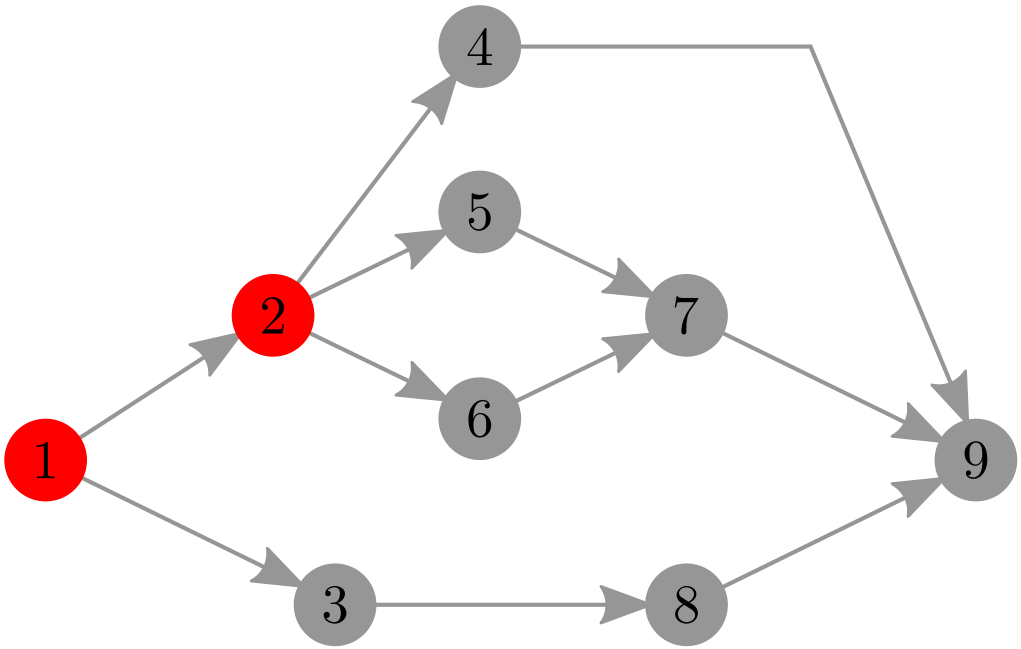

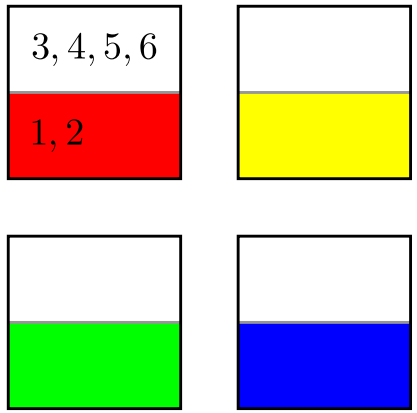

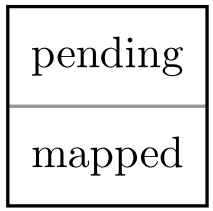

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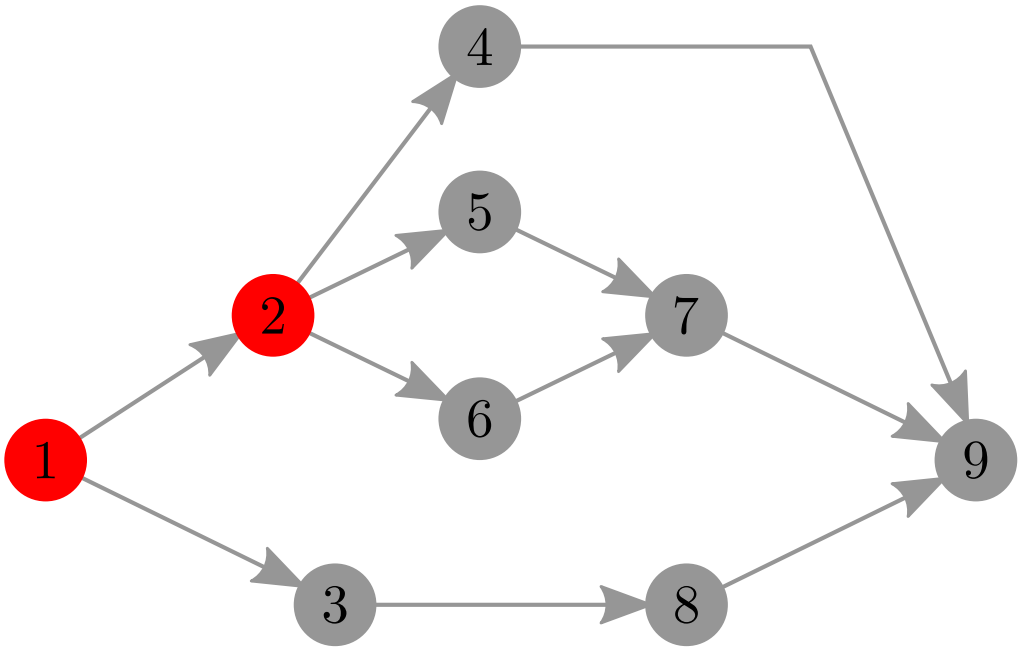

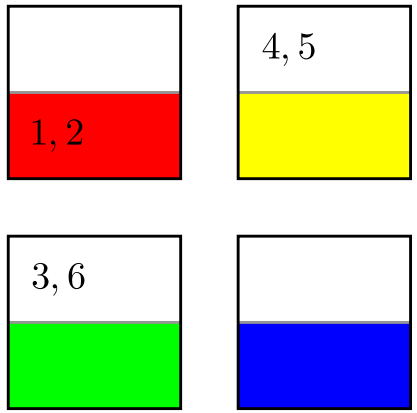

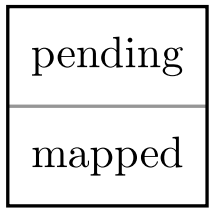

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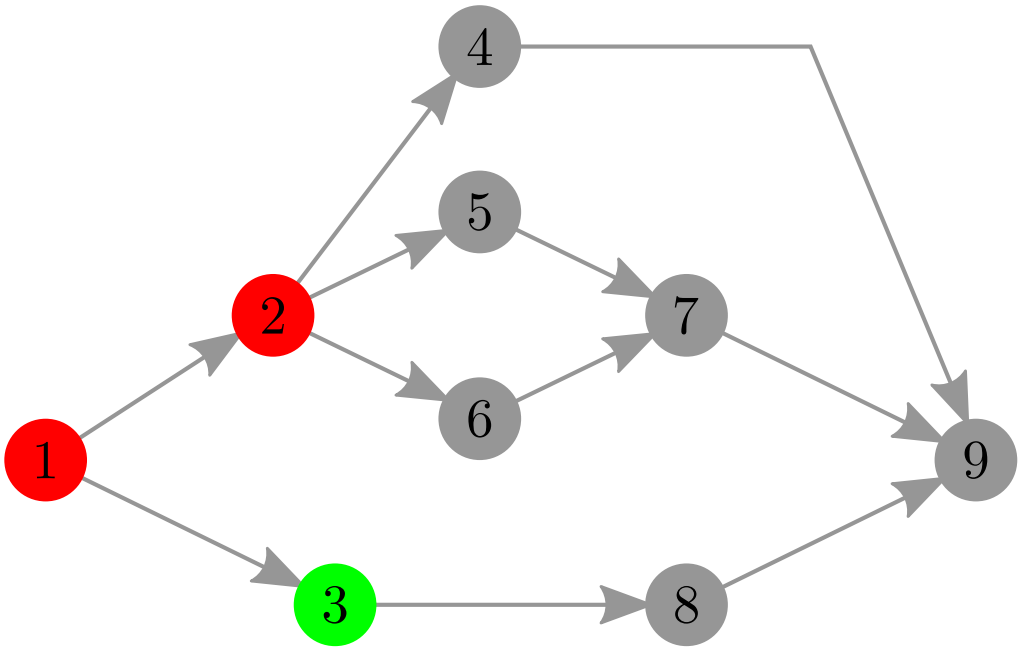

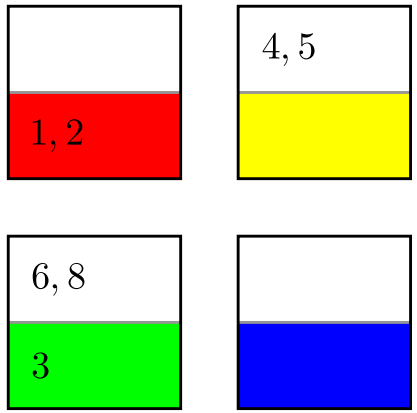

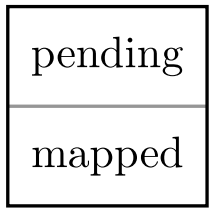

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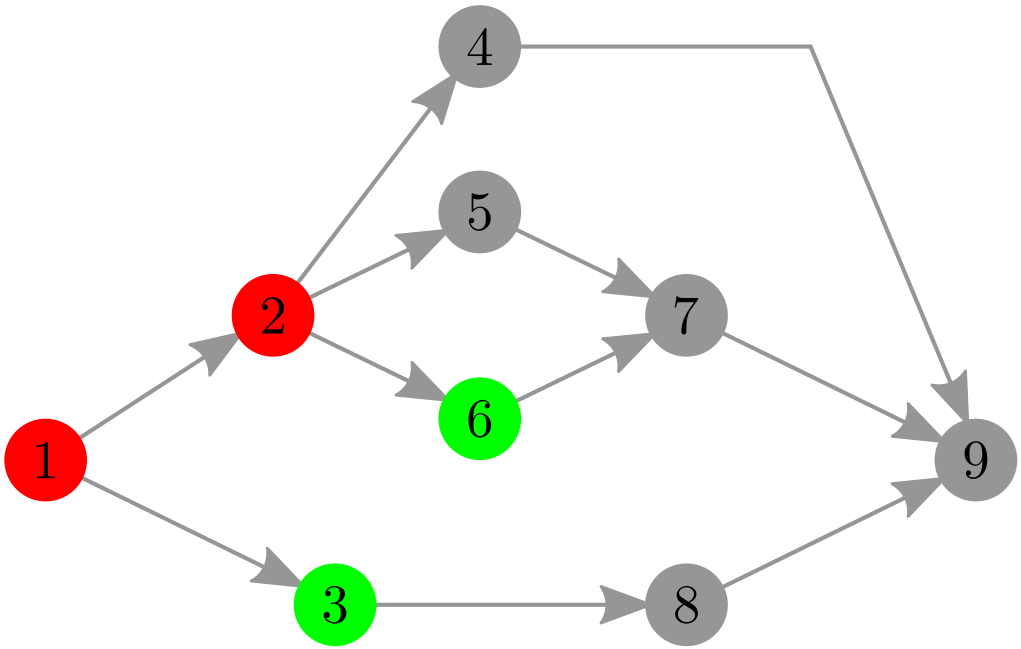

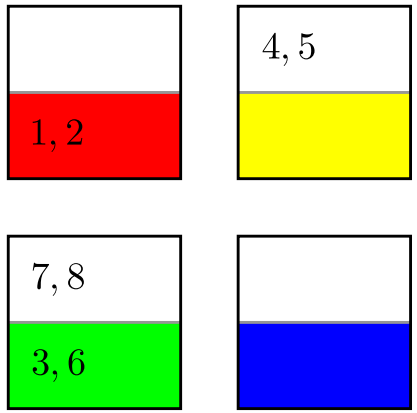

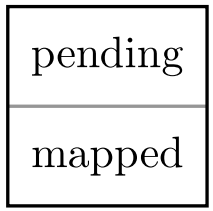

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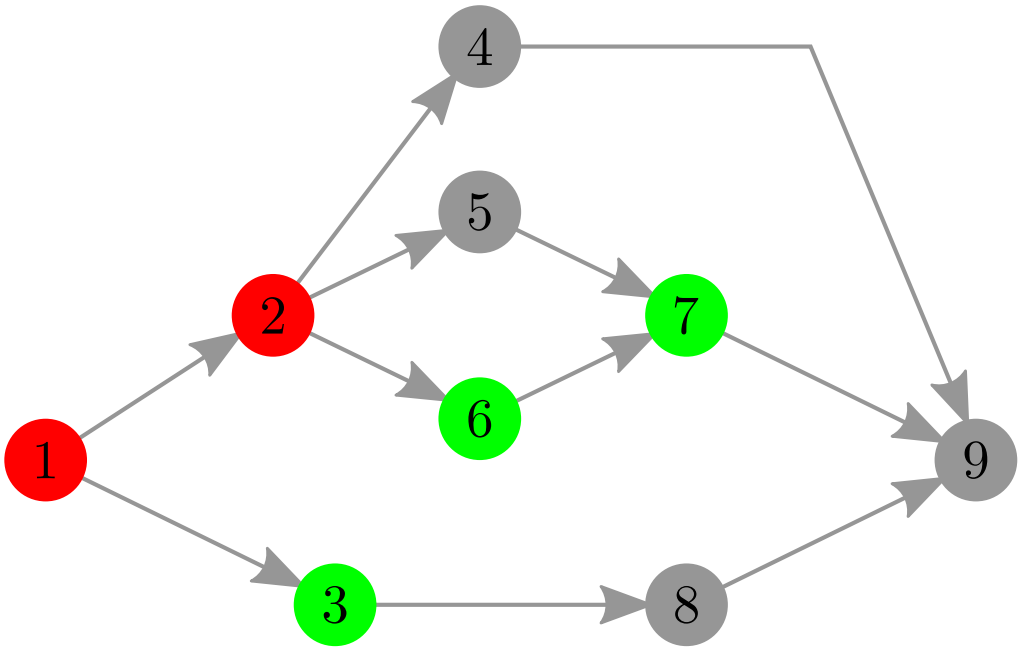

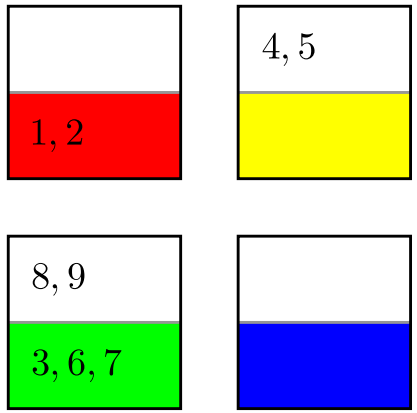

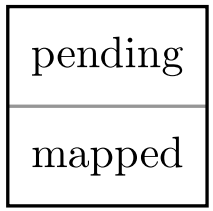

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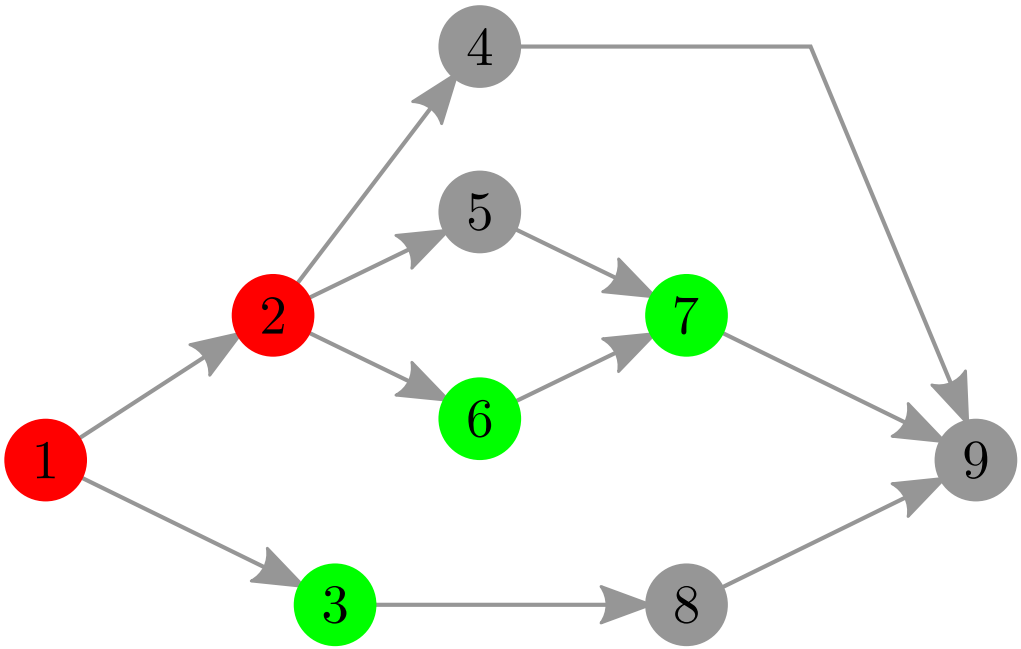

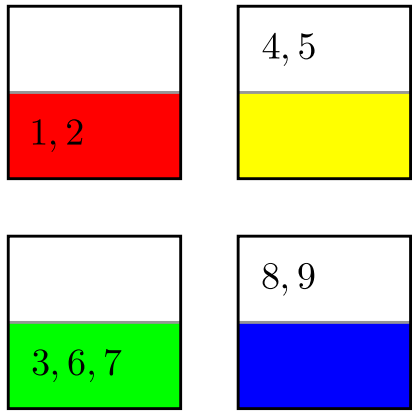

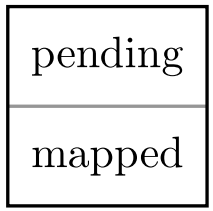

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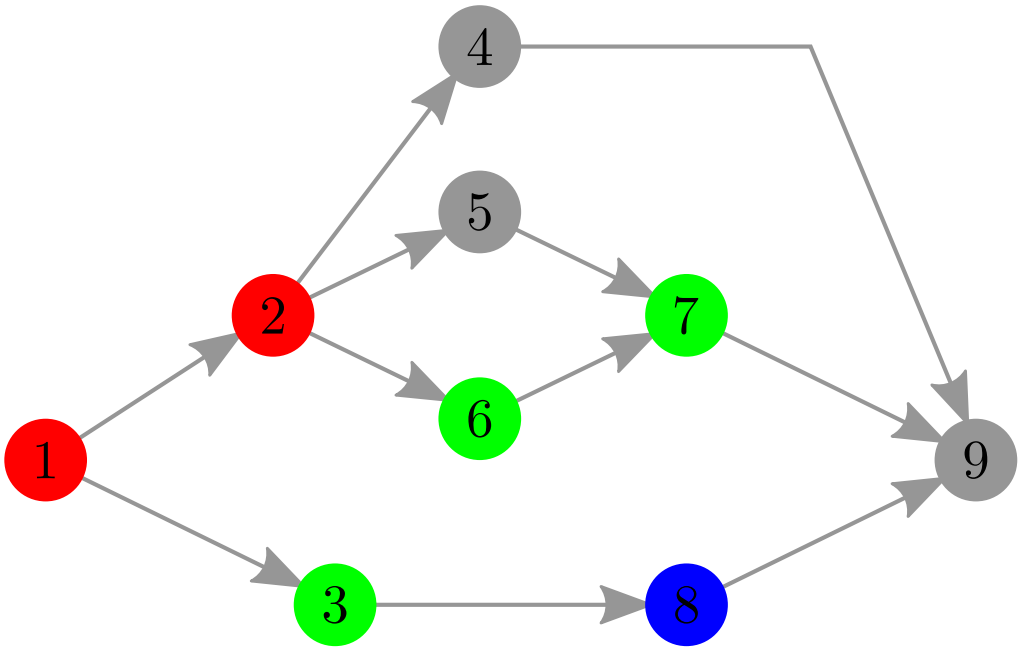
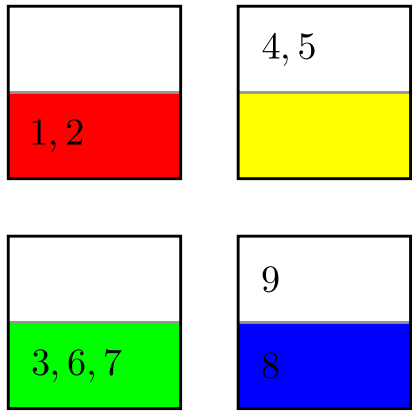
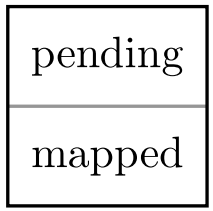
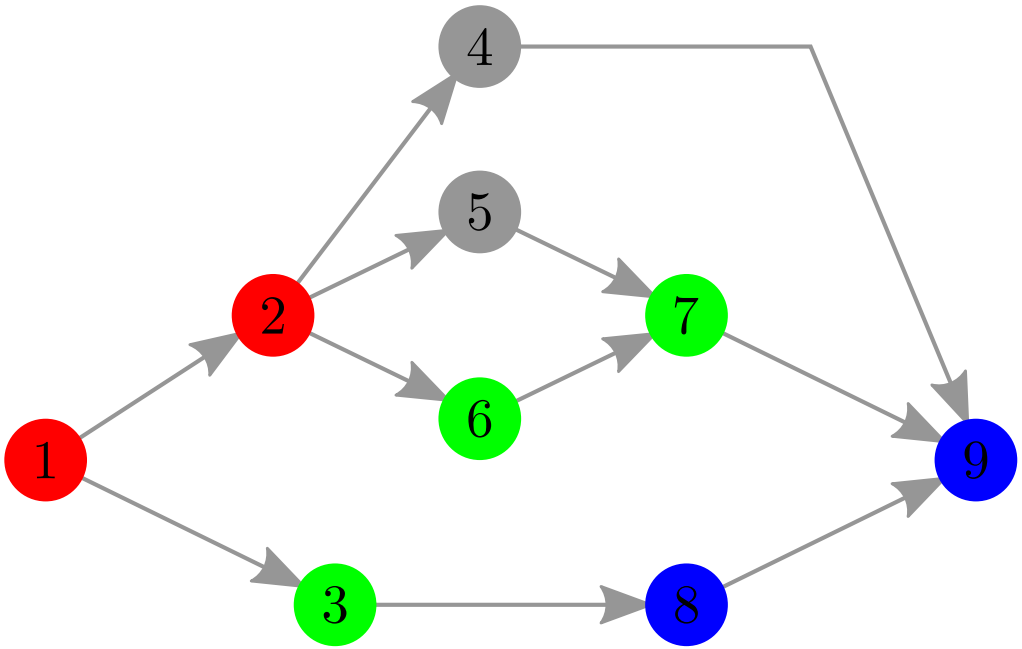
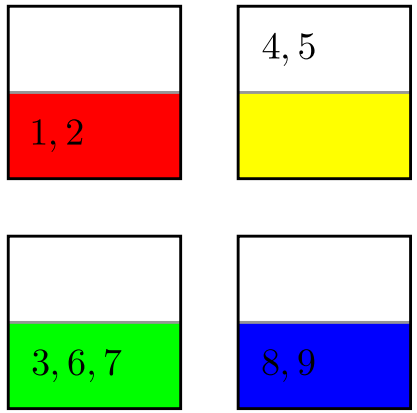


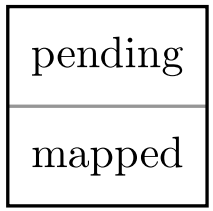




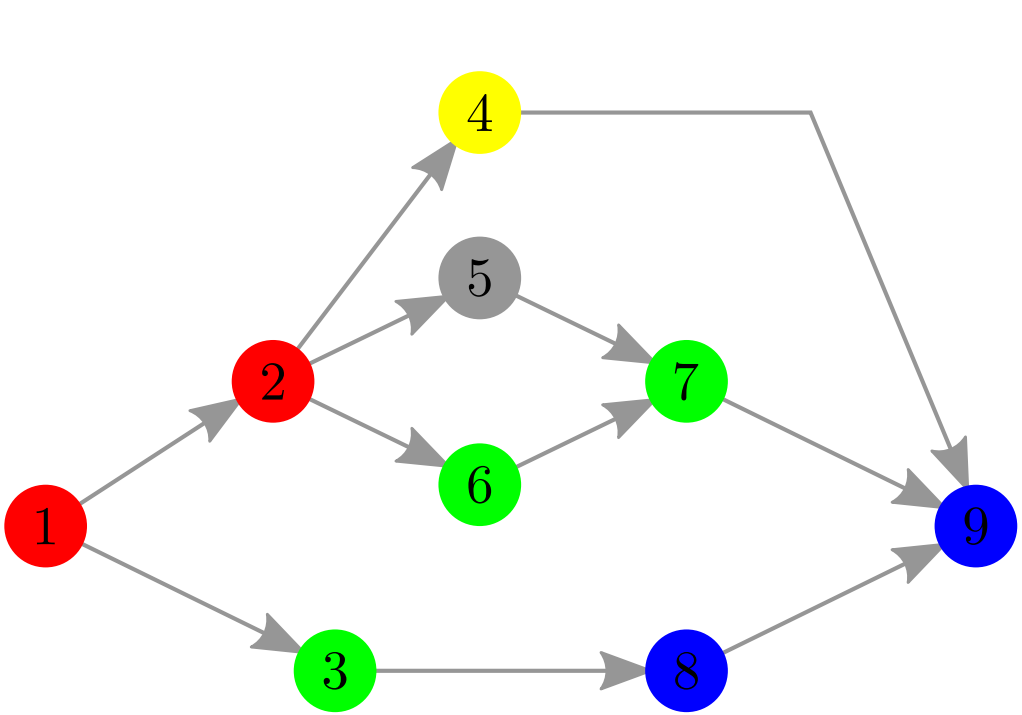
Greedy

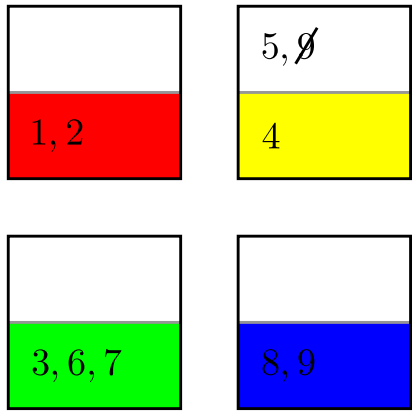


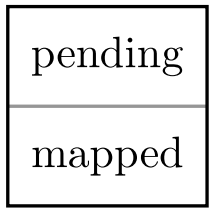




Greedy







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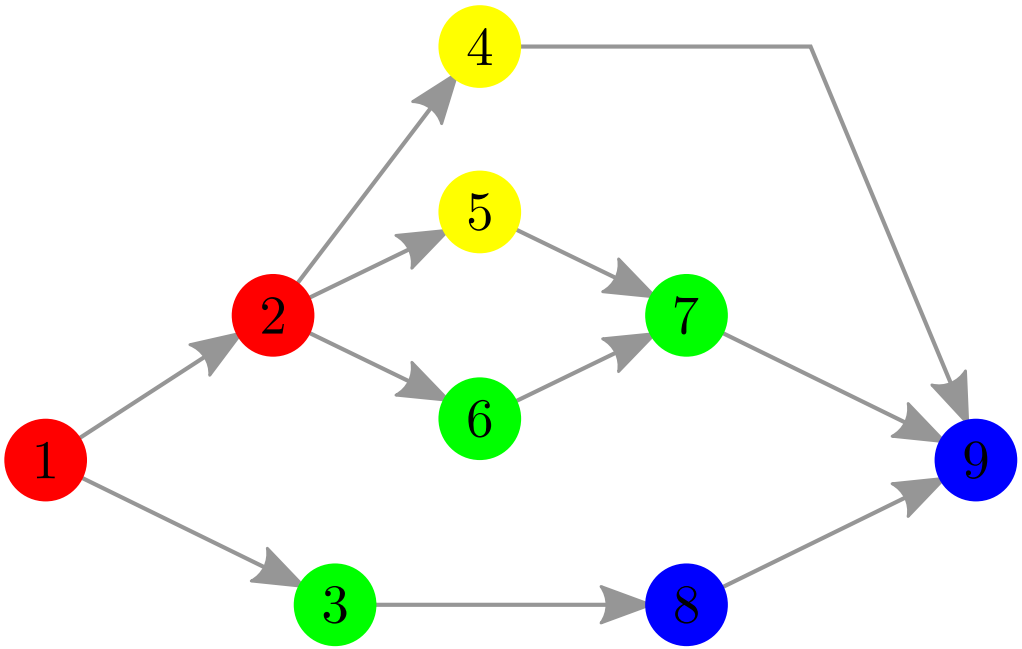

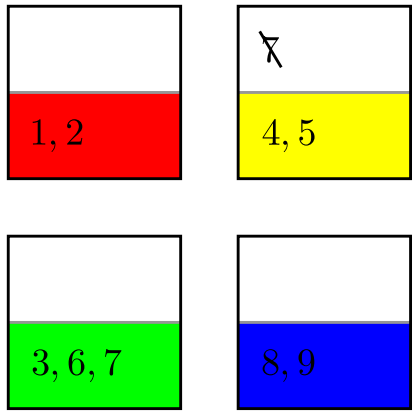

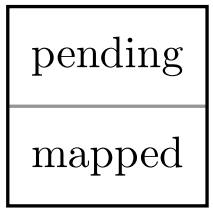

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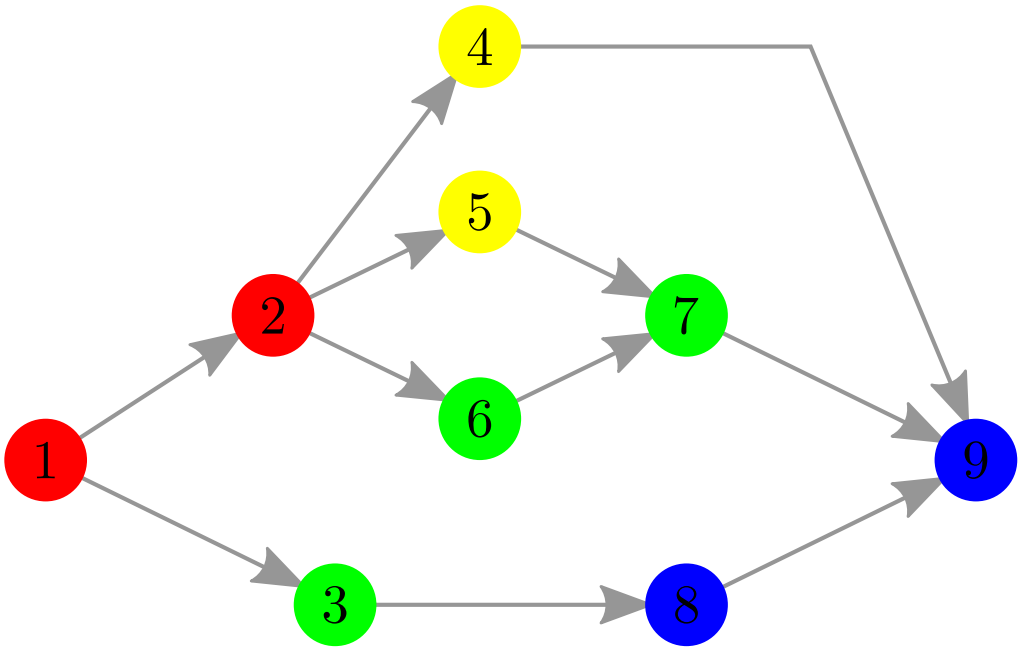
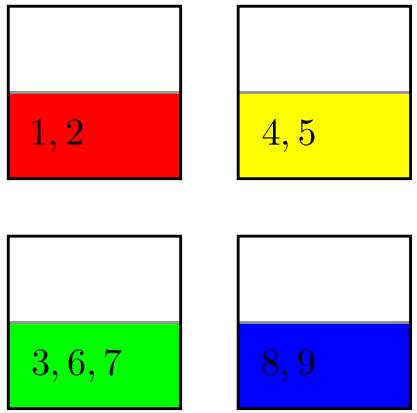
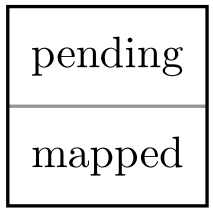
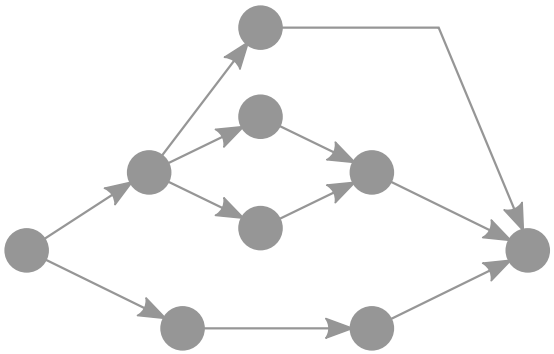


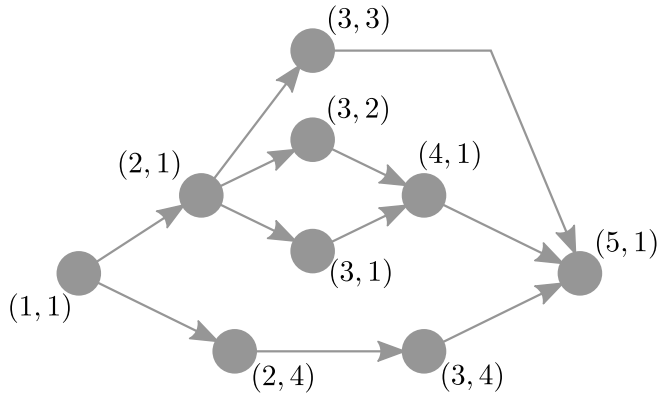




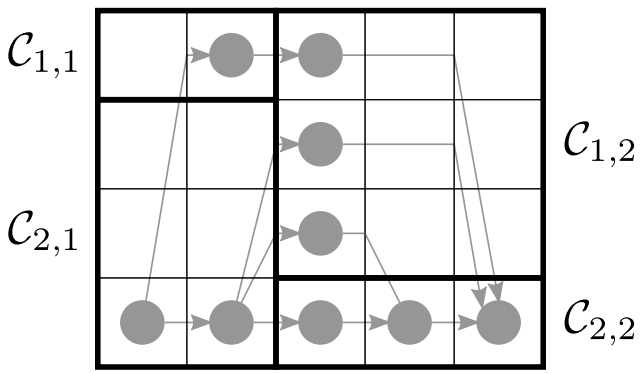
DPA2D



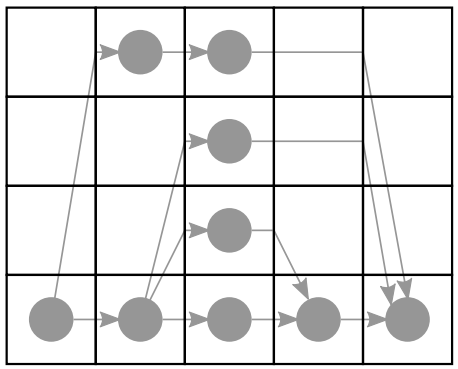
label



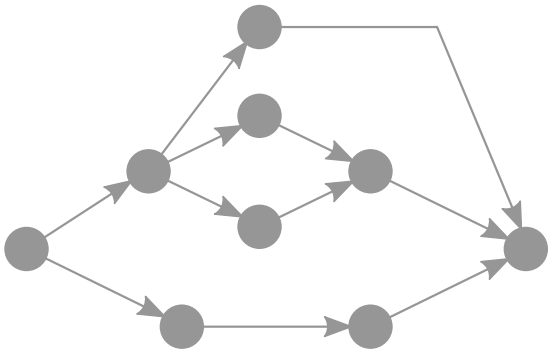
reorganize



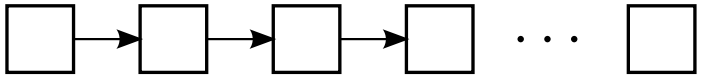
map



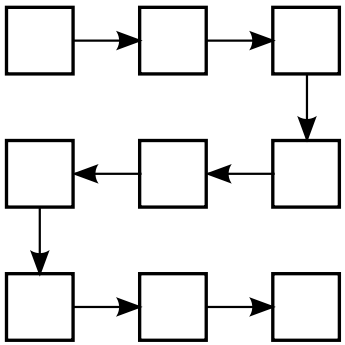
DPA1D, DPA2D1D



map



reconfigure

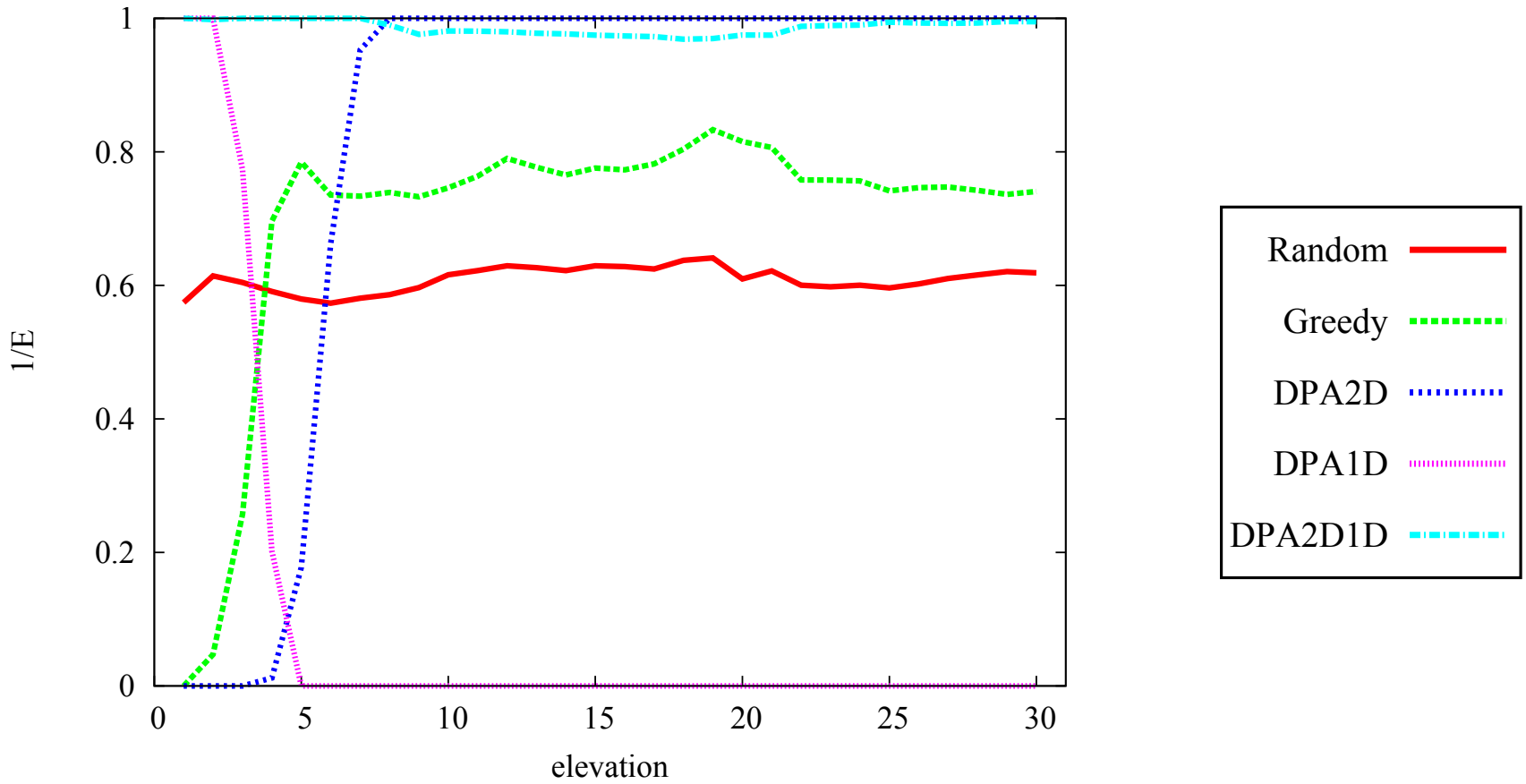


Outline of the talk

Simulation settings

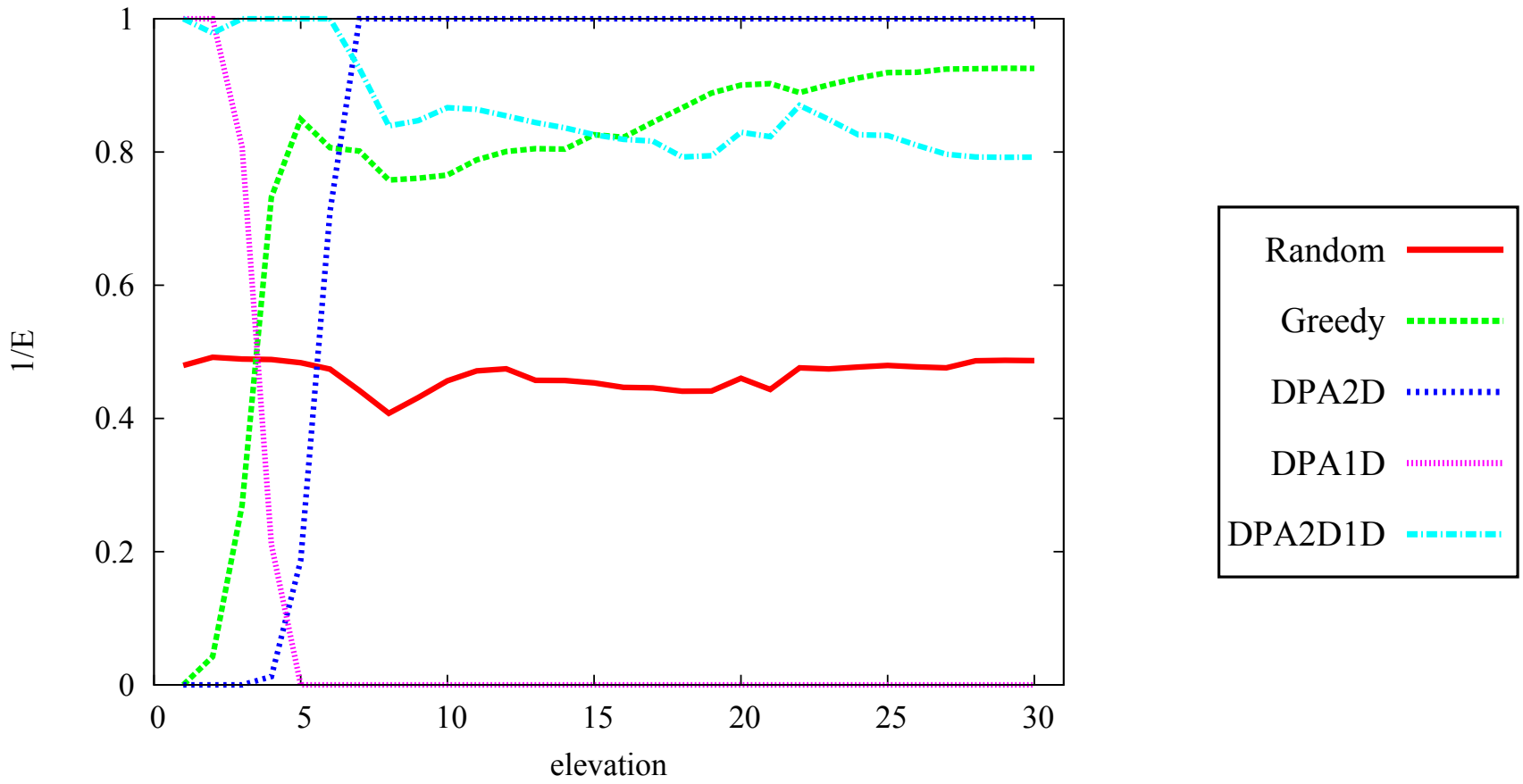
- Random SPGs
  - Averaged over 100 applications
  - 150 nodes
  - Elevation: from 1 to 30
- Real-life SPGs
  - 12 workflows
  - From 8 to 120 nodes
  - Elevation: from 1 to 17
- Varying communication-to-computation ratio

Random SPGs; computation intensive



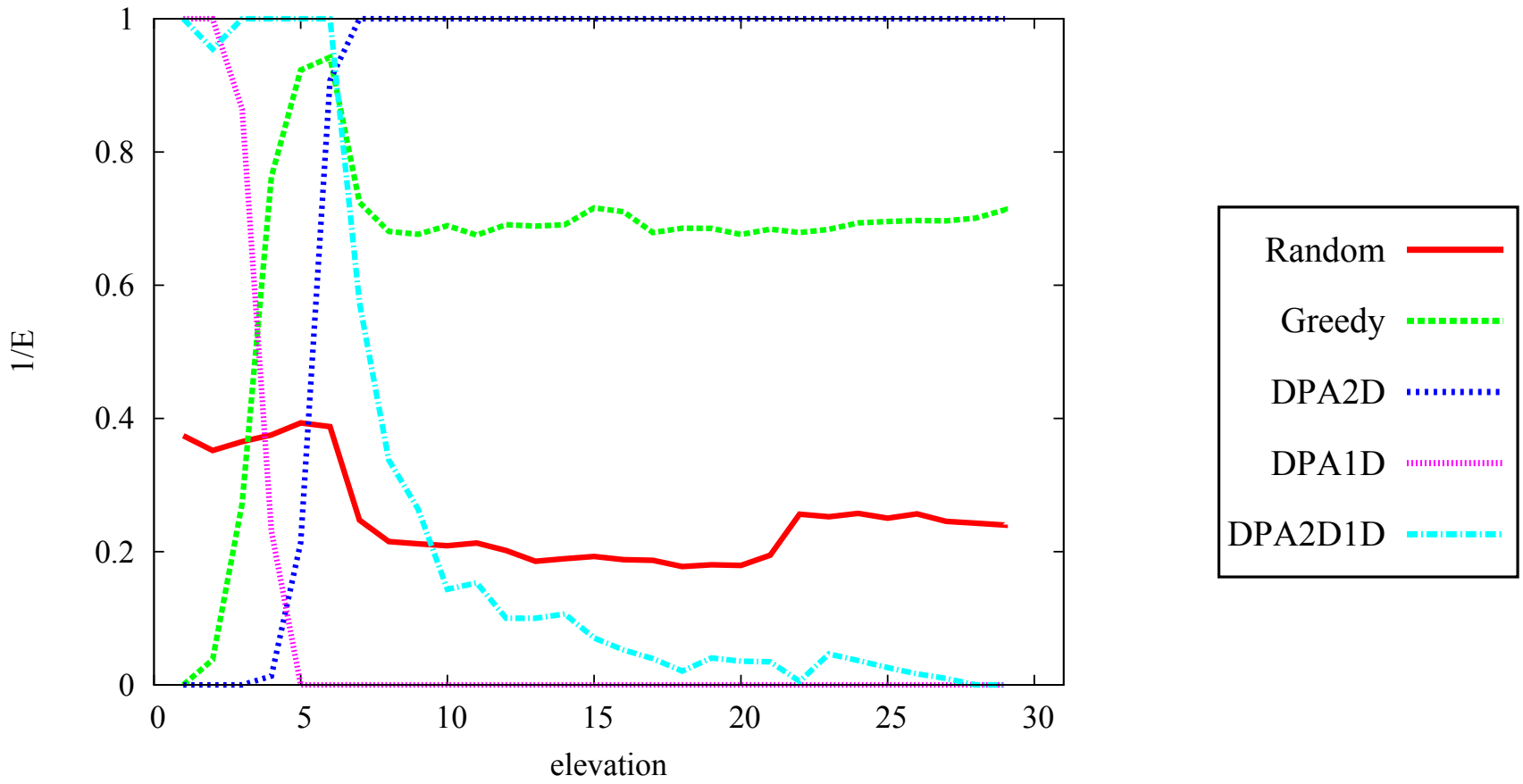
- **DPA1D** best then very rapidly useless
- **DPA2D** bad then rapidly best
- **DPA2D1D** always close to best
- **Greedy** intermediate

Random SPGs; balanced



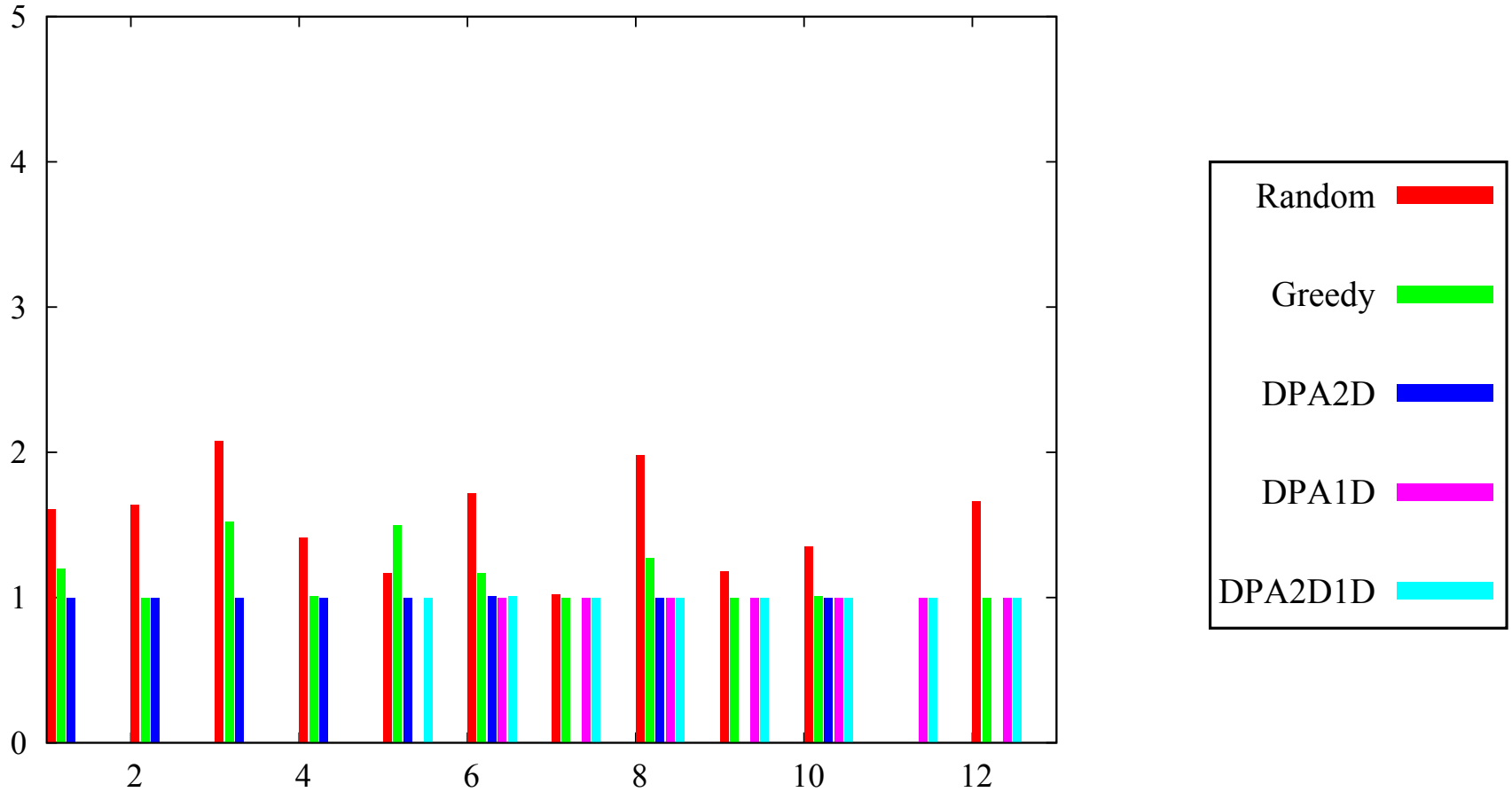
- **DPA1D**, **DPA2D** and **Greedy** better compared to **Random**
- **DPA2D1D** crumbles

Random SPGs; communication intensive

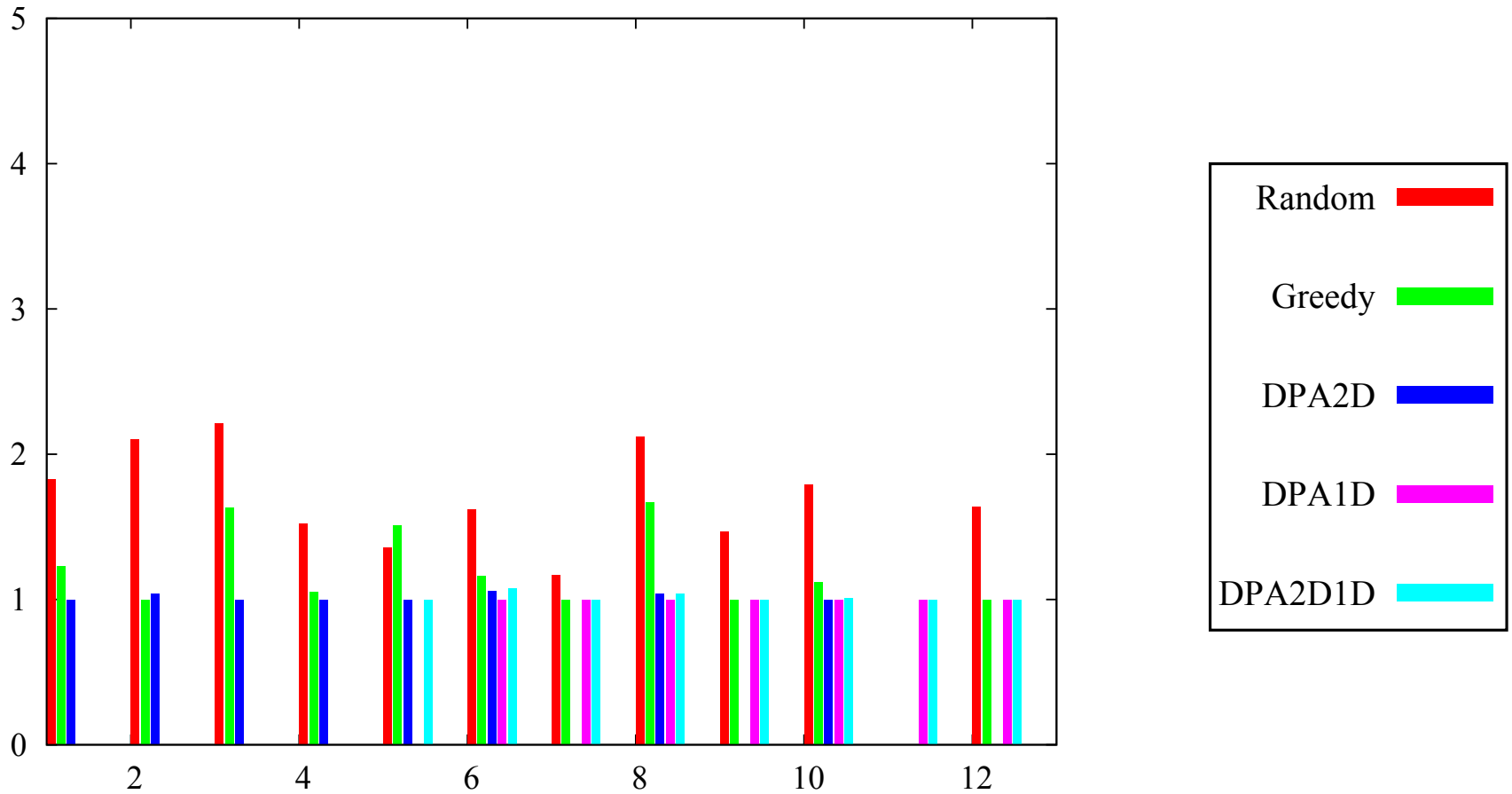


- **DPA1D**, **DPA2D** and **Greedy** better compared to **Random**
- **DPA2D1D** crumbles

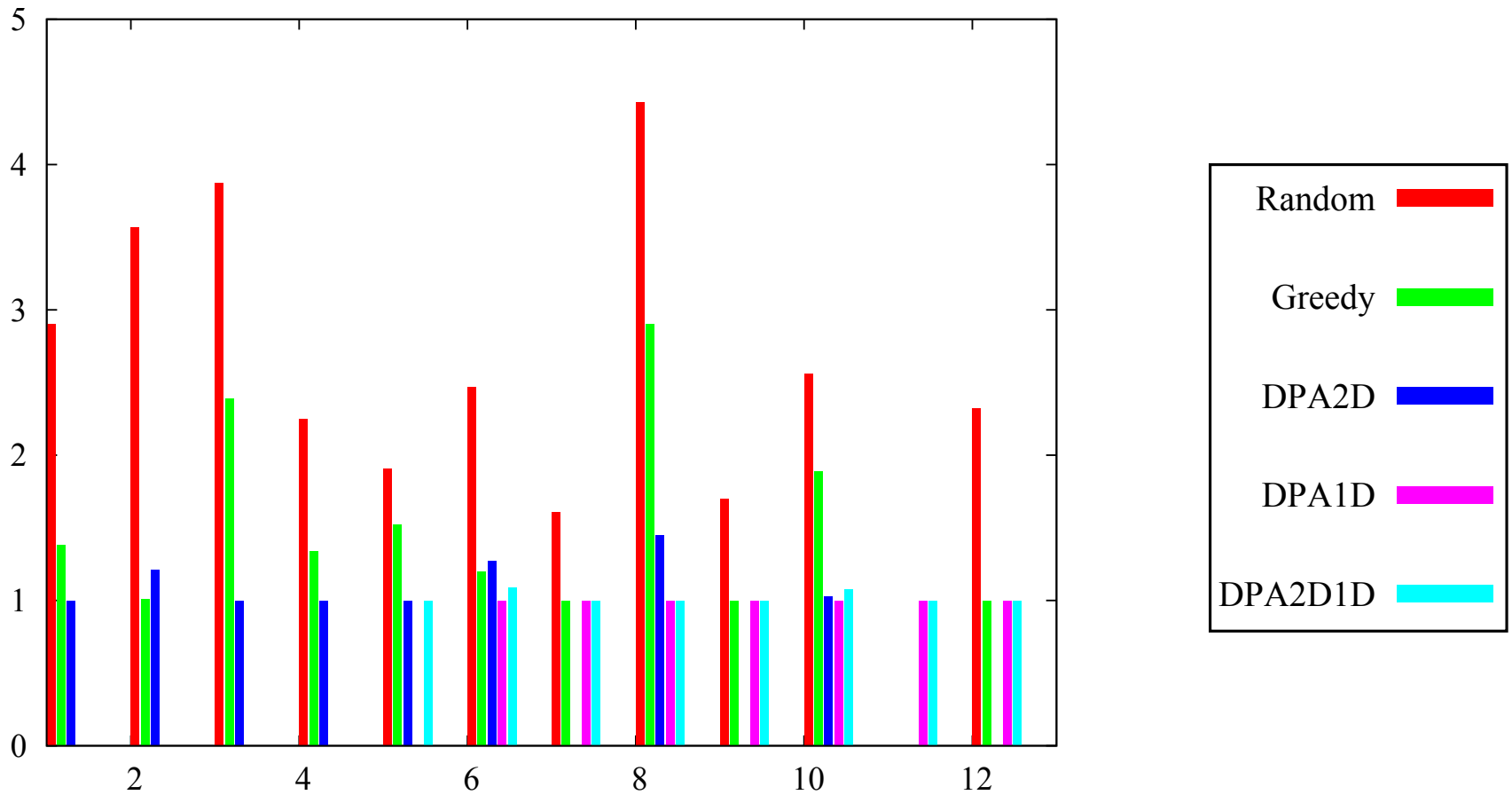
StreamIT; computation intensive



StreamIT; balanced



StreamIT; communication intensive



Conclusion

- Exhaustive complexity study
- Efficient heuristics for all kinds of SPGs
- Simulations on both randomly generated and real-life SPGs
- Future work: simplified ILP to assess the absolute performance of the heuristics, more accurate power consumption model for communications, multi-path routing

Questions

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