Using Substructure Mining to Identify Misbehavior in Network Provenance Graphs

David DeBoer, Georgetown University
Wenchao Zhou, Georgetown University
Lisa Singh, Georgetown University

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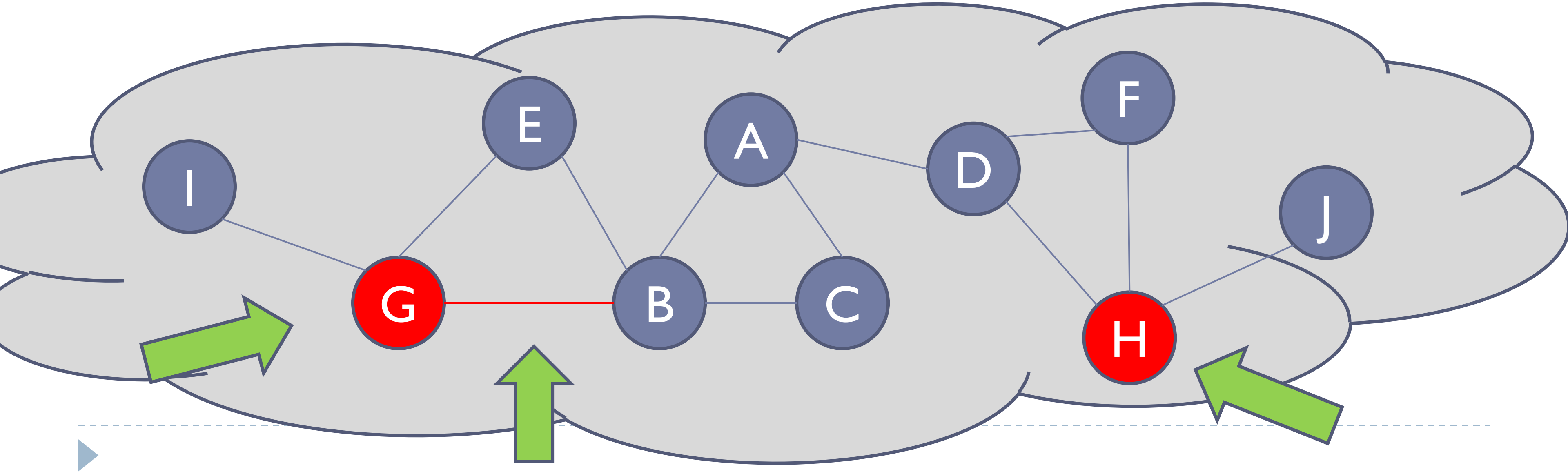
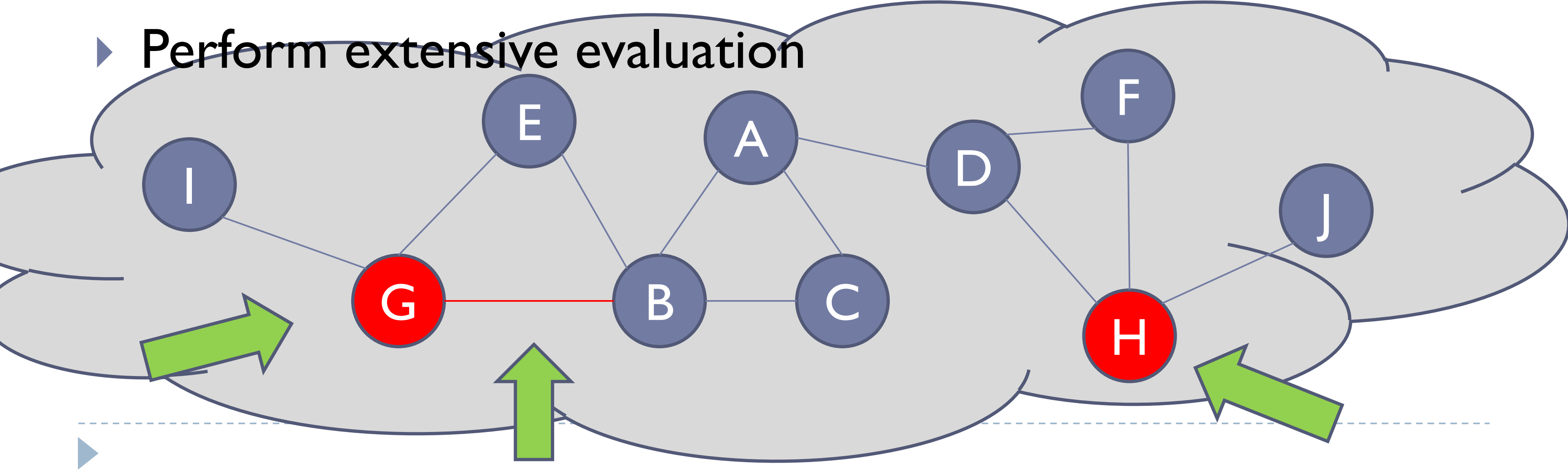
Distributed Systems

- Distributed systems have seen huge success
- They touch many parts of our daily lives
- Faults are costly
- Monitoring and maintenance is difficult
- Network Provenance is a proposed solution

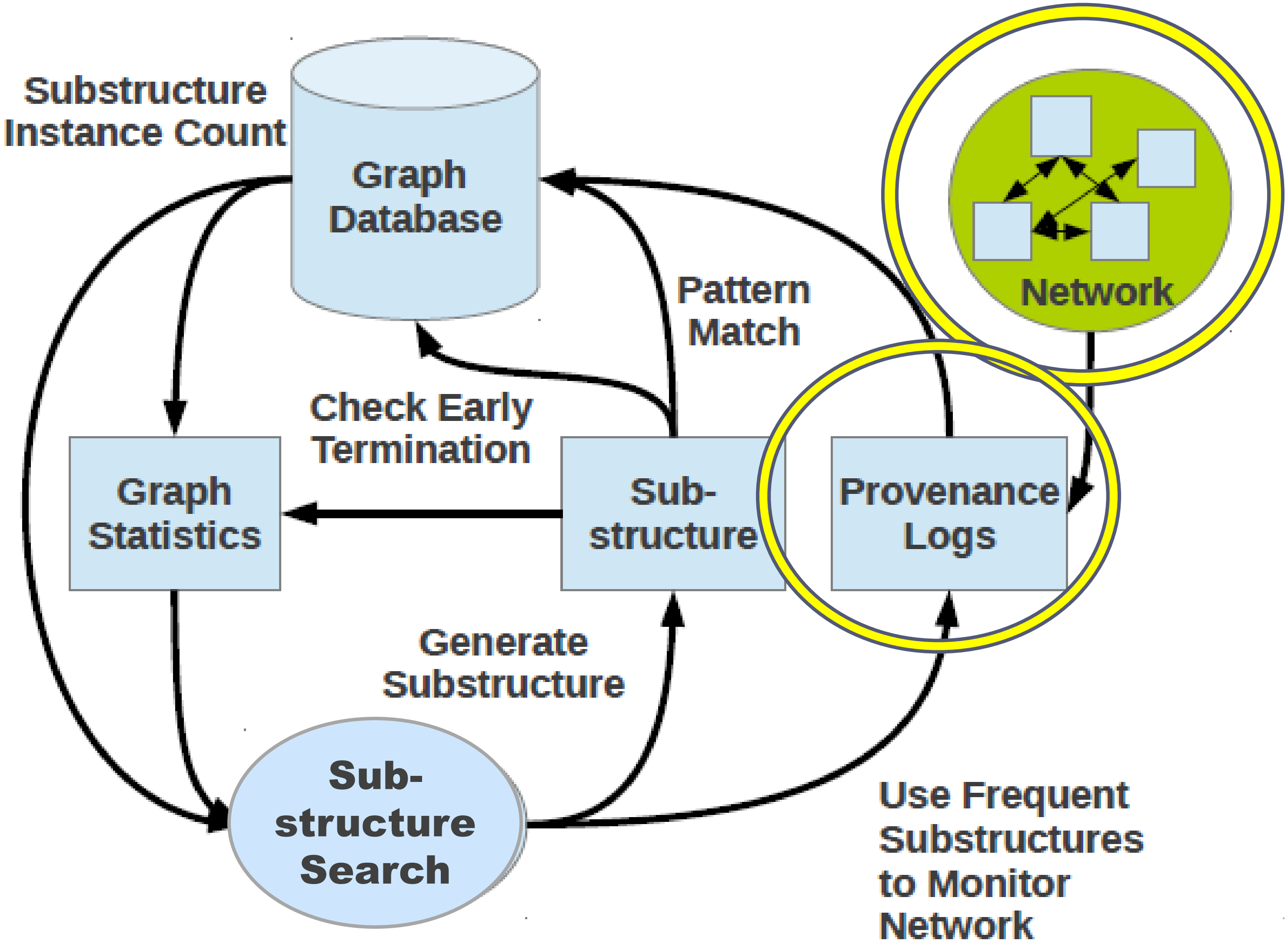


Our Contribution

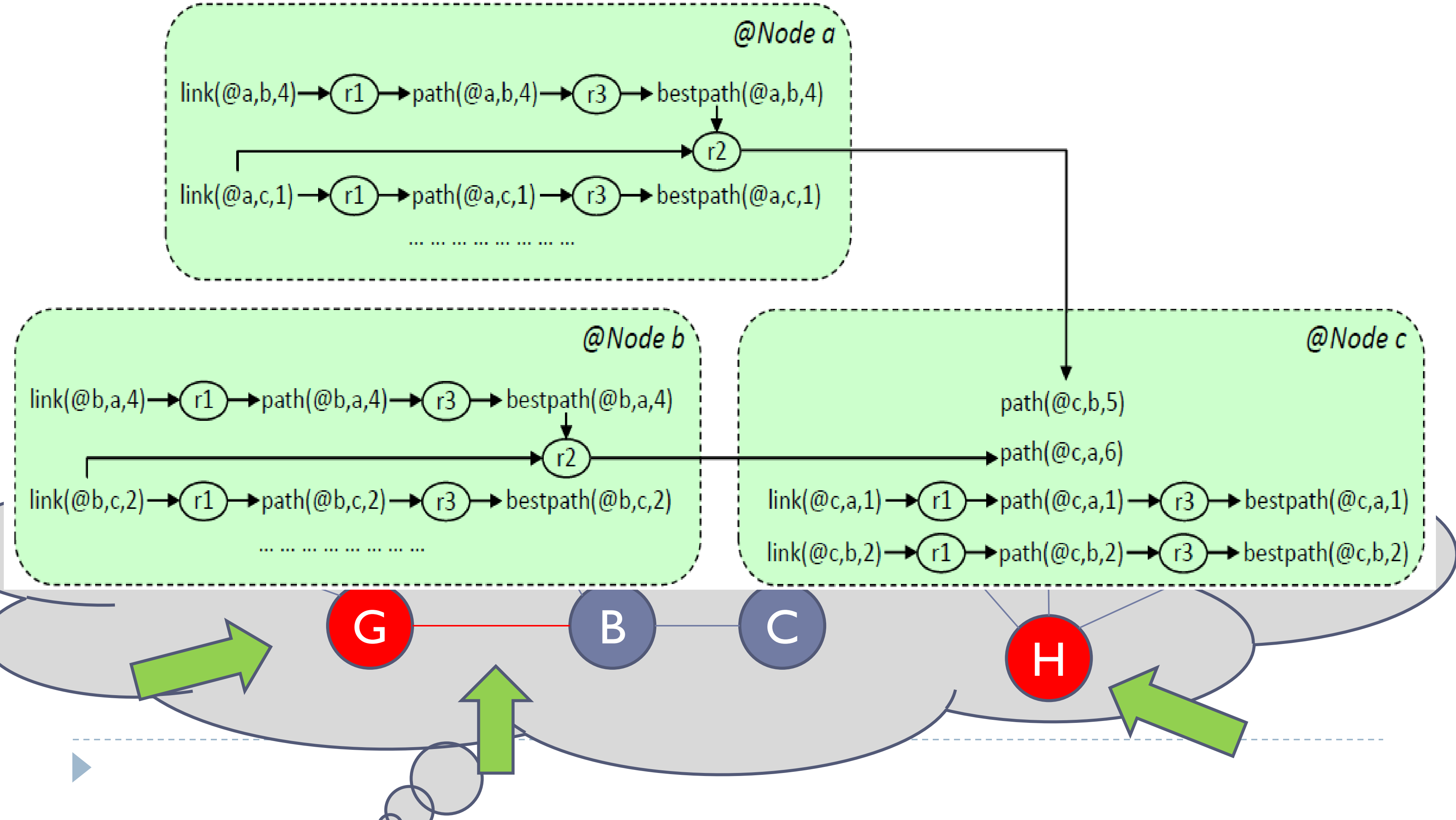
- Leverage the dependency graph of network provenance for a substructure mining application
- Find common execution patterns
- Use them as a feature set to identify misbehaving nodes
- Use heuristics to find substructures more quickly
- Implement with a graph database, neo4j
- Perform extensive evaluation



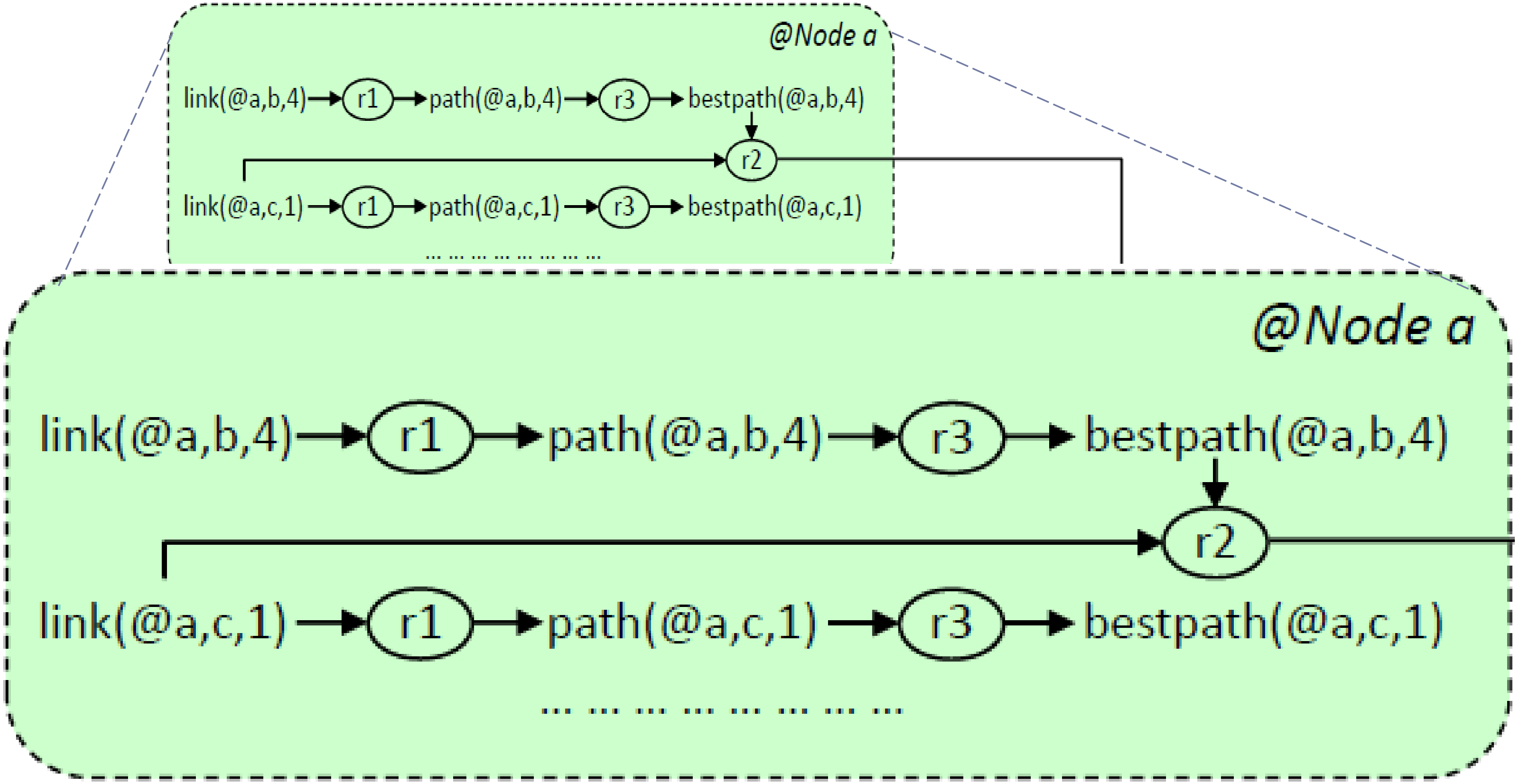
Proposed System Architecture



Example: Network Provenance



Example: Provenance Graph



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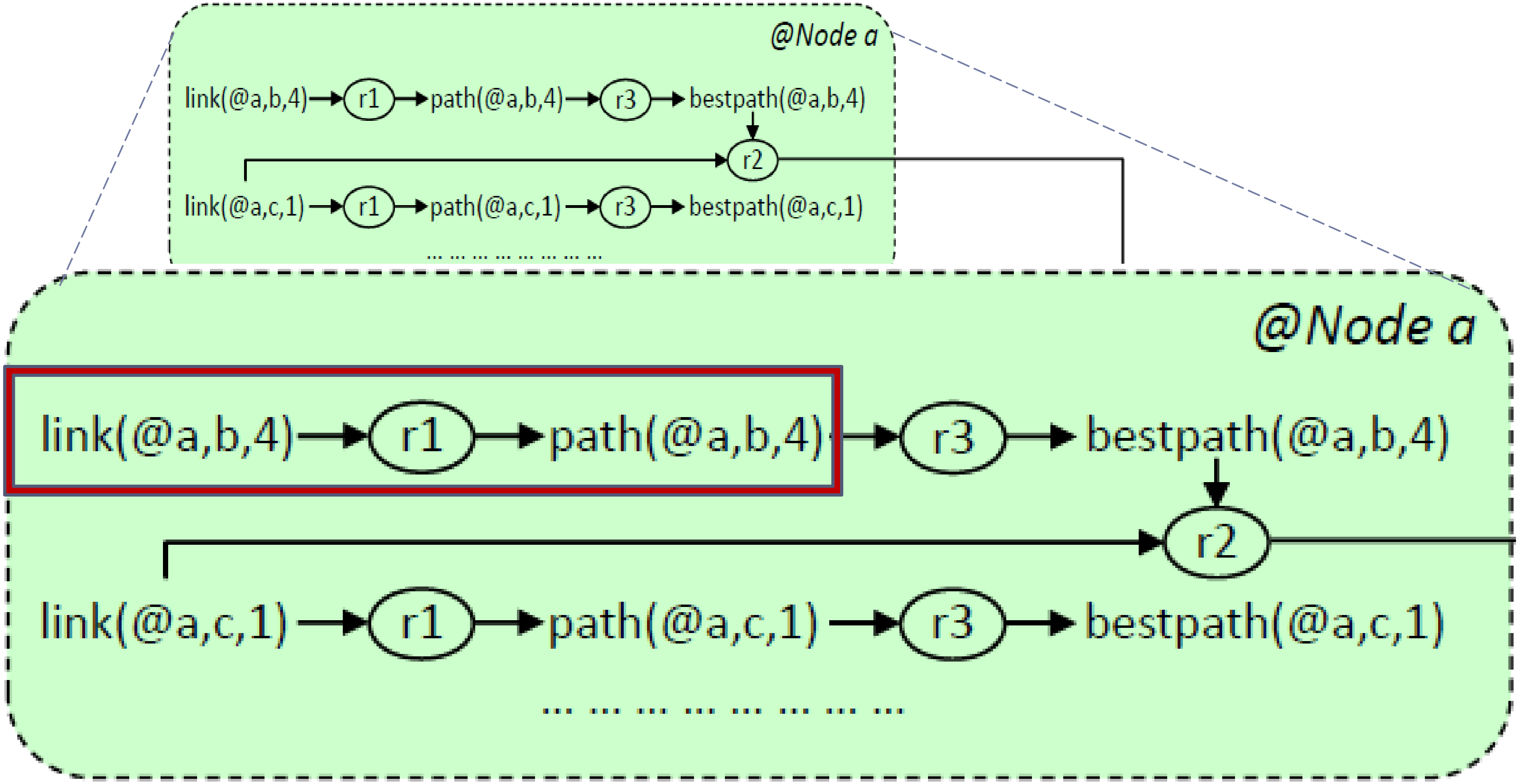

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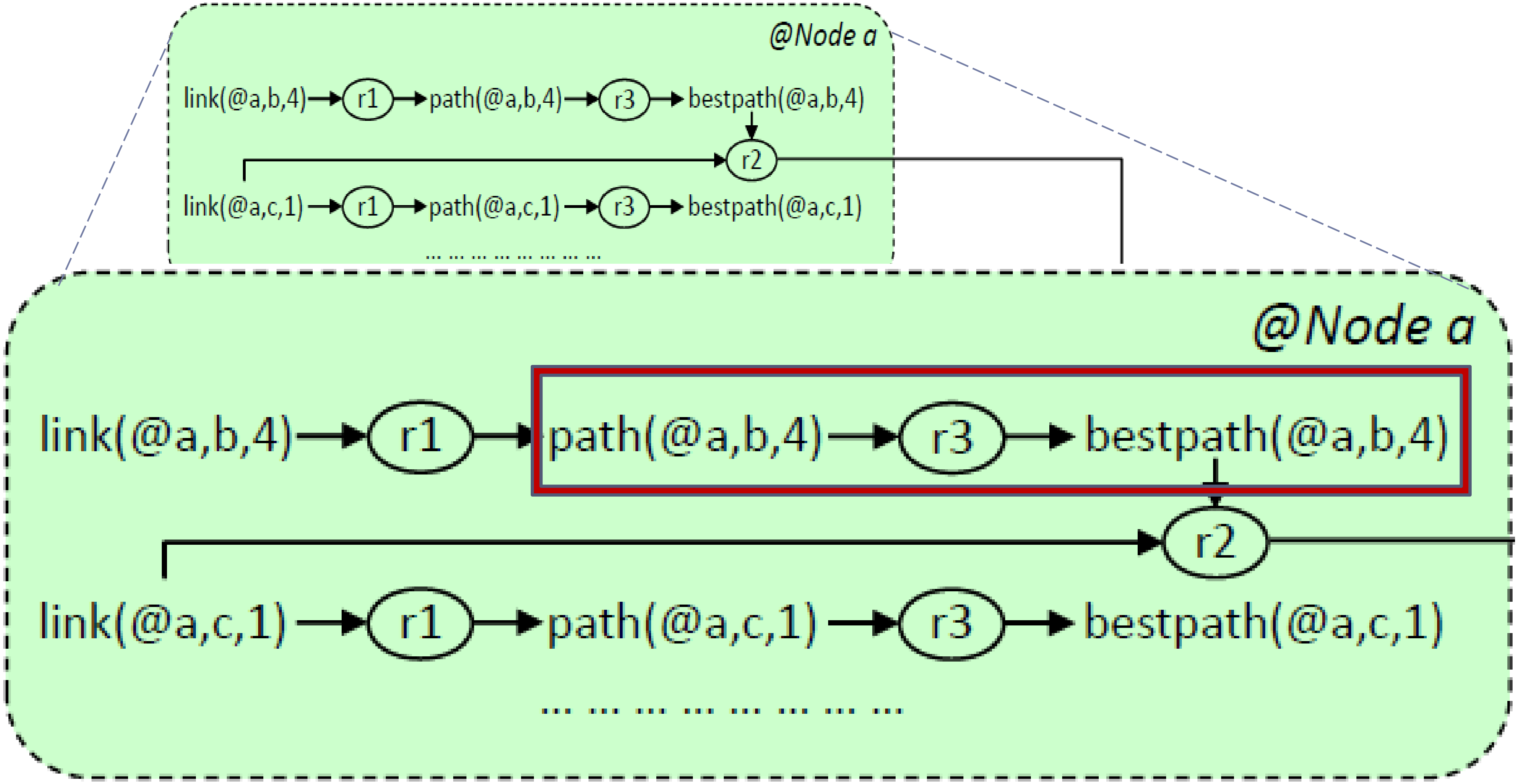

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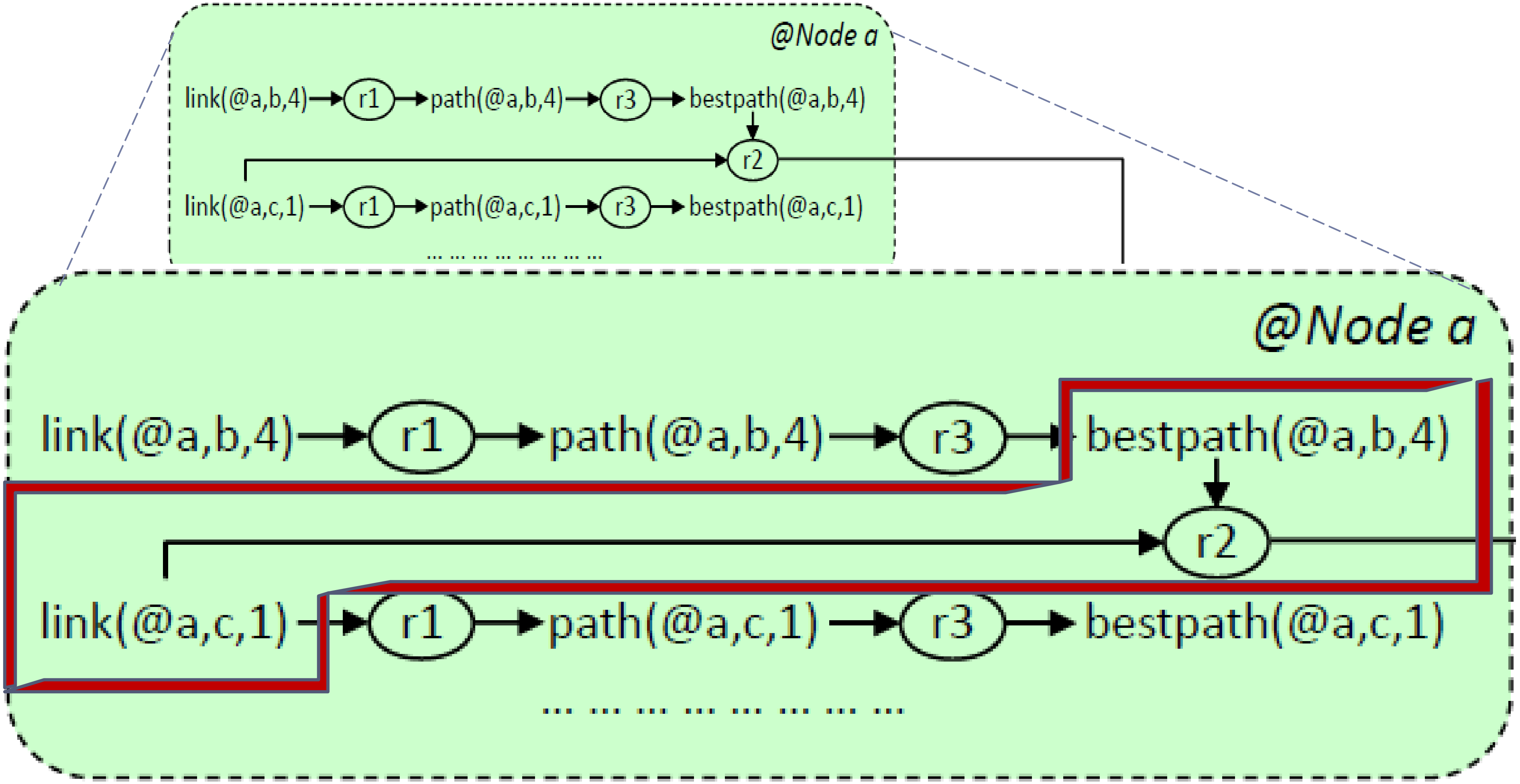

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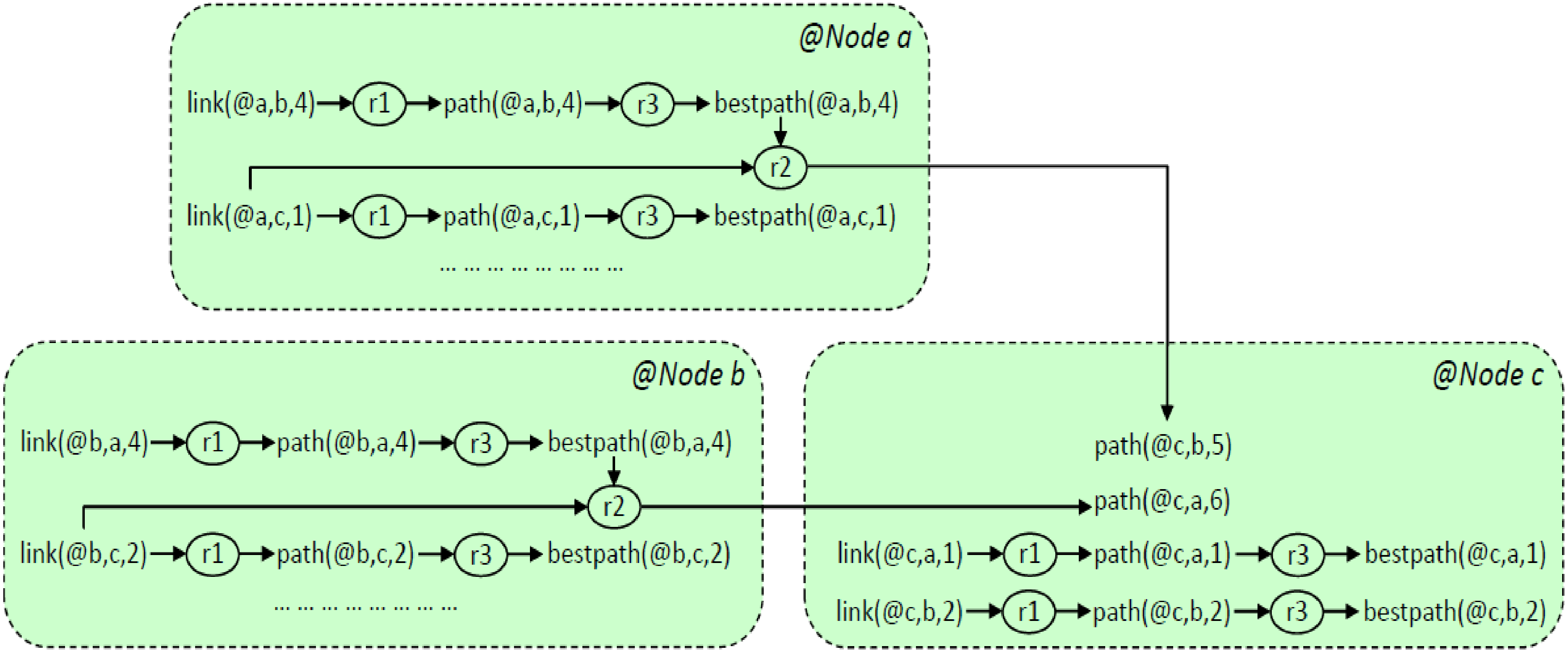

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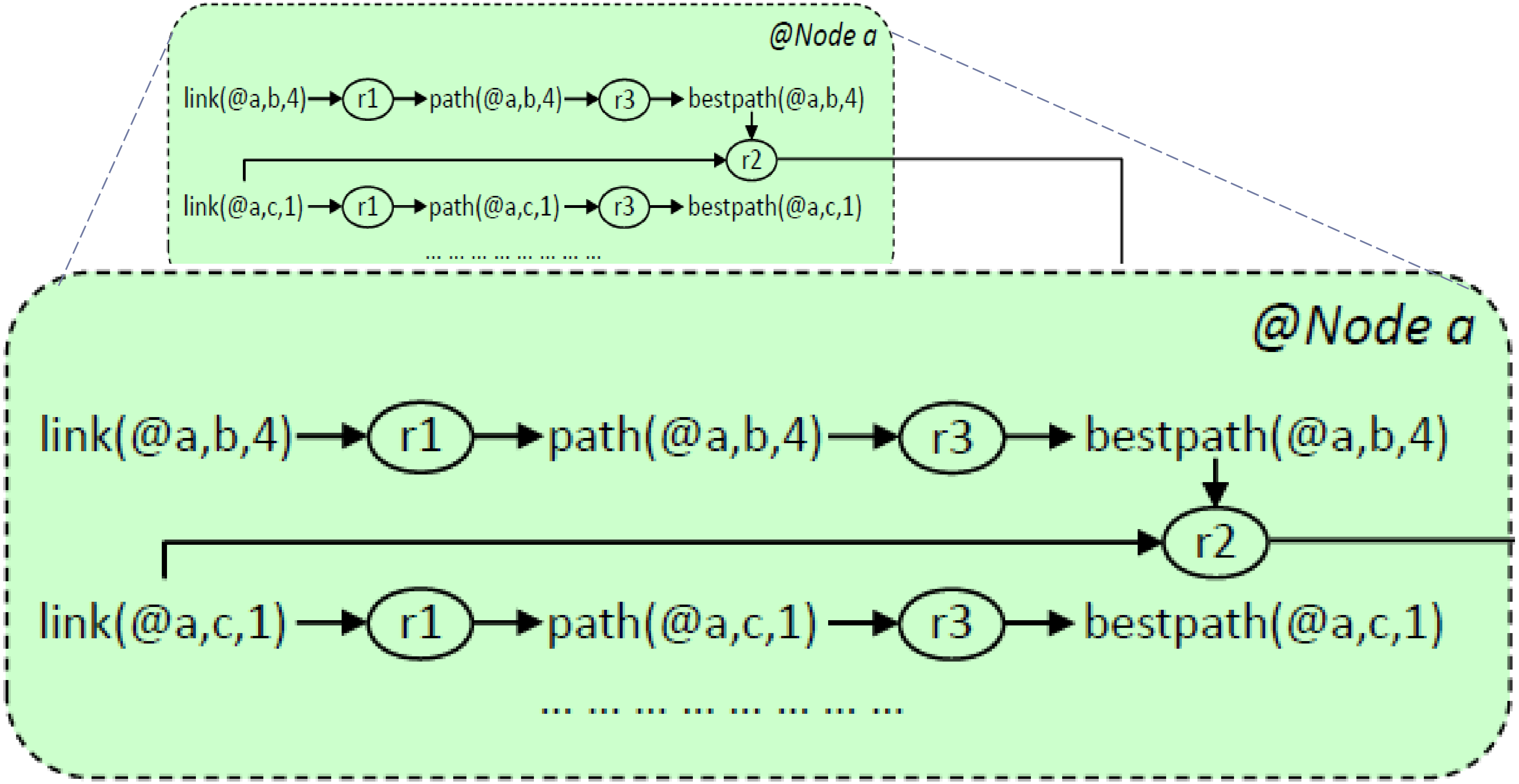
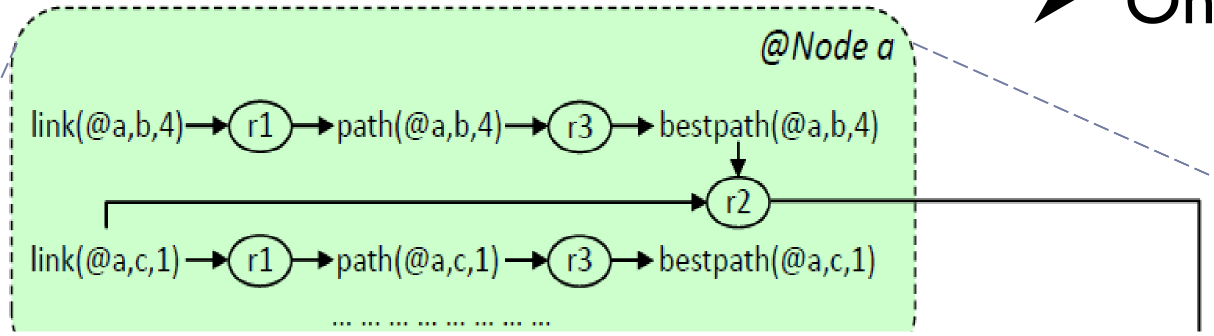
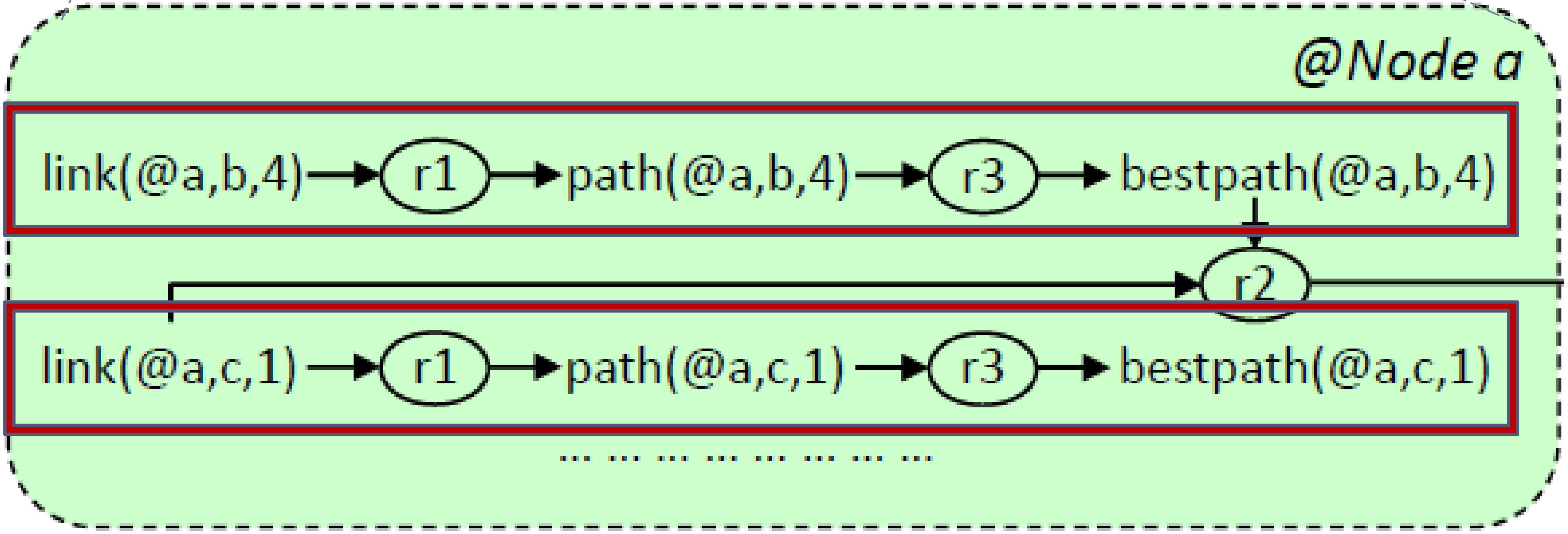


Example: Provenance Graph

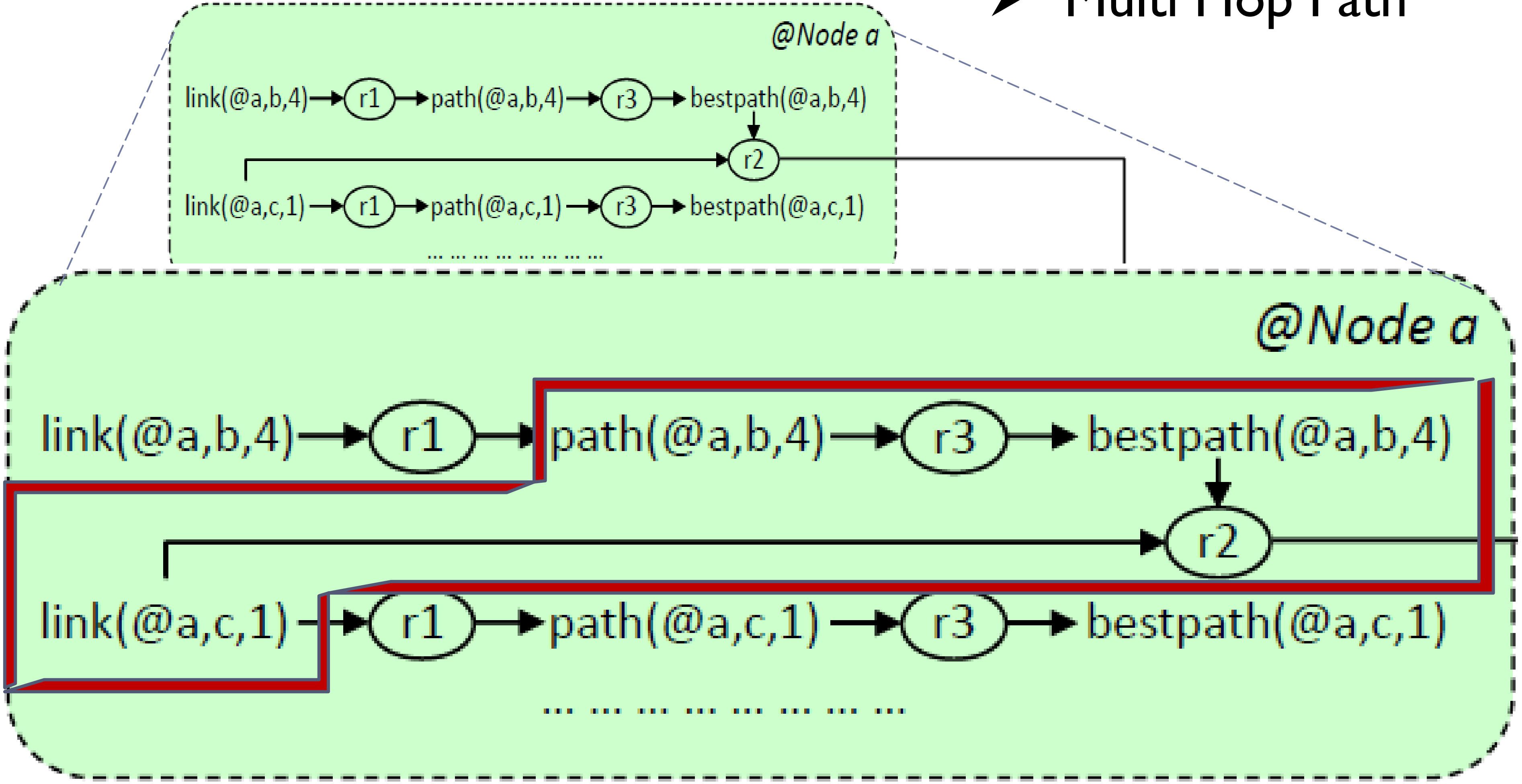
- One Hop Path



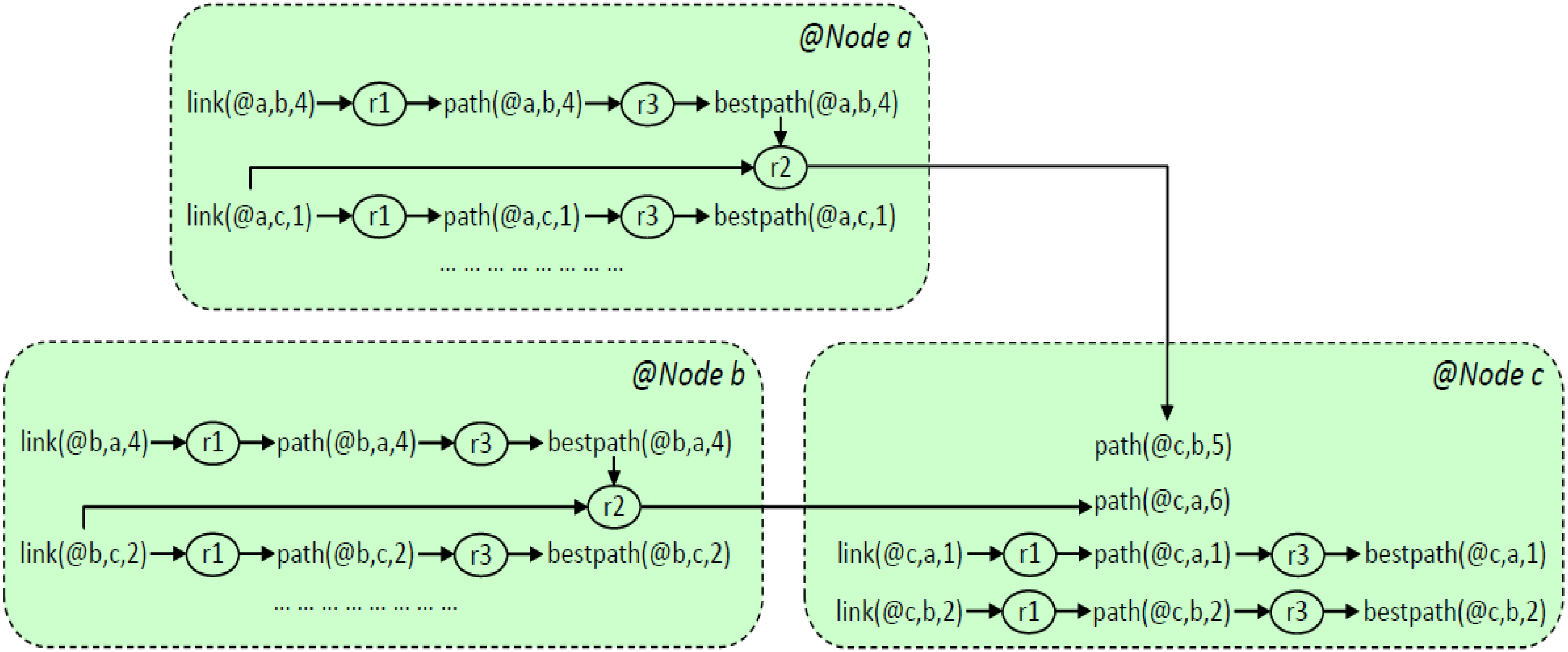


Example: Provenance Graph

- Multi Hop Path



Example: Provenance Graph



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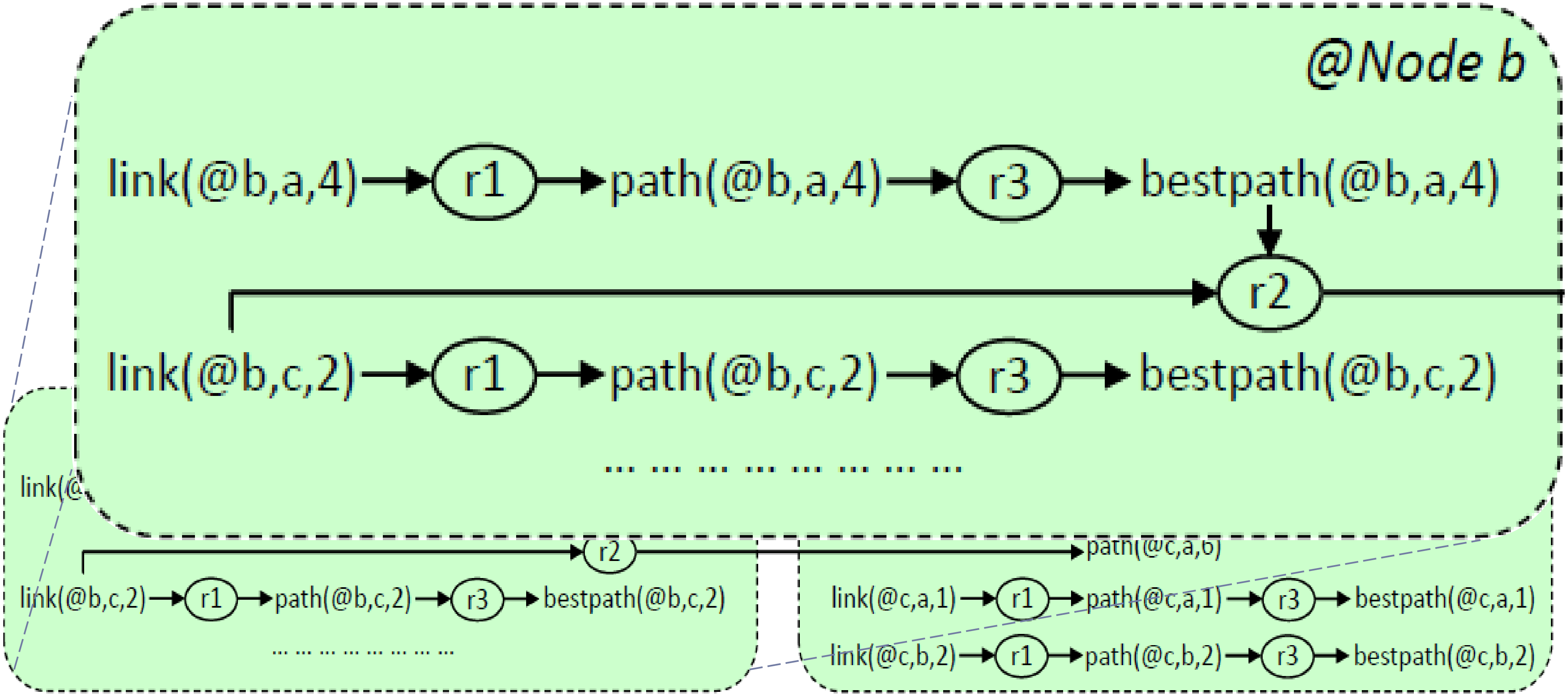

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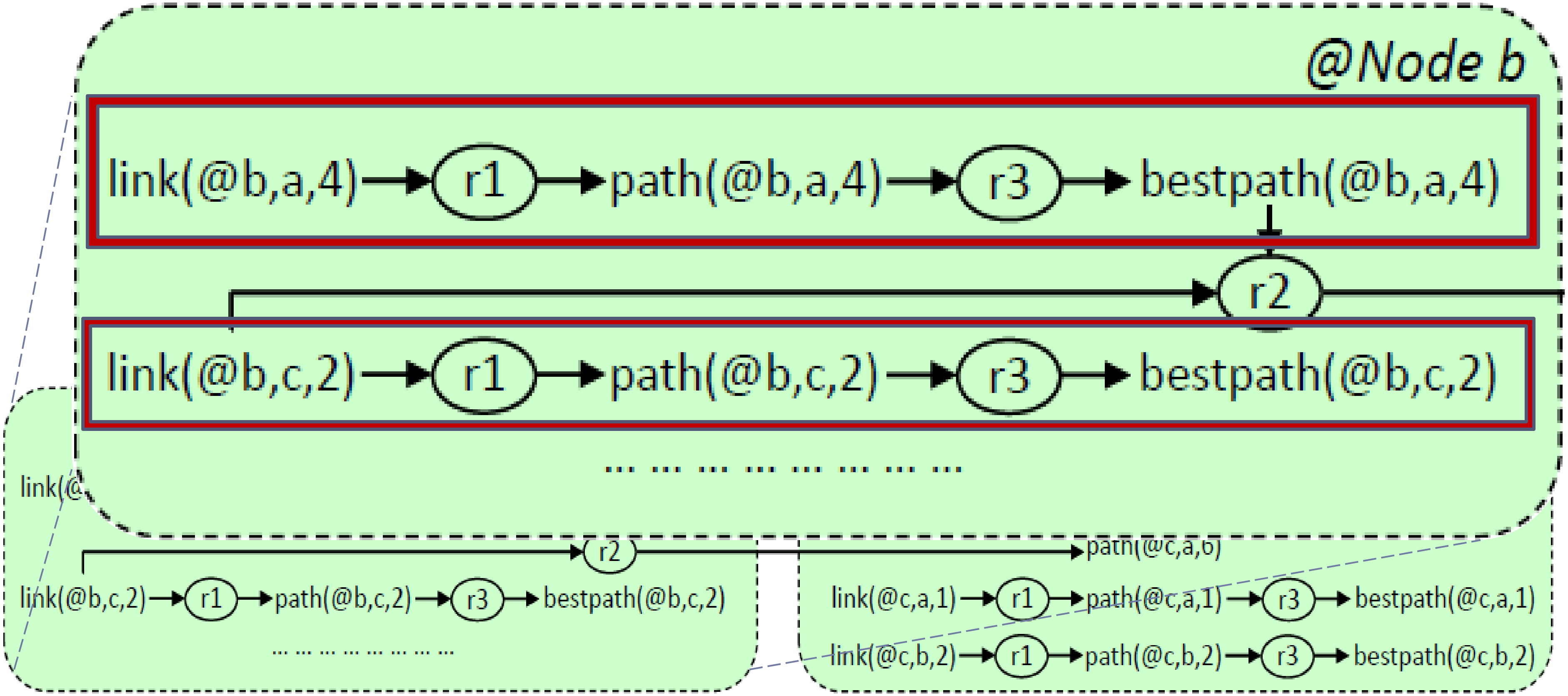

- One Hop Path

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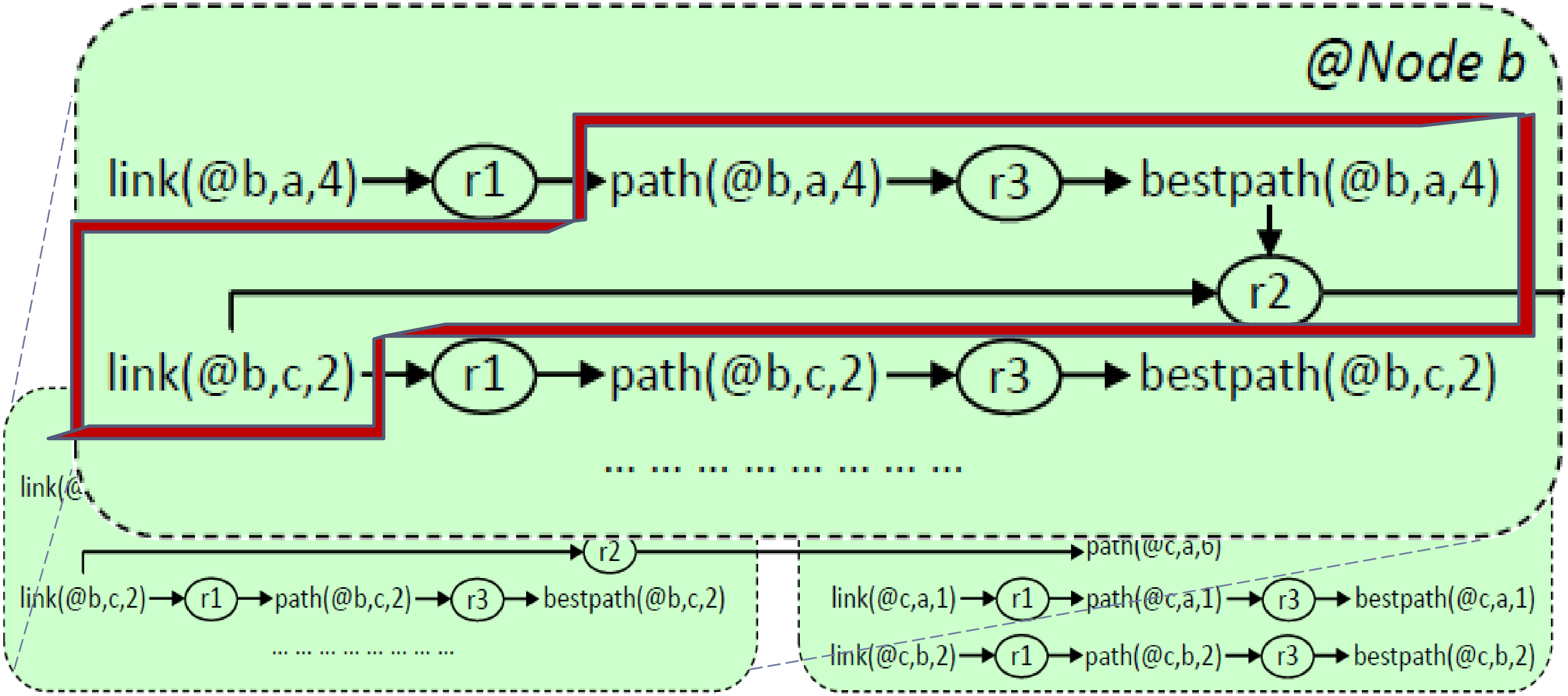

- Multi Hop Path

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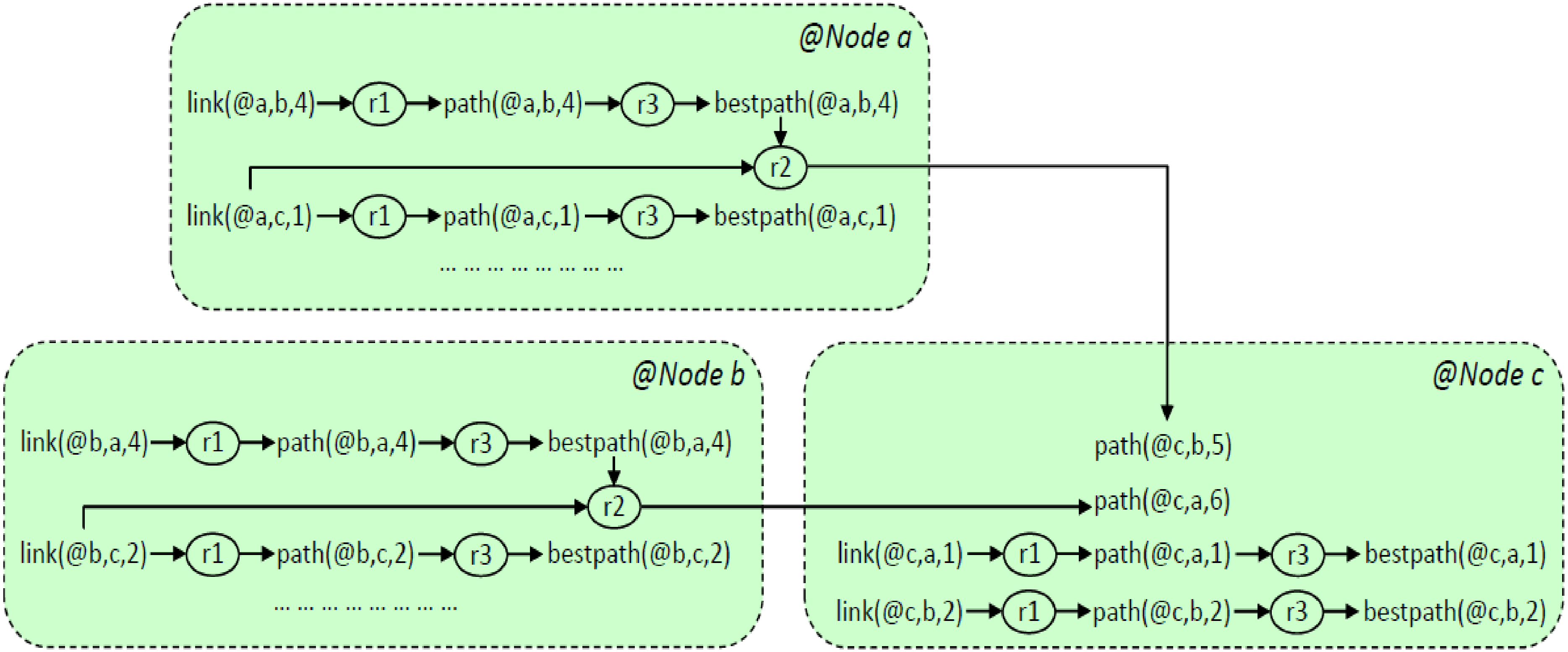

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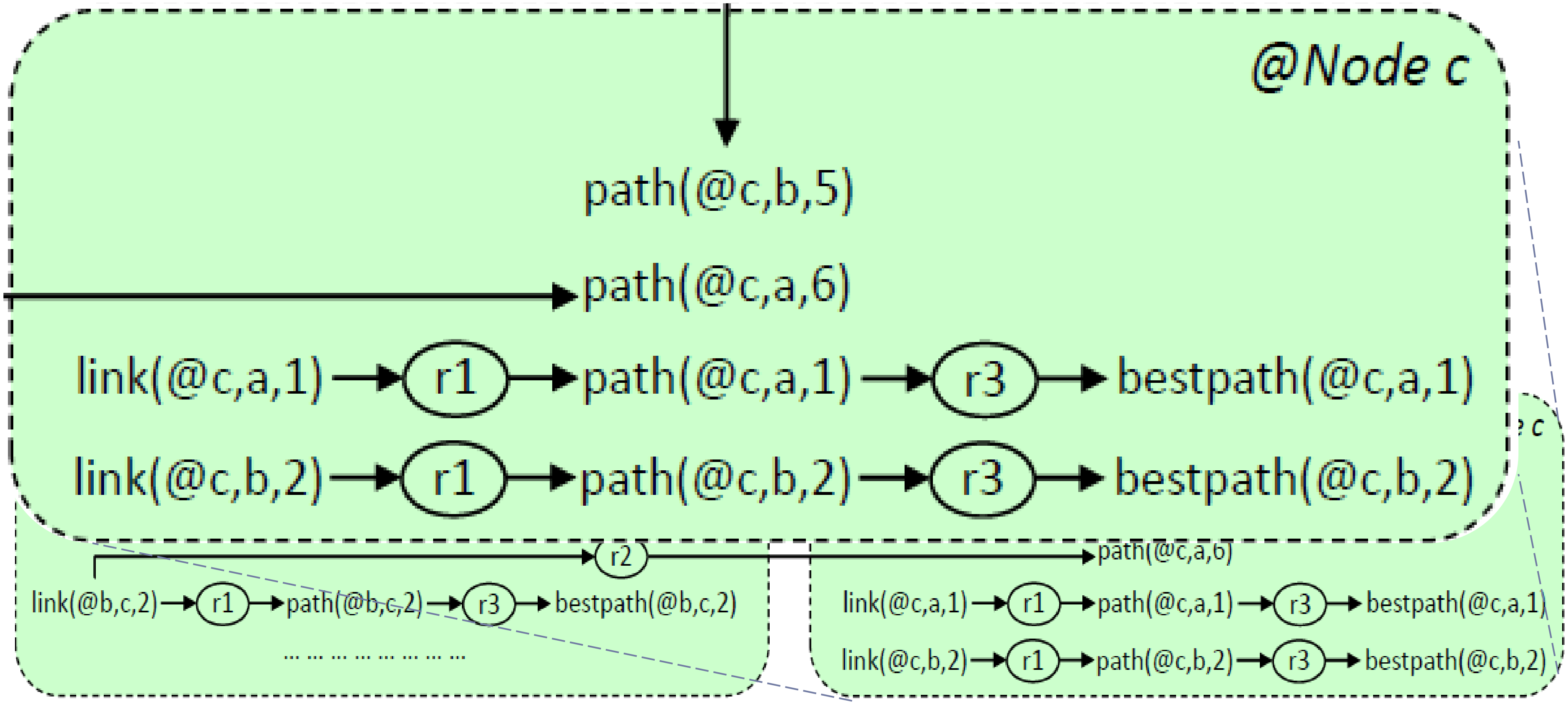

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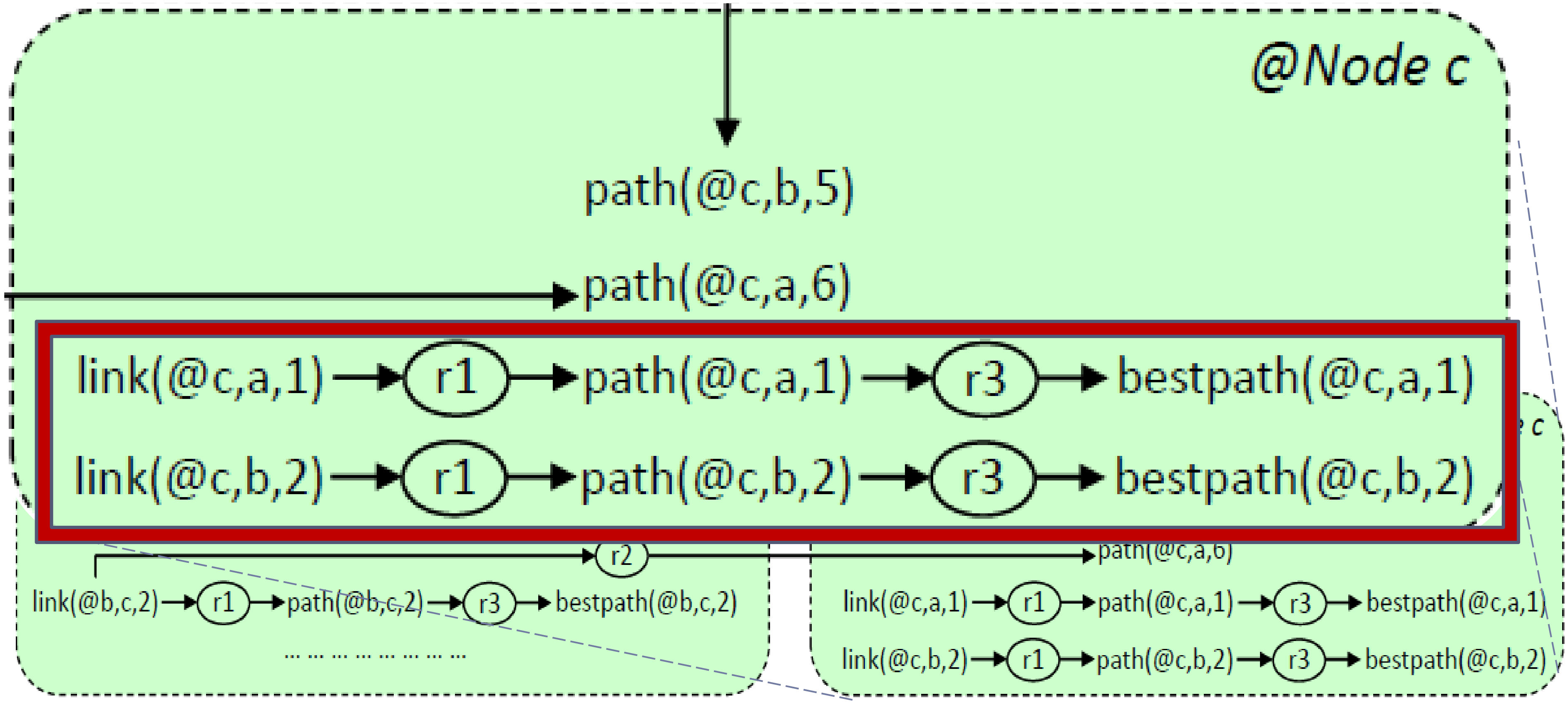
@Node c
path(@c,b,5)
path(@c,a,6)
link(@c,a,1) → r1 → path(@c,a,1) → r3 → bestpath(@c,a,1)
link(@c,b,2) → r1 → path(@c,b,2) → r3 → bestpath(@c,b,2)
r2
path(@c,a,6)
link(@b,c,2) → r1 → path(@b,c,2) → r3 → bestpath(@b,c,2)
... ...
link(@c,a,1) → r1 → path(@c,a,1) → r3 → bestpath(@c,a,1)
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- One Hop Path

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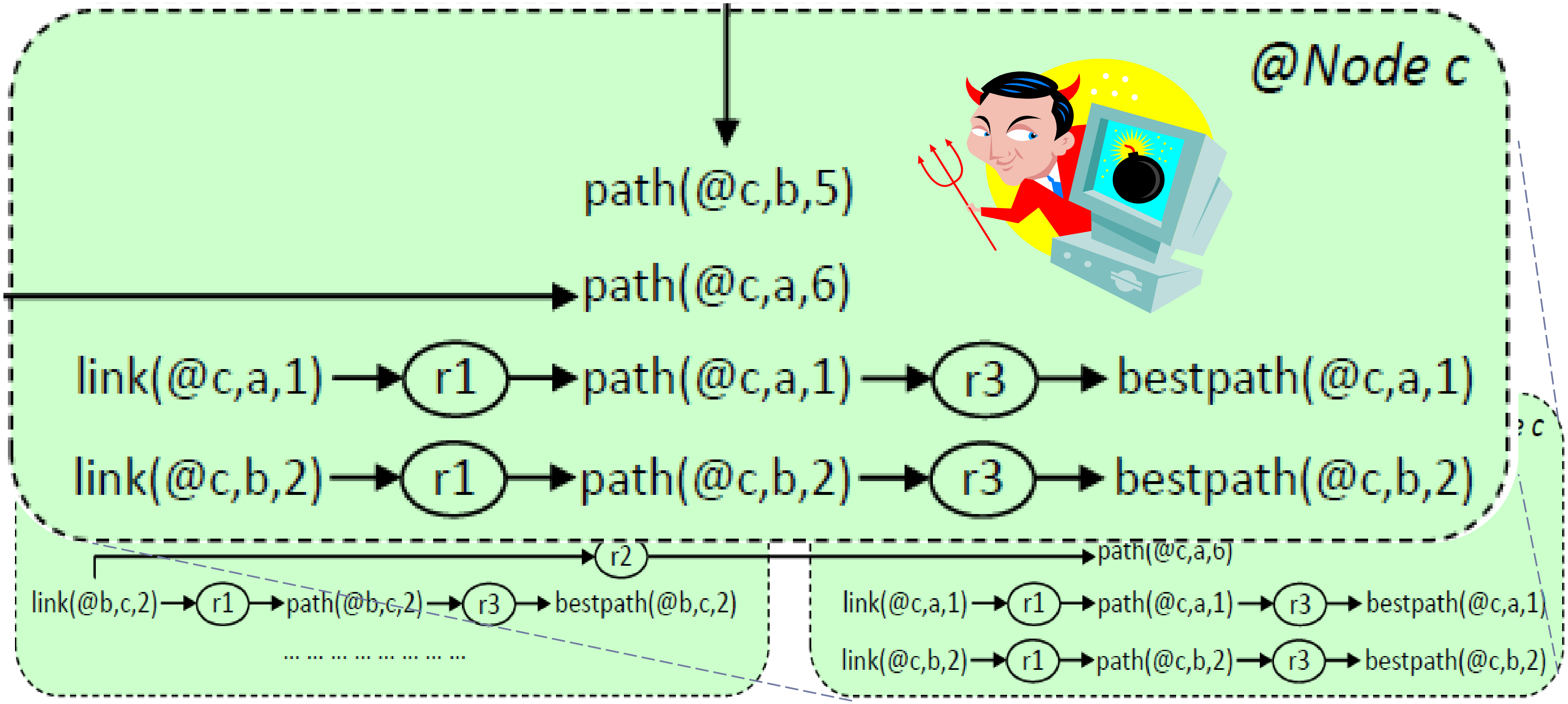
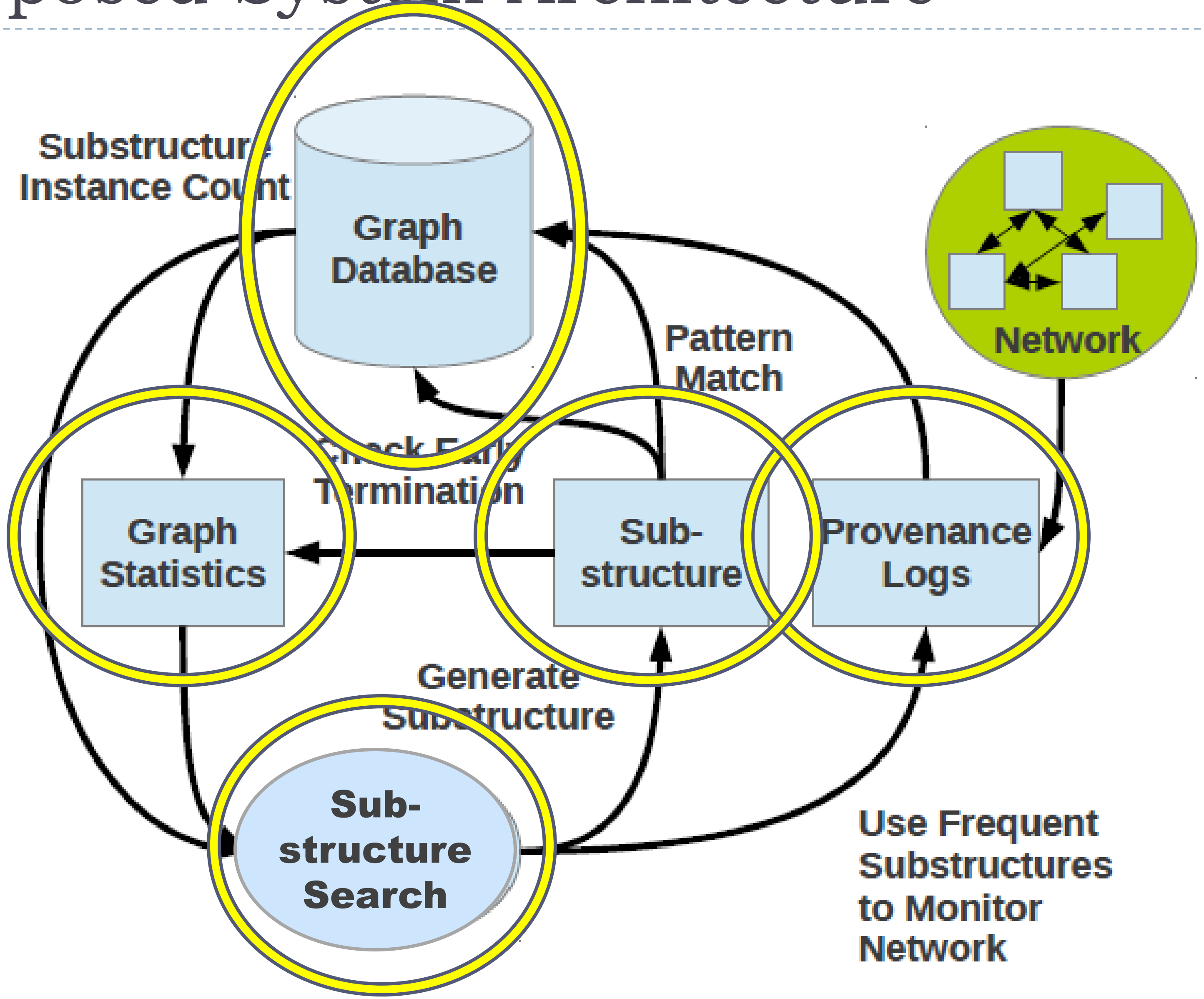


- No Multi Hop Path

Proposed System Architecture



Substructure Mining

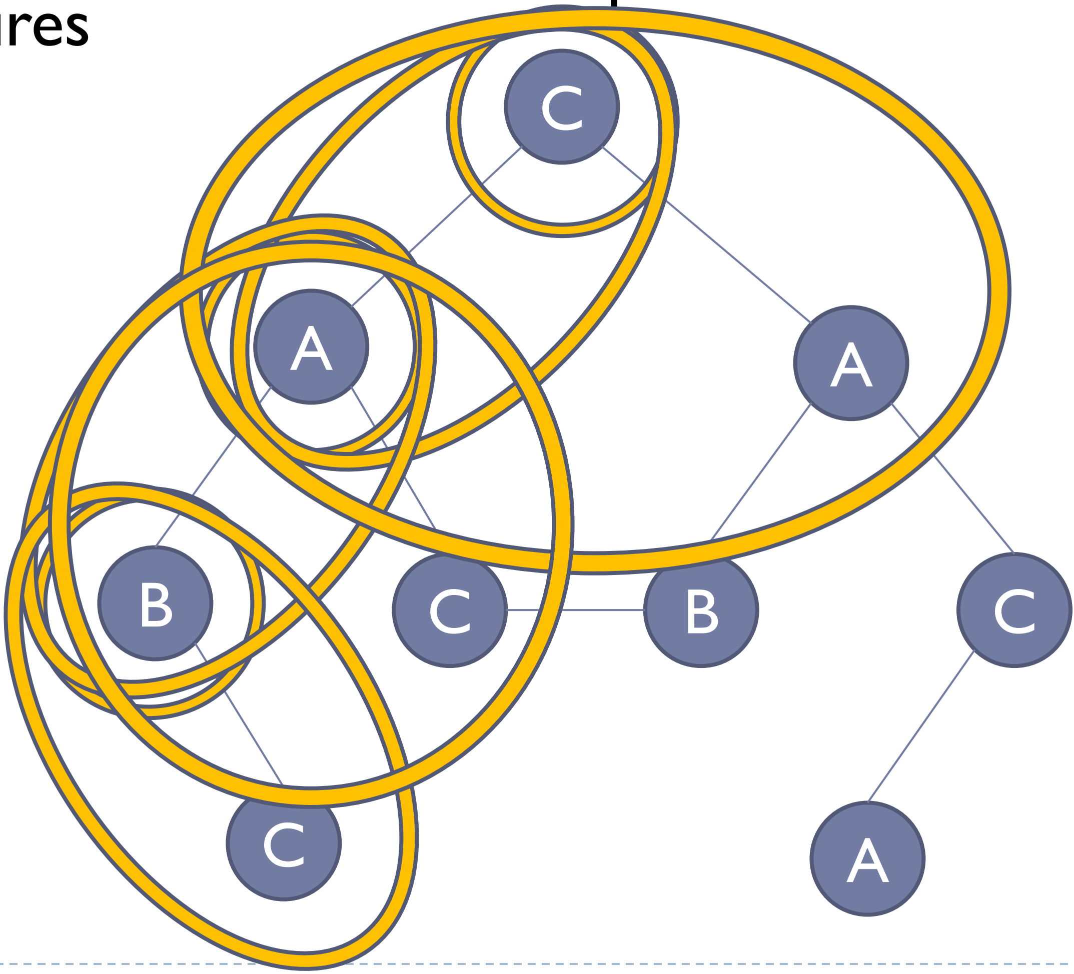
- Substructure mining is the search for "good" subgraphs within a graph or set of graphs

- Two parts:
  - Searching the space of possible substructures
  - Finding instances of an individual substructure

Substructure Mining: Substructures

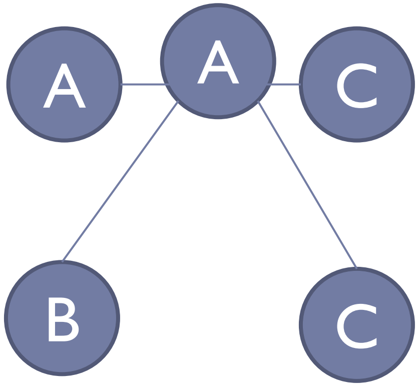
- Many Possible substructures

- Graph

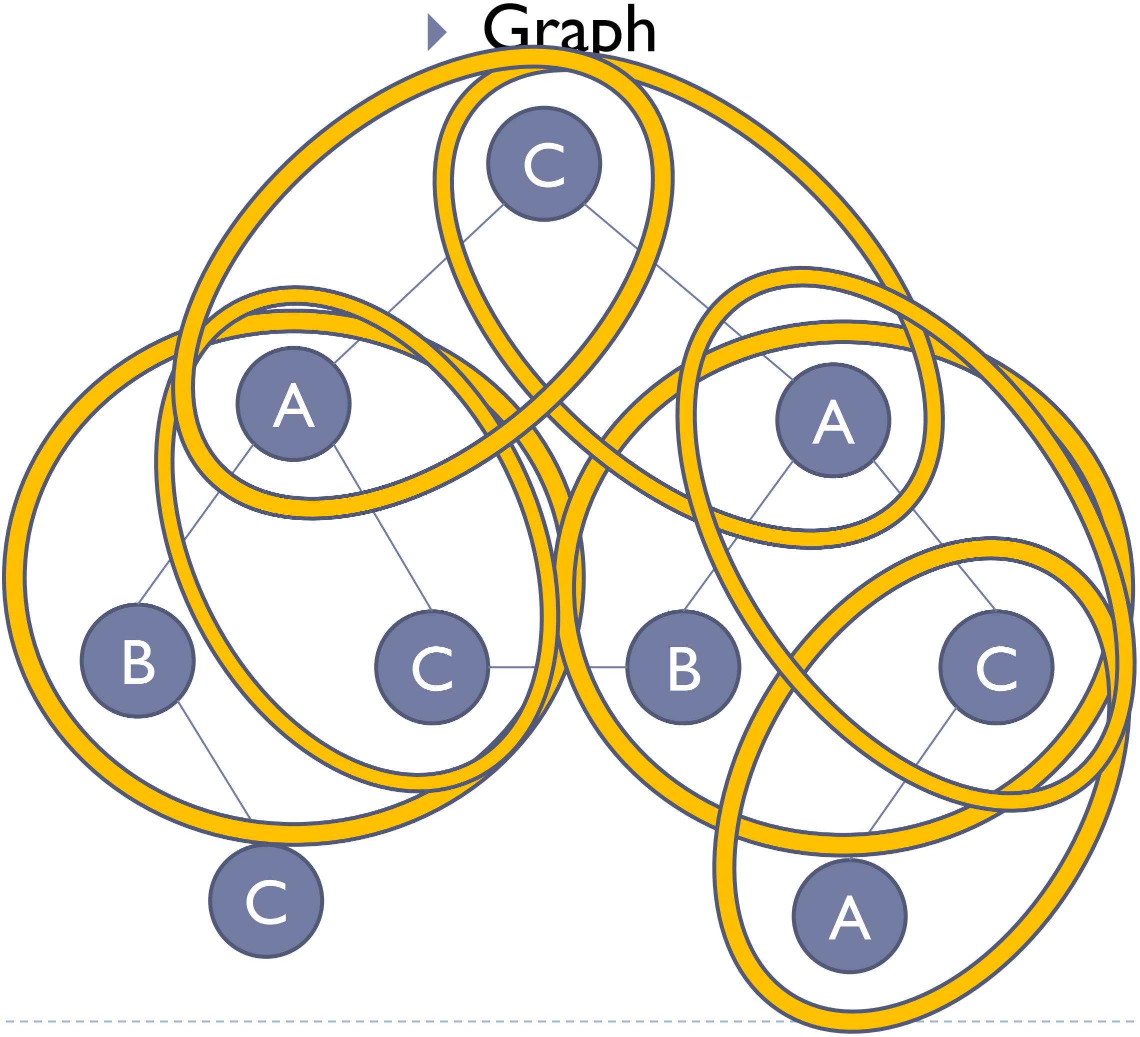


Substructure Mining: Instances

- Substructure



- Graph

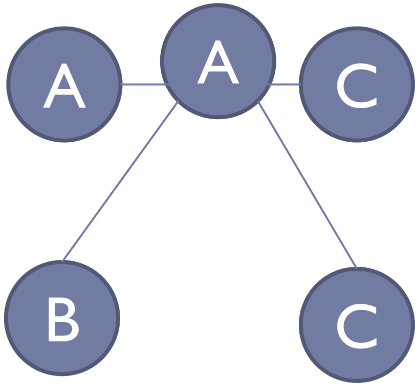


Subdue

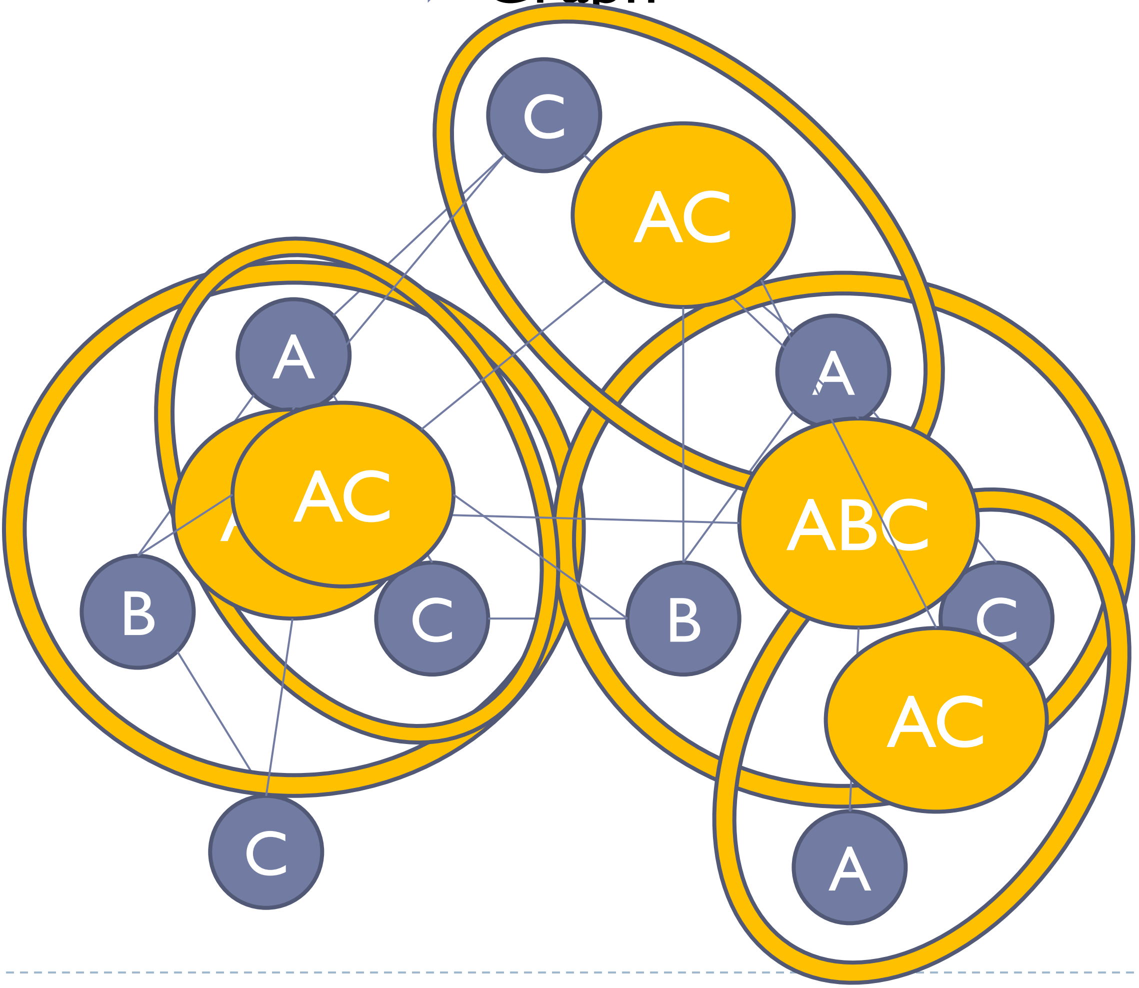
- Classical substructure mining algorithm (N.S.Ketkar et al., 2005)
- Substructures are evaluated based on how well they compress the full graph
  - Compression calculated based on non-overlapping instances
- Subdue uses a guided beam search to search the space of possible substructures
  - Structures from a previous iteration are expanded, tested, and only the best of the expanded go on to the next iteration (beam size = number of the best substructures)

Substructure Mining: Subdue

- Substructure

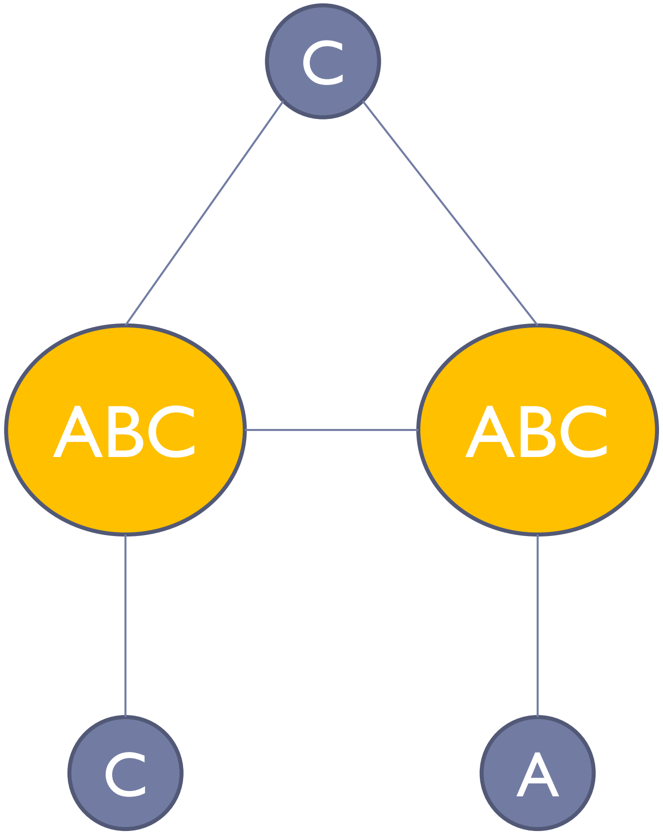


- Graph

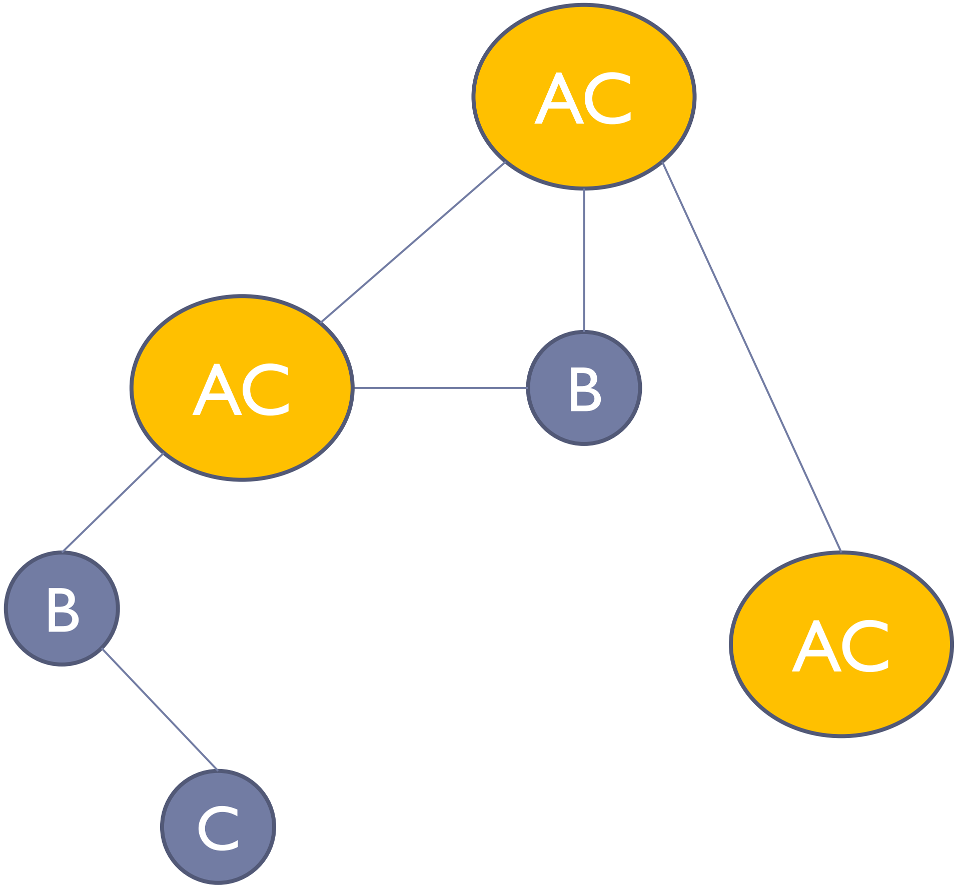


Substructure Mining: Subdue

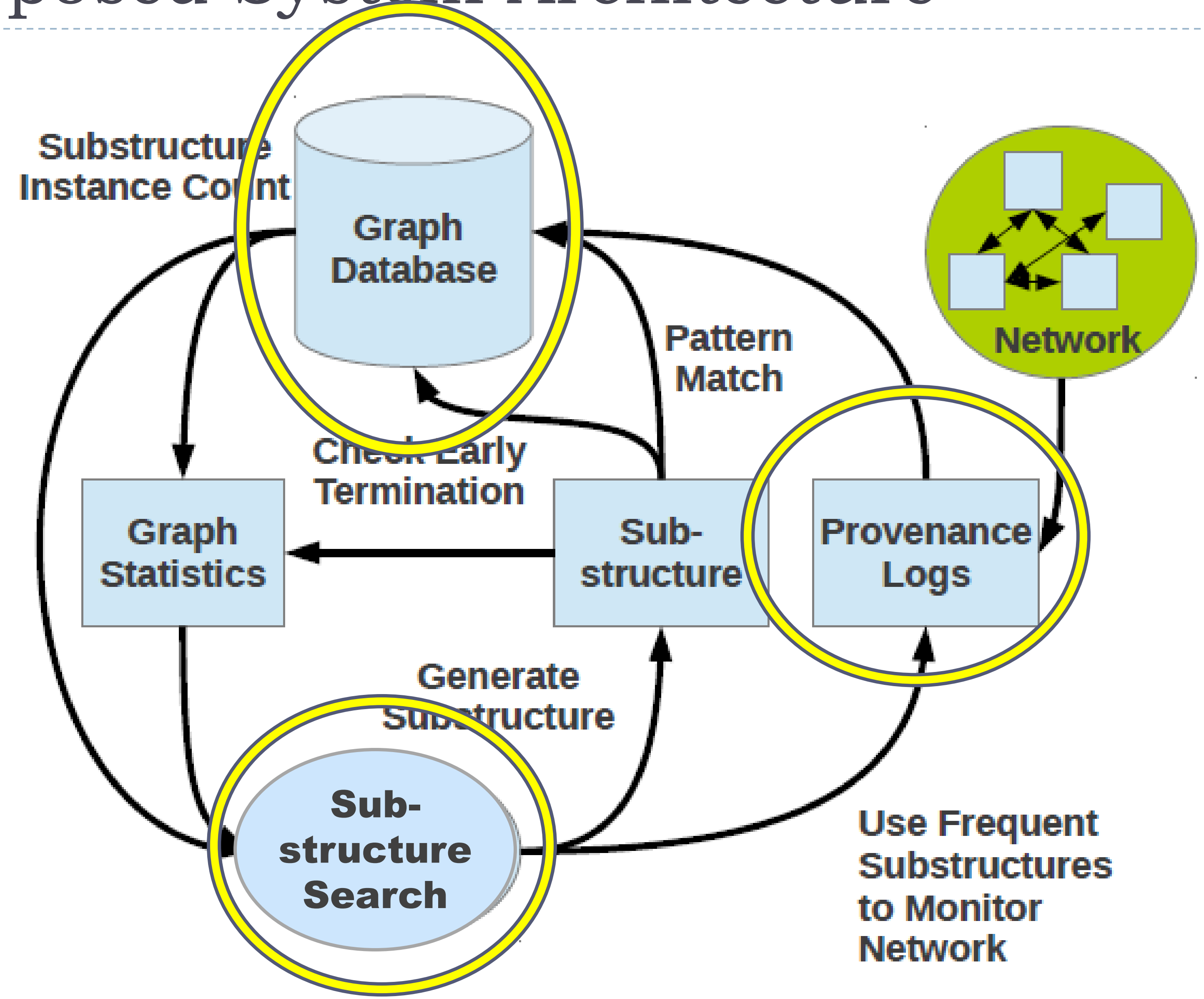
- Compressed Graph 1



- Compressed Graph 2



Proposed System Architecture



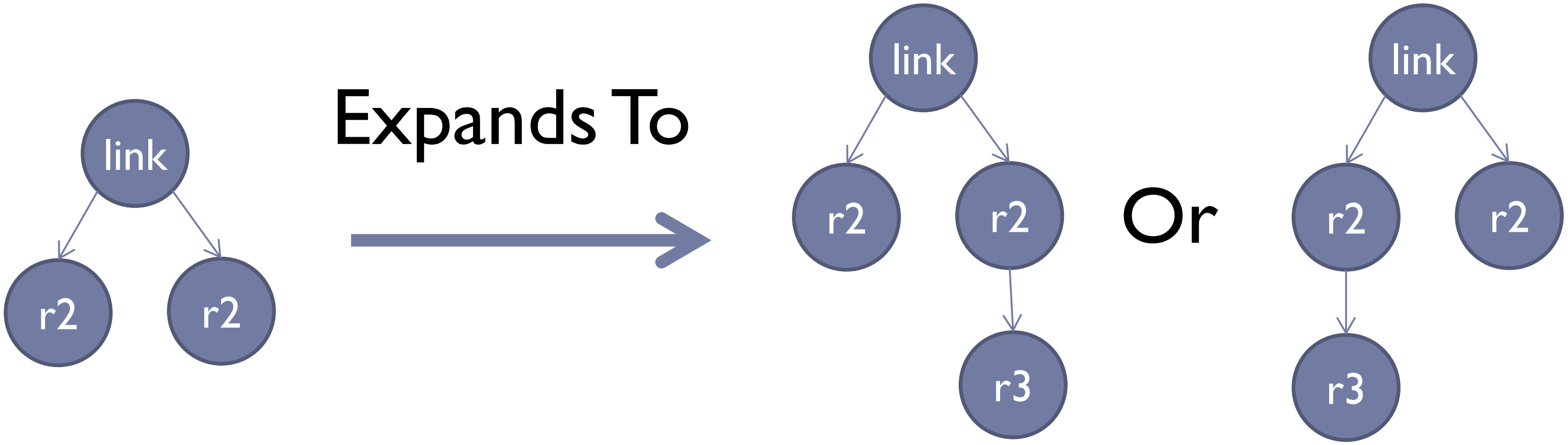
Heuristics

- Limiting the number of substructures to search
  - Duplicate Substructure Reduction
  - Outward Expansion

- Speeding up the search for substructure instances
  - Infrequent Start Vertex
  - Start Vertex Reuse

Duplicate Substructure Reduction

- During the expansion of substructures you duplicate substructures are created and tested.
- We incorporated aspects of Gspan (Yan and Han, 2003) to help reduce the number of duplicates

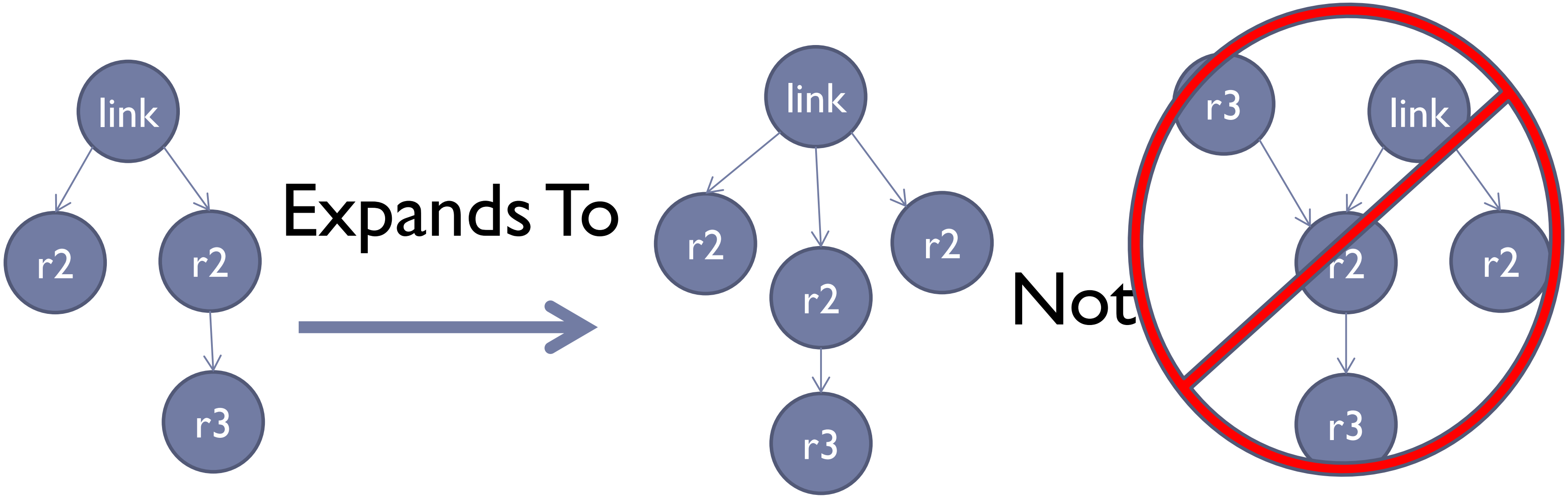


Expands To

Or

Outward Expansion

- When determining new substructures to search for, only expand using outgoing edges
- A possible problem is that certain types of substructures will be ignored.

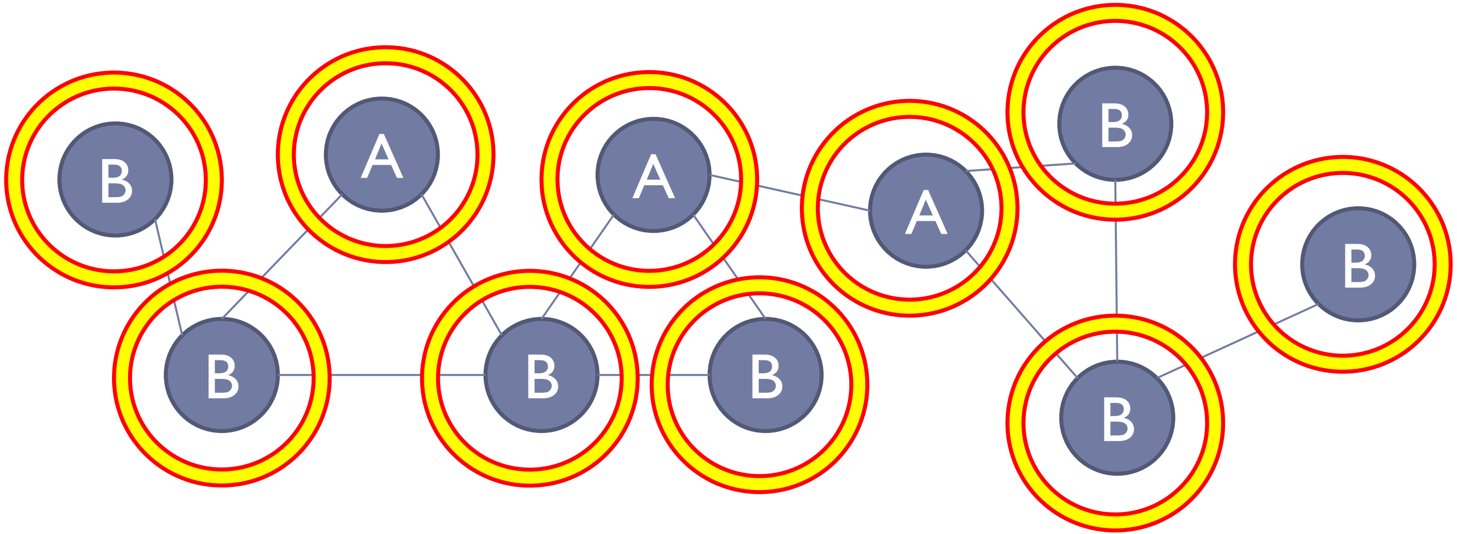


Expands To

Not

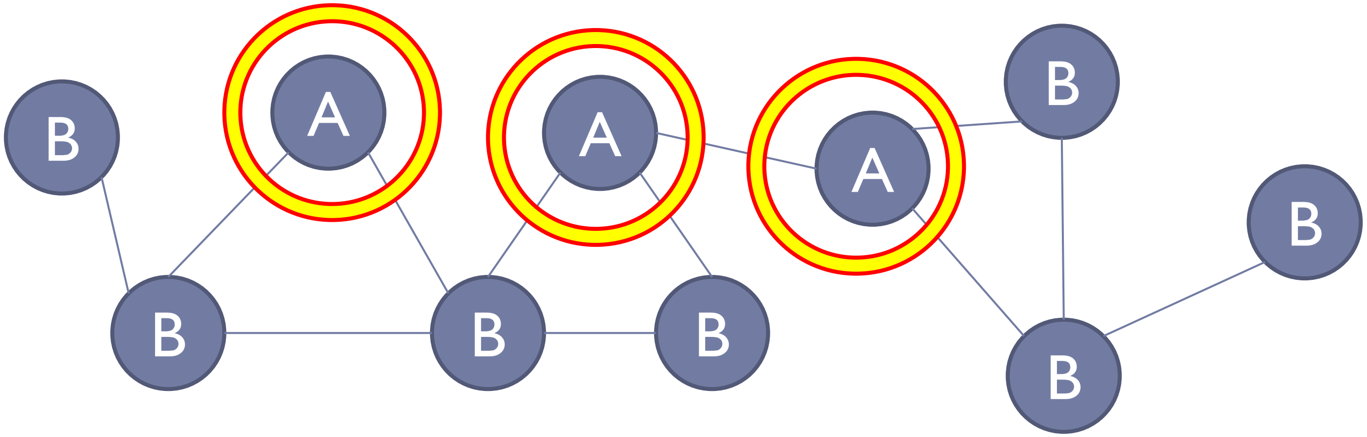
Infrequent Start Vertex

- Testing a substructure instance starts with a single vertex
- Pick start vertices based on the least frequently occurring vertex type in the substructure



Start Vertex Reuse

- Good substructures get expanded to new substructures
- Save the subset of start vertices which have a match
- New substructures can take advantage of the information from the previous substructure



Experimental Setup

- Use 5 different inferred intra-domain topologies from the Rocketfuel project (Spring et al., 2002)

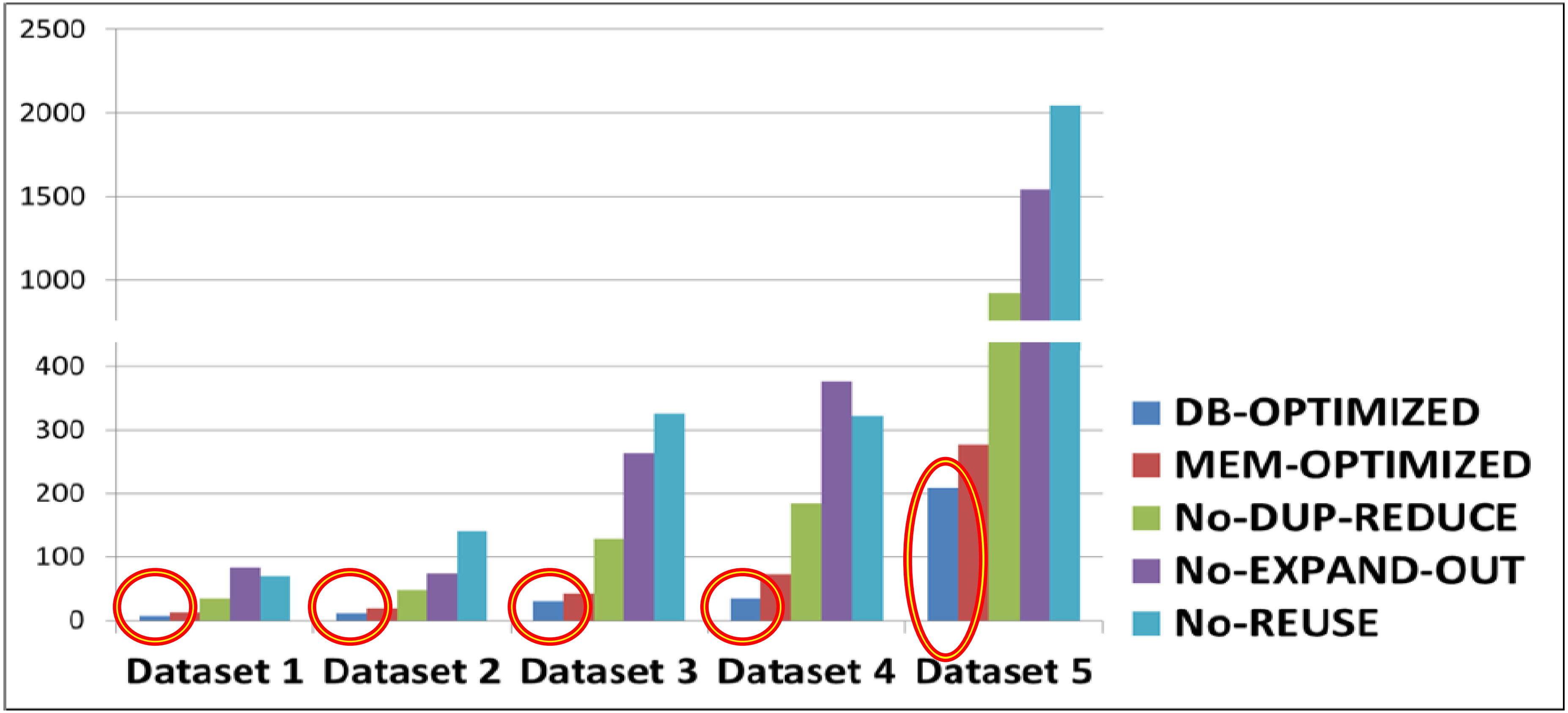
Dataset	ASN	Nodes	Links	|V(G)|	|E(G)|
1	1221	108	306	16,227	28,090
2	1755	87	322	23,015	40,725
3	3257	161	656	52,848	94,568
4	6461	141	748	73,316	134,072
5	1239	315	1,944	317,066	592,038

- Use a beam size of 10 with 100 expansions maximum
- Evaluate run time, quality of substructures, and effect of beam size

Experimental Runs

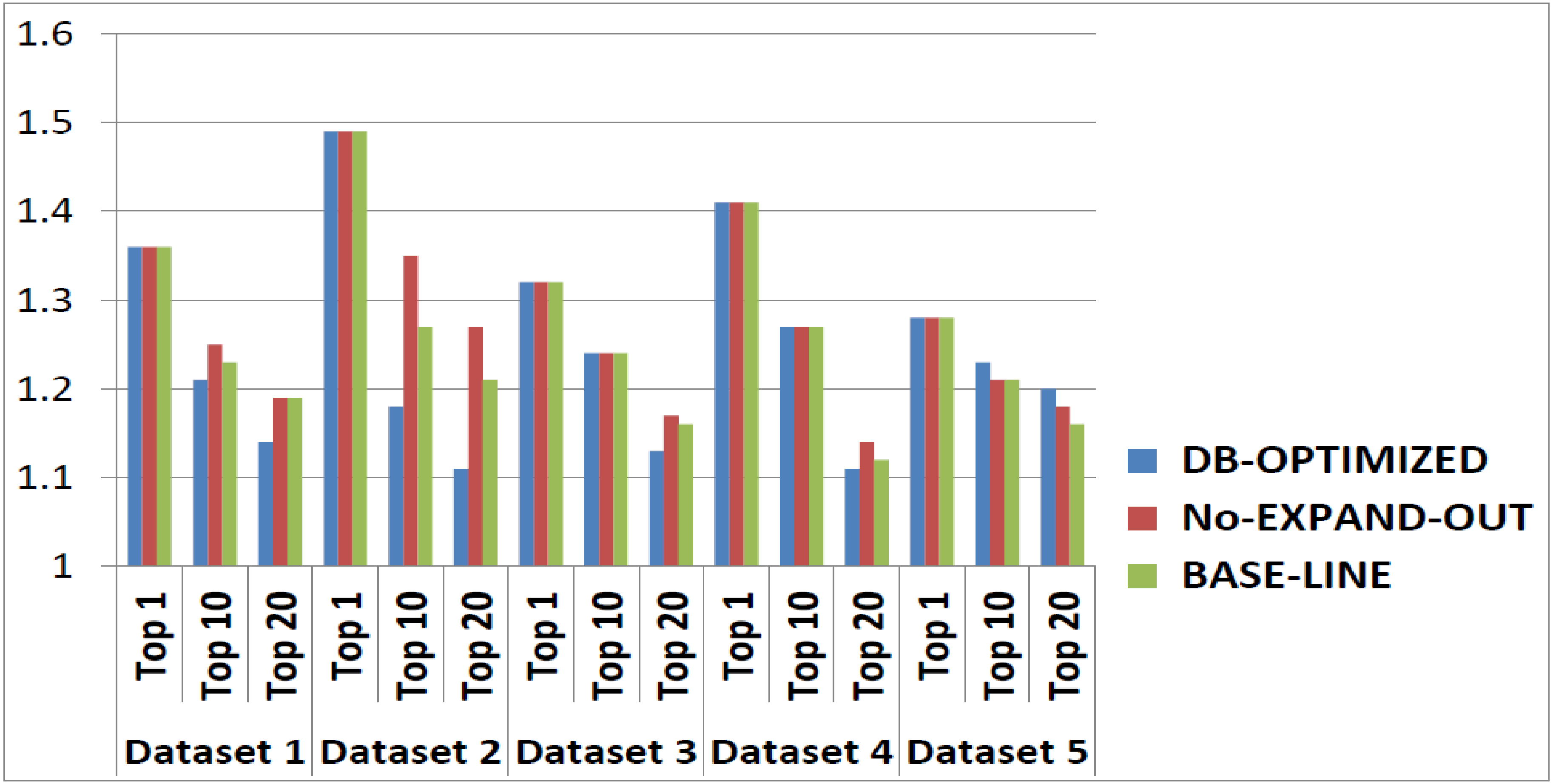
- DB-OPTIMIZED: all heuristics using Neo4j
- MEM-OPTIMIZED: all heuristics using in memory version
- No-DUP-REDUCE: all heuristics except duplication reduction
- No-EXPAND-OUT: all heuristics except outward expansion
- No-REUSE: all heuristics except reuse of start vertices
- BASE-LINE: no heuristics

Results (Run Time)



- Each heuristic improves the run time
- DB version consistently outperforms the memory version

Results (Compression)



- Top compression results the same for each run

Conclusion

- Contributions
  - Apply substructure mining to network provenance
  - Implement algorithm using the neo4j graph database
  - Propose heuristics which take advantage of provenance structure
  - Perform extensive evaluation that shows strength of our approach
- Future Work
  - Try other protocols
  - Use more advanced substructure mining techniques
  - Take advantage of the tree like structure of our graphs
  - Explore substructure mining for dynamic provenance graphs
  - Implement a complete system to test using misbehaving nodes

References

- N.S. Ketkar, L.B. Holder, and D.J. Cook. Subdue: compression-based frequent pattern discovery in graph data. In *Proc. OSDM*, 2005.
- N. Spring, R. Mahajan, and D. Wetherall. Measuring isp topologies with rocketfuel. *ACM SIGCOMM CCR*, 32(4), 2002.
- X. Yan and J. Han. Closegraph: mining closed frequent graph patterns. *In Proc. SIGKDD*, 2003.
- W. Zhou, M. Sherr, T. Tao, X. Li, B. T. Loo, and Y. Mao. Efficient querying and maintenance of network provenance at Internet-scale. In *Proc. SIGMOD*, 2010.